Variation of Manning's Roughness Coefficient with Diameter, Discharge, Slope and Depth in Partially Filled HDPE Culverts

By

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ABSTRACT

High Density Polyethylene (HDPE) culverts are increasingly used in road and railroad crossings because of their low construction cost. The changed hydraulic condition of flow inside a culvert due to a constricted river cross-section results in increased velocity and possibly decreased water depth, causing a fish passage barrier. Velocity within a culvert is a function of the cross-sectional area, slope, discharge and Manning's roughness of the culvert material. Previous researchers have found that the Manning's roughness for partial flows is greater than full flow but inadequate data were collected for flows less than 20% full. Therefore, the objective of this research was to collect water depth data in HDPE culverts and to derive a relation between Manning's roughness and relative depth.

With a 4ft x 2ft flume of 60 ft length, three test culverts of diameter 1ft, 2ft and 3.5ft were tested with the discharge ranging from 0.2 to 10.3 cfs at bed slopes of 0.2%, to 2%. A total of 11,000 depth data points were collected and 125 average depths were reported. The results could not validate previous research on relative Manning's roughness curves, though the statement by Pomeroy that the Manning's roughness should be less than full flow roughness under 18% relative depth was validated. The relation between relative depth and relative Manning's roughness for flow less than 20% was found to be fairly linear and less than the full flow roughness published by HDPE manufacturers, whereas for 20% to 40% relative depth, the roughness was found to be equal to full flow roughness. Above 40% and below 75% relative depth, Manning's roughness decreases fairly linearly to less than full flow roughness.

Acknowledgements

Conducting laboratory experiments, collecting data, analyzing them and writing this dissertation has been one of the most challenging academic tasks I have ever faced. This research project would not have been possible without the support of Dr. Hans Tritico. This is a great opportunity to express my respect to Dr Hans Tritico for his guidance, advice and support for the entire two years. I would like to extend my gratitude to Advance Drainage Systems, Inc. for their support for providing culverts that were used for my research.

I owe my deepest gratitude to the committee members Dr. Scott Martin and Dr. Yogen Panta for their assistance; without their knowledge on the specific topic; this research would not have been successful.

My special thanks go to all my friends and group members, especially Bishes, Sanket, Brad, Chris, TaiJaune and Darshan for their valuable help during data collection. Without the help of Mechanical workshop Technicians John, Tom and Bob, I would not have been able to set up the experimental model.

Last but not least, I would like to thank the Civil and Environmental Engineering Department, YSU for providing me financial support and quality education for two wonderful years, and Linda Adovasio for always being there to provide resources whenever needed.

This thesis is dedicated to my family and due to their inspiration and support, I am here.

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CHAPTER 1: INTRODUCTION

1.1 Background

In United States, there are millions of road and railroad crossings. Culverts are the most viable cross drainage structures for many of these crossings because of their low construction cost in comparison to bridges and causeways. There are approximately 100,000 culverts installed in the state of Ohio (ODOT, 2005). In the past, culverts were designed only for flood conveyance purposes while the concern of aquatic organisms was ignored (Richmond *et al.*, 2007). Nowadays, with increasing concern for protecting aquatic habitat and reducing fish passage blockage, engineers are being asked to design culverts that serve to both:

a) Pass water safely under a roadbed, and

b) Maintain ecological balance and successful migration of fish through culverts.

Culverts constructed 50 or 100 years ago are now in the maintenance or replacement phase. When culverts are replaced, high density polyethylene (HDPE) materials are now being used increasingly because of their low construction cost, resistance to corrosion, light weight, and extended life (Wilson, 2000).

Undersized culverts not only act as barriers to fish and other aquatic organisms but also affect their habitats (Federal Highway Administration, 2005). For sustainable ecological development, most of the aquatic organisms should be able to move through the culverts under typical flow conditions.

Fish and other aquatic animals can swim through the culvert if the swimming ability of the fish is greater than the actual velocity of flow. A culvert is considered to act as barrier when the flow condition exceeds the biological potential of the fish. An ideal fish passage culvert design allows the culvert width, slope, water depth and velocity to be equal to the natural stream (House *et al*., 2005). This concept is called transparency which states that a transparent fish passage culvert would allow the passage of fish and other aquatic organisms without stress, delay or any damage. (Castro-Santos *et al*.; Roscoe and Hinch, 2009). Past design of culverts were based on full pipe flow conditions such as the 20 or 50 year floods (ODOT, 2010). A pipe designed for one of these infrequent floods will run full only in high flow conditions and the rest of the period will be only partially filled. Culverts typically reduce the cross-sectional area of the flow in the stream thus making the hydraulic conditions inside the culvert different than the natural stream. The major hydraulic criteria influencing velocity and depth of water in the culvert and thus fish passage are: flow rates, material roughness, diameter and slope of the culvert.

Fish are also host species for freshwater mussels which use fish to complete their reproductive cycle (Watters, 1996). There are twenty-three species of locally endangered mussels in Ohio (ODNR, 2009). Barrier to the movement of fish not only affects fish but also affects these dependent organisms. The area available for the fish and dependent mussels to reproduce is reduced if a fish is unable to migrate upstream due to barriers (Smithson and Johnston, 1999). Culverts that act as barriers might cause fish that have migrated downstream to remain in the downstream watershed resulting in an imbalance in populations across the culvert. One way to restore this imbalance is to increase the passage efficiency of the culvert.

There are different types of barriers to fish movement imposed by the culvert. Some of them are high inlet velocity, drops at the culvert outlet, inadequate water depth in the culvert for fish to swim, and high turbulence created by the contraction at the inlet (Maine DOT, 2007). Among these barriers, excessive velocity inside the culvert and inadequate water depth are considered the most common fish passage barriers (Baker and Votapka, 1990; Votapka, 1991 and Bates *et al*., 1999). High velocity may be experienced in culverts even during low flows due to the reduced roughness and cross-sectional area (OEPA, 2007).

Velocity and depth in the culvert can be calculated from the Manning's equation. Manning's equation is an empirical equation valid for uniform flow conditions (Chow, 1959 and French, 1987). Manning's roughness (n) is the element of the Manning's equation which accounts for the hydraulic roughness of the material used. Manning's roughness and velocity within the culvert are inversely proportional. As the value of Manning's Roughness increases, the velocity of flow through the culvert decreases and vice versa. Manning's equation can be written as,

$$V = \frac{1.486}{n} (R_h)^{2/3} (S)^{1/2} \qquad 1.1$$

where, V is the average velocity of flow through the culvert (ft/s), n is the Manning's Roughness Coefficient, R_h is the hydraulic radius (ft) and S is the slope of the energy grade line within the culvert (ft/ft). Culverts are typically designed based on roughness coefficients presented in standard tables. An example of a table listing Manning's roughness in culverts is shown in Table 1.1 (American Concrete Pipe Association, 2007). The roughness values presented in these tables are typically based on the full pipe flow conditions. Under partial flow conditions, the Manning's Roughness Coefficient is generally expected to be much higher (Lang *et al*. 2004). If the culvert is designed based on the full flow pipe roughness, the velocity of flow in partially filled culverts is therefore expected to be lower than the predicted flow velocity but the exact amount is not well understood, as will be discussed in Chapter 2.

Table 1.1 Manning’s Roughness Coefficient for different pipe materials (American Concrete Pipe Association 2007).

Recommended values for Manning’s n			
Pipe Material	Values of Manning’s n		
	Lab Values	Promoted Values	ACPA Recommended Values
Concrete	0.009 to 0.010	0.010 to 0.012	Storm Sewer: 0.011 to 0.012
			Sanitary Sewer: 0.012 to 0.013
HDPE Lined	0.009 to 0.015	0.009 to 0.013	Storm Sewer: 0.012 to 0.020
PVC Solid Wall	0.009 to 0.011	0.009	Storm Sewer: 0.011 to 0.013
			Sanitary Sewer: 0.011 to 0.013
Corrugated Pipe	0.012 to 0.030	0.012 to 0.026	0.21 to 0.029

1.2 Objectives of this Research

Some studies have shown that culvert roughness changes with depth of water in the culvert (Camp, 1946 and Pomeroy, 1954), but there is an absence of consistent results and there is almost no relevant data on variation in roughness at flow depths below 20% full (Mangin, 2010). Therefore the objectives of this research were focused on:

1. Collecting water depths in the culvert at four different slopes (0.2%, 0.4%, 1% and 2%) and discharge ranging from 0.2 to 10.3 cfs.
2. Calculate the Manning’s Roughness Coefficient for each measured depth.

3. Derive the nature of variation of Manning's Roughness with depth in partially filled HDPE culverts.

HDPE culverts were studied because HDPE is the most common type of culvert material currently being used in the state of Ohio due to its low installation cost, ability to withstand aggressive environmental conditions, and ability to withstand traffic loads. OEPA's Nationwide Permit (Clean Water Act 2002) program requires a maximum of 3% installed slope for the culvert for effective performance (Tumeo and Pavlick 2011). Based on this fact, the test slopes of the culverts were selected such that they ranged from a nearly level slope of 0.2% to the average slope of 2%. Since this research was aimed at calculating Manning's Roughness Coefficient at depths less than 20%, a discharge range from 0.2 cfs to 10.3 cfs was selected such that for 3.5 ft culvert, the maximum water depth was approximately 20% of the diameter. Another reason behind the discharge range was that the maximum limit of the pump in the fluid mechanics lab is only 10.3 cfs.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Concerns about habitat fragmentation due to blockage of fish movement have been raised by Winston *et al*., (1991); Schrank *et al*., (2001); Morita and Yamamoto, (2002). When there were no stream crossings, fish and other aquatic organisms typically migrated from one reach to another freely, but with the addition of structures such as bridges and culverts, the linkage between reaches has often been broken. Barriers to fish passage can result in interrupted seasonal migrations, restricted access to food sources, increased rate of diseases and reduction in genetic diversity (Yanes *et al*., 1995). As a result, the habitat of aquatic organisms is strained, individuals become isolated from larger populations and ultimately local populations may collapse (Farhig and Merriam, 1985 and Jackson, 2003).

The understanding that culverts act as fish passage barriers arose in the late 1950s (McKinley and Webb, 1956). Since then many research studies have been completed both on new as well as existing culverts for improved fish passage, which include investigations into the proper choice of gradient, length, water depth and decreased velocity (Gebhards and Fisher, 1972). If not properly designed, culverts can prevent the upstream passage of fish and aquatic organisms (Roni *et al*., 2002 and Warren and Pardew, 1998). The traditional highway design manual specifies the criteria for headwater depth to pass a design flood but fails to provide for fish passage (Norman *et al*., 2005). The primary criteria that should be included to account for fish passage design are water depth, velocity and outlet drop (Baker and Votapka, 1990; Votapka, 1991; Fitch, 1995 and Bates, 1994).

There are different types of fish passage barriers. High velocities may preclude fish from being able to swim upstream fast enough to move up the culvert whereas at low flows, inadequate water depth may not fully submerge fish (Fitch, 1995; Barber and Downs, 1996; Maine DOT, 2007). In addition to high velocity and inadequate water depth, an excessive outfall height (Baker and Votapka, 1990) and high turbulence within the culvert (Bates *et al*., 1999) also increase the risk that a culvert acts as a fish passage barrier. The length of the culvert also affects fish passage. Longer culverts result in extended times that a fish is required to maintain elevated swimming speeds and the fish may become exhausted within the culvert (Tillinger and Stein, 1996).

2.2 Factors Known to Affect Manning's Roughness Coefficient

The Manning's roughness of the culvert greatly influences velocity and depth of water inside the culvert (Lang *et al*., 2004). Manning's Roughness is a function of many known factors such as pipe material (Chow, 1959), pipe diameter (Straub and Morris, 1951), corrugations (Normann, 2005), velocity (Yarnell and Woodward, 1920), relative depth (Camp, 1946; Pomeroy, 1967), slope of energy grade line (Cosens, 1954) and hydraulic radius (Bloodgood and Bell, 1961). Though the nature of the variation of Manning's Roughness with some variables is already defined, some still need to be addressed.

For a set of relative depth data on 18, 24 and 36 inch concrete and corrugated steel pipe at an average slope of 0.2%, Straub and Morris (1951) found that the Manning's Roughness value decreased with increase in diameter when controlling for material. Similar research was conducted by Bloodgood and Bell in 1961 on vitrified clay, cement asbestos and cast iron pipe of diameter 4 and 8 inches and flow rates ranging from 2.6 gpm to 4.32 gpm, however an opposite result was obtained such that an average Manning's Roughness Coefficient of 0.0082 for the 4 inch and 0.0108 for the 8 inch pipe for the slope of 1 in 250 for cement asbestos and clay pipe was calculated. Therefore for a set of discharge, slope and material, the Manning's Roughness Coefficient was found to increase with the increase in pipe diameter in one study (Bloodgood and Bell, 1961) and decreased (Straub and Morris, 1951). Though the variation of Manning's Roughness with different parameters was studied by many researchers, most of the practitioners do not account for the change in roughness due to change in pipe diameter. (Yarnell and Woodward, 1920; Marcus *et al.,* 1992 and Cox *et al.*, 2009).

Manning's Roughness varies with the pipe material. The coarser the material, the higher the Manning's Roughness value will be (Chow 1959). The recommended Manning's Roughness Coefficients for different pipe materials according to American Concrete Pipe Association (2007) are shown in Table 1.1. The Manning's Roughness Coefficient lies within the range of 0.009 to 0.01 for concrete pipe, 0.009 to 0.015 for HDPE lined pipes, 0.009 to 0.011 for PVC solid wall pipes and 0.012 to 0.030 for corrugated pipes.

2.2.1 Variation of Manning's Roughness Coefficient with Slope of Energy Grade Line

Manning's Roughness Coefficient is proposed to change with the slope of energy grade line (Cosens 1954). The arithmetic average of the Manning's Roughness value calculated for both clay and asbestos pipes with slopes of 0.25 to 0.4% ranged from

0.0075 to 0.011, and showed an increase of Manning's Roughness with increase in slope. The statement of Cosens about the relation between Manning's Roughness with slope is also supported by Bloodgood and Bell (1961). The Manning's Roughness Coefficient as computed for clay and cast iron pipe on an average slope of 1 in 400 was significantly less than that computed for an average slope of 1 in 250 (Bloodgood and Bell, 1961). While both of these studies indicate that Manning's Roughness Coefficient increases with slope of energy grade line (Cosens, 1954 and Bloodgood and Bell, 1961), standard methods for determining Manning's Roughness Coefficient (Marcus *et al*., 1992) currently ignore the relationship between Manning's Roughness Coefficient and energy grade line slope.

2.2.2 Variation of Manning's Roughness Coefficient with Relative Depth

The Manning's Roughness Coefficient has been shown to vary with relative depth. Relative depth is the term given to the dimensionless ratio of flow depth to the diameter of the culvert (Yarnell and Woodward, 1920). Similarly, relative Manning's Roughness is the term used to define the ratio of Manning's Roughness for partial flow to full flow (n/n_f). An experiment performed on drain tile of 8 inch to 12 inch diameter with slopes varying from 0.05% to 1.5% and discharge ranging from 25% to 100% full suggested that the Manning's Roughness value increased with the decrease in relative depth value (Yarnell and Woodward, 1920). Similar results were obtained by Wilcox (1924) on 8 inch asbestos concrete and vitrified clay pipe and slopes varying from 0.5 to 4% with similar discharge rates as that of Yarnell and Woodward (1920).

Camp (1946) used the data measured by Johnson (1946) to calculate Manning's Roughness values and agreed that Manning's Roughness is not constant for all flow conditions in a pipe. He further stated that due to the lack of sufficient data, culverts are being designed using the full flow roughness. Based on those data, Camp (1946) concluded that the partial flow roughness is greater than full flow roughness. Camp's roughness curve is shown in Figure 2.1. From Camp's curve, it could be concluded that the Manning's Roughness is maximum at 25 to 30% of the full flow and the maximum value is 20% greater than the full flow roughness. The data from Johnson (1946) upon which the curve is based are insufficient for relative depths less than 20%.

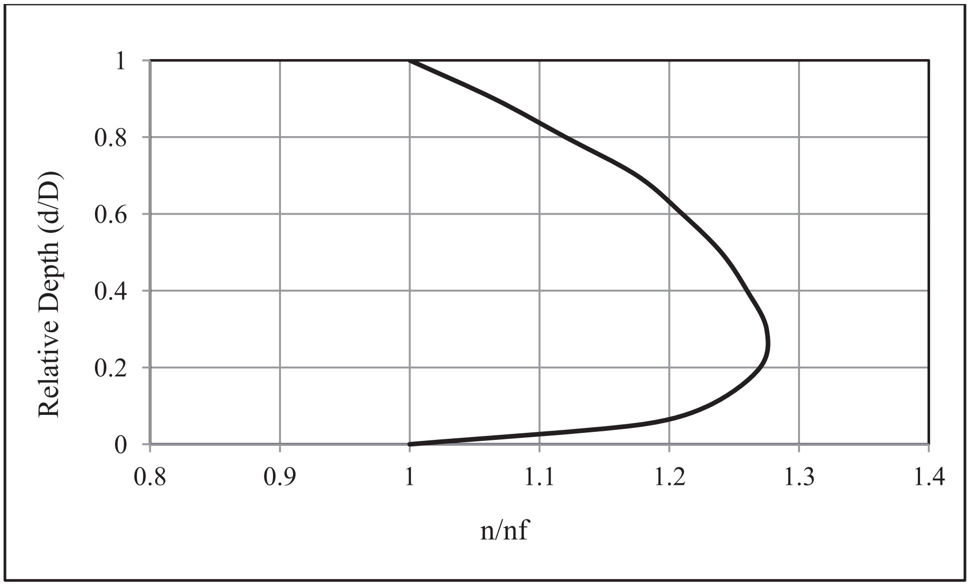


Figure 2.1 Camp's curve for the variation in relative Manning's Roughness Coefficient versus relative depth (Camp, 1946).

While the Camp curve showed that the Manning's Roughness varies with depth in a culvert, there were only three data points (calculated from the Darcy Weisbach friction factor) below 20% relative depth. Three data points are unlikely to be sufficient to describe the nature of the curve in that range. Camp's curve best describes the nature of the variation of Manning’s Roughness Coefficient for 4 inch to 12 inch diameter concrete and clay pipe. Camp (1946) calculated the relative Darcy Weisbach friction factor based on experiments conducted in Louisville sewers and calculated the value of relative Manning’s Roughness Coefficient based on the relationship in equation 2.1.

$$n/n_f = (R/R_f)^{1/6} * f/f_f \qquad 2.1$$

Camp’s calculated values of Manning’s Roughness at partial flows are higher than full flow but recent studies have shown that at very low relative depths, the partial flow roughness is lower than full flow roughness, indicating high flow velocity when compared to the design velocity (Pomeroy, 1967).

The research done by Camp (1946), Yarnell and Woodward (1920), Cosens (1954), Straub and Morris (1951) and Neale and Price (1964) do not have significant data at low relative depths (Pomeroy 1967). Pomeroy (1967) calculated Manning’s Roughness for the individual depth measurements and took the average ignoring the data points for which the Froude numbers were between 0.9 and 1.4. The Froude number is a dimensionless number which indicates flow regime and is a ratio of the inertial force to the weight of the fluid. A Froude number value equal to 1 represents critical flow (Okiishi *et al.*, 2006). At critical flow condition, the inertia force and the body force will be equal. The reason for removing the data points between Froude number 0.9 and 1.4 is that the roughness coefficient for a typical sewer may be depressed considerably at those flow conditions. The data from Wilcox (1924), Yarnell and Woodward (1920), Cosens (1954), Straub and Morris (1951) and Neale and Price (1964) produced a relationship between roughness and relative depth that is slightly different from Camp's relation. The result showed that the partial flow roughness is greater than the full flow roughness for depths greater than 18% (Pomeroy, 1967). Pomeroy's roughness curve is shown in Figure 2.2.

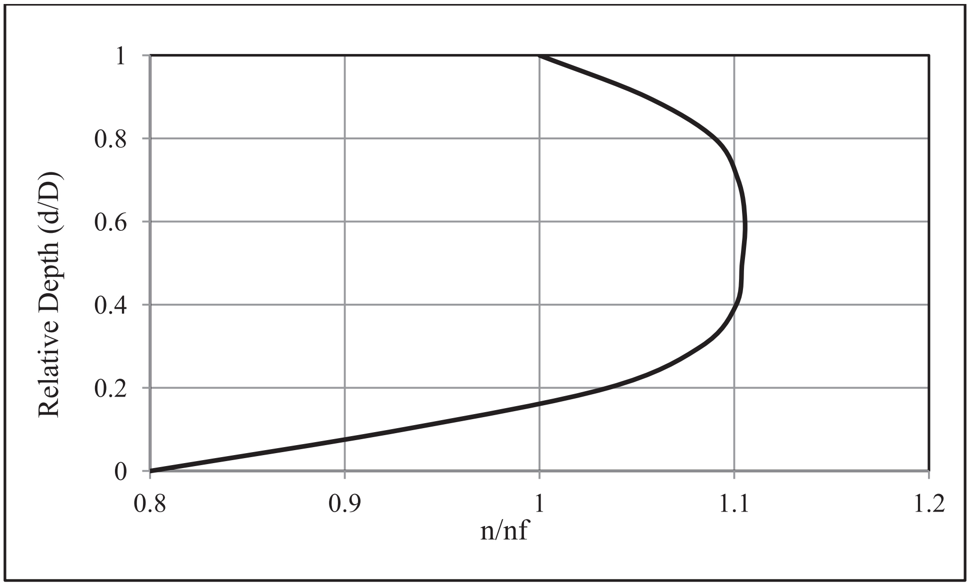


Figure 2.2 Pomeroy's Manning's Roughness versus relative depth curve (Pomeroy 1967)

While Pomeroy aimed to collect data at low flow depths he, in the end, also did not collect useable data at low flows. Pomeroy (1967) collected the data in 21 existing sewer lines. The total number of data points collected by Pomeroy (1967) below 20% relative depth was 78 and the maximum relative depth attained during his experiment was 69.9%. He did not ended up calculating full flow Manning's Roughness for the sewers because full flow was never attained in those sewer lines. Due to the fact that the sewer lines had accumulation of sediments, irregularities in the pipe bottom during construction and the material roughness changed with the culvert age, the Manning's Roughness Coefficient calculated from his research could not be compared to the data from new sewers. Those problems resulted in the absence of relative Manning's Roughness Coefficient in Pomeroy's curve at low flow depths.

Therefore neither of the curves (Camp, 1946 or Pomeroy, 1967) are supported by substantial data below 20% relative depth. The objective of this research was therefore to collect water depth in culverts in order to derive the nature of variation of Manning's Roughness with relative depth in partially filled HDPE culverts with an emphasis on relative depths less than 20% full.

CHAPTER 3: EXPERIMENTAL METHODS

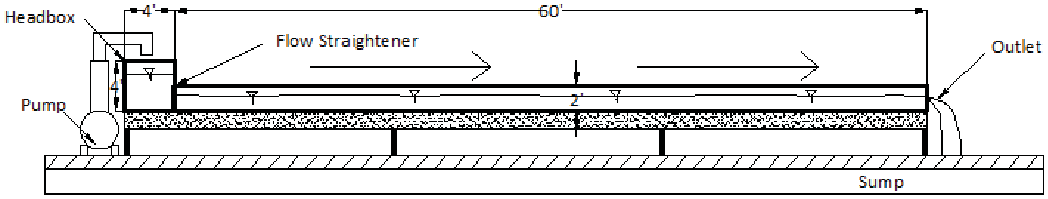
3.1 Introduction

The literature review indicated that culvert roughness changes with depth (Camp, 1946 and Pomeroy, 1967), but there is an absence of consistent results and little relevant data on roughness at relative depths below 20% (Mangin, 2009). It was therefore prudent to conduct laboratory experiments that would determine the variation of Manning's Roughness Coefficient with relative depth. Since Manning's Roughness coefficient could not be measured directly and varies with the water depth and discharge inside the culvert, the depths were measured at different discharges. In order to ensure water surface fluctuations with time, nine depth measurements were collected at 10 different cross sections such that slight temporal variations would not affect the results. A special emphasis was given to depths below 20% full.

In this study we varied discharge, slope and culvert diameter and measured water depth. The slope of the energy grade line could be computed from the measured water depth at four different flume slopes (adjusted using the flume tilt control). The diameters of the test culverts were 1 ft, 2 ft and 3.5 ft. In order to determine the discharge, a pump rating curve was created. The data collection therefore consisted of measurements of discharge for creation of the discharge rating curve and water depth in the culvert under various diameter, slope and discharge conditions in HDPE culverts.

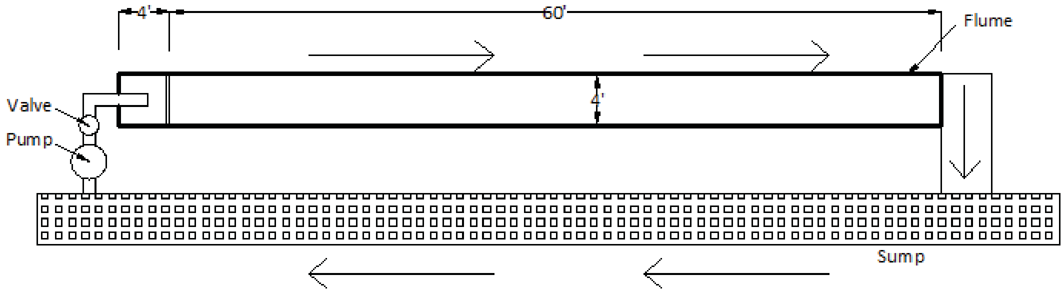
3.2 Experimental Setup

The experiments were carried out in the Fluid Mechanics Laboratory of the Civil and Environmental Engineering Department at the Youngstown State University. The experimental setup included a flume with tilting bed and test culverts, pump, outlet and sump. The flume with pump, outlet and sump is shown in Figures 3.1 and 3.2.



Profile: Flume

Figure 3.1 Flume plan showing pump, headbox and the sump area (Not to scale).



Plan

Figure 3.2 Flume profile showing pump and the sump area (Not to scale).

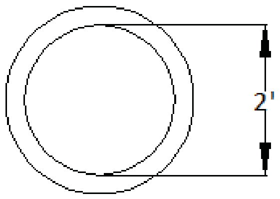
3.2.1 Flume, Sump and Pump Accessories

The flume in the Fluid Mechanics Laboratory was used for the entire experiment. The flume is a rectangular channel with aluminum bed and the side walls are made of glass sheets. The flume has dimension of 4 ft (width), 2 ft (height) and 60 ft (length) with a 4ft x 4ft head box at the upstream end. The flume has a tilting bed that can be adjusted from 0% to 3% slope.

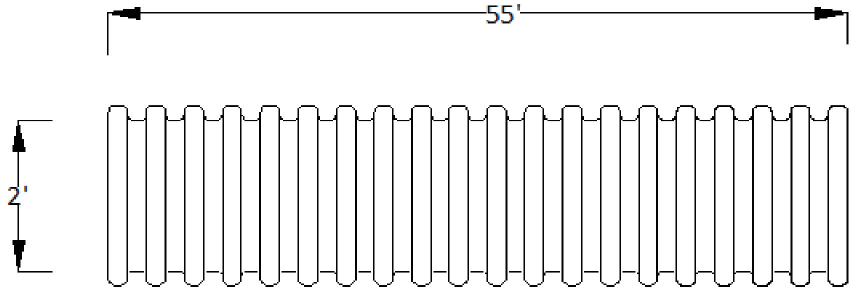
Water is supplied to the flume from a pump installed upstream of the flume. The water from the sump area is discharged into the headbox of the flume and an outlet was provided at the downstream end of the flume which returned the water to the sump, thus recirculating the water. Upstream from the pump, a control valve has been installed to limit the discharge of water into the headbox. As the number of opened turns of the valve is increased, the discharge increases.

3.2.2 Culverts

The HDPE culverts used in this research are externally corrugated but smooth inside. Three test culverts of diameter 1 ft, 2 ft and 3.5 ft were donated from Advanced Drainage Systems, Inc. Every 60 ft culvert is comprised of three 20 ft sections. Five feet of the culvert length was removed in order to place the culvert inside the flume. The final length of each of the culverts was 55 ft. The 1 ft culvert was lightweight and therefore was placed in the flume with the help of students but the 2 ft and 3.5 ft culvert were heavier and were positioned in the flume with the help of a forklift. Ten observation windows were cut in the top of each culvert at 5 ft interval along the length to allow access for data collection. The profile and cross section of the 2 ft culvert is shown in Figure 3. The 1 ft and 3.5 ft culverts have the same length but vary in terms of inside diameter.



Cross Section: Culvert



Profile: Culvert

Figure 3.3 2 Dimensional front view of the cross section and surface of the 2ft diameter culvert (Not to scale).

3.2.3 Headbox and Supports

The size of the culvert was smaller than the flume and therefore a headbox was needed to direct all the water into the culvert without any leakage. The headbox was made of plywood fit to the size of the headbox (4 ft x 4 ft). A circular hole was made in the headbox so that the culvert could fit exactly within it. Since the water was discharged by the pump with high energy, it exerted high static as well as dynamic pressure on the headbox wall. Therefore wooden bracings of 4 in x 4 in (width x depth) were provided from outside to hold the plywood firm against the pressure exerted by water from the inside. Lateral supports for the culvert were provided in order to hold the culvert in position. The supports were provided at 8 ft intervals and made of plywood.

3.2.4 Flow Straightener

In order to accurately report the water depth in the culvert, the depth of water through the culvert needed to be uniform. A flow straightener was provided to make the flow uniform and dissipate most of the kinetic energy within the headbox. Without the use of flow straightener, the flow in the culvert was highly unstable and was not reaching normal depth within the length of the culvert. Such distortions were eliminated by the use of the flow straightener. The flow straightener was made of drinking straws. The diameter of each straw was 0.296 inches while the length of each straw was 7.75 inches. The number of straws used for 1ft, 2ft and 3.5 ft were calculated and found to be 1,600, 6,500 and 20,000 respectively. The inlet of the culvert was filled with drinking straws and cotton fabric was used on the upstream and downstream side of the flow straightener straws to support the straws. A cross section of flow straightener made with drinking straws is shown in Figure 3.4.

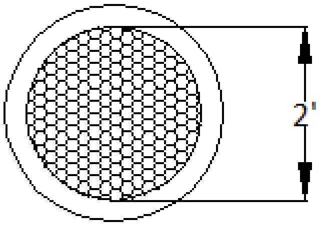


Figure 3.4 Cross section of flow straightener within the 2 ft culvert (Not to scale).

3.2.5 Waterproofing

Silicone was applied at the interface between plywood and glass, plywood and HDPE culverts and the joints between the culvert sections to make it waterproof. The waterproofing was done using Silicone I. The culverts were tested before collecting data to make sure that there were no leakages from the headbox and pipe joints.

3.2.6 Slope Setup

In the laboratory the slope of the flume was adjusted using the tilt control of the flume. The exact slope of the culvert bed was then obtained by measuring bed elevations at the upstream and downstream extents of the culvert using a surveying level (Model number 11378 CARL ZEISS Ni2 66539). Four different bed slopes were set for each of the three culverts, namely 0.2%, 0.4%, 1% and 2%.

3.3 Data Collection

The data collection process consisted of two steps:

1. Developing a discharge rating curve (Discharge Measurement)
2. Collecting water depths within the culverts (Depth Measurement)

The discharge measurements were performed to produce a discharge rating curve for the flume, and data were collected in the recirculating channel. The discharge rating curve is a plot of discharge versus the number of turns the control valve has been opened. Discharge is plotted on the Y-axis and number of turns on the X-axis. The second step was the water depth measurement. The water depth in the culvert for each change in discharge, slope and culvert diameter was measured. The water depth was measured at 10 locations along the length of the culvert and at each location; nine different depth readings were taken at different times at culvert center (invert) in order to account for minor water surface fluctuations with time.

3.3.1 Discharge Measurement

Discharge equals velocity times cross sectional area. Since the velocity within a channel varies at different points in a single cross section, the velocity at 30 different points within one cross section in the recirculation channel was measured and recorded using a Nortek Vectrino Acoustic Doppler Velocimeter (ADV) (Model number P22966). The ADV was mounted on an aluminum frame and the top of the probe was kept at least 6 cm above the bottom and away from the sides of the channel. A Nortek ADV Vectrinometer is shown in Figure 3.5.

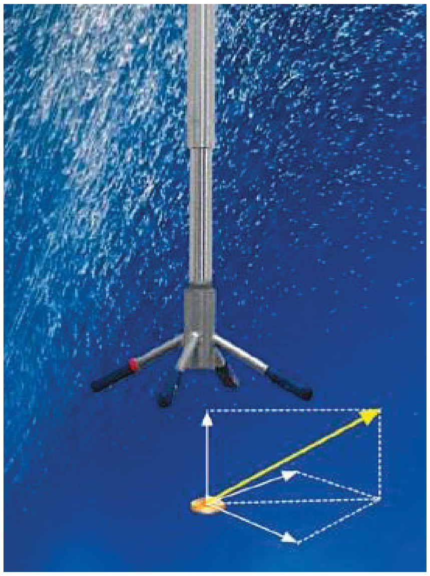


Figure 3.5 Nortek ADV Vectrinometer (www.nortek.no).

The cross section was located 20 ft downstream from the pump. With each increase in the number of turns of the control valve, the data were collected and reported via a cable which connected the vectrino probe to a computer. The data thus collected were the three dimensional velocity time series at 25 Hz for 60 seconds. The velocity readings were taken at one of the following velocity range ±0.1 m/sec, ±0.3 m/sec and ±1 m/sec (± represents the maximum and minimum velocities that can be recorded at each setting) for 60 seconds at each point. The reason different velocity ranges were used was that to measure the average velocity as accurately as possible. At low velocities a smaller range was used.

The magnitude of the average velocity was calculated as follows.

$$(V_{\text{mag- average}})_i = \sqrt{(Vx^2 + Vy^2 + Vz^2)} \tag{3.1}$$

where, i = 1 - 30 and was defined as the number of data points in the recirculating channel where velocity measurements were taken. V_x, V_y and V_z are the velocities along x, y, and z directions respectively at each point. The total area of the channel was divided into different sub regions depending on the number of velocity points taken. The subdivision of area and velocity points is shown in the Figure 3.6.

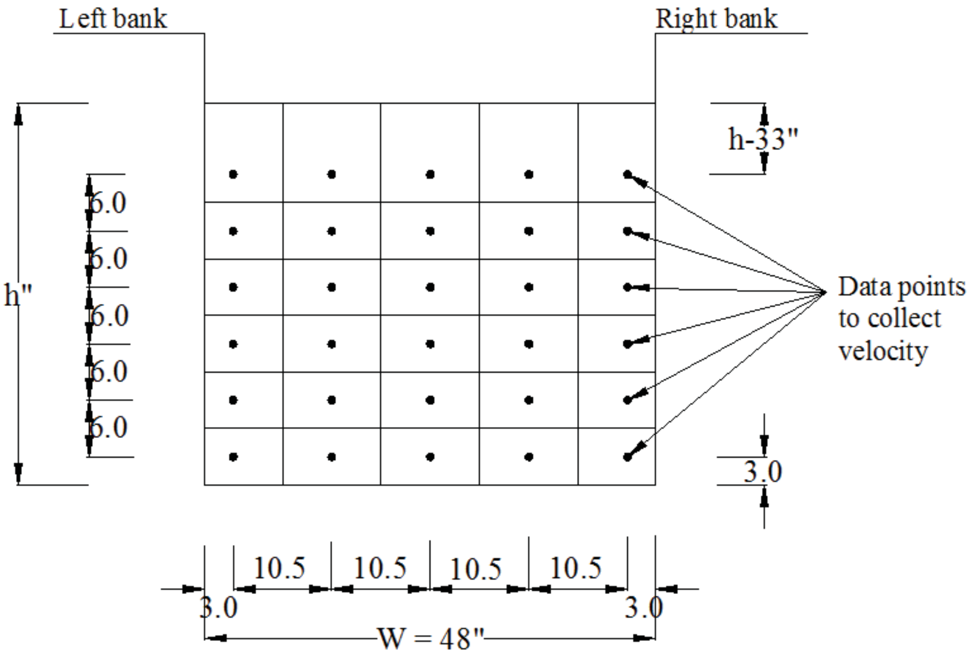


Figure 3.6 Cross section of the channel with data points used to determine discharge of the flume where, h is the measured height of water in the channel and w is the width of channel.

The water depth was measured by a yard stick. Three readings per turn were taken and were averaged to obtain the average water depth in the channel. The total area of the channel was divided into different sub regions depending on the number of velocity points taken. The subdivision of area and velocity points is shown in Figure 3.6.

The area of the sub regions a1 and a5 was calculated as follows.

$$A = (h - 33 + 3) \times (3 + 10.5/2) \text{ in}^2$$

Solving, we get $$A = (h-30) \times 8.25 \text{ in}^2 \qquad 3.2$$

where, h is the measured depth of water in the channel. The water depth was measured by a yard stick. Three depth readings per turn were taken and were averaged to obtain the average water depth in the channel.

The areas of the sub regions a2, a3 and a4 were calculated as follows.

$$A = (h - 33 + 3) \times (10.5/2 + 10.5/2) \text{ in}^2$$

Solving, we get $$A = (h - 30) \times 10.5 \text{ in}^2 \qquad 3.3$$

The areas of the sub regions b2 - b4, c2 - c4, d2 - d4, e2 - e4 and f2 - f4 were calculated as follows.

$$A = (6/2 + 6/2) \times (10.5/2 + 10.5/2) \text{ in}^2$$

Solving, we get $$A = 6 \times 10.5 \text{ in}^2 \qquad 3.4$$

The areas of the remaining regions namely b1 - f1 and b5 - f5 were calculated as follows.

$$A = (6/2 + 6/2) \times (6/2 + 10.5/2) \text{ in}^2$$

Solving, we get $$A = 6 \times 8.25 \text{ in}^2 \qquad 3.5$$

The total discharge at each turn was then calculated using Equation 3.6.

$$Q = \sum (V_{\text{mag average}})_i \times A_i \qquad 3.6$$

3.3.2 Depth Measurement

Water depth was collected at 10 locations in 5 ft intervals starting from the headbox within each of the three test culverts. For each location, culvert diameter and discharge, the water depth was recorded 9 times to avoid depth discrepancies associated with small waves and ripples. The observations were made in such a way that the measurements were taken at one location and moved to the next location and repeated 9 times over a period of 30 minutes in order to compensate for any long term variations in water depth. For this experiment, water depth in the culvert was measured by two techniques.

1. Meter stick
2. Acoustic tape measure

3.3.2.1 Meter Stick

For the 1 and 2 ft culverts, a meter stick was used to measure the water depth. To reduce the run up of water along the front edge of the ruler, the edge of the wooden ruler facing the flow of water was rounded. The maximum variation of water depth across any nine measurements was 0.12 inch.

3.3.2.2 Acoustic Tape Measure

The 3.5 ft culvert was large enough to fit exactly inside the flume with no walking space remaining along the sides. Further, the speed of the water inside of the 3.5 ft diameter culvert was generally higher than the water speed in the 1 ft and 2 ft culverts resulting in water running up the edge of the meter stick many centimeters. This run up made accurate measurement of depth difficult. Due to these problems in depth measurement using the meter stick method, an acoustic tape measure (Stanley Distance/Tape Measure Model number: 77-018) was used to measure the water depth inside the culvert. The acoustic device gave the depth from the top of the culvert to the water surface, which, when subtracted from the diameter of the culvert, gives the water depth. The accuracy of the acoustic tape measure was reported by the manufacturer to be 0.01 yards which is equal to 9 millimeters. This relatively low accuracy for a single reading has the potential to negatively affect the accuracy of the Manning's roughness results. However, with the 9 measurements taken at each location, the average error of the mean was reduced (See the Discussion Chapter for more details).

3.4 Manning's Roughness Coefficient Calculation

Manning's Roughness Coefficient can be calculated from Manning's equation. (Chow, 1959). Manning's equation can be rewritten to include the continuity equation such that:

$$Q = \frac{1.486}{n}(R_h)^{2/3}\,(S)^{½}\,A \qquad 3.7$$

Solving for n,

$$n = \frac{1.486}{Q}\,(A/P)^{2/3}\,S^{1/2}\,A \qquad 3.8$$

where, P is the wetted perimeter of the flow, A is the cross sectional area of the water inside the culvert and S is the slope of the energy grade line.

3.4.1 Calculation of Area and Wetted Perimeter:

Flow area A and wetted perimeter P were calculated as follows (Lindeburg, 1992).

i. For water flowing in a culvert less than half full (Figure 3.7):

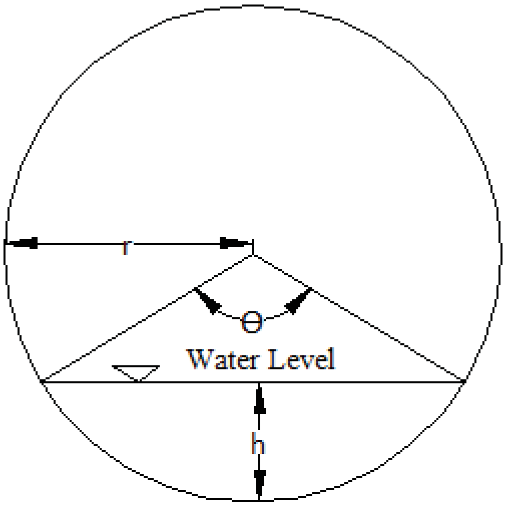


Figure 3.7 Cross section of the culvert less than half filled (Not to scale).

The area of the culvert portion filled by water was calculated as follows:

$$A = r^2 (\theta - \sin\theta)/2 \qquad 3.9$$

and $$P = r\,\theta \qquad 3.10$$

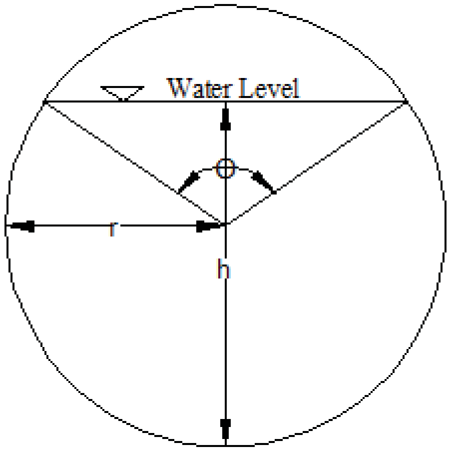
where,

$$\theta = 2 \arccos [(r - h)/r] \qquad 3.11$$

θ = central angle in radians

r = radius of the culvert

ii. For water flowing in a culvert more than half full (Figure 3.8):



$$A = \pi r^2 - r^2 (\theta - \sin\theta)/2 \qquad 3.12$$

$$\text{and} \quad P = 2\pi r - r\,\theta \qquad 3.13$$

where,

$$\theta = 2 \arccos [(r - h)/r] \qquad 3.14$$

Figure 3.8 Cross section of the culvert more than half filled (Not to scale).

3.4.2 Calculation of Energy Grade Line Slope

The energy grade line is the line that shows the total mechanical energy at any location in the culvert (Chow, 1959). The total energy of the flow through a culvert is the sum of the elevation of the culvert bottom with reference to a datum, water depth and the velocity head. The energy grade line was calculated using Equation 3.15 (Chow, 1959).

$$E = Z + h + V^2 / (2g) \qquad 3.15$$

where, Z is the elevation of the culvert bed where depth was measured from a datum, h is the water depth inside the culvert and V is the velocity of flow and g is the acceleration due to gravity.

The energy gradient along the flow direction is the slope of the energy grade line. For non uniform flow conditions, the slope of the flume does not accurately represent the slope of the water profile. In cases where the slope of the energy grade line and bed are similar but not equal, the slope of the energy grade line is used to calculate Manning's Roughness Coefficient in open channel flow (Chow, 1959).

The depth of water, h used in the above equation was the average depth of water in the culvert. The average of the 90 depth observations for each slope and discharge was used to calculate Manning's Roughness Coefficient within each of the three test culverts. The velocity of flow inside the culvert was calculated using the continuity equation as follows.

$$V = Q / A \tag{3.16}$$

where, A is the area of flow inside the culvert and Q is the discharge passing through the culvert at a particular number of valve turns.

An average slope of trend line for total mechanical energy versus distance from the headbox was calculated for each culvert slope and was used to calculate Manning's Roughness Coefficient. Thus the calculated Manning's Roughness Coefficients were reported and plotted against relative depth of water in the culvert.

CHAPTER 4: RESULTS

A discharge rating curve was obtained as a result of velocity and area measurements in the flume recirculation channel. The water depth profile was measured within culverts with varying discharge, slope and diameter. Discharge and depth thus collected were used to calculate Manning's Roughness Coefficient. The coefficients were then compared to the full flow roughness reported for HDPE culverts by Olsen (2011) and ISCO Industries, LLC (2011).

4.1 Discharge Rating Curve

The discharge rating curve is shown in Figure 4.1. The valve that controlled the discharge of water through the flume can be fully closed (0 turns) or fully opened (38 turns). The maximum discharge at 38 turns was 10.3 cfs. The rating curve indicates a nearly linear increase in discharge with turns up to turn 10. Above turn 10, the discharge increased less rapidly until turn 22. There was no considerable change in the discharge between turns 22 and 38. The percentage change in discharge between turns 22 and 38 was found to be 0.34. Rating curve was calculated multiple times for the valve opening from 0 to 38. The curve cannot be reproduced if the data were collected from fully opened (38 turns) down to fully closed (0 turns), therefore data were always collected from the closed to the open position. Discharge rating curve calculation can be found on Appendix-B.

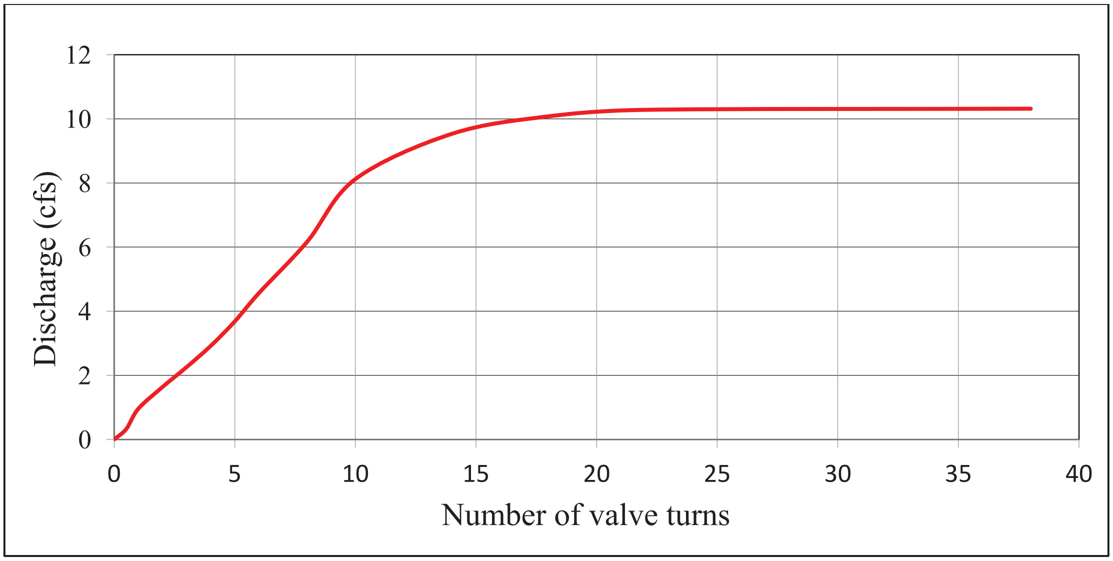


Figure 4.1 Discharge rating curve

4.2 Water Depth

For the 1 ft culvert, the maximum discharge that could be conveyed through the culvert was 3.02 cfs. Above this flow rate, water began spilling out of the top of the headbox. At 3.02 cfs, the culvert flowed full at the entrance but was only 75% full starting 5 feet downstream from the entrance. In order to examine the variation of Manning's Roughness under shallow depth conditions, a discharge increment of 0.5 control valve turns was chosen (approximately 0.25 cfs). The discharge therefore ranged from 0.22 cfs to 3.02 cfs for the 1 ft culvert. The 9 depth observations that were collected at each location were then averaged and plotted against the distance from the headbox. A typical water surface profile within the culvert is shown in Figure 4.2.

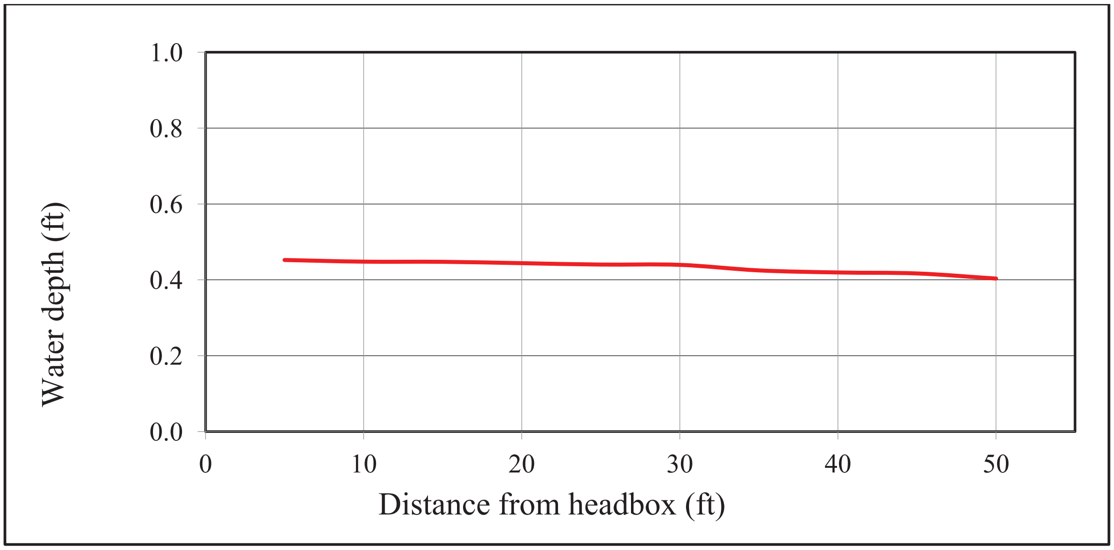


Figure 4.2 Typical water surface depth profile inside the culvert- 1ft diameter- turn 2 (0.43 cfs) - slope 1 in 250

The water depth in the 1 ft culvert ranged from 0.11 ft to 0.75 ft which corresponds to relative depth of 11% to 75% of the filled culvert. Depths were highest at 3.02 cfs and slope of 1 in 500 and lowest at 0.217 cfs and slope of 1 in 50 (i.e. the highest depth occurred at low slope and high discharge whereas the lowest depth occurred at steep slope and low discharge). For each discharge, 90 data points were collected and with 8 different values of discharges and 4 slopes, the total number of depth data points collected was 3,240 for the 1 ft culvert.

The maximum discharge that could be applied to the 2 ft diameter culvert without water spilling out from the headbox was 6.8 cfs at control valve turn 9. At 6.8 cfs, the culvert ran full at the entrance but was only 37.7% full 5 ft downstream from the entrance. In order to examine the variation of Manning's Roughness under shallow depth conditions, a discharge increment of 0.5 turns was chosen up to turn 1, and above 1 turn, an increment of 1 turn was used. The discharge therefore ranged from 0.22cfs to 6.8cfs for the 2 ft culvert. The water depth in the 2 ft culvert ranged from 0.088 ft to 0.754 ft, which corresponds to relative depth of 4% to 37.7% of the filled culvert. Depths were highest at 6.8 cfs and slope of 1 in 500 and lowest at 0.38 cfs and slope of 1 in 50. For each discharge, 90 data points were collected, and with 10 different values of discharges and 4 slopes, the total number of depth data points collected was 3,600 for the 2 ft culvert.

The 3.5 ft culvert was sufficiently large to open the control valve fully. Since the discharge did not changed significantly from 22 through 38, the water depth was collected up to turn 22. The discharge at turn 22 was 10.28 cfs. At 10.28 cfs, the culvert was 19.4% full at 1 in 500 slope. In order to examine the variation of Manning's Roughness under shallow depth conditions, the discharge increment of 1 turn was chosen. The discharge ranged from 0.96 cfs to 10.28 cfs for the 3.5 ft culvert. The water depth in the 3.5 ft culvert ranged from 0.105 ft to 0.679 ft, which corresponds to relative depth of 3% to 19.4% of the filled culvert. Depths were highest at 10.28 cfs and slope of 1 in 500 and lowest at 0.322 cfs and slope of 1 in 50. For each discharge, 90 data points were collected and with 12 different values of discharges and 4 slopes, the total number of depth data points collected was 4,320 for the 3.5 ft culvert.

In total, 11,000 data points were collected across all culverts for discharges ranging from 0.22 cfs to 10.3 cfs over slopes of 0.2% to 2%. Relative depths in the culvert ranged from 3% to 75%. Water depth data can be found on Appendix-A.

4.3 Slope of Energy Grade Line

The total recoverable head at any point inside the culvert was calculated and plotted against the distance from the head box. The gradient of this line is the slope of the energy grade line. The average slope of the energy grade line was determined by fitting a trend line passing through all the data points. The data that deviated from the trend line by more than 5% were considered to be outliers, and in most of the cases, the data were deleted to make the R-square value greater than 0.7. A trend line accounts for the most variance in the data when its R-squared value is equal to 1. As seen in Figure 4.3, the first three data points do not fit the trend line accurately. This trend that the first 10 to 15 feet of energy grade line was non-linear and inconsistent with the rest of the data was observed for most of the culvert slopes and discharges and was likely due to inlet effects. The slope obtained using all 10 data points was 1 in 86 while the flume slope was 1 in 104. After removing the first three outlier data points the slope obtained was 1 in 105.4. Therefore the equation of the trend line after omitting the outlier points gave the average slope of energy grade line for a particular discharge. The slope of this trend line was used as the slope of the energy grade line when calculating Manning's roughness. The calculations of slope of energy grade line before and after omitting outliers are shown in Figures 4.3 and Figure 4.4 respectively. Slope of energy grade line calculation can be found on Appendix-C.

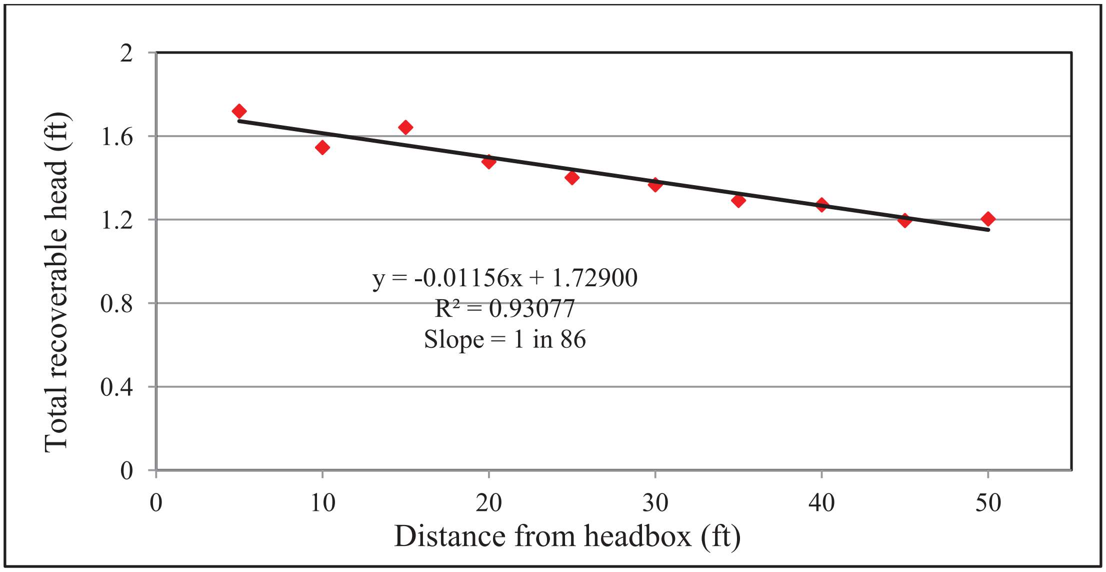


Figure 4.3 Energy grade line versus distance from headbox for 3.5 ft culvert at a slope of 1 in 100 (Q=4.6 cfs) before omitting outliers

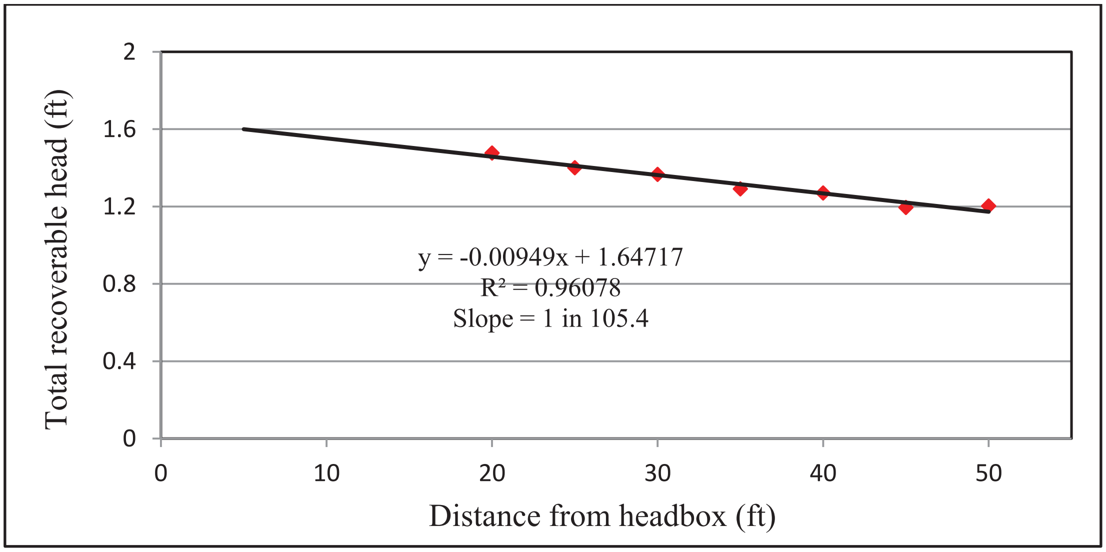


Figure 4.4 Energy grade line versus distance from headbox for 3.5 ft culvert at a slope of 1 in 100 (Q=4.6 cfs) after omitting outliers

4.4 Manning's Roughness Coefficient

With the four different values of slope of energy grade line obtained from four different flume slopes and the average water depth, Manning's Roughness

Coefficient for each discharge in each of the three test culverts was calculated. For the 1 ft culvert, 8 Manning's Roughness Coefficients were calculated at each slope and were plotted against the relative depth of water in the culvert (Figure 4.5). Similarly for 2 and 3.5 ft culvert, 10 and 12 Manning's Roughness Coefficients were calculated at each slope and were plotted against the relative depth of water in the culvert, respectively (Figures 4.6 and 4.7). Manning's Roughness Coefficient calculation can be found on Appendix-D.

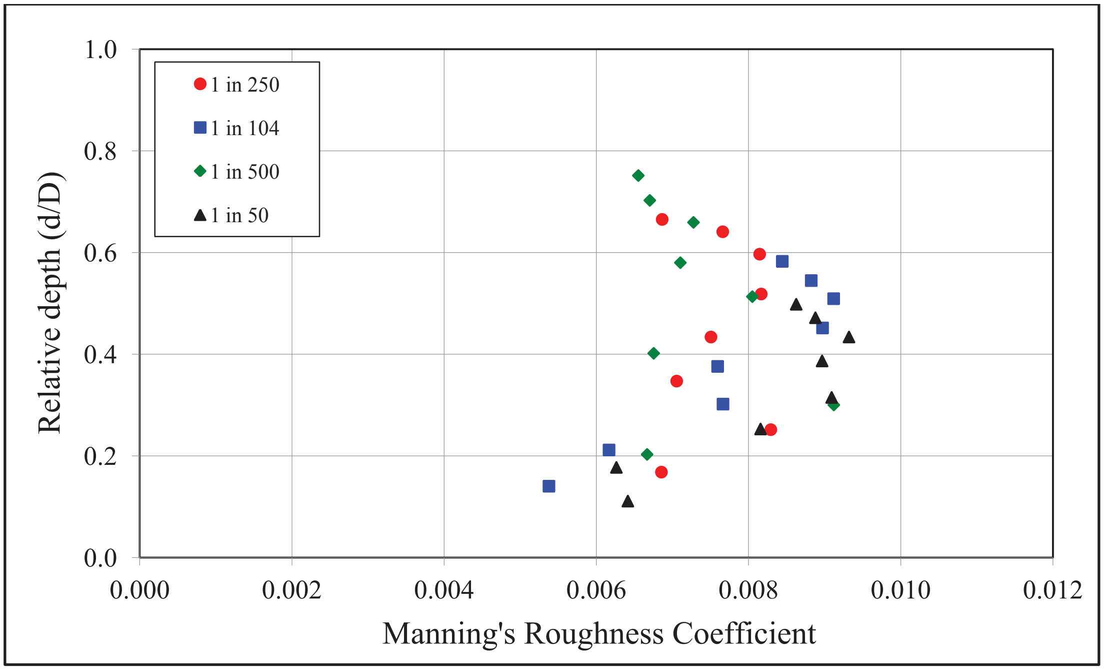


Figure 4.5 Manning's Roughness versus relative depth and slope in the 1 ft culvert

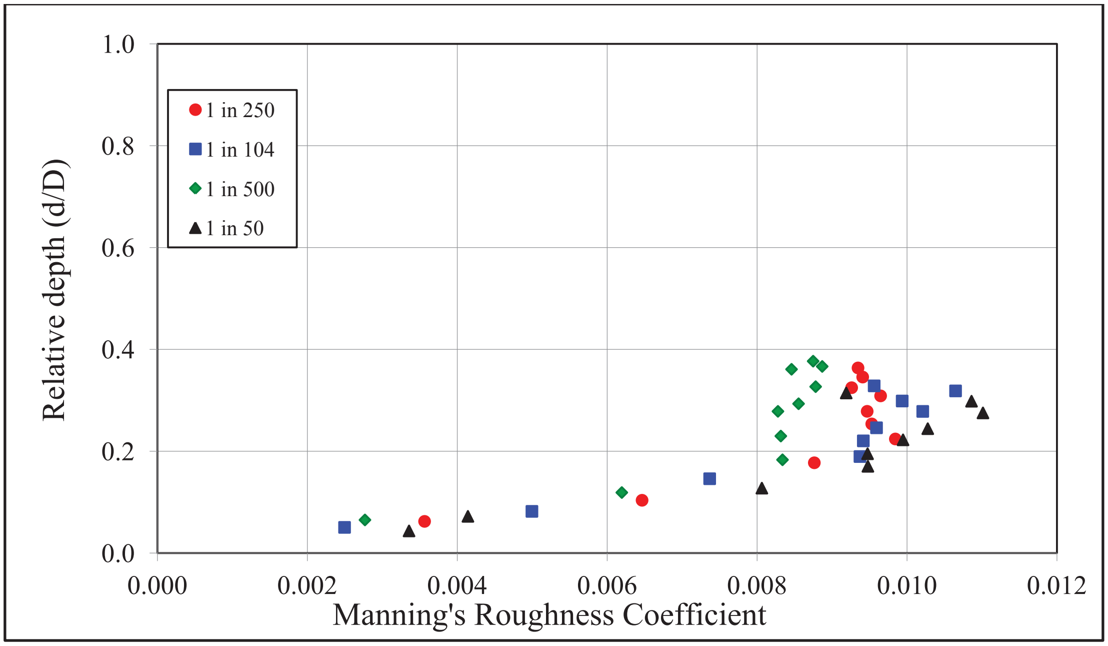


Figure 4.6 Manning's Roughness versus relative depth and Slope in the 2 ft culvert

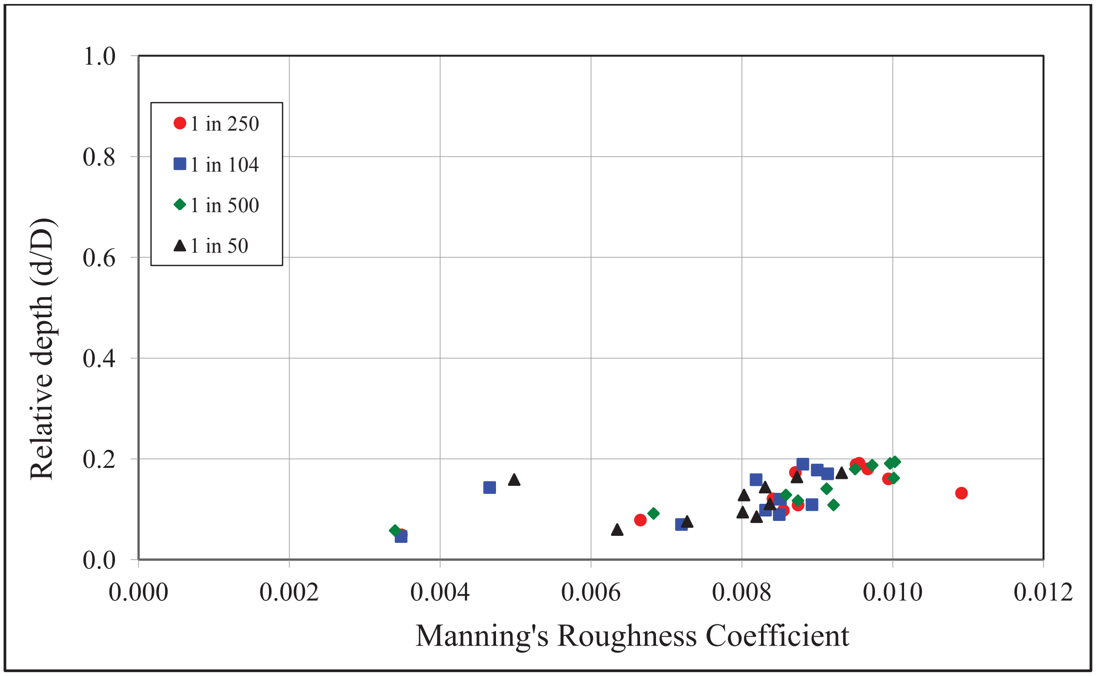


Figure 4.7 Manning's Roughness versus relative depth and slope in the 3.5 ft culvert.

The value of the Manning's Roughness Coefficient for the 1 ft culvert varied from 0.005 to 0.0093 for relative depth of 11% to 75%. The maximum Manning's Roughness Coefficient occurred at a relative depth of 43.4%. The data tended to curve back above 40% relative depth. At 75% relative depth, the average value of Manning's Roughness Coefficient was found to be 0.0066. The maximum value of Manning's Roughness Coefficient for the slope 1 in 500 was found to be 0.008. For slopes of 1 in 250, 1 in 104 and 1 in 50 slopes, the maximum values of Manning's Roughness Coefficient were found to be 0.0082, 0.0091 and 0.0093, respectively. The data followed a trend of increase in Manning's Roughness value with the increase in slope of the energy grade line.

Similarly, for the 2ft culvert, the value of the Manning's Roughness Coefficient varied from 0.0025 to 0.011 for relative depths of 4.4% to 37.7%. The maximum Manning's Roughness Coefficient occurred at relative depth of 27.5%. The Manning's Roughness Coefficient increased with the relative depth. At 37.7% relative depth, the value of Manning's Roughness Coefficient was found to be 0.0087. The maximum value of Manning's Roughness Coefficient for the slope 1 in 500 was found to be 0.0088. Similarly for slopes of 1 in 250, 1 in 104 and 1 in 50 slopes, the maximum values of Manning's Roughness Coefficient were found to be 0.0096, 0.010 and 0.011, respectively. The data followed a trend of increase in Manning's Roughness value with the increase in slope of energy grade line.

The Manning's Roughness value for the 3.5 ft culvert ranged between 0.0034 and 0.010 for relative depths of 4.6% to 19.6%. Maximum Roughness was observed at the relative depth of 19.6%. The Manning's Roughness Coefficient value increased with the increase in relative depth. Three data points were noted outside of the mainstream trend of the main data points as shown in Figure 4.8. The outliers that were noted were obtained for the discharge of 4.56 cfs and 1 in 250 slope; 6.2 cfs and

1 in 104 slope and 9.5 cfs and 1 in 50 slope. The calculated Manning's Roughness Coefficients are 0.011, 0.0046 and 0.0049 for the above mentioned three slopes, respectively. While the three Manning's Roughness values are outside the trend of the remaining data, upon review of depth collection methods, calculation of the slope of the energy grade line, and calculation of the roughness coefficient there is no physical basis to remove the data points from the dataset they have therefore not been removed. A figure showing the outlier data points for the 3.5 ft culvert is shown in Figure 4.8.

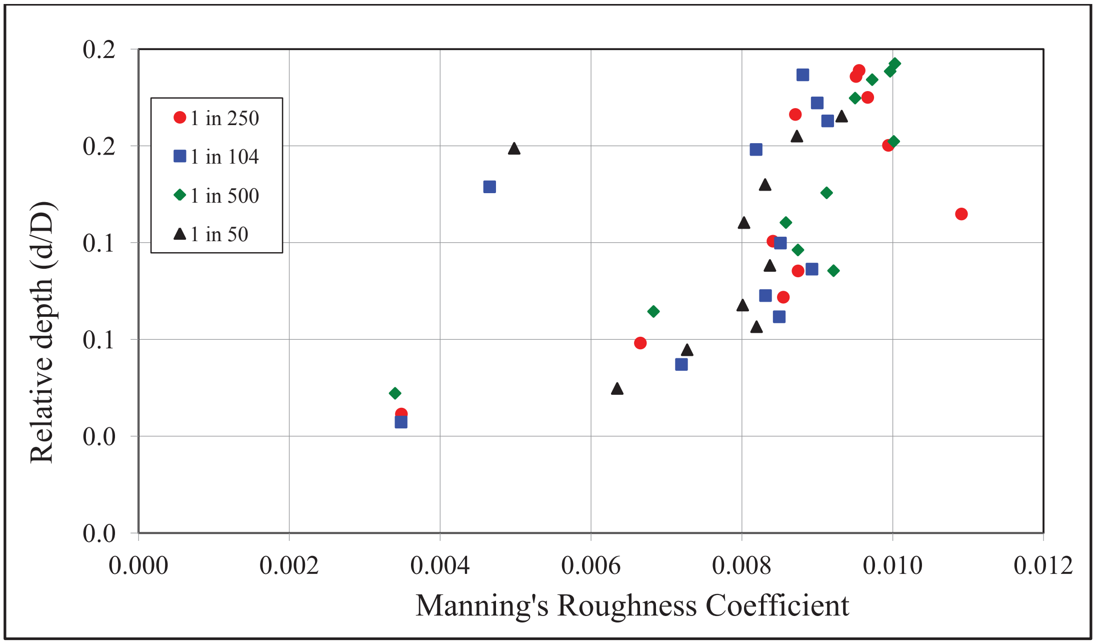


Figure 4.8 Manning's Roughness versus relative depth and slope in the 3.5 ft culvert showing outliers.

In order to compare the partial flow roughness with the full flow roughness calculated from the laboratory experiments, a full flow roughness was taken from Olsen (2011) and ISCO Industries, LLC (2011). The value of full flow roughness according to Olsen (2011) and ISCO Industries, LLC (2011) was 0.009. The relative Manning's Roughness Coefficient was plotted against the relative water depth. A plot of relative Manning's Roughness versus relative water depth for the three test culverts is shown in Figure 4.9. The plot indicates that the value of Manning's Roughness for most of the partial flows were observed to be less than 0.009 with the exception of some data between the relative depth 10% and 50% which were found to be higher than 0.009. The average Manning's Roughness value between 20 and 50% relative depth was found to be close to 0.009.

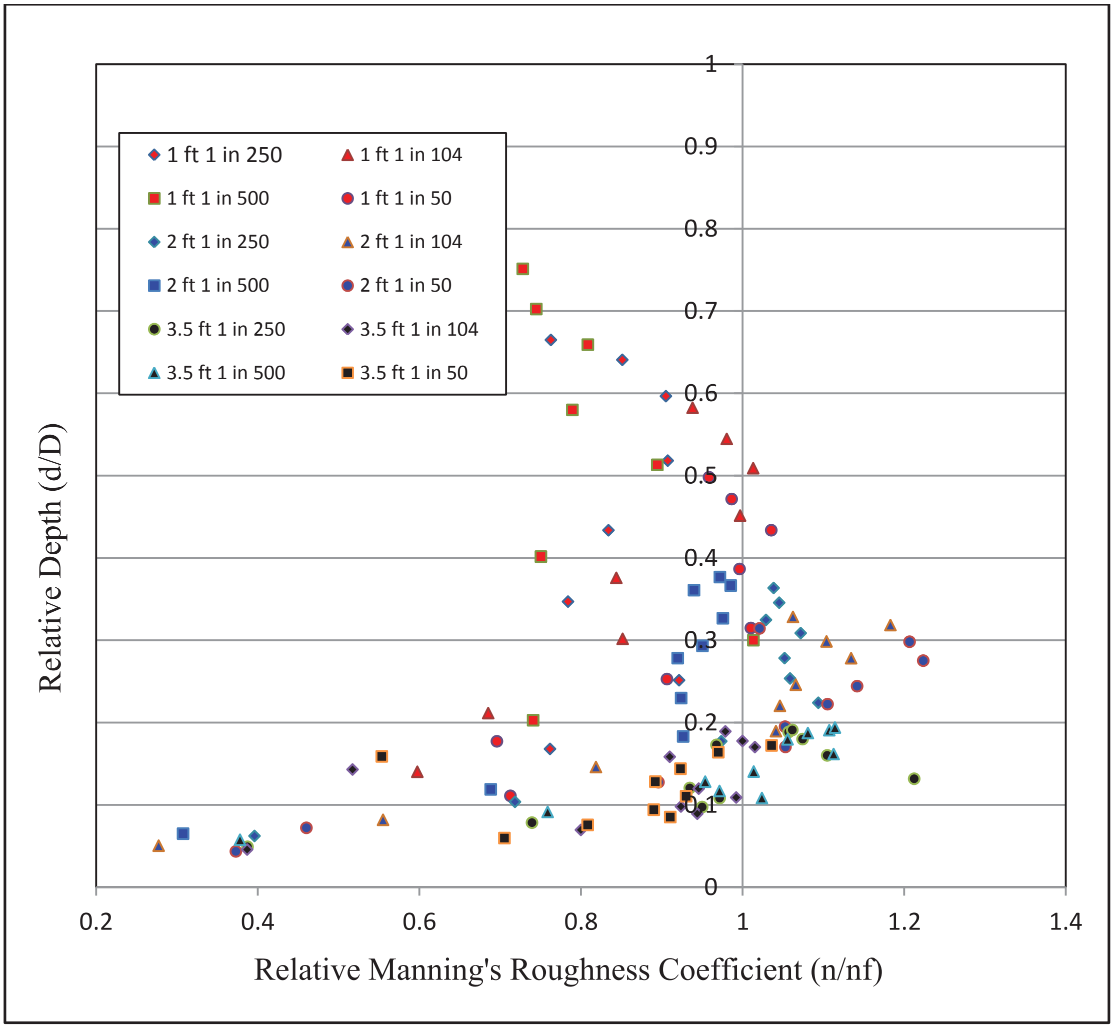


Figure 4.9 Manning's Roughness versus relative depth and slope for 1, 2 and 3.5 ft culverts. In the legend, 1 ft 1 in 250 means a 1 ft diameter culvert at a bed slope of 1 in 250. Similarly 2 ft 1 in 104 means 2 ft diameter culvert at a bed slope of 1 in 104 and so on.

CHAPTER 5: DISCUSSION

5.1 Water Depth

An example of the variation of water surface elevation inside the 1 ft diameter culvert at 1 in 250 slope and 0.38 cfs discharge is shown in Figure 5.1. The typical water depth profile was chosen as representative of all the other profiles in this study. The red dots at each sampling location represent the 9 depths collected and the blue line represents the average. According to the figure, the variation of measured depths at any point was small and that the average of the 9 data point sufficiently represents the water depth at each location inside the culvert. The maximum standard error of the mean water depth at any location for the three test culverts was found to be 0.236 inch (Moore and McCabe, 2003). The standard error of the mean represents a two-thirds likelihood of the mean being within the range given and is equal to the standard deviation divided by the square root of the number of observations. The percentage change in Manning's Roughness Coefficient due to the maximum standard error of mean of 0.236 inch was checked and found to be 7.7%.

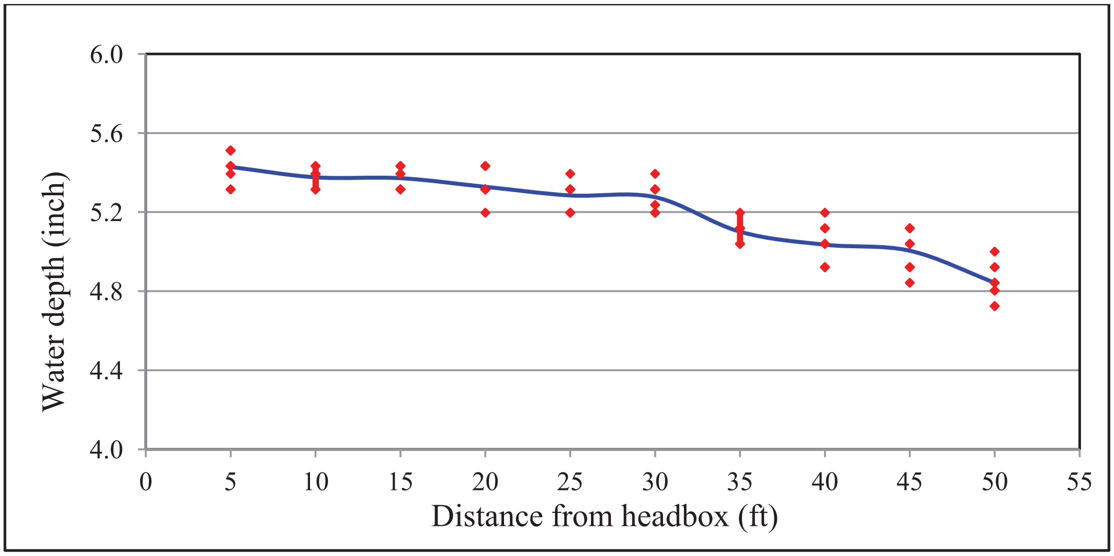


Figure 5.1 Water depth profile showing the variation in data inside 1 ft culvert at a slope of 1 in 250 (Q=1.63 cfs)

To calculate Manning's Roughness Coefficient, uniform water depth was required. In most of the cases the water surface does not reach uniform water depth in spite of the 55 ft culvert length. A spatial average of the flow depth was determined to give the most approximate estimate of uniform flow depth inside the culvert. The average of the 90 water depth readings from Figure 5.2 was found to be 3.02 inch.

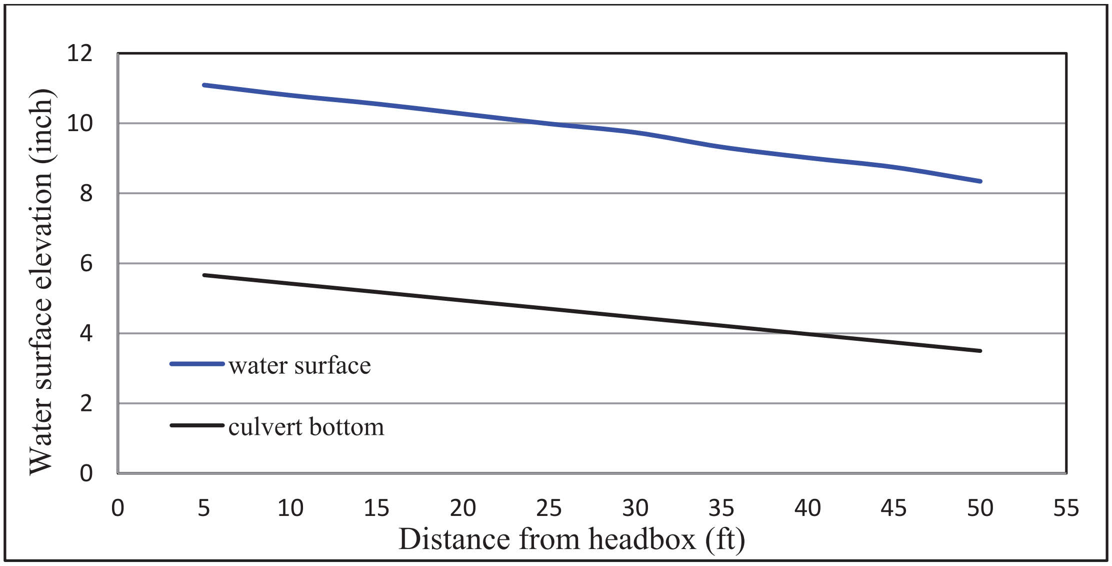


Figure 5.2 Water surface profile with culvert bottom of 1ft culvert at a slope of 1 in 250 (Q=0.43 cfs)

5.2 Manning's Roughness Coefficient

From the results presented in the previous chapter, it can be seen that the Manning's Roughness Coefficient varied from 0.002 to 0.011.

5.2.1 Variation of Manning's Roughness Coefficient with different parameters

The value of Manning's Roughness Coefficient varied with the diameter of the culvert. For instance let us take a slope of 1 in 250 and 15% relative depth. The 1 ft culvert has a Manning's Roughness Coefficient equal to 0.0069. The Manning's Roughness Coefficient was found to be 0.0074 for the 2 ft diameter culvert under the same slope and relative depth. Similarly for 3.5 ft culvert, the Manning's Roughness Coefficient was 0.0091. The 3.5 ft culvert has the maximum Manning's Roughness value among the three test culverts for the above case. The axis of the plot between Manning's Roughness Coefficient and relative depth was reversed to determine the trend line. A plot of reversed plot of Manning's Roughness Coefficient versus relative depth for 1, 2 and 3.5 ft culverts are shown in Figure 5.3, 5.4 and 5.5 respectively.

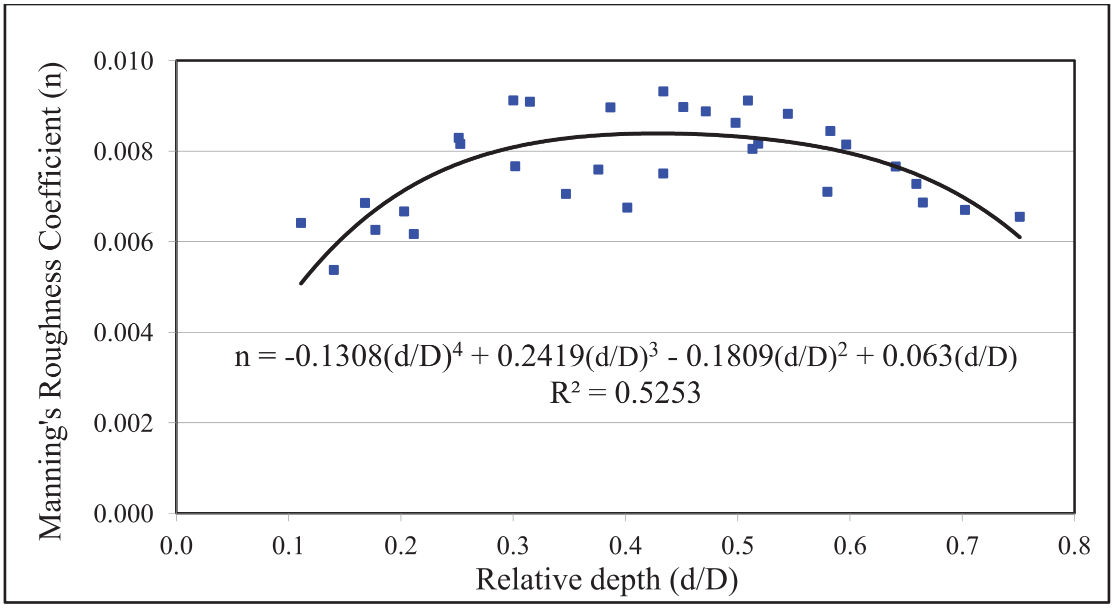


Figure 5.3 Trend line representing the relation between Manning's Roughness Coefficient and relative depth in 1 ft culvert.

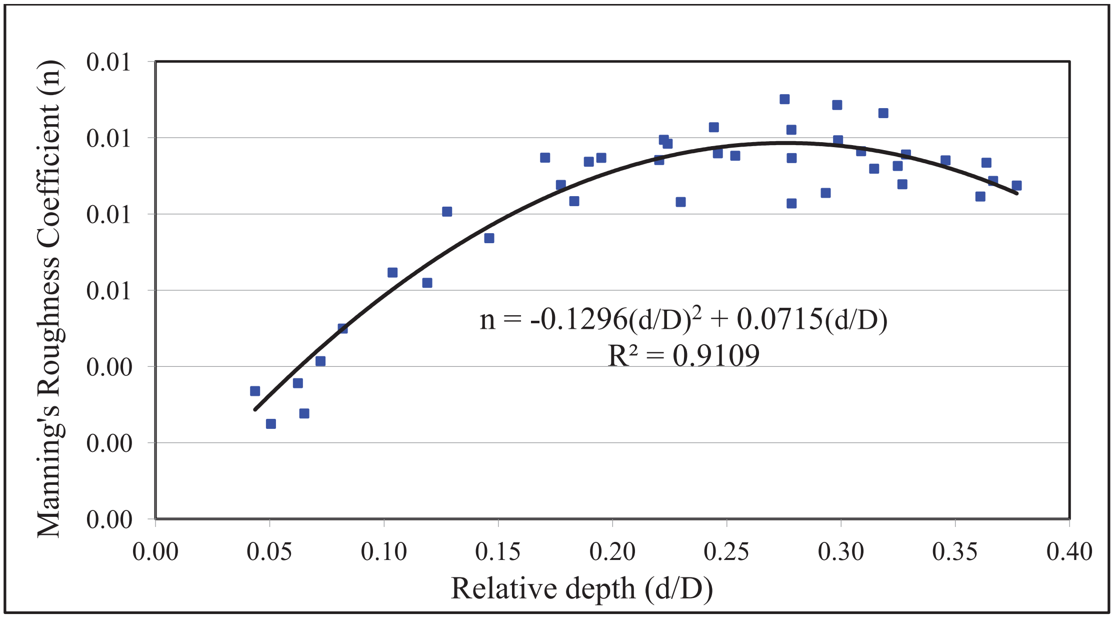


Figure 5.4 Trend line representing the relation between Manning's Roughness Coefficient and relative depth in 2 ft culvert

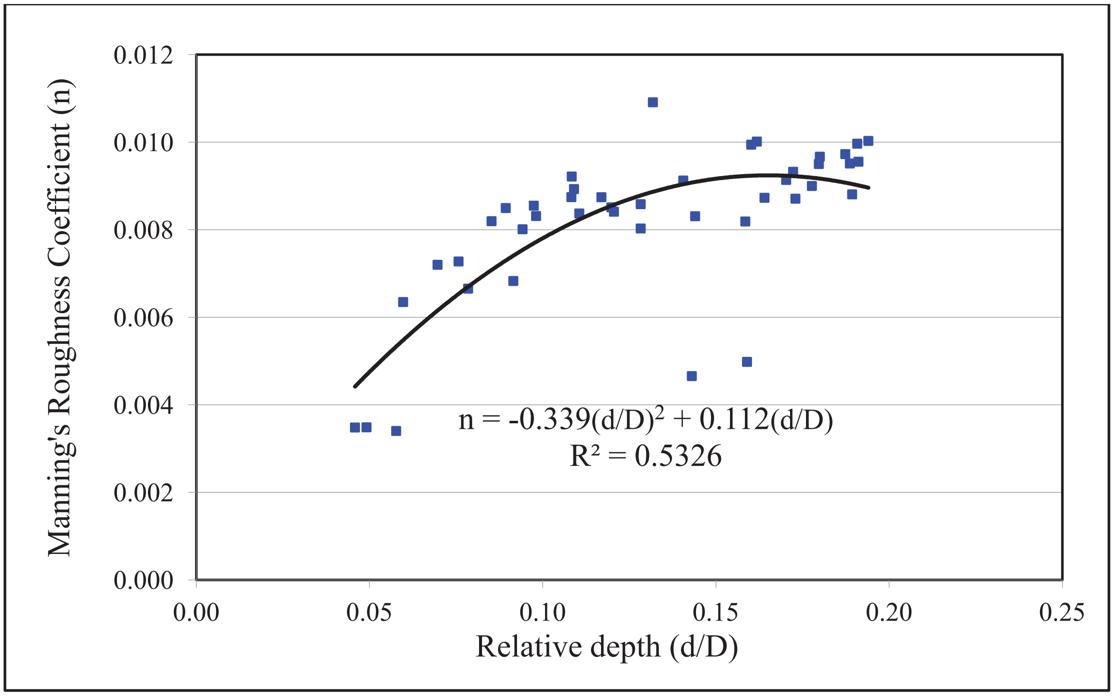


Figure 5.5 Trend line representing the relation between Manning's Roughness Coefficient and relative depth in 3.5 ft culvert

The three trend lines for different culverts were combined in one plot. A combined plot of all the three culverts with their respective trend lines are shown in Figure 5.6. A fourth order polynomial equation was used for the 1 ft culvert while a second order polynomial equation was used for the 2 ft and 3.5 ft culverts. The type of trend line (e.g. power, polynomial) most appropriate to the physical processes associated with these data was not explored.

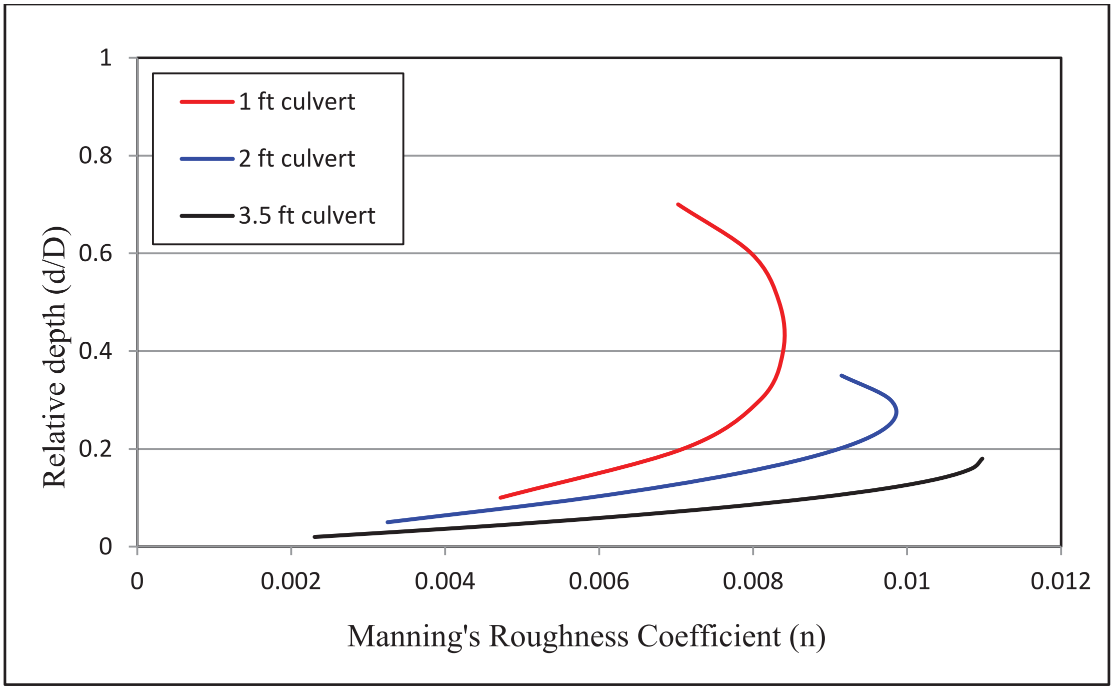


Figure 5.6 Comparison of trend lines for 1, 2 and 3.5 ft culverts. Trend line come from Figures 5.3, 5.4 and 5.5.

With this result for a particular value of relative depth, the Manning's Roughness Coefficient increases with the increase in diameter of the culvert.

As the slope of the energy grade line increased, the Manning's Roughness value also increased. The Manning's Roughness Coefficient for 1 in 500 slopes was found to be lowest and it increased with the increase in slope. The highest slope (1 in 50) had the maximum average Manning's Roughness Coefficient among the four slopes and was found to be equal to 0.011.

Manning's Roughness Coefficient varied with the depth of water in the culvert, from a minimum value of 0.0025 at 5.1% relative depth to a maximum value of 0.011 at 27.5% relative depth. The maximum roughness occurred at 27.5% relative depth and the data tend to curve backward with further increase in relative depth. For the highest measured relative depth of water in the culvert (75%), Manning's Roughness Coefficient was found to be 0.0066.

Below 20% relative depth, the value of Manning's Roughness was found to be less than 0.009. As the relative depth increased from 0 to 20%, the Manning's Roughness Coefficient increased fairly linearly from 0.0025 at a relative depth of 5.1% in the 3.5 ft culvert diameter up to a value of 0.009 at a relative depth of 20% for all the three culverts. Between 20 and 40% relative depth, the average Manning's Roughness Coefficient in this region was found to be 0.009 for the 2 ft and 3.5 ft culverts. Above 40% and below 75% relative depth, the value of Manning's Roughness decreased fairly linearly from an average of 0.009 to 0.0066 for the 1 ft diameter culvert.

The axis of the plot of relative Manning's Roughness Coefficient versus relative depth was reversed to determine a trend line that shows the relation between the variations of Manning's Roughness Coefficient with relative depth in partially filled HDPE culverts. A polynomial trend line of order 5 was drawn that passed through the average data points. A reversed plot of the data with the trend line is shown in Figure 5.7. The equation for the variation of Manning's Roughness Coefficient is shown below:

$$n/n_f = 46.82\,(d/D)^5 - 121.61(d/D)^4 + 119.76(d/D)^3 - 56.53(d/D)^2 + 12.46(d/D) \qquad 5.1$$

where, (d/D) represents the value of relative depth of water in the culvert and (n/n_f) represents the value of relative Manning's Roughness Coefficient. The value of full flow roughness was taken from Olsen, (2011) and ISCO Industries, LLC, (2011).

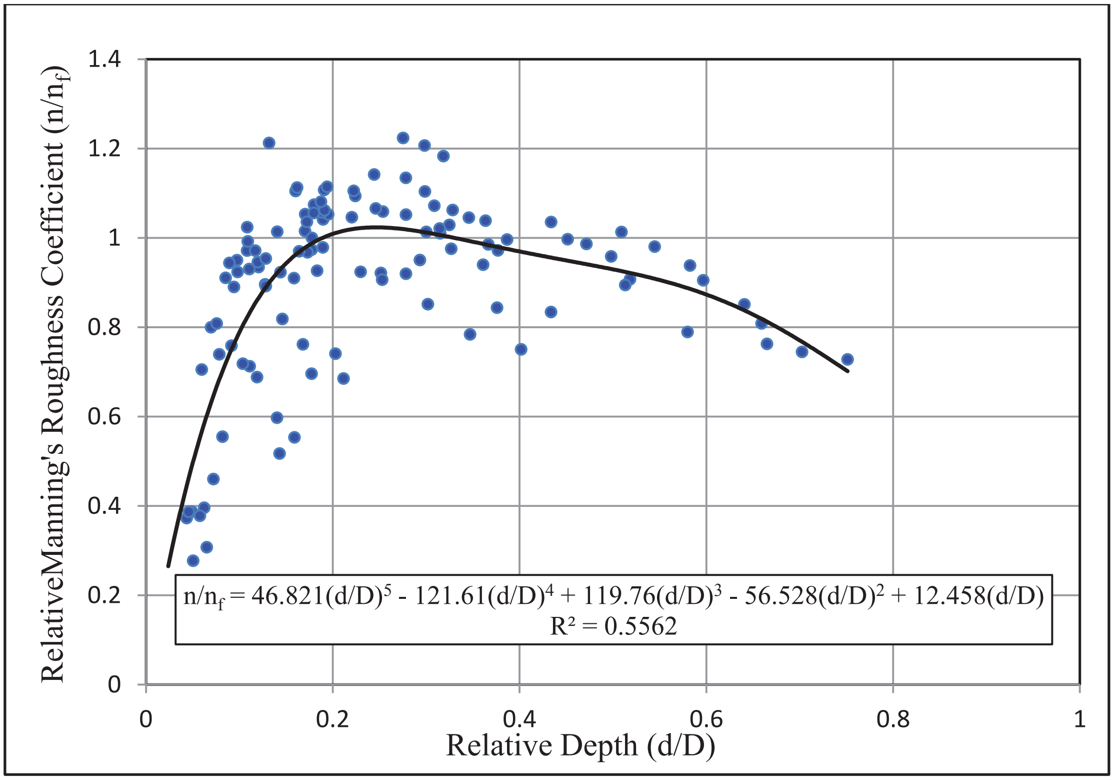


Figure 5.7 Trend line representing the relation between the relative Manning's Roughness Coefficient and relative depth

From the above trend line, it can be seen that the Manning's Roughness Coefficient is less than full flow roughness for flow less than 20%. Between 20 and 40%, the partial flow roughness is approximately equal to the full flow roughness, and above 40%, the partial flow roughness again decreases and is less than full flow roughness.

The discharge also played a vital role on the variation of Manning's Roughness Coefficient. It can be seen from the data (Figure 5.8) that as the discharge increased, the Manning's Roughness Coefficient also increased up to 3 cfs. Between 3 and 10 cfs little or no variation was found and the average Manning's Roughness value was found to be roughly constant with the increase in discharge. Figure 5.8

shows the variation of Manning's Roughness Coefficient with the discharge is shown in Figure 5.8.

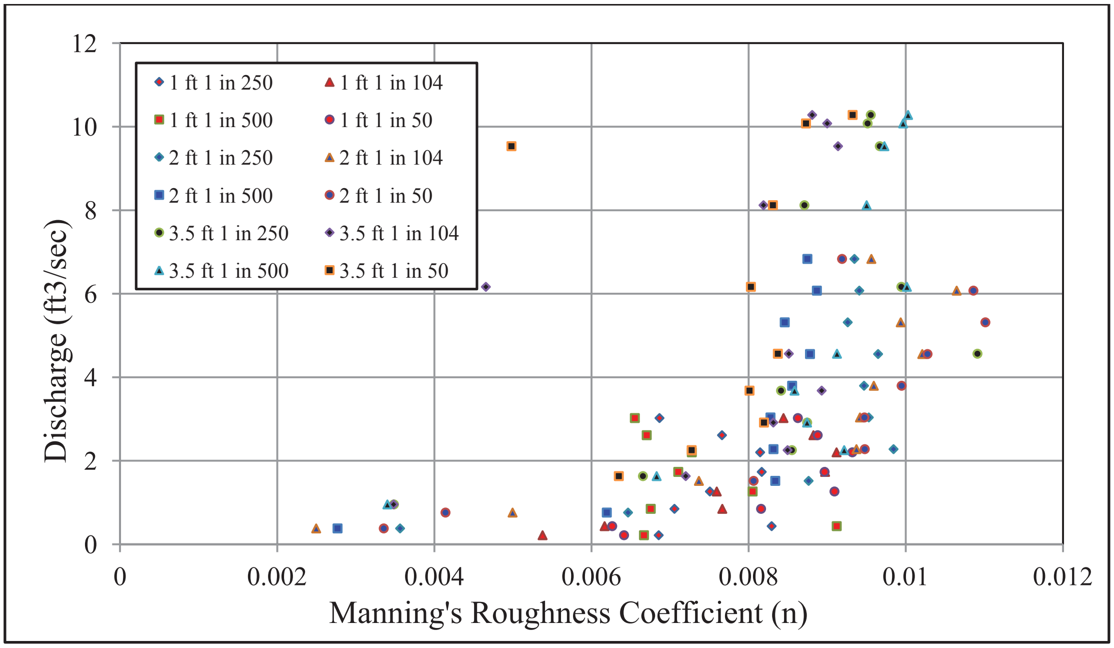


Figure 5.8 Manning's Roughness Coefficient versus discharge at different slopes

There was one data point at turn 1 whose energy grade line slope was calculated to be negative (increasing energy in the downstream direction) and was thus deleted from this thesis since energy cannot be created in the downstream direction (Florida Department of Transportation, 2009).

5.2.2 Full Flow Roughness

Full flow in the culvert was never attained during laboratory experiments due to head box height restrictions. In order to compare the partial flow roughness with the full flow roughness calculated from the laboratory experiments, a full flow roughness of 0.009 was taken from Olsen 2011 and ISCO Industries, LLC, 2011 and relative Manning's Roughness Coefficient was plotted against the relative water depth. The relative roughness versus relative depth data from the 1ft, 2ft and 3.5ft culverts did not plot exactly on top of each other as would be expected from either Camp or Pomeroy's predictions. A plot comparing the relative Manning's Roughness Coefficient calculated from the collected data with data from Camp (1947) and Pomeroy (1967) is shown in Figure 5.9.

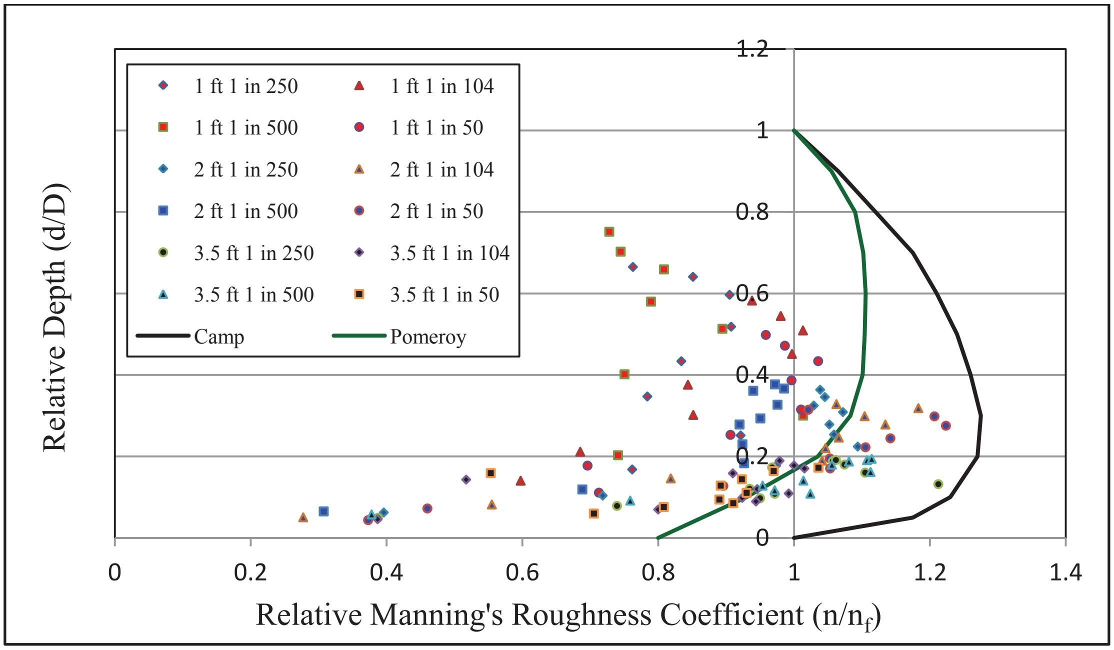


Figure 5.9 Comparison of calculated relative Manning's Roughness Coefficient versus relative depth with Camp (1947) and Pomeroy (1967)

While comparing the calculated Manning's Roughness Coefficient with the curve proposed by Camp (1947) and Pomeroy (1967), it is clear that neither of the curves were validated from the Manning's Roughness Coefficients value obtained from this research. Though the value of Manning's Roughness Coefficient was found to be different from Camp (1947) and Pomeroy (1967), the general shape is similar and the trend of the curve roughly matched the Pomeroy (1967) curve below 30% relative depth. Above 30% relative depth, the calculated Manning's Roughness was found to be less than the roughness value proposed by Pomeroy (1967). The calculated roughness tended to curve back after 40% relative depth, similar to both the Camp and Pomeroy's curves with the exception that the value was found to be less than full flow roughness. None of the data produced from this research validated Camp's (1947) curve. Despite the lack of data, the earlier assertion of Pomeroy (1967) that the Manning's Roughness Coefficient below 18% relative depth should be less than full flow roughness was validated from this research.

The trend line proposed in this research was then plotted against Camp (1946) and Pomeroy (1967) for validation. A plot of the three curves is shown in Figure 5.10 below.

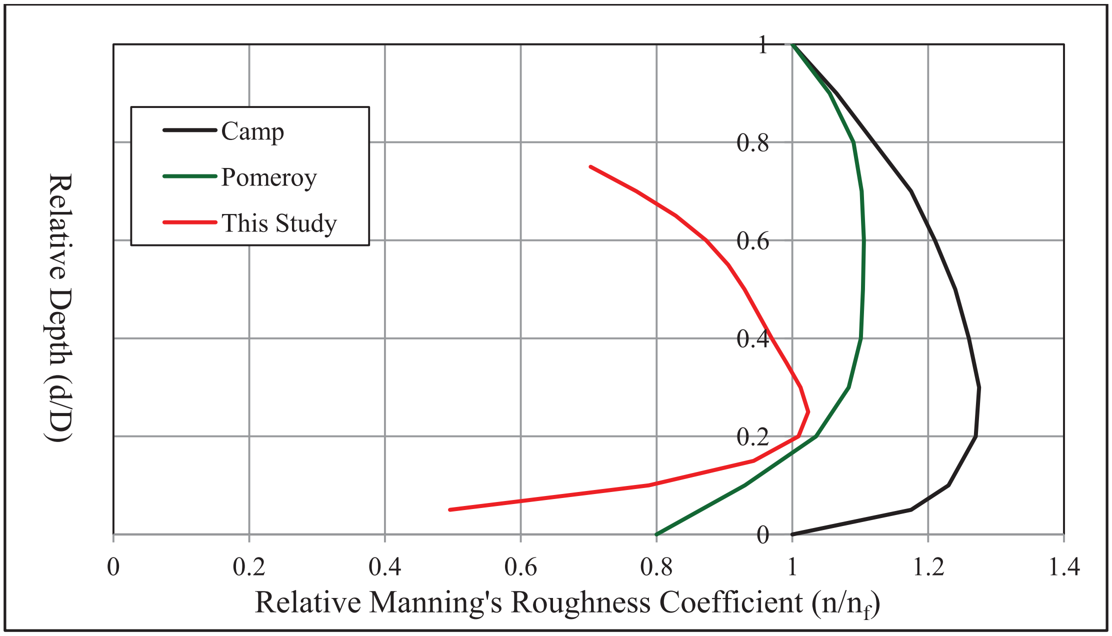


Figure 5.10 Comparison of curve proposed from this research with Camp (1947) and Pomeroy (1967)

The Reynolds's number of an open channel flow is defined as the measure of the ratio of inertia force to the viscous force acting on a fluid element (Okiishi *et al.*, 2006). The Reynolds's number at any water depth can be calculated using Equation 5.2.

$$\mathrm{Re} = \frac{VD}{\mathrm{V}} \qquad 5.2$$

where, V is the velocity of the fluid flowing through the culvert, D is the diameter of culvert and V is the kinematic viscosity of water at room temperature. For the case of partially filled conditions in a circular pipe, the appropriate length scale is considered to be equal to the hydraulic radius (R_h, Hayami, 1951 and Chow, 1959). Equation 5.2 is now modified as,

$$\mathrm{Re} = \frac{VR_h}{\mathrm{V}} \qquad 5.3$$

The Reynolds's number was calculated for the average water depth and plotted against relative Manning's Roughness Coefficient (Figure 5.11).

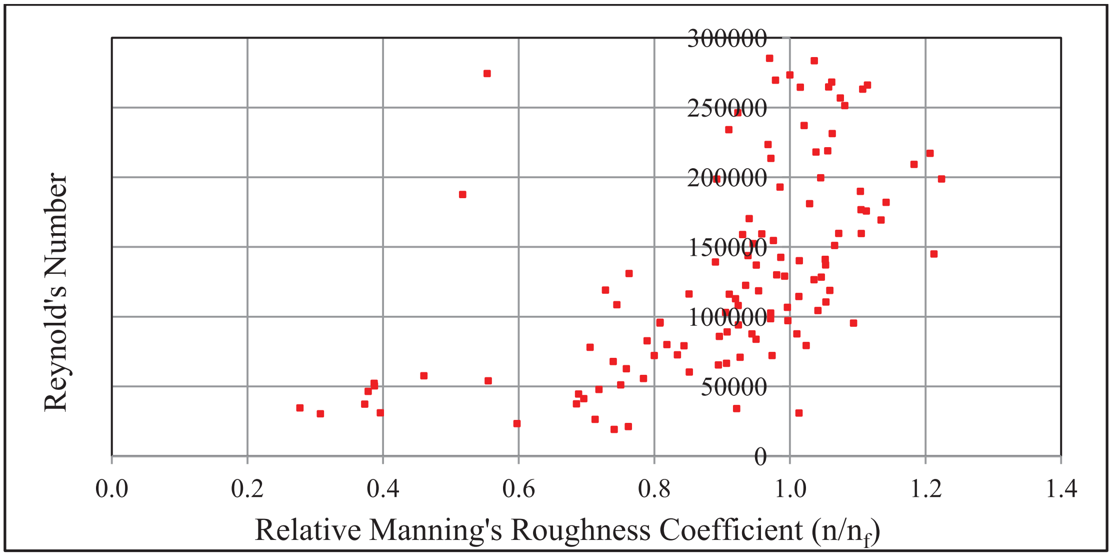


Figure 5.11 Relative Manning's Roughness Coefficient versus Reynolds's number.

Manning's Roughness value increased from 0.0025 at a Reynolds number of 3.5E4 to full flow roughness of 0.009 at Reynolds's number of 1.5E5. Between Reynolds's numbers of 1.5E5 and 3.0E5 the value of Manning's Roughness Coefficient remained roughly constant. This indicates that when the flow is wholly turbulent, the partial flow roughness is roughly equal to the full flow roughness. As can be seen from Figure 5.11, two data points seemed to be the outliers. Those points were for 1 in 50 slope at a discharge of 9.5 cfs and 1 in 500 slope at a discharge of 6.2 cfs for the 3.5 ft diameter culvert. These data while lying on the extreme inside of the remaining data points will be kept for further study since there is not a physical reason that has been identified for their removal.

Froude number is the measure of inertial forces acting on the fluid particle to the weight of that particle (Okiishi *et al.*, 2006). The Froude number can be calculated using Equation 5.4.

$$\mathrm{Fr} = \frac{V}{\sqrt{g\frac{A}{T}}} \qquad 5.4$$

where, V is the velocity of the fluid flowing through the culvert, A is the area of the cross section, g is the acceleration due to gravity and T is the top width of the fluid in the culvert. The Froude number was calculated for the average water depth and plotted against relative Manning's Roughness Coefficient (Figure 5.12).

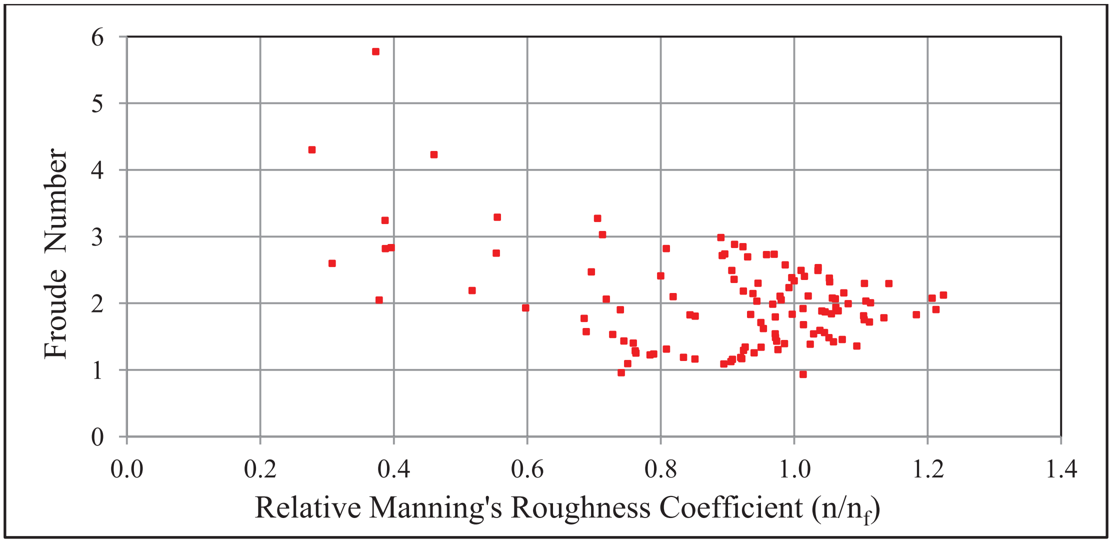


Figure 5.12 Relative Manning's Roughness Coefficient versus Froude number.

The plot between Froude number and relative Manning's Roughness Coefficient indicates that the Froude number was always greater than 1 with the exception of two data points as can be seen from Figure 5.12. A Froude number equal to 1 represents critical flow. Flow having a Froude number less than 1 represents subcritical flow and greater than 1 represents supercritical flow. Since nearly all of the data are from the supercritical flow regime, the data represent flow conditions in which inertial forces are more significant than gravitational forces. The two data points that subcritical were obtained from the 1 ft culvert at a slope of 1 in 500 with discharges of 0.22 and 0.43 cfs, respectively. There was discernible trend between the value of the Manning's Roughness Coefficient and the Froude number.

CHAPTER 6: CONCLUSION

In order to provide an answer to the question raised by Mangin (2010) concerning the need to predict Manning's Roughness Coefficient below relative depths of 20%, a set of physical experiments was begun in September 2010 in the Fluid Mechanics Laboratory of Youngstown State University. Three HDPE test culverts of diameter 1ft, 2ft and 3.5 ft, donated by Advanced Drainage Systems Inc., were hydraulically tested with different depths of water to determine the Manning's Roughness Coefficient of the culverts and to derive a relation between Manning's Roughness Coefficient and the relative depth of water. The culverts were tested at four different slopes, with discharge ranging from 0.2 cfs to 10.3 cfs. Altogether 11,000 depth data points were collected and the Manning's Roughness Coefficient was calculated for the measured depth for each of the three culverts using the calculated discharge rating curve of the flume.

The results of the experiment showed that the Manning's Roughness Coefficient varied with diameter, relative depth, slope and discharge. The result indicated that with the increase in the slope of energy grade line, the Manning's Roughness Coefficient also increases. The steep slope (1 in 50 in this case) has the higher Manning's Roughness Coefficient as compared to the flatter slope (1 in 500). The Manning's Roughness Coefficient also varied with discharge. Manning's Roughness Coefficient was found to increase with the discharge up to 3 cfs and between 3 and 10 cfs, the discharge remained relatively constant. For a particular value of relative depth, the value of Manning's Roughness Coefficient increases with the increase in diameter of the culvert. Manning's Roughness Coefficient also increased with increasing Reynolds number up to a value of 1.5E5, above which the coefficient remained constant. With the exception of two points, the water depths collected in the laboratory indicated that the flow was supercritical and the relation between Froude number and relative Manning's Roughness Coefficient could not well defined from the set of collected data.

The Manning's Roughness Coefficient increased with the relative depth below 20% such that as the depth increased the roughness increased. Below 20% relative depth the partial flow roughness is less than the full flow roughness (taken from Olsen, 2011 and ISCO Industries, LLC, 2011). Between 20% and 40% relative depth the partial flow roughness was found to be roughly equal to the full flow roughness. The results further indicate that the peak Manning's Roughness Coefficient for partial flow in the 1 ft, 2 ft and 3.5 ft diameter culvert was 0.011 and occurred at about 27.5% of the full flow. The result obtained from this research neither matched with Camp (1946) nor Pomeroy (1967) but there is a strong correlation with Pomeroy (1967) in terms of roughness below 18% full.

The fact that below 20% depth, the Manning's Roughness Coefficient is smaller than the design roughness (full flow roughness) causes the flow velocity to be higher than predicted or designed. Similarly from 20 to 40% full, the culvert has higher roughness indicating lower velocity than otherwise would be predicted. This led to the conclusion that the fish would experience higher velocity than predicted during low flows (less than 20%) which may cause a barrier to passage to exist when we currently do not predict one. At the same time for flow between 20 to 40%, the velocity will be closer to currently predicted velocities which may be more favorable for fish passage under moderate flow conditions than we currently predict.

6.1 Recommendations for Future Research

While one research question raised by Mangin (2010) related to predicting Manning's Roughness Coefficient below 20% relative depth was addressed in this research, questions still remain related to the impact of ageing on the culvert roughness.

Due to headbox height restrictions, full flow in the culvert was never attained. To compare the partial flow roughness calculated from the experimental data, the full flow roughness was taken from Olsen 2011 and ISCO Industries, LLC, 2011. Hence the actual relative roughness in our culverts is still uncertain and should ideally be determined.

Another recommendation for future research in the field of fish passage would be to determine the minimum submergence required for the different fish species for successful migration and calculate Manning's Roughness at that particular depth. Minimum submergence required for any fish species is the minimum depth of water at which the fish can swim easily through the culvert (Fitch 1995). The known value of Manning's Roughness Coefficient for the minimum depth required for fish species to swim will be useful while designing fish passage culverts.

CHAPTER 7: REFERENCES

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CHAPTER 8: APPENDIX A

Data Collection Sheets

Data Collection Sheets

Diameter of culvert: 1 ft

Slope: 1 in 104

Number of turn:		1/2											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	45	45	47	48	50	48	50	50	52	48.33		
2	10	42	45	42	47	48	48	48	50	50	46.67		
3	15	40	42	42	45	47	45	48	46	47	44.67		
4	20	42	40	42	45	45	47	47	45	46	44.33		
5	25	40	40	42	42	45	42	45	44	47	43.00	42.77	mm
6	30	42	40	40	40	45	43	45	43	43	42.33	1.68	inch
7	35	38	40	38	42	40	42	40	45	43	40.89		
8	40	38	38	38	40	42	40	42	42	40	40.00		
9	45	38	35	38	40	42	40	42	40	42	39.67		
10	50	35	35	37	38	35	40	40	40	40	37.78		
Number of turn:		1											
1	5	70	72	75	72	70	72	75	72	77	72.78		
2	10	68	68	65	68	65	70	70	68	68	67.78		
3	15	65	65	68	66	67	67	65	68	68	66.56		
4	20	65	67	67	65	65	68	65	67	67	66.22		
5	25	65	65	65	66	66	65	65	67	64	65.33	64.48	mm
6	30	62	64	64	62	65	65	65	65	65	64.11	2.54	inch
7	35	60	62	60	60	60	65	63	62	65	61.89		
8	40	60	60	60	60	62	60	60	60	65	60.78		

	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
S.N.	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
9	45	60	60	62	62	60	62	60	62	60	60.89		
10	50	50	58	60	58	60	60	60	60	60	58.44		
Number of turn:		1 1/2											
1	5	102	105	104	105	102	107	105	110	107	105.22		
2	10	95	97	94	95	90	90	98	95	98	94.67		
3	15	96	95	95	95	95	97	95	96	96	95.56		
4	20	92	92	95	95	97	97	92	95	95	94.44		
5	25	92	90	93	92	92	90	90	90	90	91.00	92.00	mm
6	30	90	90	88	90	90	89	90	90	90	89.67	3.62	inch
7	35	90	90	87	88	90	90	88	90	90	89.22		
8	40	87	88	85	88	90	87	87	90	88	87.78		
9	45	85	86	85	88	86	88	88	88	90	87.11		
10	50	84	85	82	85	85	88	85	87	87	85.33		
Number of turn:		2											
1	5	125	128	130	130	128	130	130	130	128	128.78		
2	10	122	125	126	120	122	124	125	123	123	123.33		
3	15	120	120	118	118	120	122	120	122	123	120.33		
4	20	115	115	117	115	117	117	115	115	118	116.00		
5	25	115	113	115	115	113	113	115	115	115	114.33	114.58	mm
6	30	112	115	113	112	115	113	112	110	112	112.67	4.51	inch
7	35	112	110	112	110	110	110	112	110	110	110.67		
8	40	108	105	110	108	106	106	105	107	107	106.89		
9	45	105	107	110	111	105	108	105	108	108	107.44		

	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
S.N.	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
10	50	106	105	105	105	110	105	105	102	105	105.33		
Number of turn:		2 1/2											
1	5	155	157	157	155	158	153	158	155	155	155.89		
2	10	148	150	145	148	150	150	148	148	150	148.56		
3	15	140	142	142	140	142	140	137	135	138	139.56		
4	20	138	140	140	140	138	140	137	136	137	138.44		
5	25	140	140	137	137	138	135	136	135	137	137.22	137.63	mm
6	30	136	138	138	138	138	135	135	135	135	136.44	5.42	inch
7	35	132	134	134	132	135	130	132	132	130	132.33		
8	40	132	133	130	132	130	130	130	130	134	131.22		
9	45	130	130	132	132	132	128	130	130	132	130.67		
10	50	125	125	122	127	127	127	128	125	128	126.00		
Number of turn:		3											
1	5	175	177	175	170	172	174	175	173	175	174.00		
2	10	166	164	168	165	162	165	167	170	170	166.33		
3	15	156	160	160	158	156	159	160	162	162	159.22		
4	20	158	155	157	157	158	157	157	159	157	157.22		
5	25	150	154	156	155	155	153	152	154	155	153.78	155.19	mm
6	30	152	152	154	152	152	154	155	152	152	152.78	6.11	inch
7	35	148	148	150	150	150	148	150	148	148	148.89		
8	40	150	148	148	145	145	150	146	146	148	147.33		
9	45	147	147	149	147	147	147	148	145	148	147.22		
10	50	145	147	143	145	147	145	144	145	145	145.11		

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
Number of turn:		3 1/2											
1	5	185	182	180	185	183	183	182	180	188	183.11		
2	10	175	170	172	170	172	172	172	175	172	172.22		
3	15	172	170	170	172	168	170	170	170	168	170.00		
4	20	165	165	165	163	167	167	165	167	167	165.67		
5	25	165	165	167	165	165	165	165	167	167	165.67	166.03	mm
6	30	166	164	164	162	162	165	163	165	165	164.00	6.54	inch
7	35	164	162	164	160	162	164	160	165	163	162.67		
8	40	160	162	160	160	160	165	160	162	162	161.22		
9	45	162	160	162	160	162	160	162	160	162	161.11		
10	50	157	155	155	155	155	152	153	155	155	154.67		
Number of turn:		4											
1	5	195	188	188	190	188	188	197	192	194	191.11		
2	10	180	183	183	185	183	183	182	185	185	183.22		
3	15	183	184	182	185	182	180	185	185	182	183.11		
4	20	180	180	178	180	182	180	180	185	180	180.56		
5	25	178	176	176	178	180	180	180	178	180	178.44	177.57	mm
6	30	175	178	178	180	178	180	180	180	182	179.00	6.99	inch
7	35	172	175	172	175	175	175	172	172	170	173.11		
8	40	170	170	168	170	168	172	170	170	172	170.00		
9	45	170	170	168	170	170	170	170	168	166	169.11		
10	50	166	168	166	168	170	168	170	168	168	168.00		

Diameter of culvert: 1 ft

Slope: 1 in 250

	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
S.N.	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
Number of turn:		1/2											
1	5	52	55	58	55	53	57	60	62	60	56.89		
2	10	60	62	60	60	60	62	60	62	60	60.67		
3	15	60	60	62	60	58	62	60	60	58	60.00		
4	20	51	51	54	52	50	52	52	52	52	51.78		
5	25	50	50	50	50	52	52	50	52	55	51.22	51.22	mm
6	30	50	52	50	52	50	52	50	52	52	51.11	2.02	inch
7	35	48	50	50	48	50	48	50	50	50	49.33		
8	40	48	48	48	46	49	49	48	50	50	48.44		
9	45	48	48	45	48	48	46	50	48	48	47.67		
10	50	42	43	45	45	45	47	43	43	45	44.22		
Number of turn:		1											
1	5	75	78	75	75	78	78	75	77	75	76.22		
2	10	73	72	77	75	75	76	75	75	80	75.33		
3	15	88	88	85	86	88	85	86	88	85	86.56		
4	20	78	78	78	77	78	78	78	75	80	77.78		
5	25	78	78	75	78	75	77	74	75	80	76.67	76.67	mm
6	30	77	75	75	73	78	75	75	75	73	75.11	3.02	inch
7	35	70	70	70	70	70	70	70	70	75	70.56		

	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
S.N.	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
8	40	70	68	68	70	70	68	70	70	72	69.56		
9	45	68	70	68	70	68	70	70	68	70	69.11		
10	50	65	65	67	65	68	68	65	65	65	65.89		
Number of turn:		1 1/2											
1	5	115	113	117	112	112	115	110	112	115	113.44		
2	10	110	112	112	110	112	115	110	110	112	111.44		
3	15	110	110	112	110	112	112	112	110	110	110.89		
4	20	110	112	110	110	110	110	108	110	110	110.00		
5	25	108	110	108	108	110	105	105	105	108	107.44	105.78	mm
6	30	108	110	110	110	108	108	105	107	105	107.89	4.16	inch
7	35	100	103	102	103	105	105	100	102	103	102.56		
8	40	100	102	102	100	102	98	100	100	98	100.22		
9	45	98	100	100	100	98	96	98	100	98	98.67		
10	50	95	96	98	98	95	95	93	95	92	95.22		
Number of turn:		2											
1	5	140	137	138	138	135	140	140	135	138	137.89		
2	10	137	135	137	138	137	135	137	135	138	136.56		
3	15	138	138	135	138	135	135	135	137	137	136.44		
4	20	135	135	135	138	135	138	132	135	135	135.33		
5	25	135	132	135	135	135	137	132	135	132	134.22	132.20	mm
6	30	133	135	135	135	137	135	132	132	132	134.00	5.20	inch
7	35	128	128	130	130	132	130	128	130	130	129.56		
8	40	125	125	125	128	130	132	128	130	128	127.89		

	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
S.N.	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
9	45	123	125	125	130	130	130	128	128	125	127.11		
10	50	122	125	122	127	125	123	120	120	123	123.00		
Number of turn:		2 1/2											
1	5	162	165	160	165	162	165	165	165	168	164.11		
2	10	158	158	162	160	158	160	158	160	162	159.56		
3	15	162	165	162	160	165	165	165	165	165	163.78		
4	20	162	162	162	162	165	162	165	167	163	163.33		
5	25	162	160	162	160	162	160	160	165	165	161.78	157.98	mm
6	30	160	162	160	162	160	160	162	165	162	161.44	6.22	inch
7	35	160	158	157	155	155	157	155	155	160	156.89		
8	40	155	157	153	150	152	152	152	152	150	152.56		
9	45	152	152	155	150	148	150	150	152	150	151.00		
10	50	142	145	145	145	145	148	148	145	145	145.33		
Number of turn:		3											
1	5	188	192	190	190	188	190	190	188	192	189.78		
2	10	185	188	185	185	188	190	188	185	190	187.11		
3	15	188	190	190	187	187	190	185	185	188	187.78		
4	20	190	190	190	188	188	185	185	185	187	187.56		
5	25	188	190	190	185	187	187	185	185	183	186.67	181.87	mm
6	30	190	192	188	188	185	185	182	185	187	186.89	7.16	inch
7	35	178	180	180	180	180	178	177	175	175	178.11		
8	40	172	175	175	175	175	175	172	170	175	173.78		
9	45	175	172	175	172	175	172	170	172	172	172.78		
10	50	170	172	170	167	170	170	165	165	165	168.22		

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
Number of turn:		3 1/2											
1	5	195	198	205	198	200	205	195	198	200	199.33		
2	10	198	200	200	195	197	200	200	202	198	198.89		
3	15	195	200	200	195	193	195	200	200	198	197.33		
4	20	203	203	205	205	205	200	200	202	205	203.11		
5	25	200	205	205	200	202	205	200	202	200	202.11	195.31	mm
6	30	202	205	202	205	202	205	200	202	200	202.56	7.69	inch
7	35	192	195	195	192	195	195	192	195	193	193.78		
8	40	188	188	192	188	188	190	190	188	188	188.89		
9	45	188	190	190	188	190	188	188	190	190	189.11		
10	50	175	178	175	180	180	178	178	180	178	178.00		
Number of turn:		4											
1	5	205	210	212	202	208	210	208	210	215	208.89		
2	10	205	208	210	208	205	208	208	205	210	207.44		
3	15	208	210	210	208	208	212	205	208	208	208.56		
4	20	208	210	208	208	210	205	205	205	203	206.89		
5	25	208	208	208	205	205	205	205	203	202	205.44	202.69	mm
6	30	205	210	210	205	207	205	205	200	205	205.78	7.98	inch
7	35	202	202	205	202	205	202	200	202	200	202.22		
8	40	198	200	200	198	198	200	190	195	195	197.11		
9	45	198	200	202	198	195	195	190	192	192	195.78		
10	50	190	192	190	190	188	188	188	185	188	188.78		

Diameter of culvert: 1 ft

Slope: 1 in 500

	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
S.N.	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
	Number of turn:	1/2											
1	5	70	68	68	70	72	70	70	70	68	69.56		
2	10	65	67	65	65	67	70	68	68	62	66.33		
3	15	63	65	65	65	67	67	67	65	68	65.78		
4	20	60	60	60	60	60	60	62	65	65	61.33		
5	25	60	60	58	60	62	62	63	65	62	61.33	61.84	mm
6	30	58	58	56	60	58	58	60	62	62	59.11	2.43	inch
7	35	52	55	55	56	58	60	60	62	62	57.78		
8	40	56	52	55	55	58	56	58	58	58	56.22		
9	45	58	55	55	55	58	55	58	60	58	56.89		
10	50	62	60	65	62	65	65	65	68	65	64.11		
Number of turn:		1											
1	5	97	98	102	98	102	95	97	99	95	98.11		
2	10	96	98	97	98	95	95	97	97	99	96.89		
3	15	95	97	95	95	97	98	95	97	95	96.00		
4	20	92	90	95	90	90	95	88	90	92	91.33		
5	25	93	93	93	90	92	92	88	90	90	91.22	91.49	mm
6	30	88	88	90	97	90	88	85	88	88	89.11	3.60	inch
7	35	84	87	88	86	88	85	85	85	85	85.89		
8	40	84	85	86	85	83	83	83	85	87	84.56		
9	45	80	83	85	82	82	84	80	82	80	82.00		

	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
S.N.	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
10	50	103	105	103	102	100	102	95	95	93	99.78		
Number of turn:		1 1/2											
1	5	120	118	120	118	120	120	110	110	113	116.56		
2	10	135	130	130	130	135	136	130	130	130	131.78		
3	15	130	128	130	132	134	137	130	130	130	131.22		
4	20	122	122	118	125	127	127	122	125	127	123.89		
5	25	122	120	120	128	126	165	128	131	123	129.22	122.43	mm
6	30	117	117	115	120	124	120	122	122	118	119.44	4.82	inch
7	35	112	115	115	117	117	119	110	115	115	115.00		
8	40	112	112	112	115	115	113	110	115	108	112.44		
9	45	110	113	112	108	112	112	108	115	108	110.89		
10	50	132	135	133	138	137	135	132	135	128	133.89		
Number of turn:		2											
1	5	148	150	145	150	148	148	150	149	152	148.89		
2	10	152	155	155	158	158	160	152	150	155	155.00		
3	15	165	163	160	170	170	166	170	168	168	166.67		
4	20	155	154	155	158	150	158	160	160	158	156.44		
5	25	155	158	158	162	160	162	168	165	163	161.22	156.42	mm
6	30	150	148	152	150	157	157	155	155	158	153.56	6.16	inch
7	35	140	145	143	150	155	152	155	155	153	149.78		
8	40	140	140	145	148	152	150	148	155	150	147.56		
9	45	142	145	140	140	140	138	152	148	148	143.67		
10	50	173	175	180	180	180	185	185	190	185	181.44		

	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
S.N.	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
Number of turn:		2 1/2											
1	5	175	173	175	170	170	175	178	175	180	174.56		
2	10	180	178	178	178	180	180	178	180	180	179.11		
3	15	185	182	182	183	185	183	188	185	188	184.56		
4	20	182	182	182	182	187	183	192	190	187	185.22		
5	25	182	183	185	183	180	183	182	185	185	183.11	176.77	mm
6	30	178	180	180	178	180	180	175	178	180	178.78	6.96	inch
7	35	163	165	167	168	165	166	166	164	166	165.56		
8	40	160	160	160	165	167	165	162	165	163	163.00		
9	45	158	160	162	165	162	165	165	162	162	162.33		
10	50	193	195	195	192	192	188	192	188	188	191.44		
Number of turn:		3											
1	5	192	188	190	192	192	195	188	190	188	190.56		
2	10	192	190	192	195	195	190	192	190	192	192.00		
3	15	215	210	212	220	215	217	212	215	213	214.33		
4	20	215	215	212	217	215	215	215	212	213	214.33		
5	25	207	207	210	215	212	212	210	212	212	210.78	200.92	mm
6	30	192	195	192	200	200	202	198	200	200	197.67	7.91	inch
7	35	188	186	185	192	192	190	188	190	188	188.78		
8	40	182	185	185	188	190	188	185	182	185	185.56		
9	45	185	183	185	185	190	188	183	185	183	185.22		
10	50	222	225	230	230	230	235	230	233	235	230.00		

	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
S.N.	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
Number of turn:		3 1/2											
1	5	200	198	200	198	200	198	200	198	200	199.11		
2	10	210	208	208	210	205	205	208	208	208	207.78		
3	15	215	215	215	208	210	208	210	210	208	211.00		
4	20	225	225	227	225	225	228	230	232	230	227.44		
5	25	225	227	225	225	228	228	228	225	234	227.22	214.12	mm
6	30	215	217	217	212	215	215	215	215	212	214.78	8.43	inch
7	35	202	205	207	202	205	205	207	212	208	205.89		
8	40	200	202	205	200	200	200	200	202	202	201.22		
9	45	200	202	202	198	200	202	202	200	205	201.22		
10	50	245	252	252	240	242	242	245	245	247	245.56		
Number of turn:		4											
1	5	208	210	212	200	210	205	208	205	210	207.56		
2	10	218	215	215	210	210	208	208	205	205	210.44		
3	15	230	232	228	230	235	238	232	230	228	231.44		
4	20	245	245	238	245	248	248	248	245	246	245.33		
5	25	245	248	248	248	245	245	245	247	245	246.22	229.00	mm
6	30	232	232	230	230	230	230	228	228	230	230.00	9.02	inch
7	35	225	228	225	228	225	228	222	220	222	224.78		
8	40	218	218	218	220	215	220	220	218	220	218.56		
9	45	218	218	218	218	218	218	220	215	218	217.89		
10	50	258	262	260	260	258	262	250	255	255	257.78		

Diameter of culvert: 1 ft

Slope: 1 in 50

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
Number of turn:		1/2											
1	5	38	37	35	38	36	38	38	36	37	37.00		
2	10	35	35	35	35	35	30	35	35	37	34.67		
3	15	35	35	35	36	35	37	34	34	37	35.33		
4	20	35	35	32	35	35	35	35	35	35	34.67		
5	25	35	35	32	32	32	35	35	35	32	33.67	33.84	mm
6	30	35	33	33	33	32	34	35	32	35	33.56	1.33	inch
7	35	32	32	32	32	33	35	32	32	32	32.44		
8	40	32	34	32	33	32	32	32	32	34	32.56		
9	45	32	35	32	33	32	32	32	32	32	32.44		
10	50	32	32	35	32	32	32	32	32	30	32.11		
Number of turn:		1											
1	5	65	67	67	65	67	65	62	65	65	65.33		
2	10	57	55	58	57	58	58	58	60	58	57.67		
3	15	55	53	53	55	55	55	55	55	58	54.89		
4	20	52	52	55	55	57	55	57	55	55	54.78		
5	25	52	55	52	55	53	55	52	55	56	53.89	54.04	mm
6	30	52	52	52	50	55	55	52	55	55	53.11	2.13	inch
7	35	50	50	52	50	50	53	50	50	53	50.89		

	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
S.N.	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
8	40	50	50	52	50	52	50	50	52	50	50.67		
9	45	50	50	50	50	50	50	50	50	50	50.00		
10	50	47	48	50	50	50	50	50	50	48	49.22		
Number of turn:		1 1/2											
1	5	87	88	90	88	90	92	92	90	92	89.89		
2	10	85	83	85	82	85	82	85	85	87	84.33		
3	15	78	80	80	80	80	80	82	80	85	80.56		
4	20	77	76	75	77	78	75	78	78	78	76.89		
5	25	70	75	75	75	75	75	75	78	76	74.89	77.09	mm
6	30	75	75	75	75	75	75	75	75	70	74.44	3.03	inch
7	35	75	73	75	75	75	73	75	75	75	74.56		
8	40	70	75	72	72	72	75	75	75	75	73.44		
9	45	70	72	72	72	70	70	72	75	72	71.67		
10	50	72	70	70	70	68	70	70	70	72	70.22		
Number of turn:		2											
1	5	105	107	107	110	112	110	112	112	110	109.44		
2	10	100	102	100	102	105	100	100	102	102	101.44		
3	15	97	100	97	100	100	98	97	100	98	98.56		
4	20	95	95	97	100	98	98	95	97	95	96.67		
5	25	95	95	95	95	97	95	95	95	97	95.44	96.00	mm
6	30	95	95	95	95	97	95	95	95	98	95.56	3.78	inch
7	35	92	90	92	95	93	93	92	95	92	92.67		
8	40	90	90	92	90	92	90	90	92	95	91.22		

	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
S.N.	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
9	45	92	90	90	90	90	92	92	92	95	91.44		
10	50	87	85	87	85	88	90	88	90	88	87.56		
Number of turn:		2 1/2											
1	5	140	138	135	145	145	140	145	138	138	140.44		
2	10	130	132	130	132	135	132	134	135	135	132.78		
3	15	122	125	122	122	120	125	125	127	125	123.67		
4	20	117	118	118	115	118	117	116	118	116	117.00		
5	25	116	116	115	115	115	115	115	115	115	115.22	117.86	mm
6	30	115	115	115	115	113	115	112	115	115	114.44	4.64	inch
7	35	110	108	110	112	108	112	112	112	115	111.00		
8	40	108	110	110	110	110	110	110	110	110	109.78		
9	45	106	108	110	107	108	108	110	108	108	108.11		
10	50	107	105	105	105	105	107	105	108	108	106.11		
Number of turn:		3											
1	5	155	152	153	152	155	158	150	155	155	153.89		
2	10	145	145	147	145	148	147	148	146	145	146.22		
3	15	135	137	137	135	135	135	137	135	140	136.22		
4	20	135	132	132	132	132	135	135	135	135	133.67		
5	25	132	130	130	132	132	130	132	130	135	131.44	132.22	mm
6	30	128	128	127	128	128	128	128	125	127	127.44	5.21	inch
7	35	128	126	125	127	125	125	128	125	125	126.00		
8	40	125	122	120	125	122	122	125	120	125	122.89		
9	45	125	125	121	125	125	122	125	122	122	123.56		

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
10	50	120	122	122	120	120	122	120	122	120	120.89		
Number of turn:		3 1/2											
1	5	163	165	163	165	163	167	167	163	167	164.78		
2	10	155	152	150	155	153	155	155	155	153	153.67		
3	15	148	150	146	155	153	152	150	150	155	151.00		
4	20	148	146	145	152	150	150	152	150	150	149.22		
5	25	142	140	140	145	143	143	142	143	142	142.22	143.76	mm
6	30	142	140	142	142	142	145	142	140	140	141.67	5.66	inch
7	35	143	143	140	140	138	138	137	135	137	139.00		
8	40	140	138	138	137	138	140	135	135	132	137.00		
9	45	130	130	132	130	130	132	132	130	128	130.44		
10	50	125	128	128	128	130	128	130	132	128	128.56		
Number of turn:		4											
1	5	167	170	165	170	172	170	170	166	172	169.11		
2	10	160	162	162	160	163	160	160	165	163	161.67		
3	15	160	158	158	158	157	160	160	160	158	158.78		
4	20	156	158	156	157	155	155	156	155	155	155.89		
5	25	155	152	153	153	150	155	152	155	153	153.11	151.83	mm
6	30	148	150	150	152	150	150	152	150	148	150.00	5.98	inch
7	35	145	145	145	145	145	147	145	145	148	145.56		
8	40	145	143	145	145	145	143	147	145	143	144.56		
9	45	142	140	142	142	143	140	142	142	140	141.44		
10	50	135	137	138	136	140	140	138	140	140	138.22		

Diameter of culvert: 2 ft

Slope: 1 in 104

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
Number of turn:		1/2											
1	5	30	30	30	31	32	32	31	32	31	31.00		
2	10	31	31	31	31	31	32	31	31	31	31.11		
3	15	32	30	32	31	31	32	30	30	31	31.00		
4	20	32	30	31	31	30	31	32	31	31	31.00		
5	25	30	30	31	31	31	31	31	32	31	30.89	30.79	mm
6	30	30	31	31	32	31	31	30	31	31	30.89	1.21	inch
7	35	31	31	30	31	32	31	32	31	31	31.11		
8	40	30	30	31	30	31	30	30	31	30	30.33		
9	45	30	30	30	31	30	30	30	31	31	30.33		
10	50	30	30	30	31	30	30	30	30	31	30.22		
Number of turn:		1											
1	5	53	55	55	53	52	53	53	52	53	53.22		
2	10	49	48	50	50	50	51	50	50	51	49.89		
3	15	49	50	50	48	50	48	48	50	48	49.00		
4	20	50	50	50	50	51	51	50	51	51	50.44		
5	25	49	50	49	50	49	50	50	49	50	49.56	49.94	mm
6	30	50	48	50	50	50	50	50	50	50	49.78	1.97	inch
7	35	50	50	50	50	50	49	50	50	49	49.78		
8	40	49	48	50	49	50	50	49	50	50	49.44		
9	45	50	48	48	50	50	49	50	50	49	49.33		

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
10	50	49	48	50	49	48	50	49	48	50	49.00		
Number of turn:		2											
1	5	106	105	106	105	106	102	102	107	106	105.00		
2	10	100	99	101	100	96	95	96	96	98	97.89		
3	15	94	92	92	94	93	93	90	91	91	92.22		
4	20	85	88	87	86	86	88	88	86	88	86.89		
5	25	84	83	86	82	84	84	86	84	84	84.11	89.02	mm
6	30	87	85	86	87	87	86	87	85	87	86.33	3.50	inch
7	35	86	88	88	88	86	89	86	86	85	86.89		
8	40	85	83	83	85	84	84	84	84	84	84.00		
9	45	83	84	82	84	82	82	85	82	85	83.22		
10	50	85	84	83	83	84	84	83	83	84	83.67		
Number of turn:		3											
1	5	120	120	121	118	120	120	121	121	121	120.22		
2	10	118	116	118	117	117	119	118	115	117	117.22		
3	15	117	115	116	113	113	113	115	115	116	114.78		
4	20	121	117	118	121	119	119	122	120	120	119.67		
5	25	114	115	115	114	112	112	113	114	114	113.67	115.59	mm
6	30	113	115	115	115	114	116	116	115	117	115.11	4.55	inch
7	35	113	112	115	114	116	116	117	116	113	114.67		
8	40	117	117	118	116	118	116	116	115	113	116.22		
9	45	110	108	110	110	111	111	112	110	114	110.67		
10	50	112	113	113	113	115	115	113	114	115	113.67		

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
Number of turn:		4											
1	5	135	138	138	135	138	138	140	139	140	137.89		
2	10	140	142	140	141	138	140	142	142	138	140.33		
3	15	128	136	130	128	130	132	126	126	130	129.56		
4	20	140	140	141	140	140	140	136	135	138	138.89		
5	25	140	138	138	137	138	140	137	139	140	138.56	134.37	mm
6	30	135	135	135	129	130	130	130	130	131	131.67	5.29	inch
7	35	133	132	131	130	130	134	131	134	134	132.11		
8	40	136	137	137	134	135	137	135	137	135	135.89		
9	45	128	128	128	126	128	128	130	131	130	128.56		
10	50	130	130	129	126	130	130	132	134	131	130.22		
Number of turn:		5											
1	5	148	152	150	152	150	150	155	152	155	151.56		
2	10	150	146	146	151	153	150	153	151	151	150.11		
3	15	156	152	153	156	157	158	156	158	158	156.00		
4	20	150	147	150	155	152	152	146	148	148	149.78		
5	25	147	149	149	149	151	149	148	150	147	148.78	150.01	mm
6	30	148	150	150	150	151	152	150	150	149	150.00	5.91	inch
7	35	154	151	151	150	152	150	149	152	152	151.22		
8	40	149	150	148	150	150	148	150	151	151	149.67		
9	45	145	147	147	147	148	149	146	147	147	147.00		
10	50	148	150	146	146	144	144	145	146	145	146.00		

Number of turn:		6											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	175	175	178	170	175	175	172	175	176	174.56		
2	10	163	162	163	165	163	166	164	q66	q66	163.71		
3	15	178	175	175	175	175	175	175	178	175	175.67		
4	20	181	178	178	181	180	184	181	180	180	180.33		
5	25	174	172	174	165	168	167	170	169	170	169.89	169.63	mm
6	30	162	164	164	162	162	165	162	164	165	163.33	6.68	inch
7	35	163	165	165	165	167	164	165	165	168	165.22		
8	40	165	167	167	165	166	166	164	167	166	165.89		
9	45	165	168	166	165	168	168	163	166	165	166.00		
10	50	170	170	171	172	173	173	172	171	173	171.67		
Number of turn:		7											
1	5	185	188	188	190	188	192	190	190	188	188.78		
2	10	180	175	179	175	178	177	175	178	178	177.22		
3	15	176	175	175	175	177	177	180	179	177	176.78		
4	20	185	187	185	185	185	186	185	188	188	186.00		
5	25	186	188	188	188	187	185	184	182	182	185.56	182.08	mm
6	30	195	195	197	195	192	193	188	188	192	192.78	7.17	inch
7	35	185	187	185	180	182	185	180	181	182	183.00		
8	40	184	181	184	178	177	178	176	178	177	179.22		
9	45	175	172	175	172	175	175	175	178	176	174.78		
10	50	175	175	174	178	175	177	178	179	179	176.67		

Number of turn:		8											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	200	202	202	202	198	200	205	202	202	201.44		
2	10	191	188	190	195	193	193	191	190	190	191.22		
3	15	190	190	188	190	188	190	188	190	190	189.33		
4	20	190	190	191	192	190	190	190	187	190	190.00		
5	25	189	191	191	191	190	189	190	188	188	189.67	194.17	mm
6	30	196	195	193	190	192	193	192	195	195	193.44	7.64	inch
7	35	196	198	198	195	196	198	195	196	197	196.56		
8	40	194	195	192	195	195	195	195	195	196	194.67		
9	45	198	195	198	198	194	198	200	196	198	197.22		
10	50	195	198	200	198	198	196	200	200	198	198.11		
Number of turn:		9											
1	5	209	212	213	212	215	213	208	212	215	212.11		
2	10	210	211	212	205	210	210	210	211	214	210.33		
3	15	205	205	207	210	205	207	205	207	209	206.67		
4	20	200	200	198	197	196	196	197	195	197	197.33		
5	25	196	198	200	198	197	200	197	198	198	198.00	200.19	mm
6	30	196	195	197	196	196	198	192	196	197	195.89	7.88	inch
7	35	192	196	196	195	198	195	191	194	194	194.56		
8	40	192	195	196	190	192	195	194	196	196	194.00		
9	45	197	195	197	195	194	196	197	200	197	196.44		
10	50	195	195	198	195	198	198	196	196	198	196.56		

Diameter of culvert: 2 ft

Slope: 1 in250

Number of turn:		1/2											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	36	36	36	37	36	37	36	37	37	36.44		
2	10	42	40	40	42	42	42	42	42	41	41.44		
3	15	37	35	35	36	37	37	26	35	36	34.89		
4	20	38	37	37	40	40	40	39	38	39	38.67		
5	25	37	36	36	37	37	37	37	36	36	36.56	37.98	mm
6	30	40	40	40	40	40	40	41	39	39	39.89	1.50	inch
7	35	36	37	37	37	37	37	37	36	36	36.67		
8	40	38	38	38	37	38	38	37	37	36	37.44		
9	45	38	37	37	28	37	37	37	38	37	36.22		
10	50	42	42	42	42	41	41	42	42	40	41.56		
Number of turn:		1											
1	5	55	56	56	57	57	56	56	57	57	56.33		
2	10	66	65	65	66	66	66	70	70	70	67.11		
3	15	63	65	63	63	63	63	64	62	63	63.22		
4	20	63	63	62	63	64	63	64	64	62	63.11		
5	25	63	62	61	60	62	61	62	63	63	61.89	63.23	mm
6	30	65	63	62	63	63	63	63	64	63	63.22	2.49	inch
7	35	63	63	63	63	63	63	64	63	63	63.11		
8	40	63	62	62	64	62	63	62	62	63	62.56		
9	45	63	61	61	62	62	63	63	63	63	62.33		

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
10	50	70	68	70	71	68	70	70	69	69	69.44		
Number of turn:		2											
1	5	115	116	116	114	115	114	115	113	113	114.56		
2	10	100	103	103	106	103	103	100	101	100	102.11		
3	15	101	100	102	102	101	102	103	102	103	101.78		
4	20	112	110	110	110	109	110	109	111	108	109.89		
5	25	108	110	108	108	108	107	108	107	107	107.89	108.13	mm
6	30	108	108	108	108	108	108	108	110	107	108.11	4.26	inch
7	35	110	111	110	108	108	109	110	108	108	109.11		
8	40	110	110	110	110	109	110	107	109	107	109.11		
9	45	110	108	109	110	110	109	110	109	109	109.33		
10	50	110	108	110	110	110	107	110	110	110	109.44		
Number of turn:		3											
1	5	128	130	128	130	128	128	135	132	130	129.89		
2	10	128	128	126	128	130	130	126	126	128	127.78		
3	15	135	133	134	120	135	135	133	134	133	132.44		
4	20	140	140	140	145	142	142	140	140	141	141.11		
5	25	135	135	135	140	138	138	138	138	140	137.44	136.62	mm
6	30	135	133	135	136	137	136	140	140	138	136.67	5.38	inch
7	35	138	136	136	140	142	146	138	140	140	139.56		
8	40	140	140	142	142	142	141	140	142	142	141.22		
9	45	138	140	140	138	140	142	138	140	140	139.56		
10	50	140	140	140	142	140	141	140	142	140	140.56		

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
Number of turn:		4											
1	5	150	148	152	153	148	150	154	152	154	151.22		
2	10	150	152	152	145	145	145	154	152	150	149.44		
3	15	145	150	145	144	145	145	145	146	144	145.44		
4	20	152	150	152	154	152	152	152	150	152	151.78		
5	25	155	156	156	160	160	160	155	156	157	157.22	154.64	mm
6	30	153	153	154	150	150	152	150	152	150	151.56	6.09	inch
7	35	155	158	158	160	160	161	155	160	160	158.56		
8	40	160	162	162	155	160	160	162	160	162	160.33		
9	45	155	158	158	162	162	163	162	162	162	160.44		
10	50	158	158	160	162	163	163	160	160	160	160.44		
Number of turn:		5											
1	5	163	165	165	165	164	163	165	165	165	164.44		
2	10	165	165	165	165	166	165	163	165	166	165.00		
3	15	158	157	158	158	160	160	158	159	160	158.67		
4	20	172	170	172	172	172	172	166	169	168	170.33		
5	25	162	165	165	166	163	165	168	170	166	165.56	169.71	mm
6	30	172	171	172	172	175	175	172	172	175	172.89	6.68	inch
7	35	171	172	173	172	175	173	175	175	176	173.56		
8	40	172	173	175	175	175	180	177	178	177	175.78		
9	45	170	170	172	178	174	172	170	171	170	171.89		
10	50	180	178	178	180	180	177	180	180	178	179.00		

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
Number of turn:		6											
1	5	182	182	185	186	182	182	185	185	182	183.44		
2	10	175	173	175	178	175	175	178	175	175	175.44		
3	15	192	195	196	190	190	195	190	195	194	193.00		
4	20	183	186	185	180	182	182	184	185	182	183.22		
5	25	185	186	185	182	181	187	185	188	187	185.11	188.22	mm
6	30	190	191	193	195	190	195	190	192	195	192.33	7.41	inch
7	35	190	190	190	188	190	188	189	190	190	189.44		
8	40	196	195	196	192	190	193	191	192	194	193.22		
9	45	188	190	192	190	192	191	190	190	189	190.22		
10	50	195	196	196	195	196	200	196	198	199	196.78		
Number of turn:		7											
1	5	201	200	202	200	200	205	200	200	204	201.33		
2	10	189	188	188	180	185	185	183	180	180	184.22		
3	15	189	192	193	190	193	192	190	192	193	191.56		
4	20	208	210	209	205	207	210	210	210	210	208.78		
5	25	205	202	201	200	204	206	200	202	200	202.22	198.00	mm
6	30	200	199	203	201	202	202	192	192	195	198.44	7.80	inch
7	35	202	202	205	198	199	200	200	203	105	190.44		
8	40	200	200	197	190	193	195	191	194	195	195.00		
9	45	205	207	207	202	206	202	200	205	205	204.33		
10	50	204	206	206	202	205	201	202	203	204	203.67		

Number of turn:		8											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	215	214	217	212	215	215	209	213	210	213.33		
2	10	194	195	196	195	198	198	198	195	200	196.56		
3	15	198	198	200	198	200	200	199	200	200	199.22		
4	20	215	217	216	210	215	216	215	217	216	215.22		
5	25	210	215	215	215	215	215	215	218	218	215.11	210.76	mm
6	30	197	203	200	206	204	204	203	202	203	202.44	8.30	inch
7	35	210	214	210	212	215	212	212	210	213	212.00		
8	40	217	220	222	214	217	215	215	215	218	217.00		
9	45	213	215	215	212	209	210	210	210	212	211.78		
10	50	225	222	226	222	225	228	225	225	226	224.89		
Number of turn:		9											
1	5	220	215	222	225	226	229	236	224	227	224.89		
2	10	215	216	214	215	218	216	216	212	213	215.00		
3	15	203	205	205	210	210	209	205	205	207	206.56		
4	20	220	221	220	213	215	216	215	219	216	217.22		
5	25	218	221	223	210	213	215	213	216	216	216.11	221.66	mm
6	30	223	225	226	222	225	224	225	225	223	224.22	8.73	inch
7	35	222	228	224	216	218	219	218	215	217	219.67		
8	40	230	228	231	226	226	222	222	227	225	226.33		
9	45	235	236	240	232	235	234	230	231	233	234.00		
10	50	236	233	232	232	233	231	232	234	230	232.56		

Diameter of culvert: 2 ft

Slope: 1 in 500

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
Number of turn:		1/2											
1	5	40	41	40	40	42	40	41	40	41	40.56		
2	10	42	40	40	42	42	40	42	40	40	40.89		
3	15	40	38	40	38	40	40	38	40	39	39.22		
4	20	40	38	39	40	40	39	40	40	39	39.44		
5	25	38	37	39	40	40	40	38	39	39	38.89	39.68	mm
6	30	41	40	38	41	42	40	40	40	41	40.33	1.56	inch
7	35	38	37	38	39	38	39	38	39	39	38.33		
8	40	39	38	38	39	39	40	40	40	38	39.00		
9	45	40	40	40	41	41	40	41	39	40	40.22		
10	50	39	40	39	40	40	40	40	40	41	39.89		
Number of turn:		1											
1	5	69	71	70	74	74	72	74	72	74	72.22		
2	10	79	77	78	77	77	78	77	76	76	77.22		
3	15	76	76	74	74	74	72	74	75	72	74.11		
4	20	71	71	70	69	70	71	73	71	71	70.78		
5	25	70	71	72	70	70	70	71	72	71	70.78	72.49	mm
6	30	72	72	72	75	73	73	76	73	73	73.22	2.85	inch
7	35	69	68	68	68	68	68	68	70	70	68.56		
8	40	70	70	70	70	70	70	72	71	71	70.44		
9	45	74	72	72	74	74	75	75	73	75	73.78		

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
10	50	74	72	73	76	74	74	75	73	73	73.78		
Number of turn:		2											
1	5	96	96	96	96	98	98	97	97	96	96.67		
2	10	95	95	97	95	96	95	96	96	96	95.67		
3	15	105	107	105	105	106	105	103	105	105	105.11		
4	20	108	108	108	113	115	113	115	113	115	112.00		
5	25	107	107	108	110	110	110	110	110	108	108.89	111.70	mm
6	30	118	120	118	120	118	120	120	120	121	119.44	4.40	inch
7	35	115	112	112	115	113	113	115	115	115	113.89		
8	40	117	115	115	117	115	115	116	115	113	115.33		
9	45	125	125	125	125	125	125	125	122	125	124.67		
10	50	126	125	125	126	125	125	127	124	125	125.33		
Number of turn:		3											
1	5	128	129	129	124	128	128	128	130	129	128.11		
2	10	121	121	123	123	122	122	122	121	122	121.89		
3	15	131	130	130	131	134	132	132	134	134	132.00		
4	20	133	134	133	135	135	133	136	135	134	134.22		
5	25	138	140	138	137	138	140	140	140	140	139.00	140.11	mm
6	30	142	140	140	143	142	141	143	142	141	141.56	5.52	inch
7	35	145	145	146	147	149	147	145	144	145	145.89		
8	40	147	148	147	150	149	148	146	143	145	147.00		
9	45	146	146	148	148	147	148	149	148	148	147.56		
10	50	167	163	163	163	165	162	165	163	164	163.89		

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
Number of turn:		4											
1	5	158	172	170	175	180	172	165	175	175	171.33		
2	10	165	158	155	170	165	168	165	165	170	164.56		
3	15	155	155	148	162	160	158	160	158	165	157.89		
4	20	158	160	158	165	170	160	165	160	170	162.89		
5	25	170	165	172	175	170	178	175	172	170	171.89	169.69	mm
6	30	168	172	168	165	168	167	168	165	160	166.78	6.68	inch
7	35	170	180	175	175	185	180	175	178	178	177.33		
8	40	170	175	170	170	175	170	160	160	155	167.22		
9	45	175	178	172	175	178	180	170	172	170	174.44		
10	50	195	188	192	180	178	175	175	180	180	182.56		
Number of turn:		5											
1	5	180	175	182	180	178	184	180	185	182	180.67		
2	10	168	165	165	160	172	160	158	160	165	163.67		
3	15	165	178	180	185	180	175	165	170	180	175.33		
4	20	170	175	180	170	175	175	170	175	173	173.67		
5	25	165	168	165	170	170	175	175	168	170	169.56	178.79	mm
6	30	173	180	178	180	185	183	180	178	175	179.11	7.04	inch
7	35	180	175	175	180	175	188	173	175	180	177.89		
8	40	180	180	180	185	185	180	180	185	185	182.22		
9	45	190	188	185	190	195	193	185	188	192	189.56		
10	50	195	203	205	195	195	200	188	195	190	196.22		

Number of turn:		6											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	195	198	202	198	202	208	195	200	200	199.78		
2	10	182	185	182	175	175	175	182	175	178	178.78		
3	15	205	208	215	212	205	205	205	205	202	206.89		
4	20	195	198	185	188	188	185	185	185	195	189.33		
5	25	202	202	198	192	195	201	198	198	195	197.89	199.23	mm
6	30	188	198	195	198	208	203	210	200	205	200.56	7.84	inch
7	35	202	200	205	202	208	200	205	202	208	203.56		
8	40	190	195	202	198	198	200	200	202	195	197.78		
9	45	210	215	215	205	210	212	210	205	210	210.22		
10	50	210	210	205	208	210	205	202	208	210	207.56		
Number of turn:		7											
1	5	220	218	222	223	232	230	212	225	232	223.78		
2	10	200	198	200	205	195	195	200	205	208	200.67		
3	15	200	212	210	208	203	205	212	205	208	207.00		
4	20	225	221	220	222	225	215	225	220	218	221.22		
5	25	208	225	222	215	220	218	214	220	215	217.44	220.04	mm
6	30	220	215	215	208	212	220	210	208	220	214.22	8.66	inch
7	35	232	225	225	232	228	230	225	220	220	226.33		
8	40	235	228	225	225	235	235	225	230	225	229.22		
9	45	215	225	223	235	230	225	228	232	226	226.56		
10	50	228	235	228	235	240	240	230	235	235	234.00		

Number of turn:		8											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	215	212	215	206	209	211	208	205	210	210.11		
2	10	193	197	199	197	192	195	196	196	198	195.89		
3	15	215	215	215	212	212	215	215	215	213	214.11		
4	20	225	226	226	225	228	225	228	223	226	225.78		
5	25	217	220	218	215	218	222	220	221	222	219.22	223.44	mm
6	30	225	230	230	221	223	225	225	220	222	224.56	8.80	inch
7	35	230	231	232	228	230	226	230	230	230	229.67		
8	40	230	232	228	230	232	226	230	231	226	229.44		
9	45	232	234	237	235	235	239	239	235	244	236.67		
10	50	245	248	250	246	248	255	246	255	248	249.00		
Number of turn:		9											
1	5	220	228	222	218	217	215	226	220	224	221.11		
2	10	215	217	213	213	215	211	215	216	220	215.00		
3	15	215	220	214	212	215	212	208	213	207	212.89		
4	20	236	235	237	232	236	229	230	234	230	233.22		
5	25	236	236	232	235	229	230	238	230	231	233.00	229.74	mm
6	30	225	230	225	228	225	228	221	225	217	224.89	9.05	inch
7	35	238	228	232	232	238	240	235	238	234	235.00		
8	40	235	230	232	235	239	240	234	236	239	235.56		
9	45	235	232	239	238	238	232	230	235	237	235.11		
10	50	249	250	251	250	255	251	252	255	252	251.67		

Diameter of culvert: 2 ft

Slope: 1 in 50

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
Number of turn:		1/2											
1	5	28	27	27	28	27	28	28	28	28	27.67		
2	10	26	26	27	27	26	27	27	26	25	26.33		
3	15	25	26	25	26	26	27	25	26	26	25.78		
4	20	25	26	26	27	27	27	27	26	27	26.44		
5	25	27	27	27	28	28	27	28	27	28	27.44	26.56	mm
6	30	27	26	26	28	27	27	28	28	27	27.11	1.05	inch
7	35	27	27	26	28	27	28	27	27	27	27.11		
8	40	25	26	25	27	27	26	27	25	25	25.89		
9	45	26	26	26	26	26	26	26	25	25	25.78		
10	50	25	25	26	26	27	26	27	26	26	26.00		
Number of turn:		1											
1	5	48	47	47	48	48	48	48	47	47	47.56		
2	10	46	46	47	46	45	46	46	45	46	45.89		
3	15	45	43	45	45	44	45	45	45	45	44.67		
4	20	45	45	46	43	44	45	44	44	45	44.56		
5	25	47	45	45	44	45	44	44	43	44	44.56	44.01	mm
6	30	44	45	44	45	43	44	44	43	43	43.89	1.73	inch
7	35	43	43	43	44	43	43	43	43	44	43.22		
8	40	42	42	41	43	43	42	43	42	42	42.22		
9	45	43	42	41	42	41	42	42	42	41	41.78		

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
10	50	42	40	42	42	42	42	42	42	42	41.78		
Number of turn:		2											
1	5	90	92	92	88	86	90	85	87	90	88.89		
2	10	75	78	78	80	76	78	76	75	75	76.78		
3	15	80	81	80	80	80	82	82	82	82	81.00		
4	20	78	78	80	78	76	78	78	77	78	77.89		
5	25	79	79	80	77	77	77	78	76	76	77.67	77.78	mm
6	30	80	78	79	80	79	80	80	80	80	79.56	3.06	inch
7	35	74	74	73	74	73	75	75	75	74	74.11		
8	40	76	73	75	73	75	75	75	75	74	74.56		
9	45	74	74	73	76	75	74	74	72	72	73.78		
10	50	73	73	73	74	75	74	74	74	72	73.56		
Number of turn:		3											
1	5	110	110	113	110	108	108	112	115	113	111.00		
2	10	115	110	110	105	108	108	110	111	110	109.67		
3	15	116	113	113	110	106	107	112	110	110	110.78		
4	20	105	105	106	108	108	105	105	103	105	105.56		
5	25	101	100	101	103	102	102	100	98	100	100.78	103.92	mm
6	30	100	100	100	100	102	100	98	100	100	100.00	4.09	inch
7	35	102	101	100	102	102	101	100	100	100	100.89		
8	40	101	101	102	102	100	100	100	98	101	100.56		
9	45	103	100	100	102	100	101	101	100	99	100.67		
10	50	100	98	100	98	98	101	100	99	100	99.33		

Number of turn:		4											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	126	130	128	130	128	128	132	132	130	129.33		
2	10	122	122	122	130	127	125	120	126	122	124.00		
3	15	122	125	125	127	127	124	124	125	126	125.00		
4	20	128	126	126	128	127	126	128	126	128	127.00		
5	25	115	115	113	127	116	118	119	116	116	117.22	118.91	mm
6	30	115	117	120	122	120	120	118	120	120	119.11	4.68	inch
7	35	110	117	116	115	117	117	115	113	113	114.78		
8	40	110	113	110	113	112	113	112	110	110	111.44		
9	45	110	113	112	108	110	110	110	111	113	110.78		
10	50	112	108	110	110	112	110	112	110	110	110.44		

Number of turn:		5											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	145	145	150	150	150	151	150	151	150	149.11		
2	10	135	138	136	136	137	138	137	136	135	136.44		
3	15	136	140	140	138	141	140	134	137	138	138.22		
4	20	136	136	137	135	133	136	135	134	137	135.44		
5	25	140	140	139	140	141	143	138	140	140	140.11	135.60	mm
6	30	135	138	138	137	138	136	134	136	140	136.89	5.34	inch
7	35	128	127	129	133	130	132	128	130	130	129.67		
8	40	128	130	131	135	132	135	133	131	133	132.00		
9	45	128	128	130	130	128	129	128	130	130	129.00		
10	50	124	130	130	127	131	133	127	130	130	129.11		

Number of turn:		6											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	172	168	170	170	170	174	168	170	172	170.44		
2	10	155	154	150	156	153	153	154	154	155	153.78		
3	15	148	150	148	150	148	151	150	151	150	149.56		
4	20	150	146	150	144	146	146	146	150	149	147.44		
5	25	145	144	148	146	147	146	150	150	150	147.33	148.94	mm
6	30	144	146	148	145	146	148	145	144	146	145.78	5.86	inch
7	35	142	145	144	147	146	145	144	143	143	144.33		
8	40	143	140	143	145	145	147	142	142	144	143.44		
9	45	140	141	140	143	143	143	142	145	143	142.22		
10	50	143	145	143	145	147	145	147	144	147	145.11		

Number of turn:		7											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	189	180	180	180	188	188	186	180	188	184.33		
2	10	170	172	174	174	171	172	175	175	175	173.11		
3	15	165	167	166	168	167	167	168	167	170	167.22		
4	20	160	159	160	158	162	164	160	162	161	160.67		
5	25	166	166	168	170	170	169	166	165	167	167.44	167.83	mm
6	30	168	170	166	170	166	169	168	170	170	168.56	6.61	inch
7	35	168	166	166	167	170	166	160	165	165	165.89		
8	40	167	167	167	165	165	163	164	165	166	165.44		
9	45	145	166	167	164	165	163	163	163	166	162.44		
10	50	160	162	161	162	165	165	164	165	165	163.22		

Number of turn:		8											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	196	198	195	205	205	205	210	206	205	202.78		
2	10	195	193	195	190	189	188	198	190	190	192.00		
3	15	184	182	184	189	185	176	186	188	190	184.89		
4	20	184	184	184	178	182	181	178	182	181	181.56		
5	25	185	185	186	185	183	174	175	182	186	182.33	181.84	mm
6	30	178	182	180	176	179	178	178	176	180	178.56	7.16	inch
7	35	180	180	183	180	180	178	180	180	177	179.78		
8	40	178	176	175	175	173	176	175	176	173	175.22		
9	45	178	178	179	170	170	168	170	168	172	172.56		
10	50	168	170	170	168	170	170	168	168	167	168.78		

Number of turn:		9											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	221	215	216	220	222	216	220	218	220	218.67		
2	10	205	204	209	203	206	205	208	210	206	206.22		
3	15	204	200	200	205	208	202	206	205	205	203.89		
4	20	198	200	298	202	200	200	196	198	197	209.89		
5	25	191	193	193	197	196	197	197	196	194	194.89	191.70	mm
6	30	176	177	179	189	188	188	181	185	184	183.00	7.55	inch
7	35	175	177	177	178	182	182	175	176	177	177.67		
8	40	178	175	173	175	177	176	171	170	172	174.11		
9	45	173	175	174	174	173	173	173	173	173	173.44		
10	50	176	174	177	173	175	177	174	176	175	175.22		

Diameter of culvert: 3.5 ft

Slope: 1 in 104

Number of turn:	1/2												
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	36.8	46.8	46.8	46.8	46.8	56.8	46.8	46.8	56.8	47.91		
2	10	46.8	46.8	56.8	56.8	46.8	46.8	46.8	46.8	56.8	50.13		
3	15	46.8	46.8	46.8	46.8	36.8	46.8	46.8	46.8	36.8	44.58		
4	20	46.8	56.8	56.8	46.8	46.8	36.8	46.8	36.8	46.8	46.80		
5	25	46.8	56.8	56.8	46.8	56.8	56.8	46.8	46.8	46.8	51.24	47.58	mm
6	30	46.8	46.8	36.8	36.8	46.8	46.8	36.8	46.8	46.8	43.47	1.87	inch
7	35	56.8	46.8	56.8	56.8	56.8	56.8	56.8	56.8	56.8	55.69		
8	40	36.8	36.8	36.8	46.8	36.8	46.8	36.8	46.8	46.8	41.24		
9	45	46.8	46.8	46.8	36.8	56.8	46.8	56.8	36.8	46.8	46.80		
10	50	36.8	56.8	36.8	46.8	46.8	56.8	56.8	56.8	36.8	47.91		
Number of turn:	1												
1	5	45.7	45.7	45.7	54.9	45.7	45.7	54.9	54.9	45.7	48.77		
2	10	54.9	54.9	45.7	54.9	54.9	45.7	45.7	45.7	45.7	49.78		
3	15	54.9	45.7	45.7	54.9	54.9	45.7	54.9	54.9	45.7	50.80		
4	20	45.7	45.7	54.9	45.7	54.9	45.7	45.7	54.9	45.7	48.77		
5	25	45.7	45.7	45.7	54.9	45.7	54.9	54.9	45.7	54.9	49.78	48.87	mm
6	30	45.7	45.7	45.7	45.7	45.7	45.7	45.7	45.7	45.7	45.72	1.92	inch
7	35	45.7	45.7	45.7	45.7	45.7	45.7	45.7	45.7	45.7	45.72		
8	40	45.7	45.7	54.9	45.7	54.9	54.9	45.7	54.9	45.7	49.78		
9	45	45.7	54.9	45.7	45.7	45.7	54.9	45.7	45.7	45.7	47.75		

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
10	50	54.9	54.9	54.9	45.7	54.9	45.7	45.7	54.9	54.9	51.82		
Number of turn:		2											
1	5	64.0	73.2	64.0	73.2	94.2	73.2	73.2	82.3	73.2	74.47		
2	10	73.2	73.2	73.2	82.3	82.3	82.3	73.2	82.3	64.0	76.20		
3	15	82.3	73.2	73.2	73.2	64.0	73.2	64.0	73.2	73.2	72.14		
4	20	82.3	82.3	82.3	73.2	73.2	73.2	73.2	73.2	64.0	75.18		
5	25	73.2	73.2	82.3	82.3	82.3	82.3	82.3	82.3	73.2	79.25	74.30	mm
6	30	73.2	73.2	82.3	73.2	73.2	73.2	73.2	73.2	73.2	74.17	2.93	inch
7	35	73.2	73.2	73.2	73.2	73.2	73.2	82.3	73.2	73.2	74.17		
8	40	82.3	73.2	73.2	73.2	82.3	73.2	64.0	73.2	73.2	74.17		
9	45	73.2	73.2	73.2	64.0	64.0	73.2	73.2	64.0	73.2	70.10		
10	50	73.2	73.2	73.2	64.0	73.2	73.2	73.2	73.2	82.3	73.15		
Number of turn:		3											
1	5	91.4	100.6	91.4	100.6	82.3	91.4	82.3	91.4	82.3	90.42		
2	10	82.3	91.4	100.6	100.6	91.4	100.6	100.6	100.6	91.4	95.50		
3	15	109.7	100.6	100.6	109.7	109.7	91.4	100.6	91.4	100.6	101.60		
4	20	91.4	100.6	91.4	100.6	91.4	100.6	100.6	100.6	100.6	97.54		
5	25	100.6	100.6	91.4	100.6	91.4	100.6	91.4	91.4	91.4	95.50	95.30	mm
6	30	91.4	100.6	91.4	100.6	100.6	91.4	91.4	91.4	82.3	93.47	3.75	inch
7	35	100.6	100.6	100.6	91.4	100.6	100.6	100.6	91.4	100.6	98.55		
8	40	91.4	91.4	91.4	91.4	91.4	91.4	91.4	82.3	82.3	89.41		
9	45	100.6	91.4	100.6	100.6	91.4	82.3	91.4	100.6	91.4	94.49		
10	50	91.4	100.6	91.4	100.6	91.4	100.6	100.6	100.6	91.4	96.52		

Number of turn:		4											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	100.6	100.6	109.7	91.4	91.4	82.3	91.4	100.6	91.4	95.50		
2	10	109.7	109.7	109.7	109.7	109.7	100.6	109.7	109.7	118.9	109.73		
3	15	109.7	91.4	109.7	109.7	100.6	118.9	100.6	100.6	100.6	104.65		
4	20	118.9	109.7	109.7	109.7	118.9	100.6	109.7	109.7	109.7	110.74		
5	25	109.7	91.4	109.7	100.6	109.7	100.6	100.6	109.7	100.6	103.63	104.65	mm
6	30	100.6	109.7	100.6	100.6	100.6	109.7	100.6	91.4	100.6	101.60	4.12	inch
7	35	109.7	118.9	109.7	118.9	118.9	109.7	100.6	100.6	100.6	109.73		
8	40	100.6	109.7	109.7	109.7	91.4	100.6	109.7	100.6	109.7	104.65		
9	45	109.7	100.6	100.6	109.7	91.4	109.7	100.6	109.7	100.6	103.63		
10	50	100.6	100.6	100.6	100.6	91.4	100.6	109.7	109.7	109.7	102.62		

Number of turn:		5											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	109.7	118.9	118.9	118.9	118.9	118.9	118.9	118.9	118.9	117.86		
2	10	100.6	100.6	109.7	109.7	109.7	100.6	109.7	109.7	109.7	106.68		
3	15	100.6	109.7	109.7	100.6	109.7	109.7	109.7	118.9	109.7	108.71		
4	20	109.7	118.9	109.7	109.7	118.9	118.9	118.9	118.9	118.9	115.82		
5	25	128.0	118.9	118.9	118.9	118.9	118.9	118.9	99.7	118.9	117.75	116.32	mm
6	30	118.9	118.9	109.7	118.9	118.9	118.9	128.0	118.9	118.9	118.87	4.58	inch
7	35	128.0	118.9	128.0	128.0	118.9	128.0	128.0	128.0	128.0	125.98		
8	40	118.9	109.7	109.7	109.7	118.9	118.9	118.9	118.9	118.9	115.82		
9	45	118.9	109.7	118.9	118.9	118.9	118.9	109.7	118.9	109.7	115.82		
10	50	118.9	128.0	128.0	118.9	118.9	118.9	109.7	118.9	118.9	119.89		

Number of turn:		6											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	118.9	118.9	118.9	118.9	109.7	128.0	128.0	128.0	128.0	121.92		
2	10	128.0	128.0	137.2	128.0	137.2	128.0	128.0	118.9	137.2	130.05		
3	15	128.0	128.0	118.9	118.9	109.7	128.0	118.9	118.9	118.9	120.90		
4	20	137.2	137.2	128.0	128.0	128.0	128.0	118.9	118.9	128.0	128.02		
5	25	137.2	128.0	137.2	118.9	128.0	128.0	137.2	128.0	128.0	130.05	127.81	mm
6	30	128.0	137.2	137.2	128.0	128.0	128.0	118.9	128.0	128.0	129.03	5.03	inch
7	35	118.9	137.2	137.2	137.2	128.0	128.0	128.0	128.0	137.2	131.06		
8	40	118.9	137.2	128.0	137.2	128.0	128.0	118.9	128.0	137.2	129.03		
9	45	137.2	137.2	128.0	128.0	128.0	128.0	128.0	128.0	137.2	131.06		
10	50	128.0	137.2	118.9	128.0	118.9	137.2	118.9	128.0	128.0	127.00		

Number of turn:		8											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	137.2	155.4	137.2	155.4	155.4	137.2	137.2	155.4	137.2	145.29		
2	10	173.7	173.7	173.7	155.4	164.6	173.7	155.4	155.4	137.2	162.56		
3	15	182.9	182.9	182.9	173.7	173.7	173.7	173.7	173.7	182.9	177.80		
4	20	173.7	173.7	173.7	173.7	164.6	173.7	164.6	173.7	164.6	170.69		
5	25	173.7	164.6	155.4	137.2	137.2	137.2	164.6	173.7	173.7	157.48	152.60	mm
6	30	155.4	155.4	137.2	137.2	155.4	137.2	137.2	137.2	155.4	145.29	6.01	inch
7	35	137.2	155.4	155.4	137.2	155.4	155.4	137.2	137.2	155.4	147.32		
8	40	137.2	137.2	137.2	137.2	155.4	137.2	137.2	137.2	128.0	138.18		
9	45	137.2	137.2	128.0	137.2	128.0	137.2	137.2	128.0	155.4	136.14		
10	50	155.4	137.2	155.4	137.2	137.2	155.4	137.2	155.4	137.2	145.29		

Number of turn:		10											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	173.7	173.7	155.4	173.7	173.7	173.7	173.7	173.7	155.4	169.67		
2	10	182.9	164.6	164.6	182.9	173.7	173.7	173.7	173.7	173.7	173.74		
3	15	182.9	182.9	182.9	182.9	182.9	164.6	173.7	173.7	182.9	178.82		
4	20	173.7	173.7	164.6	173.7	155.4	173.7	173.7	173.7	155.4	168.66		
5	25	155.4	164.6	155.4	155.4	155.4	164.6	164.6	164.6	155.4	159.51	169.06	mm
6	30	164.6	173.7	155.4	164.6	155.4	155.4	164.6	164.6	155.4	161.54	6.66	inch
7	35	164.6	164.6	173.7	173.7	173.7	173.7	182.9	173.7	164.6	171.70		
8	40	164.6	182.9	173.7	173.7	173.7	173.7	173.7	173.7	164.6	172.72		
9	45	155.4	173.7	164.6	173.7	155.4	173.7	164.6	173.7	155.4	165.61		
10	50	164.6	155.4	173.7	164.6	173.7	173.7	173.7	164.6	173.7	168.66		

Number of turn:		14											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	182.9	182.9	201.2	192.0	192.0	182.9	192.0	182.9	182.9	187.96		
2	10	182.9	192.0	192.0	201.2	201.2	182.9	192.0	182.9	201.2	192.02		
3	15	182.9	173.7	164.6	182.9	173.7	182.9	173.7	164.6	164.6	173.74		
4	20	173.7	182.9	173.7	173.7	173.7	182.9	173.7	173.7	173.7	175.77		
5	25	173.7	182.9	182.9	173.7	173.7	164.6	173.7	182.9	173.7	175.77	181.66	mm
6	30	192.0	192.0	173.7	173.7	182.9	182.9	173.7	192.0	182.9	182.88	7.15	inch
7	35	192.0	192.0	182.9	192.0	192.0	201.2	201.2	192.0	192.0	193.04		
8	40	192.0	192.0	182.9	192.0	182.9	182.9	182.9	182.9	182.9	185.93		
9	45	173.7	173.7	173.7	173.7	173.7	182.9	173.7	173.7	182.9	175.77		
10	50	182.9	173.7	173.7	173.7	173.7	173.7	164.6	173.7	173.7	173.74		

Number of turn:		18											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	192.0	192.0	201.2	210.3	201.2	192.0	192.0	201.2	201.2	198.12		
2	10	210.3	210.3	201.2	201.2	210.3	210.3	201.2	210.3	192.0	205.23		
3	15	173.7	182.9	182.9	182.9	192.0	182.9	192.0	173.7	192.0	183.90		
4	20	173.7	173.7	182.9	192.0	173.7	182.9	182.9	173.7	164.6	177.80		
5	25	182.9	192.0	192.0	192.0	192.0	192.0	173.7	173.7	182.9	185.93	189.59	mm
6	30	201.2	192.0	210.3	201.2	201.2	201.2	201.2	201.2	192.0	200.15	7.46	inch
7	35	192.0	201.2	210.3	201.2	201.2	201.2	182.9	192.0	201.2	198.12		
8	40	173.7	182.9	192.0	173.7	173.7	173.7	182.9	182.9	182.9	179.83		
9	45	173.7	173.7	173.7	182.9	182.9	182.9	182.9	182.9	173.7	178.82		
10	50	173.7	192.0	182.9	192.0	192.0	192.0	192.0	192.0	182.9	187.96		

Number of turn:		22											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	228.6	228.6	219.5	228.6	228.6	237.7	210.3	219.5	219.5	224.54		
2	10	201.2	219.5	210.3	210.3	201.2	201.2	201.2	201.2	210.3	206.25		
3	15	182.9	173.7	182.9	182.9	192.0	192.0	182.9	192.0	182.9	184.91		
4	20	192.0	182.9	192.0	173.7	192.0	182.9	201.2	192.0	192.0	188.98		
5	25	201.2	210.3	219.5	219.5	219.5	210.3	228.6	219.5	228.6	217.42	201.98	mm
6	30	210.3	210.3	201.2	219.5	219.5	210.3	201.2	210.3	210.3	210.31	7.95	inch
7	35	192.0	192.0	182.9	192.0	201.2	192.0	192.0	201.2	192.0	193.04		
8	40	192.0	192.0	182.9	182.9	182.9	192.0	192.0	192.0	192.0	188.98		
9	45	192.0	201.2	201.2	201.2	192.0	192.0	201.2	219.5	210.3	201.17		
10	50	201.2	201.2	201.2	201.2	210.3	192.0	210.3	210.3	210.3	204.22		

Diameter of culvert: 3.5 ft

Slope: 1 in 250

Number of turn:		1/2											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	58	56	56	57	56	56	55	56	55	56.11		
2	10	56	55	55	58	58	58	56	56	56	56.44		
3	15	57	58	56	53	58	56	55	55	55	55.89		
4	20	54	54	53	55	55	56	54	52	53	54.00		
5	25	52	52	50	54	55	55	52	52	52	52.67	53.11	mm
6	30	50	50	50	56	56	55	52	52	52	52.56	2.09	inch
7	35	52	51	51	55	56	55	52	52	54	53.11		
8	40	48	48	48	52	52	52	50	50	51	50.11		
9	45	50	49	49	52	53	53	52	50	50	50.89		
10	50	48	47	47	50	50	52	50	50	50	49.33		
Number of turn:		1											
1	5	45.7	54.9	45.7	45.7	54.9	54.9	54.9	45.7	54.9	50.80		
2	10	45.7	54.9	45.7	64.0	64.0	54.9	45.7	54.9	45.7	52.83		
3	15	45.7	64.0	45.7	54.9	54.9	54.9	54.9	54.9	54.9	53.85		
4	20	54.9	45.7	64.0	45.7	54.9	45.7	54.9	54.9	54.9	52.83		
5	25	54.9	54.9	54.9	45.7	64.0	54.9	54.9	45.7	64.0	54.86	52.43	mm
6	30	54.9	54.9	45.7	54.9	54.9	64.0	45.7	54.9	54.9	53.85	2.06	inch
7	35	54.9	45.7	54.9	45.7	45.7	45.7	45.7	54.9	54.9	49.78		
8	40	54.9	45.7	54.9	54.9	54.9	45.7	45.7	54.9	54.9	51.82		
9	45	54.9	54.9	54.9	45.7	45.7	54.9	54.9	54.9	54.9	52.83		

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)						(mm)	(mm)	(mm)	(mm)		
10	50	54.9	45.7	54.9	54.9	45.7	54.9	54.9	45.7	45.7	50.80		
Number of turn:		2											
1	5	73	110	73	82	73	73	91	82	82	82.30		
2	10	82	82	82	82	82	73	82	82	82	81.28		
3	15	82	82	82	82	82	91	73	82	82	82.30		
4	20	91	82	82	82	82	82	91	82	91	85.34		
5	25	91	91	82	91	91	82	91	82	91	88.39	83.72	mm
6	30	82	82	73	91	82	82	82	82	82	82.30	3.30	inch
7	35	91	91	91	82	82	73	82	82	73	83.31		
8	40	91	82	91	82	82	82	82	91	82	85.34		
9	45	82	91	82	82	73	91	73	91	82	83.31		
10	50	82	82	82	82	82	82	82	91	82	83.31		
Number of turn:		3											
1	5	101	91	91	110	91	101	110	101	110	100.58		
2	10	91	91	101	91	91	82	101	91	101	93.47		
3	15	101	101	101	101	91	110	91	101	110	100.58		
4	20	101	110	119	110	110	101	110	110	101	107.70		
5	25	91	101	110	101	110	101	101	110	91	101.60	103.94	mm
6	30	110	101	101	91	101	101	110	101	91	100.58	4.09	inch
7	35	110	110	110	110	110	101	119	110	110	109.73		
8	40	110	110	110	110	110	119	119	101	101	109.73		
9	45	110	110	110	110	101	110	110	101	101	106.68		
10	50	119	101	101	110	110	110	110	101	119	108.71		

Number of turn: 4

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	91	101	101	101	91	101	91	91	101	96.52		
2	10	119	119	119	110	119	110	119	119	119	116.84		
3	15	110	119	110	119	110	119	110	119	119	114.81		
4	20	110	119	110	110	119	110	110	119	101	111.76		
5	25	119	119	119	128	128	110	119	119	110	118.87	115.52	mm
6	30	119	119	119	110	119	119	110	110	110	114.81	4.55	inch
7	35	119	128	119	119	101	119	119	119	110	116.84		
8	40	128	119	110	119	119	119	128	119	110	118.87		
9	45	119	128	128	119	119	119	119	119	110	119.89		
10	50	119	128	128	119	128	128	128	128	128	125.98		

Number of turn: 5

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	119	110	119	119	110	110	128	119	119	116.84		
2	10	110	110	119	110	110	119	119	110	110	112.78		
3	15	128	128	128	119	128	119	128	119	119	123.95		
4	20	137	137	137	137	155	137	137	119	119	135.13		
5	25	137	128	137	137	128	137	128	128	137	133.10	128.63	mm
6	30	128	128	128	128	128	128	119	128	128	127.00	5.06	inch
7	35	137	137	119	128	137	155	137	137	128	135.13		
8	40	128	137	137	128	128	128	128	137	128	131.06		
9	45	137	137	128	137	137	137	128	128	137	134.11		
10	50	137	137	137	137	137	137	137	137	137	137.16		

Number of turn:		6											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	137	128	119	128	119	128	128	128	128	127.00		
2	10	128	128	137	137	119	119	119	137	137	129.03		
3	15	128	128	128	119	119	119	128	119	128	123.95		
4	20	128	137	137	137	128	128	137	128	137	133.10		
5	25	137	137	137	137	128	128	137	128	155	136.14	140.61	mm
6	30	155	155	137	137	137	155	137	155	137	145.29	5.54	inch
7	35	155	155	165	165	174	165	165	165	155	162.56		
8	40	137	155	165	155	155	155	155	155	155	154.43		
9	45	137	137	137	155	137	137	137	155	155	143.26		
10	50	137	155	155	137	155	155	155	155	155	151.38		

Number of turn:		8											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	137	155	155	137	137	155	155	137	155	147.32		
2	10	174	174	174	155	155	174	174	165	165	167.64		
3	15	174	174	192	174	183	165	174	183	183	177.80		
4	20	174	165	174	183	183	183	183	174	174	176.78		
5	25	174	183	183	174	155	155	165	165	174	169.67	170.89	mm
6	30	183	174	183	183	174	174	183	174	183	178.82	6.73	inch
7	35	183	183	174	165	174	174	183	174	174	175.77		
8	40	174	174	174	174	165	165	174	174	183	172.72		
9	45	174	174	174	174	174	174	183	174	174	174.75		
10	50	165	165	174	165	174	174	165	165	165	167.64		

Number of turn:		10											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	174	183	174	174	165	174	165	174	174	172.72		
2	10	192	183	183	174	183	174	174	183	174	179.83		
3	15	201	192	183	174	192	192	192	192	183	188.98		
4	20	192	183	183	183	192	192	183	192	183	186.94		
5	25	183	192	192	183	192	183	183	183	183	185.93	184.51	mm
6	30	183	183	183	183	174	183	192	174	174	180.85	7.26	inch
7	35	183	183	183	183	183	183	192	183	192	184.91		
8	40	192	183	174	192	183	183	183	183	183	183.90		
9	45	192	192	183	183	192	183	192	192	183	187.96		
10	50	183	192	192	201	192	201	201	192	183	193.04		
Number of turn:		14											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	192	192	183	201	192	192	192	201	192	193.04		
2	10	174	183	192	183	192	192	174	183	192	184.91		
3	15	192	192	174	192	201	192	201	192	183	191.01		
4	20	183	174	183	183	183	192	192	183	183	183.90		
5	25	192	183	192	192	192	192	183	192	192	189.99	192.02	mm
6	30	174	183	183	192	192	192	192	183	183	185.93	7.56	inch
7	35	192	183	192	192	192	183	192	201	210	193.04		
8	40	201	201	192	201	192	192	192	192	201	196.09		
9	45	201	201	201	192	201	192	201	210	201	200.15		
10	50	201	210	201	201	201	192	201	201	210	202.18		

Number of turn:		18											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	210	192	210	201	192	210	192	192	192	199.14		
2	10	201	210	201	210	210	201	201	201	201	204.22		
3	15	201	192	192	192	201	192	192	201	192	195.07		
4	20	183	183	192	183	183	192	183	192	192	186.94		
5	25	192	192	183	201	192	192	183	192	183	189.99	201.27	mm
6	30	201	192	192	192	192	201	192	183	192	193.04	7.92	inch
7	35	183	201	192	201	201	192	201	201	201	197.10		
8	40	219	219	219	219	219	219	219	219	201	217.42		
9	45	210	210	210	201	201	201	210	210	210	207.26		
10	50	229	219	229	219	219	219	229	219	219	222.50		

Number of turn:		22											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	210	192	210	192	201	201	210	201	210	203.20		
2	10	219	201	201	210	201	201	210	201	201	205.23		
3	15	201	192	192	192	201	201	201	201	201	198.12		
4	20	201	192	192	192	192	192	192	192	192	193.04		
5	25	201	192	192	192	201	192	201	192	192	195.07	203.91	mm
6	30	192	201	192	201	201	201	192	192	192	196.09	8.03	inch
7	35	219	201	219	219	219	219	219	229	229	219.46		
8	40	219	219	210	229	219	229	229	219	229	222.50		
9	45	201	210	201	201	201	201	201	201	210	203.20		
10	50	210	201	201	201	201	201	201	201	210	203.20		

Diameter of culvert: 3.5 ft

Slope: 1 in 500

Number of turn:		1/2											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	59	60	60	58	60	61	61	60	61	60.00		
2	10	64	66	66	62	60	63	64	63	65	63.67		
3	15	64	63	61	62	60	60	65	61	62	62.00		
4	20	60	61	60	63	61	61	58	58	59	60.11		
5	25	58	57	58	60	58	58	61	59	59	58.67	59.07	mm
6	30	60	59	60	63	60	59	63	60	62	60.67	2.33	inch
7	35	60	58	60	58	59	59	56	58	58	58.44		
8	40	57	58	59	57	55	58	57	56	56	57.00		
9	45	58	56	57	55	55	57	56	56	59	56.56		
10	50	55	53	51	55	55	53	54	53	53	53.56		
Number of turn:		1											
1	5	45.72	54.86	54.86	45.72	54.86	45.72	45.72	45.72	54.86	49.78		
2	10	64.01	64.01	64.01	54.86	54.86	64.01	64.01	73.15	73.15	64.01		
3	15	73.15	64.01	73.15	73.15	64.01	73.15	64.01	64.01	64.01	68.07		
4	20	64.01	54.86	54.86	54.86	64.01	64.01	64.01	64.01	64.01	60.96		
5	25	64.01	64.01	64.01	64.01	64.01	54.86	64.01	64.01	64.01	62.99	61.57	mm
6	30	73.15	64.01	73.15	64.01	64.01	64.01	54.86	64.01	64.01	65.02	2.42	inch
7	35	64.01	64.01	45.72	45.72	54.86	54.86	54.86	64.01	54.86	55.88		
8	40	64.01	64.01	64.01	64.01	73.15	64.01	64.01	64.01	54.86	64.01		
9	45	64.01	54.86	64.01	64.01	64.01	73.15	64.01	73.15	73.15	66.04		

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)						(mm)	(mm)	(mm)	(mm)		
10	50	54.86	64.01	64.01	54.86	54.86	64.01	64.01	64.01	45.72	58.93		
Number of turn:		2											
1	5	82	91	73	73	82	82	82	82	73	80.26		
2	10	82	91	91	91	91	91	91	91	91	90.42		
3	15	91	101	101	91	101	91	101	91	91	95.50		
4	20	101	101	101	101	110	101	91	101	101	100.58		
5	25	110	101	91	101	110	101	101	101	101	101.60	97.64	mm
6	30	101	101	110	101	110	110	91	101	101	102.62	3.84	inch
7	35	101	91	101	101	91	101	101	101	91	97.54		
8	40	101	91	101	101	91	110	101	101	101	99.57		
9	45	110	101	110	101	101	101	110	101	101	103.63		
10	50	101	110	101	101	110	101	110	110	101	104.65		
Number of turn:		3											
1	5	101	110	110	101	110	91	101	91	110	102.62		
2	10	101	101	110	101	110	101	101	101	101	102.62		
3	15	101	101	110	110	110	101	110	110	110	106.68		
4	20	110	110	110	119	110	110	119	110	101	110.74		
5	25	110	119	119	119	119	119	119	119	110	116.84	115.62	mm
6	30	119	110	119	119	119	119	119	119	110	116.84	4.55	inch
7	35	119	110	110	119	119	119	110	119	119	115.82		
8	40	119	119	128	119	119	119	128	119	128	121.92		
9	45	128	128	128	128	119	128	128	128	137	128.02		
10	50	137	137	137	128	128	137	137	137	128	134.11		

Number of turn:	4												
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)						(mm)	(mm)	(mm)	(mm)		
1	5	101	110	101	91	91	91	110	101	91	98.55		
2	10	119	110	119	110	110	128	101	110	110	112.78		
3	15	119	128	119	110	119	128	119	119	110	118.87		
4	20	128	119	110	119	119	119	119	119	119	118.87		
5	25	128	119	128	128	119	128	119	128	128	124.97	124.76	mm
6	30	128	128	128	128	128	128	128	119	119	125.98	4.91	inch
7	35	137	137	128	137	128	128	137	128	128	132.08		
8	40	137	128	137	128	137	137	137	137	155	137.16		
9	45	128	128	137	137	137	128	128	137	137	133.10		
10	50	137	137	137	155	155	137	155	155	137	145.29		

Number of turn:	5												
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)						(mm)	(mm)	(mm)	(mm)		
1	5	110	119	110	101	110	110	110	110	110	109.73		
2	10	119	119	119	119	119	119	110	110	119	116.84		
3	15	137	128	137	137	137	137	128	128	128	133.10		
4	20	128	137	137	137	137	137	137	137	128	135.13		
5	25	128	137	128	137	137	137	137	128	137	134.11	136.86	mm
6	30	137	155	155	137	137	137	137	137	137	141.22	5.39	inch
7	35	155	155	155	137	137	128	137	137	155	144.27		
8	40	155	137	155	155	137	155	155	155	137	149.35		
9	45	137	155	155	155	137	155	155	137	155	149.35		
10	50	155	155	155	165	155	165	155	137	155	155.45		

Number of turn:		6											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)						(mm)	(mm)	(mm)	(mm)		
1	5	119	119	137	137	128	137	128	128	128	129.03		
2	10	128	128	128	128	128	128	128	128	119	127.00		
3	15	137	128	128	128	128	128	128	128	128	129.03		
4	20	137	155	137	137	137	137	137	137	155	141.22		
5	25	155	165	165	155	155	165	165	165	155	160.53	149.96	mm
6	30	137	155	155	155	155	155	165	155	165	155.45	5.90	inch
7	35	165	165	155	155	155	155	155	155	155	157.48		
8	40	165	165	155	165	165	165	174	165	165	164.59		
9	45	165	174	165	165	165	165	174	165	165	166.62		
10	50	165	174	174	165	165	174	174	165	165	168.66		

Number of turn:		8											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)						(mm)	(mm)	(mm)	(mm)		
1	5	137	137	155	155	155	155	128	137	128	143.26		
2	10	165	174	183	155	165	174	174	174	174	170.69		
3	15	174	183	183	155	155	174	165	165	155	167.64		
4	20	183	183	183	183	192	183	183	183	183	183.90		
5	25	183	165	174	183	174	174	165	174	165	172.72	172.62	mm
6	30	183	183	165	165	174	174	183	174	174	174.75	6.80	inch
7	35	174	165	165	174	174	174	174	174	174	171.70		
8	40	174	174	165	183	174	174	174	165	174	172.72		
9	45	183	192	183	183	183	183	174	174	174	180.85		
10	50	183	192	183	192	192	192	174	192	192	187.96		

Number of turn:		10											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)						(mm)	(mm)	(mm)	(mm)		
1	5	155	165	165	165	174	174	174	174	183	169.67		
2	10	174	174	183	165	174	183	183	174	183	176.78		
3	15	174	192	192	201	192	192	201	201	201	194.06		
4	20	192	201	201	192	201	192	192	192	201	196.09		
5	25	201	192	192	183	192	183	201	192	201	193.04	191.72	mm
6	30	192	201	201	192	192	192	192	192	201	195.07	7.55	inch
7	35	210	192	210	201	210	192	192	201	210	202.18		
8	40	192	192	201	201	201	192	192	192	201	196.09		
9	45	192	201	201	192	183	201	192	192	201	195.07		
10	50	192	210	201	192	201	192	201	201	201	199.14		

Number of turn:		14											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)						(mm)	(mm)	(mm)	(mm)		
1	5	201	192	201	192	183	201	201	201	192	196.09		
2	10	183	183	183	201	192	183	192	192	192	188.98		
3	15	201	201	201	201	192	210	210	210	201	203.20		
4	20	192	192	192	192	192	210	183	183	192	192.02		
5	25	201	201	192	192	201	192	192	192	192	195.07	199.85	mm
6	30	201	201	201	201	192	192	201	201	192	198.12	7.87	inch
7	35	201	201	201	192	192	210	192	192	210	199.14		
8	40	201	210	210	210	201	201	201	201	192	203.20		
9	45	210	210	210	201	210	210	210	210	210	209.30		
10	50	219	219	210	219	210	201	210	210	219	213.36		

Number of turn:		18											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)						(mm)	(mm)	(mm)	(mm)		
1	5	192	201	192	201	201	210	201	210	192	200.15		
2	10	192	201	192	210	210	192	210	201	201	201.17		
3	15	192	201	201	201	210	210	201	210	210	204.22		
4	20	186	192	192	192	192	192	201	192	192	192.33		
5	25	201	192	201	201	210	192	192	192	192	197.10	203.54	mm
6	30	201	201	201	210	201	201	201	210	201	203.20	8.01	inch
7	35	201	201	201	201	201	201	201	201	210	202.18		
8	40	210	219	210	210	210	210	219	219	210	213.36		
9	45	210	201	210	201	210	210	201	210	210	207.26		
10	50	219	219	210	210	210	210	219	219	210	214.38		

Number of turn:		22											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)						(mm)	(mm)	(mm)	(mm)		
1	5	210	210	210	219	210	201	192	201	210	207.26		
2	10	201	201	201	201	192	201	201	210	219	203.20		
3	15	192	201	201	210	210	201	210	192	201	202.18		
4	20	201	201	192	192	192	201	192	192	192	195.07		
5	25	210	192	201	192	201	192	192	201	192	197.10	206.96	mm
6	30	201	192	201	201	192	210	210	201	201	201.17	8.15	inch
7	35	210	210	210	219	210	201	219	210	210	211.33		
8	40	219	210	210	210	210	210	219	219	210	213.36		
9	45	219	219	229	219	219	219	219	210	210	218.44		
10	50	219	219	229	219	219	219	219	219	219	220.47		

Diameter of culvert: 3.5 ft

Slope: 1 in 50

Number of turn:		1/2											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	34	32	32	33	34	34	32	33	31	32.78		
2	10	35	32	34	34	33	33	34	34	32	33.44		
3	15	33	32	33	32	32	31	31	32	32	32.00		
4	20	32	33	33	32	32	33	34	32	31	32.44		
5	25	32	33	32	33	32	33	31	32	32	32.22	31.94	mm
6	30	32	33	32	33	33	31	33	32	31	32.22	1.26	inch
7	35	32	31	31	32	30	31	30	31	30	30.89		
8	40	33	32	32	31	31	31	30	30	30	31.11		
9	45	31	31	32	30	32	30	30	30	32	30.89		
10	50	31	33	32	31	31	30	32	32	31	31.44		
Number of turn:		1											
1	5	27.4	45.7	27.4	27.4	27.4	45.7	45.7	27.4	45.7	35.56		
2	10	45.7	27.4	45.7	27.4	27.4	27.4	27.4	45.7	27.4	33.53		
3	15	27.4	45.7	45.7	27.4	27.4	27.4	27.4	27.4	27.4	31.50		
4	20	27.4	27.4	18.3	18.3	27.4	27.4	27.4	27.4	27.4	25.40		
5	25	18.3	18.3	27.4	18.3	18.3	27.4	27.4	27.4	27.4	23.37	25.30	mm
6	30	18.3	18.3	18.3	18.3	18.3	18.3	18.3	18.3	18.3	18.29	1.00	inch
7	35	27.4	18.3	18.3	18.3	27.4	18.3	27.4	18.3	18.3	21.34		
8	40	27.4	27.4	18.3	18.3	27.4	18.3	18.3	18.3	18.3	21.34		
9	45	27.4	18.3	27.4	27.4	18.3	27.4	18.3	27.4	27.4	24.38		

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
10	50	27.4	9.1	18.3	18.3	18.3	18.3	18.3	18.3	18.3	18.29		
Number of turn:		2											
1	5	73.2	64.0	73.2	64.0	54.9	73.2	64.0	54.9	64.0	65.02		
2	10	64.0	64.0	73.2	64.0	64.0	73.2	73.2	64.0	73.2	68.07		
3	15	73.2	64.0	64.0	73.2	73.2	73.2	64.0	64.0	73.2	69.09		
4	20	64.0	64.0	54.9	64.0	73.2	64.0	64.0	64.0	64.0	64.01		
5	25	64.0	64.0	64.0	73.2	64.0	64.0	54.9	64.0	73.2	65.02	63.70	mm
6	30	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.01	2.51	inch
7	35	64.0	64.0	64.0	73.2	64.0	64.0	64.0	64.0	64.0	65.02		
8	40	54.9	54.9	64.0	64.0	64.0	54.9	64.0	54.9	64.0	59.94		
9	45	54.9	64.0	64.0	64.0	64.0	54.9	54.9	54.9	54.9	58.93		
10	50	64.0	64.0	54.9	54.9	54.9	54.9	64.0	54.9	54.9	57.91		
Number of turn:		3											
1	5	82	91	91	91	82	82	82	91	82	86.36		
2	10	101	101	101	91	91	101	91	82	82	93.47		
3	15	91	82	73	73	91	91	82	82	82	83.31		
4	20	82	82	73	82	82	82	73	82	82	80.26		
5	25	91	82	82	91	82	82	82	82	82	84.33	80.77	mm
6	30	82	82	73	82	82	73	82	82	82	80.26	3.18	inch
7	35	64	73	73	82	82	82	82	73	73	76.20		
8	40	73	73	73	82	73	82	73	73	73	75.18		
9	45	73	73	82	73	73	73	82	64	64	73.15		
10	50	73	82	82	73	82	73	73	64	73	75.18		

Number of turn: 4

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	91	101	91	91	91	91	101	82	101	93.47		
2	10	91	91	101	91	101	91	91	101	101	95.50		
3	15	91	91	101	101	91	101	91	82	91	93.47		
4	20	91	91	91	91	91	101	101	101	101	95.50		
5	25	91	82	82	91	91	91	101	91	91	90.42	90.93	mm
6	30	82	82	91	91	91	91	91	91	91	89.41	4	inch
7	35	91	91	82	91	91	91	91	91	82	89.41		
8	40	82	91	91	82	91	73	91	91	91	87.38		
9	45	91	91	91	91	82	82	91	91	91	89.41		
10	50	82	82	82	91	91	64	91	91	91	85.34		

Number of turn: 5

S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	110	101	110	101	101	91	101	119	101	103.63		
2	10	91	101	101	91	91	91	101	101	110	97.54		
3	15	91	101	101	91	91	91	110	101	101	97.54		
4	20	91	101	101	101	101	101	101	101	101	99.57		
5	25	110	101	101	101	101	101	101	91	110	101.60	100.48	mm
6	30	101	110	110	110	110	101	110	110	110	107.70	3.96	inch
7	35	110	101	91	110	91	101	101	110	101	101.60		
8	40	101	110	110	101	110	101	101	101	91	102.62		
9	45	110	110	91	91	101	91	91	91	101	97.54		
10	50	101	101	82	91	101	110	91	91	91	95.50		

Number of turn:	6											
S.N.	Dist from Headbox	Depth Measured								Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	119	119	110	119	119	119	119	119	119	117.86		
2	10	128	128	119	110	119	110	128	128	128	121.92		
3	15	137	137	137	119	119	119	128	119	128	127.00		
4	20	137	128	137	137	137	137	137	128	137	135.13		
5	25	128	128	119	128	128	128	128	128	128	127.00	117.96	mm
6	30	101	110	119	101	101	101	101	119	101	105.66	4.64	inch
7	35	101	110	101	110	110	110	110	110	110	107.70		
8	40	101	110	110	101	110	119	110	110	110	108.71		
9	45	119	119	110	110	119	110	110	119	119	114.81		
10	50	110	110	119	110	119	119	110	110	119	113.79		

Number of turn:	8											
S.N.	Dist from Headbox	Depth Measured								Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	137	137	137	128	128	128	137	137	128	133.10		
2	10	155	155	165	137	155	155	155	155	155	154.43		
3	15	165	155	165	165	165	155	165	165	165	162.56		
4	20	119	119	128	137	128	128	128	128	110	124.97		
5	25	128	110	128	119	119	128	137	128	128	124.97	136.86	mm
6	30	155	137	137	137	137	137	137	137	137	139.19	5.39	inch
7	35	155	155	155	155	155	137	137	155	155	151.38		
8	40	128	128	128	137	128	137	128	110	119	127.00		
9	45	128	128	119	128	119	128	119	119	128	123.95		
10	50	128	128	137	128	128	128	119	128	119	127.00		

Number of turn:		10											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	155	174	165	174	174	155	183	174	165	168.66		
2	10	174	174	155	174	174	174	174	165	155	168.66		
3	15	155	155	155	155	165	155	137	137	155	152.40		
4	20	128	137	137	128	137	137	128	137	137	134.11		
5	25	155	137	155	155	137	155	155	137	155	149.35	153.62	mm
6	30	174	174	174	174	174	174	155	174	174	171.70	6.05	inch
7	35	137	155	155	155	155	155	137	155	137	149.35		
8	40	137	128	137	137	137	137	137	155	155	140.21		
9	45	155	137	137	155	165	155	137	155	155	150.37		
10	50	155	155	155	155	137	155	137	155	155	151.38		

Number of turn:		14											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	192	192	192	192	192	192	183	192	201	192.02		
2	10	192	192	192	201	183	174	183	174	174	184.91		
3	15	165	165	174	155	155	165	174	165	174	165.61		
4	20	155	155	174	186	155	174	165	165	155	164.90		
5	25	192	183	183	183	183	192	183	201	192	187.96	169.60	mm
6	30	174	165	174	155	165	155	174	155	165	164.59	6.68	inch
7	35	155	165	165	155	155	155	165	165	155	159.51		
8	40	174	174	174	165	165	165	174	155	174	168.66		
9	45	155	155	155	155	155	155	155	165	155	156.46		
10	50	155	155	155	155	137	155	155	137	155	151.38		

Number of turn:		18											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	192	210	192	201	192	201	192	192	192	196.09		
2	10	183	183	183	201	201	192	192	201	192	192.02		
3	15	174	165	155	146	155	155	174	165	155	160.53		
4	20	174	183	183	174	165	183	183	174	174	176.78		
5	25	183	183	183	183	183	192	183	183	192	184.91	174.99	mm
6	30	155	155	165	146	146	165	155	146	165	155.45	6.89	inch
7	35	165	165	174	165	405	165	174	165	165	193.34		
8	40	183	183	174	174	165	174	174	174	183	175.77		
9	45	146	155	155	155	155	165	165	155	146	155.45		
10	50	155	155	165	155	165	155	165	165	155	159.51		

Number of turn:		22											
S.N.	Dist from Headbox	Depth Measured									Final Water Depth	Avg. depth in culvert	
	(ft)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		
1	5	210	201	210	201	219	219	192	210	210	208.28		
2	10	768	201	192	201	201	201	192	192	192	260.10		
3	15	146	165	165	155	165	174	174	165	174	164.59		
4	20	174	174	183	174	192	183	192	183	174	180.85		
5	25	192	192	183	183	192	183	192	183	183	186.94	183.79	mm
6	30	165	155	155	155	155	165	155	155	155	157.48	7.24	inch
7	35	174	174	165	174	174	174	183	174	174	173.74		
8	40	174	174	174	174	165	165	174	174	165	170.69		
9	45	165	155	165	165	174	155	155	165	155	161.54		
10	50	174	165	174	174	174	183	174	174	174	173.74		

APPENDIX B:

Discharge Rating Curve Calculation

Discharge Rating Curve Calculation:

Valve Turn	Channel Portion	Area $_{local}$	Vmag Average (from ADV data)	$Q_{local} = Vl_{ocal}$ * A_{local}	Q_{total}
		sq in	cm/sec	cfs	cfs
1/2	5a	49.5	0.5289	0.005965	
	4a	63	0.3517	0.005048	0.322
	3a	63	0.2065	0.002964	
	2a	63	0.2879	0.004132	
	1a	49.5	0.6875	0.007753	
	1b	49.5	0.2607	0.002940	
	2b	63	0.4643	0.006664	
	3b	63	0.4378	0.006284	
	4b	63	0.4831	0.006934	
	5b	49.5	0.4636	0.005228	
	5c	49.5	0.5447	0.006143	
	4c	63	0.2054	0.002948	
	3c	63	0.133	0.001909	
	2c	63	0.1203	0.001727	
	1c	49.5	0.3463	0.003905	
	1d	49.5	0.5081	0.005730	
	2d	63	0.5293	0.007597	
	3d	63	0.3668	0.005265	
	4d	63	0.4489	0.006443	
	5d	49.5	0.3697	0.004169	
	5e	49.5	1.7305	0.019516	
	4e	63	1.4968	0.021484	
	3e	63	1.4492	0.020801	
	2e	63	1.55	0.022248	
	1e	49.5	1.4515	0.016370	
	1f	58.78125	1.9903	0.026655	
	2f	74.8125	1.8028	0.030728	
	3f	74.8125	1.7085	0.029121	
	4f	74.8125	1.5873	0.027055	
	5f	58.78125	0.6007	0.008045	
1	5a	49.5	0.2271	0.002561	
	4a	63	0.2168	0.003112	0.466
	3a	63	0.1994	0.002862	
	2a	63	0.5228	0.007504	
	1a	49.5	0.3207	0.003617	

Valve Turn	Channel Portion	Area $_{local}$	Vmag Average (from ADV data)	$Q_{local} = Vl_{ocal} * A_{local}$	Q_{total}
		sq in	cm/sec	cfs	cfs
	1b	49.5	0.9282	0.010468	
	2b	63	1.313	0.018846	
	3b	63	1.014	0.014554	
	4b	63	0.9255	0.013284	
	5b	49.5	1.0219	0.011525	
	5c	49.5	1.0734	0.012106	
	4c	63	0.7319	0.010505	
	3c	63	1.1473	0.016468	
	2c	63	1.2233	0.017559	
	1c	49.5	1.3524	0.015252	
	1d	49.5	2.035	0.022950	
	2d	63	1.6544	0.023746	
	3d	63	1.0631	0.015259	
	4d	63	1.4138	0.020293	
	5d	49.5	1.3779	0.015540	
	5e	49.5	1.3163	0.014845	
	4e	63	1.028	0.014755	
	3e	63	1.2056	0.017305	
	2e	63	1.7064	0.024493	
	1e	49.5	2.3593	0.026608	
	1f	55.6875	2.3556	0.029887	
	2f	70.875	1.685	0.027209	
	3f	70.875	0.9689	0.015645	
	4f	70.875	1.4036	0.022665	
	5f	55.6875	1.1564	0.014672	
2	5a	49.5	2.3189	0.026152	
	4a	63	4.019	0.057687	1.633
	3a	63	5.1417	0.073801	
	2a	63	3.904	0.056036	
	1a	49.5	3.4261	0.038639	
	1b	49.5	4.7117	0.053137	
	2b	63	6.5348	0.093797	
	3b	63	8.8453	0.126961	
	4b	63	6.9777	0.100154	
	5b	49.5	6.3465	0.071574	
	5c	49.5	4.3982	0.049602	
	4c	63	3.5913	0.051548	

Valve Turn	Channel Portion	Area $_{local}$	Vmag Average (from ADV data)	$Q_{local} = Vl_{ocal} * A_{local}$	Q_{total}
		sq in	cm/sec	cfs	cfs
	3c	63	2.1408	0.030728	
	2c	63	2.6061	0.037407	
	1c	49.5	3.5388	0.039910	
	1d	49.5	3.7869	0.042708	
	2d	63	3.3199	0.047652	
	3d	63	1.0791	0.015489	
	4d	63	3.5706	0.051251	
	5d	49.5	4.5225	0.051004	
	5e	49.5	4.3218	0.048740	
	4e	63	3.601	0.051687	
	3e	63	3.9991	0.057401	
	2e	63	3.4045	0.048866	
	1e	49.5	4.5989	0.051865	
	1f	49.5	3.4614	0.039037	
	2f	63	3.737	0.053639	
	3f	63	4.1104	0.058999	
	4f	63	4.1422	0.059455	
	5f	49.5	4.2229	0.047625	
3	5a	49.5	2.4694	0.027849	
	4a	63	5.1063	0.073293	2.254
	3a	63	5.9133	0.084877	
	2a	63	5.7677	0.082787	
	1a	49.5	4.8458	0.054650	
	1b	49.5	7.1574	0.080719	
	2b	63	7.1015	0.101931	
	3b	63	6.692	0.096054	
	4b	63	7.6462	0.109750	
	5b	49.5	8.062	0.090921	
	5c	49.5	5.8894	0.066419	
	4c	63	5.5307	0.079385	
	3c	63	5.2844	0.075850	
	2c	63	5.9492	0.085392	
	1c	49.5	6.4917	0.073212	
	1d	49.5	5.3536	0.060377	
	2d	63	6.3451	0.091074	
	3d	63	4.5752	0.065670	
	4d	63	4.5191	0.064865	

Valve Turn	Channel Portion	Area $_{local}$	Vmag Average (from ADV data)	Q_{local} = Vl_{ocal} * A_{local}	Q_{total}
		sq in	cm/sec	cfs	cfs
	5d	49.5	4.9283	0.055580	
	5e	49.5	5.3956	0.060850	
	4e	63	5.2946	0.075996	
	3e	63	5.5582	0.079780	
	2e	63	6.7384	0.096720	
	1e	49.5	6.899	0.077805	
	1f	45.375	7.0576	0.072961	
	2f	57.75	5.9985	0.078925	
	3f	57.75	5.3566	0.070479	
	4f	57.75	4.8541	0.063867	
	5f	45.375	5.4541	0.056384	
4	5a	49.5	4.6925	0.052921	
	4a	63	6.9039	0.099095	2.915
	3a	63	8.1631	0.117169	
	2a	63	7.9696	0.114392	
	1a	49.5	5.85	0.065975	
	1b	49.5	9.0292	0.101829	
	2b	63	8.6219	0.123754	
	3b	63	8.5635	0.122916	
	4b	63	8.6341	0.123930	
	5b	49.5	8.5612	0.096551	
	5c	49.5	6.9291	0.078145	
	4c	63	8.1473	0.116942	
	3c	63	7.7747	0.111594	
	2c	63	7.7003	0.110526	
	1c	49.5	8.3015	0.093622	
	1d	49.5	9.5342	0.107524	
	2d	63	7.8648	0.112887	
	3d	63	6.7304	0.096605	
	4d	63	7.3981	0.106189	
	5d	49.5	7.1774	0.080945	
	5e	49.5	7.1551	0.080693	
	4e	63	6.7465	0.096836	
	3e	63	6.8348	0.098103	
	2e	63	7.542	0.108254	
	1e	49.5	8.8379	0.099672	
	1f	41.25	8.8744	0.083403	

Valve Turn	Channel Portion	Area $_{local}$	Vmag Average (from ADV data)	Q_{local} = Vl_{ocal} * A_{local}	Q_{total}
		sq in	cm/sec	cfs	cfs
	2f	52.5	7.7572	0.092786	
	3f	52.5	7.361	0.088047	
	4f	52.5	6.6338	0.079349	
	5f	41.25	5.7829	0.054348	
5	5a	49.5	7.2888	0.082201	3.680
	4a	63	8.624	0.123785	
	3a	63	9.9766	0.143199	
	2a	63	10.4624	0.150172	
	1a	49.5	8.3784	0.094490	
	1b	49.5	10.329	0.116488	
	2b	63	10.6538	0.152919	
	3b	63	10.4075	0.149384	
	4b	63	11.1043	0.159386	
	5b	49.5	10.605	0.119601	
	5c	49.5	9.4805	0.106919	
	4c	63	10.7174	0.153832	
	3c	63	10.0992	0.144959	
	2c	63	9.9039	0.142156	
	1c	49.5	9.802	0.110545	
	1d	49.5	9.9578	0.112302	
	2d	63	9.9547	0.142885	
	3d	63	8.7074	0.124982	
	4d	63	9.701	0.139243	
	5d	49.5	9.9458	0.112166	
	5e	49.5	8.8832	0.100183	
	4e	63	9.8426	0.141276	
	3e	63	9.6725	0.138834	
	2e	63	9.9354	0.142608	
	1e	49.5	10.0851	0.113737	
	1f	37.125	9.9886	0.084487	
	2f	47.25	9.8295	0.105816	
	3f	47.25	9.3284	0.100421	
	4f	47.25	8.9566	0.096419	
	5f	37.125	8.7659	0.074145	
6	5a	49.5	10.0446	0.113280	4.563
	4a	63	10.108	0.145085	

Valve Turn	Channel Portion	Area $_{local}$	Vmag Average (from ADV data)	$Q_{local} = Vl_{ocal} * A_{local}$	Q_{total}
		sq in	cm/sec	cfs	cfs
	3a	63	12.1152	0.173896	
	2a	63	12.2491	0.175817	
	1a	49.5	9.7895	0.110404	
	1b	49.5	12.0502	0.135899	
	2b	63	12.3193	0.176825	
	3b	63	12.8657	0.184668	
	4b	63	12.6934	0.182195	
	5b	49.5	12.7049	0.143283	
	5c	49.5	12.0284	0.135653	
	4c	63	12.4598	0.178842	
	3c	63	11.7808	0.169096	
	2c	63	12.082	0.173419	
	1c	49.5	13.1088	0.147838	
	1d	49.5	13.514	0.152408	
	2d	63	12.0027	0.172281	
	3d	63	11.3275	0.162589	
	4d	63	13.2006	0.189475	
	5d	49.5	12.351	0.139291	
	5e	49.5	11.4804	0.129473	
	4e	63	12.6026	0.180891	
	3e	63	12.808	0.183840	
	2e	63	12.9091	0.185291	
	1e	49.5	12.873	0.145178	
	1f	33	12.9115	0.097075	
	2f	42	13.5684	0.129836	
	3f	42	13.6058	0.130194	
	4f	42	13.0146	0.124537	
	5f	33	12.5767	0.094558	
7	5a	49.5	10.6989	0.120660	5.393
	4a	63	12.0727	0.173285	
	3a	63	16.1041	0.231150	
	2a	63	15.4709	0.222062	
	1a	49.5	11.6434	0.131311	
	1b	49.5	14.5775	0.164401	
	2b	63	15.104	0.216795	
	3b	63	14.7633	0.211905	
	4b	63	15.1665	0.217692	

Valve Turn	Channel Portion	Area $_{local}$	Vmag Average (from ADV data)	Q_{local} = Vl$_{ocal}$ * A_{local}	Q_{total}
		sq in	cm/sec	cfs	cfs
	5b	49.5	14.5694	0.164310	
	5c	49.5	14.7601	0.166461	
	4c	63	14.5861	0.209362	
	3c	63	13.2767	0.190567	
	2c	63	14.7128	0.211180	
	1c	49.5	16.2596	0.183372	
	1d	49.5	16.521	0.186320	
	2d	63	15.1129	0.216923	
	3d	63	13.8225	0.198401	
	4d	63	14.9	0.213867	
	5d	49.5	14.8944	0.167975	
	5e	78.375	13.4135	0.239517	
	4e	99.75	15.6927	0.356638	
	3e	99.75	15.4117	0.350252	
	2e	99.75	15.7576	0.358113	
	1e	78.375	16.2481	0.290133	
8	5a	49.5	12.2244	0.137864	6.165
	4a	63	13.8648	0.199008	
	3a	63	18.395	0.264033	
	2a	63	18.6018	0.267001	
	1a	49.5	14.3869	0.162252	
	1b	49.5	17.9893	0.202879	
	2b	63	17.0636	0.244922	
	3b	63	16.3384	0.234513	
	4b	63	17.1754	0.246527	
	5b	49.5	16.5975	0.187182	
	5c	49.5	16.0718	0.181254	
	4c	63	16.5423	0.237440	
	3c	63	14.4552	0.207483	
	2c	63	17.4155	0.249973	
	1c	49.5	20.0426	0.226035	
	1d	49.5	19.9821	0.225353	
	2d	63	17.2986	0.248295	
	3d	63	15.6064	0.224006	
	4d	63	16.9138	0.242772	
	5d	49.5	16.5052	0.186142	
	5e	75.28125	15.6116	0.267764	

Valve Turn	Channel Portion	Area $_{local}$	Vmag Average (from ADV data)	Q_{local} = Vl_{ocal} * A_{local}	Q_{total}
		sq in	cm/sec	cfs	cfs
	4e	95.8125	17.1239	0.373802	
	3e	95.8125	18.4409	0.402552	
	2e	95.8125	18.6219	0.406503	
	1e	75.28125	19.7717	0.339116	
9	5a	49.5	15.0059	0.169233	6.790
	4a	63	15.2691	0.219165	
	3a	63	20.8676	0.299523	
	2a	63	20.5029	0.294288	
	1a	49.5	15.9337	0.179696	
	1b	49.5	20.943	0.236190	
	2b	63	20.256	0.290744	
	3b	63	17.7297	0.254483	
	4b	63	19.7982	0.284173	
	5b	49.5	17.223	0.194237	
	5c	49.5	18.0776	0.203875	
	4c	63	18.5468	0.266211	
	3c	63	14.3258	0.205625	
	2c	63	18.6869	0.268222	
	1c	49.5	21.7367	0.245141	
	1d	49.5	22.156	0.249870	
	2d	63	19.819	0.284472	
	3d	63	18.3615	0.263552	
	4d	63	18.3579	0.263500	
	5d	49.5	18.2842	0.206205	
	5e	71.16	18.2506	0.295874	
	4e	90.56	19.2311	0.396798	
	3e	90.56	20.5145	0.423279	
	2e	90.56	20.7459	0.428053	
	1e	71.16	22.6763	0.367623	
9	5a	49.5	19.5238	0.220185	7.466
	4a	63	21.2913	0.305605	
	3a	63	22.3474	0.320763	
	2a	63	21.722	0.311787	
	1a	49.5	20.6989	0.233437	
	1b	49.5	22.4834	0.253562	
	2b	63	22.917	0.328939	

Valve Turn	Channel Portion	Area $_{local}$	Vmag Average (from ADV data)	$Q_{local} = Vl_{ocal}$ $* A_{local}$	Q_{total}
		sq in	cm/sec	cfs	cfs
	3b	63	21.1162	0.303091	
	4b	63	21.2248	0.304650	
	5b	49.5	22.0364	0.248521	
	5c	49.5	22.0715	0.248917	
	4c	63	21.4696	0.308164	
	3c	63	21.1832	0.304053	
	2c	63	23.5482	0.337999	
	1c	49.5	22.7552	0.256627	
	1d	49.5	21.7634	0.245442	
	2d	63	23.5646	0.338234	
	3d	63	22.0653	0.316714	
	4d	63	23.0444	0.330768	
	5d	49.5	22.406	0.252689	
	5e	58.59	21.9075	0.292460	
	4e	74.57	22.0871	0.375274	
	3e	74.57	21.0443	0.357556	
	2e	74.57	23.4409	0.398276	
	1e	58.59	20.4059	0.272414	
10	5a	49.5	21.7754	0.245578	8.120
	4a	63	24.5705	0.352673	
	3a	63	23.8268	0.341998	
	2a	63	22.5767	0.324055	
	1a	49.5	23.7054	0.267344	
	1b	49.5	23.554	0.265636	
	2b	63	23.7433	0.340799	
	3b	63	23.0333	0.330608	
	4b	63	22.8432	0.327880	
	5b	49.5	24.6568	0.278073	
	5c	49.5	25.0731	0.282768	
	4c	63	22.2401	0.319223	
	3c	63	23.0844	0.331342	
	2c	63	23.8233	0.341948	
	1c	49.5	23.7697	0.268069	
	1d	108.09	23.7449	0.584778	
	2d	137.57	24.8839	0.779964	
	3d	137.57	24.7112	0.774551	
	4d	137.57	23.3878	0.733070	

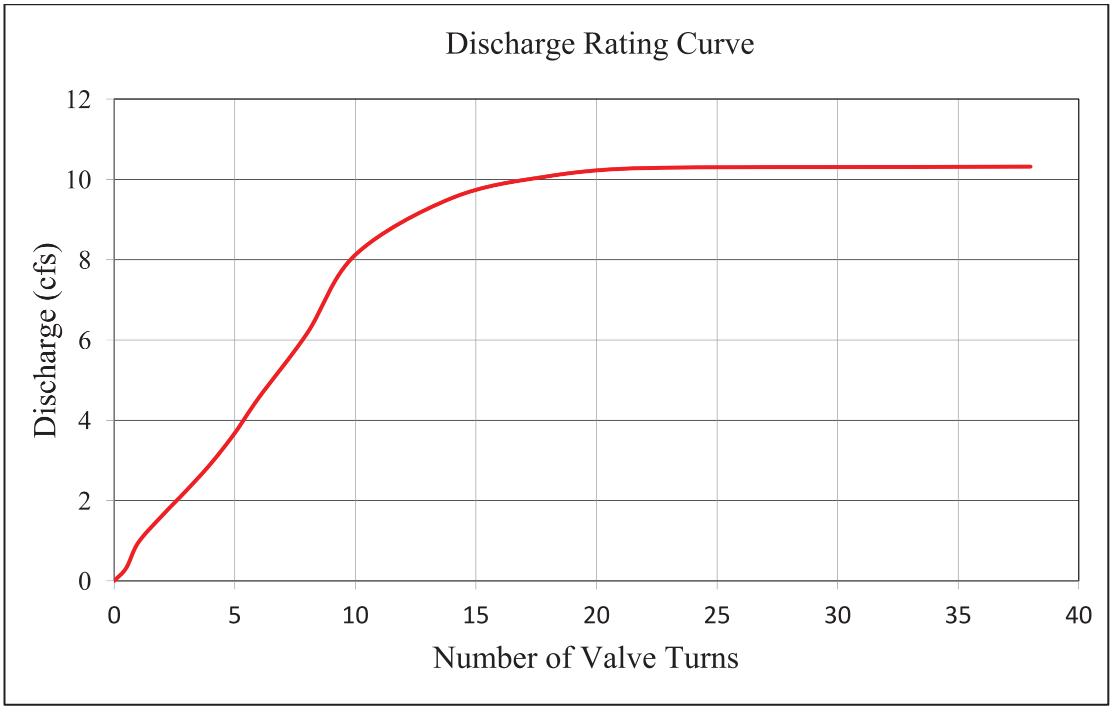
Valve Turn	Channel Portion	Area $_{local}$	Vmag Average (from ADV data)	$Q_{local} = Vl_{ocal} * A_{local}$	Q_{total}
		sq in	cm/sec	cfs	cfs
	5d	108.09	25.5527	0.629300	
14	5a	49.5	25.6229	0.288969	9.533
	4a	63	28.942	0.415419	
	3a	63	29.7354	0.426807	
	2a	63	26.6114	0.381967	
	1a	49.5	28.0475	0.316313	
	1b	49.5	29.1189	0.328396	
	2b	63	27.8626	0.399926	
	3b	63	26.8814	0.385842	
	4b	63	26.4831	0.380125	
	5b	49.5	28.9592	0.326595	
	5c	49.5	31.3147	0.353159	
	4c	63	28.3835	0.407403	
	3c	63	26.703	0.383282	
	2c	63	28.925	0.415175	
	1c	49.5	29.3471	0.330969	
	1d	101.60	28.2067	0.652915	
	2d	129.31	29.766	0.876920	
	3d	129.31	29.0457	0.855700	
	4d	129.31	30.2831	0.892154	
	5d	101.60	30.8692	0.714545	
18	5a	49.5	26.9665	0.304121	10.077
	4a	63	30.9771	0.444630	
	3a	63	31.6085	0.453693	
	2a	63	28.4169	0.407882	
	1a	49.5	29.7347	0.335341	
	1b	49.5	30.0748	0.339176	
	2b	63	30.2258	0.433846	
	3b	63	30.143	0.432658	
	4b	63	29.4874	0.423247	
	5b	49.5	31.6425	0.356856	
	5c	49.5	33.0782	0.373048	
	4c	63	30.4633	0.437255	
	3c	63	29.4952	0.423359	
	2c	63	31.3707	0.450279	
	1c	49.5	31.4136	0.354275	

Valve Turn	Channel Portion	Area $_{local}$	Vmag Average (from ADV data)	Q_{local} = Vl_{ocal} * A_{local}	Q_{total}
		sq in	cm/sec	cfs	cfs
	1d	98.35	30.1123	0.674741	
	2d	125.17	31.3674	0.894555	
	3d	125.17	30.7031	0.875610	
	4d	125.17	31.7068	0.904235	
	5d	98.35	33.853	0.758561	
22	5a	49.5	28.8412	0.325264	10.281
	4a	63	32.9283	0.472636	
	3a	63	31.889	0.457719	
	2a	63	30.5249	0.438139	
	1a	49.5	30.3596	0.342388	
	1b	49.5	32.0456	0.361402	
	2b	63	31.6518	0.454314	
	3b	63	29.6283	0.425270	
	4b	63	30.9965	0.444908	
	5b	49.5	32.8149	0.370078	
	5c	49.5	34.0101	0.383557	
	4c	63	31.3978	0.450668	
	3c	63	30.318	0.435169	
	2c	63	32.0986	0.460727	
	1c	49.5	32.4507	0.365971	
	1d	95.10	30.5533	0.662013	
	2d	121.04	33.5354	0.924799	
	3d	121.04	31.4128	0.866265	
	4d	121.04	32.3793	0.892918	
	5d	95.10	34.4688	0.746852	
38	5a	49.5	30.3845	0.342669	10.316
	4a	63	32.6186	0.468191	
	3a	63	32.5655	0.467429	
	2a	63	30.8828	0.443276	
	1a	49.5	30.3286	0.342038	
	1b	49.5	31.9883	0.360756	
	2b	63	32.3774	0.464729	
	3b	63	30.757	0.441471	
	4b	63	30.2529	0.434235	
	5b	49.5	33.9077	0.382403	
	5c	49.5	33.9547	0.382933	

Valve Turn	Channel Portion	Area $_{local}$	Vmag Average (from ADV data)	$Q_{local} = Vl_{ocal} * A_{local}$	Q_{total}
		sq in	cm/sec	cfs	cfs
	4c	63	30.2523	0.434226	
	3c	63	30.8321	0.442549	
	2c	63	32.8968	0.472184	
	1c	49.5	32.5158	0.366705	
	1d	93.48	30.4468	0.648440	
	2d	118.97	33.1426	0.898360	
	3d	118.97	32.8788	0.891209	
	4d	118.97	32.5975	0.883584	
	5d	93.48	35.1455	0.748511	

Summary of Discharge Data:

Number of Turn	Discharge (cfs)
1/2	0.322
2	1.633
3	2.254
4	2.915
5	3.680
6	4.563
7	5.393
8	6.165
9	7.466
10	8.120
14	9.533
18	10.077
22	10.281
38	10.316

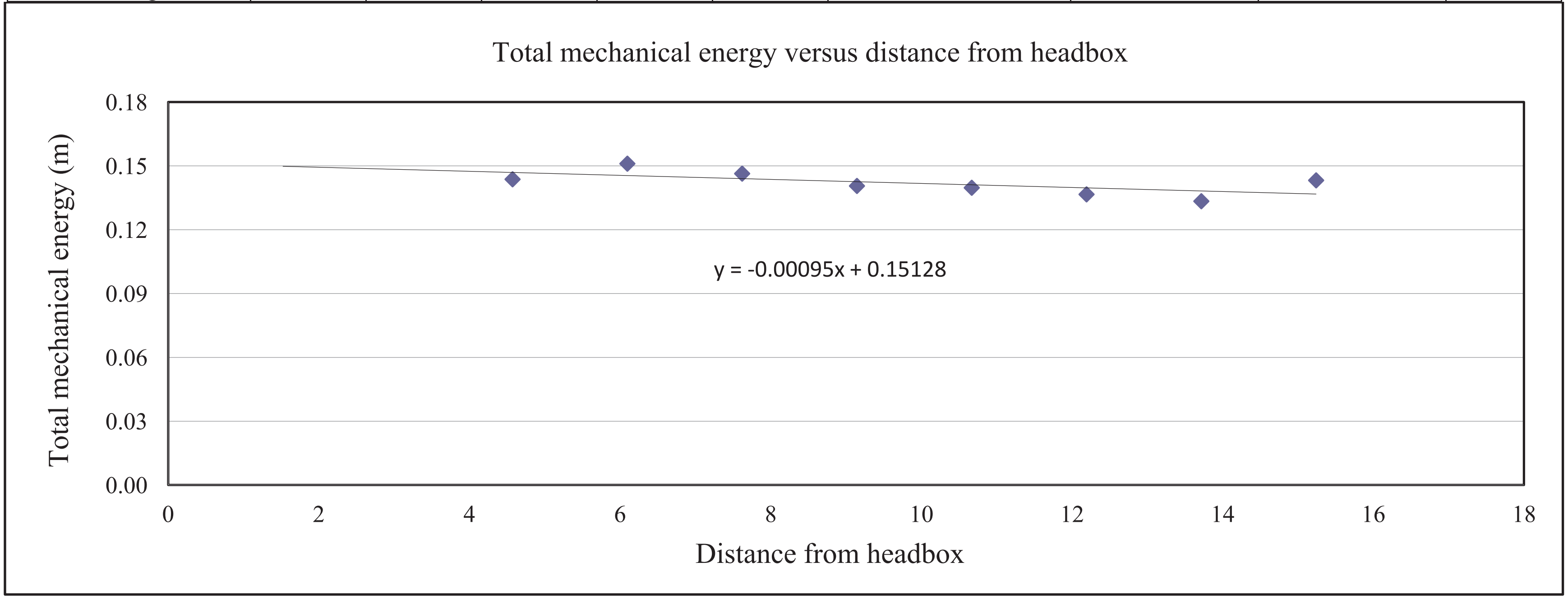


APPENDIX C:

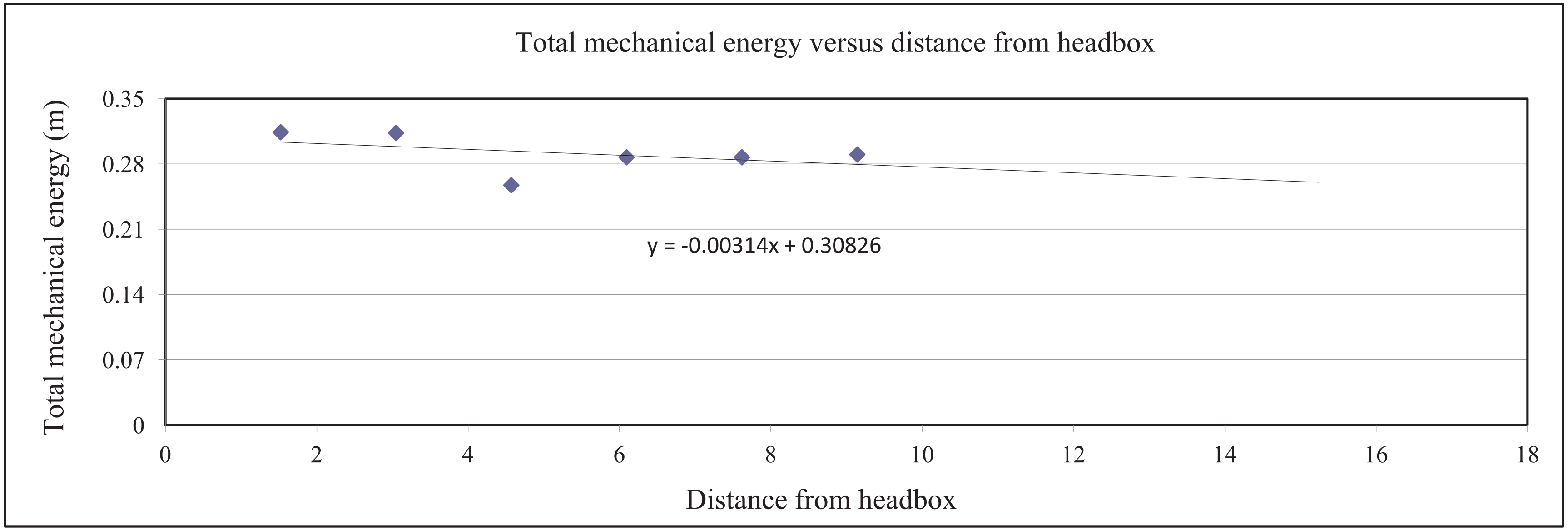
Slope of Energy Grade Line Calculation

Slope of Energy Grade Line Calculation: Culvert Dia- 1 ft/ Slope: 1 in 250

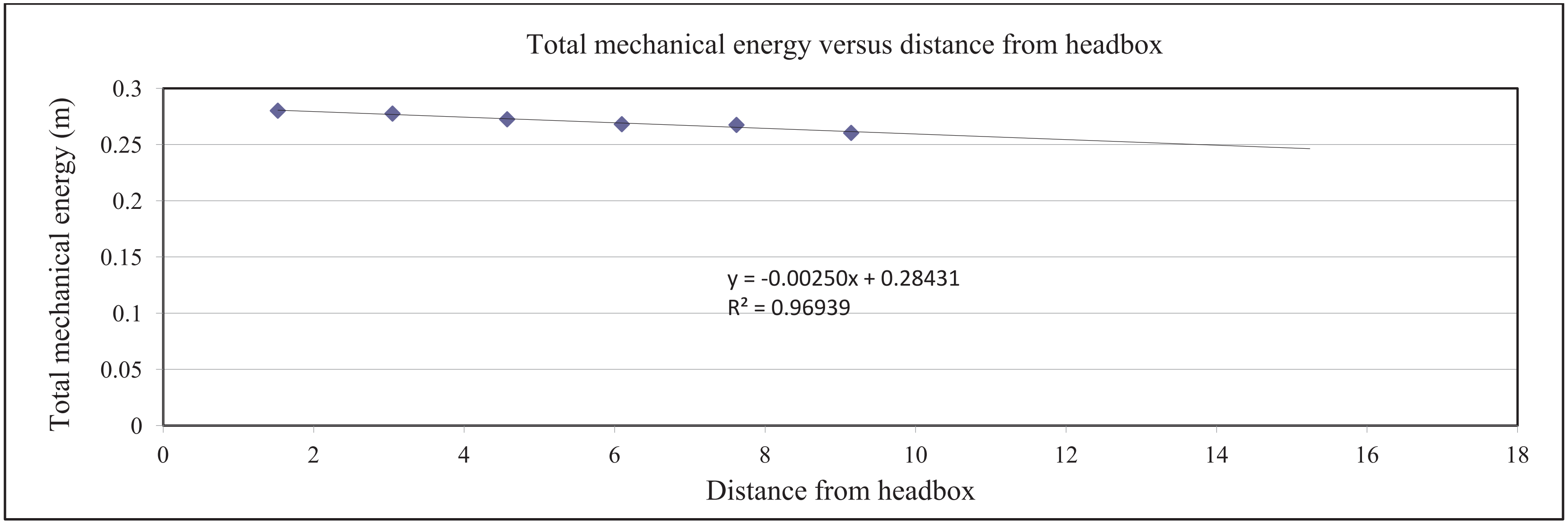
Final Water Depth	Theta	Area	Rh	Q	Velocity	Dist from headbox	Bed Height	Velocity Head	TE
(mm)		m^2	m	cms	m/s	m	m	m	m
56.89	1.79	0.009	0.035	**0.009**	0.968	1.52	0.055	0.048	
60.67	1.85	0.010	0.037	0.009	0.883	3.05	0.049	0.040	
60.00	1.84	0.010	0.036	0.009	0.897	4.57	0.043	0.041	0.14
51.78	1.70	0.008	0.032	0.009	1.109	6.10	0.037	0.063	0.15
51.22	1.69	0.008	0.031	0.009	1.126	7.62	0.030	0.065	0.15
51.11	1.69	0.008	0.031	0.009	1.130	9.14	0.024	0.065	0.14
49.33	1.66	0.008	0.030	0.009	1.189	10.67	0.018	0.072	0.14
48.44	1.64	0.007	0.030	0.009	1.221	12.19	0.012	0.076	0.14
47.67	1.63	0.007	0.029	0.009	1.250	13.72	0.006	0.080	0.13
44.22	1.56	0.007	0.027	0.009	1.393	15.24	0.000	0.099	0.14
Average	52.13		0.032						



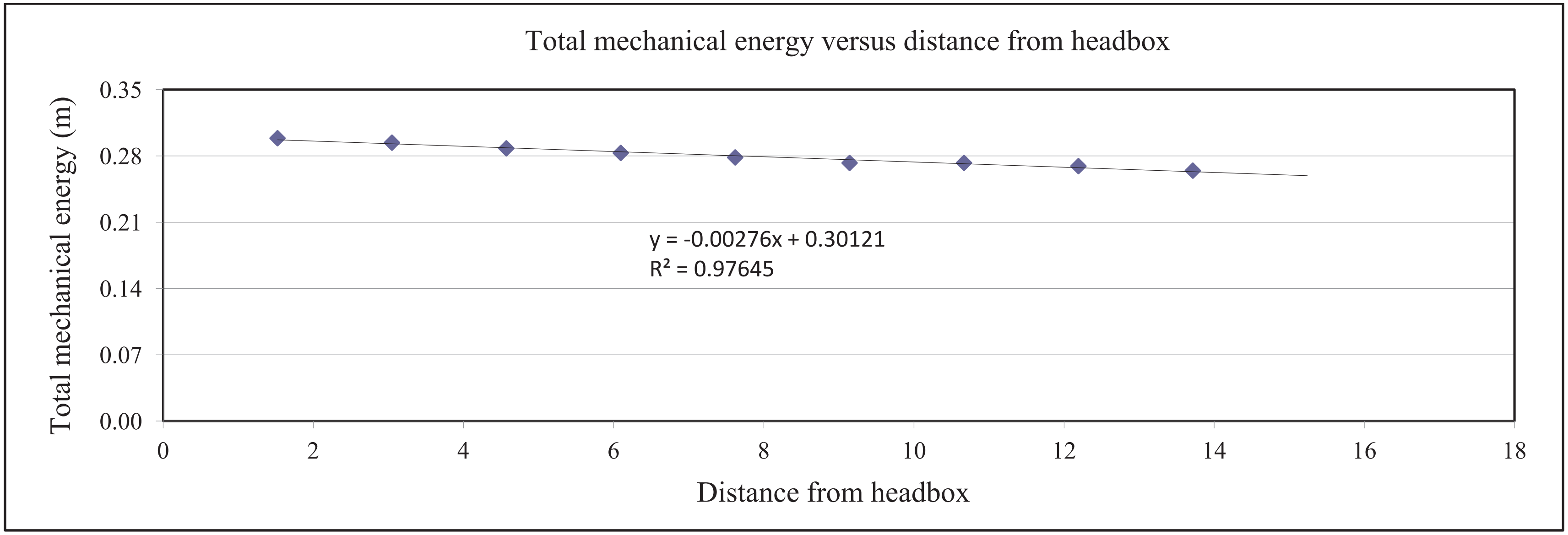
Final Water Depth	Theta	Area	Rh	Q	Velocity	Dist from headbox	Bed Height	Vel Head	TE
(mm)		m^2	m	cms	m/s	m	m	m	m
76.22	2.09473	0.01427	0.0447	**0.02703**	1.89416	1.524018532	0.054864667	0.182940212	0.31403
75.33	2.08124	0.01404	0.04425	0.02703	1.92576	3.048037064	0.048768593	0.189095837	0.3132
86.56	2.24806	0.01706	0.04979	0.02703	1.58478	4.572055596	0.042672519	0.128060219	0.25729
77.78	2.11822	0.01468	0.04548	0.02703	1.841	6.096074128	0.036576445	0.172816785	0.28717
76.67	2.10146	0.01439	0.04493	0.02703	1.87869	7.62009266	0.030480371	0.179965931	0.28711
75.11	2.07785	0.01398	0.04414	0.02703	1.93381	9.144111192	0.024384297	0.190679357	0.29017
70.56	2.00775	0.01279	0.04181	0.02703	2.11279	10.66812972	0.018288222	0.227610593	
69.56	1.99216	0.01254	0.0413	0.02703	2.15601	12.19214826	0.012192148	0.237018176	
69.11	1.9852	0.01242	0.04106	0.02703	2.17572	13.71616679	0.006096074	0.241371449	
65.89	1.93428	0.01161	0.03938	0.02703	2.32859	15.24018532	0	0.276479695	
Average	74.28		0.04368						



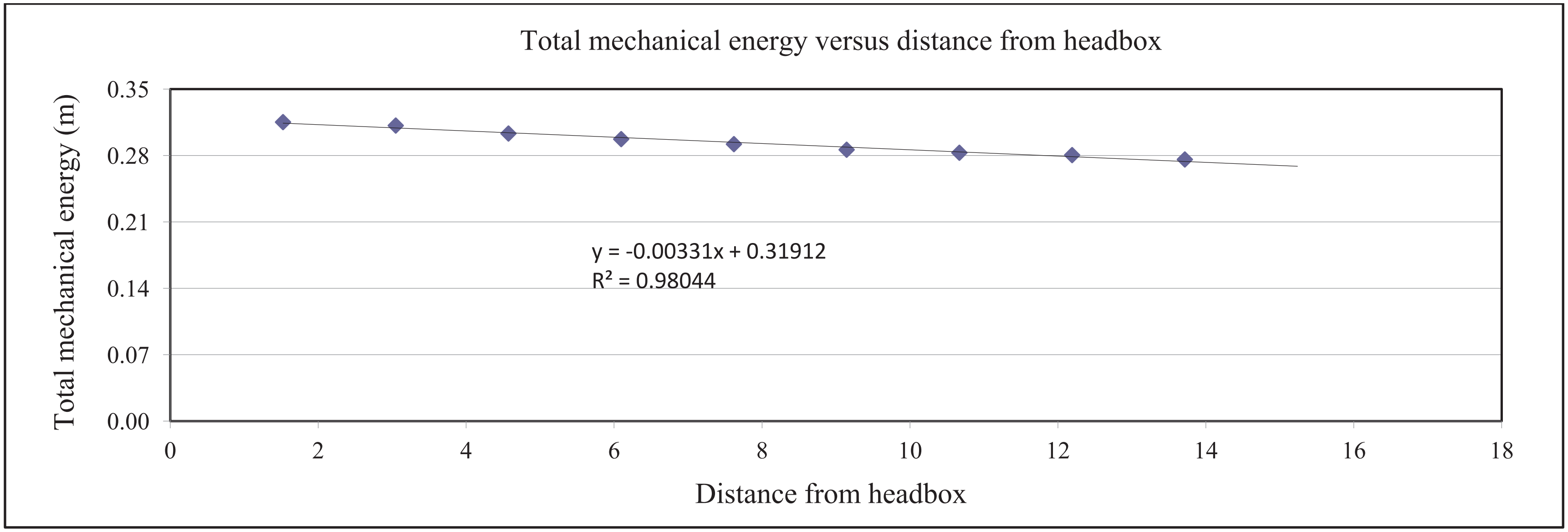
Final Water Depth	Theta	Area	Rh	Q	Velocity	Dist from headbox	Bed Height	Vel Head	TE
(mm)		m^2	m	cms	m/s	m	m	m	m
113.44	2.624	0.0247	0.06185	**0.0366**	1.480	1.524	0.0548	0.111	0.28
111.44	2.597	0.0241	0.06101	0.0366	1.516	3.048	0.0487	0.117	0.277
110.89	2.589	0.0239	0.06078	0.0366	1.527	4.572	0.0426	0.118	0.272
110.00	2.577	0.0237	0.0604	0.0366	1.543	6.096	0.0365	0.121	0.268
107.44	2.542	0.0229	0.05931	0.0366	1.59	7.620	0.0304	0.129	0.267
107.89	2.548	0.0231	0.0595	0.0366	1.584	9.144	0.0243	0.128	0.260
102.56	2.475	0.0215	0.05717	0.0366	1.698	10.668	0.0182	0.147	
100.22	2.442	0.020	0.05613	0.0366	1.753	12.192	0.0121	0.156	
98.67	2.42	0.0204	0.05543	0.0366	1.791	13.716	0.0060	0.163	
95.22	2.372	0.0194	0.05386	0.0366	1.881	15.240	0	0.180	
Average	105.78		0.05854						



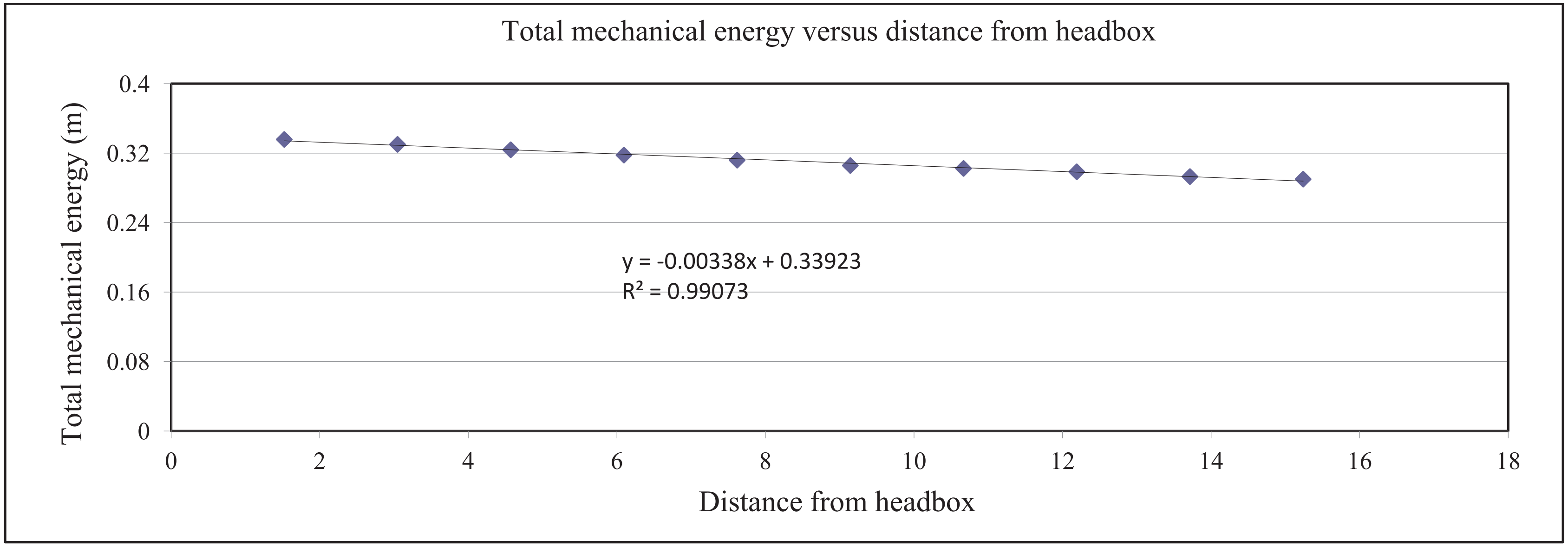
Final Water Depth	Theta	Area	Rh	Q	Velocity	Dist from headbox	Bed Height	Vel Head	TE
(mm)		m^2	m	cms	m/s	m	m	m	m
137.89	2.95	0.0321	0.0713	**0.0462**	1.442	1.524	0.0549	0.1060	0.2987
136.56	2.93	0.0317	0.0708	0.0462	1.460	3.048	0.0488	0.1087	0.2940
136.44	2.93	0.0316	0.0708	0.0462	1.462	4.572	0.0427	0.1089	0.2881
135.33	2.92	0.0313	0.0704	0.0462	1.477	6.096	0.0366	0.1113	0.2832
134.22	2.90	0.0310	0.0700	0.0462	1.493	7.620	0.0305	0.1137	0.2784
134.00	2.90	0.0309	0.0699	0.0462	1.497	9.144	0.0244	0.1142	0.2726
129.56	2.84	0.0295	0.0682	0.0462	1.565	10.668	0.0183	0.1248	0.2727
127.89	2.82	0.0290	0.0676	0.0462	1.592	12.192	0.0122	0.1292	0.2693
127.11	2.81	0.0288	0.0673	0.0462	1.605	13.716	0.0061	0.1313	0.2645
123.00	2.75	0.0276	0.0657	0.0462	1.676	15.240	0.0000	0.1433	
Average	132.2000		0.0692						



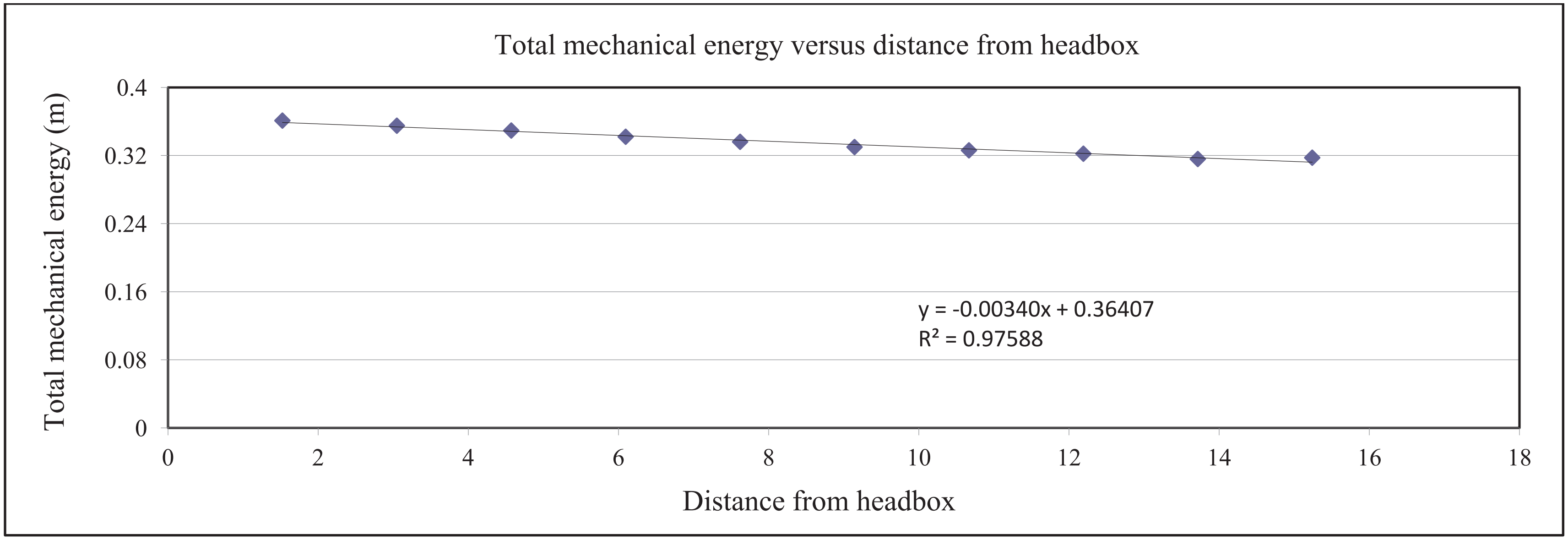
Final Water Depth	Theta	Area	Rh	Q	Velocity	Dist from headbox	Bed Height	Vel Head	TE
(mm)		m^2	m	cms	m/s	m	m	m	m
164.11	3.295	0.04005	0.07974	**0.05504**	1.3742	1.524	0.0549	0.0963	0.315
159.56	3.236	0.03866	0.07841	0.05504	1.42346	3.048	0.0488	0.1033	0.312
163.78	3.291	0.03995	0.07965	0.05504	1.37769	4.572	0.0427	0.0968	0.303
163.33	3.285	0.03981	0.07952	0.05504	1.38236	6.096	0.0366	0.0974	0.297
161.78	3.265	0.03934	0.07907	0.05504	1.39899	7.620	0.0305	0.0998	0.292
161.44	3.260	0.03924	0.07897	0.05504	1.4026	9.144	0.0244	0.1003	0.286
156.89	3.201	0.03785	0.0776	0.05504	1.454	10.668	0.0183	0.1078	0.283
152.56	3.144	0.03653	0.07625	0.05504	1.50657	12.192	0.0122	0.1157	0.280
151.00	3.123	0.03606	0.07575	0.05504	1.52638	13.716	0.0061	0.1188	0.276
145.33	3.049	0.03433	0.07388	0.05504	1.60314	15.240	0	0.1310	
Average	157.98		0.07788						



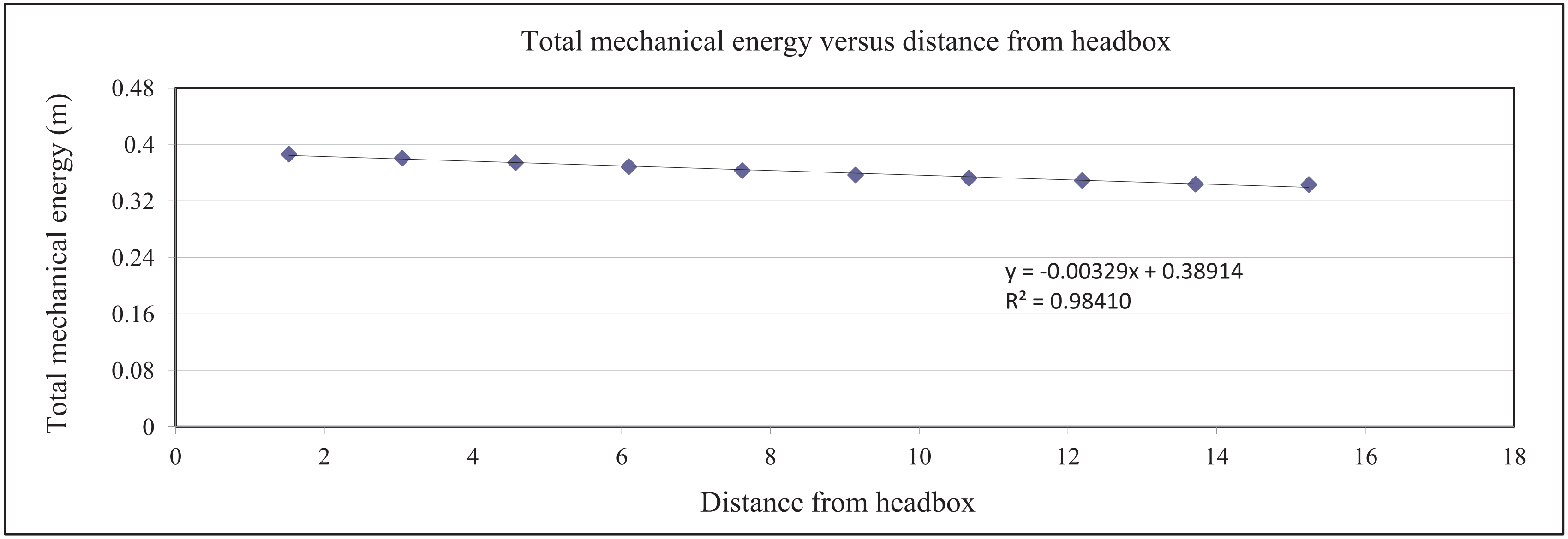
Final Water Depth	Theta	Area	Rh	Q	Velocity	Dist from headbox	Bed Height	Vel Head	TE
(mm)		m^2	m	cms	m/s	m	m	m	m
189.78	3.637	0.04776	0.08616	**0.06384**	1.337	1.524	0.055	0.091	0.33575
187.11	3.601	0.04697	0.08559	0.06384	1.359	3.048	0.049	0.094	0.33007
187.78	3.610	0.04717	0.08573	0.06384	1.353	4.572	0.043	0.093	0.32385
187.56	3.607	0.0471	0.08568	0.06384	1.355	6.096	0.037	0.094	0.3178
186.67	3.595	0.04684	0.08549	0.06384	1.363	7.620	0.030	0.095	0.31187
186.89	3.598	0.0469	0.08554	0.06384	1.361	9.144	0.024	0.094	0.30573
178.11	3.481	0.04428	0.08348	0.06384	1.442	10.668	0.018	0.106	0.30238
173.78	3.423	0.04298	0.08238	0.06384	1.485	12.192	0.012	0.113	0.29848
172.78	3.410	0.04268	0.08212	0.06384	1.496	13.716	0.006	0.114	0.29298
168.22	3.350	0.0413	0.0809	0.06384	1.546	15.240	0.000	0.122	0.29007
Average	181.87		0.08431						



Final Water Depth	Theta	Area	Rh	Q	Velocity	Dist from headbox	Bed Height	Vel Head	TE
(mm)		m^2	m	cms	m/s	m	m	m	m
199.33	3.768	0.05056	0.088	**0.073**	1.448	1.524	0.055	0.107	0.36106
198.89	3.762	0.05043	0.088	0.073	1.451	3.048	0.049	0.107	0.35507
197.33	3.740	0.04998	0.088	0.073	1.465	4.572	0.043	0.109	0.34937
203.11	3.820	0.05165	0.089	0.073	1.417	6.096	0.037	0.102	0.34209
202.11	3.806	0.05136	0.089	0.073	1.425	7.620	0.030	0.104	0.33614
202.56	3.812	0.05149	0.089	0.073	1.422	9.144	0.024	0.103	0.32997
193.78	3.692	0.04894	0.087	0.073	1.496	10.668	0.018	0.114	0.32612
188.89	3.625	0.0475	0.086	0.073	1.541	12.192	0.012	0.121	0.32216
189.11	3.628	0.04756	0.086	0.073	1.539	13.716	0.006	0.121	0.31596
178.00	3.479	0.04425	0.083	0.073	1.654	15.240	0.000	0.140	0.31751
Average	195.31		0.0872						



Final Water Depth	Theta	Area	Rh	Q	Velocity	Dist from headbox	Bed Height	Vel Head	TE
(mm)		m^2	m	cms	m/s	m	m	m	m
208.89	3.901	0.0533	0.08965	**0.08255**	1.549	1.524	0.055	0.122	0.38606
207.44	3.881	0.05289	0.08943	0.08255	1.561	3.048	0.049	0.124	0.38042
208.56	3.896	0.0532	0.0896	0.08255	1.552	4.572	0.043	0.123	0.37397
206.89	3.873	0.05273	0.08934	0.08255	1.565	6.096	0.037	0.125	0.36842
205.44	3.853	0.05232	0.08911	0.08255	1.578	7.620	0.030	0.127	0.36286
205.78	3.857	0.05241	0.08916	0.08255	1.575	9.144	0.024	0.126	0.35663
202.22	3.808	0.05139	0.08857	0.08255	1.606	10.668	0.018	0.132	0.35205
197.11	3.737	0.04991	0.08764	0.08255	1.654	12.192	0.012	0.139	0.34876
195.78	3.719	0.04952	0.08738	0.08255	1.667	13.716	0.006	0.142	0.34353
188.78	3.624	0.04746	0.08595	0.08255	1.739	15.240	0.000	0.154	0.343
	202.69		0.08858						



APPENDIX D:

Manning’s Roughness Coefficient Calculation

Manning’s Roughness Coefficient Calculation (Culvert Dia. 1 ft)

Manning's Roughness Calculation Table: 1 (Slope 1 in 250)

S.N.	Radius of Culvert (ft)	Slope	Number of Turn	Flow Depth Measured (ft)	h	Check (if flow depth < radius or > radius)	Central Angle	Circular Segment Area (K)	Flow Area (A) (ft2)	Arc Length (s) (ft)	Wetted Perimeter (Pw) (ft)	Hydraulic radius (A/Pw)	Discharge (from rating curve) (cfs)	Manning's Roughness Coefficient (η)	Diameter of Culvert (D) (ft)	Relative Depth (d/D)
1	0.5	0.00273	1/2	0.168	0.168	flow depth < radius	1.690	0.087	0.087	0.845	0.845	0.103	0.217	0.006855	1	0.168
2	0.5	0.00314	1	0.2515	0.2515	flow depth < radius	2.101	0.155	0.155	1.051	1.051	0.147	0.434	0.008293	1	0.252
3	0.5	0.00250	1 1/2	0.3470	0.3470	flow depth < radius	2.520	0.242	0.242	1.260	1.260	0.192	0.849	0.007056	1	0.347
4	0.5	0.00276	2	0.4337	0.4337	flow depth < radius	2.876	0.327	0.327	1.438	1.438	0.227	1.265	0.007507	1	0.434
5	0.5	0.00331	2 1/2	0.5183	0.482	flow depth > radius	3.068	0.374	0.411	1.534	1.607	0.256	1.733	0.008167	1	0.518
6	0.5	0.00338	3	0.5967	0.403	flow depth > radius	2.752	0.297	0.489	1.376	1.765	0.277	2.202	0.008146	1	0.597
7	0.5	0.00340	3 1/2	0.6408	0.359	flow depth > radius	2.571	0.254	0.532	1.285	1.856	0.286	2.612	0.007661	1	0.641
8	0.5	0.00329	4	0.6650	0.335	flow depth > radius	2.469	0.231	0.555	1.235	1.907	0.291	3.023	0.006865	1	0.665

Manning's Roughness Calculation Table: 1 (Slope 1 in 104)

S.N.	Radius of Culvert (ft)	Slope	Number of Turn	Flow Depth Measured (ft)	h	Check (if flow depth < radius or > radius)	Central Angle	Circular Segment Area (K)	Flow Area (A) (ft2)	Arc Length (s) (ft)	Wetted Perimeter (Pw) (ft)	Hydraulic radius (A/Pw)	Discharge (from rating curve) (cfs)	Manning's Roughness Coefficient (η)	Diameter of Culvert (D) (ft)	Relative Depth (d/D)
1	0.5	0.00354	1/2	0.140	0.140	flow depth < radius	1.536	0.067	0.067	0.768	0.768	0.087	0.217	0.005378	1	0.140
2	0.5	0.00347	1	0.2115	0.2115	flow depth < radius	1.912	0.121	0.121	0.956	0.956	0.127	0.434	0.006167	1	0.212
3	0.5	0.00503	1 1/2	0.3018	0.3018	flow depth < radius	2.327	0.200	0.200	1.163	1.163	0.172	0.849	0.007665	1	0.302
4	0.5	0.00476	2	0.3759	0.3759	flow depth < radius	2.640	0.270	0.270	1.320	1.320	0.204	1.265	0.007594	1	0.376
5	0.5	0.00642	2 1/2	0.4516	0.4516	flow depth < radius	2.947	0.344	0.344	1.474	1.474	0.234	1.733	0.008973	1	0.452
6	0.5	0.00707	3	0.5091	0.491	flow depth > radius	3.105	0.384	0.402	1.552	1.589	0.253	2.202	0.009119	1	0.509
7	0.5	0.00745	3 1/2	0.5447	0.455	flow depth > radius	2.962	0.348	0.437	1.481	1.660	0.263	2.612	0.008824	1	0.545
8	0.5	0.00737	4	0.5826	0.417	flow depth > radius	2.810	0.311	0.475	1.405	1.737	0.273	3.023	0.008444	1	0.583

Manning's Roughness Calculation Table: 1 (Slope 1 in 500)

S.N.	Radius of Culvert (ft)	Slope	Number of Turn	Flow Depth Measured (ft)	h	Check (if flow depth < radius or > radius)	Central Angle	Circular Segment Area (K)	Flow Area (A) (ft2)	Arc Length (s) (ft)	Wetted Perimeter (Pw) (ft)	Hydraulic radius (A/Pw)	Discharge (from rating curve) (cfs)	Manning's Roughness Coefficient (η)	Diameter of Culvert (D) (ft)	Relative Depth (d/D)
1	0.5	0.00120	1/2	0.203	0.203	flow depth < radius	1.869	0.114	0.114	0.935	0.935	0.122	0.217	0.006668	1	0.203
2	0.5	0.00190	1	0.3002	0.3002	flow depth < radius	2.319	0.198	0.198	1.160	1.160	0.171	0.434	0.009121	1	0.300
3	0.5	0.00133	1 1/2	0.4017	0.4017	flow depth < radius	2.746	0.295	0.295	1.373	1.373	0.215	0.849	0.006754	1	0.402
4	0.5	0.00177	2	0.5132	0.487	flow depth > radius	3.089	0.380	0.406	1.544	1.597	0.254	1.265	0.008051	1	0.513
5	0.5	0.00174	2 1/2	0.5799	0.420	flow depth > radius	2.820	0.313	0.472	1.410	1.731	0.273	1.733	0.007105	1	0.580
6	0.5	0.00201	3	0.6592	0.341	flow depth > radius	2.494	0.236	0.549	1.247	1.895	0.290	2.202	0.007277	1	0.659
7	0.5	0.00202	3 1/2	0.7025	0.297	flow depth > radius	2.308	0.196	0.590	1.154	1.988	0.297	2.612	0.006703	1	0.703
8	0.5	0.00219	4	0.7513	0.249	flow depth > radius	2.088	0.152	0.633	1.044	2.097	0.302	3.023	0.006552	1	0.751

Manning's Roughness Calculation Table: 1 (Slope 1 in 50)

S.N.	Radius of Culvert (ft)	Slope	Number of Turn	Flow Depth Measured (ft)	h	Check (if flow depth < radius or > radius)	Central Angle	Circular Segment Area (K)	Flow Area (A) (ft2)	Arc Length (s) (ft)	Wetted Perimeter (Pw) (ft)	Hydraulic radius (A/Pw)	Discharge (from rating curve) (cfs)	Manning's Roughness Coefficient (η)	Diameter of Culvert (D) (ft)	Relative Depth (d/D)
1	0.5	0.01335	1/2	0.111	0.111	flow depth < radius	1.359	0.048	0.048	0.679	0.679	0.070	0.217	0.006414	1	0.111
2	0.5	0.00733	1	0.1773	0.1773	flow depth < radius	1.739	0.094	0.094	0.869	0.869	0.108	0.434	0.006264	1	0.177
3	0.5	0.01139	1 1/2	0.2529	0.2529	flow depth < radius	2.108	0.156	0.156	1.054	1.054	0.148	0.849	0.008158	1	0.253
4	0.5	0.01332	2	0.3150	0.3150	flow depth < radius	2.383	0.212	0.212	1.192	1.192	0.178	1.265	0.009092	1	0.315
5	0.5	0.01123	2 1/2	0.3867	0.3867	flow depth < radius	2.684	0.280	0.280	1.342	1.342	0.209	1.733	0.008967	1	0.387
6	0.5	0.01289	3	0.4338	0.4338	flow depth < radius	2.876	0.327	0.327	1.438	1.438	0.227	2.202	0.009320	1	0.434
7	0.5	0.01226	3 1/2	0.4716	0.4716	flow depth < radius	3.028	0.364	0.364	1.514	1.514	0.241	2.612	0.008879	1	0.472
8	0.5	0.01284	4	0.4981	0.502	flow depth > radius	3.149	0.395	0.391	1.575	1.567	0.249	3.023	0.008627	1	0.498

Manning’s Roughness Coefficient Calculation (Culvert Dia. 2 ft)

Manning's Roughness Calculation Table: 1 (Slope 1 in 250)

S.N.	Radius of Culvert (ft)	Slope	Number of Turn	Flow Depth Measured (ft)	h	Check (if flow depth < radius or > radius)	Central Angle	Circular Segment Area (K)	Flow Area (A) (ft2)	Arc Length (s) (ft)	Wetted Perimeter (Pw) (ft)	Hydraulic radius (A/Pw)	Discharge (from rating curve) (cfs)	Manning's Roughness Coefficient (η)	Diameter of Culvert (D) (ft)	Relative Depth (d/D)
1	1	0.0036	1/2	0.125	0.125	flow depth < radius	1.009	0.081	0.081	1.009	1.009	0.081	0.3796	0.003564	2	0.062
2	1	0.0055	1	0.2075	0.2075	flow depth < radius	1.312	0.173	0.173	1.312	1.312	0.132	0.7592	0.006465	2	0.104
3	1	0.0044	2	0.3548	0.3548	flow depth < radius	1.739	0.377	0.377	1.739	1.739	0.217	1.5184	0.008763	2	0.177
4	1	0.0048	3	0.4482	0.4482	flow depth < radius	1.973	0.526	0.526	1.973	1.973	0.267	2.2776	0.009844	2	0.224
5	1	0.0049	4	0.5074	0.5074	flow depth < radius	2.111	0.627	0.627	2.111	2.111	0.297	3.0368	0.009530	2	0.254
6	1	0.0052	5	0.5568	0.5568	flow depth < radius	2.223	0.714	0.714	2.223	2.223	0.321	3.7960	0.009469	2	0.278
7	1	0.0052	6	0.6175	0.6175	flow depth < radius	2.357	0.825	0.825	2.357	2.357	0.350	4.5552	0.009648	2	0.309
8	1	0.0054	7	0.6496	0.6496	flow depth < radius	2.426	0.885	0.885	2.426	2.426	0.365	5.3144	0.009261	2	0.325
9	1	0.0057	8	0.6915	0.6915	flow depth < radius	2.514	0.964	0.964	2.514	2.514	0.383	6.0736	0.009409	2	0.346
10	1	0.0059	9	0.7272	0.7272	flow depth < radius	2.589	1.032	1.032	2.589	2.589	0.399	6.8328	0.009346	2	0.364

Manning's Roughness Calculation Table: 1 (Slope 1 in 104)

S.N.	Radius of Culvert (ft)	Slope	Number of Turn	Flow Depth Measured (ft)	h	Check (if flow depth < radius or > radius)	Central Angle	Circular Segment Area (K)	Flow Area (A) (ft2)	Arc Length (s) (ft)	Wetted Perimeter (Pw) (ft)	Hydraulic radius (A/Pw)	Discharge (from rating curve) (cfs)	Manning's Roughness Coefficient (η)	Diameter of Culvert (D) (ft)	Relative Depth (d/D)
1	1	0.00431	1/2	0.101	0.101	flow depth < radius	0.907	0.060	0.060	0.907	0.907	0.066	0.380	0.002496	2	0.051
2	1	0.00884	1	0.1639	0.1639	flow depth < radius	1.161	0.122	0.122	1.161	1.161	0.105	0.759	0.004996	2	0.082
3	1	0.00684	2	0.2921	0.2921	flow depth < radius	1.568	0.284	0.284	1.568	1.568	0.181	1.518	0.007367	2	0.146
4	1	0.00853	3	0.3792	0.3792	flow depth < radius	1.802	0.414	0.414	1.802	1.802	0.230	2.278	0.009372	2	0.190
5	1	0.00833	4	0.4408	0.4408	flow depth < radius	1.955	0.514	0.514	1.955	1.955	0.263	3.037	0.009417	2	0.220
6	1	0.00870	5	0.4922	0.4922	flow depth < radius	2.076	0.601	0.601	2.076	2.076	0.289	3.796	0.009593	2	0.246
7	1	0.00874	6	0.5565	0.5565	flow depth < radius	2.223	0.714	0.714	2.223	2.223	0.321	4.555	0.010210	2	0.278
8	1	0.00855	7	0.5974	0.5974	flow depth < radius	2.313	0.788	0.788	2.313	2.313	0.341	5.314	0.009936	2	0.299
9	1	0.01001	8	0.6370	0.6370	flow depth < radius	2.399	0.861	0.861	2.399	2.399	0.359	6.074	0.010648	2	0.319
10	1	0.00909	9	0.6568	0.6568	flow depth < radius	2.441	0.898	0.898	2.441	2.441	0.368	6.833	0.009562	2	0.328

Manning's Roughness Calculation Table: 1 (Slope 1 in 500)

S.N.	Radius of Culvert (ft)	Slope	Number of Turn	Flow Depth Measured (ft)	h	Check (if flow depth < radius or > radius)	Central Angle	Circular Segment Area (K)	Flow Area (A) (ft2)	Arc Length (s) (ft)	Wetted Perimeter (Pw) (ft)	Hydraulic radius (A/Pw)	Discharge (from rating curve) (cfs)	Manning's Roughness Coefficient (η)	Diameter of Culvert (D) (ft)	Relative Depth (d/D)
1	1	0.0018	1/2	0.130	0.130	flow depth < radius	1.032	0.087	0.087	1.032	1.032	0.084	0.380	0.002768	2	0.065
2	1	0.0028	1	0.2378	0.2378	flow depth < radius	1.408	0.211	0.211	1.408	1.408	0.150	0.759	0.006195	2	0.119
3	1	0.0035	2	0.3665	0.3665	flow depth < radius	1.769	0.395	0.395	1.769	1.769	0.223	1.518	0.008339	2	0.183
4	1	0.0031	3	0.4597	0.4597	flow depth < radius	2.000	0.545	0.545	2.000	2.000	0.273	2.278	0.008316	2	0.230
5	1	0.0026	4	0.5567	0.5567	flow depth < radius	2.223	0.714	0.714	2.223	2.223	0.321	3.037	0.008278	2	0.278
6	1	0.0035	5	0.5866	0.5866	flow depth < radius	2.289	0.768	0.768	2.289	2.289	0.336	3.796	0.008554	2	0.293
7	1	0.0035	6	0.6537	0.6537	flow depth < radius	2.434	0.892	0.892	2.434	2.434	0.367	4.555	0.008781	2	0.327
8	1	0.0030	7	0.7219	0.7219	flow depth < radius	2.578	1.022	1.022	2.578	2.578	0.396	5.314	0.008459	2	0.361
9	1	0.0041	8	0.7331	0.7331	flow depth < radius	2.601	1.043	1.043	2.601	2.601	0.401	6.074	0.008869	2	0.367
10	1	0.0045	9	0.7538	0.7538	flow depth < radius	2.644	1.083	1.083	2.644	2.644	0.410	6.833	0.008748	2	0.377

Manning's Roughness Calculation Table: 1 (Slope 1 in 50)

S.N.	Radius of Culvert (ft)	Slope	Number of Turn	Flow Depth Measured (ft)	h	Check (if flow depth < radius or > radius)	Central Angle	Circular Segment Area (K)	Flow Area (A) (ft2)	Arc Length (s) (ft)	Wetted Perimeter (Pw) (ft)	Hydraulic radius (A/Pw)	Discharge (from rating curve) (cfs)	Manning's Roughness Coefficient (η)	Diameter of Culvert (D) (ft)	Relative Depth (d/D)
1	1	0.0147	1/2	0.087	0.087	flow depth < radius	0.841	0.048	0.048	0.841	0.841	0.057	0.380	0.003356	2	0.044
2	1	0.0104	1	0.1444	0.1444	flow depth < radius	1.088	0.101	0.101	1.088	1.088	0.093	0.759	0.004142	2	0.072
3	1	0.0144	2	0.2552	0.2552	flow depth < radius	1.461	0.234	0.234	1.461	1.461	0.160	1.518	0.008064	2	0.128
4	1	0.0135	3	0.3410	0.3410	flow depth < radius	1.702	0.356	0.356	1.702	1.702	0.209	2.278	0.009478	2	0.170
5	1	0.0138	4	0.3901	0.3901	flow depth < radius	1.830	0.432	0.432	1.830	1.830	0.236	3.037	0.009474	2	0.195
6	1	0.0140	5	0.4449	0.4449	flow depth < radius	1.965	0.521	0.521	1.965	1.965	0.265	3.796	0.009947	2	0.222
7	1	0.0148	6	0.4887	0.4887	flow depth < radius	2.068	0.595	0.595	2.068	2.068	0.288	4.555	0.010277	2	0.244
8	1	0.0144	7	0.5506	0.5506	flow depth < radius	2.209	0.703	0.703	2.209	2.209	0.318	5.314	0.011013	2	0.275
8	1	0.0134	8	0.5966	0.5966	flow depth < radius	2.311	0.786	0.786	2.311	2.311	0.340	6.074	0.010861	2	0.298
8	1	0.0099	9	0.6289	0.6289	flow depth < radius	2.381	0.846	0.846	2.381	2.381	0.355	6.833	0.009189	2	0.314

Manning's Roughness Coefficient Calculation (Culvert Dia. 3.5 ft)

Manning's Roughness Calculation Table: 1 (Slope 1 in 250)

S.N.	Radius of Culvert (ft)	Slope	Number of Turn	Flow Depth Measured (ft)	h	Check (if flow depth < radius or > radius)	Central Angle	Circular Segment Area (K)	Flow Area (A) (ft2)	Arc Length (s) (ft)	Wetted Perimeter (Pw) (ft)	Hydraulic radius (A/Pw)	Discharge (from rating curve) (cfs)	Manning's Roughness Coefficient (η)	Diameter of Culvert (D) (ft)	Relative Depth (d/D)
1	1.75	0.00590	1/2	0.174	0.174	flow depth < radius	0.900	0.179	0.179	1.575	1.575	0.113	0.322	0.014856	3.5	0.050
2	1.75	0.00302	1	0.1720	0.1720	flow depth < radius	0.894	0.175	0.175	1.565	1.565	0.112	0.955	0.003486	3.5	0.049
3	1.75	0.00440	2	0.2747	0.2747	flow depth < radius	1.136	0.350	0.350	1.988	1.988	0.176	1.633	0.006655	3.5	0.078
4	1.75	0.00556	3	0.3410	0.3410	flow depth < radius	1.270	0.482	0.482	2.222	2.222	0.217	2.254	0.008550	3.5	0.097
5	1.75	0.00624	4	0.3790	0.3790	flow depth < radius	1.341	0.563	0.563	2.347	2.347	0.240	2.915	0.008745	3.5	0.108
6	1.75	0.00587	5	0.4220	0.4220	flow depth < radius	1.418	0.659	0.659	2.482	2.482	0.265	3.680	0.008412	3.5	0.121
7	1.75	0.01048	6	0.4613	0.4613	flow depth < radius	1.486	0.750	0.750	2.601	2.601	0.288	4.563	0.010912	3.5	0.132
8	1.75	0.00709	8	0.5607	0.5607	flow depth < radius	1.647	0.995	0.995	2.882	2.882	0.345	6.165	0.009944	3.5	0.160
9	1.75	0.00689	10	0.6053	0.6053	flow depth < radius	1.716	1.112	1.112	3.002	3.002	0.370	8.120	0.008710	3.5	0.173
10	1.75	0.00994	14	0.6300	0.6300	flow depth < radius	1.753	1.178	1.178	3.067	3.067	0.384	9.533	0.009669	3.5	0.180
11	1.75	0.00888	15	0.6603	0.6603	flow depth < radius	1.797	1.260	1.260	3.145	3.145	0.401	10.077	0.009514	3.5	0.189
12	1.75	0.00884	16	0.6690	0.6690	flow depth < radius	1.810	1.284	1.284	3.167	3.167	0.405	10.281	0.009555	3.5	0.191

Manning's Roughness Calculation Table: 1 (Slope 1 in 104)

S.N.	Radius of Culvert (ft)	Slope	Number of Turn	Flow Depth Measured (ft)	h	Check (if flow depth < radius or > radius)	Central Angle	Circular Segment Area (K)	Flow Area (A) (ft2)	Arc Length (s) (ft)	Wetted Perimeter (Pw) (ft)	Hydraulic radius (A/Pw)	Discharge (from rating curve) (cfs)	Manning's Roughness Coefficient (η)	Diameter of Culvert (D) (ft)	Relative Depth (d/D)
1	1.75	0.00975	1/2	0.156	0.156	flow depth < radius	0.851	0.152	0.152	1.490	1.490	0.102	0.322	0.015100	3.5	0.045
2	1.75	0.00407	1	0.1603	0.1603	flow depth < radius	0.863	0.158	0.158	1.510	1.510	0.105	0.955	0.003482	3.5	0.046
3	1.75	0.00854	2	0.2438	0.2438	flow depth < radius	1.068	0.294	0.294	1.870	1.870	0.157	1.633	0.007200	3.5	0.070
4	1.75	0.00791	3	0.3127	0.3127	flow depth < radius	1.214	0.424	0.424	2.125	2.125	0.200	2.254	0.008496	3.5	0.089
5	1.75	0.00854	4	0.3433	0.3433	flow depth < radius	1.274	0.487	0.487	2.230	2.230	0.218	2.915	0.008314	3.5	0.098
6	1.75	0.01007	5	0.3816	0.3816	flow depth < radius	1.346	0.568	0.568	2.356	2.356	0.241	3.680	0.008930	3.5	0.109
7	1.75	0.00949	6	0.4193	0.4193	flow depth < radius	1.414	0.652	0.652	2.474	2.474	0.264	4.563	0.008512	3.5	0.120
8	1.75	0.00248	8	0.5007	0.5007	flow depth < radius	1.551	0.845	0.845	2.715	2.715	0.311	6.165	0.004656	3.5	0.143
9	1.75	0.00872	10	0.5547	0.5547	flow depth < radius	1.638	0.980	0.980	2.866	2.866	0.342	8.120	0.008189	3.5	0.158
10	1.75	0.01114	14	0.5960	0.5960	flow depth < radius	1.701	1.087	1.087	2.978	2.978	0.365	9.533	0.009138	3.5	0.170
11	1.75	0.01014	18	0.6220	0.6220	flow depth < radius	1.741	1.156	1.156	3.046	3.046	0.380	10.077	0.009000	3.5	0.178
12	1.75	0.00781	22	0.6627	0.6627	flow depth < radius	1.801	1.266	1.266	3.151	3.151	0.402	10.281	0.008809	3.5	0.189

Manning's Roughness Calculation Table: 1 (Slope 1 in 500)

S.N.	Radius of Culvert (ft)	Slope	Number of Turn	Flow Depth Measured (ft)	h	Check (if flow depth < radius or > radius)	Central Angle	Circular Segment Area (K)	Flow Area (A) (ft2)	Arc Length (s) (ft)	Wetted Perimeter (Pw) (ft)	Hydraulic radius (A/Pw)	Discharge (from rating curve) (cfs)	Manning's Roughness Coefficient (η)	Diameter of Culvert (D) (ft)	Relative Depth (d/D)
1	1.75	0.00474	1/2	0.194	0.194	flow depth < radius	0.950	0.209	0.209	1.663	1.663	0.126	0.322	0.016708	3.5	0.055
2	1.75	0.00145	1	0.2020	0.2020	flow depth < radius	0.970	0.223	0.223	1.698	1.698	0.131	0.955	0.003402	3.5	0.058
3	1.75	0.00242	2	0.3203	0.3203	flow depth < radius	1.229	0.440	0.440	2.151	2.151	0.204	1.633	0.006829	3.5	0.092
4	1.75	0.00413	3	0.3793	0.3793	flow depth < radius	1.342	0.563	0.563	2.348	2.348	0.240	2.254	0.009216	3.5	0.108
5	1.75	0.00452	4	0.4093	0.4093	flow depth < radius	1.396	0.630	0.630	2.443	2.443	0.258	2.915	0.008744	3.5	0.117
6	1.75	0.00472	5	0.4490	0.4490	flow depth < radius	1.465	0.721	0.721	2.564	2.564	0.281	3.680	0.008584	3.5	0.128
7	1.75	0.00561	6	0.4920	0.4920	flow depth < radius	1.537	0.824	0.824	2.690	2.690	0.306	4.563	0.009125	3.5	0.141
8	1.75	0.00690	8	0.5663	0.5663	flow depth < radius	1.656	1.010	1.010	2.898	2.898	0.349	6.165	0.010014	3.5	0.162
9	1.75	0.00701	10	0.6290	0.6290	flow depth < radius	1.751	1.175	1.175	3.064	3.064	0.383	8.120	0.009502	3.5	0.180
10	1.75	0.00855	14	0.6557	0.6557	flow depth < radius	1.790	1.247	1.247	3.133	3.133	0.398	9.533	0.009728	3.5	0.187
11	1.75	0.00931	18	0.6678	0.6678	flow depth < radius	1.808	1.280	1.280	3.164	3.164	0.405	10.077	0.009966	3.5	0.191
12	1.75	0.00917	22	0.6790	0.6790	flow depth < radius	1.824	1.311	1.311	3.193	3.193	0.411	10.281	0.010029	3.5	0.194

Manning's Roughness Calculation Table: 1 (Slope 1 in 50)

S.N.	Radius of Culvert (ft)	Slope	Number of Turn	Flow Depth Measured (ft)	h	Check (if flow depth < radius or > radius)	Central Angle	Circular Segment Area (K)	Flow Area (A) (ft2)	Arc Length (s) (ft)	Wetted Perimeter (Pw) (ft)	Hydraulic radius (A/Pw)	Discharge (from rating curve) (cfs)	Manning's Roughness Coefficient (η)	Diameter of Culvert (D) (ft)	Relative Depth (d/D)
1	1.75	0.0262	1/2	0.105	0.105	flow depth < radius	0.696	0.084	0.084	1.217	1.217	0.069	0.322	0.010537	3.5	0.030
3	1.75	0.0128	2	0.2090	0.2090	flow depth < radius	0.987	0.234	0.234	1.728	1.728	0.135	1.633	0.006348	3.5	0.060
4	1.75	0.0117	3	0.2650	0.2650	flow depth < radius	1.115	0.332	0.332	1.951	1.951	0.170	2.254	0.007275	3.5	0.076
5	1.75	0.0150	4	0.2983	0.2983	flow depth < radius	1.185	0.396	0.396	2.074	2.074	0.191	2.915	0.008195	3.5	0.085
6	1.75	0.0150	5	0.3297	0.3297	flow depth < radius	1.248	0.459	0.459	2.184	2.184	0.210	3.680	0.008011	3.5	0.094
7	1.75	0.0128	6	0.3870	0.3870	flow depth < radius	1.356	0.580	0.580	2.373	2.373	0.245	4.563	0.008372	3.5	0.111
8	1.75	0.0116	8	0.4490	0.4490	flow depth < radius	1.465	0.721	0.721	2.564	2.564	0.281	6.165	0.008029	3.5	0.128
8	1.75	0.0133	10	0.5040	0.5040	flow depth < radius	1.557	0.853	0.853	2.725	2.725	0.313	8.120	0.008309	3.5	0.144
8	1.75	0.0044	14	0.5564	0.5564	flow depth < radius	1.641	0.984	0.984	2.871	2.871	0.343	9.533	0.004982	3.5	0.159
9	1.75	0.0133	18	0.5741	0.5741	flow depth < radius	1.668	1.030	1.030	2.919	2.919	0.353	10.077	0.008730	3.5	0.164
10	1.75	0.0129	22	0.6030	0.6030	flow depth < radius	1.712	1.106	1.106	2.996	2.996	0.369	10.281	0.009324	3.5	0.172

APPENDIX E:

Photographs

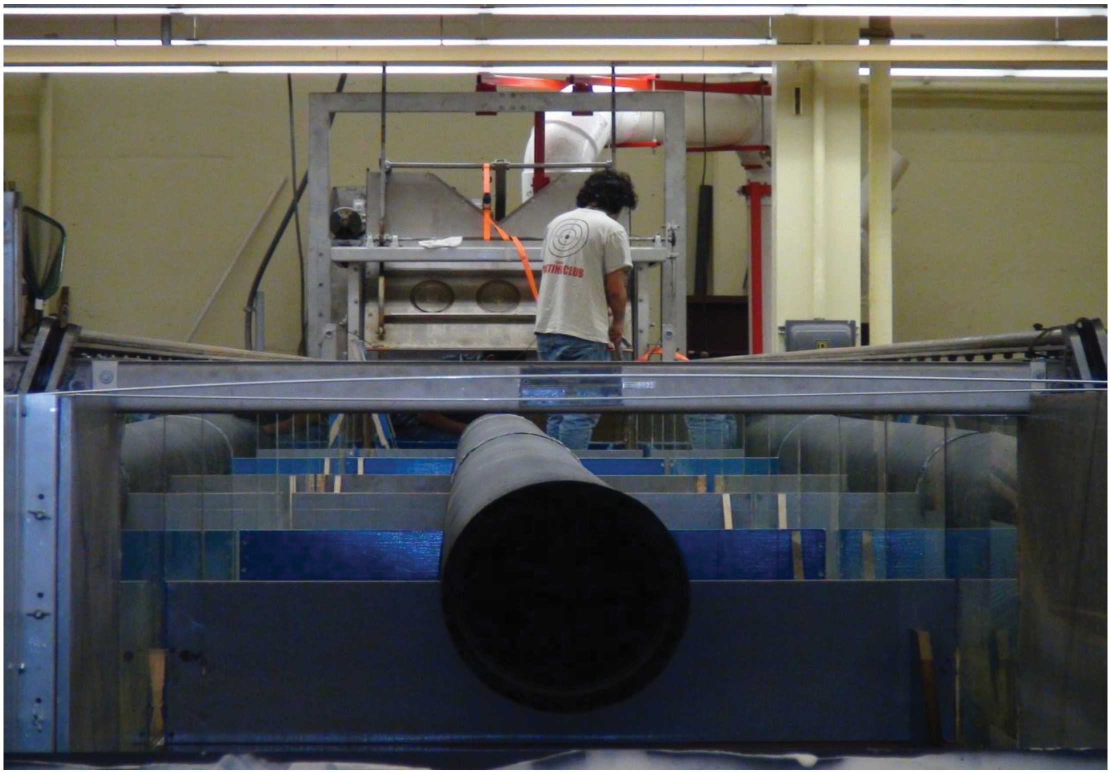
Picture showing Pump and valve

Picture showing Pump, valve, sump, headbox and the flume with 3.5 ft culvert inside

Picture showing tripod for surveying level

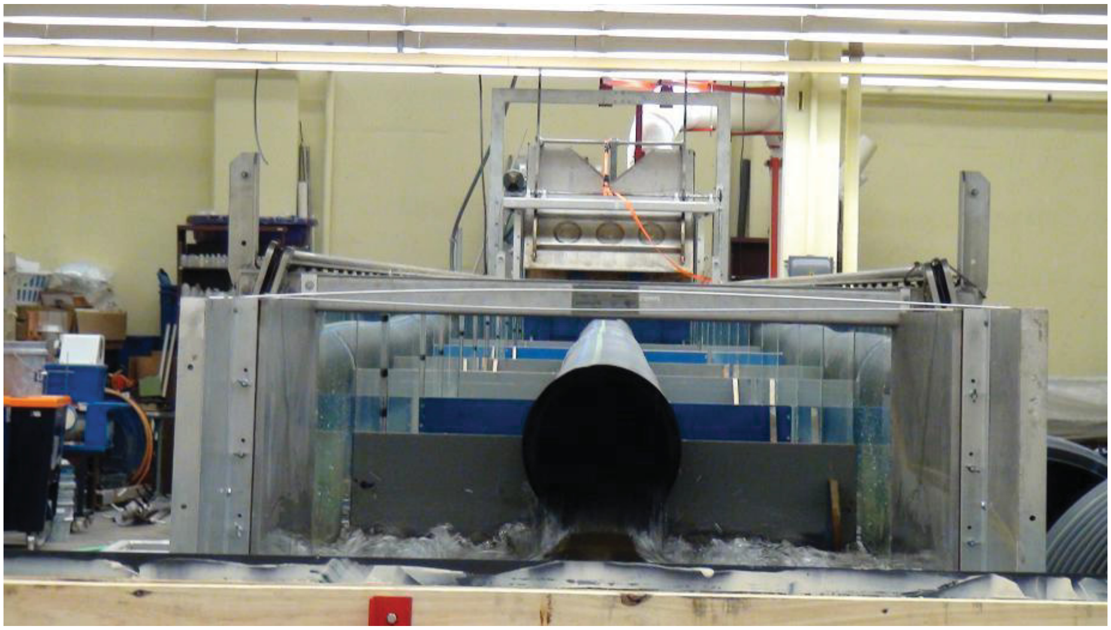
Picture showing aluminum frame for ADV over the sump area

1 ft culvert inside the 3.5 ft culvert



1 ft culvert installation (view from rear end)

Valve operation



1 ft culvert leakage testing (view from rear end)

1 ft culvert leakage testing (view from side)

Outlet view of the flume

Outlet view of the flume in operation with 2 ft culvert inside