Discussion on the Selection of the Recommended Fish Passage Design Discharge

Introduction

The provision of fish passage is a requirement for most proposed culvert and bridge installations in Alberta, depending on the recommendations from a qualified environmental professional. A fish passage design discharge is required to assess a structure's performance and evaluate fish passage through the structure. The difficulty lies in selecting an appropriate maximum fish passage discharge for culverts where insufficient historical hydrological information exists.

In 2006, Alberta Transportation undertook a statistical analysis in an attempt to establish a depth based approach for the provision of fish passage in consultation with the Department of Fisheries and Oceans. This study used physical channel characteristics (bed width, slope, etc) to calculate discharge based on the Manning's Equation. Hydraulic performance was then evaluated against a range of discharges based on flow depth, typically between 0.5 m and 1.0 m. The culvert was assumed to be passable by fish if the section averaged velocities at the prescribed depth of flow within the culvert were the same, as or lower, than the averaged velocity within the typical natural channel.

The work from 2006 has been continued here in an attempt to develop an alternate fish passage design discharge (FPDD) that could be calculated based on physical channel characteristics and applied to all sites across the Province.

Background

Various methodologies have been used in the past to determine the Fish Passage Design Discharge (FPDD). Most recently (~2006 to 2014), comparing velocities at a range of flow depths from 0.5 to 1.0m was used. Previous to this, the 1 in 10 year 3 day delay discharge (3Q10) was used. This method was related to fish swimming performance and, oftentimes, resulted in very low velocities in the culvert relative to the stream.

There are a couple of significant drawbacks in the application of the 3Q10 discharge. The first drawback is the assumption about the applicability of its use. The use of a maximum delay of three days appears to have first been recommended in a consultant report (Dillon, 1979) for construction of the Liard Highway in Alaska which led to further studies in the region. In particular, a population of arctic grayling in Fish Creek in Alaska was studied with the recommendation that arctic grayling not be subjected to an artificial delay of more than 3 days (Fleming, 1991). The recommendation did not apply a return period to this delay. It is not clear where the return period was originally recommended but it is assumed that it is related to the consecutive risk of failure of the spawning migration. The 1:10 year return period was used in calculation of fish passage discharges in the Fish Habitat Protection Guidelines for Stream Crossings (Alberta Government, 1992).

The application of 3Q10 discharge assumes that this same delay period should be applied at all locations for all fish species; there have been no additional studies completed to suggest that this is the case. Anecdotal reports from staff at Alberta Environment and Park's Fisheries Management Branch (FMB) have suggested that some species of fish may wait longer to move upstream. No studies have been completed in Alberta to suggest what length of delay would be appropriate.

The second drawback of the use of the 3Q10 discharge is the lack of data for smaller streams. Use of statistical analysis on a site by site basis to determine the FPDD does not yield accurate results for fish passage evaluation. For the purpose of this evaluation there were only 41 gauges in the entire province that were considered appropriate for review (an appropriate size where a culvert would likely be used and had more than 30 years of record). In order to evaluate a FPDD for a location on an ungauged stream, basin data transfer techniques would be required. However, these techniques have no physical meaning as each basin is unique and have yielded poor results in the past.

The 3Q10 methodology overall generally did not work unless baffle systems were installed within culverts to reduce velocities. These baffle systems were difficult to install, created maintenance issues including acting as debris catchers, reduced the lifespan of the culvert, and caused safety issues during inspections. The majority of baffles installed in the past have been abraded due to drift and bedload to the point of being ineffective, or have washed away completely from within the structure.

Methodology

The Water Survey of Canada has hundreds of active gauging staging across the provinces which were relied upon for the current study. Gauges selected for evaluation were required to be on a stream where it would be feasible to install a culvert. Based on this requirement, streams with a bed width of less than 8 m were used. The second criterion was a minimum gauge record of 30 years in order to evaluate the statistical record with some statistical reliability.

For the purpose of this review, mean daily discharges occurring during the spring spawning migration were considered, as this is the timeframe when flows are the highest for an extended period of time. The period selected by DFO staff for evaluation was March 1 to May 15 (76 days), noting that this should cover the migration period for all spring spawners along with annual variations in the run timing.

Several different discharges were evaluated for this exercise to aid in assessing an appropriate maximum FPDD. During the evaluation process five discharges were selected for further evaluation: 3Q10, 7Q10, Q90, Q95 and Q98. The methodology for determining these discharges is summarized below and their advantages and disadvantages are included in the Analysis and Discussion section.

The 3Q10 is based on the assumption that fish will only sustain a delay of up to 3 days before giving up on their migration, and the females begin reabsorbing their eggs (Fleming, 1991). The 3Q10 is evaluated by selecting the fourth highest consecutive mean daily discharge during the spawning period for each year of record. These discharges are then used to complete a frequency analysis, typically using a Pearson III distribution. For this evaluation both the Pearson III distribution and a rank and percentile evaluation were employed with no significant variation. (Alberta, 1992)

The 7Q10 is based on similar assumptions to the 3Q10 only it allows for a delay of 7 days. The 7Q10 discharge is evaluated in a similar manner to the 3Q10 with the exception that the eighth highest consecutive flow during the spring spawning migration period is selected instead of the fourth. This assumption was used based on anecdotal reports from some staff at Alberta Environment and Sustainable Resource Development (AESRD) Fish and Wildlife that some species of fish can withstand a delay of 7 days or possibly more.

The Q90, Q95 and Q98 discharges are equivalent to the 10% exceedence, 5% exceedence and 2% exceedence discharge respectively. Q90, Q95 and Q98 were used as the terminology to indicate that fish passage would be achievable 90, 95 and 98% of the time in a given year.

Exceedence discharges were calculated by using data within the spring migration period (76 days), ranking the data set from highest to lowest (for all years on record) and selecting the relevant percentile in the ranking. For example, if one were to assume 30 years of record with 76 days for each year this would result in 2280 data points for that particular gauge. In selecting the 10^{th} percentile the 228^{th} data point was used and for the 5^{th} percentile this would be the 114^{th} highest discharge in the entire period of record for the spring spawning migration window.

The flow depth for each discharge, whether delay or exceedence discharge, was calculated based on the physical channel characteristics to provide a consistent basis for comparing the discharges to one another.

As fish require adequate depth of flow for migration, the minimum depth of flow applied for determining the FPDD was 0.2 m. Below this level, there may be insufficient water depth for fish migration to occur.

Analysis and Discussion

The selection of a FPDD requires assessment of risk associated with the loss of fish passage in a particular year as well as consecutive annual losses. Several discharges were evaluated to put context to this risk. For simplicity they are referred to as delay discharges, 3Q10 and 7Q10, and exceedence discharges, Q90, Q95 and Q98.

The migration window selected for this analysis is 76 days long. Given that not all fish move at the same time, the probability of each species encountering the delay discharge is quite low. For example, the probability of fish encountering the 3Q10 is 4/76 for the given year multiplied by the frequency of 1/10 years. This results in a probability of 1/190 or 0.5%. Similarly, the probability of fish encountering the 7Q10 is 1% (8/76 x 1/10), double the probability of encountering the 3Q10. The 7Q10 is more lenient than 3Q10 with respect to the allowable delay but is still conservative when considering the probability of encountering the discharge.

Due to the low probability of encountering the delay design discharge and because most species of fish in Alberta move to spawn after the peak discharge (and many of them are less sensitive than arctic grayling), the Department is suggesting that a less conservative discharge than the 3Q10 be applied for assessing fish passage.

Two streams of analysis were taken for this discussion. The relationship between discharge and the physical parameters of the stream was explored to determine if there is a strong enough correlation that physical parameters can be relied upon to develop design criteria. Based on observations made during the first portion of the analysis, the relationship between the exceedence discharges and the delay discharges was also evaluated.

Slope was selected as the independent variable for the analysis as it is easily measured and it showed a reasonably good relationship to the depth. The data sets for each of the depths at the defined discharge were plotted against the corresponding slope. A linear regression was completed on each data set with poor results (Figures 1 and 2).

Due to the poor correlations of all the data sets, a more conservative approach was taken and a best fit envelope was established for each data set (Figures 3 and 4). The two outliers appear to be ice affected water levels and were ignored.

When the data was plotted, and in particular when the envelopes were plotted, similarities were noted between the 3Q10 and Q98 data sets and the 7Q10 and Q95 data sets. A regression analysis was completed between the 3Q10 and Q98 data sets and the 7Q10 and Q95 data sets. Figure 5 shows that the 3Q10 has a strong correlation (perfect correlation would be a 1:1 relationship) with the 2% exceedence discharge (Q98). The correlation of the 7Q10 with the 5% exceedence (Q95) discharge was reasonable with a lower R^2 was lower. However when comparing the envelope of the 7Q10 and the Q95, they are almost the same. For the purpose of further discussion, the 3Q10 will be referred to as Q98 and 7Q10 will be referred to as Q95.

With further examination of Figure 2, approximately 70 percent of the 3Q10 data points are below the 7Q10 envelope. This means that for the majority of sites, the 7Q10 envelope is more conservative than using the 3Q10 method.

The recommendation of an envelope to use for determining the FPDD depth must consider the risk to the fish populations. The Q98 has a 2% probability of exceedence during the spring spawning migration. Also, earlier in the discussion, it was shown that during the 3Q10, now Q98, there was a 0.5% probability of fish encountering the discharge. Likewise, for the Q95 there is a 5% probability of exceedence during the spring spawning migration with a 1% probability of fish encountering the discharge. The likelihood of experiencing the Q90 discharge is 10% on an annual basis. The probability of fish encountering this discharge was not determined. The probability of encountering the delay is independent of the exceedence probability. If a delay discharge were determined to correlate with the Q90, the delay would be greater than 7 days. Increases in annual probability of occurrence, and associated delay probabilities, may increase the risk of year upon year failures in the spawning and therefore could have significant negative impacts on the fish populations. Without significant, and costly, research this cannot be determined; as such a moderate approach to calculating the FPDD is suggested.

Recommendations

All of the exceedances evaluated in this study occur during high flow events with low probability where it is possible that fish may choose to wait rather migrate. Ideally, risk to fish populations and fishery management objectives during these types of events, should be considered. Without studying the movements of fish populations at specific sites in the field, this application of risk is somewhat subjective.

Based on the discussion, it is clear that the 3Q10 (Q98) discharge is the most conservative approach, the Q95 (7Q10) is somewhat conservative, and the Q90 is the least conservative of the discharges evaluated, although all are still considered to be flood events.

Due to the uncertainty with risks to the fish populations it is recommended to use the moderate approach to determination of the FPDD, the Q95 envelope. The envelope curve, Figure 6, is equated to be:

$$Y_{FPDD} = 0.8 - 34.3 * S, \text{ for } S < 0.017$$

$$Y_{FPDD} = 0.2, \text{ for } S \geq 0.017$$

While this is a somewhat conservative approach it will help to ensure that fish passage is achievable in years when larger runoff events occur. These larger events are considered to be essential for high recruitment for juvenile fish by staff at AEP Fish and Wildlife Division. This approach will also allow for consideration of site specific channel characteristics in a consistent manner.

Figure 1: Correlations for Depth as a Function of Slope at Delay Discharges

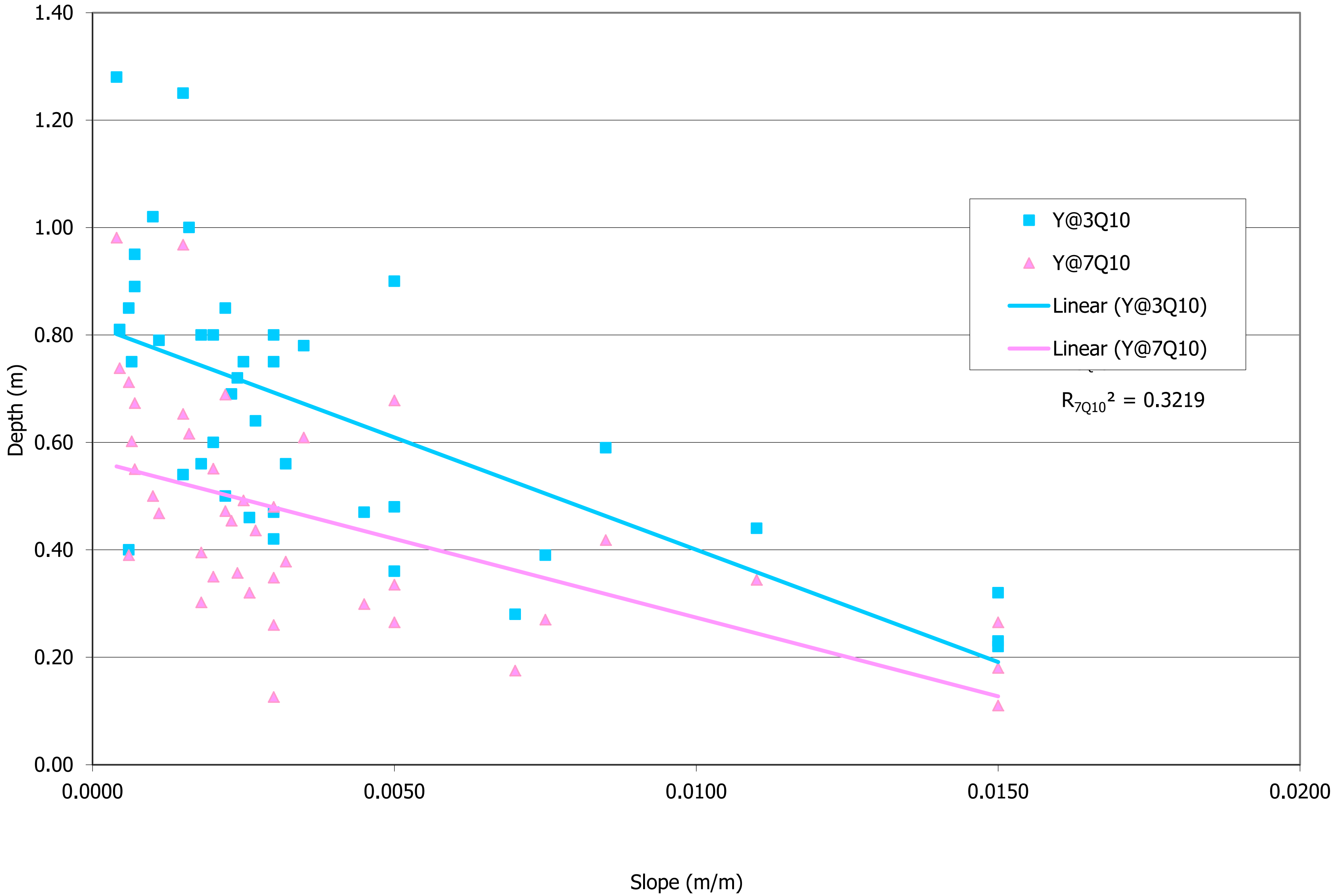


Figure 2: Correlations for Depth as a Function of Slope at Exceedence Discharges

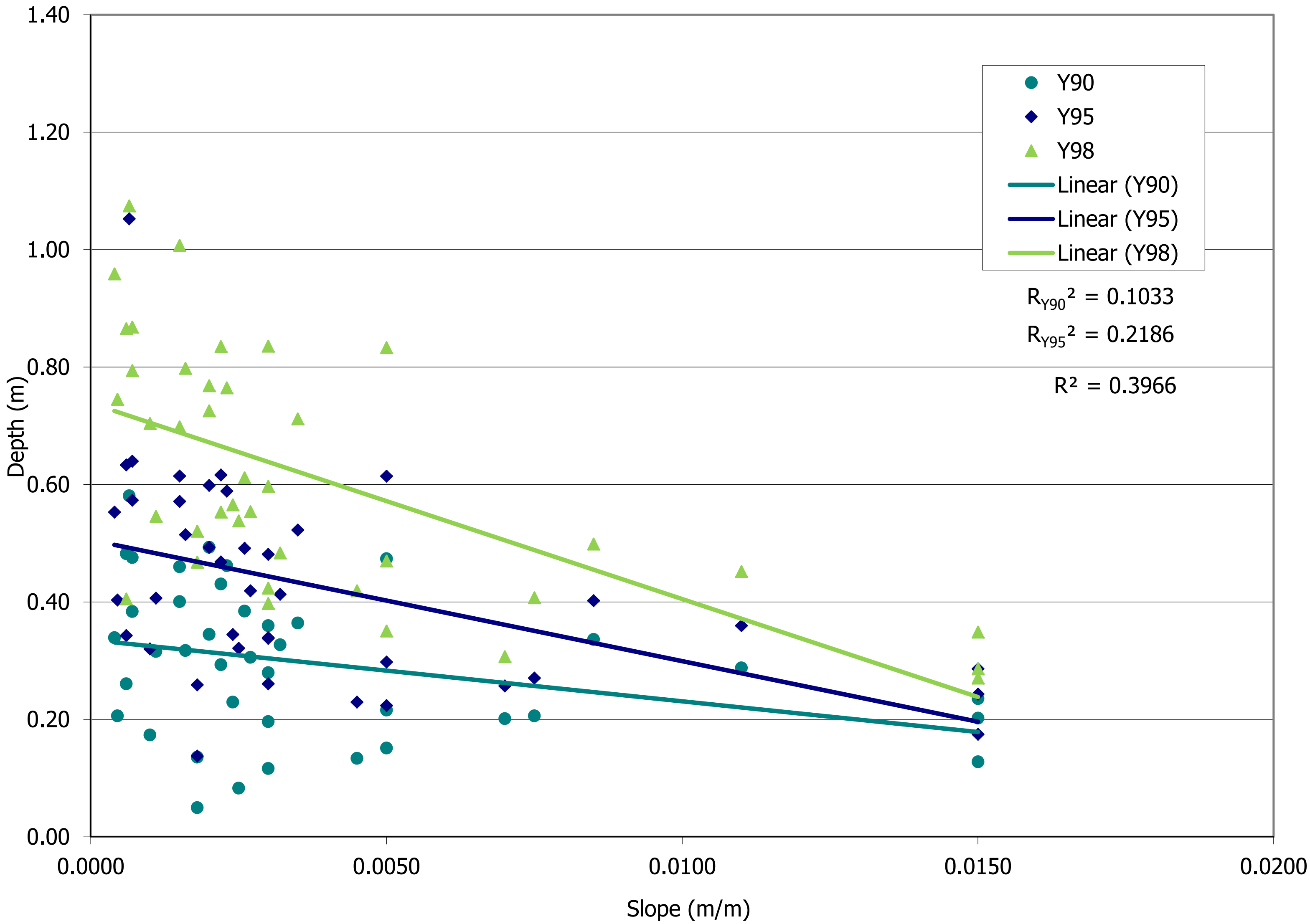


Figure 3: Envelopes for Depth as a Function of Slope at Delay Discharge

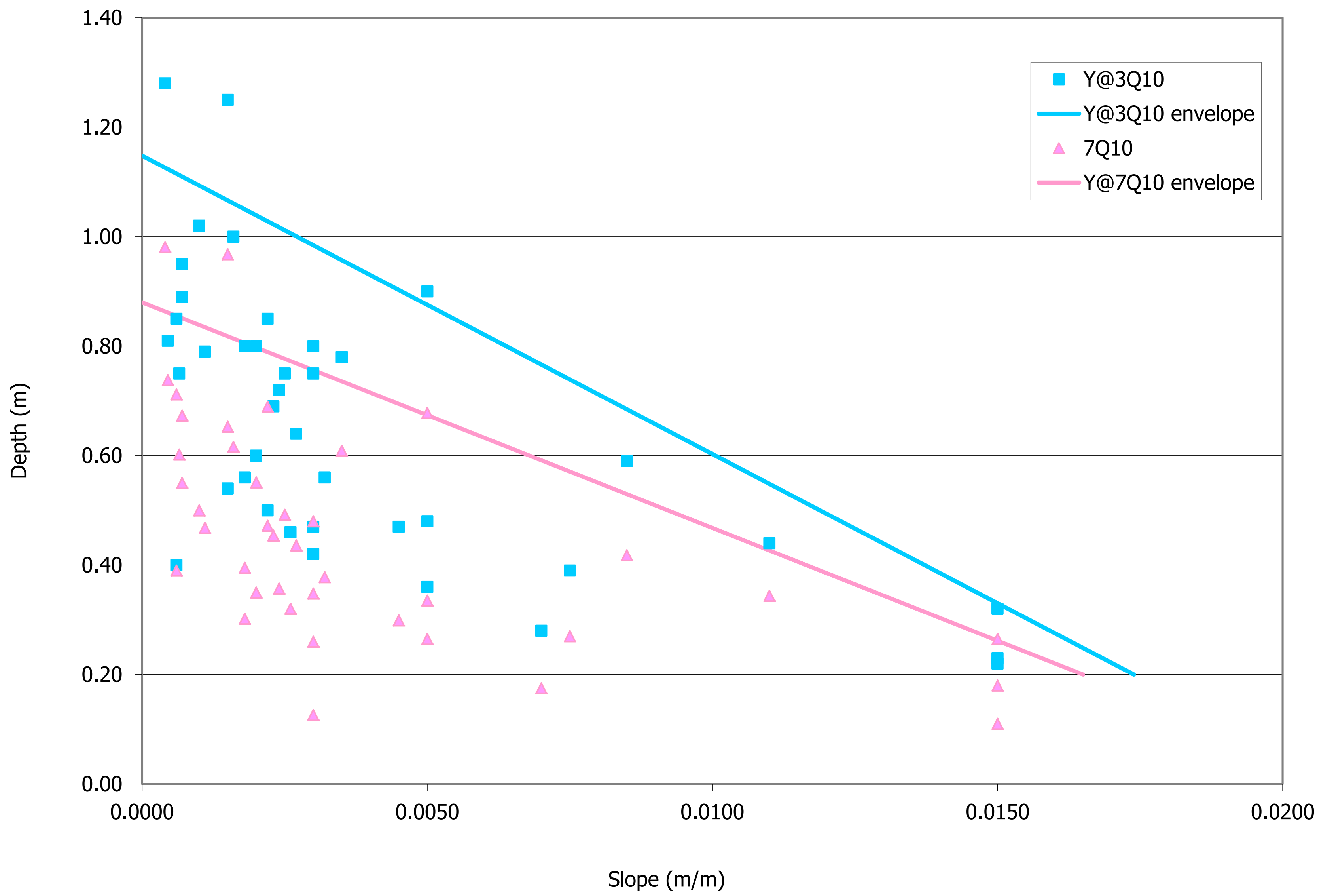


Figure 4: Envelopes for Depth as a Function of Slope at Exceedence Discharges

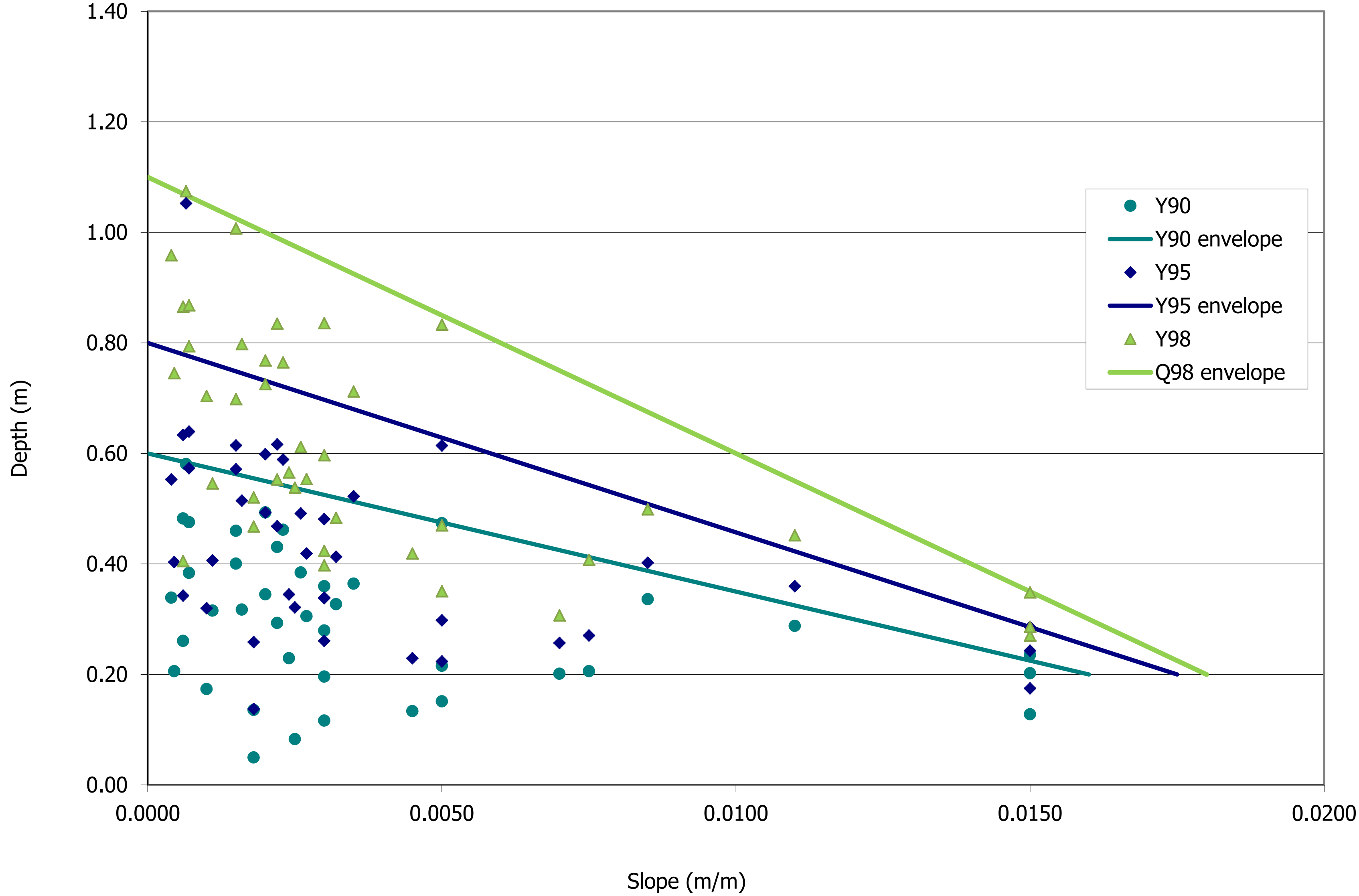


Figure 5: Correlations for Delay Discharge vs. Exceedence Discharge

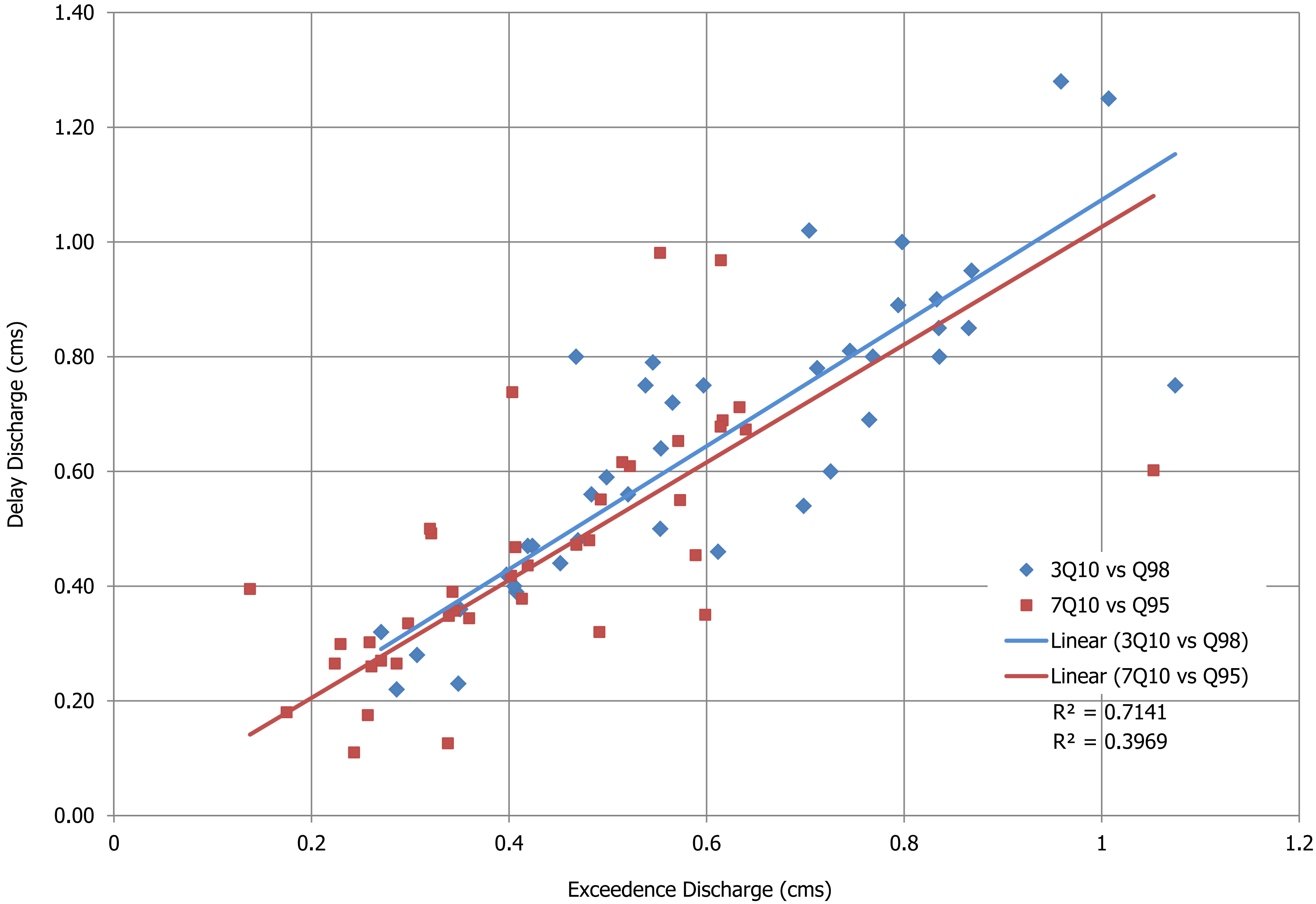
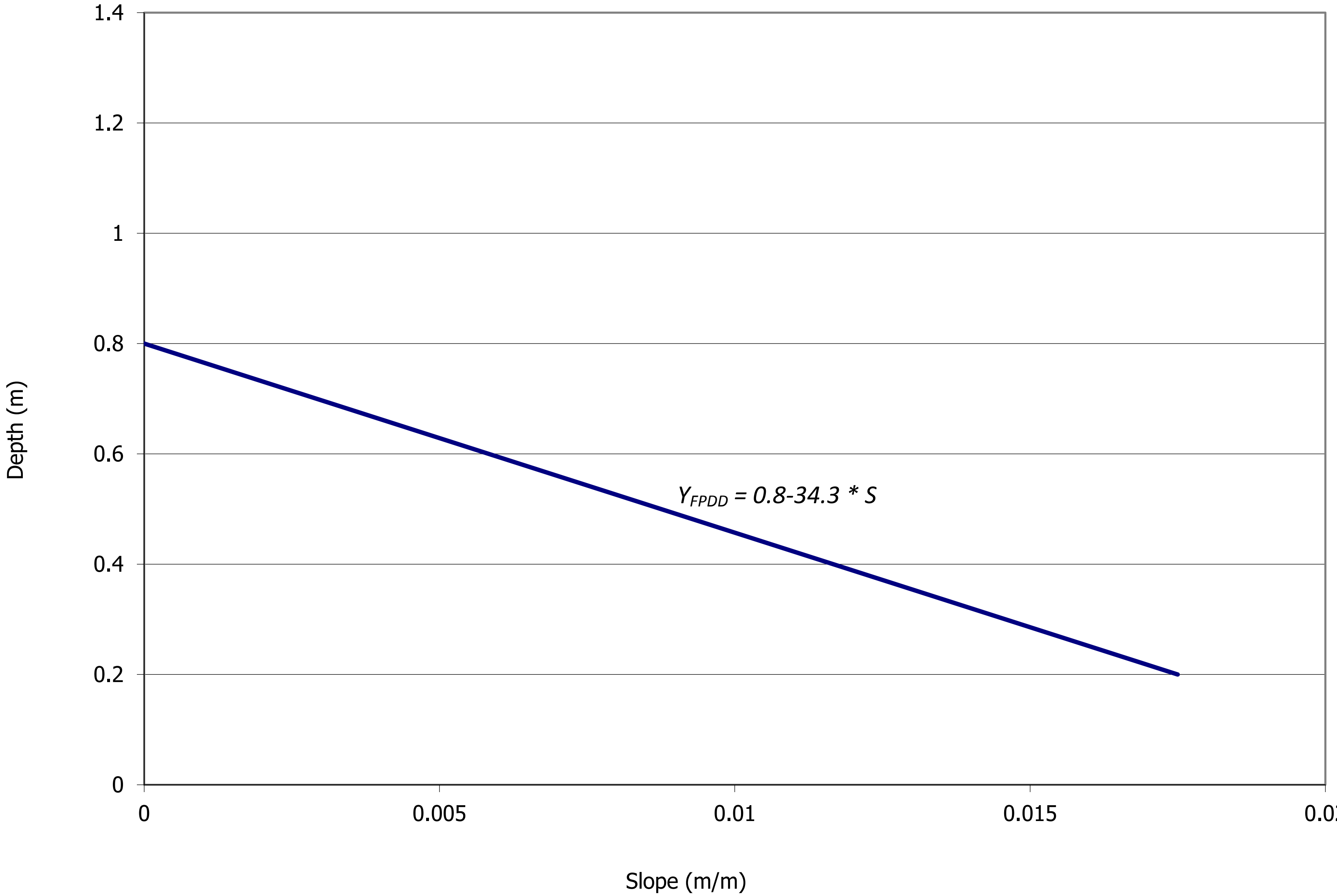


Figure 6: Recommended Envelope for Calculation of Depth at FPDD



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