THESIS

IDENTIFICATION OF SPATIAL AND TOPOGRAPHICAL METRICS FOR MICRO HYDROPOWER APPLICATIONS IN IRRIGATION INFRASTRUCTURE

Submitted by

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ABSTRACT

IDENTIFICATION OF SPATIAL AND TOPOGRAPHICAL METRICS FOR MICRO HYDROPOWER APPLICATIONS IN IRRIGATION INFRASTRUCTURE

A recent agreement between the Federal Energy Regulatory Commission and the State of Colorado seeks to streamline regulatory review of small, low-head hydropower (micro hydropower) projects located in constrained waterways, (Governor's Energy Office, 2010). This regulatory change will likely encourage the development of micro hydropower projects, primarily as upgrades to existing infrastructure. Previous studies of low-head hydropower projects have estimated the combined capacity of micro hydro projects in Colorado between 664 MW to 5,003 MW (Connor, A.M., et al. 1998; Hall, D.G., et al. 2004, 2006). However, these studies did not include existing hydraulic structures in irrigation canals as possible hydropower sites. A Colorado Department of Agriculture study (Applegate Group, 2011) identified existing infrastructure categories for low head hydropower development in irrigation systems, which included diversion structures, line chutes, vertical drops, pipelines, check structures and reservoir outlets. However, an accurate assessment of hydropower capacity from existing infrastructures could not be determined due to low survey responses from irrigation water districts.

The current study represents the first step in a comprehensive field study to quantify the type and quantity of irrigation infrastructure for potential upgrade to support micro hydropower production. Field surveys were conducted at approximately 230 sites in 6 of Colorado's 7 hydrographic divisions at existing hydraulic control structures. The United States Bureau of Reclamation contributed approximately 330 additional sample sites from the 17 western states.

The work presented here describes a novel method of identifying geospatial metrics to support an estimation of total site count and resource availability of potential micro hydropower. The proposed technique is general in nature and could be utilized to assess micro hydropower resources in any region.

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1.1 Introduction

Low-head hydropower sites, also referred to as micro hydropower, have the potential to increase contributions to the electric grid from renewable resources. Many states have implemented renewable portfolio standards mandating energy from renewable resources. Recently, Colorado has increased its renewable energy standards for investor-owned utilities to require 30% renewable sources by 2020 (Governor's Energy Office, 2010). While micro hydropower is an attractive renewable resource, a technology summit meeting hosted by Oak Ridge National Laboratory, the National Hydropower Association, and the Hydropower Research Foundation identified "complex regulatory processes" as one barrier to make micro hydropower successful. In response to the findings at the technology summit meeting, a Memorandum of Understanding (MOU) between the Federal Energy Regulatory Commission (FERC) and The State of Colorado through the Governor's Energy Office (GEO) was established in 2010 to simplify the regulatory review of micro hydropower projects located in constrained waterways that qualify for "conduit exemption" or "5 MW exemption" under FERC's permitting process. This MOU specifically outlines that the primary criterion for the pilot program is that micro hydropower projects must use existing hydraulic infrastructure, often known as "constrained waterways." The first project to successfully navigate the new streamlined process was an irrigation pipeline in Meeker, Colorado. The project will produce 100,000 kilowatt-hours of energy from one generating unit with a capacity of 23 kW. FERC approved the project in a two-month time span compared to a 3 year timespan, the historical timeline for this type of project.

Based on the simplified regulatory procedure, micro hydropower development in constructed waterways will likely occur as upgrades to existing hydraulic control structures. There are many benefits to upgrading an existing site with micro hydropower which include lower development costs and reduced environmental impact. This is largely attributed to taking advantage of existing infrastructure. Applegate Group, 2011 points out that much of the core infrastructure to support these sites are already in place.

This is a main feature which reduces impact. Additionally, technological improvements in turbine/generator packages for micro hydropower applications have made these types of sites good candidates for implementing the technology. Currently, the amount of hydropower that can be obtained from upgrades to existing structures in Colorado is unknown.

Hydraulic structures are used for flow control, energy dissipation, and flow measurement. Constructed waterways typically consist of long stretches of low thalweg slopes. Transitioning regions of steep slopes is generally made using a hydraulic control structure. As a result, there exist many locations in constructed waterways in which energy can be recovered at existing hydraulic structures designed to dissipate excess energy in the system. Types of structures can include diversion structures, concrete lined chutes, vertical drops, pipelines, checks, and reservoir outlets (Applegate Group, 2011). Upgrading these structures to include hydropower generation capitalizes on harnessing the excess energy in the hydraulic system, which is generally dissipated by the inclusion of the hydraulic structure.

Two studies have been conducted to specifically address hydropower potential in Colorado's irrigation infrastructure. A study funded by The Colorado Department of Agriculture (CDA) (Applegate Group, 2011) attempted to estimate the potential power generation available from existing, low head irrigation infrastructure. The feasibility of implementing micro hydropower projects into these existing irrigation facilities was found to be highly dependent on local site conditions. However, despite a high level of interest in micro hydropower production in irrigation canals, there was a low participation in the study's surveys to acquire data on existing structures. A conclusion included that a field study of each potential canal was needed to assess the potential head and temporal flow characteristics. Additionally, the United States Bureau of Reclamation (USBR) recently published an investigation of potential hydropower assets at hydraulic control structures in existing USBR canals (USBR, 2012). The scope of the USBR (2012) study was to identify hydropower potential in terms of potential peak power production and total annual energy production. However, inconsistent field responses produced an inaccurate account of potential micro hydropower asset.

The current methods employed to identify the type and quantity of irrigation infrastructure for potential upgrade to support micro hydropower production are executed by conducting field surveys and data requests from regional authorities or experienced field personnel. However, this type of data collection method has is costly. The inconsistencies in data collection methods can lead to inaccuracies in the data quality. In addition, regional authorities are often unable to participate and prioritize the data collection effort. While site visits to every potential hydropower site is desirable, it is impractical to perform such a survey across Colorado, let alone a multi-state region. Therefore, it is necessary to develop a methodology that can identify the type, quantity and location of promising hydraulic structures in irrigation infrastructure suitable for micro hydropower upgrades.

In the present study, field data of physical parameters of existing irrigation structures was collected and compared with geospatial data. The goal of this study is to establish a predictive model to support an estimation of total site count and resource availability of potential micro hydropower within irrigation infrastructure using geospatial data. The study was initiated by collecting field data from approximately 230 existing irrigation canal hydraulic structures in Colorado. Additionally, data for over 330 sites were contributed by the United States Bureau of Reclamation (USBR). GIS and publically available geospatial data was used to correlate observed hydraulic structure types with their geospatial profile in order to create a model capable of identifying hydraulic structures. The benefit of this model is the elimination of field visits or data collection from regional authorities. The resulting technique can be applied to quantify the attributes of the structures which have both promising characteristics and meet the exemptions listed in the Colorado/FERC MOU.

1.2 Study Area

Colorado has an estimated 2,463,803 of irrigated acres and 4,551,772 acre-feet of storage in its major reservoirs (Colorado Decision Support System). To transport the water required for use within the state, an infrastructure of canals and ditches exists approximately totaling 22,800 miles (Holleran, M

2005). Colorado's canals transverse throughout its wide variety of topographic slopes, and as a result, contain many hydraulic structures.

The initial study area included approximately 775 km of canal alignment between 36 different canals. The total number of sites visited on these canals was 233 (Figure 1.1 and Figure 1.2).

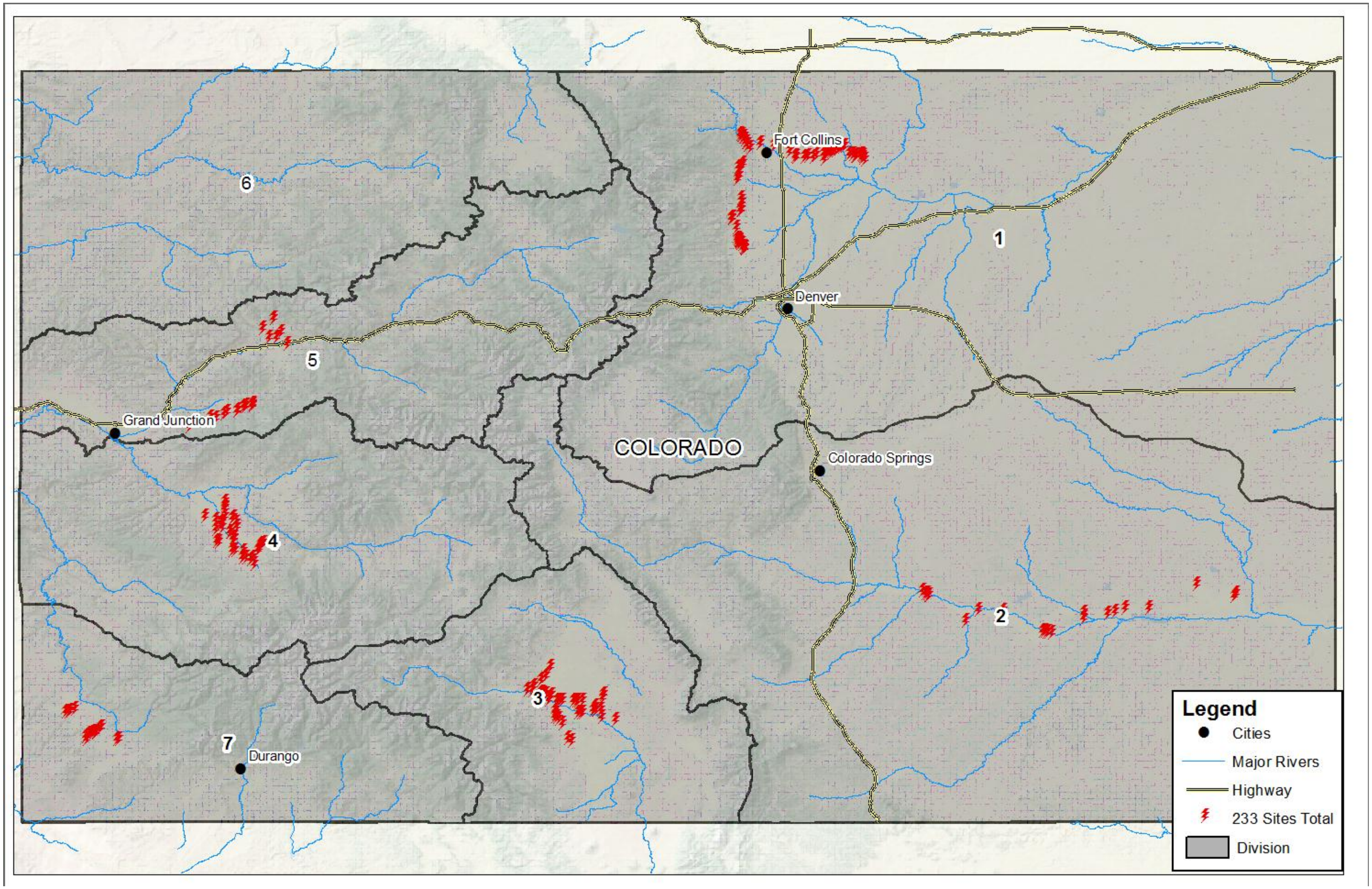


Figure 1.1 Location of field sites separated by Colorado's 7 hydrologic divisions

Colorado Hydrologic Division	Canal Names	Number of Structures	Length of Canal (km)*
1	Boulder Feeder Canal	13	21.12
	Boulder Supply Canal	7	4.43
	Dixon Feeder Canal	1	N/A*
	Hanson Feeder Canal	6	17.62
	Hanson Supply Canal	10	8.36
	Larimer and Weld Canal	32	80.38
	Poudre River	1	N/A*
	St. Vrain Supply	8	15.58
1	Arkansas River	2	N/A*
	Catlyn Canal	1	11.38
	Fort Lyon Canal	16	173.06
	Rocky Ford Highline	6	54.93
3	Costilla Canal	2	8.37
	Monte Vista Canal	8	40.93
	Prairie D	9	17.62
	Rio Grande Canal	8	26.92
	Rio Grande Canal L1	11	12.69
	San Luis Canal	12	24.17
4	East Canal	7	17.26
	Ironstone Canal	3	21.88
	Loutsenhizer Canal	1	N/A*
	Montrose & Delta Canal	9	36.2
	Selig Canal	10	37.1
	South Canal	7	18.5
	Uncompahgre River	4	N/A*
5	Grass Valley Canal	2	10.41
	Harvey Gap reservoir outlet	1	N/A*
	Leon Park Feeder Canal	1	0.96
	Park Creek Ditch	1	0.63
	Pump House	1	N/A*
	Rifle Gap Reservoir Outlet	1	N/A*
	Southside Canal	12	48.44
	West Lateral	2	9.75
7	U Lateral	4	6.5
	Canal 1	2	3.98
	Canal 2	12	9.8
Total		233	739
*N/A structures represent point measurements. Entire canal reach was not investigated *Length of canal represents the length of the canal alignment in which sites were investigated			

Figure 1.2 Summary of field sites including the number of structures and the length of the canal

Some 338 sites from the USBR were included into the dataset. Data from the USBR included site specific locations on canals and not continuous data along the canal alignment. The final unadjusted dataset included 571 sites.

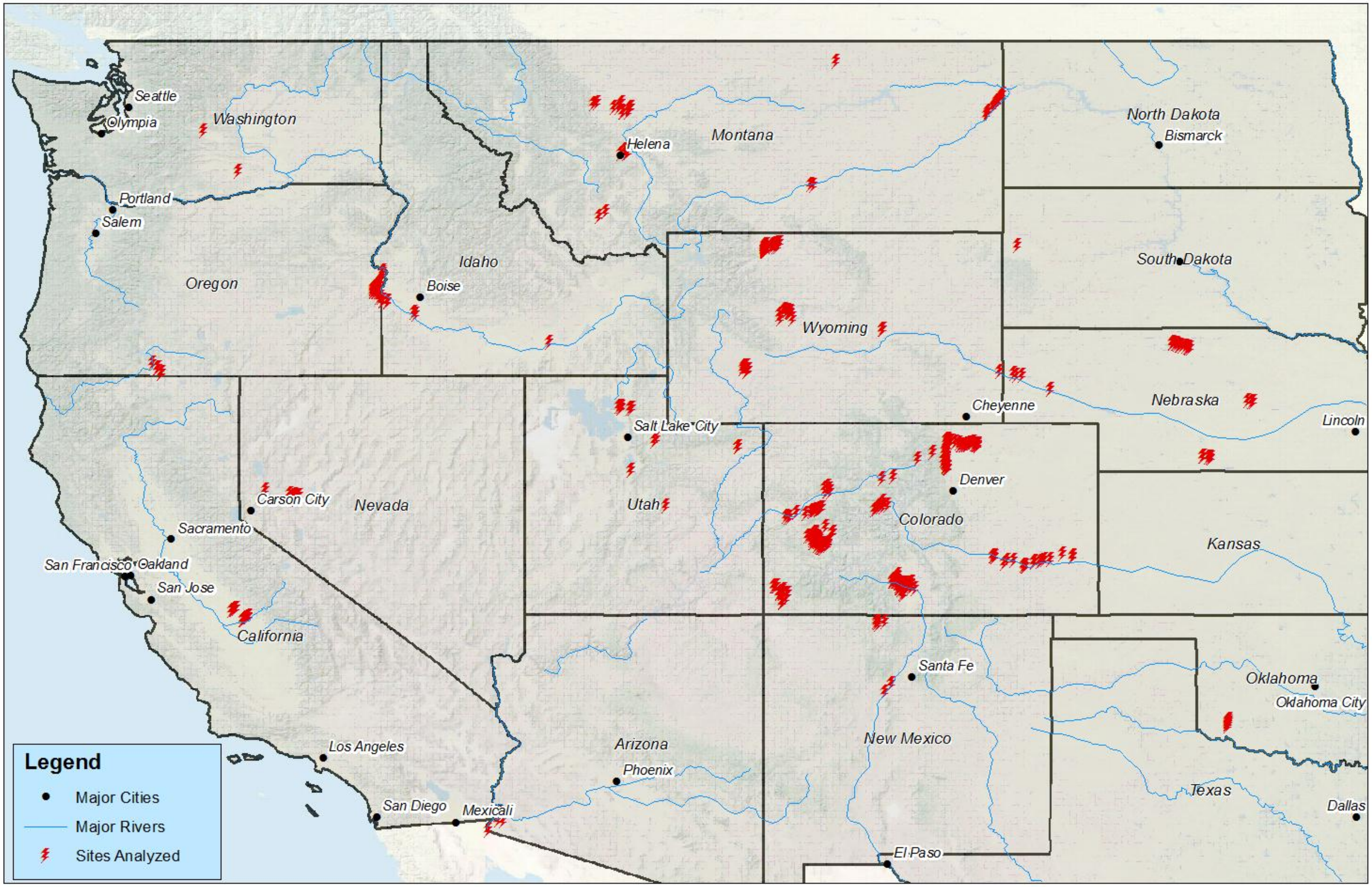
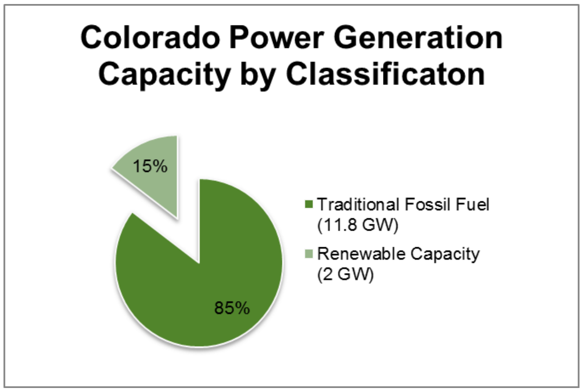


Figure 1.3 USBR and Colorado irrigation district hydraulic structures with potential for low head hydropower

1.2.1 Colorado's Existing Energy Generation Assets

As of 2011, Colorado's energy generation assets have the capacity to produce approximately 13.8 GW of electrical power. Colorado's energy generation asset are summarized in Figure 1.4 and 1.5.



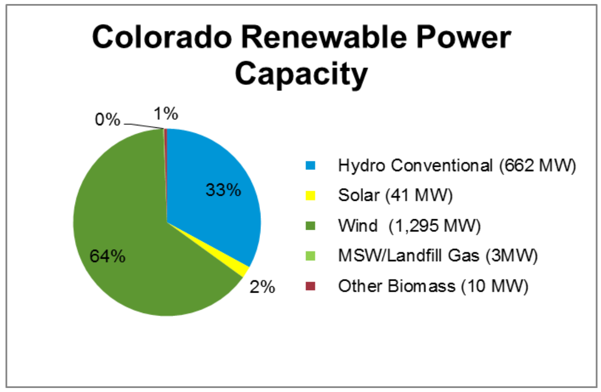
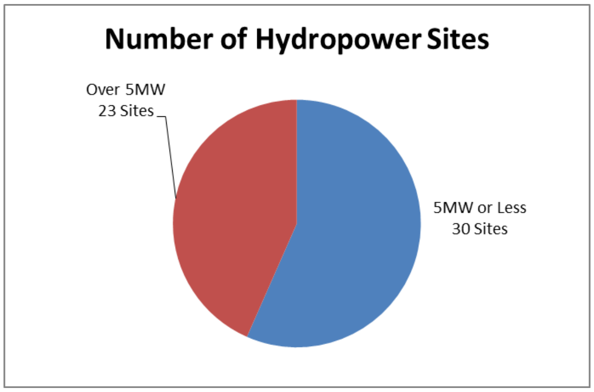


Figure 1.4 Colorado power generation assets

Renewable energy assets make up 15% of Colorado's electrical generation capacity and are capable of providing 2 GW of electrical power. This contribution is mandated to increase to 30% by the year 2030. Of the renewable energy assets, hydropower is the second largest renewable generator next to wind resources. Hydropower produces approximately 33% of renewable energy in Colorado, an equivalent capacity of 682 MW.

There are 53 hydropower sites in Colorado. More than half of these sites, 30, produce 5 MW or less each. The combined power contribution of sites with capacities less than or equal to 5 MW is 64.6 MW, an equivalent contribution of 9.8% of the hydropower pool. The scope of the present study is to try and identify methods for identifying additional sites in irrigation canals that meet this power category.

The majority of the hydropower comes from the 23 sites that produce more than 5 MW each. These 23 sites produce an equivalent of 597.2 MW, 90.2% of the hydropower contribution.



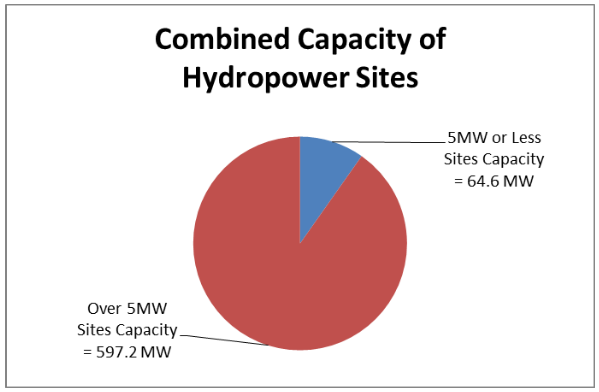


Figure 1.5 Hydropower sites summary

The energy contribution of the existing 5 MW or less hydropower sites to the overall Colorado energy generation capacity is 0.47%.

As shown above, there are 30 hydropower sites that produce 5MW or less. The combined power contribution of these sites is 64.6 MW. On average, this calculates out to 2.15 MW per site. Keeping the total power generation constant at 13.8 GW, additional power by renewable resources required to raise their contribution by 1% is 208 MW. If this was to be met with hydropower sites in the 5MW or less category, it would take approximately 97 additional sites.

1.3 Scope

This study will identify the current status of micro hydropower potential assessment as it has been pursued to date. A detailed assessment of the studies which address this question, their methodologies and conclusions, is represented in Chapter 2, Background. An analysis of shortfalls associated with micro hydropower assessment in constructed waterways is provided. Also included in Chapter 2 is a review of hydraulic theory and existing technical resources; specifically how they apply to the current study. Chapter 3, Technical Approach, will outline the systematic method of converging on a solution to this problem. Theory is explained in detail and methodologies to data collection and analysis are reviewed. Chapter 4, Results, will provide the results of the analysis conducted and Chapter 5 will contain the conclusion and future work recommendations. Included in the appendix is detailed field data for each site, specific workflow analysis which includes intermittent steps for data processing between Excel and ArcGIS, and additional supporting documentation.

Chapter 2- Background

Micro hydropower potential in constructed waterways has not been extensively researched. The scope of this Chapter is to review the background information of this subject. Prior to introducing the previous assessment work, it is necessary to review the mathematical fundamentals involved in hydropower calculations, hydropower equipment, and hydraulic structure theory. Previous assessments and their conclusion will then be reviewed in detail prior to a review of existing technical resources available to conduct this study. The goal is to address what has been done to assess micro hydropower potential in constructed waterways and where improvements are necessary.

2.1 Fundamentals of Hydropower

Water power is the rate at which the work done by water is performed and is expressed in units of energy per time (Watts). Water power is directly proportional to the amount of flow doing the work (flowrate) and the pressure associated with that flow (head).

2.1.1 Derivation of the Power Equation

Bernoulli Equation

The conservation of energy, applied to closed conduit flow, can be expressed by the Bernoulli equation.

$$\frac{P_1}{\gamma} + \frac{\alpha V_1^2}{2g} + z_1 = \frac{P_2}{\gamma} + \frac{\alpha V_2^2}{2g} + z_2 + h_l + H_T \qquad \text{Eq.2.1}$$

Where:
P = pressure at location
γ = density of water at specific temperature
V = velocity of water at location
g = gravity
z = elevation of water surface at specific location
α = cross sectional velocity correction coefficient. This value is typically 1 for engineered cross sections
h_L = head loss through the system in terms of friction and bends, valves
H_T = Net Head Available for Turbine

For our applications, the following assumptions are valid. If we assume the initial and final pressure in the system are atmospheric (zero gage) and the initial and final velocity heads are negligible (valid assumption for micro applications), eq. 2.1 can be rearranged to give

$$H_T = (\Delta z) - h_l \qquad \text{Eq.2.2}$$

The net head takes into account all energy losses from the upstream and downstream sections as defined by the Darcy-Weisbach equation.

$$h_l = f\frac{L}{D}\frac{V^2}{2g} \qquad \text{Eq.2.3}$$

$$f = f(RE, \frac{e}{D}) \qquad \text{Eq.2.4}$$

Where:
f = function of Reynolds Number (RE) and penstock roughness (e/D)
L = Length of penstock
D = Diameter of penstock
V = Velocity of water in penstock
g = gravitational constant

This is the correct way to calculate the net head available to the turbine.

Power Equation

To calculate the power output of the turbine, the following equation 2.5 is used (Warnick, C.C., et al. 1984)

$$P = pgH_TQ \qquad \text{Eq.2.5}$$

Where:
P = Power production from the system
p = density of water
H_T = Net Available Head from Eq. 2.2
g = gravitational acceleration
Q = Flowrate through the system

It can be shown that with power in units of kilowatts and head and flowrate in units of feet and cubic feet per second, equation 2.5 can be rearranged as

$$P = \frac{HQ}{11.8} xe \qquad \text{Eq. 2.6}$$

Where:
P = Power (kW)
H = net Head (ft)
Q = flowrate ft3/s
E = efficiency of machinery
11.8 = constant to incorporate density, gravity, and unit conversions

2.1.2 Hydraulic Jumps

Many of the existing hydraulic structures that have the potential for hydropower upgrades use hydraulic jumps to dissipate energy. Excess energy in open channel flow can be in the form of large kinetic (fast moving water) or potential (large drops over short distances) energy. Engineers design hydraulic structures to effectively dissipate this energy as to not compromise the structural integrity of the infrastructure and for the safe operation of the overall system. Although momentum is conserved through a hydraulic jump, it can be shown that up to 70% of energy is dissipated through the highly turbulent phenomenon of the jump itself (Chaudhry, M.H. 2008). Upgrades to these structures can be made to capture the energy as opposed to dissipating it. Micro hydropower benefits from existing infrastructure already being in place. The result will have the same intended effect of protecting the open channel conveyance system from high kinetic and potential energies while using this energy for electrical power applications. This translates to economic benefits to the owner of the system and to the surrounding community.

2.2 Introduction to Hydraulic Structures

One of the main applications of engineering in general is to design systems which aid in controlling nature to meet the needs of humanity. Hydraulic structures are a physical means of controlling a hydraulic system to meet predetermined needs. There are many different types of hydraulic structures found in irrigation systems (Novak, P., et al. 2007). These structures can be placed in 5 operational categories and can be seen in Table 2.1. The definitions for the terminology in Table 2.1 are located below.

- **Conveyance**: The purpose of a conveyance structure is to move water from one location to another. Common types of conveyance structures include open channels, tunnel and closed conduits, siphons, aqueducts and culverts.
- **Regulatory and Diversion**: The purpose of regulatory and diversion structures are to control water levels upstream of the structure for purposes of navigation, storage, hydroelectric power generation, diversions into turnout canals, control of flowrate over time. Common types of regulatory and diversion structures include sluice gates and weirs.
- **Flow Measurement:** Flow measurement structures are designed to measure the flowrate of a hydraulic system. These typically include Parshall flumes (developed here at CSU), cutthroat flumes, and trapezoidal flumes.
- **Dam Outlet Works:** Dam outlet works regulate and control the release from a dam. Guidelines for these releases can come from instream flow requirements, hydroelectric power generation requirements, navigation, recreation, and consumptive use requirements. An engineered outlet structure unique to the dam can be found controlling the flow.
- **Drop Structures:** Drop structures are a type of conveyance structure designed to convey water through areas with big elevation changes or dissipate energy with sections of high velocity head. Types of engineered structures can include spillways, chutes with stilling basins, vertical drops with stilling pools, and drop structures designed to induce hydraulic jumps. The most commonly found drop structures in irrigation canals include chutes and vertical drops. Images for each of the structures of interest can be found in Chapter 3.

Table 2.1 Hydraulic structure categories

Operational Category	Type	Purpose
Conveyance	Open Channel	Move water from one location to another
	Tunnel/Conduit	
	Siphon	
	Aqueduct	
	Drop Structure	
	Culvert	
Regulatory and Diversion	Sluice Gates	Control water level upstream side of structure. Navigation, Storage, Hydro
	Weirs	
Flow Measurement	Parshall Flume	Measure Flow
	Cuttthroat Flume	
	Trapezoidal Flume	
Dam Outlet Works	Outlet Structure	Regulate and control release from dam
Energy Dissipation	drop	Dissipate energy associated with big el change, or velocity head
	kinetic structure	

There are many subcategories to each of these systems. The detailed hydraulics of each subcategory defines the applicability and appropriate use of each type of structure. It is necessary to describe in further detail the subcategories of regulatory and diversion structures.

2.2.1 Sluice Gates

The flowrate through a sluice gate is classified as orifice flow. This is critical as the flow through a sluice gate is a function of the square root of the height over the orifice. A graphical interpretation of the flowrate as a function of the height can be seen in Figure 2.1.

$$Q = f\left(H^{\frac{1}{2}}\right) \qquad \text{Eq. 2.7}$$

Where:
Q is flowrarte
H is height above orifice

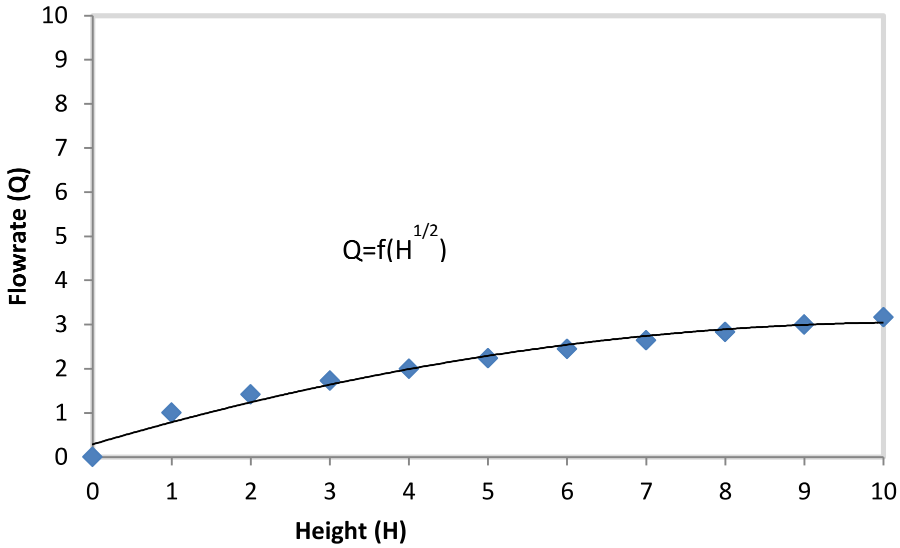


Figure 2.1 Flowrate vs height for sluice gates can be represented by a function to the ½ power

In application, sluice gates are typically applied to deliver flow from one canal to another. As graphically depicted, if the flow in a main canal significantly drops, this will not alter the flow to the turnout canal. Likewise, if there is a surge in flow in the main canal, flow in a turnout canal will not be significantly influenced.

The main types of sluice gates utilized include vertical sluice gates and radial sluice gates. These categories can be seen in Table 2.2. Any upgrades to these structures to include micro hydropower systems will need to take into consideration how the upgrades will affect the hydraulic system as a whole. The majority of micro hydropower systems operate as orifice flow devices.

Table 2.2 Sluice gates

Sluice Gates	
Flow varies $Q=f(H^{1/2})$	
Type	
Vertical Sluice Gates	
Radial Sluice Gates	
Barrage	multiple sluice gate structure, can be a combination of weirs and gates

2.2.2 Weir

The flowrate over a weir is classified as weir flow. Flow over a weir is a function of the height over the weir to the 3/2 power. A graphical interpretation of the flowrate as a function of the height can be seen in Figure 2.2.

$$Q = f\left(H^{\frac{3}{2}}\right) \qquad \text{Eq. 2.8}$$

Where:
Q is flowrarte
H is height above orifice

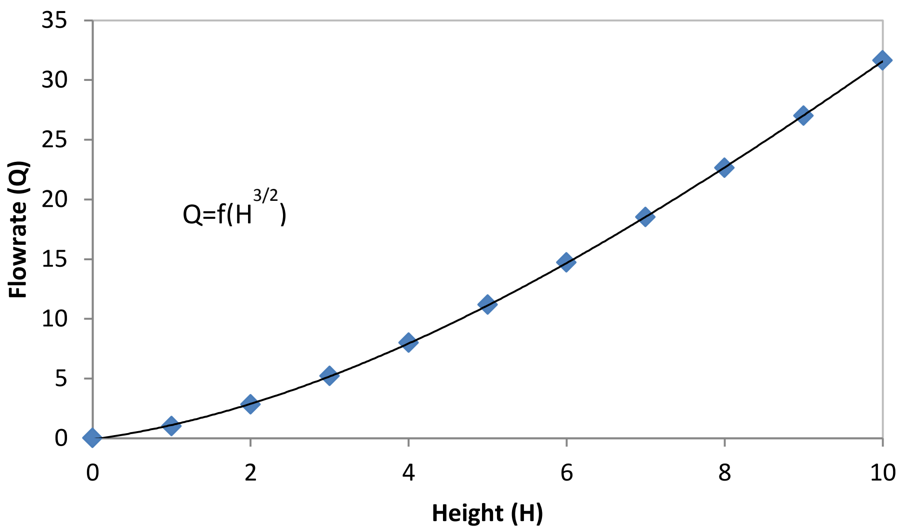


Figure 2.2 Flowrate vs height for weirs can be represented by a function to the 3/2 power

Weirs are regulatory structures used to raise the upstream water surface elevation to permit flow diversion through upstream turnouts. However, when the upstream water elevation surpasses the elevation of the weir, the weir will pass significant flow as to not impede the operations upstream. If a sluice was introduced instead of a weir, there would be a dam effect requiring significant head to pass flow through a sluice. This is why weirs can be seen as spillways and regulatory control structures. Some weirs can be used to measure the flowrate within a canal.

There are many types of weirs, each with a unique relationship between the upstream water surface and the downstream water surface established as a function of the channel geometry and flowrate through the canal. In the fixed position category, weirs include sharp crested, short crested, broad crested, and rock structures. In the adjustable category, weirs include overshot weirs and Obermeyer weirs.

There have been studies to investigate the use of waterwheels as hydroelectric generators in place of weir applications, most recently (Senior, J, et.al. 2010). This particular study investigated the use of an undershot waterwheel application in place of a weir. However, an undershot waterwheel application will most likely represent an orifice flow relationship as opposed to weir flow. Therefore, it is stressed in this work that it is absolutely necessary to take into consideration how the upgrades will affect the hydraulic system as a whole. Weir flow and orifice flow represent very different hydraulic characteristics and applications.

Table 2.3 Weirs

Weir (Flowrate varies by $Q=f(H^{3/2})$		
Type	Sub-Category	Definition
Fixed		Elevation of crest is permanent. These structures can span the entire canal or be contracted
	Sharp Crested Weir	
	Short Crested Weir	
	Broad Crested Weir	
	Rock Structure	
	Barrage	
Adjustable		Elevation of crest is adjustable. These structures can span the entire canal or be contracted
	Overshot Weir	
	Obermeyer	

Figure 2.3 Includes weir, radial sluice gate, and vertical sluice gate

2.3 Hydraulic Equipment

Decisions made on hydropower projects are often dictated by the type of turbine to be used in the energy recovery process. Turbines can be classified by the range of head and flowrates driving them. Figure 2.4 is an image reflecting the operating window for different turbine types used in the industry. Each turbine type has a specific range of head and flowrates in which they are optimized for efficiency. The two main classifications include reaction turbines and impulse turbines.

2.3.1 Reaction turbines

Reaction turbines include a class of turbine technology that are immersed in the flow path. Energy recovery is a function of the pressure drop across the turbine for any given flowrate. Reaction turbines are generally used in low head applications. Different types of reaction turbines include Francis and Kaplan turbines. Francis turbines are analogous to a pump operating backwards where flow enters from the sides through wicket gates that control the amount of flow that come in and leave in a direction perpendicular to the entrance. Energy is captured as the flow passes through the turbine and can be witnessed as a large pressure drop on the downstream end of the flow. Kaplan turbines look like a propeller in the conduit. Much like the Francis turbine, energy from a Kaplan turbine will be witnessed in the form of a large pressure drop.

2.3.2 Impulse Turbines

Impulse turbines include a class of turbine technology that are driven by the impact of water hitting the blades of the turbine. Energy recovery is a function of the change in velocity entering the system and velocity exiting the system. Impulse turbines are generally used in high head applications. Impulse turbines include:

- **Pelton Wheel**: Pelton wheels are impact turbines with a bucket section designed to capture the energy from flow from a nozzle.
- **Turgo:** This turbine works like a Pelton wheel on its side. Multiple fins are uses to route the flow through the turbine.
- **Crossflow:** A crossflow turbine most represents an air compressor for a jet engine. Flow is introduce from the side and flows across the fins, dropping lower in elevation for each unit length it travels across the fin.

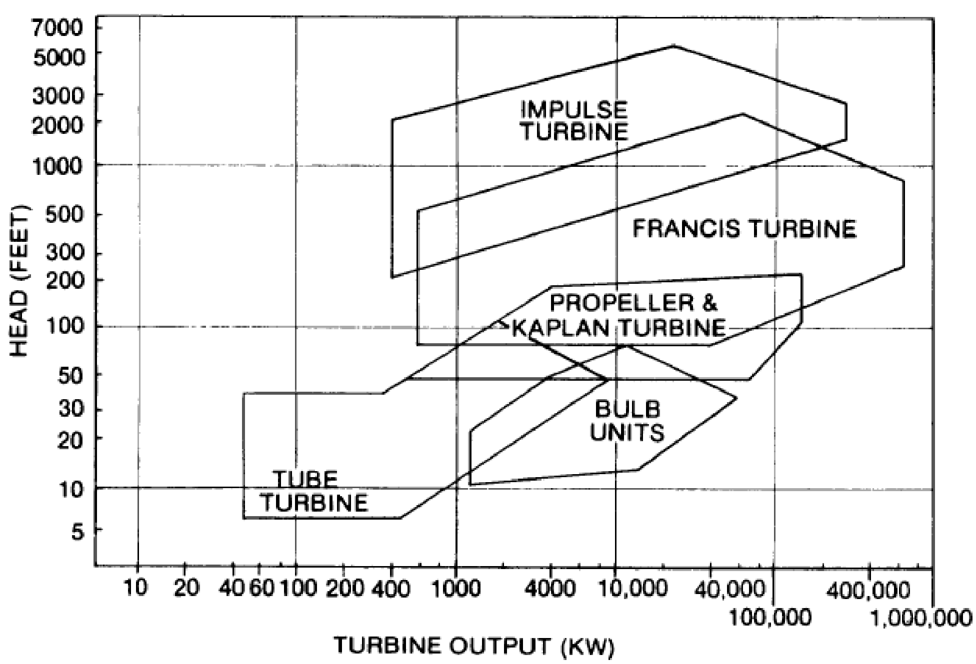


Figure 2.4 Image from The Army Corps of Engineers (USACE), Engineering and Design Hydropower, Manual EM 1110-2-1701, operating points for different turbines

Each turbine is designed to meet a range of head and flow parameters. Failure to accurately size turbines to operation points can decrease efficiency. Assumptions in this study emphasize reaction turbines as they are most applicable to low head applications. It is not likely that the sites observed from the methods presented in this paper will be upgraded with a turbine from the Impulse class. Excluding micro hydropower projects, modern day hydropower projects are dominated by four basic classifications:

- **Storage Projects** are reservoirs and large hydropower dams. Storage projects are also known as "conventional" hydropower projects. Reservoirs are constructed for many reasons, hydropower being one of them, and when water is released from the reservoir, it is routed through the turbines to create hydropower.
- **Pumped Storage Projects** are a type of storage project with one large difference: water is pumped uphill to the storage facility and then released to flow back down when needed. Pumped storage projects are analogous to a large battery for the power grid. Although counter intuitive, these plants make sense by essentially storing energy produced during off-peak electrical times and resubmitting this energy back to the grid when needed; thus pumped storage projects eliminate start stop patterns for large generating equipment.
- **Run-of-River Projects** are hydropower plants that are constructed along a river's alignment. It is operated much like a storage project where a head is created and water is passed through turbines below. Run-of-river projects do not have storage capacity and the seasonal flowrates of the river can create challenging management practices.
- **Hydrokinetic Projects** use the velocity head of moving water to extract energy. These units are similar to the operation of wind turbines. Hydrokinetic units are submerged in an existing river, canal, or even the ocean and water velocity flowing over the blades of a turbine creates the energy.

Of these four projects, micro hydropower is not listed. Micro hydropower projects in irrigation canals are classified by two of the above projects; run-of –river projects and hydrokinetic projects. Exact definitions of micro hydropower varies however (Hall, D. G, et al. 2004) defines low head as less than 30 feet and low power as less than 1 MW. Upgrades to existing structures will not provide additional storage, resembling run-of-river projects. Hydrokinetic projects in irrigation canals are still largely experimental. A comprehensive review of existing technologies to upgrade irrigation infrastructure can be found in (Applegate Group 2011).

2.4 Previous Work

2.4.1 Estimation of Hydropower Resources

Efforts to identify hydropower resources of the United States have mostly been led by the United States Department of Energy, with additional contributions from the United States Bureau of Reclamation and the Colorado Department of Agriculture. With the increasing capability of technology, studies have been conducted using methodologies not previously accessible for a macro level of analysis (primarily GIS technology). The following studies have been conducted to estimate the extent of hydropower in the United States. Table 2.4 includes a summary of the methodologies used in each study to emphasize the need for more accurate assessments. A discussion of the methods in each study is also included.

Table 2.4 Summary of resource assessment efforts

Report	Date*	US Estimated Capacity (MW)	CO Estimated Capacity (MW)	Brief Summary
U.S Hydropower Resource Assessment, Department of Energy	1989	69,897	2,346	Only review existing known sites. Applied a suitability factor to address potential for being developed. Did not focus on sites under 1 MW.
Water Energy Resources of the United States with Emphasis on Low Head/Low Power Resources, Idaho National Lab funded through Department of Energy	2004	165,551	4,892	Used GIS technology to estimate total power potential. Only focused on natural water courses (excluded constructed waterways). Identified sites > 1 MW and sites < 1 MW. Analysis methods included using total stream elevation change as head in power equation and average annual runoff within basin.
Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants, Idaho National Lab funded through Department of Energy	2006	127,758	5,061	Conducted feasibility analysis on 2004 study. Analysis methods included using GIS to identify the maximum length to head ratio within a stream reach by including the average length of existing penstock in the area and only using 1/2 of stream flowrate in this penstock.
Exploring the Viability of Low Head Hydro in Colorado's Existing Irrigation Infrastructure, Applegate Group and Colorado State University funded through Colorado Department of Agriculture	2011	N/A	N/A	Focused on identifying the power potential within Colorado's irrigatin infrastructure. Lack of participation of regional authorities led to recommending field research.
Site Inventory and Hydropower Energy Assessment of Reclamation Owned Conduits, United States Bureau of Reclamation	2012	104*	27	This is the only report that has been partial successful in identifying power potential in constructed water ways. Methods included corresponding with regional authorities. It is noted that there were missed sites and this study is not a representative sample of all power available in Reclamation constructed waterways

*Until relatively recent, it was assumed power under 1 MW was not worth investigating
*Only an estimate of 17 western state the USBR operates in
*It is emphasized that methods and research area differs for each study. Therefore, the value of comparing the estimated capacities is not significant

2.4.2 U.S Hydropower Resource Assessment (DOE, 1998)

The United States Department of Energy's (DOE) National Energy Strategy was initiated in 1989 to identify the energy resources in the United States. Prior research had not been conducted to estimated undeveloped hydropower capacity based on site characteristics, stream flow data, and available hydraulic heads. It was recognized that undeveloped hydropower resources were not well defined. This study was prior to the widespread use of GIS resources to conduct analysis of this type. The effort compiled its dataset of potential sites with conventional undeveloped hydropower potential from known sites listed by the Federal Energy Regulatory Commission (FERC), the National Park Service, and state resource/energy agencies. The authors point out the potential for missed sites using this method, "not every site in the United States with undeveloped hydropower potential was included... only sites that have been either previously identified by third parties and included in the FERC database, or sites that local state agencies are aware of, are included." The analysis tabulated 3 possibilities for hydropower upgrades to these sites which included; efficiency upgrades to facilities which already produced hydropower, upgrades to existing facilities (dams or some type of existing impoundment structure), or undeveloped sites (sites with potential but no existing structure). The analysis included incorporating environmental, legal, and institutional constraints. However, upon issuance of the preliminary assessment, it was noted the data set included "redundancies and errors that reduced confidence in the published estimates of developable hydropower capacity". This led to the development of the Hydropower Evaluation Software (HES).

The HES provided a complicated method of analyzing the extent to which each site would be developed. Data pertaining to potential hydropower sites as well as environmental, institutional, and legal attributes was entered into the HES. The HES was designed to evaluate each potential site based on uniform criteria of how well each site met a predefined list of suitability factors. These suitability factors included: Wild/Scenic Protection, Wild and Scenic Tributary, Cultural and Historic Values, Fish Presence Value, Geologic Value, Recreation Value, Scenic Value, Wildlife Value, Other Value, Threatened and Endangered Fish or Wildlife, National Park/Monument/Lakeshore/Parkway, National Forest or

Grassland, National Wildlife Refuge/Game Preserve/Fish Hatchery, National Scenic Waterway/Wilderness Area, Indian Reservation, Military Reservation, Not Federal Land. The overall suitability factor was applied to the estimated capacity of a potential hydropower development to yield an adjusted capacity. The results reported in the final report include the number of sites analyzed, the unadjusted capacity, and the capacity for the 3 possibilities for hydropower upgrades. The Hydropower Resource Assessment results for the United States and Colorado are summarized in Table 2.5.

Table 2.5 Results from Connor, A.M., J.E. Frankfort, and B.N. Rinehart, 1998, U.S. Hydropower Resource Assessment Final Report, DOE/ID-10430.2

	Category	Number of Projects	Unajusted Capacity (MW)	Adjusted Capacity (MW)
United States	With Power	389	7,820	4,316
	Without Power	2,527	29,625	16,998
	Undeveloped	2,761	32,452	8,466
	US Total	5,677	69,897	29,780
Colorado	With Power	5	156	78
	Without Power	91	782	377
	Undeveloped	**155**	**1,408**	**209**
	CO Total	251	2346	664

The finding of the study incorporated an adjusted capacity, which was provided by adjusting the unadjusted capacity column based on suitability factors. However, the suitability factors are an indicator of a site's likelihood of development, not a percentage of potential capacity developed. If a site is developed, the entire capacity will be developed, not just a portion. Due to the inconsistencies in the reporting of the capacity, the FERC MOU in Colorado used the unadjusted capacity to represent the hydropower capacity in Colorado as 1408 MW rather than 209 MW. Additional limitations of this study include (1) that only previously identified hydropower sites by third parties or FERC were included in this study, (2) redundancies and errors were identified during the assessment

2.4.3 Water Energy Resources of the United States with Emphasis on Low Head/Low Power Resources (Idaho National Labs, 2004)

The majority of sites analyzed in previous studies, *DOE 1989*, *DOE 1998*, excluded sites that had power potentials less than 1 MW. It was recognized that an assessment of power producing sites contributing less than 1 MW was needed. Idaho National Lab (INL) developed a method that used digital elevation models (DEM) and Geographic Information Systems (GIS) to estimate the power potential of water energy resources in natural water bodies (excluding tides, wave power and constructed waterways) in the United States. Through cooperation with the United States Geological Survey (USGS), INL used 30m DEM datasets and stream segments derived from the 30m DEM dataset segments for each of the US 20 hydrologic regions. The derived steam segments were validated using the National Hydrography Dataset (NHD). Annual mean flowrates for each segment were used in the calculation of power potential.

Calculation of the power producing potential of each segment was a sum of the power produced by the average annual flowrate through the entire stream segment using the total elevation difference (as obtained from 30m DEM), and the average accumulated flowrate through the entire stream segment using ½ of the total elevation difference.

$$P = \beta \left(Q_i * H + (Q_0 - Q_i) * \frac{H}{2} \right) \qquad \text{Eq. 2.9}$$

Where
P = power in kilowatts
β = constant (1/11.8)
Q_i = flowrate at upstream end of the stream reach in cfs
Q_0 = flowrate at the downstream end of the stream reach in cfs
H = Δ(elevation measured from 30m DEM)

Analyzed sites were sorted into 4 categories for power development. The categories were segregated into High Head/High Power, High Head/Low Power, Low Head/High Power, Low Head/Low Power. High power defines sites that produce greater than 1MW while low power defines sites that produce less than 1MW. Sites were then analyzed by Developed, Excluded, and Available. Developed is a class for power that has already been developed in the region. Excluded is a class for available power in areas that are not developable, special lands etc. The available class is the difference of total power calculated minus the sum of developed and excluded power classes. A summary of the total power results from the INL 2004 study is in Table 2.6.

Table 2.6 Results from Hall, D. G., S. J. Cherry, K. S. Reeves, R. D. Lee, G. R. Carroll, G. L. Sommers, and K. L. Verdin 2004, *Water Energy Resources of the United States with Emphasis on Low Head/Low Power Resources*, DOE/ID-11111, April 2004

	Category	Available (MW)
United States	High Power > 1MW	118,334
	Low Power < 1MW	47,217
	Total (MW)	165,551
Colorado	High Power > 1MW	2,978
	Low Power < 1MW	1,914
	Total (MW)	**4,892**

The INL study provided a more comprehensive assessment of potential sites for micro hydropower than the DOE study. The approach to the data collection method introduces applications of new technologies, those of which are used in the present study. However, it is questionable as to how the power potentials were calculated. The outcomes of (Pelz, P.F 2011) clearly show the maximum theoretical recoverable energy from an open channel is 50% (as opposed to the widely recognized Betz limit of 59.3% for wind turbines). Equation 2.9 assumes the energy associated with the entire stream reach is 100% recoverable, and models the stream reach as closed conduit flow which is an unrealistic assumption. However, it is emphasized throughout the article that an actual feasibility analysis had not been performed although the estimates of available power potential were large enough to justify further research in this area.

2.4.4 Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants, (Idaho National Labs, 2006)

A feasibility analysis was conducted on the sites listed in the INL 2006 study. Criteria for conducting the analysis included site accessibility, load or transmission proximity, and land use or environmental sensitivities. Additionally, the power potential methodology was revisited in the feasibility analysis which makes it of interest for the present study. The power potential methodology employs a model which identifies a hydroelectric plant producing power at an annual average rate of 30 MW or less without the use of a dam or reservoir. Working flowrates were selected as the less of half the annual mean flowrate of the stream reach or the flowrate required for an average annual power of 30MW using hydraulic head. The flowrates at each site were used to determine optimal penstock lengths and penstock lengths were compared with regional average penstock lengths to get an upper limit. A combination of penstock length and DEM data were employed to find the maximized length to head ratio on a stream segment of interest from the previous study. By reevaluating all the sites from the previous study with more definitive selection criteria, a refined analysis of hydropower potential was identified. Table 2.7 is a summary of the refined results.

Table 2.7 Results from Hall, D.G, Reeves, K.S, Brizzee, J.,Lee, R.D.,Carroll, G.R., Sommers, G.L., 2006 Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants, DOE-ID-11263

	Category	Number of Projects	Available (MW)
United States	High Power > 1MW		18,450
	Low Power < 1MW		10,988
	Total (MW)	127,758	29,438
Colorado	High Power > 1MW		245
	Low Power < 1MW		646
	Total (MW)	5,061	**891**

These results more closely match results represented in the U.S Hydropower Resource Assessment study of 1998. The ultimate value of the studies reviewed above show that there are significant power resources available. However, still outstanding is an investigation of power resources available in constructed waterways. Recommendations specifically outline the following next steps:

- An investigation is needed to address spatial distribution of gross power potential of hydrokinetic resources, constructed waterways, tidal estuaries, ocean currents, and ocean waves.
- Additionally, the industry would greatly benefit from the creation of a catalog summarizing small hydropower technologies. This catalog should include a cost estimating guide that would assist in determining preliminary estimates of development costs.

Subsequent studies conducted by the United States Bureau of Reclamation (USBR) and the Colorado Department of Agriculture address these recommendations.

2.4.5 Exploring the Viability of Low Head Hydro in Colorado's Existing Irrigation Infrastructure, 2011, Applegate Group

Due to the lack of assessment of hydropower resource in constructed waterways and the limited knowledge of viability of low head turbines in irrigation systems, a study funded by Colorado Department of Agriculture was conducted by a team of investigators compiled from experts representing Applegate Group and Colorado State University (CSU) which aimed to research low head hydropower technologies, inventory the infrastructure available in Colorado for hydropower generation, investigate interconnection issues, compare the technologies to the hydraulic structures, estimate state wide potential. An emphasis for the goals of this present study is accentuated in the comment "There is limited knowledge of the viability of these low head turbines in typical irrigation structures…there has been no systematic identification of attractive sites within irrigation systems, and no developed process to easily classify and assess sites for development". The report addresses (INL, 2006) recommendations to catalogue existing small hydropower technologies and their associated costs and begins to address estimations of power potential in constructed waterways in Colorado. Various levels of success were achieved for the 5 tasks the team outlined to accomplish. Six types of irrigation structures were available for hydropower upgrades in Colorado's irrigation systems which were not specific just to Colorado, but are a thorough identification of hydraulic control structures universally applied in open channel hydraulics. A comprehensive catalogue of existing low head technologies was developed and a list of these technologies complimentary to the 6 major categories of hydraulic structures was compiled. Additionally, the team was successful in clearly identifying interconnection issues and the associated technology required by utilities to implement low head hydro projects.

The structures were identified through the Colorado Decision Support System (CDSS), public informative sessions at applicable conferences sanctions, and survey questionnaires which asked each authority about infrastructure in their respective irrigation systems. The questionnaires were mailed, emailed and hand delivered. What the team learned was although there existed "high interest in hydropower expressed by many irrigation entities", the return rate of over 250 irrigation entities was about 10%. Reasons for the low return rate speculated the time required to participate in the surveys and level of comfort associated with irrigation districts disclosing this type of information.

The Applegate study was limited by cooperation of the irrigation authorities and a low response rate. The reasons for the low response rate were speculated to be time required to participate in the surveys and level of comfort associated with irrigation districts disclosing this type of information.

As denoted from the team's experience and noted in the following sections, one of the largest hurdles to overcome to estimate a power potential in constructed waterways is collecting information about existing infrastructure in these constructed waterways. To date, there does not exist a resource like the National Inventory of Dams for hydraulic structures other than dams. Regional authorities, be it for reasons of time restriction or others, have not cooperated to the extent required to accomplish the scope of this type of study.

2.4.6 Hydropower Resource Assessment at Existing Reclamation Facilities, 2011, Site Inventory and Hydropower Energy Assessment of Reclamation Owned Conduits, 2012, United States Bureau of Reclamation

The USBR embarked on a two part effort to address undeveloped available hydropower resources in reclamation owned facilities. The USBR owns and operates an extensive network of infrastructure which includes dams, canal, and associated hydraulic structures throughout 17 states in western United States. As part of this effort, the USBR addressed the recommendations of (INL 2006) through the development of an Excel based tool to identify preliminary cost estimates of a potential site and analyze corresponding cost benefit ratios and the analysis of its own constructed waterways. The first study (USBR,2011) focused on the development of USBR dams that did not currently operate with hydropower facilities. The second study (USBR2012) focused on upgradeable hydraulic structures in irrigation canals.

Data for these two studies was acquired by examining "project drawings, aerial imagery, utilized expertise from local area officials, and in some cases physically visited the canals". Canal sites were analyzed if elevations were greater than or equal to 5 feet and flows were a minimum of 4 months in duration. The specialized tool created in Excel was employed to evaluate power potentials of all sites. Although the results from this study are not comparable to the previous studies because they are only focused on USBR sites, it is interesting to note the magnitudes of power potential reported from the constructed waterway assessment. Table 2.8 summarizes the power potential identified for Colorado and the western 17 states of the USBR territory combined.

Table 2.8 U.S. Bureau of Reclamation. 2012. *Site Inventory and Hydropower Energy Assessment of Reclamation Owned Conduits*. Denver, CO. March 2011

	Number of Projects	Available (MW)
17 Western States	373	104
Colorado	28	27

However, as it was acknowledged that additional sites may exist, detailed analysis of data provided by USBR show that the sites missed in the analysis are not necessarily obscure and hard to reach sites. In many instances, series of drop structures continued along a canal alignment but the data submitted only included a few select sites in the sample. Additionally, many samples from my data collection expedition last summer were on portions of USBR canals. There are many instances where sites that I visited were not included in the Canal USBR samples.

Micro Hydropower Assessment

From the discussions above, it is clear that although the interest in identifying the power potential of micro hydropower exists, it is not clear the best method of conducting an assessment. The dilemma is emphasized even more so by inaccurate identification of structures by the USBR, an institution which should be able to identify and catalogue these sites within its own jurisdiction.

Furthermore, the studies listed above do not delineate how these facilities would be permitted. One of the major restrictions facing micro hydropower development is the “complex regulatory process”. Identifying specific sites that fit within the conduit and 5MW FERC exemptions is necessary to identify the true feasibility of adding these sites to the active hydropower fleet as this is the critical path for implementation.

The identification of hydraulic flow conditions of these sites warrants specialize analysis. Both studies put forth by INL use a hydrologic analysis of annual runoff conditions to calculate power potential values. However, both INL studies focused specifically on natural watercourses. Hydraulic flow conditions in constructed waterways are not necessarily a direct relationship with atmospheric conditions. Reservoir management, precipitation, and runoff are some aspects that effect how much water is released into irrigation canals for use and documented as historical release rates. Therefore, a historic analysis of irrigation water use patterns will identify flow exceedance at any structure in question. The ability to collect this information for any specific structure will be a challenge as flow stations are not located on every canal and cooperation with irrigation authorities has already been challenging.

2.4.7 GIS As a Topographical Analysis Tool

Applications of GIS technology to support decisions and aid in analysis of geospatial data is common. Applications can be seen in such industries as water resources, urban planning, transportation, and energy. (INL 2004, 2006) specifically uses GIS for drainage quantity analysis to determine available annual runoff to develop hydropower.

GIS as a topographical analysis tool employs digital elevation models (DEM) to identify changes in elevation. The quality of the DEM is dependent on the data used to create the surface. Data can be gathered from such sources as existing topographic maps or in depth Light Intensity Distance and Ranging (LIDAR) surveys. Vertical accuracy for DEMs can range from as large as 20 meters (SRTM data) to as small as 15 centimeters (LIDAR data).

Publically available DEM data has been useful to conduct cost effective, rapid assessments of physical geological features. (Lunetta et al., 1997) employs 30 meter DEM data to identify channel reach slope as an indicator of potential salmon habitats. It is pointed out that although channel slopes can be easily determined from DEM, the methods are only applicable to low gradient slopes, (less than 4 percent slopes) and samples should be taken at a minimum of 100 meters. The limiting factor is identified as the quality of the DEM used. (Peckham, 2009) looked at correction algorithms to be applied to DEMs in order to obtain a more reasonable slope value for natural channels as applied in Manning's formula. It was found that although more accurate slope values could be acquired from the methodology, the corrected elevations were often significantly off.

A great deal of emphasis is placed on the need for more readily available LIDAR datasets. The high resolution LIDAR provides the quality detail to "integrate hydrography with elevation, land cover, structures, and other geospatial features", (Poppenga et al., 2010). Poppenga et al. goes on to describe the detail obtained from LIDAR data is intrusive for bare earth drainage studies and the data needs to be buffered to remove features like bridges and roads. This can be interpreted as LIDAR successfully models the terrain of interest.

However, in the transportation sector, (Rasdorf et al., 2004) compares field data measurements of roadway lengths to measurements from 30 meter NED datasets. The study was conducted to determine if 3 dimensional roadway lengths as obtained from GIS datasets are on the level of accuracy to be acceptable for Department of Transportation (DOT) applications. Planimetric line data for roadway lengths (2 dimensional) were converted to 3 dimensional polylines using the NED as an elevation model. The study found measuring roadway lengths using GIS methods are of a degree of accuracy acceptable for DOT standards. (Cal et al., 2009) progresses the topic by comparing the 3 dimensional roadway lengths obtained from NED datasets to ones obtained by LIDAR datasets. It was found that LIDAR datasets are 28 percent more accurate than the NED dataset, however, NED datasets are still sufficient for the application.

Specific raster analyses of LIDAR datasets have been conducted to identify terrain features which pose a threat to the mobility and operation of military ground forces (Blundell et al., 2004). The authors used visual analysis of LIDAR DEM data to classify, identify and locate obstacles which had a vertical elevation change of 10 meters or less and a minimum slope of 45 degrees (100 percent) and with potential to impede terrain mobility. Cross sections of obstacles were then examined to identify the LIDAR slope breakline relationship of such hazards. An algorithm designed to identify the slope breakline relationships is introduced and future work to develop the algorithm is described. (Blundell et al.,2010) introduces the developed algorithm and its applications. The automated algorithm identifies characteristics of micro-terrain features and can be used to guide a critical path for combat troops and equipment. The methods are based on the ability to obtain LIDAR data for a given site of interest.

Unique Characteristics of Irrigation Canals

Typically, hydraulic design of irrigation systems encourages very low thalweg slopes when possible. Very flat thalweg slopes are used to maintain hydraulic control in canals by maintaining a subcritical flow regime. Additionally, the very low velocities associated with a subcritical flow regime prevent high shear stress on the canal lining. It is inevitable that the use of very low thalweg slopes will eventually require a steep slope transition when the surrounding area of greater slopes exist. The transitioning of steep terrain changes the flow regime from subcritical to supercritical. These steep slope transitions can be made with a hydraulic structure, an engineered structure designed to enable flow to transition a steep area and return to a subcritical flow regime by inducing a hydraulic jump to dissipate energy in the flow. The hydraulic structures of interest in this study, structures capable of being upgraded to micro hydropower generators, represent an abrupt vertical elevation change from the upstream to downstream thalweg of the structure when viewed in profile view. This abrupt elevation change is what makes hydraulic structures in irrigation canals a unique topographic physical feature. Although it is desired to use the highest resolution elevation models for any topographic study, the cost of obtaining LIDAR data is a limiting factor, (Stoker et al., 2008). For applications of identifying hydraulic structures in canals, NED data is sufficient for converting planimetric 2 dimensional lines to 3 dimensional polyline as shown in (Rasdorf et al., 2004). Moreover, a raster based analysis would not be beneficial in this application. Data sources exist through the National Hydrography Dataset (NHD) which outline canal alignments. This enables a vector based approach similar to (Rasdorf et al.,2004), where direction and magnitude of locations within the DEM are predetermined.

2.5 Existing Technical Resources

The data analyzed in this study utilized existing technical resources, specifically the National Hydrography Dataset and the National Elevation Dataset. These databases were utilized in obtaining canal alignment and profile data.

2.5.1 National Hydrography Dataset

The National Hydrography Dataset (NHD) is a water resource data base produced by the USGS for distribution and use in the public domain. Information included in the database consists of georeferenced 2D line work relating to water resources of the United States. Additionally, there exists data for corresponding flow direction, water volume and flowrate, and water quality among other things. The data is designed to be used in analysis with GIS systems and can be projected to multiple coordinate systems. Although the data provided by the NHD has the capability to produce complex hydrographic models, for this study only the 2D flowlines representative of canal alignments of interest were utilized. The NHD high resolution dataset was created from United States Geological Survey (USGS) digital line graph files. The accuracy of the NHD follows "USGS Map Accuracy standards for 1:24,000 scale require ninety percent of well-defined features to lie within 40 feet of their true geographic position" (NHD website).

2.5.2 National Elevation Dataset

The National Elevation Dataset (NED) is a raster based data set of bare ground elevation produced by the USGS for distribution and use in the public domain. NED data was required in this study to produce the 3D profile from the 2D alignment data obtained from the NHD. The elevation data is provided from "best available" elevation data for a given location. Resources used include the most up to date information available from the USGS using digital elevation models to Lidar surveys. The NED dataset includes an average elevation value over a given surface area. The resolution of the dataset determines the size of the surface area. Higher resolution corresponds to smaller surface area. A smaller surface area corresponds to a more accurate representation of the elevation of the surface area. NED data resolution is provided in 1 arc-second (30m) and 1/3 arc-second (10m) resolution for the majority of the U.S. 1/9 arc-second (3m) is provided for limited areas. For this study, 1 arc-second and 1/3 arc-second data was utilized.

Vertical Accuracy

(Gesch,D.B., 2007) explains the methods behind calculating the vertical accuracy of the NED. As described above, the NED is created by compiling the best available USGS data for a given area. As a result, the NED inherits the accuracy of the data used to create it. In some cases, many data sources may be used to create the NED data. Therefore, the USGS conducted a study to determine the vertical accuracy of the NED.

Vertical accuracy for NED data was established by computing the difference between NED elevations of known data points corresponding to true elevations of 13,305 known benchmarks across the United States shown in Figure 2.5. The vertical accuracy can be given as two separate categories: absolute vertical accuracy and relative vertical accuracy. Absolute vertical accuracy is a measure of how closely an elevation of an NED data point matches the true elevation of that data point. The absolute vertical accuracy is given by a representative root mean-square error (RMSE) for the dataset. The relative vertical accuracy is a measure of how closely the difference in elevation between two data points represents the true change in elevation. It is calculated using the following equation:

$$RV = \left|\Delta_{ref} - \Delta_{NED}\right| \qquad \text{Eq. 2.10}$$

Where:
Δ_{ref} = absolute value of reference elevation difference
Δ_{NED} = absolute value of NED elevation difference

The relative vertical accuracy is given as an average value of the entire sample. The relative vertical accuracy represents the measurement of interest used in this study. The results concluded and estimated RMSE of 2.44 meters for absolute vertical accuracy and an average 1.64 meter error in the relative vertical accuracy.

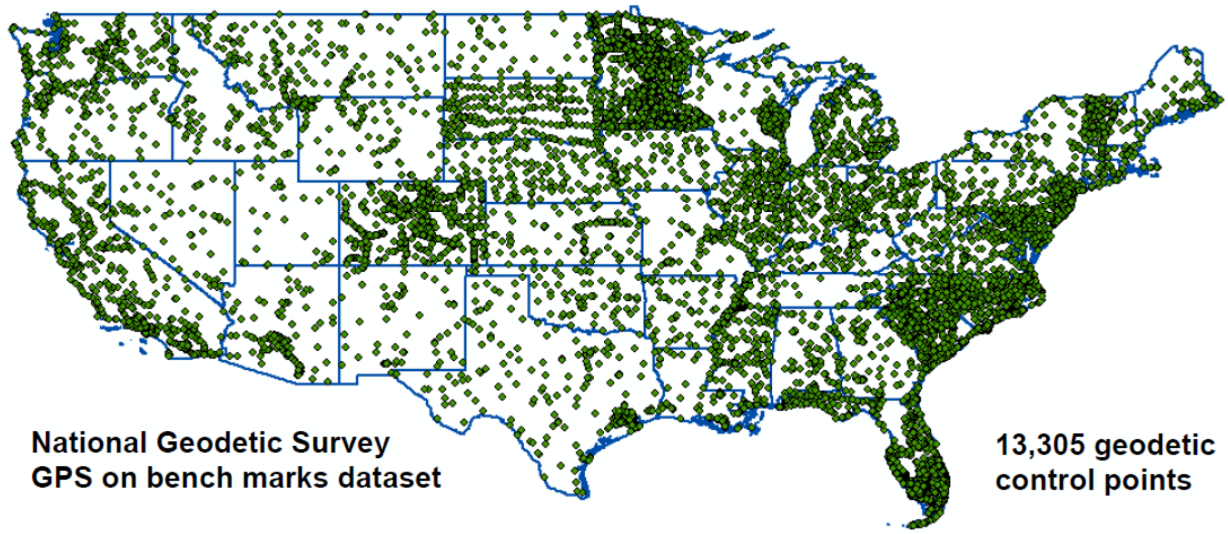


Figure 2.5 USGS control points

Comparison of NED and SRTM

Other readily available digital elevation data includes data produced from the Shuttle Radar Topography Mission (SRTM). Using radar interferometry, the SRTM mission produced topographic data for 80% of the world. One main and important difference between the SRTM datasets and NED dataset is the inclusion of canopy elevations in SRTM. Canopy elevations include elevations from treetops, buildings, and other obstructions to the true ground surface.

Prior to the elevation model selection used in this study, SRTM and NED data were compared to see if there were outstanding differences. Please see Figure 2.6. It can be seen that canopy elevations as a result of the Engineering Research Center (ERC at CSU) greatly skew the profile data for the Dixon Canal located near the ERC. It was this exact scenario which led to selecting NED data for surface model information.

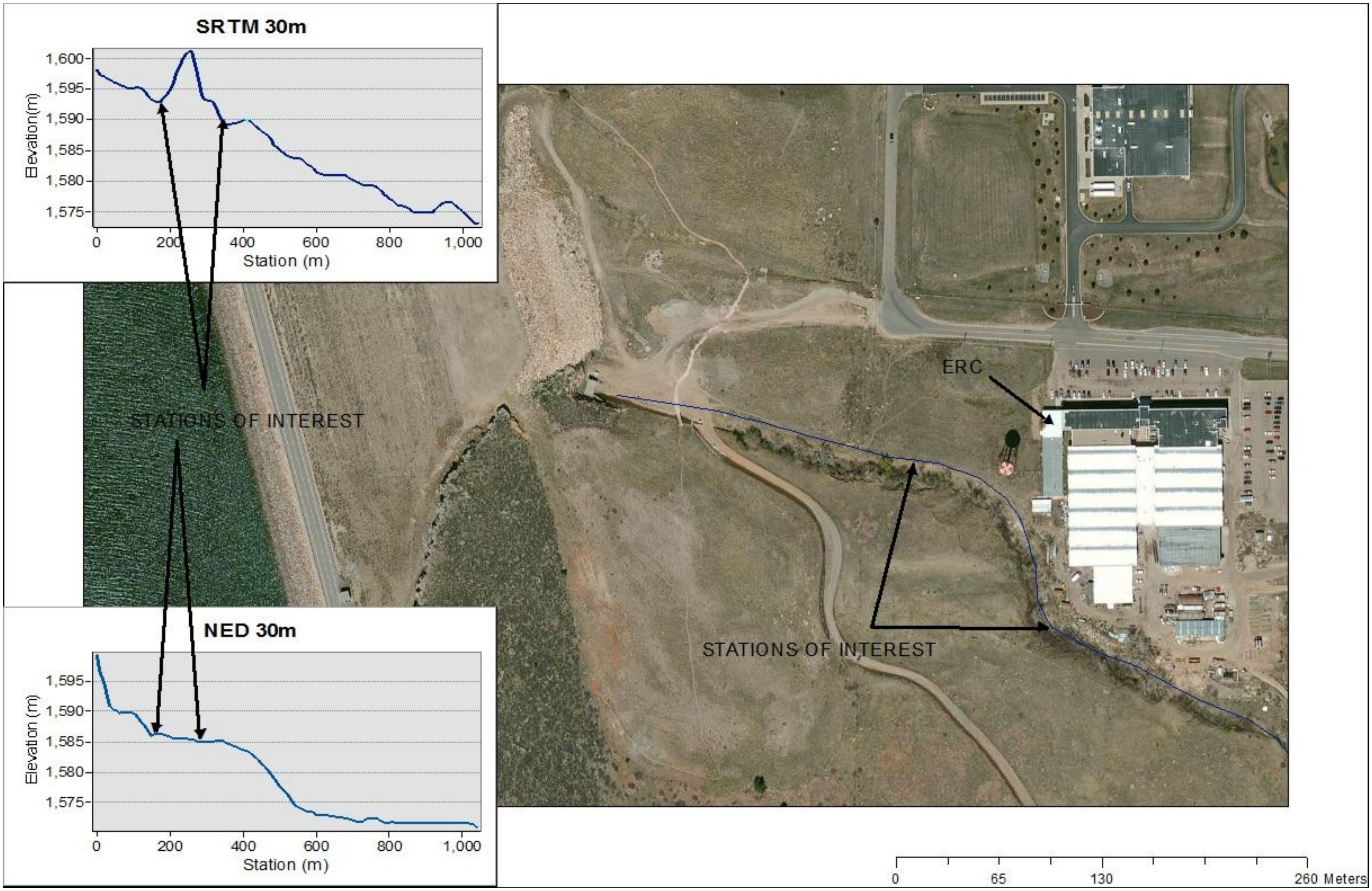


Figure 2.6 Comparison of NHD and SRTM Data

Chapter 3- Technical Approach

The identification of upgradeable sites will be conducted in a geographic information systems (GIS) environment using criteria defined in this study. The technical approach to conduct this investigation consists of organizing and executing a field data collection operation which includes accessing canals containing a variety of hydraulic structures and recording physical site measurement. GIS data is obtained and processed in a unique method specific to the analysis methodology. A significant amount of preparation and data processing of the field data is necessary to compare spatial and topographic metrics of each site. The end result is a final dataset in a format appropriate for detailed analysis and criteria specification.

3.1 Field Data Collection

3.1.1 Site Selection

The intent of field site selection was to collect data from a geographically diverse dataset representative of the different regions in Colorado. The field sites included canals in 6 of Colorado's 7 drainage divisions. The basins included the Arkansas, Colorado, Gunnison, Rio Grande, San Juan/Dolores, and South Platte as defined by the Colorado Division of Water Resources. The field visits had a wide range of hydraulic structures to catalogue (e.g. drop structures, weirs). The most important factor in dataset collection was incorporating the diverse geographical features of each region including the mountainous regions, plains and foothills in order to witness effects of canal hydraulic structure selection based on geographic location.

The initial dataset produced in (Applegate Group, 2011) was utilized and organized into canal owners whom had responded to the (Applegate Group, 2011) survey, canal owners listed with contact information in CDSS, canal owners without contact information in CDSS, and canals listed without owner information. Prioritization was given to canal owners who responded to the (Applegate Group, 2011) survey. Site owners were contacted prior to site visits and provided direction on structures of interest. It was strategized to make contacts with local canal operators in list of priority, explain the current study, and request permission to visit the canal site. Site visits would include driving the alignment, counting structures, and taking measurements along the way. In cases when canal representatives were available, requests were made to meet briefly and have the owners direct where structures of interest were located. The self-selection bias represented was applied with intention to visit sites where an acquaintance was already familiar with the project scope. The goal of the field visit was to obtain a representative selection of structures used in the field in geographically different regions of Colorado as oppose to performing a comprehensive survey of the area. The pre-selected resources where the sites were procured do not skew the results of the study. The representative selection of structures is sufficient to develop the methods described later in this report.

However, this method proved to be ineffective due to lack of response to contact requests and inaccurate contact information (by survey and CDSS). Furthermore, in some of the meetings where the location of structures of interest were pointed out by site representatives, it was later realized from examining aerial photography that crucial structures within the system were left out. It was witnessed first-hand the complexity of some of these systems and is well understood that one could overlook a structure that is not managed on a daily basis. This further emphasizes the need for developing an optimized method of identifying upgradeable structures without relying on information communicated through location submissions.

The most successful methods employed to identify structures before field work included selecting proposed canals from the CDSS and prequalifying the existence of hydraulic structures using aerial photography with Google Earth. Alignment data was obtained by identifying the location of each canals diversion structure and manually tracing the alignment downstream from that point using Google Earth. Locations of diversion structures are available through the CDSS. Structures visible on the satellite images were identified and formed the primary targets for field visits. Structures of interest were identified by visually noting white water, when visible, or identification of the structure itself. If a number of structures appeared to be present, water commissioners for the area were then contacted by phone to request the correct contact information of the area representative for the canal of interest. The pre-identification of sites using satellite images provided two critical observations: (1) the quality of publically available photography varies widely, some promising sites were missed and other sites were misidentified as drop structures (2) during site visits, it became clear that the visible white water did not serve as an appropriate evaluation of a structure's suitability for hydropower. These two outcomes illustrate that photographic investigations alone are insufficient to perform a survey.

Once permission to study a particular canal was granted, representatives were often met in the field and, in some cases, an escort would be provided by the canal operator. Typically, the sites were visited by navigating the alignment of the canal by motor vehicle. The tools and equipment used included a surveyors wheel, surveyors tape/tape measure, laser level and receiver rod (Leica Rugby 50 self-leveling model), GPS unit (iFinder Pro model), and Google Earth. Field data collected at each structure included the location and dimensions of structures (e.g. height, length, width), and the dimensions of the canal in the vicinity of the structure. Additional references for other irrigation company representatives in the area were sometimes obtained from the field visits and in one case a phone call introduction was provided. The important fact remains that once in the field, there is a general interest in the topic of upgrading irrigation structures with micro hydropower capabilities as identified in (Applegate Group, 2011).

3.1.2 Field Data Collected

Total Available Head and Coordinates

Measurement of total available head varied based on the site conditions. The majority of measurements, 189, were done with physical field measurement techniques. When there was safe access to occupy the top of the structure, usually by means of a crossing, the total available head was measured as the difference in upstream and downstream water surface elevation. This measurement was taken with a tape measure by measuring the difference in upstream and downstream distances to a known point on the structure (usually the top of the crossing as this was a fixed, level surface). When a drop occurred as a result of a steep grade change over a relatively short horizontal distance, the total available head was measured as the difference in upstream and downstream water surface elevation using a Leica Rugby 50 self-leveling laser level. In 4 instances, the total available head was recorded using a hand held GPS unit. In 34 instances, as-built drawings existed for structures of interest. In these situations, the total available head was recorded as the difference in upstream and downstream thalweg elevation. In 6 instances where accessibility was not provided, total available head values were estimated from Google Earth. WGS coordinates for each structure were recorded using a hand held GPS unit.

Location to Nearest Utility Interconnection and Interconnection Type

Generally, a utility service line was in sight of the structure of interest. For the case that a safe accessible path existed, measurements from the structure of interest to the utility line were recorded using a surveyor's wheel. In many instances, utility service distance needed to be estimated and later verified using Google Earth. Line voltage was estimated from number of insulators between the service line from the utility pole. In cases where overhead utility lines were not present (e.g. in residential areas with underground electricity service), utility interconnections were identified as a "residential or home" connection.

Flow Records

Quantification of the flowrate in irrigation structures is not the main goal of this study. However, flow records were investigated through data provided by CDSS. Since flow diminishes in any given channel as a result of withdraws, seepage loss, and evaporative losses, flow data specific to a structure of interest requires further investigation. Therefore, local experts were also questioned about historical flow patterns. In many cases, flow for a canal will vary on a daily basis. Customers generally request their flowrate order a day in advance. Any particular flow in a canal is reflective of the day's orders and canal's delivery requirements. Therefore, data availability varies per site.

Pictures and Documentation

Each site was well documented with pictures. Pictures included upstream of structure, upstream looking down at structure, downstream of structure, downstream looking up at structure, and any individual structure specifics. Additionally, video and audio recordings of notes were taken for many sites.

United States Bureau of Reclamation Field Data

Concurrent to the present study, the United States Bureau of Reclamation (USBR) was conducting a supplemental investigation to their report (USBR, 2011) in which potential hydropower assets were being evaluated in existing USBR canals. The scope of the supplemental investigation (USBR, 2012) is to identify hydropower potential in terms of power production in megawatts and annual energy generation in megawatt hours. Data for the study, geographic locations of structures, total available head, and flow patterns where available, was provided for use in this work while the USBR study was still in its preliminary phase. This valuable contribution was significant as it added to the current data set. The data provided by the USBR is diverse both geographically and topographically and enabled this study to include sites where time and funding would previously limit it. The data set was contributed during the preliminary phases and is not reflective of the final USBR data set.

3.1.3 Data Organization

Appendix A has the total site list for the data collection process. Following the data collection and measurement portion, all data for sites were organized in the following categories in Microsoft Excel: Division, State, Owner, Structure Name, Structure ID, Location of Structure, Category of Structure, Sub-Category of Structure, Additional Sub-Classification, Elevation Change, Upstream Width, Downstream Width, Flowrate, Distance to Nearest Tie In, Number of Insulators, Coordinates, and Notes. Chapter 2 provides an introduction to hydraulic structures which were assigned as categories and sub-categories.

The structure ID was a tag assigned to the structure of interest while in the field. It incorporated the initials of the canal being investigated and the sequence the structure was explored while driving the alignment. An example includes MD_2. “MD” is the initials for Montrose Delta canal and “2” is the sequence identifier. The USBR work identifies sites using a sequential numeric method base on how the sites were submitted to the researcher from the area office. An example would include, “101”.

Therefore, in the dataset, sites collected in the field are alpha-numeric and sites obtained from the USBR are numeric.

The (Applegate Group, 2011) study identified a classification system for typical structures found in irrigation canals. These structures included: Diversion Structures, Concrete Lined Chutes, Vertical Drops, Pipelines, Checks, and Reservoir Outlets. The (USBR 2012) study identified a separate but similar classification system for structures found in irrigation canals. These structures included: Check Structures, Vertical Drops, Chutes, Series of Drops, Pipelines, and Check Drops. For the purposes of this work, it was appropriate to further subdivide these classifications. Table 3.1 was used to define a specific structure and its associated properties. As previously explained, data from the USBR was used in this study. Therefore, it was necessary to use some of their structure identifiers in this report. However, it was also necessary to further define the structure into a more detailed categorical system for a complete and thorough identification system.

Table 3.1 Hydraulic structure categories

Category and Associated Classifications				
Identify Location	Drop	Weir	Gate	Flow Measurement
Inline	Vertical Drop	Overshot	Vertical	Parshall Flume
Turnout	Chute	Sharpcrested	Radial	Other
Diversion	Series of Drops	Shortcrested	Barrage	
Reservoir	Pipeline	Obermeyer		
	Check Drops	Rock Structure		
	Siphon	Barrage (2 or more)		
	Steep Grade Change			
	Engineered Drop Structure			

The hydraulic mechanics used to model open channel flow within a system are unique to each type of structure used in that system. If further investigation is conducted with the data sample obtained, the classification system defined in this report will be useful. How a particular structure functions hydraulically can affect the type of equipment selected to upgrade a structure. Further, the original purpose for selecting a typical hydraulic structure is dependent upon how the structure functions in the greater system of networked canals. If additional investigation is conducted, it will be of interest to track the specific type of structure under scrutiny. Therefore, this report uses a sequence of identifiers for labeling a hydraulic structure: Location in Canal, Category of Structure, Sub-Category of Structure and additional Sub-Classification. The additional Sub-Classification was not always utilized. In subsequent sections it is described how this identification system was revisited.

<u>*Definitions*</u>

Location of Structure

Definitions for the location of the structure are summarized in Table 3.2.

Table 3.2 Location of structure identifier

LOCATION	DEFINITION
Inline	The structure was located in the alignment of the canal. In other words, the flow going through the canal would also go through the structure.
Turnout	A turnout was where flow was diverted from the canal to another canal or property. Structures that were part of this assembly were labeled turnout. It is important to note that although a structure was a turnout from one canal, it is generally labeled as inline in another canal. However, not all alignments associated with turnouts were investigated.
Diversion	Diversions were associated with the most upstream portion of a canal. Usually an intake works of sorts were constructed at diversion points.
Reservoir	Some reservoir outlets were explored. However, it was the scope of this report to focus on canal structures, not necessarily reservoirs or small dams without hydropower in their outlet works systems.

Figure 3.1 Inline structure

Figure 3.2 Diversion off main river

Figure 3.3 Turnout

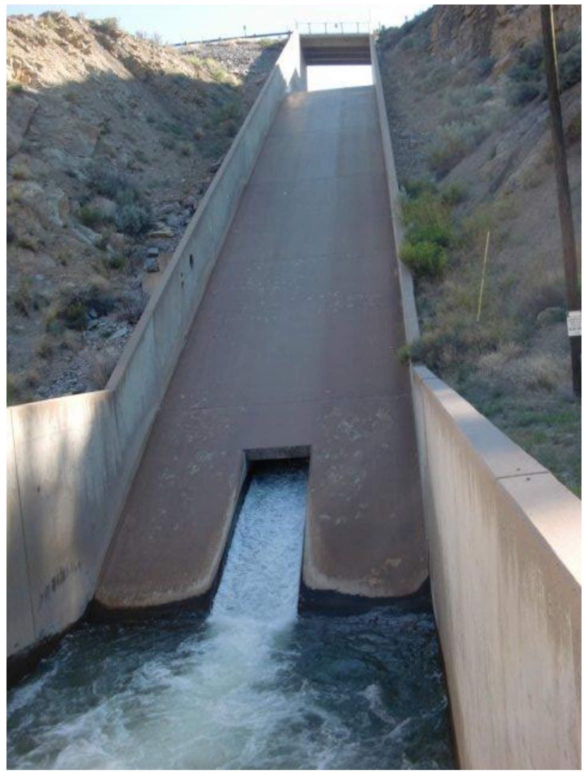


Figure 3.4 Reservoir outlet

Category of Structure

The category of structure was the first method of sorting data. Some category definitions are also included in the classification detail as the two can be mixed (example, a structure with weir functions could exist on a drop, however it would be categorized first as a drop and then further classified as a weir drop). However, it is important to note that the category is the primary definition of the structure. Table 3.3 summarizes the categories defined.

Table 3.3 Category of Structure

CATEGORY	DEFINITION
Drop	A drop category was associated with any type of structure (excluding flow measurement structures) located on the canal where a vertical change in the canal thalweg existed.
Weir	A weir category was associated with any type of structure used for the establishment of hydraulic control in a canal where the flowrate over the structure could be modeled as $Q = f(H^{3/2})$. When categorized as a weir, there was not a measurable change in elevation of the canal thalweg.
Gate	A gate category was associated with any type of structure used for the establishment of hydraulic control in a canal where the flowrate over the structure could be modeled as $Q = f(H^{1/2})$. When categorized as a gate, there was not a measurable change in elevation of the canal thalweg.
Flow Measurement	A flow measurement structure has geometries specific to the accurate measurement of flowrates within an open channel. Therefore, any flow measurement structure is deserving of a category of its own. It is unlikely that a flow measurement structure would be upgraded or replaced to produce hydropower.

Figure 3.5 Drop

Figure 3.6 Weir

Figure 3.7 Gate

Figure 3.8 Parshall flume

Sub-Category of Structure

Each category was further identified by the type of structure within that category. Chapter 2 provides a review of sluice gates, weirs, and flow measurement structures. Drop structures are review here as the category "drop" applies to many scenarios. Table 3.4 summarizes the sub-categories within the "drop" category. The first 5 classifications under "drop" are defined verbatim from the USBR canal report.

Table 3.4 Sub-Category of "Drop" category

SUB-CATEGORY	DEFINITION
Vertical Drop	"Vertical drops are used to describe a structure that enables a change in elevation over a very short length of canal alignment."
Chute	"Chutes are usually used where water is conveyed over long distances and along grades that may be flatter than those for drops but steep enough to maintain supercritical velocities."
Series of Drops	"This categorization is used to describe multiple vertical drops structures located in series. The head listed is the difference from the highest point in the alignment to the lowest point." Data listed in the USBR canal report gave elevation changes based on series of structures in an alignment instead of independent structure elevation changes.
Pipeline	"A pipeline is a closed conduit structure used to convey water."
Check Drops	"Check drops are used to describe a vertical drop structure with a check structure integrated on the upstream end." It should be noted in this report the term weir is used where in the Applegate/CSU and USBR the term check is used. Both terms can be used interchangeably. In this report, the additional sub-category of Structure is used to define the type of weir used upstream of the drop structure (Sharpcrested, Obermeyer, etc.)
Gate Drops	A gate drop incorporates a gate structure on the upstream end of the change in elevation of the canal thalweg.
Siphon	Siphons (sometimes referred to as inverted siphons) are closed conduits that convey water under existing infrastructure, usually with the headwater and tailwater above the lowest point in the siphon alignment.
Steep Grade Change	This classification was used to identify a section of canal alignment hydraulically defined as a "steep" slope with normal depth below critical depth. Examples of this type of grade change were generally analogous to short chutes.
Engineered Drop Structure	Although all structure classifications listed above are engineered, an engineered drop structure classification is used to define a drop structure with a specific energy dissipation function. These were seen as drop structures with baffle chutes, spillways with stilling basins, and general structures that were either cast in place or constructed offsite and placed within a canal alignment.

Figure 3.9 Series of drops

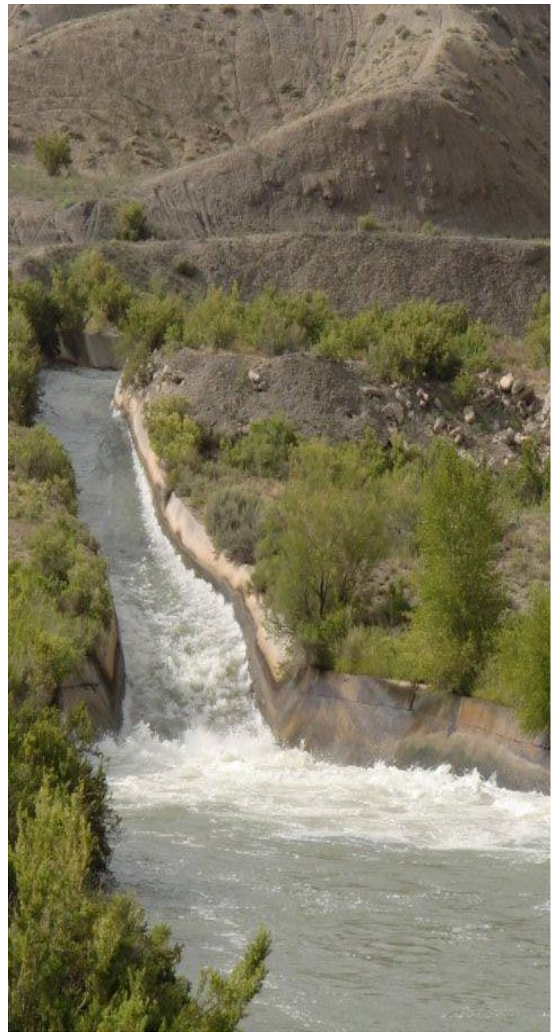


Figure 3.10 Chute


Figure 3.11 Check drop


Figure 3.12 Engineered drop structure

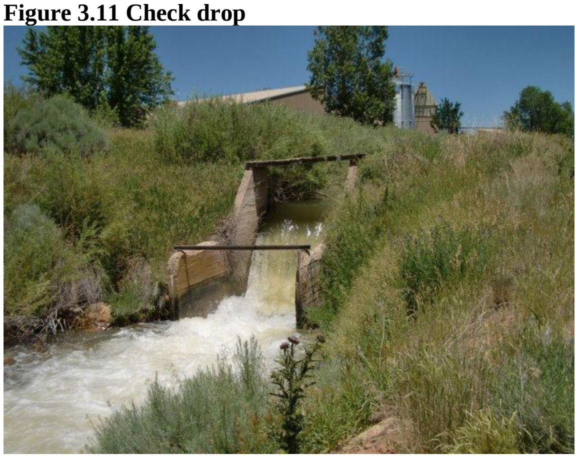


Figure 3.13 Vertical drop


Figure 3.14 Entrance to siphon


Figure 3.15 Gate drop

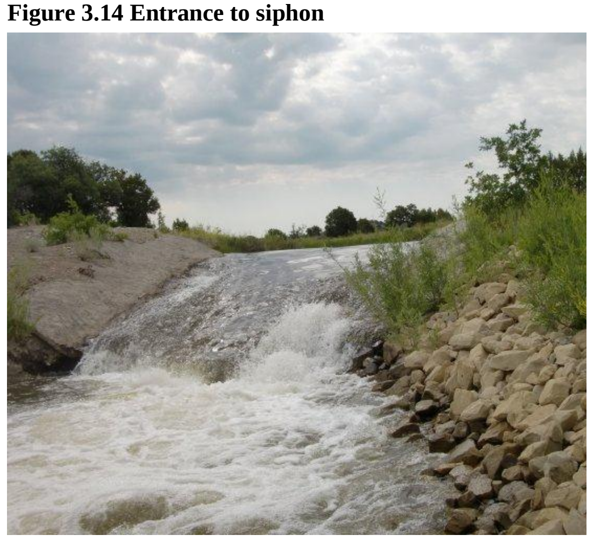


Figure 3.16 Steep grade change

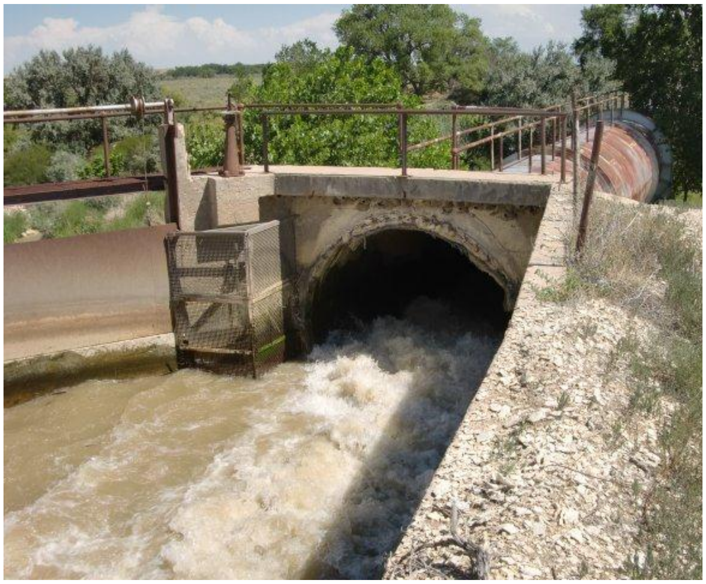


Figure 3.17 Pipeline

Additional sub-category of Structure

The additional sub-category section was used to define any details still outstanding. An example would be to identify the type of weir when a structure was tagged Inline>>Drop>>Check Drop>> Type of Weir. As stated above, this identifier was not always utilized.

3.2 GIS Data Analysis

Publically available data from the National Elevation Dataset (NED) and National Hydrography Dataset (NHD) were used, in combination with geographical information systems (GIS) technology, to produce 3 dimensional canal profile data for each canal reach associated with a canal structure location. The National Elevation Dataset (NED) is a raster based data set of bare ground elevation produced by the USGS for distribution and use in the public domain. Thirty meter resolution and ten meter resolution data sets were downloaded for each site in this study. The National Hydrography Dataset (NHD) is a water resource data base produced by the USGS for distribution and use in the public domain. High resolution datasets (1:24,000 scale) for each state in the data sample were downloaded from the NHD website. The NHD contains 2 dimensional flowlines representing canal, stream and river alignments. All of the data samples for hydraulic structures used in this study had an NHD flowline feature associated with it. For the majority of data samples collected in the field, all structures along a canal alignment were surveyed.

Therefore, there was no need to trim the NHD data for these samples. However, when the extent of a data sample on a given alignment only included one structure, as was the case for the majority of USBR sites, the NHD flowline was trimmed to extents upstream and downstream of the structure. Finally, the CDSS provided the GIS layer that represented the location of the diversion structures.

Most of the data samples for hydraulic structures used in this study had an NHD flowline feature associated with it. However, at some site locations in this study the NHD alignment data diverted significantly from the canal alignment. An example can be seen in Figure 3.18. In this example the NHD alignment diverges from the chute in the backdrop image. In these cases, the analysis was conducted between the extents of the alignment data which included the structure.

Figure 3.18 NHD Alignment not on canal

Of the 545 adjusted data sample sites, 23 sites did not align with the NHD data alignment. Twenty two of the 23 sites were actually included in the final site list. It was important to include these data samples in this analysis. For a data set of unknown structures locations where the object of the study is to find applicable structures, there will be data samples where NHD does not line up. Additionally, there were locations where NHD data did not exist at all. Figure 3.19 is an example where a significant drop existed but the alignment data needed to be manually created. In these cases, 2D alignment data was manually created by tracing the aerial imagery of the canal alignment.

Figure 3.19 Missing NHD alignment, manually added in

Of the 545 adjusted data sample sites, 28 sites did not include NHD data. Of these 28 sites, only 8 were included in the final site list. It was important to include these data samples in the final analysis as one of the primary objectives of this study is to identify how well NED data can be used for identifying drop structures. Therefore, creating alignments manually does not skew the objective of the study. Of the 8 sites in the final site list, 7 were within 70% accuracy of measured elevation change.

3.3 Data Processing

The GIS software program ArcGIS version 10.0 was used to analyze the existing datasets and create each individual structure's profile. ArcGIS was utilized to convert the 2D National Hydrography Dataset (NHD) flowlines to 3D polylines using the 30-meter and 10-meter National Elevation Dataset (NED) surface as an elevation reference. Coordinate data for each site was modified to contain two coordinates for each site, one upstream of the structure and one downstream of the structure. The adjustments from the original coordinate locations were done manually in ArcMap using aerial imagery of the structure of interest as a backdrop. Graphically, these profiles can be visualized using ArcGIS, AutoCAD, or Microsoft Excel. Cartesian coordinates for the 3D polyline vertices (X,Y, and Z data for each point on the line) and the location coordinates were exported from ArcGIS to comma-separated list files and imported into Microsoft Excel. Analysis was then conducted using metrics obtained from the NED and NHD data and comparing these metrics to physical field measurement of the structures of interest.

3.3.1 Workflow

Structure location data from the data organization section, NHD alignment data, and NED raster data were uploaded into ArcGIS and projected to their associated UTM zone with an NAD 83 datum. Functions embedded in ArcGIS were utilized to perform the necessary calculations to convert all three datasets to a useable format.

Coordinates

The coordinate data for each site was collected in decimal degree WGS format. The data was uploaded to ArcGIS and projected to its respective UTM zone. Table 3.5 was utilized as a guide for identifying what WGS range was applicable to the respective UTM zone. A coordinate shapefile for each zone was created.

Table 3.5 WGS coordinate respective UTM zone

WGS Longitude	UTM Zone
126° - 120°	10
120° - 114°	11
114° - 108°	12
108° - 102°	13
102° - 96°	14

NHD

NHD data for each state was downloaded. Prior to processing, NHD data is in WGS format. Therefore, NHD data was displayed in ArcGIS along with the coordinates of the sites in WGS format. The NHD flowlines in the proximity of the area of the sites were selected and exported as a separate shapefile. This exported shapefile was then projected to its respective UTM zone. This sequence was done to minimize the size of file in which the analysis was to be conducted. For example, there is no reason to have the entire state of North Dakota's NHD file when only a few sites were investigated in the state.

Additionally, flowline segments were generally for the entire reach of the canal of interest. However, in some cases, not all structures along the alignment of the canal of interest were surveyed. To ensure unaccounted for structures were not included in the analysis sample, flowlines were trimmed to appropriate extents by manually verifying flowline location with projected aerial photography. The flowline data was trimmed by adding a base map of projected aerial photography to ArcGIS and manually observing the flowline alignment upstream and downstream of each surveyed structure. In instances where additional structures existed that had not been surveyed, the flowline data was trimmed downstream of an upstream structure, and trimmed upstream of a downstream structure. This ensured there were not unaccounted for structures in the profile database. For the majority of data samples collected in the field, all structures along a canal alignment were surveyed. Therefore, there was no need to trim the NHD data.

NED

As explained above, NHD is 2 dimensional. Georeferenced elevation data in the form of NED tiles were required in order to obtain elevation values for points along the NHD alignment. NHD location within a township and range was documented and NED data was downloaded for the corresponding alignment shapefiles. These NED tiles were then projected to their respective UTM zone. In some cases, multiple neighboring tiles were needed to collectively cover the extents of the NHD data within a UTM zone. In this case, to ease processing, NED data were mosaiced together using the "Mosaic To New Raster" tool in ArcGIS. This new raster was then projected to its associated UTM zoned. This sequenced was verified through correspondence between ArcGIS technical personnel via email. See Appendix C for copies of this correspondence. This process was done with both 10m and 30m NED files. NHD data was then overlapped on the NED data. Elevations were assigned to vertices of the NHD data using the

“Interpolate Shape” tool in ArcGIS. Vertices were created 10m apart on the NHD data in order to have a consistent incremental spacing location.

Exporting Comma-Separated List Files

2D NHD polylines became 3D polylines once elevations were assigned to the vertices. 3D polylines are a series of coordinates, northing (Y), easting (X), and elevation (Z), which represent the vertices of that alignment. Straight lines are then connected between the vertices to create the alignment line. The XYZ information for each of the vertices was then exported to a comma-separated text file. Once the information for the alignment was available in this format, it could be manipulated and analyzed in Excel.

The horizontal length of the alignment (plan view stationing) is calculated from the change in northing and easting locations. The following equation is used to separate the vertices into their respective vector format in order to sum the length of the alignment:

$$H_d = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2} \qquad \text{Eq.3.1}$$

Where:
H_d = Horizontal Distance
X_2 = Easting Coordinate of Second Point
X_1 = Easting Coordinate of First Point
Y_2 = Northing Coordinate of Second Point
Y_1 = Northing Coordinate of First Point

The associated slope between the vertices is given by the relationship

$$S = \left(\frac{Z}{H_d}\right) x100 \qquad \text{Eq.3.2}$$

Where:
H_d = Horizontal Distance
Z = Elevation Change
S = Slope in Percent

Adjusted Coordinates/Envelope Discussion

Coordinates collected, both by the field research process and the USBR, were points along the bank of the canal in the vicinity of the structure. This was the general location of the researcher and where the GPS position was acquired. However, as explained in the section above, 3D polyline information for the NHD alignment representing the canal profile is exported in XYZ coordinates. A method needed to be developed to identify the bounds of the structure or structures of interest within each 3D polyline's XYZ profile.

The field collected coordinates were modified to contain a pair of coordinates for each site. An upstream and downstream coordinate representing the extent of the structure of interest was created at a vertice located on the representative 3D polyline. This ensured the coordinates bounding a structure of interest would have a matching XYZ vertice represents by a 3D polyline when the data was exported to Excel. This step was necessary to identify where the structure coordinates were relative to the canal coordinates in an XYZ dataset, see Figure 3.20 and 3.21.

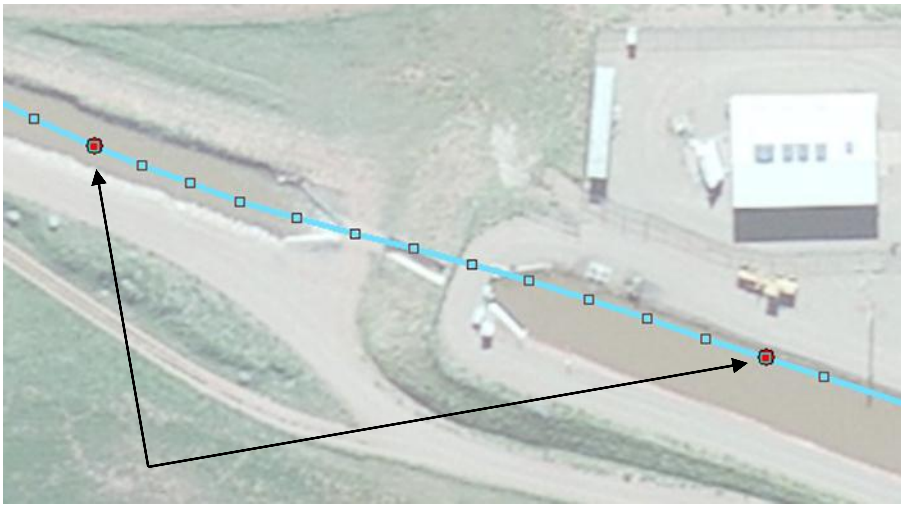


Figure 3.20 Adjusted coordinates at 40 meters US and DS

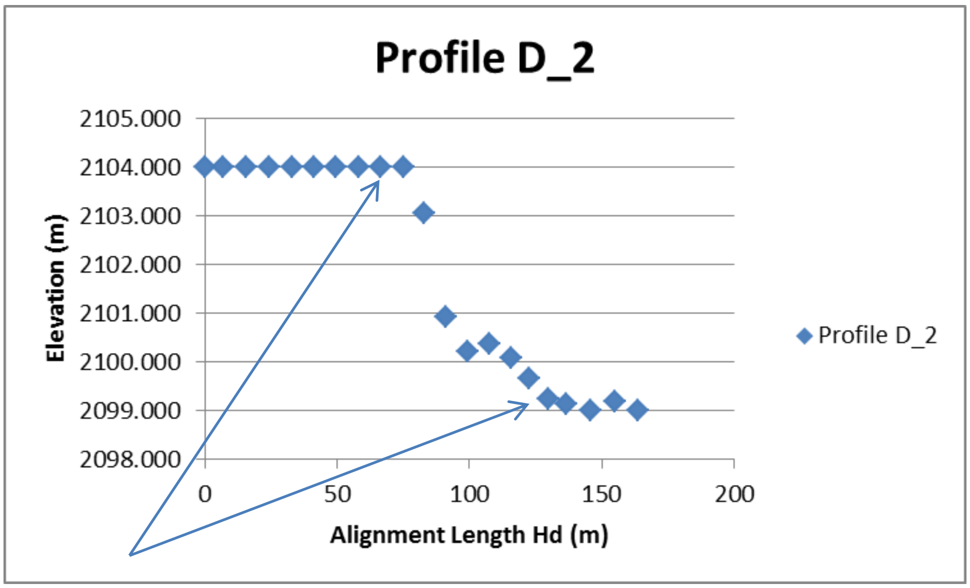


Figure 3.21 Adjusted coordinate location on profile

This modified pair of coordinates for each site is the representative coordinate "envelope" for the site. It is a pair of georeferenced markers that will be used to identify relationships in the alignment data. The envelope creation process was done manually for all sites by creating and placing each coordinate in its respective location. The initial location of the envelope is placed 40 meters upstream and 40 meters downstream of the structure. The 40 meter distance was selected to ensure changes across 30 meter NED data would be witnessed. However, as NED data assigns the average elevation value within its respective resolution (30m NED data would have a surface area of 900 m, 10m NED data would have a surface area of 100m) it was understood that the change in elevation may be more accurately represented from a larger span than the initial 40 meter upstream and 40 meter downstream envelope. An additional dataset was created for points located 70 meters upstream and 70 meters downstream of the structure. In cases where an alignment ended and a vertice did not exist within 40 meters or 70 meters, the last vertex available was selected.

The length associated with each site was the distance between the envelope markers. This distance was the envelope displacement upstream and downstream (40 meters) plus the length of the structure which was unique to each category. Figure 3.22 shows this relationship. When the structure was a diversion, the envelope usually did not include any distance upstream of the structure.

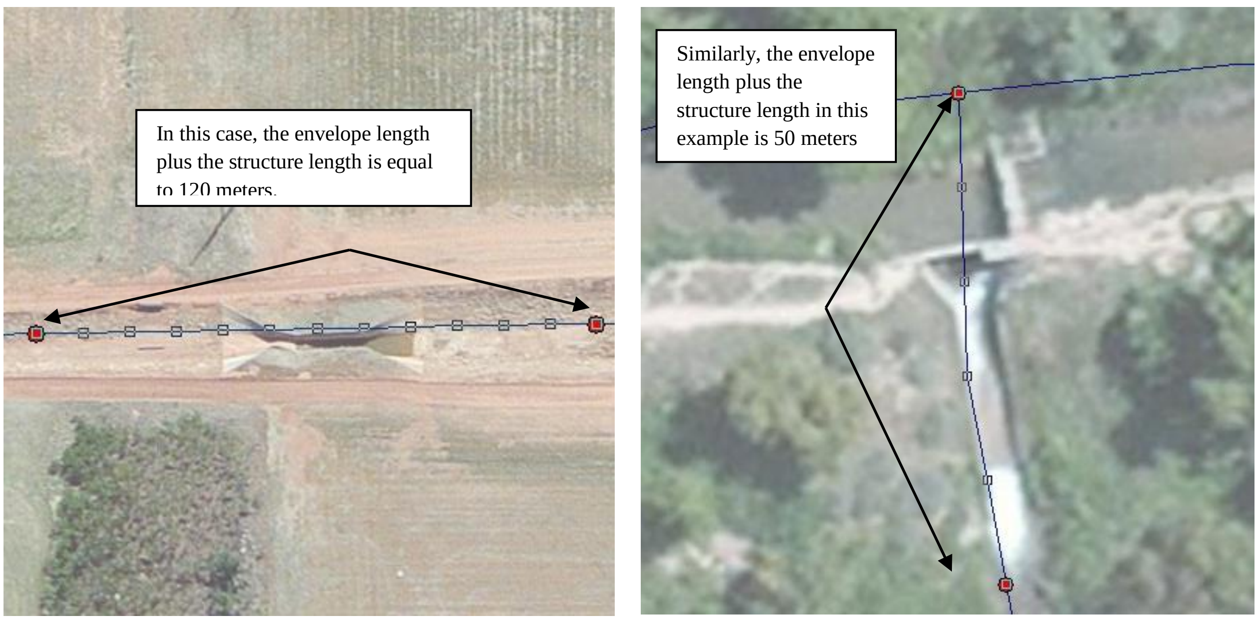


Figure 3.22 In the left image, the associated length is 120 meters. Similarly, the right image shows a length of 50 meters. The length will vary depending on the structure size and placement within the canal.

<u>*Surrounding Average Slope Discussion*</u>

The NED assigns an average elevation value, within its respective resolution, to a tile which consists of all elevation measurements within that tile. Therefore, it was questionable as to what influence the terrain surrounding the sites of interest would have on the accuracy of acquiring elevations from the NED. The average slope of the area surrounding each envelope was calculated at a 100 and 500 meter radius. Figure 3.23 shows a 100 meter radial footprint for the upstream and downstream node of a site of interest. The average slope of the surrounding area were analyzed to see if there was a correlation between the average surrounding area slope and the accuracy of the NED to model the relative elevation change.

Figure 3.23 Average slope calculated within radius

3.4 Final Dataset

After all the sites had been organized by the methods described above, 26 of the USBR sites needed to be removed from the list as a result of duplicate site visits from the field collection process, duplicate sites submitted from the USBR, or inaccurate coordinate data submitted from the USBR. The breakdown of the final dataset in the categories listed in previous sections can be seen in Figure 3.24.

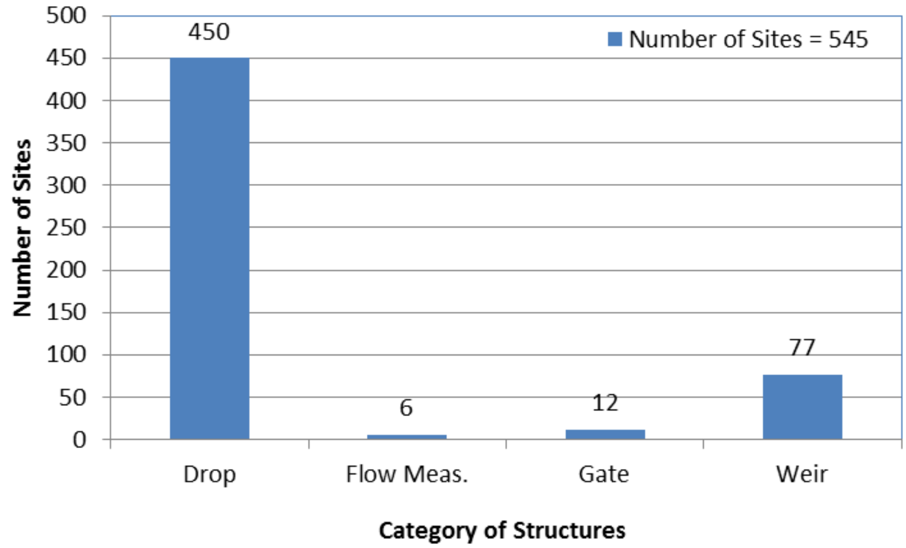


Figure 3.24 Final dataset to be analyzed after 26 duplicate sites were removed from data collection efforts

3.4.1 Data Trimming

As discussed in the national elevation dataset (NED) section of Chapter 2, the measured relative error in vertical accuracy of NED data was an average of 1.64 meters. For the purposes of this study, this number was rounded to 2 meters. This 2 meter threshold was established as a minimum expected accuracy of NED to conduct a study of this scope. As a result, it is not realistic to try and include field measurements that were less than 2 meters. Additionally, it is not realistic to include NED measurements that were less than 2 meters. The outcome of applying the 2m threshold was significantly trimming Figure 3.24.

It should be noted that the last documented test of absolute and relative vertical accuracy of NED data was done on an NED dataset published in June 2003. (Gesch, 2007) points out that over time the accuracy of the NED has greatly improved and is expected to continue to improve to increase the vertical accuracy over time. It would then be expected that the dataset used to compile information for this study, obtained February 2012, would perform far better than the tested dataset of June 2003. However, it is not within the scope of this study to measure the effectiveness of the NED. Therefore, the published average relative vertical accuracy value of 1.64 meters (2 meters) is used as a minimum vertical threshold for control in this study.

Weirs, Gates, and Flow Measurement Structures

All measured elevations and all NED measured elevations were rounded to the nearest meter. Field measurements for the weir, gate, and flow measurement structure categories did not reflect any sites greater than 2 meters in elevation. Therefore, all sites not in the drop category, 95 total, were removed from the dataset. Figure 3.25 shows the breakdown of the number of sites within each elevation bin by category that were removed from the dataset to be analyzed.

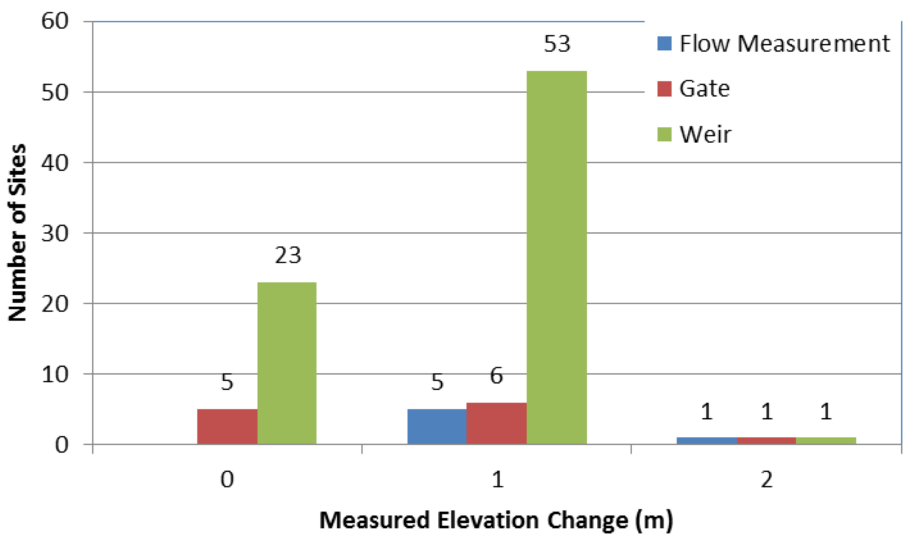


Figure 3.25 95 sites in total were removed from the final dataset as their total elevation change were not within the resolution of 2 meters for the digital elevation model used to identify the sites.

Drops

The remaining data set consisted of 450 sites in the drop category. Field measurements of less than 2 meters were removed from the list. NED measurements for both the 40 meter envelope and the 70 meter envelope that were less than 2 meters were eliminated from this list. However, there were more NED measurements less than 2 meters in the 40 meter envelope dataset. The final datasets consisted of a 40 meter envelope and a 70 meter envelope dataset. Figures 3.26 and 3.27 show the number of sites in the drop category in each elevation group for the 40 meter and 70 meter datasets respectively. The grouping system will be explained in the results section.

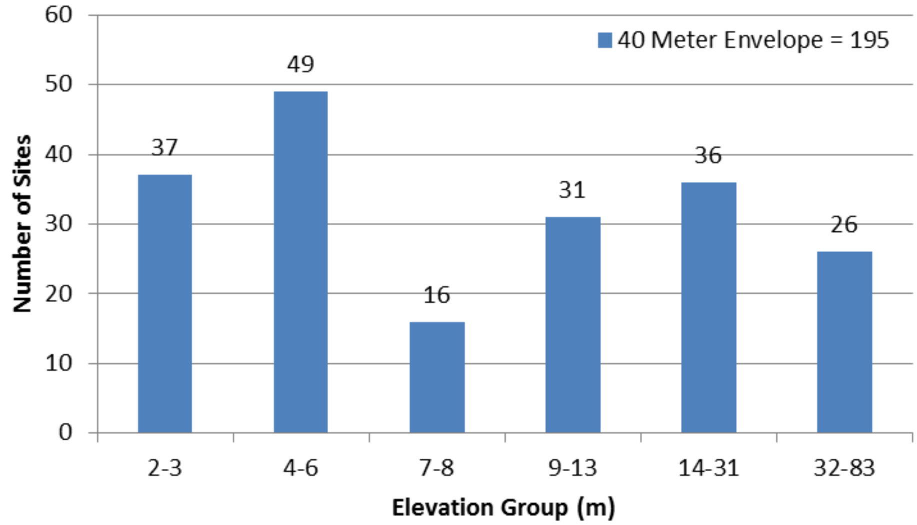


Figure 3.26 195 sites were analyzed for the 40 meter envelope datasets

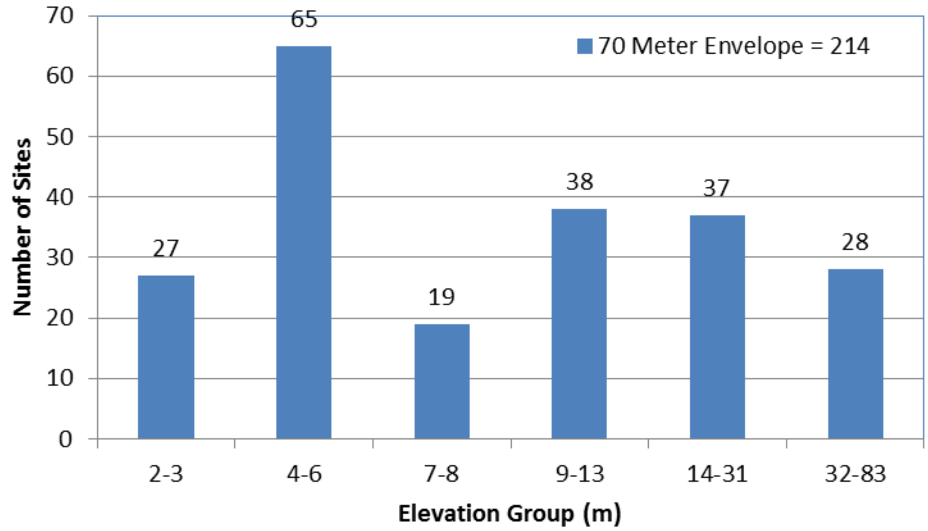


Figure 3.27 214 sites were analyzed for the 70 meter envelope datasets

Parameter Organization

These final data sets were parameterized into the following organizational categories listed in Table 3.6:

Table 3.6 Final dataset organization

CATEGORY	DEFINITION
Sub-Classification	Sub-classification of the Drop category
Measured Elevation Change	True elevation change, or height of the structure, collected from the field.
Measured Elevation Change BIN	The true elevation change was rounded to the nearest 1 meter.
NED Elevation Change	Elevation change observed by the NED for either the 40 meter envelope or the 70 meter envelope point locations.
NED Elevation Change BIN	The NED elevation change was rounded to the nearest 1 meter.
Difference between Measured Elevation Change and NED Elevation Change	Difference between measure elevation change and NED elevation change were recorded and rounded to the nearest 0.5 meter.
Length BIN	The length of the envelope representing the site of interest rounded to the nearest 10 meters.
Radial Slope Value for 100 and 500 meters	This value was discussed in the surrounding average slope section and is given in percent.
Radial Slope Value for 100 and 500 meter BIN	Each value was rounded to the nearest 0.25%.
% Error	A comparison was done between the NED elevation change and the measured elevation change. The comparison was identified as a percent error and calculated by equation 3.3.

$$\% \, Error = \frac{|True\ Measurement - NED\ Measurement|}{True\ Measurement} \mathrm{X}100 \qquad \text{Eq. 3.3}$$

Where:
True Measurement = Measurement collected from field
NED Measurement =Measurement collected from NED

Analysis of each independent reach profile was then executed using the parameters listed above in attempts to identify a unique relationship between parameters of successful NED measurements and parameters of NED measurements that displayed large errors. Using the results of this analysis, boundaries were identified in which an algorithm will follow to identify potential structure locations in an unknown data sample specific to an irrigation canal system.

Chapter 4- Results

The technical processing of the data collected produced a dataset of 195 structures. This data was formatted such that detailed analysis of site parameters could be conducted. Site parameters analyzed include the measured elevation change of the structure from the field, the elevation change as obtained from the NED dataset, the planimetric lengths in which the NED elevations were recorded, and the average slope values within proximity of the structures of interest. NED height categories were created and metric analysis was conducted on a per category basis.

In general, reviewing data obtained from methods described in Chapter 3 confirm a profile signature for drops in canals can be observed, review Figure 4.1. Figure 4.1 shows the canal and structure profile in the upper left corner. The structure profile shows a change in elevation from approximately 2,109 meters to 2105 meters. The actual height of the structure is 4.22 meters. The photographs show a plan view and front view of the actual site. NHD line data is overlaid in the plan view section and the 40 meter envelope measurement points are shown.

To date, a comprehensive survey of existing upgradeable structures in constructed waterways does not exist. The scope of this work includes identifying methods to recognize structures in canals from an unvisited site using NHD and NED datasets. It extends to the identification of NED criteria used in the design of an algorithm to identify potential structure locations, the type of structure being identified, and the accuracy of the measured elevation change from NED sources. The data analysis also includes an assessment of whether a measureable difference exists from using 10 meter NED vs. 30 meter NED resolution digital elevation models for this application of the NED datasets.

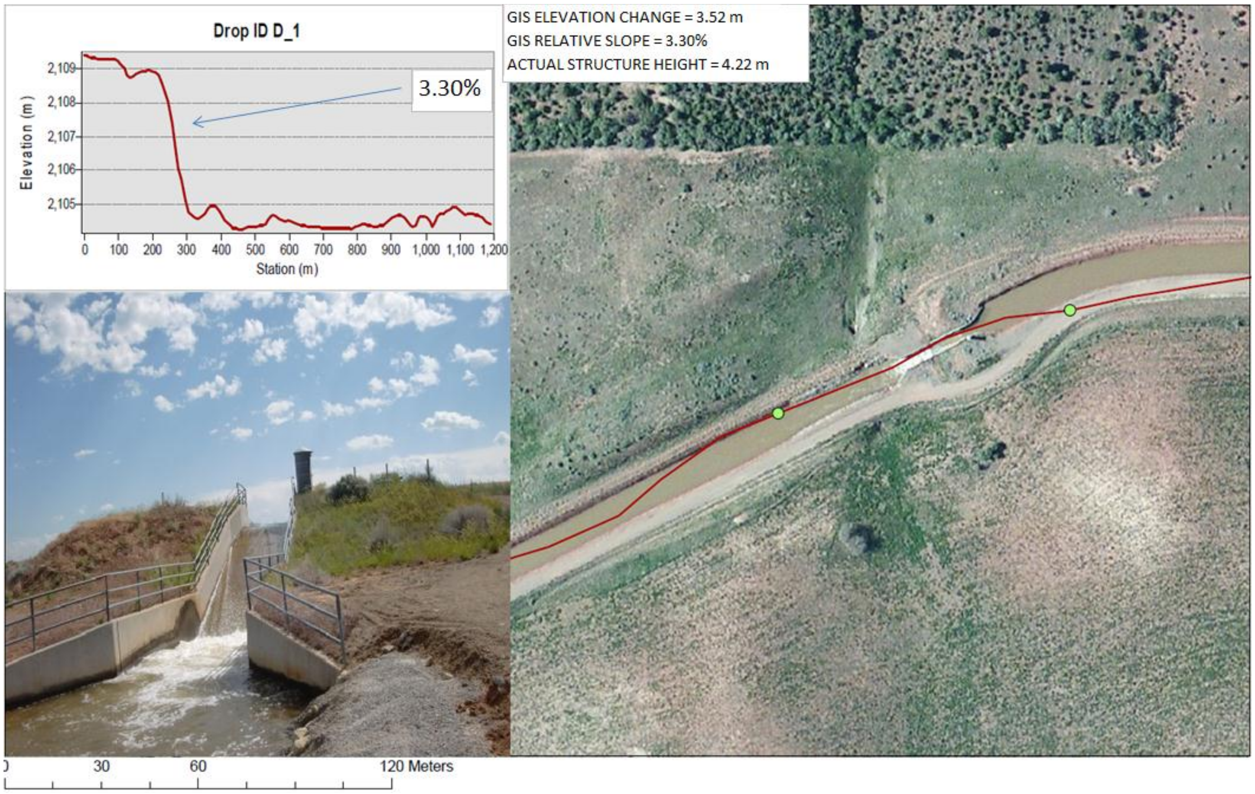


Figure 4.1 Plan, profile and image of a classic drop structure site on a canal alignment. In this case, a 3.52 meter elevation change is observed in the NED data while the actual structure height is 4.22m.

The results show the NED criteria change with the change in NED height category of the structure being measured. The best performance was obtained from the 10 meter NED dataset analyzed at the 40 meter envelope interval. In the following sections, this will be the dataset used to demonstrate how results were obtained. Appendix B will have the same information for the 10 meter NED dataset analyzed at the 70 meter envelope interval and the 30 meter NED dataset analyzed at the 40 meter envelope interval.

4.1 Final Dataset Analysis

Metrics available to be extracted from NHD and NED data include alignment lengths, elevations, and surrounding slope values. In order to provide boundaries for an algorithm to conduct an assessment of an arbitrary dataset, sites with successful measurements from NHD and NED data were isolated and an investigation was conducted to identify the metrics that were associated with these sites. Metrics were also identified for the non-successful site measurements. Comparisons between the successful and non-successful site metrics were made and criteria for the identification of sites, based on these comparisons, were selected.

4.1.1 Linear Regression

The dataset analysis began by comparing how well the NED elevations correlated to the actual field measurements. This was done by displaying the percent error and the NED elevation change bin in a linear regression analysis. The percent error was determined by employing equation 3.3. The NED elevation change bin is the NED elevation change rounded to the nearest 1 meter as described in Chapter 3. Figure 4.2 shows each site data point used in the study within their respective NED elevation change bin. A large representative error window from high error to low error exists for each NED elevation change bin. The coefficient of determination is very low which identifies the percent error for each site is not exclusively a function of the NED elevation change bin. Although the regression was not very useful, an interesting trend exists where the error begins to diminish as the sites become larger.

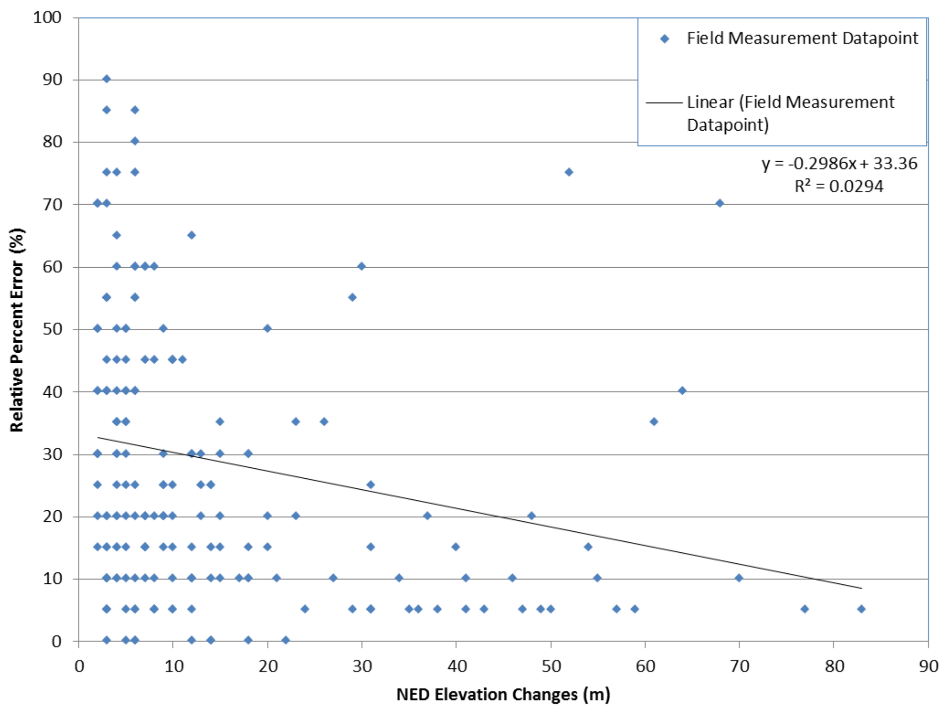


Figure 4.2 Linear regression analysis of relative percent error vs. NED elevations changes binned to the nearest 1 meter. It can be seen that as elevations get larger, the relative percent error decreases.

4.1.2 NED Height Categories and Allowable Error

Analyzing data with percent error as a primary metric was not successful because the percent error is a relative measurement to the size of the object being measured. For example, an actual 4 meter drop in the field might be recorded as a 2.50 meter drop from the NED data. Relative to the actual drop, this would represent a 37.5 percent error. Another example could be represented by an actual 18 meter drop in the field being recorded as a 15 meter drop from the NED data. Relative to the actual drop, this would represent a 17 percent error. This trend is represented in Figure 4.2.

However, when the absolute error of each example is reviewed, the 1.50 meter difference in the first example would be less than the error within the resolution of the NED data of 1.64 meters (see Chapter 3). The 3.00 meter difference in the second example exceeds the average error of the NED data. The absolute error is a method to compare the error of any site, regardless of size, to the expected accuracy of the NED data set being used. In the examples presented, the conflict is realized when comparing the outcome of the relative error to the absolute error.

Alternatively, it can be visually witnessed that an absolute error outside the average 1.64 meter accuracy of the NED data (rounded to 2.00 meters for this work) does not discount the ability to identify the existence of a structure. In the second example above, a 3.00 meter error does not conceal the existence of a large vertical change in elevation. Figure 4.3 is a graphical template to show the trend for allowing the absolute error to increase as the value of measured NED elevation change increases. While the minimum acceptable error is 2.00 meters, a standard for accepting sites on the basis of acceptable absolute error, relative to height, is required.

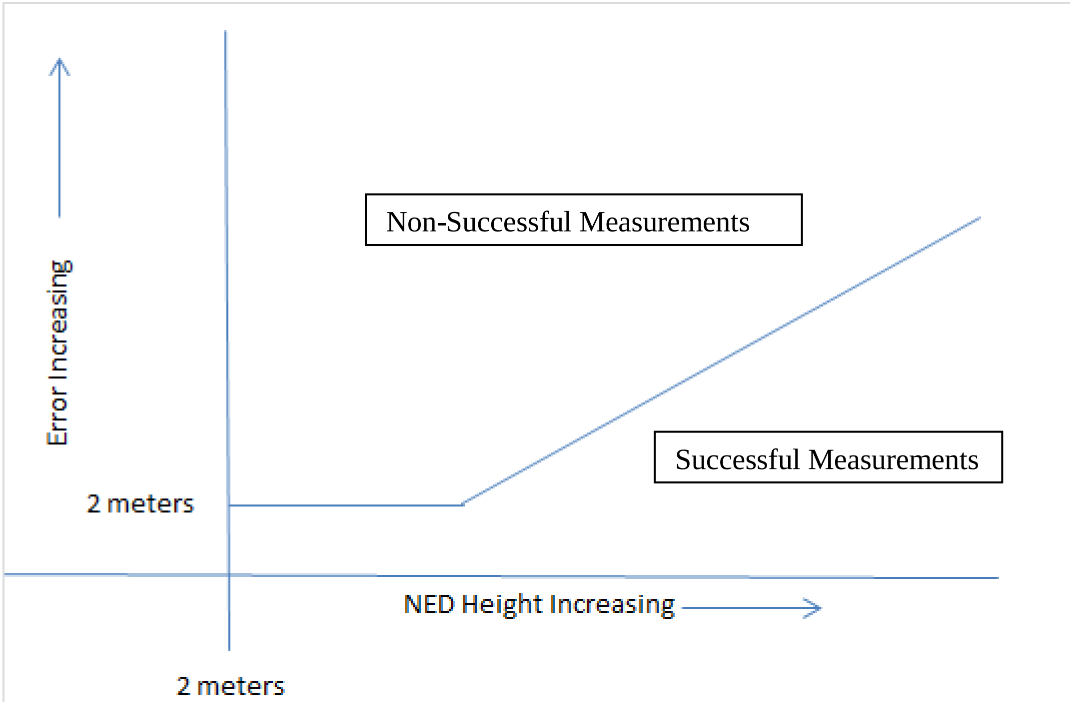


Figure 4.3 The minimum accepted absolute error is based on the NED resolution rounded to 2.00 meters. However, as elevation changes get larger, the accepted absolute error is expected to increase. A standard for accepting sites on the basis of acceptable error is required.

NED Category Selection and Absolute Error Selection

Through trial and error, the incremental NED elevation change bin values for each site were grouped together to form NED height categories. When an elevation change is measured from the NED, the value of the measurement will determine what NED height category the site of interest fits in. The NED height category groups were selected by minimizing the range between individual NED elevation change bin values while maximizing the number of samples within each group. It was desired to have a minimum of 15 samples in each group, see Figure 4.4A and Figure 4.4B below. However, as NED elevation change bin values increased, the number of samples decreased. This resulted in NED height categories with small elevation variations for heights less than 14 meters and large elevation variations for sites greater than 14 meters. The NED height categories selected were 2-3 meters, 4-6 meters, 7-8 meters, 9-13 meters, 14-31 meters, and 32-86 meters.

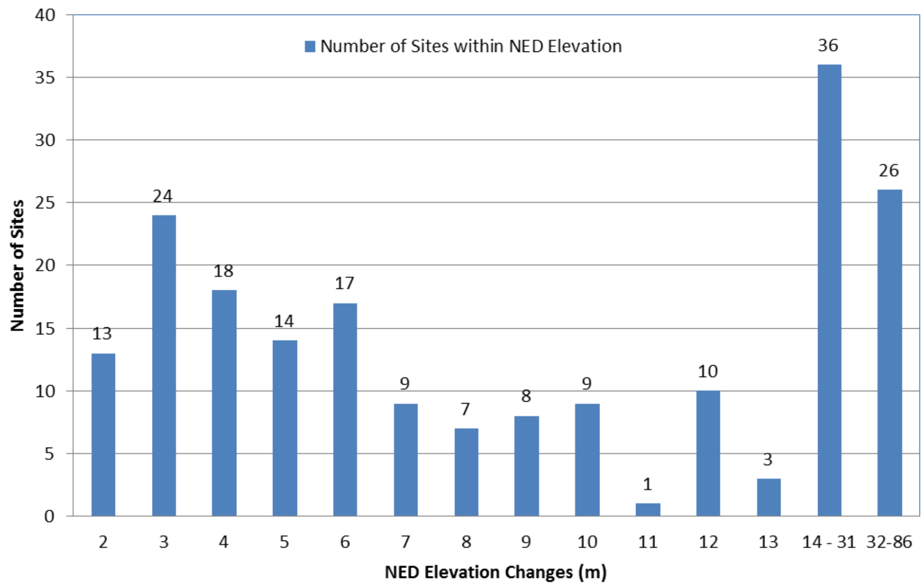


Figure 4.4A The number of sites within each NED elevation bin was listed. NED elevation categories were selected by minimizing the range between elevations within the group while maximizing the number of samples within each category.

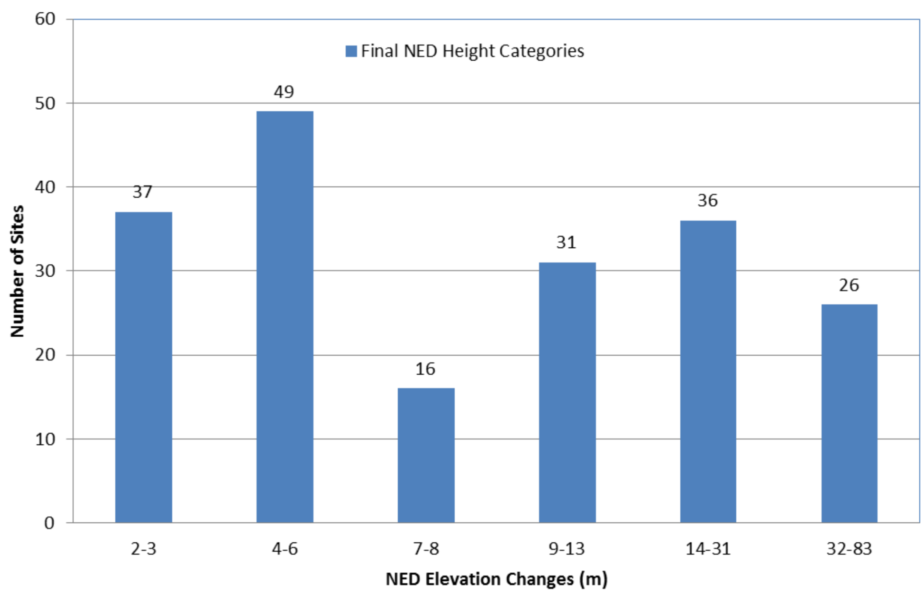
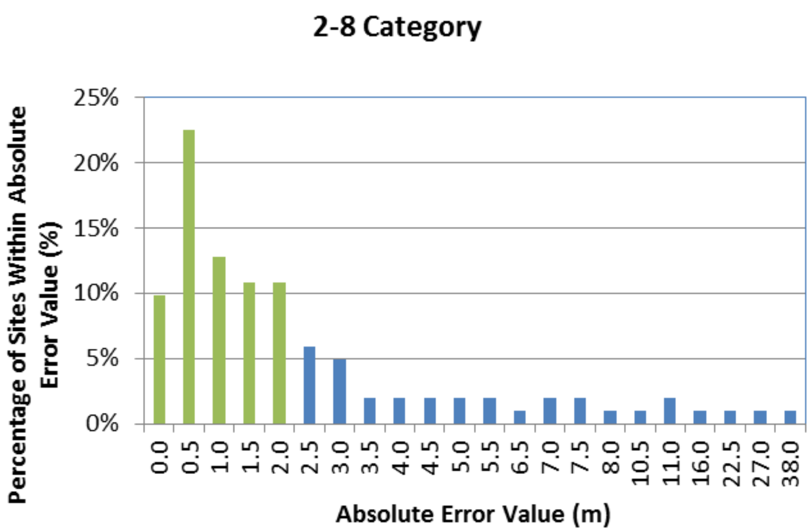
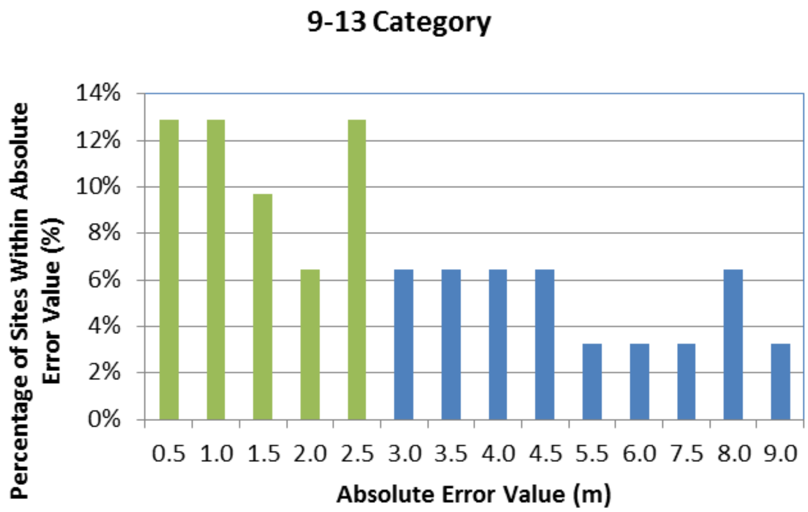


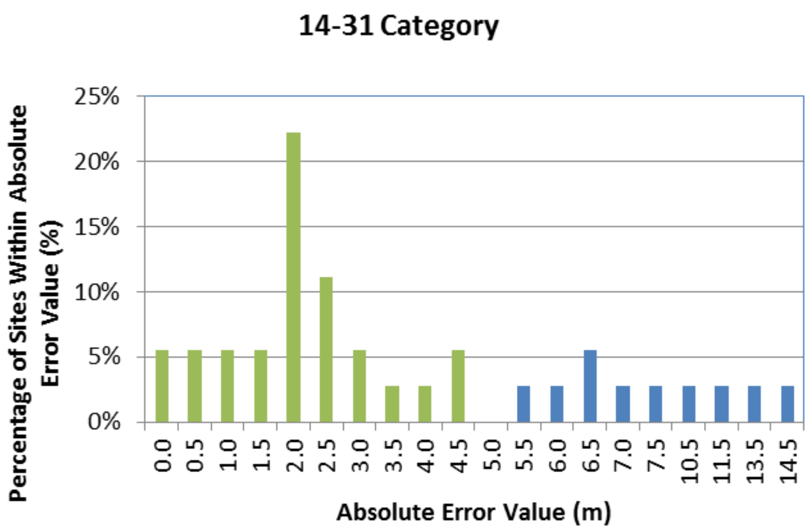
Figure 4.4B The final NED height categories were obtained by combining 2-3 meters, 4-6 meters, 7-8 meters, 9-13 meters, 14-31 meters, and 32-86 meters.

An acceptable absolute error unique to the NED height category was selected. The absolute error for each site within a respective NED height category does not appear to follow any typical error patterns and can be represented by a random error distribution. The difference between the field measured data and the NED elevation change values are dispersed among minimal error to large error. Using the standard deviation for the error distribution of each sample NED height category would require the error to represent a known error distribution pattern which does not exist. Therefore, a histogram was created for each NED height category which reflected the percentage of sites within an absolute error measurement. The selected absolute error for an NED height category was the minimal error value, greater than or equal to 2 meters, needed to contain the majority of the samples. The histograms can be seen in Figure 4.5. Height categories 2-3 meter, 4-6 meter, and 7-8 meter were further grouped together into one histogram.

Sites clusters that were less than or equal to the absolute error value are considered successful measurements as shown in Figure 4.3. Sites greater than the absolute error value are considered non-successful. The accepted error for each NED height category is summarized in Table 4.1. Metric decisions for the criteria selection came from analyzing the metrics of the two distinct datasets in Table 4.1, the successful dataset of 127 sites and the non-successful dataset of 68 sites.




9-13 Category
Percentage of Sites Within Absolute Error Value (%)
14%
12%
10%
8%
6%
4%
2%
0%
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.5 6.0 7.5 8.0 9.0
Absolute Error Value (m)


14-31 Category
Percentage of Sites Within Absolute Error Value (%)
25%
20%
15%
10%
5%
0%
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 10.5 11.5 13.5 14.5
Absolute Error Value (m)

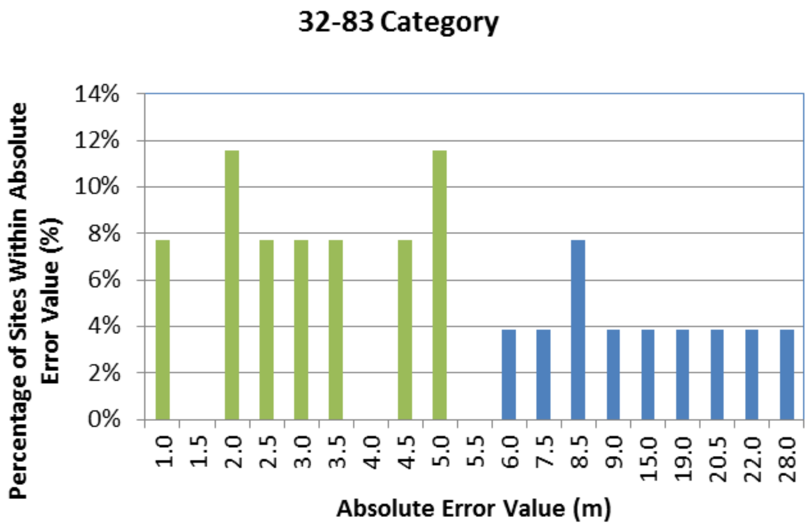


Figure 4.5 The difference of field measured data and NED elevation measurements for each NED height category was plotted for each site. The histogram's presented graphically represent the distribution of site clusters within the error values. Separations were identified by selecting absolute error values which contained the majority of the clusters. Histogram bars are color coded to separate the successful measurements from the non-successful measurements. The accepted error for each NED height category is 2.00 meters for 2-3 meters, 4-6 meters, and 7-8 meters, 2.50 meters for 9-13 meters, 4.5 meters for 14-31 meters, and 5 meters for 32-83 meters.

Table 4.1 Summary of NED height categories and their associated acceptable error

NED Site BIN (m)	Acceptable Error (m)	Number Non-Successful Sites	Number Successful Sites	Total Sites
2-3	2	12	25	**37**
4-6	2	17	32	**49**
7-8	2	5	11	**16**
9-13	2.5	14	17	**31**
14-31	4.5	10	26	**36**
32-83	5	10	16	**26**
	Total	**68**	**127**	

Although the collected field data came from a respectable and trustworthy source, it is relatively small in size. The NED height category and associated acceptable error for each category could potentially be different if a larger dataset was used. The bias applied in this process assumes the data collected is sufficiently diverse and would produce the same results if a larger dataset was collected. This bias is carried to the next steps in the algorithm creation. Although a bias is included in the final results, the outcome is a first comprehensive method of identifying upgradeable micro hydropower sites in constructed waterways and can be improved upon as investigations proceed.

4.1.3 Metric Analysis

Metrics analyzed included the envelope length BIN, 100m Radius Slope BIN, and 500m Radius Slope BIN and were done for the successful and non-successful measurements in each NED height category as shown in Table 4.1. Figure 4.6 represents sheet A of the flowchart used to step through the metric analysis.

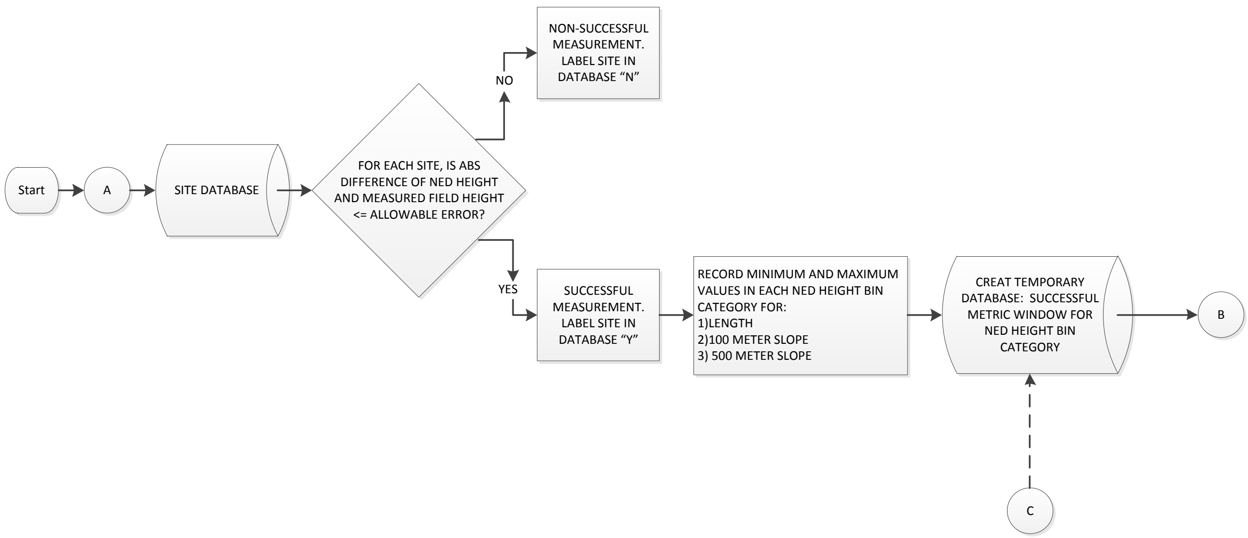


Figure 4.6 The metric analysis began by separating the successful and non-successful sites based on the acceptable error value and identifying the metrics which made up the successful sites.

Once the sites were separated into successful and non-successful categories as described in the previous section, the successful sites within each NED height category were queried and the minimum and maximum value for each metric was recorded in a temporary database used later in the analysis. Table 4.2 summarizes the metric range for the successful and non-successful datasets. The radial slope had two measurements, 100 meter radius and 500 meter radius. If the envelope length was less than or equal to 200 meters, the 100 meter radius slope value was analyzed. If the envelope length was greater than 200 meters, the 500 meter radius value was analyzed. The source datasets can be seen in Appendix B.

Table 4.2 Minimum and maximum metric analysis for successful and non-successful sites

Successful						
Site Bin	Min Length (m)	Max Length (m)	Min 100m Radius Slope (%)	Maximum 100m Radius Slope%	Min 500m Radius Slope %	Maximum 500m Radius Slope%
2-3	50	380	2.00	12.00	2.50	2.50
4-6	50	790	2.50	16.50	3.00	12.00
7-8	50	460	6.75	26.75	2.00	6.50
9-13	70	560	5.25	15.50	5.00	8.25
14-31	70	1570	11.75	28.00	2.25	34.00
32-83	110	3490	29.25	32.25	5.00	33.25

Non-Successful						
Site Bin	Min Length (m)	Max Length (m)	Min 100m Radius Slope (%)	Maximum 100m Radius Slope%	Min 500m Radius Slope %	Maximum 500m Radius Slope%
2-3	60	560	2.00	26.25	4.75	6.75
4-6	90	1140	3.50	21.75	1.25	15.50
7-8	100	300	4.75	14.50	8.25	12.75
9-13	80	1750	7.25	31.75	1.00	10.00
14-30	130	1310	20.25	20.25	3.25	42.50
31-83	250	4070	n/a	n/a	2.00	31.25

Ideally, it would be desired that comparison of the two datasets would produce clear boundaries between the successful and non-successful datasets, see Figure 4.7. If this were the case, the metrics identified in the temporary database for the successful dataset would be forwarded to the algorithm. If the algorithm was applied for an NED height category, 100 percent of the sites identified by the algorithm would be sites originally in the positive dataset. All sites ignored would be sites not within the acceptable error or they would not be sites at all.

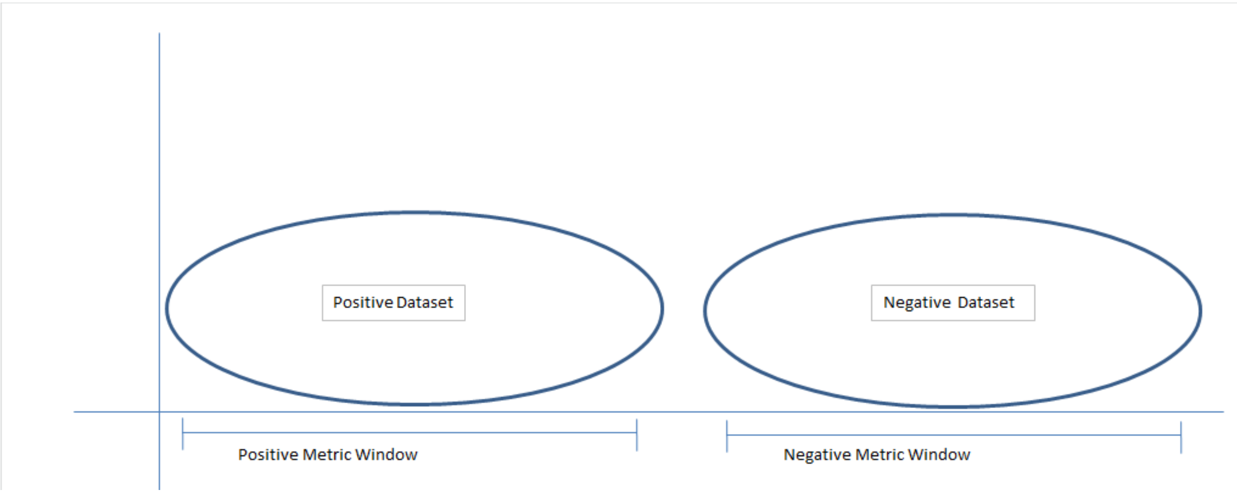


Figure 4.7 It would be desired to have a data distribution such that the metrics analyzed for each dataset would completely isolate each dataset such that no overlap would exist.

However, the data sets produced do have an overlap of metric applications for all three metrics. This overlap is not completely obvious in all cases, however, and the size of the overlap is dependent on the minimum and maximum metric window selected to analyze the datasets. Figure 4.8 is a graphical example of the overlap in question. In order to optimize the algorithm, the overlap needs to be minimized while correctly assigning each site to its correct dataset.

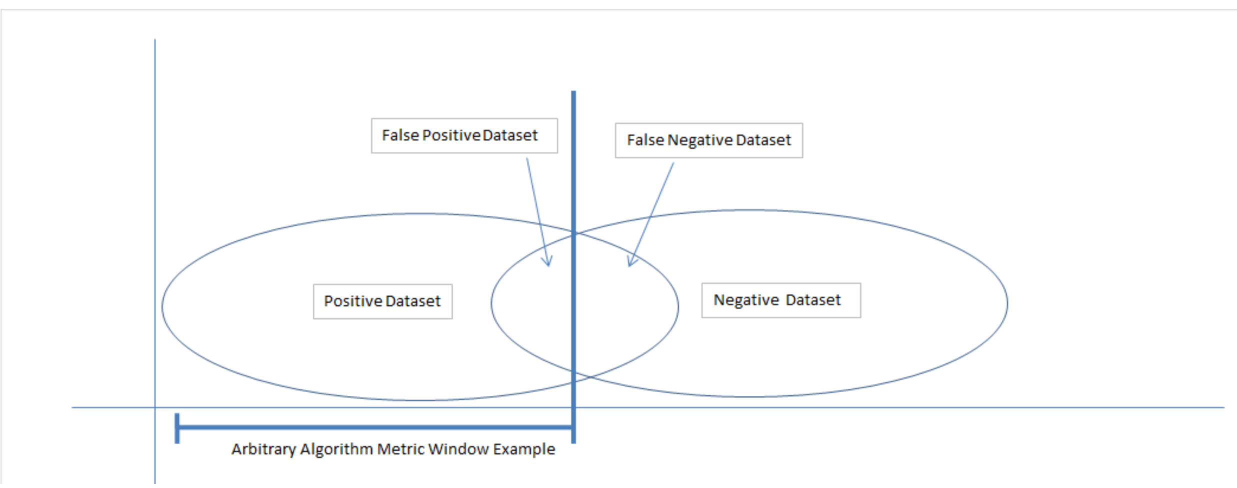


Figure 4.8 The realistic data distribution as a result of selecting metrics will result in a number of false negative and false positive sites as well as the true positive and true negative sites. The purpose of the metric selection will be to minimize the false positives and false negatives while maximizing the true positive and true negative sites.

As a result of the overlap, when the algorithm is applied, there will be a number of sites in the successful dataset that have been excluded based on the metrics assigned to the algorithm. These sites are called “false negative” sites. The metrics assigned to the algorithm did not include these sites although they were originally in the successful dataset. Therefore they are falsely not identified. Likewise, there will be a number of sites in the non-successful dataset that will be included. These sites are called “false positive” sites. The metrics assigned to the algorithm will include these sites although they were originally in the non-successful dataset. Therefore they are falsely identified. Optimization of the algorithm metrics will be achieved by varying the three metrics and comparing for each NED height category (1) percent false positive, (2) percent false negative, and (3) percent correctly placed. Minimizing the false positives and false negatives will maximize the percent correctly place and in turn the accuracy of the algorithm.

$$\emptyset_{FP} = \frac{Number\ of\ False\ Positive}{Total\ Negative\ Sample} \qquad \text{Eq. 4.1}$$

Where:
$\emptyset_{FP}$ = % False Positive

$$\emptyset_{FN} = \frac{Number\ of\ False\ Negative}{Total\ Positive\ Sample} \qquad \text{Eq. 4.2}$$

Where:
$\emptyset_{FN}$ = % False Negative

$$\emptyset_{CORRECT} = \frac{Total\ Sites - (\#False\ Negative + \#\ False\ Positive)}{Total\ Sites} \qquad \text{Eq. 4.3}$$

Where:
$\emptyset_{CORRECT}$ = % Correct

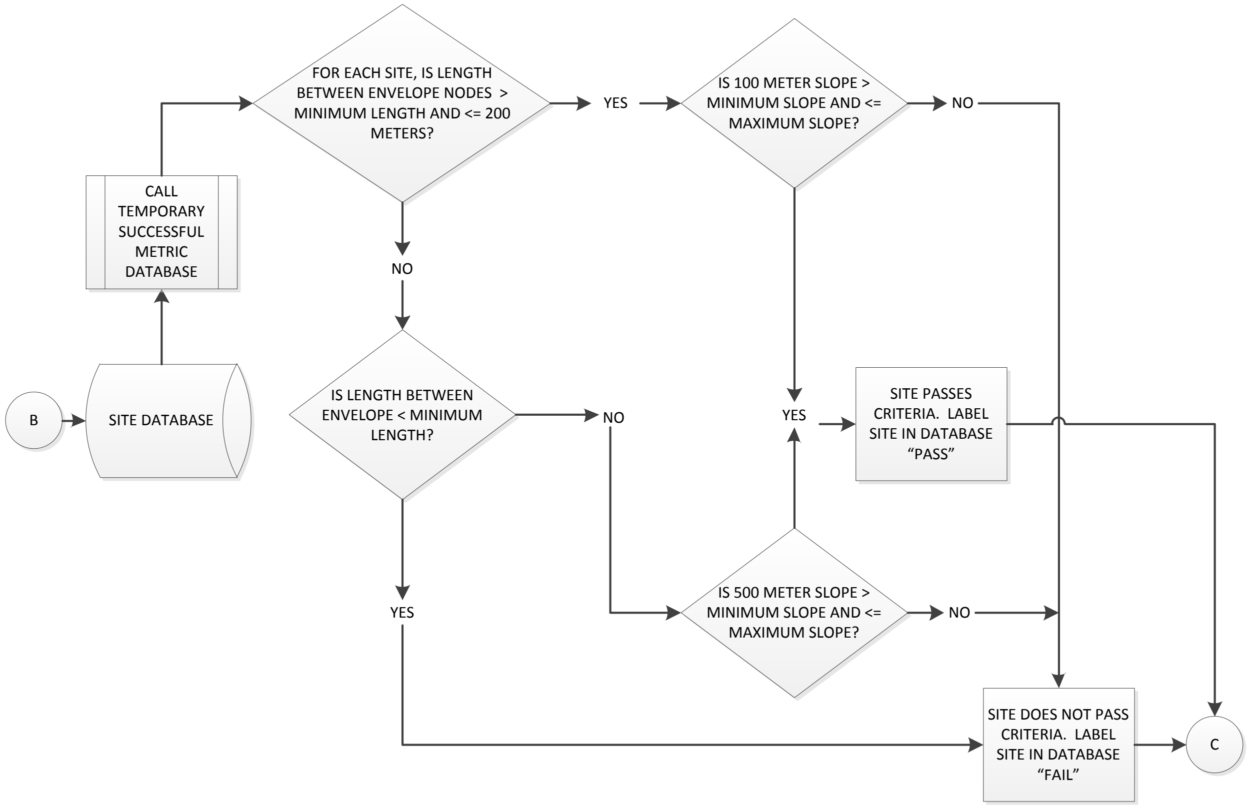


Figure 4.9 Once the temporary metric database was selected, each site was given a "pass" or "fail" identifier to reflect if the site in question met the temporary metric criteria.

To optimize the algorithm metrics as described above, a systematic process was developed. Figure 4.9 reflects sheet B of the flowchart used to step through the metric analysis. Based on the temporary metric database identified in Figure 4.6., each site was given an identifier of "pass" or "fail" to reflect if the site's metrics met all of the criteria in the temporary database. For example, assume the temporary database was compiled of minimum and maximum values for all the successful sites. Metrics for each individual site would then be scrutinized based on the values entered into the temporary database. If the lengths and the average radius slope value were within the bounds entered into the temporary database, the individual site would be labeled "pass". If either of the metrics were not within the bounds of the data entered into the temporary database, the individual site would be labeled "fail". For this specific example where the temporary database was compiled from all the successful sites, when run through the process shown in Figure 4.9 all of the successful sites would be labeled "pass". However, there would also be a number of non-successful sites labeled "pass" as well. The optimization process was designed to select metrics which would label the majority of the successful sites “pass” and the majority of the non-successful sites “fail”.

The next step in the systematic process is shown in Figure 4.10, sheet C of the flowchart used to step through the metric analysis. Comparisons were then made to calculate how well the data entered into the temporary database correctly sorted the sites from the successful and non-successful datasets. If a site originally in the successful dataset was labeled “fail” from the steps described above, this site was identified as a “false negative”. If a site originally in the successful dataset was labeled “pass”, the site was identified as “correct”. Alternatively, if a site originally in the non-successful dataset was labeled “pass”, the site was identified as “false positive”. If a site originally in the non-successful dataset was labeled “fail”, the site was identified as “correct”. After all sites in an NED height category were sorted according to this systematic process, the percent false positive, percent false negative, and percent correct were calculated. Variations were made to the temporary metric database from Figure 4.6. The variations which produced the maximum percent correct with minimum percent false negative and percent false positive were assigned as the correct algorithm variation for the NED height category. In cases where the percent correct was the same for multiple variations of metrics, the variation which minimized the false positive and false negative ratio was selected. This analysis was done using Excel. A sample spreadsheet is represented in Appendix B.

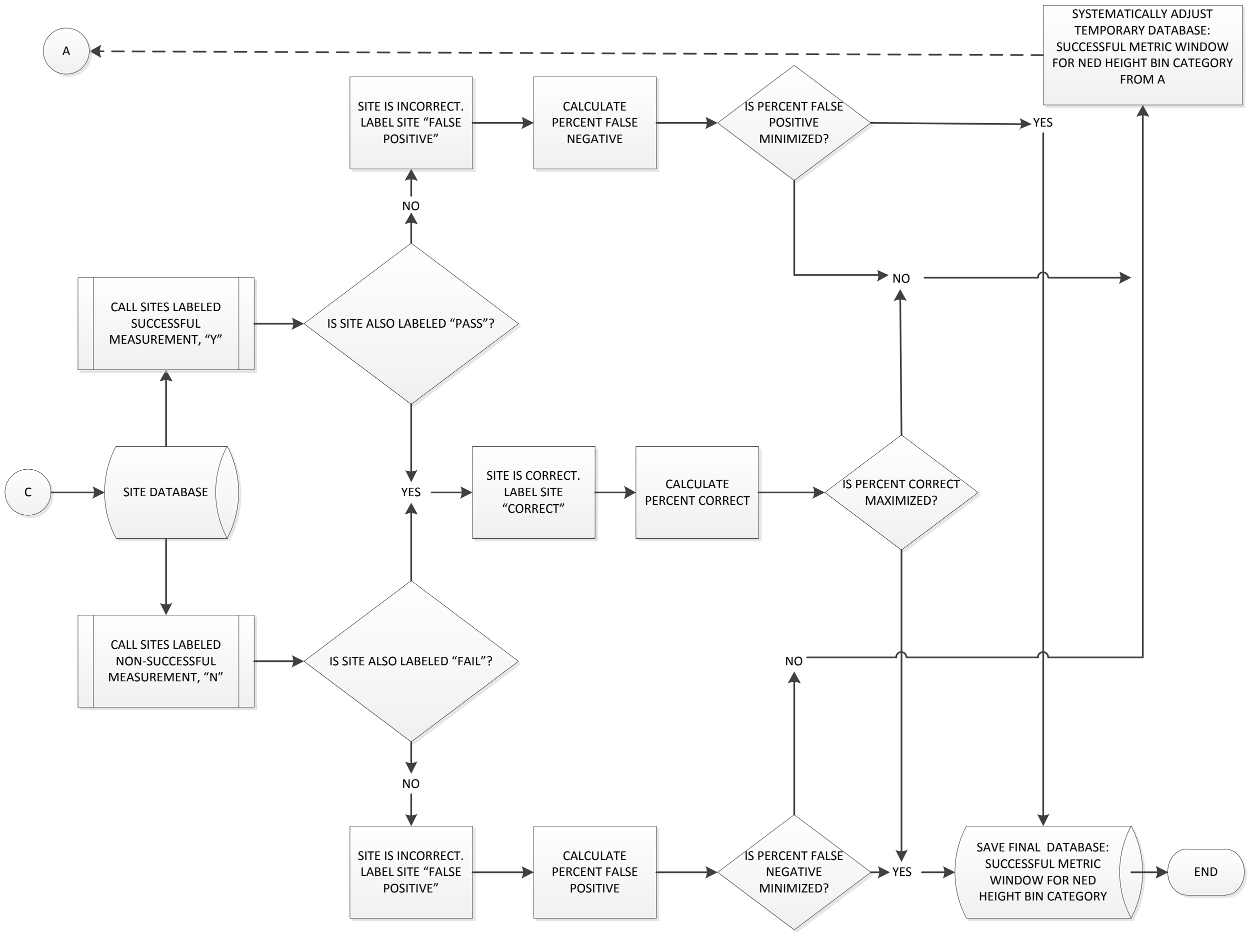


Figure 4.10 A comparison was made to identify the percent of sites which were labeled correctly by the temporary metric database. The algorithm was quantified when the percentage of false positives and false negatives were minimized and the percentage of correct sites were maximized.

Variations

The first and second metric variations applied were the minimum and maximum values for the NED categories in the (1) successful dataset and (2) non-successful dataset from the results shown in Table 4.2. The third variation was derived manually by reviewing the source data and identifying the critical path which retained as many of the positive sample as possible while minimizing the negative sample selection. Additional variations were modeled in an attempt to identify a more accurate selection and can be seen in Appendix B.

4.1.4 Results

The bias identified in the previous section has additional implications to the final results. The metrics for the algorithm were derived from analyzing the entire sample size in the dataset collected. The outcome is an algorithm which produces optimized results in terms of probabilities of successful site counts. However, the outcome was obtained by applying the algorithm to the same dataset in which it was derived and fine tuning the metrics to improve the results. This introduces the assumption to the final results that the same outcome would be obtained if the algorithm was applied to an unknown dataset. The criteria for each metric category were selected from methods described in the previous section and are reflected in Table 4.3.

Table 4.3 Final results of metric analysis for 40 meter envelope

NED Site BIN	Acceptable Error (m)	Min Length (m)	Max Length (m)	100m Radius MIN (%)	100m Radius MAX (%)	500m Radius MIN (%)	500m Radius MAX (%)
2-3	2.00	50	130	2.00	11.75		
4-6	2.00	50	320	4.50	16.00	3.00	12.00
7-8	2.00	50	460	9.00	13.50	2.00	6.50
9-13	2.50	50	290	7.50	12.50	5.00	8.25
14-31	4.50	50	920	11.75	28.00	2.25	20.75
32-83	5.00	50	2350	29.25	32.25	5.25	12.75
Total Sites	**Number Negative**	**Number False Positive**	**Number Positive**	**Number False Negative**	**False Positive in Sample (%)**	**False Negative in Sample (%)**	**Probability of Correct Selection (%)**
37	12	3	25	2	25%	8%	**86%**
49	17	8	32	6	47%	19%	**71%**
16	5	0	11	2	0%	18%	**88%**
31	14	3	17	3	21%	18%	**81%**
36	10	4	26	5	40%	19%	**75%**
26	10	2	16	4	20%	25%	**77%**

Reviewing Table 4.2, the minimum successful envelope length is 5o meters and the minimum length for the non-successful sites was 60 meters. Sites were not eliminated having an envelope length less than 50 meters, therefore this was the value selected for the minimum length for all NED site bin categories. It is expected that as the as the NED site bin increases, the envelope length will increase as well. This can be seen in the results with the exception of the 9-13 category. The envelop length for the 9-13 category seems to recess from the increasing trend. Under further review, the 7-8 category has the least amount of sites analyzed, 16. It is possible that with a larger sample size it is more likely that the correct value for 4-6, 7-8 and 9-13 NED site bin is 300 meters. This same type of trend can be witnessed in the 100 meter radius min and max % columns. The 500 meter radius reflects a much more random pattern. The changes seen in a ½ kilometer radius may be to varied to categorize any particular point within the area. However, much like the trend witnessed, additional data needs to be collected to fine tune these results. However, under the bias applied, this criteria can be applied in an algorithm to identify and count potential structure locations, the type of structure being identified, and provide a probability of finding the sites of the elevation change reflective of the NED height category.

Applying the algorithm would result in a probability of correct sites selected. For instance, if a the algorithm was applied to an unknown dataset and 100, 2-3 meter sites were identified, it is probable that 86 of the 100 sites are actually correct sites. This is the largest application of the bias presented in the previous section. This bias assumes that the dataset used to define the algorithm is a good representation of all sites in the field and any site count conducted will result in probable site locations as described by the algorithm. Applying the algorithm will be the first comprehensive attempt to count locations in constructed waterways suitable for upgrading to micro hydropower generators without going to the field or requesting information from local authorities.

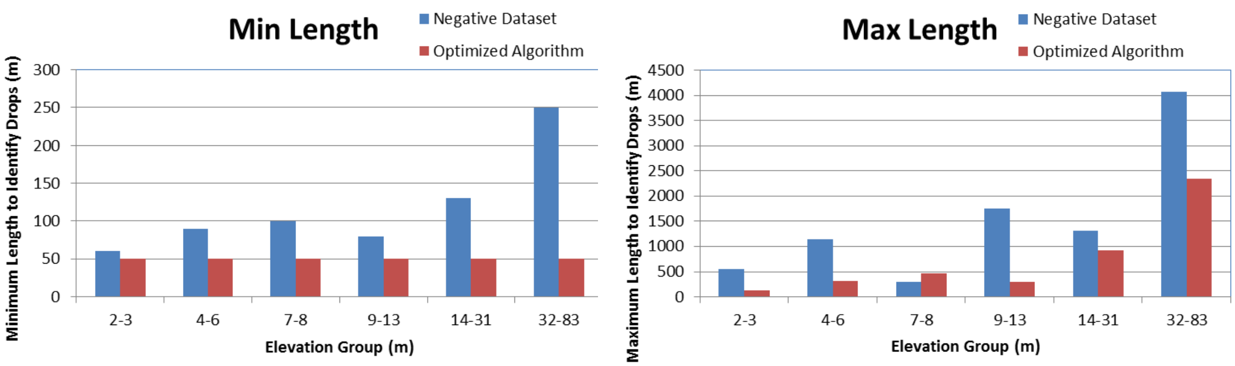


Figure 4.11 Minimum and maximum length comparisons of the optimized algorithm results to the non-successful dataset metrics

A graphical comparison is used to show the differences between the optimized algorithm and the original negative dataset. Figure 4.11 graphically compares the minimum and maximum lengths for each dataset. The minimum length identified in the algorithm was the minimum length in which any site was detected. There were no eliminations of negative sites based on identifying them in too short of a distance. However, the maximum length for the algorithm is much less than the maximum length in the negative dataset in all cases but one. This suggests that one reason the negative sites were not within the acceptable error of the field measurements is the span was too great to capture the influence of the drop structure. For instance, a 2-6 meter drop structure should not occur over 0.50 kilometers. A drop structure with that length is typically a chute with a much larger vertical drop association.

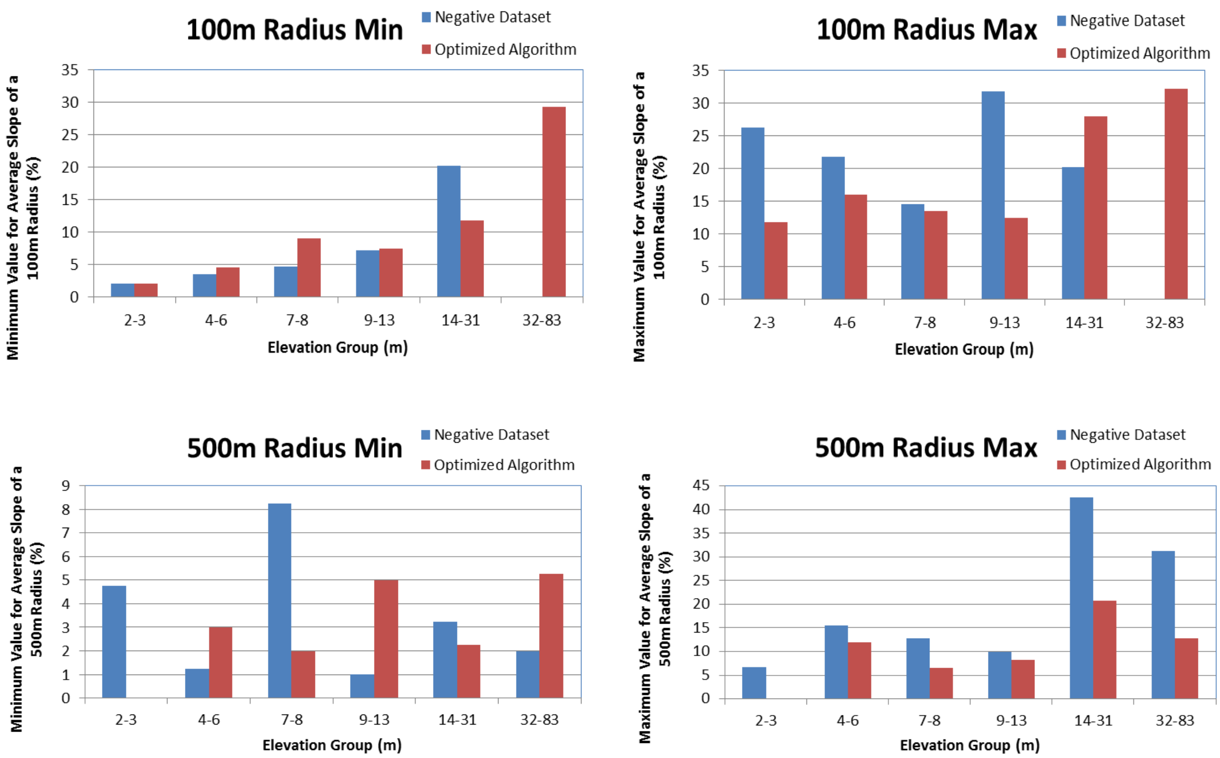


Figure 4.12 Minimum and maximum average slope value comparisons of the optimized algorithm results to the non-successful dataset metrics

The ability of the NED to accurately identify the correct elevation change of a drop structure is dependent on the average slope of the surrounding area. Figure 4.12 graphically compares the minimum and maximum average slope values for each dataset. The average slope within a 100 meter radius was used for drop structures that occurred in distances less than or equal to 200 meters. The average slope within a 500 meter radius was used for sites that occurred in distances greater than 200 meters. A limit to the maximum average slope value is identified for a drop structure of a given height. In most cases, the algorithm values are less than the negative dataset values for this limit. These results show the accuracy of the NED is influence by the geographic region's topographic patterns. The NED cannot detect a vertical change of a drop structure in areas where the NED measurements of slopes are greater than 32 percent. Additionally, 2 percent slopes are the minimum range in which the NED is applicable.

Power Calculations

The boundaries identified in the algorithm development are most useful to identify and count potential structure locations, the type of structure being identified, and provide a level of accuracy of the elevation change measured from the NED. The level of accuracy is provided in terms of the acceptable error value, see Table 4.4. When conducting a power calculation, equation 2.6, it is necessary to have a net head value. The net head value will be the value obtained from the NED. However, this value is only within the acceptable error of the NED. Therefore the net head obtained from the NED to be utilized in the power equation is

$$H_T = NED\ elevation\ \pm NED\ Acceptable\ Error \qquad \text{Eq. 4.4}$$

Where:
H_T = Net Head to be used in equation 2.6

Although the absolute value of the difference between the field measured elevation data and the NED elevation data (error in meters) was used to identify the NED categories, it is necessary to identify how the error was actually distributed by analyzing the true difference between the field measured elevation data and the NED elevation data. This is displayed in Figure 4.13.

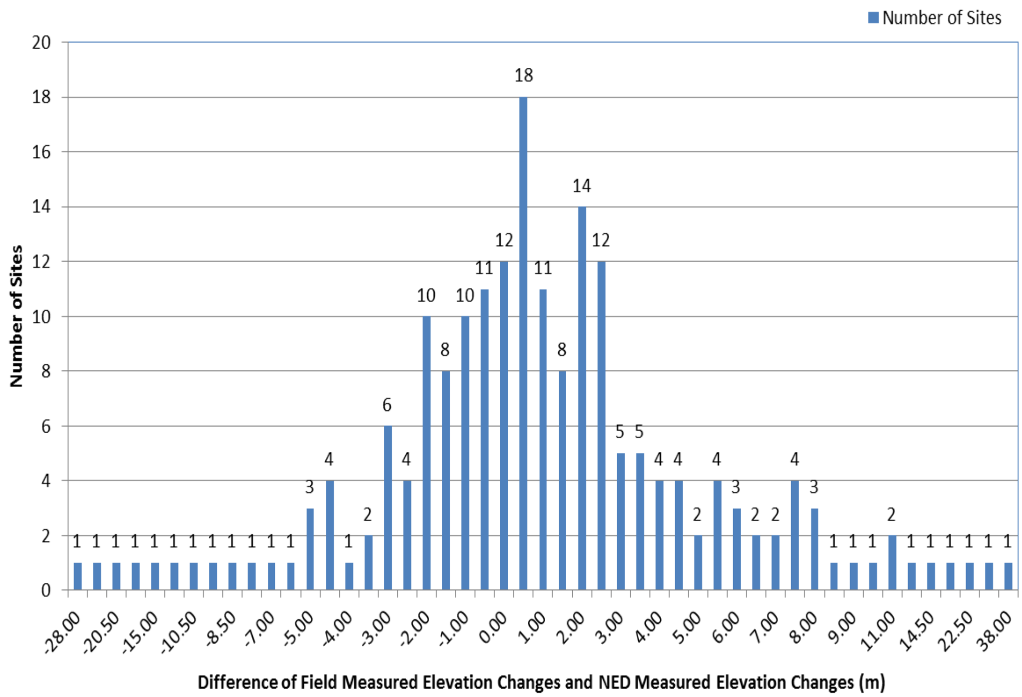


Figure 4.13 The actual error associated with the 195 sites used to conduct the study.

For any individual site measurement within the NED expected accuracy value of 2 meters, there is a ± 2 meter elevation value for each site measurement. This is significant because any power calculation based on an individual site, if the site fits in this window, would represent up to 2 meter error in the head calculation in equation 2.11. An example would be an NED elevation BIN value of 5 meter height. The actual elevation could be 7 meters or 3 meters. However, when a population of sites within 2 meter elevation value is grouped, there are a certain percentage of sites in the + 2 meter group and a certain percentage of sites in the – 2 meter group. It is necessary to analyze how the acceptable error is balanced for each NED category. The result would be to understand the probability of overestimating or underestimation the actual elevation change of a site using the NED elevation change across the site. For example, if all the 7-8 meter sites had a majority of error in the +2 meter range, using the NED elevation value in equation 2.11 would be conservative. Knowing the probability of whether net head estimates are conservative or overestimates provides a level of understanding of the realistic net head values. Figure

4.14 is a graphical display of how the acceptable error is distributed for each NED elevation class while Table 4.4 summarizes this information for each NED height category.

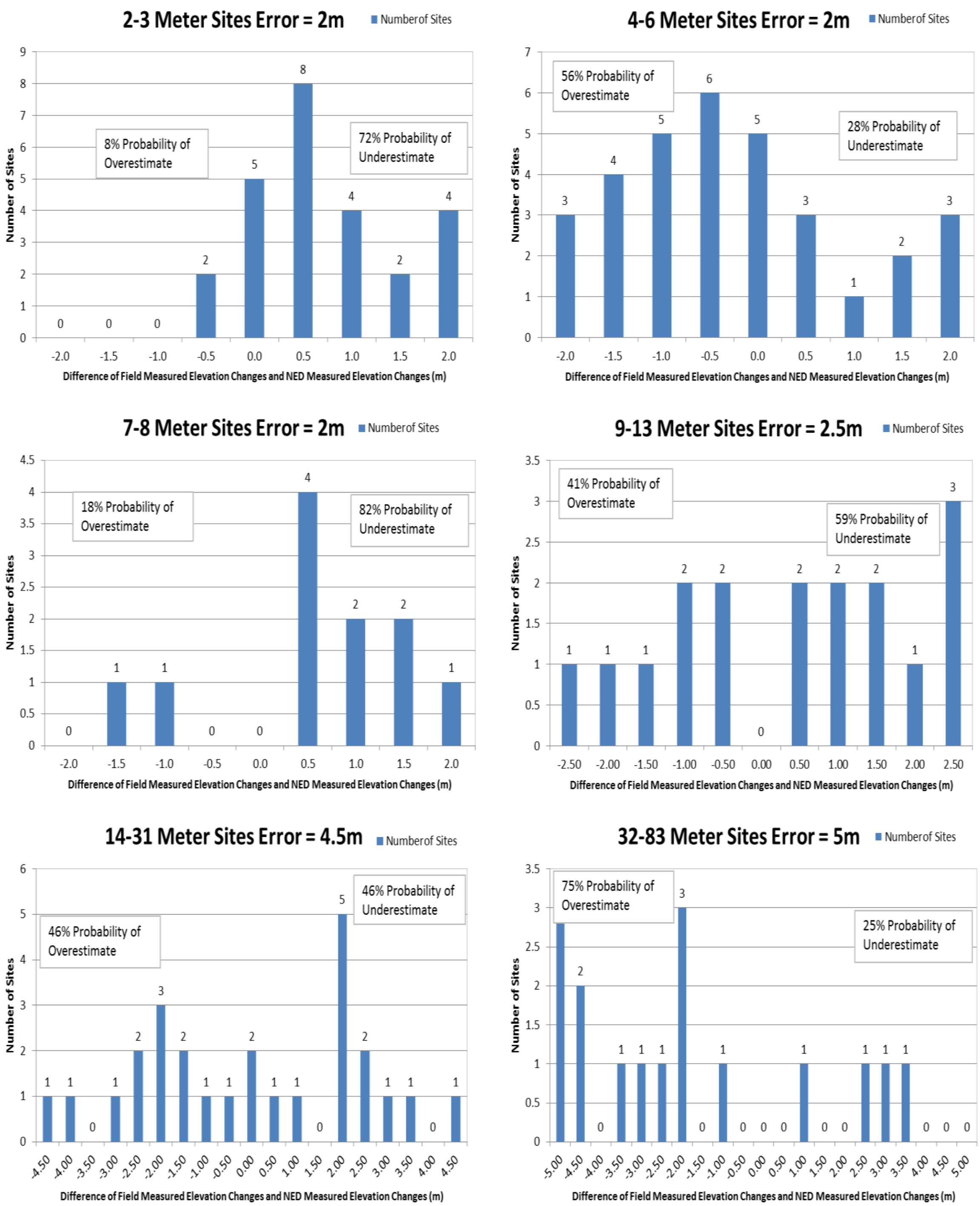


Figure 4.14 The difference in the field measured elevation change and the NED measured elevation change still reflect a random distribution pattern around the value of 0.

The difference in the field measured elevation change and the NED measured elevation change still reflect a random distribution pattern around the 0 difference value. The bias as listed in the previous section is still presented with the data selected from the algorithm. The lasting assumption is the probabilities as summarized in Table 4.4 would be detected if a larger dataset had been obtained and analyzed.

Table 4.4 Probability of overestimating or underestimation the actual elevation change of a site using the NED elevation change across the site

NED Height Category (m)	Acceptable Error (m)	Probability of Underestimate of Net Head	Probability of Overestimate of Net Head
2-3	2.00	72%	8%
4-6	2.00	28%	56%
7-8	2.00	82%	18%
9-13	2.50	59%	41%
14-31	4.50	46%	46%
32-83	5.00	25%	75%

Using the NED measured elevation value for the net head in equation 2.11 is a conservative approach for NED height categories 2-3 meter, 7-8 meter, and 9-13 meter. The 14-31 meter category has a balance between the conservative and overestimate probabilities. Therefore, for sites in the 14-31 meter category, the net head value can be assumed as correct. For sites within 4-6 meters and 32-83 meters, the NED measured elevation value would overestimate the available head in a given sample.

Comparison to 70 Meter Envelope

All the steps listed in the previous sections were applied to the 70 meter envelope as well. Results for this analysis are listed in Table 4.5. Figure 4.15 is a graphical depiction of the comparison of the accuracy of the 40 meter envelope data and the 70 meter envelope data. The 70 meter envelope produced more false positives and false negatives for each NED site category. This is reflected in the accuracy of the algorithm. The accuracy of the 70 meter envelope data is less than the 40 meter envelope value. For this reason, the 40 meter envelope was utilized in creating the algorithm.

Table 4.5 Final results of metric analysis for 70 meter envelope

NED Site BIN	Acceptable Error (m)	Min Length (m)	Max Length (m)	100m Radius MIN (%)	100m Radius MAX (%)	500m Radius MIN (%)	500m Radius MAX (%)
2-3	2.00	50	190	1.75	12.25		
4-6	2.00	50	380	2.50	11.75	3.00	12.00
7-8	2.00	50	320	6.75	16.00	2.50	17.75
9-13	2.50	50	580	7.75	12.25	2.00	8.25
14-31	4.50	50	970	7.25	20.25	2.25	20.75
32-83	5.00	50	2350	29.25	32.25	5.00	14.00
Total Sites	**Number Negative**	**Number False Positive**	**Number Positive**	**Number False Negative**	**False Positive in Sample (%)**	**False Negative in Sample (%)**	**Probability of Correct Selection (%)**
27	6	3	21	2	50%	10%	**81%**
65	28	14	37	5	50%	14%	**71%**
19	10	4	9	2	40%	22%	**68%**
38	16	4	22	4	25%	18%	**79%**
37	11	4	26	6	36%	23%	**73%**
28	10	2	18	5	20%	28%	**75%**

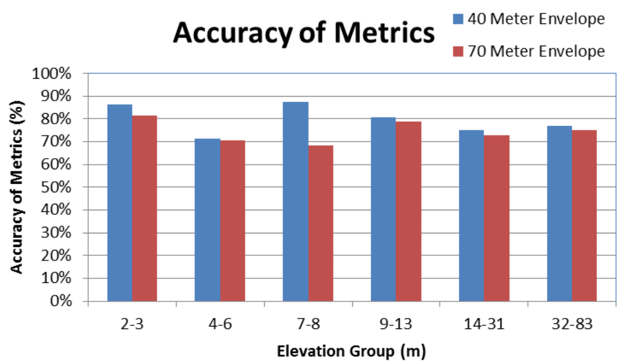


Figure 4.15 Comparison of 40 meter envelope and 70 meter envelope accuracy results

Type of Structure Identified

The range of the type of structures identified in each NED category was reviewed. For future work, it will be necessary to incorporate into the algorithm the range of equipment type available for use to upgrade the structures identified as the cost of the equipment is a large percentage of the total project cost. The structure type limits the range of applicable equipment. It is not the scope of this report to detail how each site would be upgraded. A brief overview of applicable equipment types for each structure category is documented in (Applegate, 2011). The applicable sub-category structures identified included chutes, pipelines, series of drops, steep grade changes and vertical drops. The detail of these types of structures was reviewed in Chapter 3.

The dataset produced by using the algorithm was queried to identify the range of structures within each NED classification, review Figure 4.16.

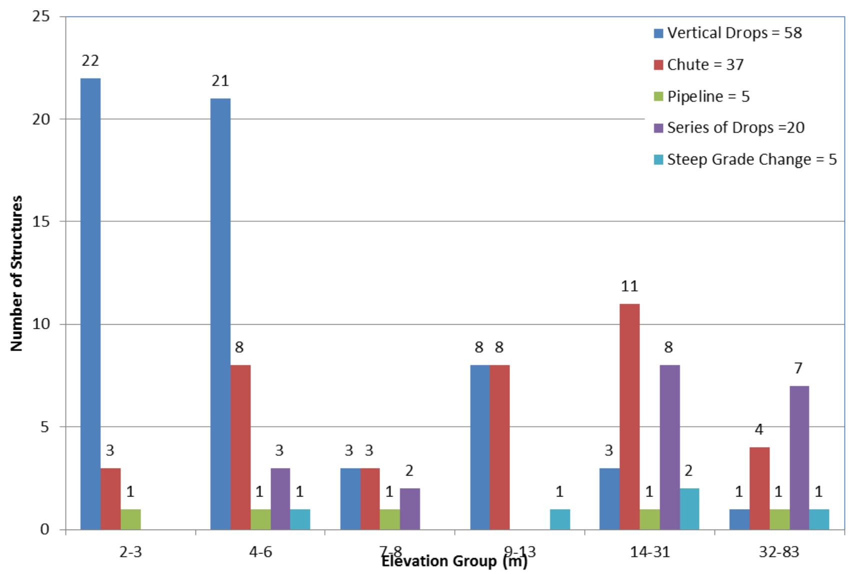


Figure 4.16 Drop types within NED height category

Vertical drops and chutes are the most frequently occurring type of structure identified. Series of drops are a category included from the data submitted by the USBR. However, an aerial photographic review of the structures within series of drops show this category consist mostly of vertical drops and chutes. When measuring the drop height from the NED using the 40 meter envelope data, 2-3 meter drops and 4-6 meter drops consist mostly of vertical drops followed by chutes. However, chutes are most prominent in elevations higher than 4-6 meters. These results suggest the types of structures most deserving of investigation of design standardization procedures would be vertical drops and chutes.

4.2 NED 30m versus 10m Resolution

For any given survey, the level of accuracy of the data collection process needs to be specified. Although the most accurate data is always desired, there is an associated cost and time allotment with obtaining the data. For instance, a survey of all potential upgradeable drop structures in irrigation canals in the United States would most accurately be conducted by visiting each individual site. This type of survey could take years and have a fairly large expense associated with it.

Free, publically available data for the surface model regions of this survey existed in the form of 30 meter resolution and 10 meter resolution NED digital elevation models. The 10 meter NED data has a much higher resolution than the 30 meter data (9X the resolution of 30 meter NED data) however, this higher resolution did not come without a tradeoff; larger files and longer processing times. Figure 4.17 is a graphical example of the differences observed between using the 30 meter and 10 meter NED data. The 30 meter data has much more variation between peaks and sinks in the alignment. Significant discrepancies in the profile can be seen in Figure 4.17 particularly downstream of the stations of interest. In this are there exists a 2 meter positive vertical change in the downstream direction suggesting water flows up and over a large hill. Additionally, in this example, the elevation captured is about 3 meters less than the elevation captured using the 10 meter NED data, the 10 meter NED data being the more correct of the two.

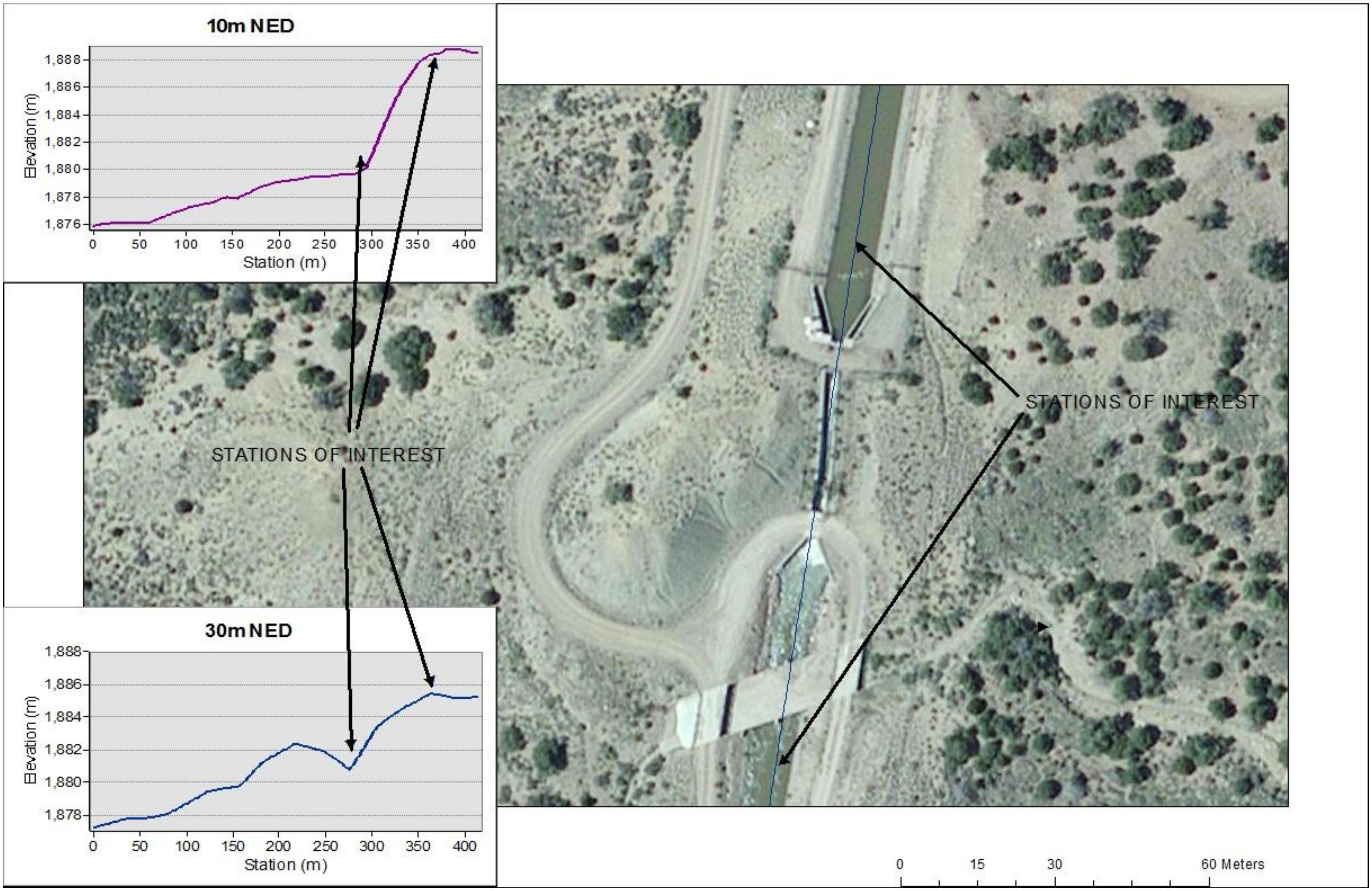


Figure 4.17 Large discrepancies can be seen when comparing the 30 meter NED profile vs. 10 meter NED profile. The 30 meter NED data produces errors which reflect large uphill slopes in the downstream direction.

The analysis shown in the previous sections was conducted using information obtained for each site from 30 meter NED files. This analysis was conducted using points relative to the 40 meter envelope placement. The similarities and differences between the 30 meter NED dataset and the 10 meter NED dataset are discussed below and shown in Table 4.6.

Table 4.6 Summary of NED height categories and their associated acceptable error for data obtained from 30 meter NED data.

NED Site BIN (m)	Acceptable Error (m)	Number Non-Successful Sites	Number Successful Sites	Total Sites
2-3	2	12	24	**37**
4-6	2	14	29	**49**
7-8	2	12	15	**16**
9-13	2.5	15	12	**31**
14-31	4.5	4	29	**36**
32-83	5	11	18	**26**
	Total	**68**	**127**	

The same number of sites were identified in the final dataset for the 30 meter NED data, 195. Of 195 sites, 189 sites are the exact same sites. Six sites are different, see Table 4.7. Of the 195 sites in the 30 meter NED dataset, the same numbers of sites are identified in the successful and non-successful datasets as the 10 meter NED data, 127 and 68 respectively.

Table 4.7 Sites Excluded from each NED dataset. Datasets excluded from each NED set were based on the NED measured elevation was less than the minimum for the study, 2 meters.

Site I.D.	Actual Height (m)	10 Meter NED Elevation Change (m)	30 Meter NED Elevation Change (m)
74	3.35	1.62	2.05
98	3.63	1.36	2.49
444	2.31	1.69	3.84
BF11	2.81	1.59	2.77
HS10	3.05	0.98	2.40
S5B	2.44	1.29	2.44
72	6.49	2.10	1.66
143	4.27	2.04	1.16
231	11.00	2.85	1.63
265	4.66	2.43	1.95
295	3.35	2.09	1.31
MD6	2.74	2.19	1.66

The 6 sites excluded from each NED measurement dataset were excluded because their respective NED elevation was less than 2 meters, the minimum requirement to include a site in the analysis. The NED measured net head values are relatively in the same range for all the sites. The same metric analysis was conducted with the 30 meter NED dataset. The results are shown in Table 4.8.

Table 4.8 Final results of metric analysis for 30 meter NED data and 40 meter envelope

NED Site BIN	**Acceptable Error (m)**	**Min Length (m)**	**Max Length (m)**	**100m Radius MIN (%)**	**100m Radius MAX (%)**	**500m Radius MIN (%)**	**500m Radius MAX (%)**
2-3	2.00	50	130	2.25	10.75	n/a	n/a
4-6	2.00	50	320	4.25	14.50	2.75	10.50
7-8	2.00	50	260	4.25	11.25	2.25	3.75
9-13	2.50	50	290	8.25	11.00	4.50	4.50
14-31	4.50	50	920	7.00	26.25	2.25	30.75
32-83	5.00	50	2350	26.50	27.50	4.75	25.50
Total Sites	**Number Negative**	**Number False Positive**	**Number Positive**	**Number False Negative**	**False Positive in Sample (%)**	**False Negative in Sample (%)**	**Probability of Correct Selection (%)**
36	12	4	24	1	33%	4%	**86%**
43	14	8	29	6	57%	21%	**67%**
27	12	7	15	3	58%	20%	**63%**
27	15	2	12	2	13%	17%	**85%**
33	4	2	29	3	50%	10%	**85%**
29	11	4	18	3	36%	17%	**76%**

The accuracy of the metrics derived for the 30 meter NED data are less than that for the 10 meter NED data for all NED site categories but 9-31 meter sites, see Figure 4.18. For these cases, 10% is the largest difference for the 14-31 meter category being the largest. The results from this analysis suggest the diminished accuracy from digital elevation models with less resolution does affect the results when identifying drop structures. The higher resolution dataset, 10 meter resolution NED digital elevation model, should be used.

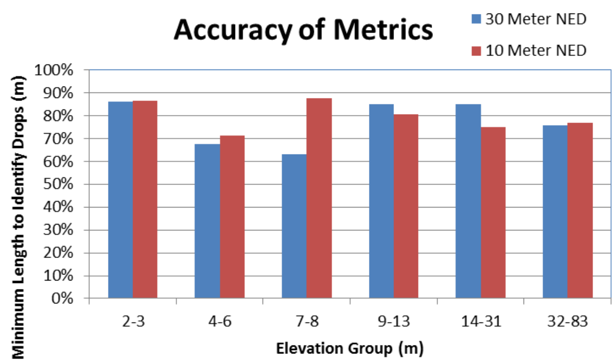


Figure 4.18 Accuracy comparison of 10 meter NED and 30 meter NED

Chapter 5- Conclusions

Advances in technology for the generation and interconnection of micro hydropower have increased the applicability of micro hydropower as a significant source of power generation. Changes to the current regulatory process pertaining to micro hydropower are being explored to encourage the development of micro hydropower projects, specifically in existing constructed waterways. Micro hydropower projects in constructed waterways will most likely take place at locations where existing hydraulic structures are present. Currently, the amount of hydropower that can be obtained from upgrades to existing structures in Colorado is unknown. The methods employed to date to identify the type and quantity of infrastructure for potential upgrade to support micro hydropower production are executed by conducting field surveys and data requests from regional authorities or experienced field personnel and have been shown to be incomplete.

The location and magnitude of upgradeable hydraulic structures can be investigated and identified using publically available GIS data. The study was conducted by collecting field data from site visits and the United States Bureau of Reclamation, and analyzing the profile of each structure as obtained from the National Elevation Dataset to these field measurements. Differences between the elevations upstream and downstream of each set were recorded and compared. The disagreement between the datasets does not follow any typical error distribution and is only classified as random. An algorithm was developed, using the obtained dataset, to locate and classify potential upgradeable structures in constructed waterways with a defined probability of success. As the algorithm was developed using the datasets collected, the inherent bias applied assumes the data collected is sufficiently diverse and the probabilities observed would be present if a larger dataset was collected.

An alternative approach to conducting this type of study would include field visits to all canals throughout a region and surveying each site extensively. A study of this magnitude would be prohibitive both financially and timely. Although a bias is included in the final results, the outcome of this work is a first comprehensive method of identifying upgradeable micro hydropower sites in constructed waterways and can be improved upon as investigations proceed. With additional data collection efforts being applied to incorporate seasonal flow conditions within canals, the results from this study imply the power potential and resulting energy potential of each individual site identified and the net results of all sites within a substantial region can be estimated within the level of acceptable error and with the understanding if the estimate is conservative or and overestimate.

The results from this study define an algorithm for application to any dataset. The algorithm identifies the probability of identifying the location and magnitude of a site as determined by the individual site's metrics. The probability is only applicable if each metric obtained from publically available GIS data is within a defined performance window. The algorithm can be applied to identify and count potential structure locations, the type of structure being identified, and identify the net head available in a region.

Table 5.1 Final results of metric analysis for 40 meter envelope

NED Site BIN	Acceptable Error (m)	Min Length (m)	Max Length (m)	100m Radius MIN (%)	100m Radius MAX (%)	500m Radius MIN (%)	500m Radius MAX (%)
2-3	2.00	50	130	2.00	11.75		
4-6	2.00	50	320	4.50	16.00	3.00	12.00
7-8	2.00	50	460	9.00	13.50	2.00	6.50
9-13	2.50	50	290	7.50	12.50	5.00	8.25
14-31	4.50	50	920	11.75	28.00	2.25	20.75
32-83	5.00	50	2350	29.25	32.25	5.25	12.75
Total Sites	Number Negative	Number False Positive	Number Positive	Number False Negative	False Positive in Sample (%)	False Negative in Sample (%)	Probability of Correct Selection (%)
37	12	3	25	2	25%	8%	**86%**
49	17	8	32	6	47%	19%	**71%**
16	5	0	11	2	0%	18%	**88%**
31	14	3	17	3	21%	18%	**81%**
36	10	4	26	5	40%	19%	**75%**
26	10	2	16	4	20%	25%	**77%**

Specifically, it was shown the best results were obtained from sampling NED 10 meter resolution elevations every 40 meters on National Hydrography Dataset alignments. The level of resolution for the datasets used directly correlate to the cost of the study. In terms of NED datasets, the cost can be realized in processing times, data acquisition and availability, and storage. A comparison was made between 10 meter and 30 meter resolution NED datasets in order to determine if the difference in resolution affected the quality for our purposes. It was shown the 10 meter resolution dataset is the dominant dataset and should be used in future applications of this work. However, higher resolution dataset in terms of LIDAR technology are increasingly becoming available. It is anticipated that the methodology explored within this work will soon be applied using LIDAR digital elevation models for the elevations datasets in which the level of accuracy is expected to increase significantly.

A method to accurately assess micro hydropower potential in constructed waterways is important because current regulations restrict the development of these resources by equating the permitting process to large, potentially environmental exhaustive projects. Policy changes to encourage hydropower in constructed waterways will require an accurate representation of the power available in these facilities. Additionally, it is desired to identify "sure shot" locations in constructed waterways in which similar micro hydropower design solutions exist. This process will aid in classifying which sites are considered applicable for step and repeat implementation procedures.

5.1 Future Work

5.1.1 Software Development

The work presented in this report identified geospatial metrics to support an estimation of total site count and resource availability of potential micro hydropower. Currently, work is being done to develop a program which will use the information in this report to conduct the site count and resource availability analysis. This analysis will be conducted, not only in Colorado, but anywhere NHD and NED data exists in the United States.

Figure 5.1 shows a clip of the software being developed. In the main window, the profile of multiple structures normalized in the x and y axis, overlaid on each other can be seen. There exists a similar profile signature for each structure unique to the type of structure being analyzed. The program will explore using similitude to identify these signatures in a large dataset.

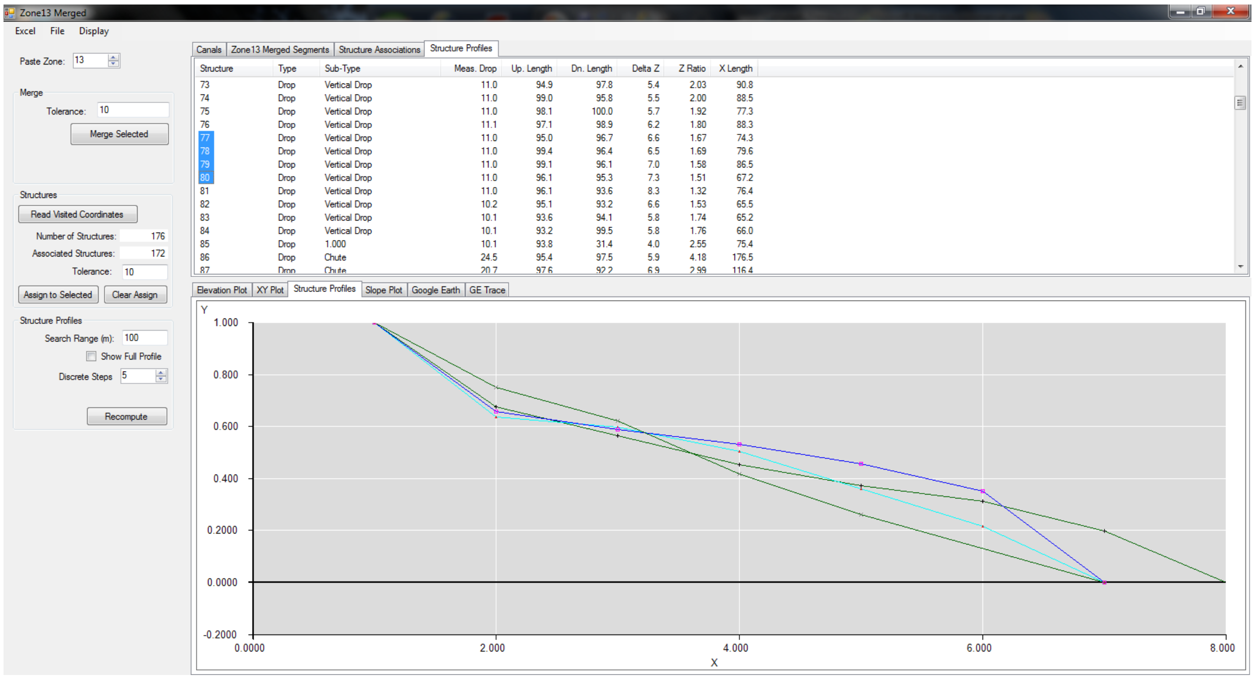


Figure 5.1 Analysis Program in Development

The immediate next steps include applying the algorithm to the same complete set of data used to develop the algorithm and documenting the results. In this effort, it is essentially being verified that the algorithm does indeed ignore sites within the dataset that are not sites and record the same sites it was successfully recording in the fine tuning process. The algorithm then needs to be applied to an unknown dataset with the results being verified using aerial photography and field visits. This application will provide insight to how well the assumptions used in the algorithm derivation withstood, and will highlight strengths and weaknesses associated with the algorithm so further fine tuning can be applied if needed.

Results from this study indicate that irrigation hydropower sites may be grouped into a relatively small set of categories, consisting of vertical drops, chutes, pipelines, and steep grade changes. The most prominent drop structure identified included vertical drops and chutes. Equipment specific to these type of structures need to be researched and the specific cost index of applying these upgrades needs to be quantified. There exists the possibility to develop a standardized engineering design for each category, reducing engineering costs, risks, and implementation time for irrigation hydropower projects. Metrics specific to this standardized engineering design can be incorporated into the software being developed. This techno-economic decision making model will enable decisions to be made that are specific to developing the resources identified. The end result will be an engineered pre-design that predetermines which technologies are most applicable to the specific site design and optimize the engineering of each site for the highest quality and most cost effective solution.

5.1.2 Flowrate Identification

One outstanding variable of the proposed analysis forecast is the accurate identification of flowrates at the structures of interest in irrigation canals. In equation 2.6, this is the variable Q. Historically, Q is based off the 30% exceedance value for the duration of the flow period at a site of interest. Flow diminishes in any given channel as a result of withdraws, seepage loss, and evaporative losses. Flow data acquisition, specific to a structure of interest, introduces additional complications. Previous assessment studies identified in this report do not address constructed waterways. Flowrate values for these reports are based on average annual hydrology calculations. However, irrigation release rates follow complex guidelines associated with water rights, reservoir rule curves, and additional regulatory regulations. An in depth study of existing historical flow resources specific to irrigation canals for every NHD flowline representative of constructed waterways is needed.

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33. Shuttle Radar Topography Mission, http://srtm.usgs.gov

Appendix A-Datasets

The appendix is organized to display the data sets used in this study and the resulting workflow to identify an optimized metric criteria. Although Chapter 4 revealed tables specific to the 10m resolution NED digital elevation models analyzed at the 40 meter envelope interval, two other datasets were also studied. These datasets include 10 meter resolution NED digital elevation models analyzed at the 70 meter envelope interval, and 30 meter resolution NED digital elevation models analyzed at the 40 meter envelope interval. The datasets will be identified in the appendix as Dataset 1, Dataset 2, and Dataset 3 respectively.

Appendix A is comprised of all data sets used in the study. Table A.1 is the original data set, unaltered, as obtained from field surveys and data provided by the United States Bureau of Reclamation. Descriptions of the columns of Table A.1 are as follows:

Div	If the site was in Colorado, Div column reflects the hydrologic division the site is located in.
State	State the site is located in.
Owner	Owner of site.
Canal Name	Canal name the site is located on. In some cases, this was unknown.
Structure I.D.	Identification tag assigned to the structures of interest.
Location	Location of structure relative to canal.
Category	Category of the structure, Drop, Weir, Flow measurement etc.
Classification	Type of structure, see Chapter 3.
Sub-Classification	Additional data on structure, see Chapter 3.
Notes	Notes for additional description of structure. May be relative to ArcGIS data, may be relative to field collection.
Elevation Change (ft)	Recorded height of structure from the field
U.S. Width (ft)	Width of canal upstream of the structure.
Distance to Nearest Tie In (ft)	Distance to nearest utility line as recorded from the field.
# of Insulators	Number of insulators on the utility line. This is used to estimate the line voltage of interconnect.
X coord	Longitude coordinate in WGS format.

Table A.1 All Dataset

Div	State	Owner	Canal Name	Structure I.D.	Location	Category	Classification	Sub-Classification	Notes	Elevation Change (ft)	U.S. Width (ft)	Distance to Nearest Tie In (ft)	# of Insulators	Xcoord	Ycoord
1	CO	NCWCD	Dixon Feeder Canal	DX_1	Inline	Drop	Vertical Drop			10	10	400	1	-105.159	40.590
1	CO	NCWCD	Hanson Supply Canal	HS_1	Inline	Drop	Spillway w Dissipation			34.32	58	1	2	-105.210	40.659
1	CO	NCWCD	Hanson Supply Canal	HS_2	Inline	Drop	Siphon		siphon not much head	3.24	58	125	4	-105.208	40.657
1	CO	NCWCD	Hanson Supply Canal	HS_3	Turnout	Drop	Pipeline		Hand Drawn	16.86	1	1	2	-105.203	40.654
1	CO	NCWCD	Hanson Supply Canal	HS_4	Inline	Drop	Siphon		siphon not much head	3	30	775	4	-105.196	40.647
1	CO	NCWCD	Hanson Supply Canal	HS_5	Inline	Weir	Sharpcrested			3	30	50	4	-105.194	40.644
1	CO	NCWCD	Hanson Supply Canal	HS_6	Inline	Drop	Siphon			17.3	30	270	H	-105.188	40.631
1	CO	NCWCD	Hanson Supply Canal	HS_7	Inline	Drop	Siphon		siphon not much head	1.8	30	1200	1	-105.184	40.619
1	CO	NCWCD	Hanson Supply Canal	HS_8	Inline	Weir	Sharpcrested			3	30	690	1	-105.178	40.615
1	CO	NCWCD	Hanson Supply Canal	HS_9	Inline	Weir	Sharpcrested			3	30	50	H	-105.173	40.603
1	CO	NCWCD	Hanson Supply Canal	HS_10	Inline	Drop	Chute			10	37	150	1	-105.172	40.602
1	CO	NCWCD	Hanson Feeder Canal 550	HF550_1	Inline	Drop	Siphon		siphon not much head	0.72	27			-105.197	40.505
1	CO	NCWCD	Hanson Feeder Canal 550	HF550_2	Inline	Drop	Siphon		siphon not much head	3.23	10.5			-105.206	40.492
1	CO	NCWCD	Hanson Feeder Canal 550	HF550_3	Inline	Drop	Siphon		siphon not much head	0.57	27			-105.220	40.486
1	CO	NCWCD	Hanson Feeder Canal 550	HF550_4	Turnout	Drop	Pipeline		Steep Grade Change	42	1	1	2	-105.216	40.442
1	CO	NCWCD	Hanson Feeder Canal 930	HF930_1	Inline	Drop	Siphon		siphon not much head	0.81	27			-105.219	40.440
1	CO	NCWCD	Hanson Feeder Canal 930	HF930_2	Inline	Drop	Siphon		siphon not much head	1.49	27			-105.226	40.423
1	CO	NCWCD	St. Vrain Supply	SV_1	Inline	FlowMeasurement	Parshall			2.52	30	30	4	-105.258	40.216
1	CO	NCWCD	St. Vrain Supply	SV_2	Inline	Drop	Chute			158.3	27	1	2	-105.258	40.218
1	CO	NCWCD	St. Vrain Supply	SV_3A	Turnout	Drop	Chute		Steep Grade Change/Hand Drawn	256	27	1	PC	-105.209	40.256
1	CO	NCWCD	St. Vrain Supply	SV_3B	Inline	Weir	Overshot			3	27	1	PC	-105.209	40.256
1	CO	NCWCD	St. Vrain Supply	SV_4	Inline	Drop	Siphon			5.39	27	350	PC	-105.209	40.257
1	CO	NCWCD	St. Vrain Supply	SV_5	Turnout	Drop	Pipeline			257	1	1	2	-105.209	40.258
1	CO	NCWCD	St. Vrain Supply	SV_6	Inline	Drop	Chute			84.02	27	480	4	-105.201	40.298

Div	State	Owner	Canal Name	Structure I.D.	Location	Category	Classification	Sub-Classification	Notes	Elevation Change (ft)	U.S. Width (ft)	Distance to Nearest Tie In (ft)	# of Insulators	Xcoord	Ycoord
1	CO	NCWCD	St. Vrain Supply	SV_7	Inline	Weir	Overshot			1.57	15	1	PC	-105.207	40.319
1	CO	NCWCD	Boulder Feeder Canal	BF_1	Inline	Drop	Drop Structure			34.65	32	1230	H	-105.217	40.086
1	CO	NCWCD	Boulder Feeder Canal	BF_2	Inline	Weir	Sharpcrested			2	32	1850	H	-105.217	40.088
1	CO	NCWCD	Boulder Feeder Canal	BF_3	Inline	Drop	Drop Structure			3.85	32	2500	PC	-105.217	40.090
1	CO	NCWCD	Boulder Feeder Canal	BF_4	Inline	Drop	Drop Structure			5.69	32	800	PC	-105.218	40.094
1	CO	NCWCD	Boulder Feeder Canal	BF_5	Inline	Drop	Drop Structure			5.69	32	370	PC	-105.219	40.094
1	CO	NCWCD	Boulder Feeder Canal	BF_6	Inline	Drop	Siphon			6.24	32	1	PC	-105.221	40.095
1	CO	NCWCD	Boulder Feeder Canal	BF_7	Turnout	Drop	Pipeline		skipped, NHD data does not line up good, don't know how to hand draw	3	1			-105.221	40.095
1	CO	NCWCD	Boulder Feeder Canal	BF_8	Turnout	Drop	Pipeline			3	1			-105.223	40.099
1	CO	NCWCD	Boulder Feeder Canal	BF_9	Inline	Weir	Overshot			1.5	32	1	3	-105.227	40.104
1	CO	NCWCD	Boulder Feeder Canal	BF_10	Turnout	Drop	Pipeline			1	32			-105.227	40.104
1	CO	NCWCD	Boulder Feeder Canal	BF_11	Inline	Drop	Siphon			9.23	32	475	H	-105.231	40.163
1	CO	NCWCD	Boulder Feeder Canal	BF_12	Inline	Drop	Drop Structure			3.85	32	30	2	-105.255	40.214
1	CO	NCWCD	Boulder Feeder Canal	BF_13	Inline	Drop	Siphon			7.37	32	95	1	-105.256	40.215
1	CO	NCWCD	Boulder Supply Canal	BS_1	Inline	Drop	Spillway w Dissipation			21.48	27	140	5	-105.187	40.051
1	CO	NCWCD	Boulder Supply Canal	BS_2	Inline	FlowMeasurement	Parshall			5.76	27	150	H	-105.188	40.053
1	CO	NCWCD	Boulder Supply Canal	BS_3	Inline	Drop	Drop Structure			5.25	27	140	H	-105.192	40.056
1	CO	NCWCD	Boulder Supply Canal	BS_4	Inline	Drop	Drop Structure			8.17	27	1	PC	-105.192	40.059
1	CO	NCWCD	Boulder Supply Canal	BS_5	Inline	Gate	Vertical			0	10	1	PC	-105.201	40.076
1	CO	NCWCD	Boulder Supply Canal	BS_6	Turnout	Drop	Vertical			12	1	100	2	-105.211	40.078
1	CO	NCWCD	Boulder Supply Canal	BS_7	Reservoir	Drop	Pipline			20	1	100	2	-105.211	40.078
1	CO	Poudre River	Poudre River	PR_1	Diversion	Drop	Barrage					1	240	-105.107	40.612
1	CO	LWC	Larimer and Weld Canal	LWC_1	Diversion	Gate	Barrage	Vertical		2		1	240	-105.107	40.612
1	CO	LWC	Larimer and Weld Canal	LWC_2	Inline	FlowMeasurement	Parshall			2	40	1	H	-105.105	40.613
1	CO	LWC	Larimer and Weld Canal	LWC_3	Inline	Drop	Checkdrop			2.5	40	275	7	-105.032	40.602
1	CO	LWC	Larimer and Weld Canal	LWC_4	Turnout	Drop	Pipeline			4	40	245	7	-105.027	40.602

Div	State	Owner	Canal Name	Structure I.D.	Location	Category	Classification	Sub-Classification	Notes	Elevation Change (ft)	U.S. Width (ft)	Distance to Nearest Tie In (ft)	# of Insulators	Xcoord	Ycoord
1	CO	LWC	Larimer and Weld Canal	LWC_5	Inline	Weir	Rockstructure			3	40	950		-104.950	40.569
1	CO	LWC	Larimer and Weld Canal	LWC_6	Inline	Drop	Gate Drop	Other		4	40	1	7	-104.920	40.544
1	CO	LWC	Larimer and Weld Canal	LWC_7	Inline	Drop	Checkdrop	Obermyer		6	40	1	Obermeyer	-104.912	40.541
1	CO	LWC	Larimer and Weld Canal	LWC_8	Inline	Weir	Obermeyer			0	40	1	Obermeyer	-104.870	40.540
1	CO	LWC	Larimer and Weld Canal	LWC_9	Inline	Drop	Steep Grade Change			3	40	240	2	-104.850	40.543
1	CO	LWC	Larimer and Weld Canal	LWC_10	Inline	Drop	Checkdrop	Obermyer		4	40	650	2	-104.821	40.540
1	CO	LWC	Larimer and Weld Canal	LWC_11	Inline	Weir	Obermeyer			1	40	730		-104.804	40.547
1	CO	LWC	Larimer and Weld Canal	LWC_12	Inline	Drop	Checkdrop	Obermyer		2.5	40	340	H	-104.763	40.532
1	CO	LWC	Larimer and Weld Canal	LWC_13	Inline	Weir	Obermeyer			1	40	800		-104.765	40.551
1	CO	LWC	Larimer and Weld Canal	LWC_14	Inline	Weir	Obermeyer			2.5	40	1	Obermeyer	-104.755	40.558
1	CO	LWC	Larimer and Weld Canal	LWC_15	Inline	Weir	Obermeyer			0	40	1	Obermeyer	-104.749	40.568
1	CO	LWC	Larimer and Weld Canal	LWC_16	Inline	Weir	Obermeyer			0	40	270		-104.730	40.568
1	CO	LWC	Larimer and Weld Canal	LWC_17	Inline	Weir	Obermeyer			0	30	1	Obermeyer	-104.722	40.565
1	CO	LWC	Larimer and Weld Canal	LWC_18	Inline	Weir	Obermeyer			0	30	460	H	-104.705	40.575
1	CO	LWC	Larimer and Weld Canal	LWC_19	Inline	Weir	Obermeyer			0	30	340	2	-104.690	40.581
1	CO	LWC	Larimer and Weld Canal	LWC_20	Inline	Weir	Adjustable			3.5	30	1	2	-104.687	40.585
1	CO	LWC	Larimer and Weld Canal	LWC_21	Inline	Weir	Obermeyer			0	30	950		-104.669	40.594
1	CO	LWC	Larimer and Weld Canal	LWC_22	Inline	Drop	Checkdrop	Obermyer		0	30	75		-104.658	40.596
1	CO	LWC	Larimer and Weld Canal	LWC_23	Inline	Drop	Steep Grade Change				30	300	H	-104.629	40.555
1	CO	LWC	Larimer and Weld Canal	LWC_24	Inline	Weir	Rockstructure				30	1560	H	-104.609	40.551
1	CO	LWC	Larimer and Weld Canal	LWC_25	Inline	Weir	Obermeyer			3	20	1	H	-104.601	40.543
1	CO	LWC	Larimer and Weld Canal	LWC_26	Inline	Drop	Checkdrop			2.5	20	1	H	-104.597	40.542
1	CO	LWC	Larimer and Weld Canal	LWC_27	Inline	Weir	Obermeyer			0	20	1	4	-104.590	40.547
1	CO	LWC	Larimer and Weld Canal	LWC_28	Inline	Weir	Obermeyer			2.5	20	1	2	-104.568	40.552
1	CO	LWC	Larimer and Weld Canal	LWC_29	Inline	Weir	Obermeyer			0	20	1	2	-104.563	40.549
1	CO	LWC	Larimer and Weld Canal	LWC_30	Inline	Drop	Checkdrop			0	20	430	2	-104.560	40.546
1	CO	LWC	Larimer and Weld Canal	LWC_31	Inline	Weir	Obermeyer			1	20	1	2	-104.559	40.537
1	CO	LWC	Larimer and Weld Canal	LWC_32	Inline	Weir	Rockstructure			2.5	20	1	2	-104.547	40.523

Div	State	Owner	Canal Name	Structure I.D.	Location	Category	Classification	Sub-Classification	Notes	Elevation Change (ft)	U.S. Width (ft)	Distance to Nearest Tie In (ft)	# of Insulators	Xcoord	Ycoord
2	CO	Arkansas River	Arkansas River	AR_1	Diversion	Drop	check drop			9		1	PC	-103.944	38.126
2	CO	Catlyn Canal	Catlyn Canal	CT_1	Diversion	Drop	Pipeline			5	1	1	PC	-103.944	38.126
2	CO	Arkansas River	Arkansas River	AR_2	Inline	Drop	Check Drop	Obermeyer		9		1	4	-103.809	38.118
2	CO	Fort Lyon Canal	Fort Lyon Canal	FLC_1	Diversion	Gate	Barrage	Radial		7.5	56	1	4	-103.809	38.118
2	CO	Fort Lyon Canal	Fort Lyon Canal	FLC_2	Diversion	Weir	Barrage	Overshot		0	85	1	4	-103.599	38.013
2	CO	Fort Lyon Canal	Fort Lyon Canal	FLC_3	Diversion	Weir	Barrage	Overshot		3	77	1	2	-103.589	38.011
2	CO	Fort Lyon Canal	Fort Lyon Canal	FLC_4	Turnout	Drop	Gate Drop	Radial		4.58	15	1	4	-103.578	38.009
2	CO	Fort Lyon Canal	Fort Lyon Canal	FLC_5	Inline	FlowMeasurement	Parshall			2.5	60	1	4	-103.569	38.007
2	CO	Fort Lyon Canal	Fort Lyon Canal	FLC_6	Inline	Weir	Overshot			2.5	60	1	2	-103.550	38.005
2	CO	Fort Lyon Canal	Fort Lyon Canal	FLC_7	Inline	Weir	Overshot			4.17	60	1	2	-103.380	38.083
2	CO	Fort Lyon Canal	Fort Lyon Canal	FLC_8	Inline	Drop	Siphon	Pipeline		20	60	400	2	-103.378	38.111
2	CO	Fort Lyon Canal	Fort Lyon Canal	FLC_9	Inline	Weir	Overshot			1.5	60	1	240	-103.252	38.107
2	CO	Fort Lyon Canal	Fort Lyon Canal	FLC_10	Inline	Weir	Overshot			2.5	60	1	240	-103.214	38.113
2	CO	Fort Lyon Canal	Fort Lyon Canal	FLC_11	Inline	Weir	Overshot			1.5	60	1	4	-103.157	38.135
2	CO	Fort Lyon Canal	Fort Lyon Canal	FLC_12	Inline	Gate	Barrage	Radial		1	65	520	PC	-103.030	38.133
2	CO	Fort Lyon Canal	Fort Lyon Canal	FLC_13	Inline	Weir	Overshot			4	50	1	4	-102.780	38.259
2	CO	Fort Lyon Canal	Fort Lyon Canal	FLC_14A	Inline	Gate	Radial			2	25	5150	H	-102.569	38.214
2	CO	Fort Lyon Canal	Fort Lyon Canal	FLC_14B	Turnout	Weir	Overshot			3	25	5150	H		
2	CO	Fort Lyon Canal	Fort Lyon Canal	FLC_15	Inline	Drop	Vertical Drop	Check Drop		24.66	25	150	2	-102.576	38.199
2	CO	Rocky Ford Highline	Rocky Ford Highline	RHC_1	Diversion	Gate	Barrage	Vertical		0.17	26	480	H	-104.240	38.226
2	CO	Rocky Ford Highline	Rocky Ford Highline	RHC_2	Turnout	Drop	Gate Drop	Radial	Hand Drawn	2.5	12	0	0	-104.223	38.216
2	CO	Rocky Ford Highline	Rocky Ford Highline	RHC_3	Turnout	Drop	Gate Drop	Radial	Hand Drawn	3	12	3030	PC	-104.216	38.211
2	CO	Rocky Ford Highline	Rocky Ford Highline	RHC_4	Turnout	Drop	Gate Drop	Vertical	Hand Drawn	4.58	10	260	PC	-104.208	38.206
2	CO	Rocky Ford Highline	Rocky Ford Highline	RHC_5	Inline	FlowMeasurement	Parshall			3	40	380	PC	-104.208	38.205
2	CO	Rocky Ford Highline	Rocky Ford Highline	RHC_6	Turnout	Drop	Gate Drop	Radial		4	10	1	H	-104.011	38.066
3	CO	Costilla Canal	Costilla Canal	C_1	Diversion	Drop	Gate Drop	Radial		4.6	40	1670	PC	-105.950	37.553
3	CO	Costilla Canal	Costilla Canal	C_2	Inline	Drop	Check Drop	Adjustible		3	25	2230	PC	-105.879	37.536
3	CO	Monte Vista Canal	Monte Vista Canal	MV_5	Inline	Weir	short crested			2.5	50	56	2	-106.198	37.588

Div	State	Owner	Canal Name	Structure I.D.	Location	Category	Classification	Sub-Classification	Notes	Elevation Change (ft)	U.S. Width (ft)	Distance to Nearest Tie In (ft)	# of Insulators	Xcoord	Ycoord
3	CO	Monte Vista Canal	Monte Vista Canal	MV_6	Inline	Weir	short crested			2.5	50	100	4	-106.195	37.574
3	CO	Monte Vista Canal	Monte Vista Canal	MV_7	Inline	Weir	short crested			2.5	45	45	4	-106.197	37.560
3	CO	Monte Vista Canal	Monte Vista Canal	MV_8	Inline	Weir	short crested			1.5	50	1200	4	-106.189	37.553
3	CO	Monte Vista Canal	Monte Vista Canal	MV_9	Inline	Weir	short crested			2	50	500	4	-106.180	37.545
3	CO	Monte Vista Canal	Monte Vista Canal	MV_10	Inline	Weir	short crested			1.5	50	120	2	-106.163	37.520
3	CO	Monte Vista Canal	Monte Vista Canal	MV_11	Inline	Weir	short crested			2	50	82	2	-106.130	37.440
3	CO	Monte Vista Canal	Monte Vista Canal	MV_12	Inline	Weir	short crested			2.5	50	50	P	-106.110	37.425
3	CO	Prairie D	Prairie D	PD_1	Diversion	Gate	barrage	vertical		3	25	1	240	-106.233	37.645
3	CO	Prairie D	Prairie D	PD_2	Inline	Weir	adjustable			2.5	20	50	7	-106.191	37.640
3	CO	Prairie D	Prairie D	PD_3	Inline	Weir	adjustable			2.5	20	50	7	-106.173	37.641
3	CO	Prairie D	Prairie D	PD_4	Inline	Weir	adjustable			2.5	20	50	7	-106.158	37.640
3	CO	Prairie D	Prairie D	PD_5	Inline	Weir	adjustable			3.5	20	40	2	-106.103	37.640
3	CO	Prairie D	Prairie D	PD_6	Inline	Weir	adjustable			2	20	1000	PC	-106.089	37.640
3	CO	Prairie D	Prairie D	PD_7	Inline	Weir	adjustable			2	20	1000	2	-106.079	37.640
3	CO	Prairie D	Prairie D	PD_8	Inline	Weir	adjustable			2	20	50	2	-106.075	37.640
3	CO	Prairie D	Prairie D	PD_9	Inline	Weir	adjustable			3	20	1200	PC	-106.054	37.640
3	CO	Rio Grande Canal	Rio Grande Canal	RGC_2	Inline	Drop	gate drop	radial barrage		3.33	70	100	1	-106.346	37.700
3	CO	Rio Grande Canal	Rio Grande Canal	RGC_3	Inline	Weir	overshot	barrage		1	30	200	2	-106.312	37.719
3	CO	Rio Grande Canal	Rio Grande Canal	L3_1	Turnout	drop	gate drop	radial		0.83	30	200	2	-106.312	37.719
3	CO	Rio Grande Canal	Rio Grande Canal	RGC_4	Inline	Weir	overshot	barrage		1.5	45	2000	P	-106.273	37.754
3	CO	Rio Grande Canal	Rio Grande Canal	L4_1	Turnout	drop	gate drop	radial		3	45	2000	P	-106.273	37.754
3	CO	Rio Grande Canal	Rio Grande Canal	RGC_5	Inline	Drop	steep grade change			1	40	2340	H	-106.247	37.772
3	CO	Rio Grande Canal	Rio Grande Canal	L5_1	Turnout	drop	gate drop	radial		2.33	40	2340	H	-106.247	37.772
3	CO	Rio Grande Canal	Rio Grande Canal	RGC_6	Inline	Weir	overshot	barrage		2	40	150	P	-106.226	37.821
3	CO	Rio Grande Canal Lateral No. 1	Rio Grande Canal Lateral No. 1	L1_1	Diversion	Drop	gate drop	radial barrage		3	70	100	1	-106.346	37.700
3	CO	Rio Grande Canal Lateral No. 1	Rio Grande Canal Lateral No. 1	L1_2	Inline	Weir	adjustable			4.33	40	20	4	-106.321	37.694
3	CO	Rio Grande Canal Lateral No. 1	Rio Grande Canal Lateral No. 1	L1_3	Inline	Drop	gate drop	radial barrage		2.58	40	40	4	-106.275	37.684

Div	State	Owner	Canal Name	Structure I.D.	Location	Category	Classification	Sub-Classification	Notes	Elevation Change (ft)	U.S. Width (ft)	Distance to Nearest Tie In (ft)	# of Insulators	Xcoord	Ycoord
3	CO	Rio Grande Canal Lateral No. 1	Rio Grande Canal Lateral No. 1	L1_4	Turnout	Drop	gate drop	radial barrage		3.67	40	40	4	-106.275	37.684
3	CO	Rio Grande Canal Lateral No. 1	Rio Grande Canal Lateral No. 1	L1_5	Inline	FlowMeasurement	Parshall			2	30	40	4	-106.272	37.683
3	CO	Rio Grande Canal Lateral No. 1	Rio Grande Canal Lateral No. 1	L1_6A	Inline	Weir	overshot			3	30	40	4	-106.261	37.680
3	CO	Rio Grande Canal Lateral No. 1	Rio Grande Canal Lateral No. 1	L1_7	Inline	Drop	gate drop	vertical barrage		3	30	50	4	-106.248	37.677
3	CO	Rio Grande Canal Lateral No. 1	Rio Grande Canal Lateral No. 1	L1_8	Turnout	Drop	gate drop	radial barrage		2.5	30	50	4	-106.248	37.677
3	CO	Rio Grande Canal Lateral No. 1	Rio Grande Canal Lateral No. 1	L1_6B	Inline	Weir	overshot			3	30	40	4		
3	CO	Rio Grande Canal Lateral No. 1	Rio Grande Canal Lateral No. 1	L1_9	Inline	Drop	gate drop	vertical barrage		2.5	40	50	5	-106.219	37.669
3	CO	Rio Grande Canal Lateral No. 1	Rio Grande Canal Lateral No. 1	L1_10	Turnout	Drop	gate drop	radial barrage		3	40	50	5	-106.219	37.669
3	CO	San Luis Canal	San Luis Canal	SLC_1	Diversion	Gate	Barrage	Vertical		4	26	7350	H	-106.074	37.580
3	CO	San Luis Canal	San Luis Canal	SLC_2	Inline	Gate	Barrage	Radial		3.5	45	3690	H	-106.064	37.578
3	CO	San Luis Canal	San Luis Canal	SLC_3	Inline	Drop	Gate drop	vertical barrage		3.25	45	925	H	-106.055	37.577
3	CO	San Luis Canal	San Luis Canal	SLC_4	Inline	Weir	adjustable			3	24		2	-105.994	37.590
3	CO	San Luis Canal	San Luis Canal	SLC_5	Turnout	Weir	adjustable		Hand Drawn	3	24		2	-105.994	37.590
3	CO	San Luis Canal	San Luis Canal	SLC_6	Inline	Weir	adjustable			3.5	20		2	-105.981	37.592
3	CO	San Luis Canal	San Luis Canal	SLC_7	Turnout	Weir	adjustable			2.5	20		2	-105.981	37.592
3	CO	San Luis Canal	San Luis Canal	SLC_8	Inline	Weir	adjustable			2.5	25		P	-105.956	37.592
3	CO	San Luis Canal	San Luis Canal	SLC_9	Inline	Weir	adjustable			2	25		H	-105.984	37.611
3	CO	San Luis Canal	San Luis Canal	SLC_10	Inline	Weir	adjustable			2.5	32		2	-105.947	37.654
3	CO	San Luis Canal	San Luis Canal	SLC_11	Inline	Weir	adjustable			3	15	50	4	-105.942	37.675
3	CO	San Luis Canal	San Luis Canal	SLC_12	Turnout	Weir	adjustable			3.5	16	50	4	-105.942	37.675
4	CO	Uncompahgre River	Uncompahgre River	UR_1	Inline	Drop	Gate drop			7		1	PC	-107.978	38.591
4	CO	Uncompahgre Valley Water User Association	East Canal	E_1	Diversion	Drop	Gate drop	vertical		4	12	1	PC	-107.978	38.591
4	CO	Uncompahgre Valley Water User Association	East Canal	E_2	Inline	Drop	vertical drops			3.5	25	60	2	-107.979	38.595
4	CO	Uncompahgre Valley Water	East Canal	E_3	Inline	Weir	Adjustable			1	40	650	PC	-107.958	38.622

Div	State	Owner	Canal Name	Structure I.D.	Location	Category	Classification	Sub-Classification	Notes	Elevation Change (ft)	U.S. Width (ft)	Distance to Nearest Tie In (ft)	# of Insulators	Xcoord	Ycoord
		User Association													
4	CO	Uncompahgre Valley Water User Association	East Canal	E_4A	Inline	Drop	vertical drops			4.5	25	345	PC	-107.962	38.669
4	CO	Uncompahgre Valley Water User Association	East Canal	E_4B	Turnout	Drop	vertical drops			3.5	25	345	PC	-107.962	38.669
4	CO	Uncompahgre Valley Water User Association	East Canal	E_5	Inline	weir	rock structure			3	25	800	H	-107.959	38.683
4	CO	Uncompahgre Valley Water User Association	East Canal	E_6	Inline	Drop	drop structure	baffled		60	30	275	PC	-107.961	38.700
4	CO	Uncompahgre River	Uncompahgre River	UR_2	Inline	Drop	Barrage	Radial				1	PC	-107.973	38.566
4	CO	Uncompahgre Valley Water User Association	Ironstone Canal	I_1	Diversion	Drop	Gate drop	radial barrage		2.5	30	1	PC	-107.973	38.566
4	CO	Uncompahgre Valley Water User Association	Ironstone Canal	I_2	Inline	Weir	barrage	overshot / radial		2.5	25	120	H	-108.009	38.605
4	CO	Uncompahgre Valley Water User Association	Ironstone Canal	I_3	Inline	Weir	adjustable			2.5	25	20	H	-108.068	38.624
4	CO	Uncompahgre River	Uncompahgre River	UR_3	Inline	Drop	Barrage	Radial				1	4	-107.824	38.393
4	CO	Uncompahgre Valley Water User Association	Montrose & Delta Canal	MD_1	Diversion	Gate	barrage	radial		0	40	1	4	-107.824	38.393
4	CO	Uncompahgre Valley Water User Association	Montrose & Delta Canal	MD_2	Inline	Drop	chute			5.5	40	330	2	-107.845	38.401
4	CO	Uncompahgre Valley Water User Association	Montrose & Delta Canal	MD_3	Inline	Drop	chute							-107.865	38.405
4	CO	Uncompahgre Valley Water User Association	Montrose & Delta Canal	MD_4	Inline	Weir	rock structure			2.5	40	360	8	-107.904	38.440
4	CO	Uncompahgre Valley Water User Association	Montrose & Delta Canal	MD_5	Inline	Drop	chute			3	35	150	1	-107.919	38.441
4	CO	Uncompahgre Valley Water User Association	Montrose & Delta Canal	MD_6	Inline	Drop	check drop	steep grade change		9	30	700	H	-107.994	38.488
4	CO	Uncompahgre Valley Water User Association	Montrose & Delta Canal	MD_7	Inline	Drop	steep grade change		el from usbr	125	30	750	PC	-108.001	38.491

Div	State	Owner	Canal Name	Structure I.D.	Location	Category	Classification	Sub-Classification	Notes	Elevation Change (ft)	U.S. Width (ft)	Distance to Nearest Tie In (ft)	# of Insulators	Xcoord	Ycoord
4	CO	Uncompahgre Valley Water User Association	Montrose & Delta Canal	MD_8	Turnout	Drop	gate drop	radial		3	8	1	2	-108.007	38.555
4	CO	COAL CREEK	COAL CREEK	CC_1	Inline	Drop	Vertical			9		1	2	-108.007	38.555
4	CO	Uncompahgre River	Uncompahgre River	UR_4	Inline	Drop	Vertical Drop			15		1	PC	-107.911	38.504
4	CO	Uncompahgre Valley Water User Association	Selig Canal	S_1	Diversion	Gate	barrage	vertical		2	30	1	PC	-107.911	38.504
4	CO	Uncompahgre Valley Water User Association	Selig Canal	S_2	Inline	Drop	chute			2.5	35	150	PC	-107.910	38.508
4	CO	Uncompahgre Valley Water User Association	Selig Canal	S_3	Inline	Drop	chute		el from usbr	5	35	140	2	-107.913	38.511
4	CO	Uncompahgre Valley Water User Association	Selig Canal	S_4	Inline	Weir	rock structure			3	35	1	3	-107.915	38.512
4	CO	Uncompahgre Valley Water User Association	Selig Canal	S_5A	Inline	Weir	adjustable			2	20	100	H	-107.932	38.542
4	CO	Uncompahgre Valley Water User Association	Selig Canal	S_5B	Turnout	Drop	vertical drop			8	20	100	H	-107.932	38.542
4	CO	Uncompahgre Valley Water User Association	Selig Canal	S_6	Inline	Drop	vertical drop			5	10	75	4	-107.896	38.568
4	CO	Uncompahgre Valley Water User Association	Selig Canal	S_7	Inline	Weir	adjustable			2	15	110	4	-107.899	38.591
4	CO	Uncompahgre Valley Water User Association	Selig Canal	S_8	Inline	Drop	vertical drop			5	25	1375	H	-107.920	38.615
4	CO	Uncompahgre Valley Water User Association	Selig Canal	S_9	Inline	Weir	adjustable			3	25	180	H	-107.916	38.618
4	CO	Uncompahgre Valley Water User Association	Loutsenhizer Canal	LC_1	Diversion	Drop	gate drop	radial						-107.862	38.438
4	CO	Uncompahgre Valley Water User Association	South Canal	STH_1	Inline	Drop	gate drop	vertical barrage	el from usbr	16	65	300	H	-107.800	38.371
4	CO	Uncompahgre Valley Water User Association	South Canal	STH_2	Inline	Drop	chute		el from usbr	29	15	730	PC	-107.810	38.404
4	CO	Uncompahgre Valley Water User	South Canal	STH_3	Inline	Drop	chute			3	20	2575	H	-107.783	38.445

Div	State	Owner	Canal Name	Structure I.D.	Location	Category	Classification	Sub-Classification	Notes	Elevation Change (ft)	U.S. Width (ft)	Distance to Nearest Tie In (ft)	# of Insulators	Xcoord	Ycoord
		Association													
4	CO	Uncompahgre Valley Water User Association	South Canal	STH_4	Inline	Drop	steep grade change			0	20	3400	H	-107.780	38.450
4	CO	Uncompahgre Valley Water User Association	South Canal	STH_5	Inline	Drop	chute			56	80	8380	4	-107.771	38.471
4	CO	Uncompahgre Valley Water User Association	South Canal	STH_6	Inline	Drop	check drop			12	55	6000	4	-107.767	38.477
4	CO	Uncompahgre Valley Water User Association	South Canal	STH_7	Inline	Drop	chute	drop structure		62	20	1350	4	-107.755	38.483
5	CO	Collbran Conservancy District	Leon Park Feeder Canal	LP_1	Inline	Drop	drop structue	baffled		12	20	1040	H	-107.812	39.218
5	CO	Collbran Conservancy District	Park Creek Ditch	PC_1	Inline	Drop	steep grade change			100	15	1230	H	-107.811	39.217
5	CO	Collbran Conservancy District	Southside Canal	SS_1	Inline	Weir	adjustable			0	25			-107.814	39.225
5	CO	Collbran Conservancy District	Southside Canal	SS_2	Inline	Drop	chute			270	30	2275	H	-107.849	39.214
5	CO	Collbran Conservancy District	Southside Canal	SS_3	Inline	Drop	chute			99	35	770	H	-107.853	39.210
5	CO	Collbran Conservancy District	Southside Canal	SS_4	Inline	Drop	Siphon			5	30	1675	H	-107.861	39.210
5	CO	Collbran Conservancy District	Southside Canal	SS_5	Inline	Drop	chute			132	30	4300	H	-107.890	39.190
5	CO	Collbran Conservancy District	Southside Canal	SS_6	Inline	Drop	chute			133	30	2200	H	-107.897	39.187
5	CO	Collbran Conservancy District	Southside Canal	SS_7	Inline	Drop	chute			72	30	130	2	-107.950	39.181
5	CO	Collbran Conservancy District	Southside Canal	SS_8	Turnout	Drop	pipeline			58	30	130	2	-107.950	39.181
5	CO	Collbran Conservancy District	Southside Canal	SS_9	Inline	Drop	chute			69	30	8800	2	-107.965	39.173
5	CO	Collbran Conservancy District	Southside Canal	SS_10	Turnout	Drop	chute			117	30	1700	PC	-108.007	39.148
5	CO	Collbran Conservancy District	Southside Canal	SS_11	Inline	Drop	pipeline			55	20	1620	H	-108.038	39.149
5	CO	Collbran Conservancy District	Southside Canal	SS_12	Inline	Drop	drop structue	baffled		11	20	550	H	-108.148	39.101
5	CO	Silt Water Conservancy	Grass Valley Canal	GV_1A	Turnout	Drop	chute			20	26	240	PC	-107.698	39.677

Div	State	Owner	Canal Name	Structure I.D.	Location	Category	Classification	Sub-Classification	Notes	Elevation Change (ft)	U.S. Width (ft)	Distance to Nearest Tie In (ft)	# of Insulators	Xcoord	Ycoord
		District													
5	CO	Silt Water Conservancy District	Grass Valley Canal	GV_1B	Inline	Gate	barrage	vertical		1.5	26	240	PC	-107.699	39.677
5	CO	Silt Water Conservancy District	Harvey Gap reservoir outlet	HG_1	Reservoir	Drop	pipeline			58	1	2800	H	-107.661	39.606
5	CO	Silt Water Conservancy District	Pump House	PH_1	Inline	Drop	vertical drop			8	10	1	PC	-107.629	39.545
5	CO	Silt Water Conservancy District	Rifle Gap Reservoir Outlet	RG_1	Reservoir	Drop	pipeline			62	1	1	2	-107.758	39.627
5	CO	Silt Water Conservancy District	West Lateral	WL_1	Inline	Drop	vertical drop			35	5	1		-107.724	39.574
5	CO	Silt Water Conservancy District	West Lateral	WL_2	Inline	Drop	steep grade change			155	10	1	6	-107.686	39.577
7	CO	Dolores Water Conservancy District	U Lateral	D_1	Inline	Drop	chute			13.83	34	850	PC	-108.761	37.595
7	CO	Dolores Water Conservancy District	U Lateral	D_2	Inline	Drop	chute			13.86	30	1	PC	-108.783	37.587
7	CO	Dolores Water Conservancy District	U Lateral	D_3	Inline	Drop	chute			5.38	30	1	PC	-108.796	37.581
7	CO	Dolores Water Conservancy District	U Lateral	D_4	Inline	Drop	siphon			3.5	30	1	PC	-108.811	37.585
7	CO	Montezuma Valley Irrigation District		M_1	Inline	Weir	adjustable			2	18	3380	4	-108.694	37.434
7	CO	Montezuma Valley Irrigation District		M_2	Inline	Drop	check drop	steep grade change		12	16	1200	4	-108.650	37.469
7	CO	Montezuma Valley Irrigation District		M_3	Inline	Drop	check drop	steep grade change		12	12	80	4	-108.647	37.472
7	CO	Montezuma Valley Irrigation District		M_4A	Inline	Drop	check drop	adjustable		3.33	36	250	4	-108.647	37.476
7	CO	Montezuma Valley Irrigation District		M_4B	Inline	Drop	check drop	adjustable	not visited, but was directed to. See from aerial	3.33	36	250	4	-108.659	37.476
7	CO	Montezuma Valley Irrigation District		M_5	Inline	Weir	adjustable			3.08	24	425	4	-108.665	37.472

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7	CO	Montezuma Valley Irrigation District		M_6	Inline	Drop	vertical drop			10	24	200	H	-108.673	37.472
7	CO	Montezuma Valley Irrigation District		M_7	Inline	Drop	check drop	adjustable	hand drawn	4	36	600	H	-108.685	37.466
7	CO	Montezuma Valley Irrigation District		M_8	Inline	Drop	Siphon		hand drawn	3	30	850	H	-108.698	37.457
7	CO	Montezuma Valley Irrigation District		M_9	Inline	Drop	vertical drop	check drop	hand drawn	9.4	29	3000	H	-108.700	37.450
7	CO	Montezuma Valley Irrigation District		M_11	Inline	Drop	steep grade change		hand drawn	10	20	200	H	-108.526	37.435
7	CO	Montezuma Valley Irrigation District		M_12	Turnout	Drop	vertical drop		hand drawn	35		528	H	-108.533	37.435
7	CO	Montezuma Valley Irrigation District		M_13	Inline	Drop	steep grade change			7.3	25	2640	PC	-108.620	37.500
7	CO	Montezuma Valley Irrigation District		M_14	Inline	Drop	steep grade change			6.55	25	5280	PC	-108.623	37.500
13/1	CO	Colorado - Big Thompson	Adams Tunnel West Portal	218		Gated Check			bad coord	0 - 8				-105.801	40.242
13/1	CO	Colorado - Big Thompson	Dille Discharge	220	Turnout	Drop	Check Drop							-105.243	40.418
13/1	CO	Colorado - Big Thompson	Dille Tunnel Inlet	221	Turnout	Drop	Gate Drop							-105.243	40.419
13/1	CO	Colorado - Big Thompson	Elliot Creek Chute	222	inline	Drop	Chute							-106.331	39.874
13/1	CO	Colorado - Big Thompson	Olympus Tunnel Inlet	223	Reservoir	Drop	Gate Drop							-105.488	40.375
13/2	CO	Fryingpan - Arkansas	Boustead Tunnel Outlet Structure	224	inline	Drop	Vertical Drop			28.4150585				-106.437	39.277
13/5	CO	Fryingpan - Arkansas	Chapman Diversion Dam	225		Diversion Dam			not Clear what drop					-106.630	39.263
13/5	CO	Fryingpan - Arkansas	Fryingpan Diversion Dam	226	Diversion	Drop	Vertical Drop							-106.530	39.245
13/5	CO	Fryingpan - Arkansas	Hunter Creek Diversion Structure	227	inline	Drop	Pipeline			44				-106.719	39.183
13/5	CO	Fryingpan - Arkansas	Ivanhoe Diversion Dam	228		Spillway			bad coord					-106.558	39.829
13/5	CO	Fryingpan - Arkansas	No Name Creek Diversion	229	inline	Drop	Gate Drop			30				-106.679	39.207

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			Structure												
13/5	CO	Fryingpan - Arkansas	North Fork Diversion Structure	230	inline	Drop	Pipeline			102				-106.538	39.361
13/5	CO	Fryingpan - Arkansas	South Fork Diversion Dam	231	Diversion	Drop	Vertical Drop							-106.590	39.238
13/4	CO	Pojoaque Valley	Drop 1	232	inline	Drop	Steep grade change			99				-107.677	38.492
13/4	CO	Pojoaque Valley	Huston Drop	233	inline	Drop	Steep grade change			45				-107.692	38.492
13/4	CO	Pojoaque Valley	Cinmarron to Veral Mesa Drop	234		Drop			bad coord	179				-107.692	38.438
13/4	CO	Pojoaque Valley	Olivers Drop	235	inline	Drop	Chute			82				-107.670	38.484
13/4	CO		Chute 1 Loutz	236	inline	Drop	Vertical Drop			30				-107.853	38.503
13/4	CO		Chute 2 Loutz	237	inline	Drop	Vertical Drop			57				-107.864	38.525
13/4	CO		Chute 3 Loutz	238	inline	Drop	Vertical Drop			28				-107.878	38.548
13/4	CO		Double E Chute	239	inline	Drop	Vertical Drop			42				-107.904	38.553
13/4	CO		Dragons Teeth	240	inline	Drop	Vertical Drop			31				-107.959	38.698
13/4	CO		Fire Mountain "The Drop"	241	inline	Drop	Vertical Drop			12				-107.742	38.833
12/5	CO	Mesa County	Palisade Pipeline	242		Other			not Clear what drop	60				-108.340	39.117
12/4	CO	Mesa County	End Canal #2	243	inline	Drop	Steep grade change			85				-108.520	39.026
12/5	CO	Mesa County	Canal 2 to 1 Transfer	244		Drop	Chute			71				-108.485	39.019
12/4	CO	Mesa County	Duck Pond	245		Drop	Vertical Drop			46				-108.564	39.041
13/4	CO		S.F. Drop To Reservior	246		Drop	Vertical Drop			58				-107.588	38.696
13/4	CO		S.F. Feeder Drop	247		Drop	Vertical Drop			12				-107.576	38.708
13/4	CO		Holly Rd Check	381		Check	Check Drop			6				-107.903	38.557
13/4	CO		East Canal Pipeline	383		Drop	Vertical Drop			6				-107.979	38.602
13/4	CO		GH Lateral	384		Drop	Vertical Drop			34				-107.968	38.703
12/4	CO		Junction Ironstone & M&D	385		Drop	Vertical Drop		not Clear what drop	18				-108.113	38.638
13/4	CO		South Canal Drop 4	387		Drop	Chute			73				-107.772	38.454
12/7	CO		Pipe Chute at 1058+00	391		Drop	Pipeline		Do Not Know Where Outlet Is, NHD Data Not Updated, Presumably bad Data Set To Use	326				-108.647	37.241

Div	State	Owner	Canal Name	Structure I.D.	Location	Category	Classification	Sub-Classification	Notes	Elevation Change (ft)	U.S. Width (ft)	Distance to Nearest Tie In (ft)	# of Insulators	Xcoord	Ycoord
12/7	CO		Drop at 725+45	392		Drop	Vertical Drop		Hand Drawn	44				-108.571	37.307
12/7	CO		Drop at 1041+50	393		Drop	Vertical Drop		Hand Drawn	38				-108.641	37.250
12/7	CO		Drop at 1058+00	394		Drop	Vertical Drop		Hand Drawn	37				-108.644	37.246
10	WA		Sulphur Drain Fish Barrier	310		Weir	Sharpcrested			7.8				-120.020	46.252
10	WA		Taneum Chute KRD	311		Drop	Chute			204				-120.750	47.090
10	OR		Station 48	312		Drop	Vertical Drop		Hand Drawn	18.4				-121.689	42.140
10	OR		G Canal Drop	313		Drop	Vertical Drop			12				-121.691	42.149
10	OR		D Canal Drop	314		Drop	Vertical Drop			6.5				-121.600	42.054
10	OR		A-canal headworks	315		Drop	Vertical Drop			5.8				-121.802	42.239
10	OR		C Canal Spill	316		Drop	Vertical Drop		Hand Drawn	40				-121.626	42.037
10	CA		Station 1631+70	320		Drop	Pipeline			8.28				-120.050	37.121
10	CA		Lateral 32.2: Sta. 35+20.75	333		Drop	Vertical Drop			6.03				-120.082	37.114
10	CA		Lateral 32.2: Sta. 84+00.00	334		Drop	Vertical Drop			6.03				-120.093	37.109
10	CA		Lateral 32.2: Sta. 132+00.00	335		Drop	Vertical Drop			5.5				-120.105	37.106
10	CA		Lateral 32.2: Sta. 173+00	336		Drop	Vertical Drop			6.03				-120.111	37.099
10	CA		Lateral 32.2: Sta. 402+00.00	337		Drop	Vertical Drop			6				-120.156	37.071
11	AZ		242 Lateral	303		Drop	Vertical Drop			50.268				-114.787	32.486
11	CA		North Gila Turnout 1	304		Drop	Vertical Drop			19.79				-114.534	32.830
11	CA		Reservation Main Canal Turnout	305		Drop	Vertical Drop			13.82				-114.514	32.818
11	AZ		South Gila Terminus	306			Check Drop		cannot find ends of alignment	19.58				-114.581	32.693
11	AZ		South Gila Turnout	307		Drop	Vertical Drop			9.71				-114.472	32.687
11	CA		Yaqui Turnout	308		Drop	Vertical Drop			5.25				-114.589	32.811
11	CA		Lateral 6.2: Sta. 61+26.44	321		Drop	Vertical Drop			9.91				-119.794	36.955
11	CA		Lateral 6.2: Sta. 104+00.00	322		Drop	Vertical Drop			10.03				-119.805	36.947
11	CA		Lateral 6.2: Sta. 162+00	323		Drop	Vertical Drop			10.03				-119.822	36.939
11	CA		Lateral 6.2: 201+00	324		Drop	Vertical Drop			7.53				-119.835	36.937
11	CA		Lateral 6.2: 231+00	325		Drop	Vertical Drop			15.03				-119.845	36.934
11	CA		Lateral 6.2: Sta: 279+00	326		Drop	Vertical Drop			7.53				-119.858	36.929

Div	State	Owner	Canal Name	Structure I.D.	Location	Category	Classification	Sub-Classification	Notes	Elevation Change (ft)	U.S. Width (ft)	Distance to Nearest Tie In (ft)	# of Insulators	Xcoord	Ycoord
11	CA		Lateral 6.2: Sta. 337+00	327		Drop	Vertical Drop			7.53				-119.869	36.920
11	CA		Lateral 6.2: Sta. 372+00	328		Drop	Vertical Drop			10.03				-119.880	36.917
11	CA		Lateral 6.2: Sta. 444+25.0	329		Drop	Pipeline			7.68				-119.894	36.907
11	CA		Lateral 6.2: Sta. 485+65.0	330		Drop	Vertical Drop			8.02				-119.894	36.896
11	CA		Lateral 6.2: Sta. 513+50.00	331		Drop	Vertical Drop			5.61				-119.899	36.890
11	CA		Lateral 6.2: Sta. 563+40.0	332		Drop	Vertical Drop			5.6				-119.916	36.888
11	NV		A-Head	338		Drop	Gate Drop			5.51				-118.867	39.474
11	NV		AC1 8.52	339		Drop	Check Drop			8.52				-118.865	39.458
11	NV		AC2 9.07	340		Drop	Check Drop			9.07				-118.845	39.444
11	NV		AC3 11.33	341		Drop	Check Drop			11.33				-118.826	39.424
11	NV		AC6 5.36	342		Drop	Check Drop			5.36				-118.799	39.406
11	NV		L-Head 5.11	343		Drop	Check Drop			5.11				-118.830	39.469
11	NV		LC1 7.63	344		Drop	Gate Drop			7.63				-118.814	39.463
11	NV		LC2 8.1	345		Drop	Check Drop		cannot find	8.1				-118.814	39.463
11	NV		VC3 5.19	347		Drop	Check Drop			5.19				-118.867	39.474
11	NV		VC6 6.01	349		Drop	Check Drop			6.01				-118.830	39.469
11	NV		VC7 6.39	350		Drop	Check Drop			6.42				-118.812	39.480
11	NV		VC8 7.34	351		Drop	Check Drop			7.34				-118.791	39.485
11	NV		SC2 8.24	352		Drop	Check Drop			8.24				-118.742	39.483
11	NV		TC2 7.54	353	Turnout	Drop	Gate Drop			7.54				-118.942	39.506
11	NV		TC10 9.54	354		Drop	Check Drop			9.54				-118.836	39.489
11	NV		Derby 10.48	356	Inline	Drop	Check Drop	Barrage		10.48				-119.449	39.586
11	OR		Kingman Lateral Station 137+00 Drop	444		Drop	Vertical Drop			7				-117.144	43.731
11	OR		Kingman Lateral Station 392+70	445		Drop	Series of Drops			109				-117.093	43.742
11	OR		Kingman Sublateral 7.7	446		Drop	Series of Drops			121				-117.088	43.744
11	OR		Kingman Sublateral 5.4	447		Drop	Series of Drops			18				-117.126	43.746
11	OR		Kingman Sublateral 5.4	448		Drop	Series of Drops			153				-117.125	43.752

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11	OR		North Canal Station 3454+65 Chute	449		Drop	Chute			95				-116.993	44.180
11	OR		North Canal lateral 5.3 Station 0+85	450		Drop	Series of Drops			103				-117.185	43.744
11	OR		North Canal Lateral 12.4 Station 1+00	451		Drop	Series of Drops			151				-117.188	43.809
11	OR		North Canal Lateral 13.6 Station 7+60	452		Drop	Series of Drops		Hand Drawn	176				-117.176	43.821
11	OR		North Canal Lateral 14.5 Station 52+30	453		Drop	Chute			20				-117.172	43.831
11	OR		North Canal lateral 14.5 Station 153+60	454		Drop	Chute			33				-117.145	43.825
11	OR		North Canal Lateral 25.4 Station 1+30	455		Drop	Series of Drops			37				-117.111	43.863
11	OR		North Canal Lateral 25.4 Station 31+25	456		Drop	Series of Drops			20				-117.106	43.859
11	OR		North Canal Lateral 26.4 Station 3+00	457		Drop	Series of Drops			165				-117.106	43.868
11	OR		North Canal Lateral 28.7 Station 11+75	458		Drop	Series of Drops			27				-117.089	43.886
11	OR		North Canal Lateral 28.7 Station 36+20	459		Drop	Series of Drops			69				-117.084	43.881
11	OR		North Canal Lateral 31.0 Station 18+00	460		Drop	Series of Drops		Hand Drawn	52				-117.078	43.908
11	OR		North Canal Lateral 37.6 Station 1+10	461		Drop	Series of Drops		Hand Drawn	148				-117.045	43.953
11	OR		North Canal Lateral 38.7 Station 1+00	462		Drop	Series of Drops		Hand Drawn	121				-117.045	43.963
11	OR		North Canal Lateral 38.7 Station 42+80	463		Drop	Series of Drops		Hand Drawn	76				-117.045	43.974
11	OR		North Canal Lateral 60.0 Station 1+60	464		Drop	Series of Drops		Hand Drawn	66				-116.996	44.137
11	OR		South Canal Lateral 5.7 Station 26+50	465		Drop	Chute			40				-117.065	43.623
11	ID		South Canal Lateral 5.7 Station 291+00	466		Drop	Series of Drops			54				-117.023	43.625
11	ID		South Canal Lateral 17.1 Station 25+00	467		Drop	Series of Drops			94				-116.986	43.559
11	ID		South Canal Lateral 17.7 Station 0+00	468		Drop	Series of Drops			137				-116.979	43.552
11	ID		South Canal Lateral 28.5-1.1 Station 14+20	469		Drop	Pipeline			56				-116.896	43.537

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11	ID		South Canal Lateral 28.5 Station 0+00	470		Drop	Pipeline			23				-116.887	43.522
11	ID		Mora Canal	471		Drop	Check Drop		Not there	10				-116.293	43.275
11	ID		End of New York Canal	472		Drop	Check Drop		Not there	10				-116.344	43.303
11	OR		North Canal Lateral 8.5 Station 6+96	475		Drop	Series of Drops			53				-117.193	43.766
11	OR		North Canal Lateral 8.5 Station 82+65	476		Drop	Series of Drops			129				-117.175	43.759
11	OR		North Canal Lateral 10.5 Station 0+85	477		Drop	Series of Drops		Hand Drawn	163				-117.182	43.791
12	MT	East Bench Unit	Lateral 27.9	1		Drop	Series of Drops		Hand Drawn	16				-112.466	45.320
12	MT	East Bench Unit	Lateral 41.2	2		Drop	Series of Drops		Hand Drawn	61				-112.330	45.406
12	MT	Helena Valley Unit	Drop into regulating res	3		Drop	Vertical Drop			10				-111.869	46.649
12	MT	Helena Valley Unit	Lateral 11.9	4		Drop	Series of Drops			47				-111.885	46.637
12	MT	Helena Valley Unit	Lateral 14.8	5		Drop	Series of Drops			25				-111.905	46.624
12	MT	Helena Valley Unit	Lateral 20.7	6		Drop	Series of Drops			31				-112.010	46.626
12	MT	Helena Valley Unit	Lateral 32.6	7		Drop	Series of Drops			47				-111.946	46.712
12	MT	Huntley	Couts drop	8		Drop	Vertical Drop			38				-108.058	45.969
12	MT	Sun River Ft Shaw	Ft Shaw A-drop	22		Drop	Vertical Drop			44.5				-111.963	47.489
12	MT	Sun River Ft Shaw	Ft Shaw C-drop	23		Drop	Chute			59				-111.862	47.494
12	MT	Sun River Ft Shaw	Sequest Check to A-drop	24		Drop	Pipeline			62				-111.975	47.485
12	MT	Sun River Greenfields	9-ft Drop, Spring Valley	25		Drop	Vertical Drop			9				-112.060	47.590
12	MT	Sun River Greenfields	Arnold Coulee Drop, Pishkun Canal	26		Drop	Vertical Drop			36				-112.582	47.663
12	MT	Sun River Greenfields	Pishkun Res Inlet Drop	27		Drop	Vertical Drop			35.83101461				-112.507	47.682
12	MT	Sun River Greenfields	GM 47 Drop	28		Drop	Series of Drops			81				-112.007	47.677
12	MT	Sun River Greenfields	Lower Ashlot Drop	29		Drop	Chute			22				-111.817	47.577
12	MT	Sun River Greenfields	Middle Ashlot Drop	30		Drop	Chute			42				-111.818	47.581
12	MT	Sun River Greenfields	Old SRS Drop	31		Drop	Pipeline			125				-112.161	47.581
12	MT	Sun River Greenfields	Upper Ashlot Drop	32		Drop	Chute			115				-111.812	47.586
12	WY	Heart Mountain	Lateral 79 after 79-5	70		Drop	Chute			39.59				-108.962	44.626

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12	WY	Heart Mountain	Lateral 79-6	71		Drop	Chute			18.49				-108.962	44.643
12	WY	Heart Mountain	Lateral 79-6	72		Drop	Chute			21.29				-108.961	44.643
12	WY	Heart Mountain	Lateral 79	73		Drop	Vertical Drop			11				-109.015	44.638
12	WY	Heart Mountain	Lateral 79	74		Drop	Vertical Drop			11				-109.013	44.638
12	WY	Heart Mountain	Lateral 79	75		Drop	Vertical Drop			11				-109.012	44.638
12	WY	Heart Mountain	Lateral 79	76		Drop	Vertical Drop			11.1				-109.011	44.639
12	WY	Heart Mountain	Lateral 79	77		Drop	Vertical Drop			11				-109.010	44.639
12	WY	Heart Mountain	Lateral 79	78		Drop	Vertical Drop			11				-109.009	44.639
12	WY	Heart Mountain	Lateral 79	79		Drop	Vertical Drop			11				-109.007	44.639
12	WY	Heart Mountain	Lateral 79	80		Drop	Vertical Drop			11				-109.006	44.639
12	WY	Heart Mountain	Lateral 79	81		Drop	Vertical Drop			11				-109.005	44.639
12	WY	Heart Mountain	Lateral 79	82		Drop	Vertical Drop			10.15				-109.004	44.639
12	WY	Heart Mountain	Lateral 79	83		Drop	Vertical Drop			10.12				-109.003	44.639
12	WY	Heart Mountain	Lateral 79	84		Drop	Vertical Drop			10.12				-109.002	44.639
12	WY	Heart Mountain	Lateral 79	85		Drop	Vertical Drop			10.12				-109.001	44.639
12	WY	Heart Mountain	Lateral 89 after 89-10	86		Drop	Chute			24.52				-108.969	44.649
12	WY	Heart Mountain	Lateral 89 after 89-10	87		Drop	Chute			20.69				-108.964	44.648
12	WY	Heart Mountain	Lateral 89	88		Drop	Vertical Drop			15.01				-109.019	44.654
12	WY	Heart Mountain	Lateral 89	89		Drop	Vertical Drop			14.8				-109.016	44.654
12	WY	Heart Mountain	Lateral 89	90		Drop	Chute			37.39				-109.014	44.654
12	WY	Heart Mountain	Lateral 89	91		Drop	Vertical Drop			14.82				-109.012	44.653
12	WY	Heart Mountain	Lateral 89	92		Drop	Vertical Drop			11.9				-109.008	44.651
12	WY	Heart Mountain	Lateral 89	93		Drop	Vertical Drop			11.97				-109.007	44.651
12	WY	Heart Mountain	Lateral 89	94		Drop	Vertical Drop			11.9				-109.006	44.651
12	WY	Heart Mountain	Lateral 89	95		Drop	Vertical Drop			11.91				-109.004	44.651
12	WY	Heart Mountain	Lateral 89	96		Drop	Vertical Drop			11.85				-109.004	44.651
12	WY	Heart Mountain	Lateral 89	97		Drop	Vertical Drop			10.45				-109.003	44.651
12	WY	Heart Mountain	Lateral 89	98		Drop	Vertical Drop			11.89				-109.002	44.651

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12	WY	Heart Mountain	Lateral 89	99		Drop	Vertical Drop			9.9				-109.000	44.651
12	WY	Heart Mountain	Lateral H-103	100		Drop	Pipeline			145				-109.023	44.669
12	WY	Heart Mountain	Lateral H57	101		Drop	Chute			23.53				-109.008	44.583
12	WY	Heart Mountain	Lateral H57	102		Drop	Chute			22.24				-109.007	44.581
12	WY	Heart Mountain	Lateral H57	103		Drop	Chute			22.1				-109.004	44.578
12	WY	Heart Mountain	Lateral H57	104		Drop	Chute			18.34				-109.003	44.576
12	WY	Heart Mountain	Lateral H57	105		Drop	Chute			24.8				-109.002	44.574
12	WY	Heart Mountain	Lateral H57	106		Drop	Chute		Not there	65.38				-108.992	44.576
12	WY	Heart Mountain	Lateral H65	107		Drop	Chute			37.09				-109.012	44.605
12	WY	Heart Mountain	Lateral H65	108		Drop	Chute			40.75				-109.010	44.605
12	WY	Heart Mountain	Lateral H65	109		Drop	Vertical Drop			14.79				-109.007	44.604
12	WY	Heart Mountain	Lateral H65	110		Drop	Vertical Drop			15.19				-109.005	44.602
12	WY	Heart Mountain	Lateral H65	111		Drop	Chute			36.33				-109.002	44.601
12	WY	Heart Mountain	Lateral H65	112		Drop	Chute			23.04				-108.999	44.601
12	WY	Heart Mountain	Lateral H65	113		Drop	Chute			25.71				-108.998	44.598
12	WY	Heart Mountain	Lateral H65	114		Drop	Chute			29.47				-108.997	44.596
12	WY	Heart Mountain	Lateral H65	115		Drop	Chute			28.74				-108.995	44.594
12	WY	Heart Mountain	Lateral H65	116		Drop	Chute			57.78				-108.987	44.589
12	WY	Heart Mountain	Lateral H71	117		Drop	Chute			37.14				-109.008	44.617
12	WY	Heart Mountain	Lateral R45	118		Drop	Vertical Drop			12				-108.996	44.719
12	WY	Heart Mountain	Lateral R45	119		Drop	Chute			60				-108.988	44.716
12	WY	Heart Mountain	Lateral R45	120		Drop	Chute			110				-108.967	44.710
12	WY	Heart Mountain	Ralston Chute lower	121		Drop	Chute			130				-108.966	44.728
12	WY	Heart Mountain	Ralston Chute upper	122		Drop	Chute			110				-109.023	44.728
12	WY	Midvale	Piilot	123		Drop	Chute			30				-108.677	43.162
12	WY	Midvale	Piilot	124		Drop	Chute			150				-108.424	43.161
12	WY	Midvale	Pavillion Main	125		Drop	Chute			100				-108.690	43.263
12	WY	Midvale	Wyoming	126		Drop	Vertical Drop			12				-108.608	43.360

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12	WY	Midvale	Wyoming	127		Drop	Vertical Drop			14				-108.545	43.347
12	WY	Midvale	Wyoming	128		Drop	Vertical Drop			11				-108.542	43.347
12	WY	Midvale	Wyoming	129		Drop	Vertical Drop			11				-108.537	43.347
12	WY	Midvale	Wyoming	130		Drop	Vertical Drop			10				-108.534	43.344
12	WY	Midvale	Wyoming	131		Drop	Vertical Drop			8				-108.512	43.334
12	WY	Midvale	Wyoming	132		Drop	Vertical Drop			10				-108.507	43.332
12	WY	Midvale	Wyoming	133		Drop	Vertical Drop			8				-108.497	43.329
12	WY	Midvale	Wyoming	134		Drop	Vertical Drop			10				-108.493	43.328
12	WY	Midvale	Wyoming	135		Drop	Vertical Drop			7				-108.487	43.324
12	WY	Midvale	Wyoming	136		Drop	Vertical Drop			11				-108.486	43.322
12	WY	Midvale	Wyoming	137		Drop	Vertical Drop			10				-108.482	43.317
12	WY	Midvale	Wyoming	138		Drop	Vertical Drop			10				-108.477	43.316
12	WY	Midvale	Wyoming	139		Drop	Vertical Drop			10				-108.471	43.315
12	WY	Midvale	Wyoming	140		Drop	Vertical Drop			8				-108.466	43.313
12	WY	Shoshone	Garland Canal	147		Drop	Vertical Drop			6.2				-108.849	44.724
12	WY	Shoshone	Garland Canal	148		Drop	Vertical Drop			7				-108.844	44.726
12	WY	Shoshone	Garland Canal	149		Drop	Vertical Drop			6				-108.838	44.728
12	WY	Shoshone	Garland Canal	150		Drop	Vertical Drop			5.86				-108.834	44.729
12	WY	Shoshone	Garland Canal	151		Drop	Vertical Drop			5.84				-108.830	44.730
12	WY	Shoshone	Garland Canal	152		Drop	Vertical Drop			9.4				-108.826	44.731
12	WY	Shoshone	Garland Canal	153		Drop	Vertical Drop			8				-108.821	44.732
12	WY	Shoshone	Garland Canal	154		Drop	Vertical Drop			8				-108.816	44.734
12	WY	Shoshone	Garland Canal	155		Drop	Vertical Drop			10				-108.812	44.735
12	WY	Shoshone	Garland Canal	156		Drop	Vertical Drop			10				-108.806	44.737
12	WY	Shoshone	Garland Canal	157		Drop	Vertical Drop			8				-108.800	44.739
12	WY	Shoshone	Garland Canal	158		Drop	Vertical Drop			8				-108.796	44.740
12	WY	Shoshone	Garland Canal	159		Drop	Vertical Drop			10				-108.791	44.741
12	WY	Shoshone	Garland Canal	160		Drop	Vertical Drop			8.3				-108.783	44.744

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12	WY	Shoshone	Garland Canal	161		Drop	Vertical Drop			8				-108.779	44.745
12	WY	Shoshone	Garland Canal	162		Drop	Vertical Drop			6				-108.773	44.746
12	WY	Shoshone	Garland Canal	163		Drop	Vertical Drop			10				-108.769	44.748
12	WY	Shoshone	Garland Canal	164		Drop	Vertical Drop			10				-108.761	44.750
12	WY	Shoshone	Garland Canal	165		Drop	Vertical Drop			8				-108.755	44.752
12	WY	Shoshone	Garland Canal	166		Drop	Vertical Drop			8				-108.749	44.754
12	WY	Shoshone	Garland Canal	167		Drop	Vertical Drop			9.5				-108.743	44.755
12	WY	Shoshone	Garland Canal	168		Drop	Vertical Drop			8				-108.738	44.757
12	WY	Shoshone	Garland Canal	169		Drop	Vertical Drop			6				-108.733	44.758
12	WY	Shoshone	Garland Canal	170		Drop	Vertical Drop			6				-108.727	44.760
12	WY	Shoshone	Garland Canal	171		Drop	Vertical Drop			8				-108.719	44.762
12	WY	Shoshone	Garland Canal	172		Drop	Vertical Drop			8				-108.713	44.764
12	WY	Shoshone	Garland Canal	173		Drop	Vertical Drop			8				-108.709	44.765
12	WY	Shoshone	Garland Canal	174		Drop	Vertical Drop			8				-108.703	44.767
12	WY	Shoshone	Garland Canal	175		Drop	Vertical Drop			6				-108.695	44.769
12	WY	Shoshone	Garland Canal	176		Drop	Vertical Drop			6				-108.692	44.770
12	WY	Willwood	Willwood Canal	177		Drop	Pipeline			45				-108.828	44.685
12	WY	Willwood	Willwood Canal	178		Drop	Chute			35				-108.771	44.678
12	WY	Willwood	Willwood Canal	179		Drop	Chute			40				-108.738	44.680
12	UT		Steinaker Feeder Canal (1)	248		Drop	Vertical Drop			6				-109.564	40.497
12	UT		Steinaker Feeder Canal (2)	249		Drop	Vertical Drop			6				-109.563	40.498
12	UT		Steinaker Feeder Canal (3)	250		Drop	Vertical Drop			6				-109.562	40.498
12	UT		Steinaker Feeder Canal (4)	251		Drop	Vertical Drop			6				-109.561	40.499
12	UT		Steinaker Feeder Canal (5)	252		Drop	Vertical Drop			6				-109.560	40.499
12	UT		Steinaker Feeder Canal (6)	253		Drop	Vertical Drop			6				-109.560	40.500
12	UT		Steinaker Feeder Canal (7)	254		Drop	Vertical Drop			6				-109.559	40.500
12	UT		Steinaker Feeder Canal (8)	255		Drop	Vertical Drop			6				-109.558	40.500
12	UT		Steinaker Feeder Canal (9)	256		Drop	Vertical Drop			6				-109.557	40.501

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12	UT		Steinaker Feeder Canal (10)	257		Drop	Vertical Drop			6				-109.556	40.501
12	UT		Steinaker Feeder Canal (11)	258		Drop	Vertical Drop			6				-109.555	40.502
12	UT		Steinaker Feeder Canal (12)	259		Drop	Vertical Drop			6				-109.554	40.502
12	WY		Eden Canal (1)	260		Drop	Vertical Drop			8.5				-109.348	42.111
12	WY		Eden Canal (2)	261		Drop	Vertical Drop			7.5				-109.365	42.094
12	WY		Eden Canal (3)	262		Drop	Vertical Drop			7.5				-109.381	42.080
12	WY		West Side Lateral (1)	263		Drop	Vertical Drop			8.2				-109.447	42.186
12	WY		West Side Lateral (2)	264		Drop	Vertical Drop		Not there	10.3				-109.447	42.154
12	WY		West Side Lateral (3)	265		Drop	Vertical Drop			15.3				-109.463	42.120
12	WY		Farson Lateral (1)	266		Drop	Vertical Drop			20				-109.381	42.188
12	WY		Farson Lateral (2)	267		Drop	Vertical Drop			10				-109.382	42.178
12	UT		CC&H(1)	268		Drop	Vertical Drop			24.6				-111.075	39.253
12	UT		Ogden- Brigham Canal (1)	269		Drop	Vertical Drop		Not there	24.9				-111.995	41.330
12	UT		Ogden- Brigham Canal (2)	270		Drop	Vertical Drop			22.7				-112.014	41.335
12	UT		Weber - Provo Diversion (1)	271		Drop	Vertical Drop			11				-111.274	40.652
12	UT		Weber - Provo Diversion (2)	272		Drop	Vertical Drop			127.4				-111.305	40.613
12	UT		Strawberry-Highline Canal (1)	273		Drop	Chute			60				-111.806	40.003
12	UT		Strawberry-Highline Canal (2)	274		Drop	Chute			20				-111.812	40.004
12	UT		Ogden Valley Canal (1)	275		Drop	Vertical Drop			26.2				-111.777	41.300
12	UT		Ogden Valley Canal (2)	276		Drop	Vertical Drop			11				-111.816	41.310
12	UT		Willard Canal (1)	277		Drop	Pipeline		Not there	9.8				-112.013	41.299
12	UT		Willard Canal (2)	278		Drop	Vertical Drop			13.2				-112.063	41.349
12	ID		MIN Main Canal Drop	309		Drop	Vertical Drop			6.64				-113.508	42.685
12	WY		Eden Canal (4)	358		Drop	Vertical Drop			8.5				-109.389	42.075
13	MT	Huntley	Rod McCoy Drop	9		Drop	Vertical Drop			16.5				-107.985	45.956
13	MT	Lower Yellowstone	Lateral C4	10		Drop	Vertical Drop			16				-104.151	47.689
13	MT	Lower Yellowstone	Lateral D	11		Drop	Vertical Drop			15				-104.142	47.699

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13	MT	Lower Yellowstone	Lateral D6	12		Drop	Vertical Drop			16				-104.135	47.703
13	MT	Lower Yellowstone	Lateral F	13		Drop	Series of Drops			25				-104.165	47.733
13	MT	Lower Yellowstone	Lateral H	14		Drop	Chute			25				-104.090	47.811
13	ND	Lower Yellowstone	Lateral N	15		Drop	Series of Drops			41				-104.039	47.870
13	MT	Lower Yellowstone	Lateral PP 1st & 2nd drops	16		Drop	Series of Drops			26				-104.245	47.587
13	MT	Lower Yellowstone	Lateral PP5	17		Drop	Vertical Drop		Not there	13				-104.207	47.635
13	MT	Milk River	Nelson North	18		Drop	Vertical Drop			46				-107.517	48.540
13	MT	Savage	Lateral 1.9	19		Drop	Chute		Hand Drawn	15				-104.385	47.429
13	MT	Savage	Lateral 5.7 1st	20		Drop	Chute		Hand Drawn	13				-104.341	47.501
13	MT	Savage	Lateral 5.7 2nd	21		Drop	Chute		Hand Drawn	10				-104.340	47.500
13	WY	Casper Alcova	Johnson/256 Lateral	63		Drop	Vertical Drop			12.97				-106.552	42.943
13	WY	Casper Alcova	Johnson/256 Lateral	64		Drop	Vertical Drop			13.5				-106.543	42.950
13	WY	Casper Alcova	Johnson/256 Lateral	65		Drop	Vertical Drop			13.7				-106.540	42.950
13	NE	Northport	Northport	141		Drop	Vertical Drop			10				-103.044	41.700
13	NE	Northport	Northport	142		Drop	Vertical Drop			10				-103.043	41.699
13	WY	Pathfinder	#1 Lateral M.P.	143		Drop	Vertical Drop			14				-104.103	42.073
13	NE	Pathfinder	#18 Lateral M.P.	144		Drop	Vertical Drop			21				-103.807	42.040
13	NE	Pathfinder	#21 Lateral M.P.	145		Drop	Vertical Drop			7				-103.755	41.996
13	NE	Pathfinder	Lake Alice Inlet Check	146		Drop	Vertical Drop			17				-103.633	41.998
13	NM		1st Bridge	279		Drop	Vertical Drop			12				-106.666	36.841
13	NM		1st Drop Structure sta. 1565	280		Drop	Vertical Drop			18				-106.660	36.823
13	NM		2nd Drop Structure sta. 1702	281		Drop	Vertical Drop			12				-106.653	36.820
13	NM		3rd Drop Structure sta. 1831	282		Drop	Vertical Drop			18				-106.635	36.778
13	NM		Azotea Drop	283		Drop	Vertical Drop		Not there	13				-106.505	36.851
13	SD		DK-10.1	300		Drop	Vertical Drop			6.5				-103.734	44.701
13	NM		Angostura Diversion Dam	359		Drop	Vertical Drop			5				-106.499	35.380
13	NM		Sile Canal Drop E	371		Drop	Vertical Drop		Not there	13				-106.355	35.540
13	NM		Sile Canal Drop F	474		Drop	Vertical Drop			19				-106.370	35.539

Div	State	Owner	Canal Name	Structure I.D.	Location	Category	Classification	Sub-Classification	Notes	Elevation Change (ft)	U.S. Width (ft)	Distance to Nearest Tie In (ft)	# of Insulators	Xcoord	Ycoord
14	NE	Ainsworth	Ainsworth	35		Drop	Vertical Drop			8.1				-100.497	42.673
14	NE	Ainsworth	Ainsworth	36		Drop	Vertical Drop			4.92				-100.477	42.665
14	NE	Ainsworth	Ainsworth	38		Drop	Vertical Drop			5.07				-100.423	42.657
14	NE	Ainsworth	Ainsworth	39		Drop	Vertical Drop			5.08				-100.408	42.655
14	NE	Ainsworth	Ainsworth	41		Drop	Vertical Drop			6.09				-100.379	42.644
14	NE	Ainsworth	Ainsworth	42		Drop	Vertical Drop			9.59				-100.343	42.627
14	NE	Ainsworth	Ainsworth	43		Drop	Vertical Drop			5.58				-100.339	42.625
14	NE	Ainsworth	Ainsworth	44		Drop	Vertical Drop			6.07				-100.321	42.619
14	NE	Ainsworth	Ainsworth	45		Drop	Vertical Drop			9.31				-100.288	42.607
14	NE	Ainsworth	Ainsworth	46		Drop	Vertical Drop			12.15				-100.221	42.591
14	NE	Ainsworth	Ainsworth	47		Drop	Vertical Drop			10.65				-100.183	42.574
14	NE	Ainsworth	Ainsworth	48		Drop	Vertical Drop			13.1				-100.165	42.568
14	NE	Ainsworth	Ainsworth	49		Drop	Vertical Drop			13.35				-100.148	42.563
14	NE	Ainsworth	Ainsworth	50		Drop	Vertical Drop			6.2				-100.121	42.566
14	NE	FCID	Cambridge	51		Drop	Vertical Drop			14.9				-99.853	40.305
14	NE	FCID	Cambridge	52		Drop	Vertical Drop			7.81				-99.831	40.299
14	NE	FCID	Cambridge	53		Drop	Vertical Drop			7.82				-40.295	40.295
14	NE	FCID	Cambridge	54		Drop	Vertical Drop			6.23				-99.752	40.286
14	NE	FCID	Cambridge	55		Drop	Vertical Drop			5.97				-99.696	40.274
14	NE	FCID	Cambridge	56		Drop	Vertical Drop			6.1				-99.681	40.266
14	NE	FCID	Cambridge	57		Drop	Vertical Drop			6.1				-99.680	40.265
14	NE	Twin Loups	Mirdan	59		Drop	Vertical Drop			27.47				-98.911	41.462
14	NE	Twin Loups	Mirdan	60		Drop	Vertical Drop			24.78				-98.845	41.449
14	NE	Twin Loups	Mirdan	61		Drop	Vertical Drop			11.83				-98.801	41.449
14	NE	Twin Loups	Mirdan	62		Drop	Vertical Drop			61.6				-98.792	41.446
14	OK		OT-6.2	291		Drop	Vertical Drop			0				-99.318	34.794
14	OK		OT-6.3	292		Drop	Vertical Drop			7.03				-99.319	34.776
14	OK		OT-6.4	293		Drop	Vertical Drop			8.99				-99.318	34.766

Div	State	Owner	Canal Name	Structure I.D.	Location	Category	Classification	Sub-Classification	Notes	Elevation Change (ft)	U.S. Width (ft)	Distance to Nearest Tie In (ft)	# of Insulators	Xcoord	Ycoord
14	OK		OT-6.53.1	294		Drop	Vertical Drop			6				-99.319	34.757
14	OK		OT-6.6	295		Drop	Vertical Drop			11				-99.333	34.721
14	OK		OT-6.7	296		Drop	Vertical Drop			6.03				-99.334	34.716
14	OK		OT-6.8	297		Drop	Vertical Drop			12.04				-99.334	34.707
14	OK		OT-6.9	298		Drop	Vertical Drop			13.51				-99.334	34.698
14	OK		OT-6.10	299		Drop	Vertical Drop			9.31				-99.322	34.659

Table A.2, A.3, and A.4 are the filtered datasets used in the final study. Table A.2 reflects the measurements for Dataset 1, Table A.3 reflects the measurements for Dataset 2, and Table A.4 reflects the measurements for Dataset 3. Filters included removing duplicate sites from USBR data and field data collection, isolating "Drop" category as described in Chapter 4, removing field measured sites less than 2 meters in height, and removing NED measured sites less than 2 meters in height. Descriptions of the columns of Table A.2, A.3, and A.4 are as follows:

Zone	UTM zone the sites is located in.
Structure I.D.	Identification tag assigned to the structures of interest.
Classification	Type of structure
Measured Elevation Change	Recorded height of structure from the field
Measured Elevation Change BIN 1m	Recorded heights were binned in 1 meter blocks
Difference Measured and Envelope BIN 0.5 m	Difference between the measured elevation change and the elevation change as obtained from the NED, values binned to 0.5 meters.
ABS Difference Measured and Envelope BIN 0.5m	Absolute value of previous column.
Within Error?	Labeled "Y" if the difference of the previous column was within the determined error, labeled "N" if the difference of the previous column was not within the determined error. The determined error was identified by methods listed in Chapter 4.
Diff <= 2 m?	"Y" for yes, "N" for no.
Envelope Length	Length between nodes used to identify structure boundaries.
Envelope Length BIN 10m	Envelope length value binned at 10 meter intervals
Envelope Z	Recorded height of structure from NED data
Envelope Z BIN 1m	Recorded heights were binned in 1 meter blocks
Adjusted BIN Category	Sites were sorted to fit within the previously determined category
Envelope % Error of Orig	A comparison was done between the NED elevation change and the measured elevation change. The comparison was identified as a percent error and calculated by equation 3.3.
Radial Slope Value for 100 and 500 meter BIN	This value was discussed in the surrounding average slope section in Chapter 3 and is given in percent. Each value was rounded to the nearest 0.25%.

Table A.2 Dataset 1

Structure I.D.	Classification	Measured Elevation Change (m)	Measured Elevation Change BIN 1m	Difference Measured and Envelope BIN 0.5m	ABS Difference Measured and Envelope BIN 0.5m	WITHIN ERROR?	Diff <=2m?	Envelope Length BIN 10m	Envelope Z BIN 1m	Adjusted BIN Category	10mSP_100_BIN 0.25%	10mSP_500_BIN_0.25%
72.00	Chute	6.49	6.00	4.50	4.50	N	N	80.00	2.00	2-3	4.25	4.00
29.00	Chute	6.71	7.00	3.50	3.50	N	N	120.00	3.00	2-3	5.75	4.75
101.00	Chute	7.17	7.00	4.00	4.00	N	N	120.00	3.00	2-3	12.00	11.50
24.00	Pipeline	18.90	19.00	16.00	16.00	N	N	560.00	3.00	2-3	4.50	6.75
243.00	Steep Grade Change	25.91	26.00	22.50	22.50	N	N	80.00	3.00	2-3	26.25	14.75
270.00	Vertical Drop	6.92	7.00	5.00	5.00	N	N	120.00	2.00	2-3	21.50	17.25
FLC15	Vertical Drop	7.52	8.00	5.00	5.00	N	N	150.00	2.00	2-3	2.00	2.00
146.00	Vertical Drop	5.18	5.00	2.50	2.50	N	N	100.00	3.00	2-3	2.50	2.50
231.00	Vertical Drop	11.00	11.00	8.00	8.00	N	N	90.00	3.00	2-3	20.75	47.25
240.00	Vertical Drop	9.45	9.00	7.00	7.00	N	N	220.00	3.00	2-3	5.50	4.75
282.00	Vertical Drop	5.49	5.00	3.00	3.00	N	N	60.00	3.00	2-3	16.25	10.00
474.00	Vertical Drop	5.79	6.00	2.50	2.50	N	N	190.00	3.00	2-3	4.50	3.50
UR3	Vertical Drop	3.30	3.00	1.00	1.00	Y	Y	130.00	2.00	2-3	2.75	2.00
MD6	Vertical Drop	2.74	3.00	0.50	0.50	Y	Y	70.00	2.00	2-3	4.25	7.50
21.00	Chute	3.05	3.00	1.00	1.00	Y	Y	90.00	2.00	2-3	6.00	6.50
320.00	Pipeline	2.52	3.00	-0.50	0.50	Y	Y	380.00	3.00	2-3	4.00	2.50
HS3	Pipeline	5.14	5.00	2.00	2.00	Y	Y	50.00	3.00	2-3	6.50	6.50
45.00	Vertical Drop	2.84	3.00	0.50	0.50	Y	Y	120.00	2.00	2-3	2.50	3.25
76.00	Vertical Drop	3.38	3.00	1.50	1.50	Y	Y	100.00	2.00	2-3	10.50	10.50
79.00	Vertical Drop	3.35	3.00	1.00	1.00	Y	Y	100.00	2.00	2-3	8.50	8.00
143.00	Vertical Drop	4.27	4.00	2.00	2.00	Y	Y	90.00	2.00	2-3	3.75	5.50
265.00	Vertical Drop	4.66	5.00	2.00	2.00	Y	Y	120.00	2.00	2-3	2.00	1.00
295.00	Vertical Drop	3.35	3.00	1.50	1.50	Y	Y	130.00	2.00	2-3	2.25	1.50
AlternateM9	Vertical Drop	2.87	3.00	1.00	1.00	Y	Y	90.00	2.00	2-3	5.25	4.75
42.00	Vertical Drop	2.92	3.00	-0.50	0.50	Y	Y	100.00	3.00	2-3	5.50	3.75
63.00	Vertical Drop	3.95	4.00	0.50	0.50	Y	Y	110.00	3.00	2-3	2.50	1.75
75.00	Vertical Drop	3.35	3.00	0.00	0.00	Y	Y	90.00	3.00	2-3	11.50	10.50

Structure I.D.	Classification	Measured Elevation Change (m)	Measured Elevation Change BIN 1m	Difference Measured and Envelope BIN 0.5m	ABS Difference Measured and Envelope BIN 0.5m	WITHIN ERROR?	Diff <=2m?	Envelope Length BIN 10m	Envelope Z BIN 1m	Adjusted BIN Category	10mSP_100_BIN 0.25%	10mSP_500_BIN_0.25%
77.00	Vertical Drop	3.35	3.00	0.50	0.50	Y	Y	80.00	3.00	2-3	12.00	10.50
78.00	Vertical Drop	3.35	3.00	0.50	0.50	Y	Y	90.00	3.00	2-3	9.50	10.50
81.00	Vertical Drop	3.35	3.00	0.50	0.50	Y	Y	90.00	3.00	2-3	7.75	9.00
82.00	Vertical Drop	3.09	3.00	0.00	0.00	Y	Y	70.00	3.00	2-3	5.50	7.75
84.00	Vertical Drop	3.09	3.00	0.00	0.00	Y	Y	80.00	3.00	2-3	4.50	5.50
91.00	Vertical Drop	4.52	5.00	2.00	2.00	Y	Y	100.00	3.00	2-3	11.75	9.00
99.00	Vertical Drop	3.02	3.00	0.00	0.00	Y	Y	90.00	3.00	2-3	5.50	4.75
142.00	Vertical Drop	3.05	3.00	0.50	0.50	Y	Y	50.00	3.00	2-3	11.00	15.25
276.00	Vertical Drop	3.35	3.00	0.50	0.50	Y	Y	70.00	3.00	2-3	6.50	5.25
293.00	Vertical Drop	2.74	3.00	0.00	0.00	Y	Y	120.00	3.00	2-3	2.50	1.75
STH6	Vertical Drop	3.66	4.00	-3.00	3.00	N	N	160.00	6.00	4-6	9.75	14.75
105.00	Chute	7.56	8.00	3.50	3.50	N	N	90.00	4.00	4-6	13.75	7.25
178.00	Chute	10.67	11.00	7.00	7.00	N	N	270.00	4.00	4-6	4.00	2.25
14.00	Chute	7.62	8.00	2.50	2.50	N	N	100.00	5.00	4-6	4.25	4.25
86.00	Chute	7.48	7.00	3.00	3.00	N	N	190.00	5.00	4-6	5.50	3.00
STH2	Chute	8.84	9.00	4.00	4.00	N	N	200.00	5.00	4-6	14.25	17.75
122.00	Chute	33.54	34.00	27.00	27.00	N	N	450.00	6.00	4-6	2.00	2.00
229.00	Vertical Drop	9.15	9.00	4.50	4.50	N	N	120.00	4.00	4-6	9.75	23.00
100.00	Pipeline	44.21	44.00	38.00	38.00	N	N	1140.00	6.00	4-6	22.50	15.50
177.00	Pipeline	13.72	14.00	7.50	7.50	N	N	160.00	6.00	4-6	16.50	8.00
SS11	Pipeline	16.77	17.00	10.50	10.50	N	N	130.00	6.00	4-6	21.75	15.50
BS7	Pipeline	6.10	6.00	2.50	2.50	N	N	110.00	4.00	4-6	9.75	9.75
6.00	Series of Drops	9.45	9.00	5.50	5.50	N	N	1050.00	4.00	4-6	2.25	1.50
13.00	Series of Drops	7.62	8.00	2.50	2.50	N	N	320.00	5.00	4-6	1.50	1.25
22.00	Vertical Drop	13.57	14.00	7.50	7.50	N	N	140.00	6.00	4-6	3.50	3.25
238.00	Vertical Drop	8.54	9.00	2.50	2.50	N	N	110.00	6.00	4-6	10.75	9.00
307.00	Vertical Drop	2.96	3.00	-3.00	3.00	N	N	100.00	6.00	4-6	5.50	4.00
D1	Chute	4.22	4.00	0.50	0.50	Y	Y	110.00	4.00	4-6	4.50	5.25

Structure I.D.	Classification	Measured Elevation Change (m)	Measured Elevation Change BIN 1m	Difference Measured and Envelope BIN 0.5m	ABS Difference Measured and Envelope BIN 0.5m	WITHIN ERROR?	Diff <=2m?	Envelope Length BIN 10m	Envelope Z BIN 1m	Adjusted BIN Category	10mSP_100_BIN 0.25%	10mSP_500_BIN_0.25%
19.00	Chute	4.57	5.00	0.00	0.00	Y	Y	790.00	5.00	4-6	2.75	3.25
D2	Chute	4.23	4.00	-0.50	0.50	Y	Y	100.00	5.00	4-6	6.75	5.25
71.00	Chute	5.64	6.00	0.00	0.00	Y	Y	210.00	6.00	4-6	4.25	4.00
87.00	Chute	6.31	6.00	0.00	0.00	Y	Y	130.00	6.00	4-6	3.75	3.00
102.00	Chute	6.78	7.00	0.50	0.50	Y	Y	130.00	6.00	4-6	12.25	11.50
453.00	Chute	6.10	6.00	0.00	0.00	Y	Y	120.00	6.00	4-6	6.75	7.25
LP1	Vertical Drop	3.66	4.00	-0.50	0.50	Y	Y	70.00	4.00	4-6	5.25	9.25
456.00	Series of Drops	6.10	6.00	2.00	2.00	Y	Y	320.00	4.00	4-6	2.50	4.00
1.00	Series of Drops	4.88	5.00	0.00	0.00	Y	Y	320.00	5.00	4-6	2.75	3.00
447.00	Series of Drops	5.49	5.00	-0.50	0.50	Y	Y	160.00	6.00	4-6	6.00	8.00
BS1	Steep Grade Change	6.55	7.00	1.50	1.50	Y	Y	100.00	5.00	4-6	3.00	3.00
M11	Steep Grade Change	3.05	3.00	-1.00	1.00	Y	Y	270.00	4.00	4-6	7.50	12.00
BS6	Vertical Drop	3.66	4.00	-1.00	1.00	Y	Y	50.00	4.00	4-6	9.75	9.75
10.00	Vertical Drop	4.88	5.00	1.00	1.00	Y	Y	100.00	4.00	4-6	2.50	1.00
52.00	Vertical Drop	2.38	2.00	-2.00	2.00	Y	Y	260.00	4.00	4-6	8.75	4.75
73.00	Vertical Drop	3.35	3.00	-0.50	0.50	Y	Y	100.00	4.00	4-6	10.25	10.50
80.00	Vertical Drop	3.35	3.00	-0.50	0.50	Y	Y	80.00	4.00	4-6	8.75	8.50
88.00	Vertical Drop	4.58	5.00	0.50	0.50	Y	Y	80.00	4.00	4-6	10.25	9.00
97.00	Vertical Drop	3.19	3.00	-1.00	1.00	Y	Y	80.00	4.00	4-6	4.50	8.00
280.00	Vertical Drop	5.49	5.00	2.00	2.00	Y	Y	60.00	4.00	4-6	12.00	15.50
304.00	Vertical Drop	6.03	6.00	2.00	2.00	Y	Y	90.00	4.00	4-6	6.00	7.75
95.00	Vertical Drop	3.63	4.00	-1.00	1.00	Y	Y	90.00	5.00	4-6	5.00	8.00
110.00	Vertical Drop	4.63	5.00	-1.00	1.00	Y	Y	80.00	5.00	4-6	16.00	11.50
141.00	Vertical Drop	3.05	3.00	-1.50	1.50	Y	Y	80.00	5.00	4-6	11.00	15.25
241.00	Vertical Drop	3.66	4.00	-1.50	1.50	Y	Y	100.00	5.00	4-6	12.00	19.25
298.00	Vertical Drop	4.12	4.00	-0.50	0.50	Y	Y	130.00	5.00	4-6	2.50	1.00
DX1	Vertical Drop	3.05	3.00	-1.50	1.50	Y	Y	100.00	5.00	4-6	14.25	14.25
93.00	Vertical Drop	3.65	4.00	-2.00	2.00	Y	Y	110.00	6.00	4-6	5.25	8.75

Structure I.D.	Classification	Measured Elevation Change (m)	Measured Elevation Change BIN 1m	Difference Measured and Envelope BIN 0.5m	ABS Difference Measured and Envelope BIN 0.5m	WITHIN ERROR?	Diff <=2m?	Envelope Length BIN 10m	Envelope Z BIN 1m	Adjusted BIN Category	10mSP_100_BIN 0.25%	10mSP_500_BIN_0.25%
109.00	Vertical Drop	4.51	5.00	-2.00	2.00	Y	Y	100.00	6.00	4-6	16.50	14.00
275.00	Vertical Drop	7.99	8.00	1.50	1.50	Y	Y	120.00	6.00	4-6	9.25	8.50
305.00	Vertical Drop	4.21	4.00	-1.50	1.50	Y	Y	110.00	6.00	4-6	13.00	9.50
70.00	Chute	12.07	12.00	5.50	5.50	N	N	130.00	7.00	7-8	7.25	5.50
273.00	Chute	18.29	18.00	11.00	11.00	N	N	210.00	7.00	7-8	10.50	12.75
E6	Vertical Drop	18.29	18.00	11.00	11.00	N	N	100.00	7.00	7-8	4.75	5.50
HS6	Pipeline	5.27	5.00	-3.00	3.00	N	N	130.00	8.00	7-8	14.50	14.50
245.00	Vertical Drop	14.02	14.00	6.50	6.50	N	N	300.00	8.00	7-8	11.00	8.25
113.00	Chute	7.84	8.00	1.00	1.00	Y	Y	190.00	7.00	7-8	6.75	11.00
115.00	Chute	8.76	9.00	1.50	1.50	Y	Y	150.00	7.00	7-8	9.75	9.75
GV1A	Chute	6.10	6.00	-1.00	1.00	Y	Y	50.00	7.00	7-8	26.75	41.00
114.00	Chute	8.98	9.00	0.50	0.50	Y	Y	150.00	8.00	7-8	13.50	10.25
123.00	Chute	9.15	9.00	1.00	1.00	Y	Y	250.00	8.00	7-8	5.25	4.00
16.00	Series of Drops	7.93	8.00	0.50	0.50	Y	Y	350.00	8.00	7-8	3.75	2.00
458.00	Series of Drops	8.23	8.00	0.50	0.50	Y	Y	410.00	8.00	7-8	5.50	6.50
FLC8	Pipeline	6.10	6.00	-1.50	1.50	Y	Y	260.00	7.00	7-8	4.00	2.50
59.00	Vertical Drop	8.37	8.00	1.50	1.50	Y	Y	130.00	7.00	7-8	9.00	14.00
60.00	Vertical Drop	7.55	8.00	0.50	0.50	Y	Y	110.00	7.00	7-8	13.50	13.75
384.00	Vertical Drop	10.37	10.00	2.00	2.00	Y	Y	460.00	8.00	7-8	2.50	3.00
179.00	Chute	12.20	12.00	3.50	3.50	N	N	360.00	9.00	9-13	7.75	6.25
274.00	Chute	6.10	6.00	-3.00	3.00	N	N	200.00	9.00	9-13	8.25	10.25
116.00	Chute	17.62	18.00	8.00	8.00	N	N	190.00	10.00	9-13	8.75	8.50
465.00	Chute	12.20	12.00	2.50	2.50	Y	N	280.00	10.00	9-13	3.50	8.25
STH7	Chute	18.90	19.00	6.00	6.00	N	N	500.00	13.00	9-13	9.25	10.00
SS8	Pipeline	17.68	18.00	7.50	7.50	N	N	120.00	10.00	9-13	31.75	15.75
470.00	Pipeline	7.01	7.00	-4.50	4.50	N	N	300.00	12.00	9-13	5.50	5.50
469.00	Pipeline	17.07	17.00	4.00	4.00	N	N	440.00	13.00	9-13	5.50	5.25
15.00	Series of Drops	12.50	13.00	3.00	3.00	N	N	680.00	9.00	9-13	1.75	2.25

Structure I.D.	Classification	Measured Elevation Change (m)	Measured Elevation Change BIN 1m	Difference Measured and Envelope BIN 0.5m	ABS Difference Measured and Envelope BIN 0.5m	WITHIN ERROR?	Diff <=2m?	Envelope Length BIN 10m	Envelope Z BIN 1m	Adjusted BIN Category	10mSP_100_BIN 0.25%	10mSP_500_BIN_0.25%
5.00	Series of Drops	7.62	8.00	-3.50	3.50	N	N	1180.00	11.00	9-13	1.00	1.00
466.00	Series of Drops	16.46	16.00	4.50	4.50	N	N	1750.00	12.00	9-13	2.75	3.00
27.00	Vertical Drop	10.92	11.00	2.50	2.50	Y	N	140.00	9.00	9-13	8.00	7.50
393.00	Vertical Drop	11.59	12.00	2.50	2.50	Y	N	140.00	9.00	9-13	7.75	14.00
18.00	Vertical Drop	14.02	14.00	4.00	4.00	N	N	110.00	10.00	9-13	7.25	6.75
246.00	Vertical Drop	17.68	18.00	8.00	8.00	N	N	150.00	10.00	9-13	7.75	9.00
61.00	Vertical Drop	3.61	4.00	-9.00	9.00	N	N	80.00	12.00	9-13	18.00	15.50
237.00	Vertical Drop	17.38	17.00	5.50	5.50	N	N	100.00	12.00	9-13	13.25	11.00
WL1	Vertical Drop	10.67	11.00	-2.50	2.50	Y	N	160.00	13.00	9-13	15.50	13.00
112.00	Chute	7.02	7.00	-2.00	2.00	Y	Y	110.00	9.00	9-13	11.75	11.25
90.00	Chute	11.40	11.00	1.50	1.50	Y	Y	150.00	10.00	9-13	10.50	9.00
30.00	Chute	12.80	13.00	1.00	1.00	Y	Y	190.00	12.00	9-13	10.00	8.50
111.00	Chute	11.08	11.00	-0.50	0.50	Y	Y	130.00	12.00	9-13	12.25	11.75
454.00	Chute	10.06	10.00	-1.50	1.50	Y	Y	140.00	12.00	9-13	11.25	10.00
BF1	Vertical Drop	10.56	11.00	0.50	0.50	Y	Y	80.00	10.00	9-13	5.25	5.25
455.00	Series of Drops	11.28	11.00	-1.00	1.00	Y	Y	560.00	12.00	9-13	4.25	5.50
HS1	Steep Grade Change	10.46	10.00	1.50	1.50	Y	Y	200.00	9.00	9-13	12.50	12.50
394.00	Vertical Drop	11.28	11.00	2.00	2.00	Y	Y	140.00	9.00	9-13	8.50	14.00
224.00	Vertical Drop	8.66	9.00	-1.00	1.00	Y	Y	100.00	10.00	9-13	12.25	19.25
M12	Vertical Drop	10.67	11.00	0.50	0.50	Y	Y	70.00	10.00	9-13	10.75	8.50
8.00	Vertical Drop	11.59	12.00	-0.50	0.50	Y	Y	290.00	12.00	9-13	5.25	5.00
239.00	Vertical Drop	12.80	13.00	1.00	1.00	Y	Y	190.00	12.00	9-13	9.00	4.50
107.00	Chute	11.31	11.00	-2.50	2.50	Y	N	150.00	14.00	14-31	12.00	14.00
117.00	Chute	11.32	11.00	-4.00	4.00	Y	N	190.00	15.00	14-31	13.75	14.50
119.00	Chute	18.29	18.00	3.50	3.50	Y	N	230.00	15.00	14-31	5.50	6.25
SS9	Chute	21.04	21.00	6.50	6.50	N	N	220.00	15.00	14-31	36.75	21.50
SV6	Chute	25.62	26.00	7.50	7.50	N	N	350.00	18.00	14-31	11.25	11.25
235.00	Chute	25.00	25.00	5.50	5.50	N	N	240.00	20.00	14-31	23.25	25.25

Structure I.D.	Classification	Measured Elevation Change (m)	Measured Elevation Change BIN 1m	Difference Measured and Envelope BIN 0.5m	ABS Difference Measured and Envelope BIN 0.5m	WITHIN ERROR?	Diff <=2m?	Envelope Length BIN 10m	Envelope Z BIN 1m	Adjusted BIN Category	10mSP_100_BIN 0.25%	10mSP_500_BIN_0.25%
SS5	Chute	40.24	40.00	14.50	14.50	N	N	250.00	26.00	14-31	47.50	42.50
32.00	Chute	35.06	35.00	4.50	4.50	Y	N	300.00	31.00	14-31	11.50	6.50
HG1	Pipeline	17.68	18.00	-2.50	2.50	Y	N	270.00	20.00	14-31	10.75	33.00
RG1	Pipeline	18.90	19.00	-10.50	10.50	N	N	330.00	29.00	14-31	17.75	31.25
475.00	Series of Drops	16.16	16.00	2.50	2.50	Y	N	280.00	14.00	14-31	11.25	19.25
459.00	Series of Drops	21.04	21.00	2.50	2.50	Y	N	1340.00	18.00	14-31	2.75	5.25
462.00	Series of Drops	36.89	37.00	13.50	13.50	N	N	410.00	23.00	14-31	9.25	8.75
467.00	Series of Drops	28.66	29.00	6.00	6.00	N	N	1310.00	23.00	14-31	7.00	5.00
2.00	Series of Drops	18.60	19.00	-11.50	11.50	N	N	1060.00	30.00	14-31	3.50	3.50
28.00	Series of Drops	24.70	25.00	-7.00	7.00	N	N	770.00	31.00	14-31	2.25	3.25
233.00	Steep Grade Change	13.72	14.00	-4.50	4.50	Y	N	310.00	18.00	14-31	10.75	11.75
PC1	Steep Grade Change	30.49	30.00	3.00	3.00	Y	N	630.00	27.00	14-31	7.75	16.25
26.00	Vertical Drop	10.98	11.00	-3.00	3.00	Y	N	230.00	14.00	14-31	11.75	8.00
392.00	Vertical Drop	13.41	13.00	-6.50	6.50	N	N	130.00	20.00	14-31	20.25	10.50
108.00	Chute	12.42	12.00	-1.50	1.50	Y	Y	190.00	14.00	14-31	11.75	14.00
STH5	Chute	17.07	17.00	2.00	2.00	Y	Y	400.00	15.00	14-31	11.25	20.75
23.00	Chute	17.99	18.00	0.00	0.00	Y	Y	240.00	18.00	14-31	9.00	11.00
SS7	Chute	21.95	22.00	-0.50	0.50	Y	Y	70.00	22.00	14-31	28.00	15.75
387.00	Chute	22.26	22.00	-1.50	1.50	Y	Y	920.00	24.00	14-31	18.50	34.00
SS3	Chute	30.18	30.00	1.00	1.00	Y	Y	190.00	29.00	14-31	26.25	23.00
125.00	Chute	30.49	30.00	-1.00	1.00	Y	Y	1570.00	31.00	14-31	4.50	3.25
449.00	Chute	28.96	29.00	-2.00	2.00	Y	Y	180.00	31.00	14-31	18.00	10.50
227.00	Pipeline	13.41	13.00	-2.00	2.00	Y	Y	110.00	15.00	14-31	24.50	28.00
4.00	Series of Drops	14.33	14.00	0.00	0.00	Y	Y	300.00	14.00	14-31	5.25	3.25
7.00	Series of Drops	14.33	14.00	0.50	0.50	Y	Y	660.00	14.00	14-31	2.25	2.25
460.00	Series of Drops	15.85	16.00	-2.00	2.00	Y	Y	890.00	18.00	14-31	8.50	8.50
464.00	Series of Drops	20.12	20.00	2.00	2.00	Y	Y	1410.00	18.00	14-31	3.50	3.50
463.00	Series of Drops	23.17	23.00	2.00	2.00	Y	Y	870.00	21.00	14-31	2.50	3.75

Structure I.D.	Classification	Measured Elevation Change (m)	Measured Elevation Change BIN 1m	Difference Measured and Envelope BIN 0.5m	ABS Difference Measured and Envelope BIN 0.5m	WITHIN ERROR?	Diff <=2m?	Envelope Length BIN 10m	Envelope Z BIN 1m	Adjusted BIN Category	10mSP_100_BIN 0.25%	10mSP_500_BIN_0.25%
445.00	Series of Drops	33.23	33.00	2.00	2.00	Y	Y	530.00	31.00	14-31	15.25	16.50
62.00	Vertical Drop	18.78	19.00	2.00	2.00	Y	Y	130.00	17.00	14-31	12.25	13.75
124.00	Chute	45.73	46.00	9.00	9.00	N	N	770.00	37.00	32-83	10.75	4.75
SS10	Chute	35.67	36.00	-5.00	5.00	Y	N	110.00	40.00	32-83	29.25	19.25
SS6	Chute	40.55	41.00	-5.00	5.00	Y	N	350.00	46.00	32-83	23.75	27.50
311.00	Chute	62.20	62.00	3.00	3.00	Y	N	460.00	59.00	32-83	10.50	12.75
121.00	Chute	39.63	40.00	-28.00	28.00	N	N	4070.00	68.00	32-83	1.50	2.00
SV3A	Chute	78.05	78.00	8.50	8.50	N	N	250.00	70.00	32-83	31.25	31.25
SS2	Chute	82.32	82.00	6.00	6.00	N	N	370.00	77.00	32-83	24.75	27.00
HF5504	Pipeline	12.80	13.00	-20.50	20.50	N	N	420.00	33.00	32-83	15.50	15.50
31.00	Pipeline	38.11	38.00	2.50	2.50	Y	N	440.00	36.00	32-83	8.50	6.00
SV5	Pipeline	78.35	78.00	-4.50	4.50	Y	N	220.00	83.00	32-83	33.25	33.25
450.00	Series of Drops	31.40	31.00	-3.00	3.00	Y	N	840.00	34.00	32-83	15.00	12.50
446.00	Series of Drops	36.89	37.00	-4.50	4.50	Y	N	560.00	41.00	32-83	7.75	10.50
457.00	Series of Drops	50.30	50.00	3.50	3.50	Y	N	3490.00	47.00	32-83	5.50	5.00
476.00	Series of Drops	39.33	39.00	-8.50	8.50	N	N	1250.00	48.00	32-83	7.75	9.25
448.00	Series of Drops	46.65	47.00	-7.50	7.50	N	N	2740.00	54.00	32-83	9.25	6.00
477.00	Series of Drops	49.70	50.00	-5.00	5.00	Y	N	1360.00	55.00	32-83	6.50	6.00
452.00	Series of Drops	53.66	54.00	-3.50	3.50	Y	N	2350.00	57.00	32-83	6.50	6.75
451.00	Series of Drops	46.04	46.00	-15.00	15.00	N	N	2490.00	61.00	32-83	3.75	4.75
461.00	Series of Drops	45.12	45.00	-19.00	19.00	N	N	1100.00	64.00	32-83	11.50	9.00
MD7	Steep Grade Change	38.11	38.00	-2.50	2.50	Y	N	370.00	41.00	32-83	14.25	8.75
232.00	Steep Grade Change	30.18	30.00	-22.00	22.00	N	N	790.00	52.00	32-83	21.75	21.00
120.00	Chute	33.54	34.00	-2.00	2.00	Y	Y	280.00	35.00	32-83	10.75	8.25
SV2	Chute	48.26	48.00	-2.00	2.00	Y	Y	890.00	50.00	32-83	11.25	11.25
468.00	Series of Drops	41.77	42.00	-1.00	1.00	Y	Y	1800.00	43.00	32-83	6.50	5.25
WL2	Steep Grade Change	47.26	47.00	-2.00	2.00	Y	Y	340.00	49.00	32-83	16.25	14.00
272.00	Vertical Drop	38.84	39.00	1.00	1.00	Y	Y	130.00	38.00	32-83	32.25	18.75

Table A.3 Dataset 2

Structure I.D.	Classification	Measured Elevation Change (m)	Measured Elevation Change BIN 1m	Difference Measured and Envelope BIN 0.5m	ABS Difference Measured and Envelope BIN 0.5m	WITHIN ERROR?	Diff <=2m?	Envelope Length_BIN 10m	Envelope Z_BIN 1m	Adjusted BIN Category	30mSP_100_BIN 0.25%	30mSP_500_BIN_0.25%
AlternateM9	vertical drop	2.87	3.00	1.00	1.00	Y	Y	90.00	2.00	2-3	4.50	4.25
HS3	Pipeline	5.14	5.00	3.00	3.00	N	N	50.00	2.00	2-3	6.00	6.00
74.00	Vertical Drop	3.35	3.00	1.50	1.50	Y	Y	100.00	2.00	2-3	10.75	9.50
84.00	Vertical Drop	3.09	3.00	1.00	1.00	Y	Y	80.00	2.00	2-3	4.00	5.00
21.00	Chute	3.05	3.00	1.00	1.00	Y	Y	90.00	2.00	2-3	5.75	5.25
79.00	Vertical Drop	3.35	3.00	1.00	1.00	Y	Y	100.00	2.00	2-3	8.50	8.50
142.00	Vertical Drop	3.05	3.00	0.50	0.50	Y	Y	50.00	2.00	2-3	8.75	11.50
BS7	Pipline	6.10	6.00	3.50	3.50	N	N	110.00	2.00	2-3	5.25	5.25
HS10	Chute	3.05	3.00	0.50	0.50	Y	Y	70.00	2.00	2-3	10.50	10.50
45.00	Vertical Drop	2.84	3.00	0.50	0.50	Y	Y	120.00	2.00	2-3	2.50	3.25
81.00	Vertical Drop	3.35	3.00	1.00	1.00	Y	Y	90.00	2.00	2-3	8.00	8.00
S5B	vertical drop	2.44	2.00	0.00	0.00	Y	Y	90.00	2.00	2-3	4.25	2.50
FLC15	Vertical Drop	7.52	8.00	5.00	5.00	N	N	150.00	2.00	2-3	1.75	2.00
77.00	Vertical Drop	3.35	3.00	1.00	1.00	Y	Y	80.00	2.00	2-3	9.50	9.50
98.00	Vertical Drop	3.63	4.00	1.00	1.00	Y	Y	90.00	2.00	2-3	5.00	7.25
76.00	Vertical Drop	3.38	3.00	1.00	1.00	Y	Y	100.00	3.00	2-3	9.25	9.50
146.00	Vertical Drop	5.18	5.00	2.50	2.50	N	N	100.00	3.00	2-3	1.75	2.25
UR3	Barrage	3.30	3.00	0.50	0.50	Y	Y	130.00	3.00	2-3	2.50	2.00
243.00	Steep grade change	25.91	26.00	23.50	23.50	N	N	80.00	3.00	2-3	21.75	12.25
D1	chute	4.22	4.00	1.50	1.50	Y	Y	110.00	3.00	2-3	4.00	4.75
282.00	Vertical Drop	5.49	5.00	2.50	2.50	N	N	60.00	3.00	2-3	16.00	9.00
BF11	Siphon	2.81	3.00	0.00	0.00	Y	Y	130.00	3.00	2-3	8.50	8.50
320.00	Pipeline	2.52	3.00	-0.50	0.50	Y	Y	380.00	3.00	2-3	4.00	2.50
101.00	Chute	7.17	7.00	4.00	4.00	N	N	120.00	3.00	2-3	10.50	10.00
270.00	Vertical Drop	6.92	7.00	4.00	4.00	N	N	120.00	3.00	2-3	21.50	17.00
63.00	Vertical Drop	3.95	4.00	1.00	1.00	Y	Y	110.00	3.00	2-3	2.25	1.75

Structure I.D.	Classification	Measured Elevation Change (m)	Measured Elevation Change BIN 1m	Difference Measured and Envelope BIN 0.5m	ABS Difference Measured and Envelope BIN 0.5m	WITHIN ERROR?	Diff <=2m?	Envelope Length_BIN 10m	Envelope Z_BIN 1m	Adjusted BIN Category	30mSP_100_BIN 0.25%	30mSP_500_BIN_0.25%
304.00	Vertical Drop	6.03	6.00	3.00	3.00	N	N	90.00	3.00	2-3	5.25	6.75
276.00	Vertical Drop	3.35	3.00	0.00	0.00	Y	Y	70.00	3.00	2-3	6.25	5.25
24.00	Pipeline	18.90	19.00	15.50	15.50	N	N	560.00	3.00	2-3	4.50	6.75
75.00	Vertical Drop	3.35	3.00	0.00	0.00	Y	Y	90.00	3.00	2-3	10.25	9.50
240.00	Vertical Drop	9.45	9.00	6.00	6.00	N	N	220.00	3.00	2-3	4.50	4.00
293.00	Vertical Drop	2.74	3.00	-0.50	0.50	Y	Y	120.00	3.00	2-3	2.50	1.50
80.00	Vertical Drop	3.35	3.00	0.00	0.00	Y	Y	80.00	3.00	2-3	9.00	8.00
178.00	Chute	10.67	11.00	7.00	7.00	N	N	270.00	3.00	2-3	3.50	2.00
42.00	Vertical Drop	2.92	3.00	-0.50	0.50	Y	Y	100.00	3.00	2-3	5.50	3.75
BS6	Vertical	3.66	4.00	0.00	0.00	Y	Y	50.00	3.00	2-3	5.25	5.25
78.00	Vertical Drop	3.35	3.00	0.00	0.00	Y	Y	90.00	4.00	4-6	9.25	9.50
10.00	Vertical Drop	4.88	5.00	1.50	1.50	Y	Y	100.00	4.00	4-6	2.50	1.00
97.00	Vertical Drop	3.19	3.00	-0.50	0.50	Y	Y	80.00	4.00	4-6	4.25	7.25
275.00	Vertical Drop	7.99	8.00	4.50	4.50	N	N	120.00	4.00	4-6	8.50	8.50
73.00	Vertical Drop	3.35	3.00	-0.50	0.50	Y	Y	100.00	4.00	4-6	11.00	9.50
LP1	drop structue	3.66	4.00	0.00	0.00	Y	Y	70.00	4.00	4-6	5.75	9.00
444.00	Vertical Drop	2.13	2.00	-1.50	1.50	Y	Y	80.00	4.00	4-6	8.50	16.25
52.00	Vertical Drop	2.38	2.00	-1.50	1.50	Y	Y	260.00	4.00	4-6	7.00	4.00
393.00	Vertical Drop	11.59	12.00	7.50	7.50	N	N	140.00	4.00	4-6	6.50	12.00
91.00	Vertical Drop	4.52	5.00	0.50	0.50	Y	Y	100.00	4.00	4-6	10.00	8.25
105.00	Chute	7.56	8.00	3.50	3.50	N	N	90.00	4.00	4-6	11.50	6.75
474.00	Vertical Drop	5.79	6.00	1.50	1.50	Y	Y	190.00	4.00	4-6	3.50	2.75
M11	steep grade change	3.05	3.00	-1.00	1.00	Y	Y	270.00	4.00	4-6	7.00	10.50
280.00	Vertical Drop	5.49	5.00	1.00	1.00	Y	Y	60.00	4.00	4-6	10.75	14.25
298.00	Vertical Drop	4.12	4.00	0.00	0.00	Y	Y	130.00	4.00	4-6	1.75	0.75
6.00	Series of Drops	9.45	9.00	5.00	5.00	N	N	1050.00	4.00	4-6	1.75	1.50
238.00	Vertical Drop	8.54	9.00	4.00	4.00	N	N	110.00	4.00	4-6	8.00	6.75

Structure I.D.	Classification	Measured Elevation Change (m)	Measured Elevation Change BIN 1m	Difference Measured and Envelope BIN 0.5m	ABS Difference Measured and Envelope BIN 0.5m	WITHIN ERROR?	Diff <=2m?	Envelope Length_BIN 10m	Envelope Z_BIN 1m	Adjusted BIN Category	30mSP_100_BIN 0.25%	30mSP_500_BIN_0.25%
305.00	Vertical Drop	4.21	4.00	0.00	0.00	Y	Y	110.00	4.00	4-6	11.25	7.75
141.00	Vertical Drop	3.05	3.00	-1.50	1.50	Y	Y	80.00	4.00	4-6	8.75	11.50
102.00	Chute	6.78	7.00	2.00	2.00	Y	Y	130.00	5.00	4-6	11.00	10.00
99.00	Vertical Drop	3.02	3.00	-1.50	1.50	Y	Y	90.00	5.00	4-6	4.75	4.75
177.00	Pipeline	13.72	14.00	9.00	9.00	N	N	160.00	5.00	4-6	13.75	6.75
13.00	Series of Drops	7.62	8.00	3.00	3.00	N	N	320.00	5.00	4-6	1.50	1.00
88.00	Vertical Drop	4.58	5.00	0.00	0.00	Y	Y	80.00	5.00	4-6	9.00	8.00
95.00	Vertical Drop	3.63	4.00	-1.00	1.00	Y	Y	90.00	5.00	4-6	4.25	7.25
BS1	Spillway w Dissipation	6.55	7.00	1.50	1.50	Y	Y	100.00	5.00	4-6	2.75	2.75
100.00	Pipeline	44.21	44.00	39.50	39.50	N	N	1140.00	5.00	4-6	19.75	13.75
456.00	Series of Drops	6.10	6.00	1.00	1.00	Y	Y	320.00	5.00	4-6	2.50	3.75
82.00	Vertical Drop	3.09	3.00	-2.00	2.00	Y	Y	70.00	5.00	4-6	6.50	7.00
86.00	Chute	7.48	7.00	2.50	2.50	N	N	190.00	5.00	4-6	4.75	3.00
229.00	Gate Drop	9.15	9.00	4.00	4.00	N	N	120.00	5.00	4-6	10.25	22.50
19.00	Chute	4.57	5.00	-0.50	0.50	Y	Y	790.00	5.00	4-6	2.25	3.00
93.00	Vertical Drop	3.65	4.00	-1.50	1.50	Y	Y	110.00	5.00	4-6	4.50	7.50
DX1	Vertical Drop	3.05	3.00	-2.00	2.00	Y	Y	100.00	5.00	4-6	14.50	14.50
29.00	Chute	6.71	7.00	1.50	1.50	Y	Y	120.00	5.00	4-6	5.50	4.50
71.00	Chute	5.64	6.00	0.00	0.00	Y	Y	210.00	5.00	4-6	4.00	3.50
1.00	Series of Drops	4.88	5.00	-0.50	0.50	Y	Y	320.00	5.00	4-6	2.75	2.75
E6	drop structure	18.29	18.00	13.00	13.00	N	N	100.00	6.00	4-6	3.75	4.50
D2	chute	4.23	4.00	-1.50	1.50	Y	Y	100.00	6.00	4-6	6.25	4.75
273.00	Chute	18.29	18.00	12.50	12.50	N	N	210.00	6.00	4-6	8.75	11.50
307.00	Vertical Drop	2.96	3.00	-3.00	3.00	N	N	100.00	6.00	4-6	5.00	3.75
87.00	Chute	6.31	6.00	0.00	0.00	Y	Y	130.00	6.00	4-6	3.25	3.25
22.00	Vertical Drop	13.57	14.00	7.00	7.00	N	N	140.00	6.00	4-6	3.25	3.00
447.00	Series of Drops	5.49	5.00	-1.00	1.00	Y	Y	160.00	7.00	7-8	5.25	7.25

Structure I.D.	Classification	Measured Elevation Change (m)	Measured Elevation Change BIN 1m	Difference Measured and Envelope BIN 0.5m	ABS Difference Measured and Envelope BIN 0.5m	WITHIN ERROR?	Diff <=2m?	Envelope Length_BIN 10m	Envelope Z_BIN 1m	Adjusted BIN Category	30mSP_100_BIN 0.25%	30mSP_500_BIN_0.25%
122.00	Chute	33.54	34.00	27.00	27.00	N	N	450.00	7.00	7-8	1.75	2.00
HS6	Siphon	5.27	5.00	-1.50	1.50	Y	Y	130.00	7.00	7-8	10.00	10.00
59.00	Vertical Drop	8.37	8.00	1.50	1.50	Y	Y	130.00	7.00	7-8	8.25	10.75
241.00	Vertical Drop	3.66	4.00	-3.00	3.00	N	N	100.00	7.00	7-8	10.25	17.50
453.00	Chute	6.10	6.00	-1.00	1.00	Y	Y	120.00	7.00	7-8	6.25	6.75
14.00	Chute	7.62	8.00	0.50	0.50	Y	Y	100.00	7.00	7-8	4.25	3.75
STH6	check drop	3.66	4.00	-3.50	3.50	N	N	160.00	7.00	7-8	8.00	12.25
113.00	Chute	7.84	8.00	0.50	0.50	Y	Y	190.00	7.00	7-8	6.00	8.75
FLC8	Siphon	6.10	6.00	-1.50	1.50	Y	Y	260.00	7.00	7-8	3.00	2.25
BF1	Drop Structure	10.56	11.00	3.00	3.00	N	N	80.00	8.00	7-8	5.00	5.00
115.00	Chute	8.76	9.00	1.00	1.00	Y	Y	150.00	8.00	7-8	7.25	7.75
60.00	Vertical Drop	7.55	8.00	0.00	0.00	Y	Y	110.00	8.00	7-8	11.25	11.50
465.00	Chute	12.20	12.00	4.50	4.50	N	N	280.00	8.00	7-8	4.00	7.00
109.00	Vertical Drop	4.51	5.00	-3.00	3.00	N	N	100.00	8.00	7-8	13.25	12.50
GV1A	chute	6.10	6.00	-1.50	1.50	Y	Y	50.00	8.00	7-8	24.25	37.50
114.00	Chute	8.98	9.00	1.00	1.00	Y	Y	150.00	8.00	7-8	9.75	8.50
16.00	Series of Drops	7.93	8.00	0.00	0.00	Y	Y	350.00	8.00	7-8	3.25	1.75
384.00	Vertical Drop	10.37	10.00	2.50	2.50	N	N	460.00	8.00	7-8	2.25	2.50
110.00	Vertical Drop	4.63	5.00	-3.50	3.50	N	N	80.00	8.00	7-8	13.00	9.50
458.00	Series of Drops	8.23	8.00	0.00	0.00	Y	Y	410.00	8.00	7-8	5.25	6.00
394.00	Vertical Drop	11.28	11.00	3.00	3.00	N	N	140.00	8.00	7-8	6.75	12.00
70.00	Chute	12.07	12.00	4.00	4.00	N	N	130.00	8.00	7-8	5.25	4.50
123.00	Chute	9.15	9.00	1.00	1.00	Y	Y	250.00	8.00	7-8	4.75	3.75
246.00	Vertical Drop	17.68	18.00	9.50	9.50	N	N	150.00	8.00	7-8	6.50	8.00
224.00	Vertical Drop	8.66	9.00	0.50	0.50	Y	Y	100.00	8.00	7-8	11.00	19.00
27.00	Vertical Drop	10.92	11.00	2.50	2.50	N	N	140.00	8.00	7-8	7.25	6.50
112.00	Chute	7.02	7.00	-2.00	2.00	Y	Y	110.00	9.00	9-13	9.75	9.50

Structure I.D.	Classification	Measured Elevation Change (m)	Measured Elevation Change BIN 1m	Difference Measured and Envelope BIN 0.5m	ABS Difference Measured and Envelope BIN 0.5m	WITHIN ERROR?	Diff <=2m?	Envelope Length_BIN 10m	Envelope Z_BIN 1m	Adjusted BIN Category	30mSP_100_BIN 0.25%	30mSP_500_BIN_0.25%
HS1	Spillway w Dissipation	10.46	10.00	1.50	1.50	Y	Y	200.00	9.00	9-13	11.00	11.00
15.00	Series of Drops	12.50	13.00	3.50	3.50	N	N	680.00	9.00	9-13	1.50	2.00
SS11	pipeline	16.77	17.00	7.50	7.50	N	N	130.00	9.00	9-13	19.75	14.75
STH2	chute	8.84	9.00	-0.50	0.50	Y	Y	200.00	9.00	9-13	9.50	14.00
18.00	Vertical Drop	14.02	14.00	4.50	4.50	N	N	110.00	9.00	9-13	7.00	6.25
179.00	Chute	12.20	12.00	3.00	3.00	N	N	360.00	9.00	9-13	6.75	5.00
274.00	Chute	6.10	6.00	-3.50	3.50	N	N	200.00	10.00	9-13	8.75	9.25
M12	vertical drop	10.67	11.00	1.00	1.00	Y	Y	70.00	10.00	9-13	8.75	7.50
61.00	Vertical Drop	3.61	4.00	-6.50	6.50	N	N	80.00	10.00	9-13	14.50	12.75
90.00	Chute	11.40	11.00	1.00	1.00	Y	Y	150.00	11.00	9-13	9.50	8.00
SS8	pipeline	17.68	18.00	7.00	7.00	N	N	120.00	11.00	9-13	27.00	13.75
SS9	chute	21.04	21.00	10.50	10.50	N	N	220.00	11.00	9-13	35.50	20.75
5.00	Series of Drops	7.62	8.00	-3.00	3.00	N	N	1180.00	11.00	9-13	0.75	1.00
111.00	Chute	11.08	11.00	0.00	0.00	Y	Y	130.00	11.00	9-13	9.50	9.75
454.00	Chute	10.06	10.00	-1.00	1.00	Y	Y	140.00	11.00	9-13	11.00	9.75
470.00	Pipeline	7.01	7.00	-4.50	4.50	N	N	300.00	12.00	9-13	5.00	5.00
8.00	Vertical Drop	11.59	12.00	-0.50	0.50	Y	Y	290.00	12.00	9-13	4.00	4.50
466.00	Series of Drops	16.46	16.00	4.50	4.50	N	N	1750.00	12.00	9-13	2.00	3.00
455.00	Series of Drops	11.28	11.00	-1.00	1.00	Y	Y	560.00	12.00	9-13	4.25	5.25
239.00	Vertical Drop	12.80	13.00	0.50	0.50	Y	Y	190.00	13.00	9-13	8.25	4.00
237.00	Vertical Drop	17.38	17.00	4.50	4.50	N	N	100.00	13.00	9-13	9.75	8.50
30.00	Chute	12.80	13.00	0.00	0.00	Y	Y	190.00	13.00	9-13	9.50	7.75
469.00	Pipeline	17.07	17.00	4.00	4.00	N	N	440.00	13.00	9-13	5.50	5.00
STH7	chute	18.90	19.00	6.00	6.00	N	N	500.00	13.00	9-13	10.50	8.75
227.00	Pipeline	13.41	13.00	0.00	0.00	Y	Y	110.00	13.00	9-13	21.00	27.50
WL1	vertical drop	10.67	11.00	-3.00	3.00	N	N	160.00	13.00	9-13	15.50	11.75
116.00	Chute	17.62	18.00	4.00	4.00	Y	N	190.00	14.00	14-31	7.00	7.25

Structure I.D.	Classification	Measured Elevation Change (m)	Measured Elevation Change BIN 1m	Difference Measured and Envelope BIN 0.5m	ABS Difference Measured and Envelope BIN 0.5m	WITHIN ERROR?	Diff <=2m?	Envelope Length_BIN 10m	Envelope Z_BIN 1m	Adjusted BIN Category	30mSP_100_BIN 0.25%	30mSP_500_BIN_0.25%
STH5	chute	17.07	17.00	3.00	3.00	Y	N	400.00	14.00	14-31	9.00	17.00
107.00	Chute	11.31	11.00	-2.50	2.50	Y	N	150.00	14.00	14-31	11.25	12.50
245.00	Vertical Drop	14.02	14.00	0.00	0.00	Y	Y	300.00	14.00	14-31	9.50	7.50
26.00	Vertical Drop	10.98	11.00	-3.50	3.50	Y	N	230.00	14.00	14-31	11.50	7.00
108.00	Chute	12.42	12.00	-2.00	2.00	Y	Y	190.00	14.00	14-31	10.75	12.50
119.00	Chute	18.29	18.00	4.00	4.00	Y	N	230.00	14.00	14-31	5.75	6.00
7.00	Series of Drops	14.33	14.00	-0.50	0.50	Y	Y	660.00	15.00	14-31	2.25	2.25
4.00	Series of Drops	14.33	14.00	-0.50	0.50	Y	Y	300.00	15.00	14-31	5.00	3.25
475.00	Series of Drops	16.16	16.00	1.00	1.00	Y	Y	280.00	15.00	14-31	10.25	18.00
117.00	Chute	11.32	11.00	-4.50	4.50	Y	N	190.00	16.00	14-31	10.75	11.50
62.00	Vertical Drop	18.78	19.00	3.00	3.00	Y	N	130.00	16.00	14-31	11.50	11.50
460.00	Series of Drops	15.85	16.00	-1.50	1.50	Y	Y	890.00	17.00	14-31	7.75	7.75
392.00	Vertical Drop	13.41	13.00	-4.00	4.00	Y	N	130.00	17.00	14-31	16.25	9.00
233.00	Steep grade change	13.72	14.00	-3.50	3.50	Y	N	310.00	17.00	14-31	10.75	11.50
464.00	Series of Drops	20.12	20.00	2.00	2.00	Y	Y	1410.00	18.00	14-31	3.50	3.25
459.00	Series of Drops	21.04	21.00	2.50	2.50	Y	N	1340.00	19.00	14-31	2.50	4.75
SS7	chute	21.95	22.00	3.50	3.50	Y	N	70.00	19.00	14-31	23.00	13.75
SV6	Chute	25.62	26.00	6.50	6.50	N	N	350.00	19.00	14-31	9.75	9.75
23.00	Chute	17.99	18.00	-1.50	1.50	Y	Y	240.00	20.00	14-31	8.75	11.50
HG1	pipeline	17.68	18.00	-3.00	3.00	Y	N	270.00	21.00	14-31	11.00	30.75
463.00	Series of Drops	23.17	23.00	2.00	2.00	Y	Y	870.00	21.00	14-31	2.50	3.50
462.00	Series of Drops	36.89	37.00	15.00	15.00	N	N	410.00	22.00	14-31	8.50	8.25
235.00	Chute	25.00	25.00	3.00	3.00	Y	N	240.00	22.00	14-31	18.50	23.50
467.00	Series of Drops	28.66	29.00	6.00	6.00	N	N	1310.00	22.00	14-31	7.50	4.75
387.00	Chute	22.26	22.00	-0.50	0.50	Y	Y	920.00	23.00	14-31	16.00	26.50
PC1	steep grade change	30.49	30.00	3.00	3.00	Y	N	630.00	27.00	14-31	7.75	15.75
SS3	chute	30.18	30.00	0.50	0.50	Y	Y	190.00	30.00	14-31	26.25	21.50

Structure I.D.	Classification	Measured Elevation Change (m)	Measured Elevation Change BIN 1m	Difference Measured and Envelope BIN 0.5m	ABS Difference Measured and Envelope BIN 0.5m	WITHIN ERROR?	Diff <=2m?	Envelope Length_BIN 10m	Envelope Z_BIN 1m	Adjusted BIN Category	30mSP_100_BIN 0.25%	30mSP_500_BIN_0.25%
449.00	Chute	28.96	29.00	-1.00	1.00	Y	Y	180.00	30.00	14-31	17.00	9.50
2.00	Series of Drops	18.60	19.00	-11.50	11.50	N	N	1060.00	30.00	14-31	3.00	3.25
32.00	Chute	35.06	35.00	4.50	4.50	Y	N	300.00	31.00	14-31	9.25	6.00
125.00	Chute	30.49	30.00	0.00	0.00	Y	Y	1570.00	31.00	14-31	3.75	3.00
445.00	Series of Drops	33.23	33.00	2.00	2.00	Y	Y	530.00	31.00	14-31	13.50	15.00
124.00	Chute	45.73	46.00	14.00	14.00	N	N	770.00	32.00	32-83	8.75	4.50
28.00	Series of Drops	24.70	25.00	-7.00	7.00	N	N	770.00	32.00	32-83	2.25	3.25
450.00	Series of Drops	31.40	31.00	-2.00	2.00	Y	Y	840.00	34.00	32-83	14.75	11.75
272.00	Vertical Drop	38.84	39.00	4.50	4.50	Y	N	130.00	34.00	32-83	26.50	17.75
31.00	Pipeline	38.11	38.00	3.50	3.50	Y	N	440.00	35.00	32-83	8.25	5.75
HF5504	Pipeline	12.80	13.00	-22.50	22.50	N	N	420.00	36.00	32-83	15.50	15.50
RG1	pipeline	18.90	19.00	-17.00	17.00	N	N	330.00	36.00	32-83	17.25	28.75
MD7	steep grade change	38.11	38.00	2.00	2.00	Y	Y	370.00	36.00	32-83	12.00	7.75
SS10	chute	35.67	36.00	-1.00	1.00	Y	Y	110.00	37.00	32-83	27.50	18.00
120.00	Chute	33.54	34.00	-3.50	3.50	Y	N	280.00	37.00	32-83	9.50	7.50
446.00	Series of Drops	36.89	37.00	-3.00	3.00	Y	N	560.00	40.00	32-83	7.25	10.00
SS6	chute	40.55	41.00	-0.50	0.50	Y	Y	350.00	41.00	32-83	19.75	23.75
468.00	Series of Drops	41.77	42.00	-1.00	1.00	Y	Y	1800.00	43.00	32-83	5.50	4.75
SS5	chute	40.24	40.00	-4.00	4.00	Y	N	250.00	44.00	32-83	32.00	35.75
457.00	Series of Drops	50.30	50.00	4.00	4.00	Y	N	3490.00	47.00	32-83	5.25	4.50
WL2	steep grade change	47.26	47.00	-1.50	1.50	Y	Y	340.00	49.00	32-83	15.00	13.00
232.00	Steep grade change	30.18	30.00	-20.50	20.50	N	N	790.00	51.00	32-83	18.25	19.25
SV2	Chute	48.26	48.00	-3.00	3.00	Y	N	890.00	51.00	32-83	9.50	9.50
476.00	Series of Drops	39.33	39.00	-13.00	13.00	N	N	1250.00	52.00	32-83	7.00	9.00
448.00	Series of Drops	46.65	47.00	-7.00	7.00	N	N	2740.00	53.00	32-83	8.75	5.50
477.00	Series of Drops	49.70	50.00	-5.00	5.00	Y	N	1360.00	55.00	32-83	6.00	5.75
452.00	Series of Drops	53.66	54.00	-5.00	5.00	Y	N	2350.00	59.00	32-83	5.25	6.00

Structure I.D.	Classification	Measured Elevation Change (m)	Measured Elevation Change BIN 1m	Difference Measured and Envelope BIN 0.5m	ABS Difference Measured and Envelope BIN 0.5m	WITHIN ERROR?	Diff <=2m?	Envelope Length_BIN 10m	Envelope Z_BIN 1m	Adjusted BIN Category	30mSP_100_BIN 0.25%	30mSP_500_BIN_0.25%
311.00	Chute	62.20	62.00	3.00	3.00	Y	N	460.00	59.00	32-83	10.75	12.25
451.00	Series of Drops	46.04	46.00	-15.00	15.00	N	N	2490.00	61.00	32-83	3.25	4.75
SV3A	Chute	78.05	78.00	14.00	14.00	N	N	250.00	64.00	32-83	28.50	28.50
461.00	Series of Drops	45.12	45.00	-19.50	19.50	N	N	1100.00	65.00	32-83	10.75	8.50
121.00	Chute	39.63	40.00	-28.00	28.00	N	N	4070.00	68.00	32-83	1.50	2.00
SV5	Pipeline	78.35	78.00	-1.50	1.50	Y	Y	220.00	80.00	32-83	34.00	34.00
SS2	chute	82.32	82.00	-1.00	1.00	Y	Y	370.00	83.00	32-83	23.50	25.50

Table A.4 Dataset 3

Structure I.D.	Classification	Measured Elevation Change (m)	Measured Elevation Change BIN 1m	Difference Measured and 30_ BIN 0.5m	ABSDifference Measured and 30_ BIN 0.5m	WITHIN ERROR?	Diff <=2m?	30_Length BIN 1m	30_ Z_BIN 1m	Adjusted BIN Category	10mSP_100_BIN 0.25%	10mSP_500_BIN_0.25%
20.00	Chute	3.96	4.00	1.50	1.50	Y	Y	70.00	2.00	2-3	9.75	6.50
96.00	Vertical Drop	3.61	4.00	1.50	1.50	Y	Y	130.00	2.00	2-3	4.75	8.00
118.00	Vertical Drop	3.66	4.00	1.50	1.50	Y	Y	160.00	2.00	2-3	8.75	6.75
127.00	Vertical Drop	4.27	4.00	2.00	2.00	Y	Y	120.00	2.00	2-3	4.00	5.00
134.00	Vertical Drop	3.05	3.00	1.00	1.00	Y	Y	120.00	2.00	2-3	4.00	4.00
144.00	Vertical Drop	6.40	6.00	4.00	4.00	N	N	130.00	2.00	2-3	3.25	3.75
247.00	Vertical Drop	3.66	4.00	1.50	1.50	Y	Y	160.00	2.00	2-3	31.50	16.50
270.00	Vertical Drop	6.92	7.00	4.50	4.50	N	N	180.00	2.00	2-3	21.50	17.25
295.00	Vertical Drop	3.35	3.00	1.50	1.50	Y	Y	190.00	2.00	2-3	2.25	1.50
MD6	check drop	2.74	3.00	0.50	0.50	Y	Y	120.00	2.00	2-3	4.25	7.50
PH1	vertical drop	2.44	2.00	0.50	0.50	Y	Y	140.00	2.00	2-3	2.75	10.00
21.00	Chute	3.05	3.00	0.00	0.00	Y	Y	150.00	3.00	2-3	6.00	6.50
24.00	Pipeline	18.90	19.00	15.50	15.50	N	N	610.00	3.00	2-3	4.50	6.75
45.00	Vertical Drop	2.84	3.00	-0.50	0.50	Y	Y	180.00	3.00	2-3	2.50	3.25
65.00	Vertical Drop	4.18	4.00	1.00	1.00	Y	Y	170.00	3.00	2-3	1.75	1.00
74.00	Vertical Drop	3.35	3.00	0.50	0.50	Y	Y	140.00	3.00	2-3	11.00	10.50
85.00	1.00	3.09	3.00	0.00	0.00	Y	Y	140.00	3.00	2-3	4.00	5.50
92.00	Vertical Drop	3.63	4.00	1.00	1.00	Y	Y	160.00	3.00	2-3	6.25	8.50
143.00	Vertical Drop	4.27	4.00	1.50	1.50	Y	Y	140.00	3.00	2-3	3.75	5.50
146.00	Vertical Drop	5.18	5.00	2.50	2.50	N	N	160.00	3.00	2-3	2.50	2.50
265.00	Vertical Drop	4.66	5.00	1.50	1.50	Y	Y	180.00	3.00	2-3	2.00	1.00
320.00	Pipeline	2.52	3.00	-0.50	0.50	Y	Y	440.00	3.00	2-3	4.00	2.50
AR2	Check Drop	2.74	3.00	0.00	0.00	Y	Y	140.00	3.00	2-3	4.50	3.50
BS7	Pipline	6.10	6.00	2.50	2.50	N	N	140.00	3.00	2-3	9.75	9.75
FLC15	Vertical Drop	7.52	8.00	4.50	4.50	N	N	210.00	3.00	2-3	2.00	2.00
HS3	Pipeline	5.14	5.00	2.00	2.00	Y	Y	50.00	3.00	2-3	6.50	6.50
SS12	drop structue	3.35	3.00	1.00	1.00	Y	Y	100.00	3.00	2-3	12.25	11.75
6.00	Series of Drops	9.45	9.00	5.50	5.50	N	N	1080.00	4.00	4-6	2.25	1.50
29.00	Chute	6.71	7.00	3.00	3.00	N	N	170.00	4.00	4-6	5.75	4.75
52.00	Vertical Drop	2.38	2.00	-2.00	2.00	Y	Y	300.00	4.00	4-6	8.75	4.75
63.00	Vertical Drop	3.95	4.00	-0.50	0.50	Y	Y	160.00	4.00	4-6	2.50	1.75
72.00	1.00	6.49	6.00	3.00	3.00	N	N	110.00	4.00	4-6	4.25	4.00
76.00	Vertical Drop	3.38	3.00	-1.00	1.00	Y	Y	150.00	4.00	4-6	10.50	10.50
83.00	Vertical Drop	3.09	3.00	-1.00	1.00	Y	Y	130.00	4.00	4-6	5.00	6.25
99.00	Vertical Drop	3.02	3.00	-1.50	1.50	Y	Y	120.00	4.00	4-6	5.50	4.75
105.00	Chute	7.56	8.00	3.50	3.50	N	N	120.00	4.00	4-6	13.75	7.25
178.00	Chute	10.67	11.00	7.00	7.00	N	N	320.00	4.00	4-6	4.00	2.25
226.00	Vertical Drop	11.00	11.00	7.50	7.50	N	N	110.00	4.00	4-6	15.00	33.00
231.00	Vertical Drop	11.00	11.00	7.00	7.00	N	N	130.00	4.00	4-6	20.75	47.25
240.00	Vertical Drop	9.45	9.00	5.50	5.50	N	N	270.00	4.00	4-6	5.50	4.75
276.00	Vertical Drop	3.35	3.00	-0.50	0.50	Y	Y	100.00	4.00	4-6	6.50	5.25
282.00	Vertical Drop	5.49	5.00	1.50	1.50	Y	Y	110.00	4.00	4-6	16.25	10.00
293.00	Vertical Drop	2.74	3.00	-1.00	1.00	Y	Y	180.00	4.00	4-6	2.50	1.75
444.00	Vertical Drop	2.13	2.00	-1.50	1.50	Y	Y	120.00	4.00	4-6	9.25	17.75
474.00	Vertical Drop	5.79	6.00	2.00	2.00	Y	Y	200.00	4.00	4-6	4.50	3.50
AlternateM9	vertical drop	2.87	3.00	-1.00	1.00	Y	Y	150.00	4.00	4-6	5.25	4.75
M11	steep grade change	3.05	3.00	-1.50	1.50	Y	Y	300.00	4.00	4-6	7.50	12.00

Structure I.D.	Classification	Measured Elevation Change (m)	Measured Elevation Change BIN 1m	Difference Measured and 30_ BIN 0.5m	ABSDifference Measured and 30_ BIN 0.5m	WITHIN ERROR?	Diff <=2m?	30_Length BIN 1m	30_ Z_BIN 1m	Adjusted BIN Category	10mSP_100_BIN 0.25%	10mSP_500_BIN_0.25%
UR3	Barrage	3.30	3.00	-1.00	1.00	Y	Y	180.00	4.00	4-6	2.75	2.00
10.00	Vertical Drop	4.88	5.00	0.50	0.50	Y	Y	150.00	5.00	4-6	2.50	1.00
13.00	Series of Drops	7.62	8.00	2.50	2.50	N	N	340.00	5.00	4-6	1.50	1.25
19.00	Chute	4.57	5.00	0.00	0.00	Y	Y	790.00	5.00	4-6	2.75	3.25
60.00	Vertical Drop	7.55	8.00	3.00	3.00	N	N	150.00	5.00	4-6	13.50	13.75
73.00	Vertical Drop	3.35	3.00	-1.50	1.50	Y	Y	150.00	5.00	4-6	10.25	10.50
75.00	Vertical Drop	3.35	3.00	-1.50	1.50	Y	Y	130.00	5.00	4-6	11.50	10.50
78.00	Vertical Drop	3.35	3.00	-2.00	2.00	Y	Y	140.00	5.00	4-6	9.50	10.50
79.00	Vertical Drop	3.35	3.00	-1.00	1.00	Y	Y	150.00	5.00	4-6	8.50	8.00
84.00	Vertical Drop	3.09	3.00	-2.50	2.50	N	N	130.00	5.00	4-6	4.50	5.50
88.00	Vertical Drop	4.58	5.00	0.00	0.00	Y	Y	130.00	5.00	4-6	10.25	9.00
97.00	Vertical Drop	3.19	3.00	-1.50	1.50	Y	Y	140.00	5.00	4-6	4.50	8.00
101.00	Chute	7.17	7.00	2.50	2.50	N	N	180.00	5.00	4-6	12.00	11.50
243.00	Steep grade change	25.91	26.00	21.00	21.00	N	N	130.00	5.00	4-6	26.25	14.75
298.00	Vertical Drop	4.12	4.00	-0.50	0.50	Y	Y	190.00	5.00	4-6	2.50	1.00
456.00	Series of Drops	6.10	6.00	1.50	1.50	Y	Y	360.00	5.00	4-6	2.50	4.00
BS1	Spillway w Dissipation	6.55	7.00	1.50	1.50	Y	Y	130.00	5.00	4-6	3.00	3.00
BS6	Vertical	3.66	4.00	-1.00	1.00	Y	Y	70.00	5.00	4-6	9.75	9.75
D1	chute	4.22	4.00	-1.00	1.00	Y	Y	160.00	5.00	4-6	4.50	5.25
D2	chute	4.23	4.00	-0.50	0.50	Y	Y	160.00	5.00	4-6	6.75	5.25
1.00	Series of Drops	4.88	5.00	-1.00	1.00	Y	Y	380.00	6.00	4-6	2.75	3.00
14.00	Chute	7.62	8.00	2.00	2.00	Y	Y	120.00	6.00	4-6	4.25	4.25
42.00	Vertical Drop	2.92	3.00	-3.00	3.00	N	N	150.00	6.00	4-6	5.50	3.75
71.00	Chute	5.64	6.00	0.00	0.00	Y	Y	230.00	6.00	4-6	4.25	4.00
77.00	Vertical Drop	3.35	3.00	-2.50	2.50	N	N	130.00	6.00	4-6	12.00	10.50
80.00	Vertical Drop	3.35	3.00	-3.00	3.00	N	N	130.00	6.00	4-6	8.75	8.50
81.00	Vertical Drop	3.35	3.00	-3.00	3.00	N	N	140.00	6.00	4-6	7.75	9.00
82.00	Vertical Drop	3.09	3.00	-2.50	2.50	N	N	130.00	6.00	4-6	5.50	7.75
86.00	Chute	7.48	7.00	2.00	2.00	Y	Y	240.00	6.00	4-6	5.50	3.00
91.00	Vertical Drop	4.52	5.00	-2.00	2.00	Y	Y	150.00	6.00	4-6	11.75	9.00
93.00	Vertical Drop	3.65	4.00	-2.50	2.50	N	N	170.00	6.00	4-6	5.25	8.75
95.00	Vertical Drop	3.63	4.00	-3.00	3.00	N	N	150.00	6.00	4-6	5.00	8.00
98.00	1.00	3.63	4.00	-2.00	2.00	Y	Y	150.00	6.00	4-6	5.50	8.00
100.00	Pipeline	44.21	44.00	37.50	37.50	N	N	1190.00	6.00	4-6	22.50	15.50
141.00	Vertical Drop	3.05	3.00	-3.00	3.00	N	N	130.00	6.00	4-6	11.00	15.25
142.00	Vertical Drop	3.05	3.00	-3.00	3.00	N	N	90.00	6.00	4-6	11.00	15.25
229.00	Gate Drop	9.15	9.00	3.00	3.00	N	N	170.00	6.00	4-6	9.75	23.00
241.00	Vertical Drop	3.66	4.00	-2.50	2.50	N	N	150.00	6.00	4-6	12.00	19.25
275.00	Vertical Drop	7.99	8.00	2.00	2.00	Y	Y	170.00	6.00	4-6	9.25	8.50
280.00	Vertical Drop	5.49	5.00	0.00	0.00	Y	Y	110.00	6.00	4-6	12.00	15.50
304.00	Vertical Drop	6.03	6.00	0.50	0.50	Y	Y	120.00	6.00	4-6	6.00	7.75
307.00	Vertical Drop	2.96	3.00	-3.00	3.00	N	N	130.00	6.00	4-6	5.50	4.00
447.00	Series of Drops	5.49	5.00	-0.50	0.50	Y	Y	180.00	6.00	4-6	6.00	8.00
LP1	drop structue	3.66	4.00	-2.50	2.50	N	N	100.00	6.00	4-6	5.25	9.25
SS11	pipeline	16.77	17.00	10.50	10.50	N	N	180.00	6.00	4-6	21.75	15.50
22.00	Vertical Drop	13.57	14.00	7.00	7.00	N	N	200.00	7.00	7-8	3.50	3.25
87.00	Chute	6.31	6.00	-0.50	0.50	Y	Y	180.00	7.00	7-8	3.75	3.00
94.00	1.00	3.63	4.00	-3.00	3.00	N	N	150.00	7.00	7-8	4.25	8.50
110.00	Vertical Drop	4.63	5.00	-2.00	2.00	Y	Y	130.00	7.00	7-8	16.00	11.50
113.00	Chute	7.84	8.00	0.50	0.50	Y	Y	250.00	7.00	7-8	6.75	11.00

Structure I.D.	Classification	Measured Elevation Change (m)	Measured Elevation Change BIN 1m	Difference Measured and 30_ BIN 0.5m	ABSDifference Measured and 30_ BIN 0.5m	WITHIN ERROR?	Diff <=2m?	30_Length BIN 1m	30_ Z_BIN 1m	Adjusted BIN Category	10mSP_100_BIN 0.25%	10mSP_500_BIN_0.25%
122.00	Chute	33.54	34.00	27.00	27.00	N	N	480.00	7.00	7-8	2.00	2.00
177.00	Pipeline	13.72	14.00	7.00	7.00	N	N	220.00	7.00	7-8	16.50	8.00
273.00	Chute	18.29	18.00	11.00	11.00	N	N	240.00	7.00	7-8	10.50	12.75
305.00	Vertical Drop	4.21	4.00	-2.50	2.50	N	N	140.00	7.00	7-8	13.00	9.50
453.00	Chute	6.10	6.00	-1.00	1.00	Y	Y	160.00	7.00	7-8	6.75	7.25
GV1A	chute	6.10	6.00	-1.00	1.00	Y	Y	50.00	7.00	7-8	26.75	41.00
27.00	Vertical Drop	10.92	11.00	2.50	2.50	N	N	200.00	8.00	7-8	8.00	7.50
102.00	Chute	6.78	7.00	-1.00	1.00	Y	Y	180.00	8.00	7-8	12.25	11.50
109.00	Vertical Drop	4.51	5.00	-3.50	3.50	N	N	150.00	8.00	7-8	16.50	14.00
115.00	Chute	8.76	9.00	0.50	0.50	Y	Y	200.00	8.00	7-8	9.75	9.75
179.00	Chute	12.20	12.00	4.00	4.00	N	N	410.00	8.00	7-8	7.75	6.25
E6	drop structure	18.29	18.00	10.50	10.50	N	N	150.00	8.00	7-8	4.75	5.50
FLC8	Siphon	6.10	6.00	-1.50	1.50	Y	Y	320.00	8.00	7-8	4.00	2.50
STH2	chute	8.84	9.00	1.00	1.00	Y	Y	250.00	8.00	7-8	14.25	17.75
15.00	Series of Drops	12.50	13.00	3.00	3.00	N	N	710.00	9.00	9-13	1.75	2.25
16.00	Series of Drops	7.93	8.00	-1.50	1.50	Y	Y	390.00	9.00	9-13	3.75	2.00
59.00	Vertical Drop	8.37	8.00	0.00	0.00	Y	Y	190.00	9.00	9-13	9.00	14.00
114.00	Chute	8.98	9.00	0.00	0.00	Y	Y	180.00	9.00	9-13	13.50	10.25
123.00	Chute	9.15	9.00	0.00	0.00	Y	Y	290.00	9.00	9-13	5.25	4.00
238.00	Vertical Drop	8.54	9.00	-1.00	1.00	Y	Y	160.00	9.00	9-13	10.75	9.00
274.00	Chute	6.10	6.00	-3.00	3.00	N	N	220.00	9.00	9-13	8.25	10.25
384.00	Vertical Drop	10.37	10.00	1.00	1.00	Y	Y	520.00	9.00	9-13	2.50	3.00
458.00	Series of Drops	8.23	8.00	-0.50	0.50	Y	Y	460.00	9.00	9-13	5.50	6.50
DX1	Vertical Drop	3.05	3.00	-6.00	6.00	N	N	140.00	9.00	9-13	14.25	14.25
HS6	Siphon	5.27	5.00	-4.00	4.00	N	N	190.00	9.00	9-13	14.50	14.50
STH6	check drop	3.66	4.00	-5.50	5.50	N	N	210.00	9.00	9-13	9.75	14.75
61.00	Vertical Drop	3.61	4.00	-6.50	6.50	N	N	120.00	10.00	9-13	18.00	15.50
112.00	Chute	7.02	7.00	-3.00	3.00	N	N	160.00	10.00	9-13	11.75	11.25
246.00	Vertical Drop	17.68	18.00	7.50	7.50	N	N	190.00	10.00	9-13	7.75	9.00
393.00	Vertical Drop	11.59	12.00	2.00	2.00	Y	Y	200.00	10.00	9-13	7.75	14.00
394.00	Vertical Drop	11.28	11.00	1.00	1.00	Y	Y	200.00	10.00	9-13	8.50	14.00
BF1	Drop Structure	10.56	11.00	0.50	0.50	Y	Y	110.00	10.00	9-13	5.25	5.25
SS8	pipeline	17.68	18.00	7.50	7.50	N	N	120.00	10.00	9-13	31.75	15.75
5.00	Series of Drops	7.62	8.00	-3.50	3.50	N	N	1200.00	11.00	9-13	1.00	1.00
18.00	Vertical Drop	14.02	14.00	3.50	3.50	N	N	150.00	11.00	9-13	7.25	6.75
224.00	Vertical Drop	8.66	9.00	-2.50	2.50	Y	N	120.00	11.00	9-13	12.25	19.25
465.00	Chute	12.20	12.00	1.00	1.00	Y	Y	330.00	11.00	9-13	3.50	8.25
8.00	Vertical Drop	11.59	12.00	-0.50	0.50	Y	Y	320.00	12.00	9-13	5.25	5.00
245.00	Vertical Drop	14.02	14.00	1.50	1.50	Y	Y	340.00	12.00	9-13	11.00	8.25
454.00	Chute	10.06	10.00	-1.50	1.50	Y	Y	160.00	12.00	9-13	11.25	10.00
455.00	Series of Drops	11.28	11.00	-1.00	1.00	Y	Y	580.00	12.00	9-13	4.25	5.50
466.00	Series of Drops	16.46	16.00	4.50	4.50	N	N	1750.00	12.00	9-13	2.75	3.00
470.00	Pipeline	7.01	7.00	-5.00	5.00	N	N	320.00	12.00	9-13	5.50	5.50
M12	vertical drop	10.67	11.00	-1.50	1.50	Y	Y	90.00	12.00	9-13	10.75	8.50
26.00	Vertical Drop	10.98	11.00	-2.50	2.50	Y	N	290.00	13.00	9-13	11.75	8.00
30.00	Chute	12.80	13.00	0.00	0.00	Y	Y	220.00	13.00	9-13	10.00	8.50
111.00	Chute	11.08	11.00	-1.50	1.50	Y	Y	180.00	13.00	9-13	12.25	11.75
237.00	Vertical Drop	17.38	17.00	4.50	4.50	N	N	140.00	13.00	9-13	13.25	11.00
239.00	Vertical Drop	12.80	13.00	0.00	0.00	Y	Y	250.00	13.00	9-13	9.00	4.50
469.00	Pipeline	17.07	17.00	4.00	4.00	N	N	450.00	13.00	9-13	5.50	5.25

Structure I.D.	Classification	Measured Elevation Change (m)	Measured Elevation Change BIN 1m	Difference Measured and 30_ BIN 0.5m	ABSDifference Measured and 30_ BIN 0.5m	WITHIN ERROR?	Diff <=2m?	30_Length BIN 1m	30_ Z_BIN 1m	Adjusted BIN Category	10mSP_100_BIN 0.25%	10mSP_500_BIN_0.25%
HS1	Spillway w Dissipation	10.46	10.00	-2.50	2.50	Y	N	220.00	13.00	9-13	12.50	12.50
STH7	chute	18.90	19.00	6.00	6.00	N	N	560.00	13.00	9-13	9.25	10.00
7.00	Series of Drops	14.33	14.00	0.00	0.00	Y	Y	690.00	14.00	14-31	2.25	2.25
70.00	Chute	12.07	12.00	-1.50	1.50	Y	Y	170.00	14.00	14-31	7.25	5.50
116.00	Chute	17.62	18.00	3.50	3.50	Y	N	250.00	14.00	14-31	8.75	8.50
475.00	Series of Drops	16.16	16.00	2.50	2.50	Y	N	280.00	14.00	14-31	11.25	19.25
WL1	vertical drop	10.67	11.00	-3.00	3.00	Y	N	200.00	14.00	14-31	15.50	13.00
4.00	Series of Drops	14.33	14.00	-1.00	1.00	Y	Y	320.00	15.00	14-31	5.25	3.25
107.00	Chute	11.31	11.00	-3.50	3.50	Y	N	180.00	15.00	14-31	12.00	14.00
108.00	Chute	12.42	12.00	-2.00	2.00	Y	Y	240.00	15.00	14-31	11.75	14.00
119.00	Chute	18.29	18.00	3.50	3.50	Y	N	290.00	15.00	14-31	5.50	6.25
STH5	chute	17.07	17.00	1.50	1.50	Y	Y	450.00	15.00	14-31	11.25	20.75
90.00	Chute	11.40	11.00	-4.50	4.50	Y	N	210.00	16.00	14-31	10.50	9.00
SS9	chute	21.04	21.00	5.00	5.00	N	N	270.00	16.00	14-31	36.75	21.50
62.00	Vertical Drop	18.78	19.00	1.50	1.50	Y	Y	170.00	17.00	14-31	12.25	13.75
392.00	Vertical Drop	13.41	13.00	-3.50	3.50	Y	N	190.00	17.00	14-31	20.25	10.50
23.00	Chute	17.99	18.00	-0.50	0.50	Y	Y	270.00	18.00	14-31	9.00	11.00
460.00	Series of Drops	15.85	16.00	-2.00	2.00	Y	Y	950.00	18.00	14-31	8.50	8.50
464.00	Series of Drops	20.12	20.00	2.00	2.00	Y	Y	1420.00	18.00	14-31	3.50	3.50
459.00	Series of Drops	21.04	21.00	2.00	2.00	Y	Y	1400.00	19.00	14-31	2.75	5.25
SS5	chute	40.24	40.00	21.00	21.00	N	N	300.00	19.00	14-31	47.50	42.50
117.00	Chute	11.32	11.00	-8.00	8.00	N	N	240.00	20.00	14-31	13.75	14.50
233.00	Steep grade change	13.72	14.00	-6.50	6.50	N	N	360.00	20.00	14-31	10.75	11.75
227.00	Pipeline	13.41	13.00	-8.00	8.00	N	N	160.00	21.00	14-31	24.50	28.00
235.00	Chute	25.00	25.00	4.00	4.00	Y	N	300.00	21.00	14-31	23.25	25.25
463.00	Series of Drops	23.17	23.00	2.00	2.00	Y	Y	900.00	21.00	14-31	2.50	3.75
SV6	Chute	25.62	26.00	5.00	5.00	N	N	400.00	21.00	14-31	11.25	11.25
SS7	chute	21.95	22.00	-0.50	0.50	Y	Y	70.00	22.00	14-31	28.00	15.75
387.00	Chute	22.26	22.00	-0.50	0.50	Y	Y	970.00	23.00	14-31	18.50	34.00
462.00	Series of Drops	36.89	37.00	13.50	13.50	N	N	410.00	23.00	14-31	9.25	8.75
467.00	Series of Drops	28.66	29.00	6.00	6.00	N	N	1340.00	23.00	14-31	7.00	5.00
HG1	pipeline	17.68	18.00	-5.00	5.00	N	N	330.00	23.00	14-31	10.75	33.00
PC1	steep grade change	30.49	30.00	3.00	3.00	Y	N	630.00	27.00	14-31	7.75	16.25
SS3	chute	30.18	30.00	2.00	2.00	Y	Y	230.00	28.00	14-31	26.25	23.00
445.00	Series of Drops	33.23	33.00	3.50	3.50	Y	N	580.00	30.00	14-31	15.25	16.50
449.00	Chute	28.96	29.00	-1.50	1.50	Y	Y	230.00	30.00	14-31	18.00	10.50
2.00	Series of Drops	18.60	19.00	-12.50	12.50	N	N	1090.00	31.00	14-31	3.50	3.50
32.00	Chute	35.06	35.00	4.50	4.50	Y	N	350.00	31.00	14-31	11.50	6.50
RG1	pipeline	18.90	19.00	-12.00	12.00	N	N	380.00	31.00	14-31	17.75	31.25
125.00	Chute	30.49	30.00	-1.50	1.50	Y	Y	1600.00	32.00	32-83	4.50	3.25
28.00	Series of Drops	24.70	25.00	-8.50	8.50	N	N	830.00	33.00	32-83	2.25	3.25
450.00	Series of Drops	31.40	31.00	-3.00	3.00	Y	N	840.00	34.00	32-83	15.00	12.50
HF5504	Pipeline	12.80	13.00	-21.00	21.00	N	N	440.00	34.00	32-83	15.50	15.50
120.00	Chute	33.54	34.00	-2.00	2.00	Y	Y	340.00	35.00	32-83	10.75	8.25
31.00	Pipeline	38.11	38.00	2.50	2.50	Y	N	460.00	36.00	32-83	8.50	6.00
124.00	Chute	45.73	46.00	8.50	8.50	N	N	790.00	37.00	32-83	10.75	4.75
272.00	Vertical Drop	38.84	39.00	0.50	0.50	Y	Y	170.00	39.00	32-83	32.25	18.75
SS10	chute	35.67	36.00	-5.00	5.00	Y	N	110.00	40.00	32-83	29.25	19.25
446.00	Series of Drops	36.89	37.00	-4.50	4.50	Y	N	560.00	41.00	32-83	7.75	10.50
MD7	steep grade change	38.11	38.00	-3.50	3.50	Y	N	430.00	42.00	32-83	14.25	8.75

Structure I.D.	Classification	Measured Elevation Change (m)	Measured Elevation Change BIN 1m	Difference Measured and 30_ BIN 0.5m	ABSDifference Measured and 30_ BIN 0.5m	WITHIN ERROR?	Diff <=2m?	30_Length BIN 1m	30_ Z_BIN 1m	Adjusted BIN Category	10mSP_100_BIN 0.25%	10mSP_500_BIN_0.25%
SS6	chute	40.55	41.00	-1.00	1.00	Y	Y	400.00	42.00	32-83	23.75	27.50
468.00	Series of Drops	41.77	42.00	-1.00	1.00	Y	Y	1820.00	43.00	32-83	6.50	5.25
457.00	Series of Drops	50.30	50.00	3.00	3.00	Y	N	3510.00	47.00	32-83	5.50	5.00
WL2	steep grade change	47.26	47.00	-1.00	1.00	Y	Y	390.00	48.00	32-83	16.25	14.00
476.00	Series of Drops	39.33	39.00	-10.00	10.00	N	N	1310.00	49.00	32-83	7.75	9.25
SV2	Chute	48.26	48.00	-1.00	1.00	Y	Y	940.00	49.00	32-83	11.25	11.25
232.00	Steep grade change	30.18	30.00	-25.00	25.00	N	N	840.00	55.00	32-83	21.75	21.00
448.00	Series of Drops	46.65	47.00	-8.50	8.50	N	N	2760.00	55.00	32-83	9.25	6.00
477.00	Series of Drops	49.70	50.00	-5.00	5.00	Y	N	1360.00	55.00	32-83	6.50	6.00
452.00	Series of Drops	53.66	54.00	-3.50	3.50	Y	N	2350.00	57.00	32-83	6.50	6.75
311.00	Chute	62.20	62.00	3.00	3.00	Y	N	520.00	59.00	32-83	10.50	12.75
451.00	Series of Drops	46.04	46.00	-15.00	15.00	N	N	2490.00	61.00	32-83	3.75	4.75
461.00	Series of Drops	45.12	45.00	-19.00	19.00	N	N	1100.00	64.00	32-83	11.50	9.00
121.00	Chute	39.63	40.00	-28.50	28.50	N	N	4100.00	68.00	32-83	1.50	2.00
SV3A	Chute	78.05	78.00	8.50	8.50	N	N	250.00	70.00	32-83	31.25	31.25
SS2	chute	82.32	82.00	4.00	4.00	Y	N	420.00	78.00	32-83	24.75	27.00
SV5	Pipeline	78.35	78.00	-5.00	5.00	Y	N	280.00	83.00	32-83	33.25	33.25

Appendix B-Analysis

Once the acceptable error was determined, see Chapter 4, section NED Height Categories and Allowable Error, Tables A.2, A.3 and A.4 were queried to identify the minimum and maximum values for each metric in question for the non-successful measurements and the successful measurements of each NED category for Dataset 1, Dataset 2, and Dataset 3. These values reflect values entered into Table 4.2 in Chapter 4.

Tables B.1, B.2, and B.3 below show the process used to identify the minimum and maximum metric window. Pivot table analysis was conducted to isolate the variables in question. The upper left corner of the pivot table displays the filters used to create the table. For example, the upper left corner in Table B.1, reflects the pivot table isolated only the successful measurements of the NED category 2-3 meter sites. The first column reflects the length value, the second column reflects the number of sites with this length value. The minimum and maximum length values were recorded and entered into Table 4.2. The subsequent columns reflect the minimum and maximum surrounding area average slope values for the 100 meter radius and the 500 meter radius. If the length value was less than or equal to 200 meters, then the 100 meter radius value was used. If the length value was greater than 200 meters, the 500 meter radius values were used. Minimum and maximum values were selected from each column analyzing the sections highlighted in yellow.

Table B.1 Dataset 1

WITHIN ERROR?	Y
Adjusted BIN Category	2-3

Row Labels	Count of Envelope Length BIN 10m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
50.000	2	6.5	11	6.5	15.25
70.000	3	4.25	6.5	5.25	7.75
80.000	2	4.5	12	5.5	10.5
90.000	7	3.75	11.5	4.75	10.5
100.000	4	5.5	11.75	3.75	10.5
110.000	1	2.5	2.5	1.75	1.75
120.000	3	2	2.5	1	3.25
130.000	2	2.25	2.75	1.5	2
380.000	1	4	4	2.5	2.5
Grand Total	**25**	**2**	**12**	**1**	**15.25**

WITHIN ERROR?	Y
Adjusted BIN Category	4-6

Row Labels	Count of Envelope Length BIN 10m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
50.000	1	9.75	9.75	9.75	9.75
60.000	1	12	12	15.5	15.5
70.000	1	5.25	5.25	9.25	9.25
80.000	5	4.5	16	8	15.25
90.000	2	5	6	7.75	8
100.000	7	2.5	16.5	1	19.25
110.000	3	4.5	13	5.25	9.5
120.000	2	6.75	9.25	7.25	8.5
130.000	3	2.5	12.25	1	11.5
160.000	1	6	6	8	8
210.000	1	4.25	4.25	4	4
260.000	1	8.75	8.75	4.75	4.75
270.000	1	7.5	7.5	12	12
320.000	2	2.5	2.75	3	4
790.000	1	2.75	2.75	3.25	3.25
Grand Total	**32**	**2.5**	**16.5**	**1**	**19.25**

WITHIN ERROR?	Y
Adjusted BIN Category	7-8

Row Labels	Count of Envelope Length BIN 10m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
50.000	1	26.75	26.75	41	41
110.000	1	13.5	13.5	13.75	13.75
130.000	1	9	9	14	14
150.000	2	9.75	13.5	9.75	10.25
190.000	1	6.75	6.75	11	11
250.000	1	5.25	5.25	4	4
260.000	1	4	4	2.5	2.5
350.000	1	3.75	3.75	2	2
410.000	1	5.5	5.5	6.5	6.5
460.000	1	2.5	2.5	3	3
Grand Total	**11**	**2.5**	**26.75**	**2**	**41**

WITHIN ERROR?	Y
Adjusted BIN Category	9-13

Row Labels	Count of Envelope Length BIN 10m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
70.000	1	10.75	10.75	8.5	8.5
80.000	1	5.25	5.25	5.25	5.25
100.000	1	12.25	12.25	19.25	19.25
110.000	1	11.75	11.75	11.25	11.25
130.000	1	12.25	12.25	11.75	11.75
140.000	4	7.75	11.25	7.5	14
150.000	1	10.5	10.5	9	9
160.000	1	15.5	15.5	13	13
190.000	2	9	10	4.5	8.5
200.000	1	12.5	12.5	12.5	12.5
280.000	1	3.5	3.5	8.25	8.25
290.000	1	5.25	5.25	5	5
560.000	1	4.25	4.25	5.5	5.5
Grand Total	**17**	**3.5**	**15.5**	**4.5**	**19.25**

WITHIN ERROR?	Y
Adjusted BIN Category	14-31

Row Labels	Count of Envelope Length BIN 10m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
70.000	1	28	28	15.75	15.75
110.000	1	24.5	24.5	28	28
130.000	1	12.25	12.25	13.75	13.75
150.000	1	12	12	14	14
180.000	1	18	18	10.5	10.5
190.000	3	11.75	26.25	14	23
230.000	2	5.5	11.75	6.25	8
240.000	1	9	9	11	11
270.000	1	10.75	10.75	33	33
280.000	1	11.25	11.25	19.25	19.25
300.000	2	5.25	11.5	3.25	6.5
310.000	1	10.75	10.75	11.75	11.75
400.000	1	11.25	11.25	20.75	20.75
530.000	1	15.25	15.25	16.5	16.5
630.000	1	7.75	7.75	16.25	16.25
660.000	1	2.25	2.25	2.25	2.25
870.000	1	2.5	2.5	3.75	3.75
890.000	1	8.5	8.5	8.5	8.5
920.000	1	18.5	18.5	34	34
1340.000	1	2.75	2.75	5.25	5.25
1410.000	1	3.5	3.5	3.5	3.5
1570.000	1	4.5	4.5	3.25	3.25
Grand Total	**26**	**2.25**	**28**	**2.25**	**34**

WITHIN ERROR?	Y
Adjusted BIN Category	32-83

Row Labels	Count of Envelope Length BIN 10m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
110.000	1	29.25	29.25	19.25	19.25
130.000	1	32.25	32.25	18.75	18.75
220.000	1	33.25	33.25	33.25	33.25
280.000	1	10.75	10.75	8.25	8.25
340.000	1	16.25	16.25	14	14
350.000	1	23.75	23.75	27.5	27.5
370.000	1	14.25	14.25	8.75	8.75
440.000	1	8.5	8.5	6	6
460.000	1	10.5	10.5	12.75	12.75
560.000	1	7.75	7.75	10.5	10.5

840.000	1	15	15	12.5	12.5
890.000	1	11.25	11.25	11.25	11.25
1360.000	1	6.5	6.5	6	6
1800.000	1	6.5	6.5	5.25	5.25
2350.000	1	6.5	6.5	6.75	6.75
3490.000	1	5.5	5.5	5	5
Grand Total	**16**	**5.5**	**33.25**	**5**	**33.25**

WITHIN ERROR?	N
Adjusted BIN Category	2-3

Row Labels	Count of Envelope Length BIN 10m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
60.000	1	16.25	16.25	10	10
80.000	2	4.25	26.25	4	14.75
90.000	1	20.75	20.75	47.25	47.25
100.000	1	2.5	2.5	2.5	2.5
120.000	3	5.75	21.5	4.75	17.25
150.000	1	2	2	2	2
190.000	1	4.5	4.5	3.5	3.5
220.000	1	5.5	5.5	4.75	4.75
560.000	1	4.5	4.5	6.75	6.75
Grand Total	**12**	**2**	**26.25**	**2**	**47.25**

WITHIN ERROR?	N
Adjusted BIN Category	4-6

Row Labels	Count of Envelope Length BIN 10m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
90.000	1	13.75	13.75	7.25	7.25
100.000	2	4.25	5.5	4	4.25
110.000	2	9.75	10.75	9	9.75
120.000	1	9.75	9.75	23	23
130.000	1	21.75	21.75	15.5	15.5
140.000	1	3.5	3.5	3.25	3.25
160.000	2	9.75	16.5	8	14.75
190.000	1	5.5	5.5	3	3
200.000	1	14.25	14.25	17.75	17.75
270.000	1	4	4	2.25	2.25
320.000	1	1.5	1.5	1.25	1.25
450.000	1	2	2	2	2
1050.000	1	2.25	2.25	1.5	1.5

1140.000	1	22.5	22.5	15.5	15.5
Grand Total	**17**	**1.5**	**22.5**	**1.25**	**23**

WITHIN ERROR?	N
Adjusted BIN Category	7-8

Row Labels	Count of Envelope Length BIN 10m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
100.000	1	4.75	4.75	5.5	5.5
130.000	2	7.25	14.5	5.5	14.5
210.000	1	10.5	10.5	12.75	12.75
300.000	1	11	11	8.25	8.25
Grand Total	**5**	**4.75**	**14.5**	**5.5**	**14.5**

WITHIN ERROR?	N
Adjusted BIN Category	9-13

Row Labels	Count of Envelope Length BIN 10m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
80.000	1	18	18	15.5	15.5
100.000	1	13.25	13.25	11	11
110.000	1	7.25	7.25	6.75	6.75
120.000	1	31.75	31.75	15.75	15.75
150.000	1	7.75	7.75	9	9
190.000	1	8.75	8.75	8.5	8.5
200.000	1	8.25	8.25	10.25	10.25
300.000	1	5.5	5.5	5.5	5.5
360.000	1	7.75	7.75	6.25	6.25
440.000	1	5.5	5.5	5.25	5.25
500.000	1	9.25	9.25	10	10
680.000	1	1.75	1.75	2.25	2.25
1180.000	1	1	1	1	1
1750.000	1	2.75	2.75	3	3
Grand Total	**14**	**1**	**31.75**	**1**	**15.75**

WITHIN ERROR?	N
Adjusted BIN Category	14-31

Row Labels	Count of Envelope Length BIN 10m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
130.000	1	20.25	20.25	10.5	10.5
220.000	1	36.75	36.75	21.5	21.5

240.000	1	23.25	23.25	25.25	25.25
250.000	1	47.5	47.5	42.5	42.5
330.000	1	17.75	17.75	31.25	31.25
350.000	1	11.25	11.25	11.25	11.25
410.000	1	9.25	9.25	8.75	8.75
770.000	1	2.25	2.25	3.25	3.25
1060.000	1	3.5	3.5	3.5	3.5
1310.000	1	7	7	5	5
Grand Total	**10**	**2.25**	**47.5**	**3.25**	**42.5**

WITHIN ERROR?	N
Adjusted BIN Category	32-83

Row Labels	Count of Envelope Length BIN 10m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
250.000	1	31.25	31.25	31.25	31.25
370.000	1	24.75	24.75	27	27
420.000	1	15.5	15.5	15.5	15.5
770.000	1	10.75	10.75	4.75	4.75
790.000	1	21.75	21.75	21	21
1100.000	1	11.5	11.5	9	9
1250.000	1	7.75	7.75	9.25	9.25
2490.000	1	3.75	3.75	4.75	4.75
2740.000	1	9.25	9.25	6	6
4070.000	1	1.5	1.5	2	2
Grand Total	**10**	**1.5**	**31.25**	**2**	**31.25**

Table B.2 Dataset 2

WITHIN ERROR?	Y
Adjusted BIN Category	2-3

Row Labels	Count of Envelope Length_BIN 10m	Min of 30mSP_100_BIN 0.25%	Max of 30mSP_100_BIN 0.25%2	Min of 30mSP_500_BIN_0.25%	Max of 30mSP_500_BIN_0.25%2
50	2	5.25	8.75	5.25	11.5
70	2	6.25	10.5	5.25	10.5
80	3	4	9.5	5	9.5
90	6	4.25	10.25	2.5	9.5
100	4	5.5	10.75	3.75	9.5
110	2	2.25	4	1.75	4.75
120	2	2.5	2.5	1.5	3.25
130	2	2.5	8.5	2	8.5
380	1	4	4	2.5	2.5
Grand Total	**24**	**2.25**	**10.75**	**1.5**	**11.5**

WITHIN ERROR?	Y
Adjusted BIN Category	4-6

Row Labels	Count of Envelope Length_BIN 10m	Min of 30mSP_100_BIN 0.25%	Max of 30mSP_100_BIN 0.25%2	Min of 30mSP_500_BIN_0.25%	Max of 30mSP_500_BIN_0.25%2
60	1	10.75	10.75	14.25	14.25
70	2	5.75	6.5	7	9
80	4	4.25	9	7.25	16.25
90	3	4.25	9.25	4.75	9.5
100	6	2.5	14.5	1	14.5
110	2	4.5	11.25	7.5	7.75
120	1	5.5	5.5	4.5	4.5
130	3	1.75	11	0.75	10
190	1	3.5	3.5	2.75	2.75
210	1	4	4	3.5	3.5
260	1	7	7	4	4
270	1	7	7	10.5	10.5
320	2	2.5	2.75	2.75	3.75
790	1	2.25	2.25	3	3
Grand Total	**29**	**1.75**	**14.5**	**0.75**	**16.25**

WITHIN ERROR?	Y
Adjusted BIN Category	7-8

Row Labels	Count of Envelope Length_BIN 10m	Min of 30mSP_100_BIN 0.25%	Max of 30mSP_100_BIN 0.25%2	Min of 30mSP_500_BIN_0.25%	Max of 30mSP_500_BIN_0.25%2
50	1	24.25	24.25	37.5	37.5
100	2	4.25	11	3.75	19
110	1	11.25	11.25	11.5	11.5
120	1	6.25	6.25	6.75	6.75
130	2	8.25	10	10	10.75
150	2	7.25	9.75	7.75	8.5
160	1	5.25	5.25	7.25	7.25
190	1	6	6	8.75	8.75
250	1	4.75	4.75	3.75	3.75
260	1	3	3	2.25	2.25
350	1	3.25	3.25	1.75	1.75
410	1	5.25	5.25	6	6
Grand Total	**15**	**3**	**24.25**	**1.75**	**37.5**

WITHIN ERROR?	Y
Adjusted BIN Category	9-13

Row Labels	Count of Envelope Length_BIN 10m	Min of 30mSP_100_BIN 0.25%	Max of 30mSP_100_BIN 0.25%2	Min of 30mSP_500_BIN_0.25%	Max of 30mSP_500_BIN_0.25%2
70	1	8.75	8.75	7.5	7.5
110	2	9.75	21	9.5	27.5
130	1	9.5	9.5	9.75	9.75
140	1	11	11	9.75	9.75
150	1	9.5	9.5	8	8
190	2	8.25	9.5	4	7.75
200	2	9.5	11	11	14
290	1	4	4	4.5	4.5
560	1	4.25	4.25	5.25	5.25
Grand Total	**12**	**4**	**21**	**4**	**27.5**

WITHIN ERROR?	Y
Adjusted BIN Category	14-31

Row Labels	Count of Envelope Length_BIN 10m	Min of 30mSP_100_BIN 0.25%	Max of 30mSP_100_BIN 0.25%2	Min of 30mSP_500_BIN_0.25%	Max of 30mSP_500_BIN_0.25%2
70	1	23	23	13.75	13.75
130	2	11.5	16.25	9	11.5
150	1	11.25	11.25	12.5	12.5

180	1	17	17	9.5	9.5
190	4	7	26.25	7.25	21.5
230	2	5.75	11.5	6	7
240	2	8.75	18.5	11.5	23.5
270	1	11	11	30.75	30.75
280	1	10.25	10.25	18	18
300	3	5	9.5	3.25	7.5
310	1	10.75	10.75	11.5	11.5
400	1	9	9	17	17
530	1	13.5	13.5	15	15
630	1	7.75	7.75	15.75	15.75
660	1	2.25	2.25	2.25	2.25
870	1	2.5	2.5	3.5	3.5
890	1	7.75	7.75	7.75	7.75
920	1	16	16	26.5	26.5
1340	1	2.5	2.5	4.75	4.75
1410	1	3.5	3.5	3.25	3.25
1570	1	3.75	3.75	3	3
Grand Total	**29**	**2.25**	**26.25**	**2.25**	**30.75**

WITHIN ERROR?	Y
Adjusted BIN Category	32-83

Row Labels	**Count of Envelope Length_BIN 10m**	**Min of 30mSP_100_BIN 0.25%**	**Max of 30mSP_100_BIN 0.25%2**	**Min of 30mSP_500_BIN_0.25%**	**Max of 30mSP_500_BIN_0.25%2**
110	1	27.5	27.5	18	18
130	1	26.5	26.5	17.75	17.75
220	1	34	34	34	34
250	1	32	32	35.75	35.75
280	1	9.5	9.5	7.5	7.5
340	1	15	15	13	13
350	1	19.75	19.75	23.75	23.75
370	2	12	23.5	7.75	25.5
440	1	8.25	8.25	5.75	5.75
460	1	10.75	10.75	12.25	12.25
560	1	7.25	7.25	10	10
840	1	14.75	14.75	11.75	11.75
890	1	9.5	9.5	9.5	9.5
1360	1	6	6	5.75	5.75
1800	1	5.5	5.5	4.75	4.75
2350	1	5.25	5.25	6	6
3490	1	5.25	5.25	4.5	4.5
Grand Total	**18**	**5.25**	**34**	**4.5**	**35.75**

WITHIN ERROR?	N
Adjusted BIN Category	2-3

Row Labels	Count of Envelope Length_BIN 10m	Min of 30mSP_100_BIN 0.25%	Max of 30mSP_100_BIN 0.25%2	Min of 30mSP_500_BIN_0.25%	Max of 30mSP_500_BIN_0.25%2
50	1	6	6	6	6
60	1	16	16	9	9
80	1	21.75	21.75	12.25	12.25
90	1	5.25	5.25	6.75	6.75
100	1	1.75	1.75	2.25	2.25
110	1	5.25	5.25	5.25	5.25
120	2	10.5	21.5	10	17
150	1	1.75	1.75	2	2
220	1	4.5	4.5	4	4
270	1	3.5	3.5	2	2
560	1	4.5	4.5	6.75	6.75
Grand Total	**12**	**1.75**	**21.75**	**2**	**17**

WITHIN ERROR?	N
Adjusted BIN Category	4-6

Row Labels	Count of Envelope Length_BIN 10m	Min of 30mSP_100_BIN 0.25%	Max of 30mSP_100_BIN 0.25%2	Min of 30mSP_500_BIN_0.25%	Max of 30mSP_500_BIN_0.25%2
90	1	11.5	11.5	6.75	6.75
100	2	3.75	5	3.75	4.5
110	1	8	8	6.75	6.75
120	2	8.5	10.25	8.5	22.5
140	2	3.25	6.5	3	12
160	1	13.75	13.75	6.75	6.75
190	1	4.75	4.75	3	3
210	1	8.75	8.75	11.5	11.5
320	1	1.5	1.5	1	1
1050	1	1.75	1.75	1.5	1.5
1140	1	19.75	19.75	13.75	13.75
Grand Total	**14**	**1.5**	**19.75**	**1**	**22.5**

WITHIN ERROR?	N
Adjusted BIN Category	7-8

Row Labels	Count of Envelope Length_BIN 10m	Min of 30mSP_100_BIN 0.25%	Max of 30mSP_100_BIN 0.25%2	Min of 30mSP_500_BIN_0.25%	Max of 30mSP_500_BIN_0.25%2
80	2	5	13	5	9.5
100	2	10.25	13.25	12.5	17.5

130	1	5.25	5.25	4.5	4.5
140	2	6.75	7.25	6.5	12
150	1	6.5	6.5	8	8
160	1	8	8	12.25	12.25
280	1	4	4	7	7
450	1	1.75	1.75	2	2
460	1	2.25	2.25	2.5	2.5
Grand Total	**12**	**1.75**	**13.25**	**2**	**17.5**

WITHIN ERROR?	N
Adjusted BIN Category	9-13

Row Labels	Count of Envelope Length_BIN 10m	Min of 30mSP_100_BIN 0.25%	Max of 30mSP_100_BIN 0.25%2	Min of 30mSP_500_BIN_0.25%	Max of 30mSP_500_BIN_0.25%2
80	1	14.5	14.5	12.75	12.75
100	1	9.75	9.75	8.5	8.5
110	1	7	7	6.25	6.25
120	1	27	27	13.75	13.75
130	1	19.75	19.75	14.75	14.75
160	1	15.5	15.5	11.75	11.75
200	1	8.75	8.75	9.25	9.25
220	1	35.5	35.5	20.75	20.75
300	1	5	5	5	5
360	1	6.75	6.75	5	5
440	1	5.5	5.5	5	5
500	1	10.5	10.5	8.75	8.75
680	1	1.5	1.5	2	2
1180	1	0.75	0.75	1	1
1750	1	2	2	3	3
Grand Total	**15**	**0.75**	**35.5**	**1**	**20.75**

WITHIN ERROR?	N
Adjusted BIN Category	14-31

Row Labels	Count of Envelope Length_BIN 10m	Min of 30mSP_100_BIN 0.25%	Max of 30mSP_100_BIN 0.25%2	Min of 30mSP_500_BIN_0.25%	Max of 30mSP_500_BIN_0.25%2
350	1	9.75	9.75	9.75	9.75
410	1	8.5	8.5	8.25	8.25
1060	1	3	3	3.25	3.25
1310	1	7.5	7.5	4.75	4.75
Grand Total	**4**	**3**	**9.75**	**3.25**	**9.75**

WITHIN ERROR?	N
Adjusted BIN Category	32-83

Row Labels	Count of Envelope Length_BIN 10m	Min of 30mSP_100_BIN 0.25%	Max of 30mSP_100_BIN 0.25%2	Min of 30mSP_500_BIN_0.25%	Max of 30mSP_500_BIN_0.25%2
250	1	28.5	28.5	28.5	28.5
330	1	17.25	17.25	28.75	28.75
420	1	15.5	15.5	15.5	15.5
770	2	2.25	8.75	3.25	4.5
790	1	18.25	18.25	19.25	19.25
1100	1	10.75	10.75	8.5	8.5
1250	1	7	7	9	9
2490	1	3.25	3.25	4.75	4.75
2740	1	8.75	8.75	5.5	5.5
4070	1	1.5	1.5	2	2
Grand Total	**11**	**1.5**	**28.5**	**2**	**28.75**

Table B.3 Dataset 3

WITHIN ERROR?	Y
Adjusted BIN Category	2-3

Row Labels	Count of 30_Length BIN 1m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%2	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
50.000	1	6.5	6.5	6.5	6.5
70.000	1	9.75	9.75	6.5	6.5
100.000	1	12.25	12.25	11.75	11.75
120.000	3	4	4.25	4	7.5
130.000	1	4.75	4.75	8	8
140.000	5	2.75	11	3.5	10.5
150.000	1	6	6	6.5	6.5
160.000	3	6.25	31.5	6.75	16.5
170.000	1	1.75	1.75	1	1
180.000	2	2	2.5	1	3.25
190.000	1	2.25	2.25	1.5	1.5
440.000	1	4	4	2.5	2.5
Grand Total	**21**	**1.75**	**31.5**	**1**	**16.5**

WITHIN ERROR?	Y
Adjusted BIN Category	4-6

Row Labels	Count of 30_Length BIN 1m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%2	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
70.000	1	9.75	9.75	9.75	9.75
100.000	1	6.5	6.5	5.25	5.25
110.000	2	12	16.25	10	15.5
120.000	4	4.25	9.25	4.25	17.75
130.000	4	3	11.5	3	10.5
140.000	2	4.5	9.5	8	10.5
150.000	7	2.5	11.75	1	10.5
160.000	3	2.5	6.75	1.75	5.25
170.000	1	9.25	9.25	8.5	8.5
180.000	3	2.5	6	1.75	8
190.000	1	2.5	2.5	1	1
200.000	1	4.5	4.5	3.5	3.5
230.000	1	4.25	4.25	4	4
240.000	1	5.5	5.5	3	3
300.000	2	7.5	8.75	4.75	12
360.000	1	2.5	2.5	4	4
380.000	1	2.75	2.75	3	3

790.000	1	2.75	2.75	3.25	3.25
Grand Total	**37**	**2.5**	**16.25**	**1**	**17.75**

WITHIN ERROR?	Y
Adjusted BIN Category	7-8

Row Labels	Count of 30_Length BIN 1m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%2	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
50.000	1	26.75	26.75	41	41
130.000	1	16	16	11.5	11.5
160.000	1	6.75	6.75	7.25	7.25
180.000	2	3.75	12.25	3	11.5
200.000	1	9.75	9.75	9.75	9.75
250.000	2	6.75	14.25	11	17.75
320.000	1	4	4	2.5	2.5
Grand Total	**9**	**3.75**	**26.75**	**2.5**	**41**

WITHIN ERROR?	Y
Adjusted BIN Category	9-13

Row Labels	Count of 30_Length BIN 1m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%2	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
90.000	1	10.75	10.75	8.5	8.5
110.000	1	5.25	5.25	5.25	5.25
120.000	1	12.25	12.25	19.25	19.25
160.000	2	10.75	11.25	9	10
180.000	2	12.25	13.5	10.25	11.75
190.000	1	9	9	14	14
200.000	2	7.75	8.5	14	14
220.000	2	10	12.5	8.5	12.5
250.000	1	9	9	4.5	4.5
290.000	2	5.25	11.75	4	8
320.000	1	5.25	5.25	5	5
330.000	1	3.5	3.5	8.25	8.25
340.000	1	11	11	8.25	8.25
390.000	1	3.75	3.75	2	2
460.000	1	5.5	5.5	6.5	6.5
520.000	1	2.5	2.5	3	3
580.000	1	4.25	4.25	5.5	5.5
Grand Total	**22**	**2.5**	**13.5**	**2**	**19.25**

WITHIN ERROR?	Y
Adjusted BIN Category	14-31

Row Labels	Count of 30_Length BIN 1m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%2	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
70.000	1	28	28	15.75	15.75
170.000	2	7.25	12.25	5.5	13.75
180.000	1	12	12	14	14
190.000	1	20.25	20.25	10.5	10.5
200.000	1	15.5	15.5	13	13
210.000	1	10.5	10.5	9	9
230.000	2	18	26.25	10.5	23
240.000	1	11.75	11.75	14	14
250.000	1	8.75	8.75	8.5	8.5
270.000	1	9	9	11	11
280.000	1	11.25	11.25	19.25	19.25
290.000	1	5.5	5.5	6.25	6.25
300.000	1	23.25	23.25	25.25	25.25
320.000	1	5.25	5.25	3.25	3.25
350.000	1	11.5	11.5	6.5	6.5
450.000	1	11.25	11.25	20.75	20.75
580.000	1	15.25	15.25	16.5	16.5
630.000	1	7.75	7.75	16.25	16.25
690.000	1	2.25	2.25	2.25	2.25
900.000	1	2.5	2.5	3.75	3.75
950.000	1	8.5	8.5	8.5	8.5
970.000	1	18.5	18.5	34	34
1400.000	1	2.75	2.75	5.25	5.25
1420.000	1	3.5	3.5	3.5	3.5
Grand Total	**26**	**2.25**	**28**	**2.25**	**34**

WITHIN ERROR?	Y
Adjusted BIN Category	32-83

Row Labels	Count of 30_Length BIN 1m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%2	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
110.000	1	29.25	29.25	19.25	19.25
170.000	1	32.25	32.25	18.75	18.75
280.000	1	33.25	33.25	33.25	33.25
340.000	1	10.75	10.75	8.25	8.25
390.000	1	16.25	16.25	14	14
400.000	1	23.75	23.75	27.5	27.5
420.000	1	24.75	24.75	27	27

430.000	1	14.25	14.25	8.75	8.75
460.000	1	8.5	8.5	6	6
520.000	1	10.5	10.5	12.75	12.75
560.000	1	7.75	7.75	10.5	10.5
840.000	1	15	15	12.5	12.5
940.000	1	11.25	11.25	11.25	11.25
1360.000	1	6.5	6.5	6	6
1600.000	1	4.5	4.5	3.25	3.25
1820.000	1	6.5	6.5	5.25	5.25
2350.000	1	6.5	6.5	6.75	6.75
3510.000	1	5.5	5.5	5	5
Grand Total	**18**	**4.5**	**33.25**	**3.25**	**33.25**

WITHIN ERROR?	N
Adjusted BIN Category	2-3

Row Labels	Count of 30_Length BIN 1m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%2	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
130.000	1	3.25	3.25	3.75	3.75
140.000	1	9.75	9.75	9.75	9.75
160.000	1	2.5	2.5	2.5	2.5
180.000	1	21.5	21.5	17.25	17.25
210.000	1	2	2	2	2
610.000	1	4.5	4.5	6.75	6.75
Grand Total	**6**	**2**	**21.5**	**2**	**17.25**

WITHIN ERROR?	N
Adjusted BIN Category	4-6

Row Labels	Count of 30_Length BIN 1m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%2	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
90.000	1	11	11	15.25	15.25
100.000	1	5.25	5.25	9.25	9.25
110.000	2	4.25	15	4	33
120.000	1	13.75	13.75	7.25	7.25
130.000	8	4.5	26.25	4	47.25
140.000	1	7.75	7.75	9	9
150.000	4	5	13.5	3.75	19.25
170.000	3	5.25	9.75	4.75	23
180.000	2	12	21.75	11.5	15.5
270.000	1	5.5	5.5	4.75	4.75
320.000	1	4	4	2.25	2.25
340.000	1	1.5	1.5	1.25	1.25

1080.000	1	2.25	2.25	1.5	1.5
1190.000	1	22.5	22.5	15.5	15.5
Grand Total	**28**	**1.5**	**26.25**	**1.25**	**47.25**

WITHIN ERROR?	N
Adjusted BIN Category	7-8

Row Labels	**Count of 30_Length BIN 1m**	**Min of 10mSP_100_BIN 0.25%**	**Max of 10mSP_100_BIN 0.25%2**	**Min of 10mSP_500_BIN_0.25%**	**Max of 10mSP_500_BIN_0.25%2**
140.000	1	13	13	9.5	9.5
150.000	3	4.25	16.5	5.5	14
200.000	2	3.5	8	3.25	7.5
220.000	1	16.5	16.5	8	8
240.000	1	10.5	10.5	12.75	12.75
410.000	1	7.75	7.75	6.25	6.25
480.000	1	2	2	2	2
Grand Total	**10**	**2**	**16.5**	**2**	**14**

WITHIN ERROR?	N
Adjusted BIN Category	9-13

Row Labels	**Count of 30_Length BIN 1m**	**Min of 10mSP_100_BIN 0.25%**	**Max of 10mSP_100_BIN 0.25%2**	**Min of 10mSP_500_BIN_0.25%**	**Max of 10mSP_500_BIN_0.25%2**
120.000	2	18	31.75	15.5	15.75
140.000	2	13.25	14.25	11	14.25
150.000	1	7.25	7.25	6.75	6.75
160.000	1	11.75	11.75	11.25	11.25
190.000	2	7.75	14.5	9	14.5
210.000	1	9.75	9.75	14.75	14.75
220.000	1	8.25	8.25	10.25	10.25
320.000	1	5.5	5.5	5.5	5.5
450.000	1	5.5	5.5	5.25	5.25
560.000	1	9.25	9.25	10	10
710.000	1	1.75	1.75	2.25	2.25
1200.000	1	1	1	1	1
1750.000	1	2.75	2.75	3	3
Grand Total	**16**	**1**	**31.75**	**1**	**15.75**

WITHIN ERROR?	N
Adjusted BIN Category	14-31

Row Labels	Count of 30_Length BIN 1m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%2	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
160.000	1	24.5	24.5	28	28
240.000	1	13.75	13.75	14.5	14.5
270.000	1	36.75	36.75	21.5	21.5
300.000	1	47.5	47.5	42.5	42.5
330.000	1	10.75	10.75	33	33
360.000	1	10.75	10.75	11.75	11.75
380.000	1	17.75	17.75	31.25	31.25
400.000	1	11.25	11.25	11.25	11.25
410.000	1	9.25	9.25	8.75	8.75
1090.000	1	3.5	3.5	3.5	3.5
1340.000	1	7	7	5	5
Grand Total	**11**	**3.5**	**47.5**	**3.5**	**42.5**

WITHIN ERROR?	N
Adjusted BIN Category	32-83

Row Labels	Count of 30_Length BIN 1m	Min of 10mSP_100_BIN 0.25%	Max of 10mSP_100_BIN 0.25%2	Min of 10mSP_500_BIN_0.25%	Max of 10mSP_500_BIN_0.25%2
250.000	1	31.25	31.25	31.25	31.25
440.000	1	15.5	15.5	15.5	15.5
790.000	1	10.75	10.75	4.75	4.75
830.000	1	2.25	2.25	3.25	3.25
840.000	1	21.75	21.75	21	21
1100.000	1	11.5	11.5	9	9
1310.000	1	7.75	7.75	9.25	9.25
2490.000	1	3.75	3.75	4.75	4.75
2760.000	1	9.25	9.25	6	6
4100.000	1	1.5	1.5	2	2
Grand Total	**10**	**1.5**	**31.25**	**2**	**31.25**

The flowchart in Figure 4.8 in Chapter 4 graphically reflects the next steps in the process. The recorded minimum and maximum values from the previous section were then modified to minimize the false positives and false negatives in a sample while maximizing the percent correct of the sample. Table B.4 is a sample from the Excel workbook used to run this analysis for all NED categories. The decision support logic is represented in Table B.5 in a formula print out of columns F, K, P, and Q.

Table B.4 Example

Structure I.D.	Measured Elevation Change BIN 1m	ABS Difference Measured and Envelope BIN 0.5m	WITHIN ERROR?	Envelope Length BIN 10m	Envelope Z BIN 1m	Adjusted BIN Category	10mSP_100_BIN 0.25%	10mSP_500_BIN_0.25%	PASS FAIL Analysis WITH ALGORITHM	FalsePositive False Negative Analysis	Max Length	100mRadius MIN	100mRadius MAX	500mRadius MIN	500mRadius MAX
142.00	3.00	0.50	Y	50.00	3.00	2-3	11.00	15.25	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
HS3	5.00	2.00	Y	50.00	3.00	2-3	6.50	6.50	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
282.00	5.00	3.00	N	60.00	3.00	2-3	16.25	10.00	PASS	FALSE POSITIVE	130.00	2.00	16.25	2.50	2.50
MD6	3.00	0.50	Y	70.00	2.00	2-3	4.25	7.50	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
82.00	3.00	0.00	Y	70.00	3.00	2-3	5.50	7.75	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
276.00	3.00	0.50	Y	70.00	3.00	2-3	6.50	5.25	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
84.00	3.00	0.00	Y	80.00	3.00	2-3	4.50	5.50	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
243.00	26.00	22.50	N	80.00	3.00	2-3	26.25	14.75	FAIL	CORRECT	130.00	2.00	16.25	2.50	2.50
21.00	3.00	1.00	Y	90.00	2.00	2-3	6.00	6.50	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
143.00	4.00	2.00	Y	90.00	2.00	2-3	3.75	5.50	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
AlternateM9	3.00	1.00	Y	90.00	2.00	2-3	5.25	4.75	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
75.00	3.00	0.00	Y	90.00	3.00	2-3	11.50	10.50	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
78.00	3.00	0.50	Y	90.00	3.00	2-3	9.50	10.50	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
81.00	3.00	0.50	Y	90.00	3.00	2-3	7.75	9.00	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
99.00	3.00	0.00	Y	90.00	3.00	2-3	5.50	4.75	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
231.00	11.00	8.00	N	90.00	3.00	2-3	20.75	47.25	FAIL	CORRECT	130.00	2.00	16.25	2.50	2.50
76.00	3.00	1.50	Y	100.00	2.00	2-3	10.50	10.50	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
79.00	3.00	1.00	Y	100.00	2.00	2-3	8.50	8.00	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
42.00	3.00	0.50	Y	100.00	3.00	2-3	5.50	3.75	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
91.00	5.00	2.00	Y	100.00	3.00	2-3	11.75	9.00	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
63.00	4.00	0.50	Y	110.00	3.00	2-3	2.50	1.75	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
45.00	3.00	0.50	Y	120.00	2.00	2-3	2.50	3.25	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
265.00	5.00	2.00	Y	120.00	2.00	2-3	2.00	1.00	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
270.00	7.00	5.00	N	120.00	2.00	2-3	21.50	17.25	FAIL	CORRECT	130.00	2.00	16.25	2.50	2.50
101.00	7.00	4.00	N	120.00	3.00	2-3	12.00	11.50	PASS	FALSE POSITIVE	130.00	2.00	16.25	2.50	2.50

293.00	3.00	0.00	Y	120.00	3.00	2-3	2.50	1.75	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
295.00	3.00	1.50	Y	130.00	2.00	2-3	2.25	1.50	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
UR3	3.00	1.00	Y	130.00	2.00	2-3	2.75	2.00	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
FLC15	8.00	5.00	N	150.00	2.00	2-3	2.00	2.00	FAIL	CORRECT	130.00	2.00	16.25	2.50	2.50
474.00	6.00	2.50	N	190.00	3.00	2-3	4.50	3.50	FAIL	CORRECT	130.00	2.00	16.25	2.50	2.50
240.00	9.00	7.00	N	220.00	3.00	2-3	5.50	4.75	FAIL	CORRECT	130.00	2.00	16.25	2.50	2.50
24.00	19.00	16.00	N	560.00	3.00	2-3	4.50	6.75	FAIL	CORRECT	130.00	2.00	16.25	2.50	2.50
77.00	3.00	0.50	Y	80.00	3.00	2-3	12.00	10.50	PASS	CORRECT	130.00	2.00	16.25	2.50	2.50
320.00	3.00	0.50	Y	380.00	3.00	2-3	4.00	2.50	FAIL	FALSE NEGATIVE	130.00	2.00	16.25	2.50	2.50
72.00	6.00	4.50	N	80.00	2.00	2-3	4.25	4.00	PASS	FALSE POSITIVE	130.00	2.00	16.25	2.50	2.50
146.00	5.00	2.50	N	100.00	3.00	2-3	2.50	2.50	PASS	FALSE POSITIVE	130.00	2.00	16.25	2.50	2.50
29.00	7.00	3.50	N	120.00	3.00	2-3	5.75	4.75	PASS	FALSE POSITIVE	130.00	2.00	16.25	2.50	2.50
ENTER TRIAL HERE	Max Length	100m Radius MAX	Total Sites	Number False Positive	Number False Negative	%False Positive in Sample	% Correct								
	380.00	12.00	37.00	5.00	1.00	0.42	0.84								
	560.00	26.25													
	130.00	11.75													
	130.00	12.00													
	130.00	16.25													

Table B.5 Equations

WITHIN ERROR?
=IF(AND(G51="2-3",A51<=2),"Y",IF(AND(G51="4-6",A51<=2),"Y",IF(AND(G51="7-8",A51<=2),"Y",IF(AND(G51="9-13",A51<=2.5),"Y",IF(AND(G51="14-30",A51<=4.5),"Y",IF(AND(G51="31-83",A51<=9),"Y","N"))))))
Adjusted BIN Category
=IF(AND(2<=A54,3>=A54),"2-3",IF(AND(4<=A54,6>=A54),"4-6",IF(AND(7<=A54,8>=A54),"7-8",IF(AND(9<=A54,13>=A54),"9-13",IF(AND(14<=A54,30>=A54),"14-30",IF(AND(31<=A54,83>=A54),"31-83","FIX"))))))
PASS FAIL Analysis WITH ALGORITHM
=IF(AND(H14>=50,H14<=R14,M14>=S14,M14<=T14),"PASS","FAIL")
FalsePositive False Negative Analysis
=IF(AND(F17="Y",P17="PASS"),"CORRECT",IF(AND(F17="Y",P17="FAIL"),"FALSE NEGATIVE",IF(AND(F17="N",P17="FAIL"),"CORRECT",IF(AND(F17="N",P17="PASS"),"FALSE POSITIVE","ERROR"))))

Tables B.6, B.7, and B.8 are the summary analysis for running different metric trials through the Excel spreadsheet shown in Table B.4 for Dataset 1, Dataset 2, and Dataset 3. The first two trials, "Within Wrror, Not Within Error" were selected directly from the minimum and maximum values identified in Table B.1, B.2, and B.3. These two trials were used as an outline in which to begin altering the metrics and were not selected as the final set in any of the trials. The "Assumed Best" trial was selected by narrowing the metric window of Table B.1, B.2 and B.3 to capture the majority of sites within error and exclude the majority of sites not within error. "Variation 1 and Variation 2" were further attempts to improve results with larger narrowing of the metric window.

Table B.6 Dataset 1

2-3m											
Trial Description	**Max Length**	**100m Radius MIN**	**100m Radius MAX**	**Total Sites**	**Number of Negative**	**Number False Positive**	**Number of Possitive**	**Number False Negative**	**%False Positive in Sample**	**% False Negative in Sample**	**% Correct**
Within Error	380.00	2.00	12.00	37.00	12	7	25	0	58%	0%	81%
Not Within Error	560.00	2.00	26.25	37.00	12	12	25	0	100%	0%	68%
Assumed Best	130.00	2.00	11.75	37.00	12	3	25	2	25%	8%	86%
Variation 1	130.00	2.00	12.00	37.00	12	4	25	1	33%	4%	86%
Variation 2	130.00	2.00	16.25	37.00	12	5	25	1	42%	4%	84%
Best	130.00	2.00	11.75	37.00	12	3	25	2	25%	8%	86%

4-6m													
Trial Description	**Max Length**	**100m Radius MIN**	**100m Radius MAX**	**500m Radius MIN**	**500m Radius MAX**	**Total Sites**	**Number of Negative**	**Number False Positive**	**Number of Possitive**	**Number False Negative**	**%False Positive in Sample**	**% False Negative in Sample**	**% Correct**
Within Error	790.00	2.50	16.50	3.00	12.00	49	17	11	32	0	65%	0%	78%
Not Within Error	1140.00	3.50	21.75	1.25	15.50	49	17	17	32	3	100%	9%	59%
Assumed Best	320.00	4.50	16.00	3.00	12.00	49	17	8	32	6	47%	19%	71%
Variation 1	320.00	2.00	16.00	3.00	12.00	49	17	10	32	2	59%	6%	76%
Variation 2	320.00	2.00	16.00	5.00	12.00	49	17	10	32	6	59%	19%	67%
Best	320.00	4.50	16.00	3.00	12.00	49	17	8	32	6	47%	19%	71%
7-8m													
Trial Description	**Max Length**	**100m Radius MIN**	**100m Radius MAX**	**500m Radius MIN**	**500m Radius MAX**	**Total Sites**	**Number of Negative**	**Number False Positive**	**Number of Possitive**	**Number False Negative**	**%False Positive in Sample**	**% False Negative in Sample**	**% Correct**
Within Error	460.00	6.75	26.75	2.00	6.50	16	5	2	11	0	40%	0%	88%
Not Within Error	300.00	4.75	14.50	8.25	12.75	16	5	5	11	6	100%	55%	31%
Assumed Best	460.00	9.00	26.75	2.00	6.50	16	5	1	11	1	20%	9%	88%
Variation 1	460.00	6.75	26.75	2.00	6.50	16	5	2	11	0	40%	0%	88%
Variation 2	460.00	9.00	13.50	2.00	6.50	16	5	0	11	2	0%	18%	88%
Best	460.00	9.00	13.50	2.00	6.50	16	5	0	11	2	0%	18%	88%

9-13m													
Trial Description	**Max Length**	**100m Radius MIN**	**100m Radius MAX**	**500m Radius MIN**	**500m Radius MAX**	**Total Sites**	**Number of Negative**	**Number False Positive**	**Number of Possitive**	**Number False Negative**	**%False Positive in Sample**	**% False Negative in Sample**	**% Correct**
Within Error	560.00	5.25	15.50	5.00	8.25	31	14	8	17	0	57%	0%	74%
Not Within Error	1750.00	7.25	31.75	1.00	10.00	31	14	14	17	1	100%	6%	52%
Assumed Best	290.00	7.50	12.50	5.00	8.25	31	14	3	17	3	21%	18%	81%
Variation 1	560.00	7.50	12.50	5.00	8.25	31	14	6	17	2	43%	12%	74%
Variation 2	290.00	7.50	13.25	5.00	8.25	31	14	4	17	3	29%	18%	77%
Best	290.00	7.50	12.50	5.00	8.25	31	14	3	17	3	21%	18%	81%

14-31m													
Trial Description	**Max Length**	**100m Radius MIN**	**100m Radius MAX**	**500m Radius MIN**	**500m Radius MAX**	**Total Sites**	**Number of Negative**	**Number False Positive**	**Number of Possitive**	**Number False Negative**	**%False Positive in Sample**	**% False Negative in Sample**	**% Correct**
Within Error	1570.00	11.75	28.00	2.25	34.00	36	10	9	26	0	90%	0%	75%
Not Within Error	1310.00	20.25	20.25	3.25	42.50	36	10	10	26	12	100%	46%	39%
Assumed Best	920.00	11.75	28.00	2.25	20.75	36	10	4	26	5	40%	19%	75%
Variation 1	920.00	11.75	28.00	3.25	20.75	36	10	4	26	6	40%	23%	72%
Variation 2	920.00	11.75	28.00	2.25	33.00	36	10	7	26	4	70%	15%	69%
Best	920.00	11.75	28.00	2.25	20.75	36	10	4	26	5	40%	19%	75%

32-83m													
Trial Description	**Max Length**	**100m Radius MIN**	**100m Radius MAX**	**500m Radius MIN**	**500m Radius MAX**	**Total Sites**	**Number of Negative**	**Number False Positive**	**Number of Possitive**	**Number False Negative**	**%False Positive in Sample**	**% False Negative in Sample**	**% Correct**
Within Error	3490.00	29.25	32.25	5.00	33.25	26	10	7	16	0	70%	0%	73%
Not Within Error	4070.00	n/a	n/a	2.00	31.25	26	10	10	16	3	100%	19%	50%
Assumed Best	2350.00	29.25	32.25	5.25	27.00	26	10	5	16	3	50%	19%	69%
Variation 1	890.00	29.25	32.25	5.25	27.00	26	10	3	16	6	30%	38%	65%
Variation 2	2350.00	29.25	32.25	5.25	12.75	26	10	2	16	4	20%	25%	77%
Best	2350.00	29.25	32.25	5.25	12.75	26	10	2	16	4	20%	25%	77%

Table B.7 Dataset 2

2-3m													
Trial Description	**Max Length**	**100m Radius MIN**	**100m Radius MAX**	**500m Radius MIN**	**500m Radius MAX**	**Total Sites**	**Number of Negative**	**Number False Positive**	**Number of Positive**	**Number False Negative**	**%False Positive in Sample**	**% False Negative in Sample**	**% Correct**
Within Error	380	2.25	10.75	2.50	2.50	36	12	6	24	0	50%	0%	83%
Not Within Error	560	1.75	21.75	2.00	6.75	36	12	12	24	0	100%	0%	67%
Assumed Best	130	2.25	10.75	n/a	n/a	36	12	4	24	1	33%	4%	86%
Variation 1	130	5.50	10.75	n/a	n/a	36	12	2	24	11	17%	46%	64%
Variation 2	130	2.25	4.00	n/a	n/a	36	12	0	24	18	0%	75%	50%
Best	130	2.25	10.75	n/a	n/a	36	12	4	24	1	33%	4%	86%
4-6m													
Trial Description	**Max Length**	**100m Radius MIN**	**100m Radius MAX**	**500m Radius MIN**	**500m Radius MAX**	**Total Sites**	**Number of Negative**	**Number False Positive**	**Number of Possitive**	**Number False Negative**	**%False Positive in Sample**	**% False Negative in Sample**	**% Correct**
Within Error	790	1.75	14.50	2.75	10.50	43	14	10	29	0	71%	0%	77%
Not Within Error	1140	3.25	13.75	1.00	13.75	43	14	14	29	4	100%	14%	58%
Assumed Best	320	4.25	14.50	2.75	10.50	43	14	8	29	6	57%	21%	67%
Variation 1	320	4.50	14.50	3.00	10.50	43	14	8	29	9	57%	31%	60%
Variation 2	320	4.50	14.50	2.75	10.50	43	14	8	29	8	57%	28%	63%
Best	320	4.25	14.50	2.75	10.50	43	14	8	29	6	57%	21%	67%
7-8m													
Trial Description	**Max Length**	**100m Radius MIN**	**100m Radius MAX**	**500m Radius MIN**	**500m Radius MAX**	**Total Sites**	**Number of Negative**	**Number False Positive**	**Number of Possitive**	**Number False Negative**	**%False Positive in Sample**	**% False Negative in Sample**	**% Correct**
Within Error	410	4.25	24.25	1.75	6.00	27	12	9	15	0	75%	0%	67%
Not Within Error	460	5.00	13.25	2.00	7.00	27	12	12	15	3	100%	20%	44%
Assumed Best	260	4.25	11.25	2.25	3.75	27	12	7	15	3	58%	20%	63%
Variation 1	260	5.25	11.25	2.25	3.75	27	12	6	15	4	50%	27%	63%
Variation 2	260	5.00	11.25	2.25	3.75	27	12	7	15	4	58%	27%	59%
Best	260	4.25	11.25	2.25	3.75	27	12	7	15	3	58%	20%	63%
9-13m													

Trial Description	Max Length	100m Radius MIN	100m Radius MAX	500m Radius MIN	500m Radius MAX	Total Sites	Number of Negative	Number False Positive	Number of Possitive	Number False Negative	%False Positive in Sample	% False Negative in Sample	% Correct
Within Error	560	8.25	21.00	4.50	5.25	27	15	8	12	0	53%	0%	70%
Not Within Error	1750	7.00	19.75	1.00	20.75	27	15	14	12	1	93%	8%	44%
Assumed Best	290	8.25	11.00	4.50	4.50	27	15	2	12	2	13%	17%	85%
Variation 1	290	9.50	11.00	4.50	4.50	27	15	1	12	4	7%	33%	81%
Variation 2	290	9.75	11.00	4.50	4.50	27	15	1	12	8	7%	67%	67%
Best	290	8.25	11.00	4.50	4.50	27	15	2	12	2	13%	17%	85%

14-31m

Trial Description	Max Length	100m Radius MIN	100m Radius MAX	500m Radius MIN	500m Radius MAX	Total Sites	Number of Negative	Number False Positive	Number of Possitive	Number False Negative	%False Positive in Sample	% False Negative in Sample	% Correct
Within Error	1570	7.00	26.25	2.25	30.75	33	4	4	29	0	100%	0%	88%
Not Within Error	1310	n/a	n/a	3.25	9.75	33	4	4	29	22	100%	76%	21%
Assumed Best	920	7.00	26.25	3.50	30.75	33	4	2	29	5	50%	17%	79%
Variation 1	920	7.00	26.25	6.00	30.75	33	4	2	29	6	50%	21%	76%
Variation 2	920	7.00	26.25	2.25	30.75	33	4	2	29	3	50%	10%	85%
Best	920	7.00	26.25	2.25	30.75	33	4	2	29	3	50%	10%	85%

32-83m

Trial Description	Max Length	100m Radius MIN	100m Radius MAX	500m Radius MIN	500m Radius MAX	Total Sites	Number of Negative	Number False Positive	Number of Possitive	Number False Negative	%False Positive in Sample	% False Negative in Sample	% Correct
Within Error	3490	26.50	27.50	4.50	35.75	29	11	9	18	0	82%	0%	69%
Not Within Error	4070	n/a	n/a	2.00	28.75	29	11	11	18	4	100%	22%	48%
Assumed Best	2350	26.50	27.50	4.75	25.50	29	11	4	18	3	36%	17%	76%
Variation 1	890	26.50	27.50	4.75	25.50	29	11	2	18	6	18%	33%	72%
Variation 2	2350	26.50	27.50	4.50	25.50	29	11	5	18	3	45%	17%	72%
Best	2350	26.50	27.50	4.75	25.50	29	11	4	18	3	36%	17%	76%

Table B.8 Dataset 3

Max Length	100m Radius MIN	100m Radius MAX	500m Radius MIN	500m Radius MAX	Total Sites	Number of Negative	Number False Positive	Number of Possitive	Number False Negative	%False Positive in Sample	% False Negative in Sample	% Correct
440	1.75	31.50	2.50	2.50	27	6	4	21	0	67%	0%	85%
1080	2.50	21.50	1.50	6.75	27	6	6	21	4	100%	19%	63%
190	1.75	12.25	n/a	n/a	27	6	3	21	2	50%	10%	81%
190	2.75	12.25	n/a	n/a	27	6	2	21	6	33%	29%	70%
190	1.75	6.50	n/a	n/a	27	6	2	21	6	33%	29%	70%
190	1.75	12.25	n/a	n/a	27	6	3	21	2	50%	10%	81%
Max Length	**100m Radius MIN**	**100m Radius MAX**	**500m Radius MIN**	**500m Radius MAX**	**Total Sites**	**Number of Negative**	**Number False Positive**	**Number of Possitive**	**Number False Negative**	**%False Positive in Sample**	**% False Negative in Sample**	**% Correct**
790	2.50	16.25	3.00	12.00	65	28	21	37	0	75%	0%	68%
1190	4.25	26.25	1.25	15.50	65	28	28	37	6	100%	16%	48%
380	2.50	11.75	3.00	12.00	65	28	14	37	5	50%	14%	71%
380	2.50	9.75	3.00	12.00	65	28	13	37	8	46%	22%	68%
380	2.50	11.75	3.00	4.00	65	28	14	37	5	50%	14%	71%
380	2.50	11.75	3.00	12.00	65	28	14	37	5	50%	14%	71%
Max Length	**100m Radius MIN**	**100m Radius MAX**	**500m Radius MIN**	**500m Radius MAX**	**Total Sites**	**Number of Negative**	**Number False Positive**	**Number of Possitive**	**Number False Negative**	**%False Positive in Sample**	**% False Negative in Sample**	**% Correct**
320	3.75	26.75	2.50	17.75	19	10	7	9	0	70%	0%	63%
480	3.50	16.50	2.00	12.75	19	10	10	9	2	100%	22%	37%
320	6.75	26.75	2.50	17.75	19	10	5	9	1	50%	11%	68%
320	6.75	16.00	2.50	17.75	19	10	4	9	2	40%	22%	68%
320	6.75	16.00	11.00	17.75	19	10	3	9	3	30%	33%	68%
320	6.75	16.00	2.50	17.75	19	10	4	9	2	40%	22%	68%
Max Length	**100m Radius MIN**	**100m Radius MAX**	**500m Radius MIN**	**500m Radius MAX**	**Total Sites**	**Number of Negative**	**Number False Positive**	**Number of Possitive**	**Number False Negative**	**%False Positive in Sample**	**% False Negative in Sample**	**% Correct**
580	5.25	13.50	2.00	12.50	38	16	8	22	0	50%	0%	79%
1750	7.25	31.75	1.00	14.75	38	16	16	22	1	100%	5%	55%
580	7.75	13.50	2.00	8.25	38	16	5	22	3	31%	14%	79%

580	7.75	12.25	2.00	8.25	38	16	4	22	4	25%	18%	79%
580	7.75	13.50	2.00	8.00	38	16	5	22	5	31%	23%	74%
580	7.75	12.25	2.00	8.25	38	16	4	22	4	25%	18%	79%
Max Length	**100m Radius MIN**	**100m Radius MAX**	**500m Radius MIN**	**500m Radius MAX**	**Total Sites**	**Number of Negative**	**Number False Positive**	**Number of Possitive**	**Number False Negative**	**%False Positive in Sample**	**% False Negative in Sample**	**% Correct**
1420	7.25	28.00	2.25	34.00	37	11	10	26	0	91%	0%	73%
1340	24.50	24.50	3.50	42.50	37	11	11	26	10	100%	38%	43%
970	12.00	20.25	2.25	20.75	37	11	4	26	7	36%	27%	70%
970	7.25	20.25	2.25	20.75	37	11	4	26	6	36%	23%	73%
970	12.00	20.25	2.25	25.25	37	11	5	26	5	45%	19%	73%
970	7.25	20.25	2.25	20.75	37	11	4	26	6	36%	23%	73%
Max Length	**100m Radius MIN**	**100m Radius MAX**	**500m Radius MIN**	**500m Radius MAX**	**Total Sites**	**Number of Negative**	**Number False Positive**	**Number of Possitive**	**Number False Negative**	**%False Positive in Sample**	**% False Negative in Sample**	**% Correct**
3510	29.25	32.25	3.25	33.25	28	10	9	18	0	90%	0%	68%
4100	n/a	n/a	2.00	31.25	28	10	10	18	3	100%	17%	54%
2350	29.25	32.25	5.00	27.50	28	10	4	18	4	40%	22%	71%
2350	29.25	32.25	3.25	27.50	28	10	6	18	2	60%	11%	71%
2350	29.25	32.25	5.00	14.00	28	10	2	18	5	20%	28%	75%
2350	29.25	32.25	5.00	14.00	28	10	2	18	5	20%	28%	75%

Appendix C-Correspondence

Chapter 3 lists the technical ArcGIS workflow conducted in this study. Correspondence between ArcGIS technical personnel was required to ensure the correct steps were being conducted in the workflow. Figures C.1 and C.2 are the email correspondence conducted.

ACNSMail
Colorado State University

Subjec **Esri Incident #976811 (Lisa G) How to extract the slope data from an existing polyline?**
Sende Esri Support <nimbus@esri.com>
Recipi bcamp@lamar.colostate.edu <bcamp@lamar.colostate.edu>
Copy Diane Noren <diane.noren@colostate.edu>, Kimberly.Catton@colostate.edu <Kimberly.Catton@colostate.edu>
Date 25.10.2011 15:48

```
*** Do not write below this line ***
Hello Brian,

It was a pleasure speaking with you today. We discussed the options available to you as
a means of deriving elevation values from the underlying surface, which include the
following:

A. Use 3D Analyst tools in ArcGIS 9.3.1 to derive existing features' heights from a
surface

or

B. Download a trial version of ArcGIS 10 and use 3D Analyst tools in ArcGIS 10 to
derive existing features' heights from a surface

Below is information about the options available to you at 9.3.1, specifically the
section entitled "Deriving the existing features' heights from a surface".

Converting 2D features to 3D features
http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?
id=3509&pid=3505&topicname=Converting_2D_features_to_3D_features

If you choose to download ArcGIS 10 (trial version), you can do so from this link:

http://www.esri.com/software/arcgis/arcgis10/trial.html

Note: You cannot have more than one version of ArcGIS installed on a single machine at
a time.

More information about the tools available to you can be found in the following article:

http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#//00q80000005m000000.htm

You also asked about training options avaiable for customizing ArcGIS with scripting.
I've included the following link, which will provide you with information about a wide
variety of Esri Training options:

http://training.esri.com/gateway/index.cfm?fa=search.results&searchterm=Python

The link below will provide a page from which you can search with any keyword. The
above link has the search set to training options that involve Python.
http://training.esri.com/gateway/index.cfm?fa=catalog.gateway&tab=0

I am going to go ahead and mark this issue as resolved, but if you have further
questions directly related to this incident's original topic, please feel free to
contact me at 888-377-4575, referencing your incident #976811, or simply reply to this
email without changing the subject line and I will be more than happy to reverse the
status of the incident as necessary. It was a pleasure assisting you today.

Regards,

Lisa G.
```

Figure C.1 Correspondence between ArcGIS personnel.

Subjec **RE: Esri Incident #998037**
Sender Esri Support <nimbus@esri.com>
Recipie bcamp@lamar.colostate.edu <bcamp@lamar.colostate.edu>
Date **12.01.2012 19:03**

ACNSMail
Colorado State University

*** Do not write below this line ***
Hi Brian,

One more thing, you might want to check off Background Processing if you are going to do this in ArcGIS 10.

- click the Geoprocessing menu > Geoprocessing Options... > within the Background Processing box, check off "Enable"

Because it may cause some problems with the alignment of the cells.

Please let me know if you have additional questions.

Regards,

Kailai Z.

To contact Esri Technical Support (USA only):
Tel: (888)377-4575 | E-mail: support@esri.com
Hours of Operation: 5AM-5PM (PT) Monday-Friday
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For 24 hour technical support resources:

Esri's WWW homepage http://www.esri.com
Online Support Center http://support.esri.com
My Support http://support.esri.com/en/login
Support Center News Blog http://blogs.esri.com/Support/blogs/supportcenter/
ArcGIS Resource Centers http://resources.arcgis.com
Discussion Forums http://forums.arcgis.com
Ideas http://ideas.arcgis.com

==

-----Original Message-----
From: Esri Support <nimbus@esri.com>
Sent: 1/12/2012 4:38:33 PM
To: bcamp <bcamp@lamar.colostate.edu>
Subject: RE: Esri Incident #998037

Hi Brian,

The correct workflow should be to mosaic the raw DEMs first, then reproject it to the projection you want.

The reason for that is the different distortion resulted from the individual reprojection can cause the cells not line up exactly in the later mosaic. Reprojection will shift the data somewhat when you transform the coordinate systems. You could also get the cells to align correctly by snapping 105 raster to the reprojected 106, when you reproject 105. Please let me know if you have additional questions or if you would like to discuss the workflow on the phone.

Regards,

Kailai Z.

--> Reply to note dated 1/10/2012 1:06:24 PM <--

Figure C.2 Correspondence between ArcGIS personnel.