THESIS

DEVELOPING A PHYSICAL EFFECTIVENESS MONITORING PROTOCOL FOR AQUATIC ORGANISM PASSAGE RESTORATION AT ROAD-STREAM CROSSINGS

Submitted by

Heidi M. Klingel

Department of Geosciences

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Master's Committee:

Advisor: Ellen Wohl

Brian Bledsoe
Daniel Cenderelli
Sara Rathburn

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ABSTRACT

DEVELOPING A PHYSICAL EFFECTIVENESS MONITORING PROTOCOL FOR AQUATIC ORGANISM PASSAGE RESTORATION AT ROAD-STREAM CROSSINGS

Two US Forest Service draft monitoring protocols are used to assess the effectiveness of design channels at road-stream crossings by comparing their physical channel dimensions to those in the natural channel. The premise is that if the constructed channel dimensions are similar in gradient, length, and channel type to those within a representative natural reach, the design will be effective at providing geomorphic function, ecological continuity, and aquatic organism passage through the crossing for a wide range of flows. Level II physical monitoring is a time intensive, quantitative and statistically based procedure for assessing effectiveness at selected sites. Level I physical monitoring is a less detailed, rapid procedure limited to a few simple measurements and observations for assessing effectiveness at a large number of sites.

The channel metrics measured and analyzed for level II monitoring include channel width at three different flow elevations, maximum flow depth, bank margin irregularity, bed irregularity, the coarse fraction of the gradation, step geometry (height, length, particle size, width, residual pool depth), and bank continuity. The channel metrics for level I monitoring include (fewer) channel width measurements at two flow elevations, maximum flow depth, step geometry, the largest particles along the channel bed, as well as qualitative assessments of bank margin irregularity and bank continuity.

In 2011 and 2012, the draft levels I and II monitoring protocols were applied at 18 sites on six National Forests throughout the US. Study objectives were to: 1) test and refine the field methods for collecting data by the levels I and II physical monitoring protocols; 2) find a meaningful way to combine the data collected by levels I and II into separate effectiveness evaluations by each protocol; and, 3) evaluate

whether the level I protocol can be used as a proxy for the level II protocol. Where the two protocols systematically differ, field data help distinguish why.

Study results for all objectives (combined) include: improved field methodologies, recommendations for further development, and separate summary rubrics for the levels I and II monitoring protocols. The recommendations are of three categories; channel metrics/data collection, methods of scoring each metric, and sample sizes. Some of most significant of those recommendations are described within the following paragraphs.

Data collection methods might be improved to save time, increase the accuracy of protocol evaluations, and facilitate agreement between the levels I and II protocol evaluation results. The techniques by which the level I bankfull stage and coarse fraction of the gradation metrics are collected should incorporate level II methods. Instructions for collecting level II coarse fraction of the gradation data should specify measuring all particles within the channel, including particles much larger than the sampling frame. The level I method by which the representative reach is selected should incorporate a basic longitudinal profile survey in which only the most prominent grade controls separating slope segments are captured. Decreasing the allowable gradient difference between the level II design channel and representative reach might also improve accuracy. The method by which the levels I and II protocols compare channel units (or channel unit sequences) between the design and representative reach should be equivalent, as should the rules by which slope segments and channel units are defined. Finally, the channel metrics of low flow width and bed irregularity are inconsistent with the objectives of physical effectiveness monitoring, in that they are aspects of habitat, rather than strong controls on channel form. I suggest they be eliminated from the levels I and II protocols.

The level II summary rubric scores most metrics statistically by a Wilcoxon Rank-Sum test of medians. For most metrics, the Wilcoxon Rank-Sum test appears to be a reasonable way to compare representative reach and design zone data. For the metrics of bed and bank irregularity, however, a test of distributions (e.g., Kolmogorov–Smirnov) is recommended instead. The coarse fraction of the gradation metric would be more fairly assessed if the modes of the particle size (in phi units) were compared instead of the medians. Doing so would allow the design and representative reach gradients to be slightly different (as does the criteria for selecting a representative reach) without penalizing the metric score.

In order to improve the accuracy of effectiveness evaluations and create better agreement between the levels I and II protocol results, the measured sample size, for several metrics, should be increased. More steps should be measured within the representative reach so as to better establish the natural range of variability to which design steps are compared. Where metrics currently collect only one measurement per step, sample sizes should be increased to at least three. Data studies showed the level I sample size of five for the channel metrics of bankfull and low flow widths was too small for adequately approximating the level II distribution. A sample size of nine performed better and is still practical. For the channel metrics of width at low flow, half bankfull and bankfull stage, maximum depth, and bank irregularity, the level II sampling interval is set to collect a minimum of twenty measurements within the representative reach or structure, whichever is shorter. Instead, to be consistent with how data are analyzed, sampling intervals should be set to obtain the minimum statistically significant sample size within the shortest channel unit or channel unit sequence. Further, it seems calculating the minimum statistically significant sample and minimum sampling interval for each channel metric would both help to avoid type two errors (whereby favorable evaluations are erroneously generated) and make the level II protocol more time efficient.

Because the protocols are not yet finalized, and some adjustments to both levels I and II are likely to be made, definitively determining whether the level I protocol is a reasonable proxy for the level II protocol is not yet possible. Should the suggested improvements which have resulted from this study be

incorporated, and more field testing at stream simulation, step-pool, and mobile bed channels is conducted, the limitations of the level I protocol might be fairly evaluated.

The levels I and II summary rubric tools created were used to evaluate twelve AOP road-stream crossing designs. The performance of the levels I and II summary rubrics were then assessed by the evaluation results at those twelve sites. Levels I and II generally seemed to provide effectiveness evaluations which agreed with site observations, data, and photographs. Further, the summary rubrics facilitated concurrent evaluation of the many channel dimensions which together affect the hydraulic conditions experienced by aquatic organisms. In addition, the simple utility of the levels I and II summary rubric tools should encourage effectiveness monitoring and help restoration practitioners learn from their mistakes, ultimately improving aquatic organism passage design methods and results.

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My field assistants Dr. David Dust, Mark Hussey, and Clare Murphy-Hagan were asked to help with all tasks, many of which were uncomfortable and tedious. Field logistics and data collection would have been impossible without them. Their endurance and dedication to quality data was exceptional. Further, they made the work a great deal more fun. Dr. David Dust also provided me with an Excel macro for quickly analyzing and graphing pebble count data.

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1 INTRODUCTION

1.1 THESIS ORGANIZATION AND OVERVIEW

The thesis is organized into sections based on standard scientific writing: Introduction, Objectives, Methods, Results, Discussion and Conclusions. Within most sections, the text is further divided into subsections which are defined by my three research objectives. It is important to remember that every section is really just a small piece of the main project goal of developing a physical monitoring protocol for assessing the effectiveness of channel designs at road-stream crossings. This goal is accomplished through protocol field testing (collecting, analyzing and interpreting data) at selected sites. The end product of this project are two separate field monitoring protocols (one more data and time intensive than the other), and two corresponding methods for summarizing the field data to determine the physical effectiveness of the channel design at the road-stream crossing. Although the field protocols and summary methods are not yet finalized, they are better defined and are more robust than the drafts with which I began. The most current versions (2013) are located in Appendices B, C, and E [Level II Draft Field Protocol, Level I Draft Field Protocol, and Summary Rubrics]. Finalized products which result from this research can be utilized across the National Forest system, and on other lands managed for aquatic ecosystem restoration.

1.2 BACKGROUND

1.2.1 HABITAT FRAGMENTATION, ROADS, AND RESTORATION

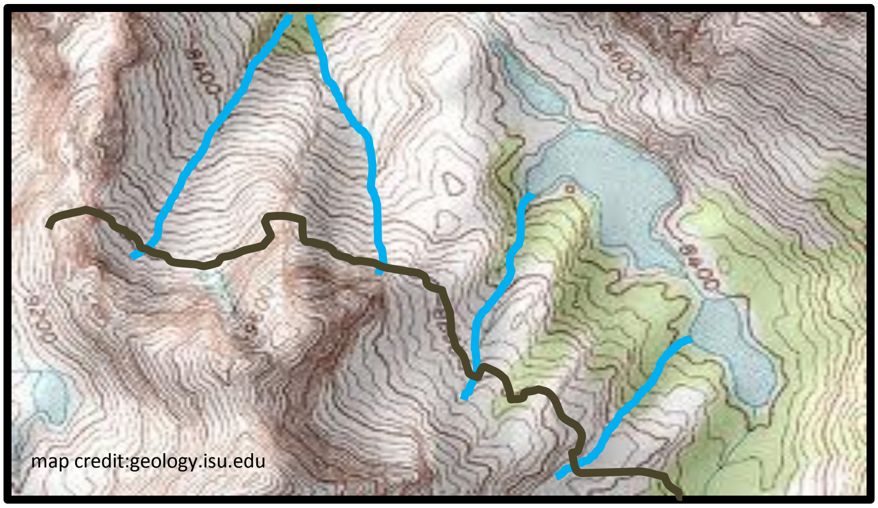
Habitat fragmentation is the subdivision of once continuous areas of habitat into smaller, discontinuous patches. Dams are notorious for fragmenting basins and interrupting stream continuity, but roads are the real culprits because of their frequency and ubiquity (Januchowski-Hartley et al., 2013). Road-stream crossings fragment habitat when impassable (undersized and/or plugged) culverts divide river basins into short isolated reaches (Jackson, 2003; Stream Simulation Working Group, 2008). If one considers a typical scenario where a single road contours beneath a mountain ridge, the scale of the problem becomes clear (Figure 1). The road potentially crosses every headwater stream within the basin. Commonly, small watersheds have roads which contour across them at several elevations, so that a single stream is crossed several times. Roads on National Forest lands are typically located on mountain slopes within the headwaters of a basin because roads were built to access and remove timber growing there.

Fragmentation is considered to be a threat to ecosystem integrity and species persistence globally (Saunders et al., 1991). Studies comparing populations in fragmented and connected watersheds have shown that fragmentation leads to reduced fish re-colonization, life history, and habitat diversity (Dunham, et al., 1997), as well as determines fish species distribution and community composition (Santucci et al., 2005; Catalano et al., 2007). The risk of species extinction increases when available habitat and habitat complexity are decreased and genes are no longer shared between isolated populations (Dunham et al., 1997; Jackson, 2003). Smaller populations are more vulnerable to extinction due to chance disturbance events, genetic drift (Wofford et al., 2005), loss of resilience, and inbreeding depression. Movement between habitat patches also helps ensure that recently vacated habitat is utilized (Jackson, 2003).

Biological communities are affected directly and indirectly through alterations to their habitat. Road-stream crossing structures can alter downstream habitat by impounding water, sediment, nutrients, flora drift material, and wood (Andersson et al., 2000; Stanley and Doyle, 2002; Wipfli and Gregovich, 2002; Jackson, 2003; Freeman et al., 2007; Meyer et al., 2007; Wipfli et al., 2007). Sediment regimes are affected when crossing structures cause chronic erosion or divert streams from their channels. Multiple barriers amplify these effects by dividing streams into short reaches.

Addressing watershed fragmentation by removing or retro-fitting barrier culverts is recognized as one of the most effective and cost-efficient means of restoring ecological integrity (Roni et al., 2002), out-competing dam removal in a cost-benefit analysis (Januchowski-Hartley et al., 2013). Further, addressing barrier culverts is more socially acceptable than removing dams because of the additional social benefits dams provide (Januchowski-Hartley et al., 2013).

Prioritizing which road-stream crossing structures will be removed or improved is commonly necessary. Factors which might affect prioritization are the cost, the extent and quality of upstream habitat, the presence of threatened and endangered species, the presence of invasive species isolated by the barrier, the risk of plugging, the age and condition of the structure and stakeholder interests (Hotchkiss and Frei, 2007). Further, the assessment should optimize ecological continuity by considering all crossings within the watershed together (Kemp and O'Hanley, 2010). Some prioritization procedures have been published by the California Department of Fish and Game, the Oregon Department of Fish and Wildlife, and the Washington Department of Fish and Wildlife (Hotchkiss and Frei, 2007).



map credit:geology.isu.edu

FIGURE 1: CONTOURING ROAD CROSSES MANY HEADWATER STREAMS

BROWN LINE IS THE ROAD AND THE BLUE LINES ARE STREAMS IN FIGURE 1

1.2.2 HEADWATER STREAMS

Headwater streams (springs, intermittent, zero, first and second order channels) account for most (70%-80%) of the total stream kilometers within any watershed (Alan and Castillo, 2007; Freeman et al., 2007), and about 70% of the stream channel length within the United states (Leopold et al., 1964). Cumulatively, they provide more habitat area than large rivers (Stream Simulation Working Group, 2008).

Headwater streams are extremely diverse and unique habitats, even between adjacent streams within the same watershed. They vary physically from swift flowing and steep to low gradient and swampy. They are also highly variable chemically because of the strong influence local soil, geology, vegetation and human activities have on their composition (Meyer et al., 2007). Biologically, headwater streams are species rich because their catchments are small, allowing subtle environmental changes (natural and anthropogenic) to greatly affect them. Within a single watershed, species composition can vary greatly between individual headwater streams (e.g., macrocrustacean species) (Meyer et al., 2007).

Some species live in both the headwaters and the larger river downstream, while some species only occur within small headwater springs and streams (e.g., certain crayfish, stoneflies and salamanders (Freeman et al., 2007). In Oregon, sampled springs and seeps included 106 species, 92% of which were exclusive to the springs (Anderson and Anderson, 1995). Species use the headwater streams seasonally or only during different life stages. For example, within the Sierra Nevada mountains of California, spawning is observed within intermittent tributaries that flow for less than half the year (Erman and Hawthorne, 1976). In Oregon, a study of coastal streams showed that 11-21% of adult coho salmon populations spawn in intermittent streams (Wigington et al., 2006). Dieterich and Anderson (2000) have shown headwater intermittent streams may actually host more species than perennial streams.

Strong linkages exist between headwaters and adjacent ecosystems. Emergent aquatic insects feed birds, bats and spiders in the surrounding terrestrial ecosystem. Because headwaters are well coupled with the surrounding terrain, they are not only a source of food, but also provide energy to downstream ecosystems (Meyer et al., 2007). Biological activity within the headwaters affects the supply of nutrients such as dissolved organic carbon, nitrogen, and phosphorous to downstream ecosystems (Meyer and Wallace, 2001; Wiegner et al., 2005). In addition, headwaters provide habitat components like sediment and in-stream wood to downstream portions of the river network. Finally, headwaters serve as movement corridors through the landscape for many species.

1.2.3 MIGRATORY ORGANISMS AND BARRIERS

Movement is how animals acquire the essential resources necessary to complete their life-cycles (Dingle, 1996). Migration can refer to several types of movement whereby animals travel just a short distance, or a much greater length, daily, seasonally (round-trip), or to permanently re-locate (one-way) (Dingle and Drake, 2007). Animals migrate along a river system for many reasons: spawning, foraging, seeking refuge, and dispersing (Jackson, 2003). Upstream movement counters downstream migration, thereby returning nutrients to the headwaters of the system (Jackson, 2003). For some organisms, migration may simply be individual preference; for others, it is a matter of species survival (Dingle and Drake, 2007). Barriers in the stream network restrict these movements. The life history of a species can determine the effectiveness of a barrier in a particular location (Cote et al., 2009; USDA Forest Service, 2009); a blockage near a river mouth will affect a diadromous species (migrates between salt and freshwater) more than a potadromous (migratory in freshwater) species (Freeman et al., 2007; Stream Simulation Working Group, 2008).

Because they sustain an economically important fishery, salmonids are commonly used as examples of organisms drastically impacted by barriers. Adult salmonids spend most of their lives in the ocean.

When they are ready to breed, they migrate up the rivers to spawn. The juveniles develop in the headwater streams which have higher productivity, fewer predators and suitable substrates (Jackson, 2003; Stream Simulation Working Group, 2008). When they are large enough, they migrate downstream to estuary and ocean habitats. Plugged or otherwise impassable culverts can prevent adults from accessing their spawning habitat and juveniles from reaching the nutrient-rich oceans crucial to their growth. Freeman et al. (2007) state that one of the many factors limiting coho and steelhead productivity are culverts.

Although barriers to fish migration are now commonly assessed, other large aquatic animals also migrate. For example, many salamanders move along a stream for reproduction. They use intermittent headwater streams as adults, but lay their eggs in lower reaches with stable perennial flow (Jackson, 2003; Stream Simulation Working Group, 2008). Most US streams support species of aquatic salamanders, many of which are vulnerable to movement barriers.

Other commonly affected animals that travel long distances are crayfish and soft-shell musk turtles. Crayfish are dominant components of the Ozark and southern Appalachian mountains. They rival aquatic insects in ecological importance. Some headwater populations of crayfish have been isolated so long that they are now distinct species. Further fragmentation could endanger their already small populations (Jackson, 2003). For long-lived species with low reproductive rates (i.e., turtles), barriers can significantly undermine the viability of the population.

Some of the US species most vulnerable to blocked migration are freshwater mussels. Over 70% of the 297 species native to the US and Canada are endangered, threatened, or of special concern (Williams et al., 1993). Mussel dispersal depends entirely on the presence and movement of fish or salamanders. Larval stages of these mussels attach themselves to the gills or the fins of hosts in order to disperse. Without their hosts, freshwater mussels are unable to reproduce or occupy otherwise appropriate habitat (Jackson, 2003).

Other aquatic organisms potentially affected are worms, flatworms, leeches, mites, amphipods, isopods, and snails. Movement through the water for these organisms is less critical than movement through the substrate. Where barriers are culverts constructed without substrate (or those which have lost their substrate), passage is blocked. Together these organisms make up a significant amount of the biomass and diversity of any stream ecosystem (Jackson, 2003).

Rivers and streams are also used as travel corridors by terrestrial species. Semi-aquatic animals like muskrats, minks, otters, frogs, some salamanders, turtles, and snakes travel along the water in the riparian zone. When forced to cross the road, they are more likely to be killed (Jackson, 2003).

1.2.4 How Road-Stream Crossings Interrupt Continuity

Road-stream crossings become barriers to ecologic and geomorphic continuity when the physical dimensions of the natural stream channel do not influence the crossing design. In particular, the gradient and (at a minimum) bankfull width of the surrounding natural channel should be matched by the structure in order to maintain continuity.

Structures narrower than the natural channel will impact the stream channel immediately upstream. An undersized culvert will restrict the flow of water through the structure causing backwater conditions and deposition of sediment and wood upstream of the inlet. This channel aggradation at the inlet typically results in flow being directed toward the channel margins causing bank erosion and channel widening (Figure 2). The decrease in stream gradient will cause more sediment to deposit, sometimes creating a mid-channel bar deposit to form. As the local gradient at the inlet steepens with aggradation, hydraulic conditions shift to erode the sediment wedge, transporting it through the culvert. In this way, the stream bed at the inlet may cyclically aggrade and erode.

At channels with large sediment loads (i.e., landslide prone uplands) the culvert inlet may become buried and completely block flow. Plugged culverts are not only barriers to aquatic organism passage, but are also likely to cause stream diversions, which can deliver extremely large volumes of sediment to stream channels by mass failure and road fill erosion (Furniss et al., 1997).

The stream channel downstream of a road-stream crossing is equally affected by a poor crossing design. Commonly, accelerated flow through the narrow crossing structure will erode the channel bed and banks at the structure outlet forming a deep plunge pool (Figure 2). Also, if the supply of sediment from upstream is significantly interrupted, channel incision and/or bank erosion (depending on boundary conditions) may occur downstream. When the out-flowing water maintains erosive energy, channel and bank degradation can extend for some distance downstream of the structure outlet (Kondolf, 1997), but typically is limited to three bankfull channel widths (D. Cenderelli, pers. comm., 2013).

When the wood supply is interrupted, reach scale river morphology may also change. Large and stable pieces of in-stream wood influence channel form by causing turbulence which erodes banks, scours pools, deposits sediment, and forms bars. Wood can influence floodplain inundation, a critical occurrence for riparian ecosystems (Wohl, 2013). A decrease of in-stream wood may have as large an effect on a channel's form as changing the sediment or hydrologic regime (Montgomery et al., 2003).

Where road-stream crossings create physical obstacles and challenging hydraulic conditions, the migration of aquatic organisms though the structure may be prevented. Passage depends on the physical conditions within and just downstream of a crossing structure, as well as the physiology of each organism (Hoffman and Dunham, 2007). The more similar a crossing structure is to the natural channel, the more likely aquatic organisms will be able to navigate through it. This is the premise upon which the physical effectiveness monitoring protocol was built.

Structures with streambeds wider than the natural channel may spread flow, decreasing the depth. Shallow depths can immobilize larger bodied swimming organisms. Structures with a v-shaped bottom concentrate water, helping to ensure adequate depth during periods of low flow.

Natural channels have variable bed and bank features which project into the flow of water. These projections create micro-eddies which provide resting areas for many aquatic organisms. Most undersized road-stream crossing structures, however, lack natural substrates, eliminating these low velocity areas. The corrugations within metal pipes can help reduce stream velocity within the structure, although average velocities can still prohibit passage. Baffles, riprap or simply the inlet configuration itself can create turbulence within a structure which can be confusing or physically disabling to many organisms (Pavlov et al., 2000; Jackson, 2003; Stream Simulation Working Group, 2008). By creating structures with variable bed surfaces, weaker swimming organisms are more likely to pass upstream. If particles similar in size to those found within the natural channel are used, organisms which travel through the substrate are also able to pass (Stream Simulation Working Group, 2008).

The velocity within an undersized structure increases in order to pass the same volume as the wider, natural channel. Average velocities within culverts can easily exceed 3 m/s, a speed far greater than the swimming or crawling abilities of many organisms (Jackson, 2003; Stream Simulation Working Group, 2008). The faster flowing water also has more erosive power than the natural stream. Typically, the channel will adjust vertically and laterally at a culvert outlet by forming a pool that is much deeper than other pools along the natural channel. The undersized culvert may eventually be left hanging high above the streambed downstream (Figure 3), creating an impassable obstacle to upstream migration (Stream Simulation Working Group, 2008). The plunge pool just below the undersized culvert outlet typically widens (Figure 2) because banks become unstable and collapse as the plunge pool deepens.

Pools enable fish to jump by allowing them to gain speed and momentum. Passable obstacles have pools beneath them. The necessary size of pool is determined by the size of the obstacle, the jumping ability of the fish, and the age and species of fish. For example, coho and Chinook adult salmon need a pool 3 m deep if they are to clear a step 2.4 m high (Parker, 2000).

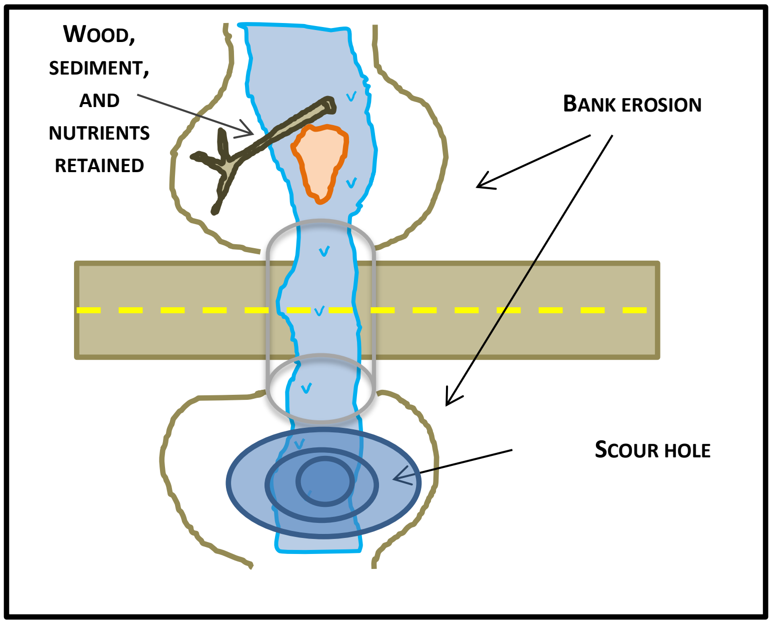


FIGURE 2: PLAN VIEW OF BED AND BANK EROSION CAUSED BY AN UNDERSIZED CROSSING STRUCTURE

Figure 3: Undersized culvert outlet over time

Figure 3shows that within 19 years, the velocity at the outlet of this undersized culvert has scoured a deep hole into the channel bed. Photos copied from the Stream Simulation Manual (Stream Simulation Working Group, 2008. Figure 1.17 a and b).

1.2.5 Helpful Barriers?

In some circumstances, barriers to animal movement may serve a useful purpose, such as where an invasive species could threaten an isolated native population above an impassable culvert (Peterson et al., 2008). Another example is where the transmission of parasites or disease from one isolated population to another is suddenly possible because of passage restoration. There are risks and tradeoffs which need to be fully evaluated when considering barrier removal (Hotchkiss and Frei, 2007; Stream Simulation Working Group, 2008). This evaluation, however, should take place before the restoration plan gets underway and is therefore out of the scope of this project.

1.2.6 The United States Forest Service and Roads

The Forest Service has been restoring watersheds and streams for many decades. Since the late 1980's, restoring streams and ecological continuity along the stream corridor has received considerable attention and funding from the agency (D. Cenderelli, pers. comm., 2012). The new Forest Service planning rule, effective 2012, legally cements this priority for all National Forests (USDA Forest Service, 2012). Removing barriers to aquatic organism passage is one action taken towards restoring and improving watersheds on National Forests. Since the 1970's, fish passage projects have been implemented on Forest Service lands. Starting in the 1990's, the goal shifted from passing only fish to passing all aquatic organisms. Aquatic organism passage (AOP) restoration will likely continue to be prevalent on National Forests well into the future.

National Forests and Grasslands represent about 8% of the total US land area (including territories), on which the Forest Service manages nearly 650,000 kilometers of streams (USDA Forest Service, 2007). In the western US, the majority of these lands occupy the headwaters of the major drainage basins (USDA Forest Service, 2000). These streams are important high-quality habitat for more than 124 threatened and endangered aquatic species (USDA Forest Service, 2011). They are, however, affected by a legacy of logging. Logging has created a vast road system throughout most watersheds. Nation-wide, there are about 600,000 kilometers of road on National Forest lands and these roads frequently cross rivers and streams. Nationally, on Forest Service lands, there are an estimated 25,000 road-stream crossings that are partial or complete barriers to the movement of fish and other aquatic organisms (USDA Forest Service, 2011). In actuality, there are likely many more. In Washington and Oregon alone, there are more than 6,500 road-stream crossings on fish-bearing streams (5.8 kilometers of stream per crossing) and about 90% of these are considered to be at least partial barriers to anadromous fish passage. Together, they block about 15% of fish-bearing stream kilometers on National Forest lands in the region (Stream Simulation Working Group, 2008).

1.2.7 THE HISTORY OF AOP DESIGN AND THE STREAM SIMULATION METHOD

There are three main categories of aquatic organism passage design: hydraulic design, roughened channel design, and stream simulation. The US Forest Service (2008), National Marine Fisheries Service (2001), and Washington State (2003) have developed the stream simulation technique (Hotchkiss and Frei, 2007) . The Oregon Department of Fish and Wildlife, and the states of Alaska and Maryland developed the roughened channel design technique. Hydraulic design methods were created by the states of Maine and Washington, and the Oregon Department of Fish and Wildlife (Hotchkiss and Frei, 2007). Several other design methods also exist (velocity simulation and no-slope design), but are not discussed.

<u>Hydraulic design</u> is aimed at passing target fish species during a specific period of their life-cycle. Baffles within the culvert create slower velocities, deeper depths, and decreased turbulence for the range of flows at which the target species migrates. Downstream, weirs, fish ladders and larger than natural substrates create backwaters which serve as resting and leaping preparation pools for fish. Hydraulic design is especially applicable to retrofits, whereby barrier culverts are made passable by the installation of additional features. Channels with gradients up to 5% are appropriate for this technique (Hotchkiss and Frei, 2007). Figure 4 and Figure 5 show an example hydraulic design road-stream crossing. Hydraulic designs however, have several draw-backs. Because they are commonly applied to already undersized structures (much less than bankfull width), they are more likely to affect the flow through and around the structure than stream simulation designs. In addition, they may require regular

maintenance due to aggradation, degradation and wood accumulation. Further, the baffles and roughness elements may decrease the structure's conveyance, making them especially susceptible to plugging and failure, as well as create excessive turbulence which can in itself be a fish passage barrier (Hotchkiss, 2007 and Stream Simulation Working Group, 2008). Finally, there are many biological unknowns which hamper effectively designing for a target species: fish swimming abilities, migration timing, migration flows, and juvenile capabilities (Cenderelli et al., 2011). Today, hydraulic designs are typically used as a short-term fix until the barrier culvert can be replaced with a larger structure (Hotchkiss and Frei, 2007).

FIGURE 4: HYDRAULIC DESIGN EXAMPLE STRUCTURE RETROFIT

(PHOTO FROM HOTCHKISS AND FREI, 2007. FIGURE 8.14)

FIGURE 4 SHOWS THE BAFFLES ARE HIGHER ON ONE SIDE THAN THE OTHER. THE LOW SIDE IS DESIGNED TO ALLOW SOME SEDIMENT TRANSPORT THROUGH THE STRUCTURE. THE HIGH SIDE SHOULD CREATE DEEPER DEPTHS AND LOWER WATER VELOCITY AREAS.

FIGURE 5: HYDRAULIC DESIGN EXAMPLE OUTLET

(PHOTO FROM HOTCHKISS AND FREI, 2007. FIGURE 8.16)
FIGURE 5 SHOWS THE RETROFITTED BAFFLES DOWNSTREAM OF THE STRUCTURE OUTLET. THE BAFFLES CREATE POOLS IN WHICH FISH CAN REST, PREPARING TO LEAP UPSTREAM.

<u>Roughened channel design</u> (also known as hydraulic simulation) is the middle ground between hydraulic design and stream simulation. The idea is to create a channel bed and gradient similar, but not necessarily identical, to the natural channel. It is assumed that if hydraulics and depths are similar, the design will be passable for all *fish* species (Hotchkiss and Frei, 2007). The structure slope, substrate particle size, average stream velocity, and turbulence may all be greater than those within the natural channel. The bed material is not intended to adjust, or be replenished over time; it is a semi-rigid structure (Stream Simulation Working Group, 2008).

Roughened channel design uses embedded structures, natural or synthetic bed substrates and "key pieces" to create hydraulic diversity, depth, velocity and low-turbulence conditions favorable to fish passage (Stream Simulation Working Group, 2008). Some designs create an immobile roughened bed over which sediment transport occurs. To accommodate fish migration at any time, low-flow paths are created. The structure width is generally as wide as, or slightly less than bankfull width (Hotchkiss and Frei, 2007). Figure 6 depicts a roughened channel design beneath a bridge in Humboldt County, CA.

Drawbacks to roughened channel designs include required maintenance. Sediment and debris may need to be removed from the structure and inlet if roughness elements encourage aggradation. Where structures are narrower than bankfull width, flows greater than bankfull may wash away the mobile substrate within the structure, exposing the bare culvert bottom. These particles are not likely to be replaced with upstream particles (Stream Simulation Working Group, 2008). Without an upstream grade control, this discontinuity can lead to channel incision within the upstream channel (Hotchkiss and Frei, 2007).

A roughened channel design is the preferred option within certain settings because the channel bed is not dependent on sediment supply, nor should it scour. Road-stream crossings at incising channels, immediately downstream from lakes or dams, and at unstable channels are good candidates for this design technique (Stream Simulation Working Group, 2008).

FIGURE 6: A ROAD-STREAM CROSSING ROUGHENED CHANNEL DESIGN

JANES CREEK, ROUGHENED CHANNEL BY LLANOS AND LOVE (2005). PHOTO FROM THE FISHXING WEBSITE.

Stream simulation (also known as geomorphic simulation) integrates fluvial geomorphology concepts with engineering principles to design a natural and dynamic channel through the road-stream crossing structure. Stream simulation is based on creating and maintaining channel features and characteristics through the road-stream crossing that are similar to those in the natural channel (e.g., slope, channel bed width, bedform, and bed materials) (Hotchkiss and Frei, 2007). Ideally, structures are wider than the natural channel width at bankfull stage and incorporate constructed banks which facilitate the movement of terrestrial species as well as protect the structure (Hotchkiss and Frei, 2007; Stream Simulation Working Group, 2008). Barnard (2003) found structures should be at least 1.3 times the natural channel bankfull width to avoid affecting natural processes.

Stream simulation assumes that when channel dimensions, slope, and streambed structure are similar to the natural channel, water velocities and depths will also be similar for a wide range of flow conditions. Therefore, the simulated channel should present no more of an obstacle to aquatic organisms than the natural channel, making it unnecessary to design the structure for targeted species, specific life-stages, migration periods, or fish passage hydrology (Hotchkiss and Frei, 2007; Stream Simulation Working Group, 2008). Stream simulation channels are designed to adjust laterally and vertically (within the physical limits of the structure) to accommodate a wide range of floods, sediment, and wood inputs without compromising the movement of fish and other aquatic organisms or the hydraulic capacity of the structure (Stream Simulation Working Group, 2008). Figure 7 shows an undersized culvert; Figure 8 shows the same culvert after it was replaced with a stream simulation design.

In the 1970's, the Forest Service began replacing road-stream crossings that were impeding the life-cycle migrations of salmon and steelhead. Initially, replacements were designed for adult fish passage using hydraulic design methods. Forest practitioners started to move away from hydraulic design in the late 1980s when it was noted that designs did not accommodate various swimming abilities. In addition, designing for many species which migrate at different times of the year at various discharges was not practical. The design approach dramatically changed in 1999 when stream simulation was introduced by the Washington Department of Fish and Wildlife. Stream simulation has been improved upon for over a decade (Cenderelli et al., 2011).

The stream simulation method for aquatic organism passage design is an interdisciplinary effort; biologists, hydrologists, geomorphologists, engineers and contractors must work together to create and implement a successful project. A stream simulation project consists of a six phase process: initial assessment, site assessment, stream simulation design, final design/contract preparation, construction, and finally maintenance and monitoring (summarized in Appendix F [Stream Simulation Methodology]). Stream simulation is increasingly recognized as the national standard of aquatic organism passage design (USDA Forest Service, 2012b). In 2008, the Forest Service published a guide which offers instruction for how to collect and integrate data into a stream simulation design (Stream Simulation Working Group, 2008, Cenderelli, et al., 2011).

FIGURE 7: ROAD-STREAM CROSSING ON THE BOISE NF, CULVERT PRE-REPLACEMENT

(PHOTO FROM THE STREAM SIMULATION WORKING GROUP, 2008. FIGURE 3.1)

FIGURE 8: ROAD-STREAM CROSSING ON THE BOISE NF, STREAM SIMULATION DESIGN CULVERT POST-REPLACEMENT

(PHOTO FROM THE STREAM SIMULATION WORKING GROUP, 2008. FIGURE 3.1)

1.2.8 MONITORING

1.2.8.1 WHY MONITOR?

Restoration projects should be viewed as experiments where the scientific process is incorporated into the project plan from an early stage (Wohl et al., 2005). Adaptive management is a project framework which incorporates monitoring throughout the “experiment.” Monitoring is imperative for understanding and learning from the failure or successes of a project (Kondolf and Micheli, 1995; Bash and Ryan, 2002; Downs and Kondolf, 2002; Palmer et al., 2005; Kondolf et al., 2007; Palmer et al., 2007). In addition, monitoring can help validate project assumptions, provide insight into problems, improve designs, and highlight areas of uncertainty. With monitoring, patterns of failure will become apparent (Johansen et al., 2009). Ultimately, adaptive management uses the results of project monitoring to guide planning, enabling us to minimize future problems. If scientists, agencies and practitioners were to collaborate from the beginning, meaningful and applicable monitoring and reporting methods might be created (Jansson et al., 2005; Palmer et al., 2005; Wohl et al., 2005; Bernhardt et al., 2007; Palmer et al., 2007).

Some academics have said that advances in stream restoration science have been hampered because we know very little about the success (or failure) of different restoration approaches (Kondolf et al., 2007). Monitoring and reporting on project outcomes is not always done. Estimates as of 2005 suggested that only 10% of restoration projects in the US had post-project evaluations (Bernhardt et al., 2005). A 2007 study on a select group of large restoration projects found that 83% reported post-project monitoring (Bernhardt et al., 2007). The true number of monitored stream restoration projects in the U.S. is likely somewhere between 10% and 83% (Bernhardt et al., 2007). One reason monitoring is not common is because funding sources offer tight budgets and/or simply do not require it (Hill, 2001;

Bernhardt et al., 2007; Kondolf et al., 2007). Without monitoring, however, we cannot improve methods or outcomes.

When post-project monitoring *is* done, valuable information tied to project goals is often missing. The Bernhardt et al. (2007) study evaluated 317 project managers across the US. The study results are disturbing, illuminating the blind state of restoration science. In particular, large disconnects exist between the original intentions of a project and the goals and metrics used to evaluate its success. Bernhardt et al. provide the following example: the motivation for restoration might be channel degradation, but the metrics of success are aesthetics and public opinion. Less than half of the projects included in the study had set measureable objectives, while far more than half of the projects claimed they were “completely successful.” For nearly half of all study projects, “success” was based only on site observations or positive public opinion. The Bernhardt et al. (2007) study indicates that projects with post-project monitoring are less likely to be deemed completely successful, suggesting that careful study will illuminate valuable lessons, or, the more we look, the more we will find.

Monitoring should be incorporated into a project plan at three points in time. Implementation monitoring occurs immediately after the project is completed. Implementation monitoring should answer the question: Did we build what we designed? Long-term monitoring requires repeated visits over a longer period of time to answer the questions: Has the design reach changed over time? How does the project respond to extreme events? Are project goals still being met (Johansen et al., 2009)? Effectiveness monitoring occurs after implementation monitoring when enough time for adjustment and natural processes has passed. At road-stream crossing restoration sites effectiveness monitoring asks: Did it work? Is the designed stream profile stable? Is it providing continuity of habitat and process through the structure? Road-stream crossing designs and their impacts on fish and other organisms have been well studied (Bates et al., 2003; Coffman, 2005; Hotchkiss and Frei, 2007). However, the effectiveness of designs implemented to provide fish and other aquatic organism passage through road-stream crossing structures is generally not monitored (Price et al., 2010). Effectiveness monitoring of AOP restoration designs at road-stream crossing structures is the focus of this thesis.

Fiscal accountability provides yet another reason to monitor restoration projects. For example, the US Forest Service is a federal agency largely funded by tax-payer dollars. Between 2005 and 2011, under the Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users, at least $10 million was annually allocated for aquatic passage improvement at road-stream crossings on National Forest lands (USDA Forest Service, 2011). Between 2006 and 2010, the replacement or removal of road-stream crossing barriers using the stream simulation method has restored 1,265 km of stream at an average cost of $36,800/km. This represents about $46,500,000 of federal money funding these projects (USDA Forest Service, 2011). The Forest Service must report to Congress each year. Without a way to evaluate project effectiveness, it is impossible to demonstrate the restoration budget has been well spent and should continue to be funded.

To facilitate more accurate accomplishment reporting, as well as improve restoration practices, the Forest Service has drafted monitoring methods for assessing the effectiveness of AOP road-stream crossing designs. Monitoring objectives include: evaluating the performance of individual restoration projects, improving road-stream crossing design techniques, and demonstrating project results to stakeholders and the public. Both biological and physical effectiveness studies are part of this effort. Biological effectiveness monitoring studies generally track fish passage through road-stream crossing structures via mark-recapture (individual movement), occupancy models, abundance studies, and molecular genetic markers (Hoffman et al., 2012). Physical effectiveness monitoring addresses whether the channel design at the road-stream crossing structure has similar physical characteristics to the natural channel, which in turn allows for fluvial and ecosystem processes to occur as if the crossing were not there.

1.2.8.2 INTRODUCTION TO THE CURRENT FOREST SERVICE PHYSICAL EFFECTIVENESS MONITORING APPROACH

Two, separate, physical effectiveness monitoring protocols have been created by the Forest Service to assess whether a road stream crossing is allowing for geomorphic continuity, thereby also allowing for ecologic continuity. The underlying premise for both protocols is; if the design channel features and characteristics through the crossing are physically similar to an adjacent representative reach within the natural channel, then the stream simulation channel is considered an effective and sustainable design which provides long-term geomorphic ,and therefore, ecologic continuity. Figure 9 is a logistical model which describes how the AOP design process and physical effectiveness monitoring fit together.

The Level II physical effectiveness monitoring protocol is a detailed and time intensive method for collecting physical channel metrics. The level I physical monitoring procedure is a scaled down version of level II; metrics are quantitative, but fewer metrics and fewer measurements are collected. The metrics for both protocols require collecting measurements such as: width, depth, particle size, and step height (among others). For each metric, data measured within the design channel are compared with data measured within the representative reach. Level II requires about 5 days of field data collection; level I requires about 3 hours.

Levels I and II combine the metric data into effectiveness evaluations through summary rubric tools. The rubric scores each metric comparison based on the degree of similarity between design and representative reach data. The level II rubric is scored by statistically comparing (testing) the design and representative reach groups. The level I rubric is scored by comparing the design median to the range of representative reach data. Metric scores are then weighted by the rubric (identically for metrics common to both levels I and II). The weight reflects how much control a metric has on geomorphic processes through the road-stream crossing. The weighted scores are finally summed to produce a total score. The total score is compared with a perfect score and the percentage is labeled to reflect how effectively the design mimics the natural channel (i.e., ≥75% is “similar,” between 50% and 75% is “questionable,” and <50% is “dissimilar”).

Both the levels I and II protocols are necessary because, although much information can be learned from detailed monitoring, collecting and analyzing field data are very time intensive. Realistically, if effectiveness monitoring is to become common practice at National Forest AOP restoration sites, a rapid assessment method is required. Conversely, the rapid assessment needs the defensible support of a statistically significant method, should the results be questioned.

It is expected that the Level I protocol will be applied to most AOP road-stream crossing designs, while the level II protocol will be applied to sites where more informative and detailed insights are needed. Both protocols are described in detail within Appendices B[Level II 2013 Field Protocol], C [Level I 2013 Field Protocol], and E [Summary Rubrics]. The protocols are summarized within sections 3.4.1 and 3.4.2 of this thesis.

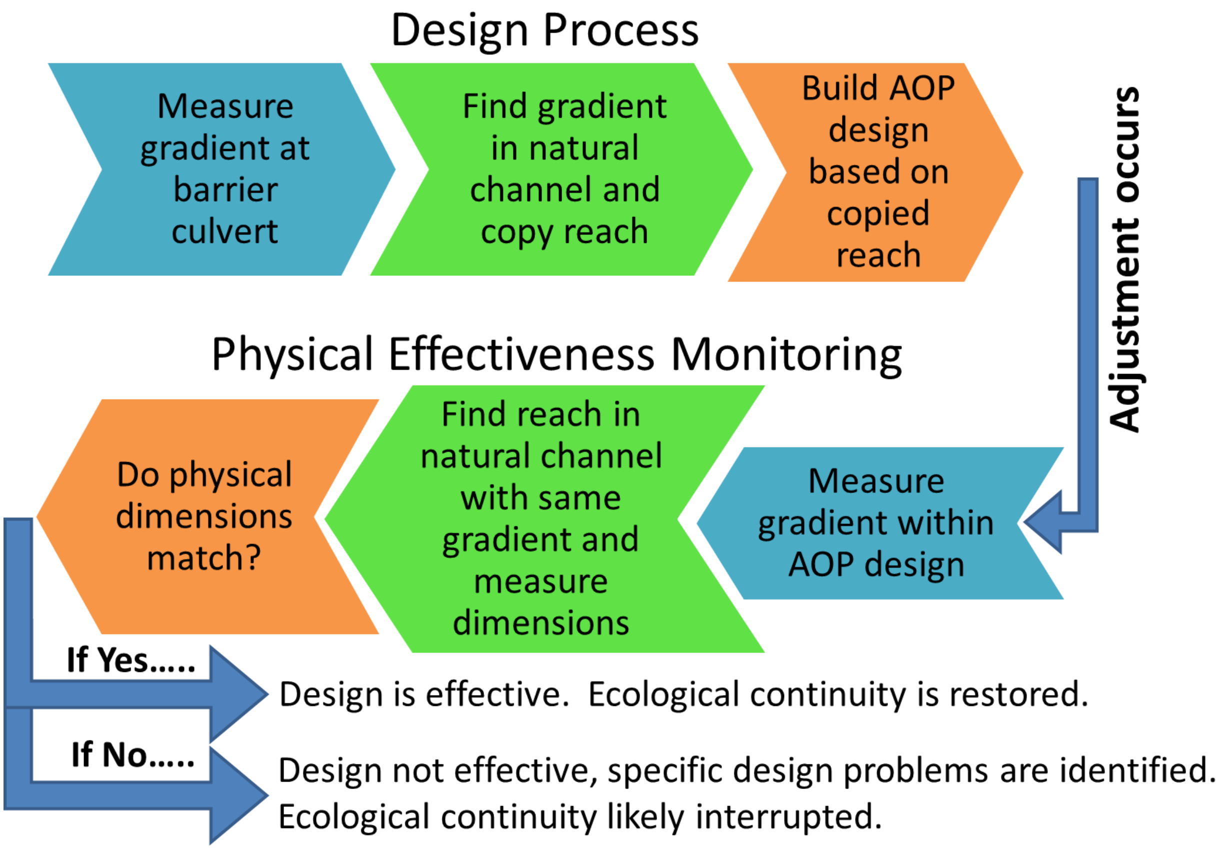


Figure 9: Logistical model of stream simulation design and physical effectiveness monitoring

1.2.8.3 Previous Physical Effectiveness Monitoring Studies at Road Stream Crossings

Searches for “fish passage monitoring” and “aquatic organism passage monitoring” on Google Scholar gave results related to biological monitoring techniques for passage at fish-ways associated with dams. The majority of literature relevant to culverts covers biological monitoring, if monitoring is mentioned at all. At culverts, there are, however, a number of studies aimed at assessing the passability of aquatic organisms at a site. Passability differs from effectiveness monitoring because it is evaluated before a barrier culvert is replaced, typically during the inventory and prioritization phases of watershed restoration.

The state of Washington has been especially active in the development of fish passage science at road-stream crossings. The state Department of Fish and Wildlife (WDFW) published a fish passage assessment protocol and barrier standard (2000) for assessing the impacts of barrier culverts and prioritizing those structures for replacement. Their passability determination at a fish-bearing stream crossing requires an in-depth physical survey at the structure as well as a subjective assessment of the barrier degree (partial to complete) (Kemp and O'Hanley, 2010). This passability protocol is also incorporated into their permitting process. In 2010, Price et al. used the WDFW passability protocol as an effectiveness monitoring tool at 77 AOP sites (stream simulation designs were specifically omitted). Their goal was to assess how well the Washington permitting program protects aquatic resources. The study concluded that 30% of the AOP culverts evaluated were not effective, and that increased implementation and effectiveness monitoring is needed (Price et al., 2010).

Stream simulation designs were specifically evaluated in a WDFW study by Barnard et al. (2009), whose approach is more similar to this study than that by Price and others. Like the underlying premise of the levels I and II monitoring protocols, the effectiveness of aquatic organism passage was evaluated by Barnard et al. (2009) by comparing the designed structure channel to representative reaches within the natural channel, assuming that a constructed channel which is very similar to the natural channel will present no more of an obstacle to an organism than the natural channel. At 50 sites in Washington State, they examined the physical characteristics within each culvert and compared them with those at a representative reach in the adjacent natural channel. Specifically, Barnard et al. analyzed the following metrics at the design channel with those in the representative reach (those marked with an * are also levels I and II protocol metrics of this study, although they differ slightly):

- culvert bed width/natural channel bankfull width*,
- slope*
- mean thalweg depth*
- standard deviation of thalweg depth
- D50
- D84*
- D100
- Q2 stage
- Q2 width
- Q2 velocity
- Q100 stage
- Q100 width
- Q100 velocity

The Barnard et al. culvert bed width/natural channel bankfull width ratio is similar to the levels I and II protocol width at bankfull stage metrics. Level II however, statistically compares bankfull widths within the design zone to those within the representative reach. Level I compares the design median to the range of representative reach data. Also, instead of measuring the width from the centerline to each bank (as in level II), the authors measured across the channel with a laser level.

Channel bed slope was measured by Barnard et al. by surveying 30 m up and downstream of the structure, as well as within the representative reach (using a laser level). The level II protocol specifies surveying a detailed longitudinal profile (using a total station) for 40 to 60 bankfull widths up and downstream of the structure. The level I protocol simply requires an ocular estimate of gradient.

D84 is measured by Barnard et al. by pebble count within the culvert and the representative reach. Data were collected longitudinally down the stream, regular sampling intervals were marked, and 100 particles were measured to the half phi increment. The level II protocol approximates D84 by statistically comparing the median of the larger half of the full distribution (coarse fraction). The level II protocol specifies collecting ~200 particles across the channel by adjustable vertices sampling frame. A pebble count is conducted at every unique riffle within the design and representative reach slope segments. The Level I protocol measures only 9 to 11 of the largest particles within a riffle or cascade. The Barnard et al. study collected the thalweg depth measurements in a manner similar to those by level II. The authors spaced the measurements so as to obtain a sample (n=26) which would maintain some statistical power. They found 10 m culvert lengths are common, and therefore set the sampling interval at 0.3 m. The level II protocol similarly ensures a minimum sample of 20 within the structure and representative reach. For statistical and logistical reasons, it also specifies a minimum sampling interval of 0.3 m for maximum depth and width measurements. The level I protocol has a sample size of five, and the measurement interval is set by dividing the channel unit length by five. Further, the Barnard et al. study compares the mean depth, whereas the level II protocol compares the median depth.

Barnard et al. also analyze bed irregularity. However, instead of analyzing the deviations from the median depth at several cross sections (lateral irregularity) as specified by the level II protocol, they use the standard deviation of the thalweg depths (longitudinal irregularity). Bed irregularity is not a level I metric.

Entirely different from the levels I and II protocols, Barnard et al. utilize regional regressions for discharge, WinXSPro, and the Hey (1979) and Bathurst (1978) equations for flow resistance to hydraulically model the Q2 and Q100 width, stage and velocity metrics. For two cross sections collected within the structure, and two within the representative reach, the discharge metrics were calculated and averaged.

Barnard et al. selected the representative reach based on similarity of channel type (length, slope, channel units) to that within the structure (among other criteria). Channel gradient however, was not the dominant criteria for selecting the representative reach, as it is for the levels I and II protocols. It is not clear within their 2009 draft paper how slope segments were delineated, nor how different gradients were allowed to be before a potential representative reach became unacceptable. Also different from the levels I and II protocols, Barnard et al. did not compare the inlet and outlet transition zones with a representative reach.

For each physical metric, Barnard et al. calculated the structure to representative reach ratio. By using ratios, Barnard et al. were able to compare metrics across sites, which enabled them to make general conclusions about how well, or poorly, stream simulation designs are implemented and functioning in Washington State. They were also able to look for correlations between metrics, the time passed since construction, and flow history. Because the goal of this thesis is not to make comparisons and generalizations *across* sites, but instead to analyze each site in-depth, ratios (or other techniques) are not used by levels I or II protocols to normalize data, nor are correlations studied.

Barnard et al. found that the majority of stream simulation designs closely mimic the natural channel. Differences appeared to occur where it was assumed that a design channel would adjust over time to create banks and bed forms similar to the natural channel. Barnard et al. found constructing these features is best. The modeled flow stage during the 100 year flood was found to be well below the maximum height of the structures, meaning a pressurized condition within the structures was not occurring. Slope ratios (design: representative reach) were not correlated with time since construction or flow history, indicating large floods are not causing hydraulic conditions which aggrade or incise the design beds.

In contrast to this study, Barnard et al. did not combine the metrics into effectiveness evaluations at each site, nor did they try to create a method intended for wide distribution as a monitoring tool.

Further their 2009 study was specifically aimed at evaluating stream simulation designs, whereas the levels I and II protocols are applicable to other design methods as well.

More similar to this study than Barnard et al., Bair and Robertson (2010) authored a pilot study of stream simulation AOP effectiveness at 25 sites on National Forests in Washington and Oregon. Their study goals were both to determine if aquatic organism passage is occurring, and whether the designed channels are geomorphically simulating the natural stream channels. They also intended to create a protocol which could be distributed and applied by others at sites within the Pacific Northwest Region (Forest Service Region 6).

Bair and Robertson created separate physical and biological monitoring protocols to address their project objectives. The biological protocol used mark and re-capture electrofishing as well as snorkel sampling techniques; they are not discussed within this thesis. Metrics collected by their physical protocol are as follows (those metrics also evaluated by the levels I and II protocols are marked with an *, although they may differ slightly):

- D50
- Five largest particles*
- Bankfull width*
- Bankfull width-to-depth ratio
- Wetted width-to-depth ratio
- Slope*
- Riffle slope
- Riffle length

A Wolman pebble count was used by Bair and Robertson to objectively measure 100 substrate particles. Transects were set up perpendicular to flow and 100 particles within the bankfull channel were measured with a ruler at their b-axes. The level II physical monitoring protocol also specifies a pebble count, but 200 particles are measured within each unique riffle. Objectivity within the level II pebble count is achieved through the use of an adjustable vertices sampling frame, moved across transects also oriented perpendicular to flow. The D50 is not specifically evaluated (see the next paragraph). A true pebble count is not part of the level I protocol.

Bair and Robertson also independently measured the five largest particles in each segment (representative reaches and the structure). Each segment was divided into five longitudinal sections in which the largest particle was measured. Level II does not separately measure the five largest particles, instead the largest half of the full particle size distribution is sub-sampled; and approximately the D75 is compared between design and representative reach. Level I does specifically measure the largest particles, but riffles are not sampled by section, instead simply nine to eleven of the largest particles are measured (b-axis only).

Cross sections were collected by Bair and Robertson in the same locations as pebble counts. In addition, one cross section was collected within each representative reach, three just upstream of the structure inlet, three just downstream of the structure outlet and one at the structure mid-point. Cross sections were measured by stringing a tape from left bank to right bank across the channel at the floodplain elevation. I assume the authors also used a rod to measure down from the leveled tape but it is unclear. The floodplain, wetted perimeters, bankfull elevation and thalweg features were measured by Bair and Robertson. The level II protocol specifies collecting cross section data in a similar manner, but instead of targeting specific features, a minimum of 20 measurements within the wetted width are collected. Cross sections are not part of the level I protocol.

Bair and Robertson surveyed a longitudinal profile for approximately 400 m centered on the structure. They used a laser range finder or fiberglass tape and laser level to survey the thalweg of the stream channel. Features collected were pool tail crests, maximum pool depths, the head of each pool, riffle, run, glide, step crests, the base of steps, and log sills. The level II protocol also surveys a longitudinal profile (with a total station), but for a distance based on the bankfull width of the stream channel (40 to 60 bankfull channel widths centered on the structure). The same channel features were collected, in addition to zone boundaries, as well as key points on the structure and road. Additionally, level II data points should not be greater than a half bankfull width apart. The level I protocol does not require surveying a longitudinal profile.

Bair and Robertson selected two representative reaches (one upstream and one downstream of the crossing structure) to which they compare the structure. The inlet and outlet transition zones are not analyzed. The representative reaches are selected based on their length and slope. They must be within 50 m, or five times the bankfull width of the structure inlet and outlet. They are truncated at major tributaries and large sediment-retaining debris jams (discontinuities in morphology and process). It is not clear within the 2010 report how the reaches were delineated, nor how different gradients could be before a potential representative reach was ineligible.

Similar to Barnard et al. (2009), ratios of the physical dimensions within the design channel to those within the representative reaches were used. Like the levels I and II summary rubrics, a scoring method was used to summarize all metrics into an effectiveness evaluation. The Bair and Robertson metrics within the structure are separately compared with the upstream representative reach and the downstream representative reach. Instead of statistical tests, or comparing the median to the extent of data (as in the levels I and II protocols), Bair and Robertson use a tolerance interval to score metrics. The tolerance interval for most metrics is ± 20% of the average representative reach value; for the bankfull width metric, it is ≥ 90% of the average representative reach value. A single point is granted where the structure metric is within the tolerance interval, otherwise zero points are awarded. Unlike the levels I and II protocols, all metrics affect the total score equally as no weights are utilized. A design channel by the Bair and Robertson study is considered effective if ≥ 60% of the total possible points are accumulated.

Bair and Robertson state the majority of their sites were simulating natural channels, but their results table shows that only 50% of the evaluated structures were similar to the upstream representative reach, and only 30% were similar to the downstream representative reach. They found design channel units were more simple and homogeneous (less velocity breaks and pocket pools) than those within the natural channel. Interestingly, they found no correlation between passage effectiveness (biological monitoring) and the degree to which the design channel simulated the natural channel. The authors explain that some sites appeared to aid fish passage when the design thalweg gradients, riffle slopes, and wetted width to depth ratios were lower than those within the natural channel (i.e., less hydraulically challenging). The authors did not, however, discuss any results which indicate the opposite scenario; where stream channel dimensions were well simulated, but fish passage was prevented. Interestingly, Bair and Robertson also evaluated two of the sites I visited (Lower and Upper Stillwell). I however, only analyzed the data for Lower Stillwell. Their results show Lower Stillwell scored 63% of the total possible points when compared with a representative reach upstream of the structure, and only 38% of the total possible points when compared with a representative reach downstream of the structure. Upstream, the structure lost points for having a greater width/depth ratio, a gentler riffle slope, and a longer riffle length. Downstream, the structure lost points for having smaller large particles, a narrower bankfull width, a much greater width to depth ratio, a smaller wetted width to depth ratio, and a much longer riffle length.

My level II summary rubric results are very similar to those by Bair and Robertson indicating the Lower Stillwell structure scored 64% of the total possible points. The structure was evaluated as "questionable" when compared with a representative reach located upstream. It also lost points in my study for being wider than the natural channel at bankfull.

My level I summary rubric results are also similar to those by the Bair and Robertson study (although there are significant issues with the level I protocol, see section 6.3). The Lower Stillwell structure scored 70% of the total possible points when compared with a representative reach located upstream and was evaluated as “questionable”. Similar to the Bair and Robertson results, the level I protocol also subtracted points for excessive width at the bankfull stage.

The Bair and Robertson 2010 study was the first known attempt at creating a physical effectiveness monitoring protocol for distribution and application over a large geographic area (FS regional scale). This study expands upon what they accomplished in the Pacific Northwest for physical effectiveness monitoring in terms of the field protocol, the method of summarizing effectiveness, and the geographic extent to which it has been tested, and to which it will be distributed and ultimately applied. These standardized monitoring protocols will facilitate sharing monitoring results because monitoring data obtained with the finalized field protocols and summary rubrics should be easy to incorporate into any restoration database.

2 OBJECTIVES

My objectives are three fold:

1. Test and refine the field methods for collecting data by the levels I and level II physical effectiveness monitoring protocols. Make recommendations for improvement.
2. Find a meaningful way to combine the data for each metric collected within the level II field protocol. Create an effectiveness summary tool (rubric) for the level II data. Create a similar summary tool for level I data. Test the levels I and II summary rubrics with site data.
3. Evaluate, whether level I can be used as a proxy for level II. Compare the effectiveness results of the level I and level II protocols. Where they systematically differ, try to distinguish why. Based on those results, make recommendations for altering data collection procedures and the levels I and II summary rubrics.

3 FIELD METHODS

3.1 STUDY AREAS (SITES)

Field work was divided between two field seasons across six National Forests in six US states (Figure 10). During the summer months of 2011, I collected data at two National Forests near Missoula, Montana. Two sites are located on the Lolo National Forest; one site is on the Clearwater National Forest in Idaho. I also collected data at three sites on the Monongahela National Forest in central West Virginia. During the summer and fall of 2012, data were collected at three National Forests. Four sites were evaluated on the Green Mountain National Forest in central Vermont. Five sites are located on the Siuslaw National Forest in central coastal Oregon. Three sites are located on the Daniel Boone National Forest in eastern Kentucky. In total, 18 sites were visited. Fourteen of those sites were evaluated with the level II protocol, 16 sites were evaluated with level I, 4 sites were only evaluated with level I, 2 sites were only evaluated with level II, and 12 sites were evaluated with both levels I and II. At 7 of those 12 sites, the selected representative reaches for levels I and II are the same. Most sites have characteristics of more than one channel type, but some generalizations can be made. Nine sites are dominantly pool-riffle channels, 5 are pool-riffle with wood-forced steps, 3 sites are step-pool channels and 1 site is pool-riffle but with a bedrock bed. The hydro-geomorphic setting varies considerably between sites (able 2). Eight of the 18 sites visited would be considered stream simulation designs.

It should be noted that three other scientists (Dan Cenderelli, USFS; Margaret Lang, Humboldt State University; and Mark Weinhold, USFS) collected data at additional sites in Colorado and California. Their field experiences, data and analysis helped to create the 2013 levels I and II field protocols as well as site summary rubrics.

All sites (18) were used to meet objective 1: field test the levels I and II protocols. 8 sites were used to meet objective 3: comparing levels I and II results. One of those 8 sites (Lower Stillwell) was used to meet objective 2: creating summary rubric tools. Weinhold and Lang analyzed two additional sites whose results and insights greatly contributed to objective 2. Twelve sites were chosen from the pool of 18 for testing the objective 2 levels I and II summary rubrics. See able 1 for a site by objective summary.

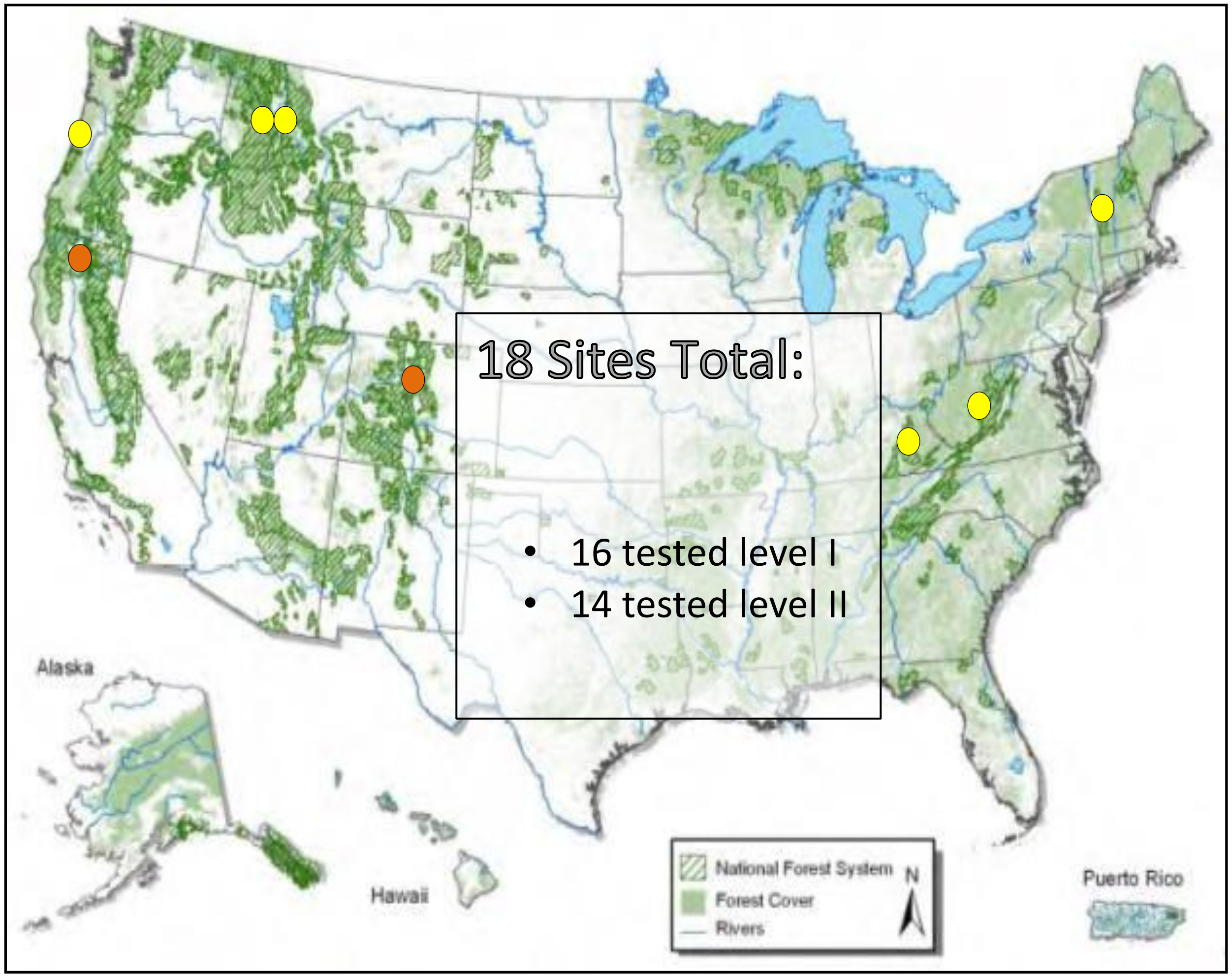


FIGURE 10: SITE LOCATION MAP

🟡 = KLINGEL AND CENDERELLI SITES (FOR THESIS)
🟠 = LANG AND WEINHOLD SITES (TEST SITES)

TABLE 1: SITES USED TO MEET SPECIFIC OBJECTIVES

Forest	Site Name	Stream Simulation?	Objective 1	Objective 2		Objective 3
			Field Testing Level I And II	Creating Rubrics	Testing Rubrics	Comparing Level I And II
Siuslaw NF	Lower Stillwell	No	x	x	x	x
	North Fork Indian	Yes	x		x	x*
	Big Creek	Yes	x			
	Bays Creek	No	x		x	
	Upper Stillwell	Yes	x			
Monongahela NF	WF01	No	x		x	x
	WF02	No	x		x	x
	Site 3	No	x		x	x
Daniel Boone NF	Dog Slaughter	No	x		x	x
	Big Lick	No	x		x	x
	Caney Creek	No	x		x	
Green Mountain NF	Jenny Coolidge	Yes	x			
	Sparks Brook	Yes	x		x	x
	Joe Smith Brook	No	x		x	
	Utley Brook	No	x		x	
Lolo NF	461 4.4	Yes	x			
	461 3.1	Yes	x			
Clearwater NF	Haskell Creek	Yes	x			

*LEVELS I AND II DO NOT HAVE THE SAME REPRESENTATIVE REACH

TABLE 2: BIO-GEO-HYDRO SETTING OF NATIONAL FORESTS WITH SITES

National Forest	State	Climate	Lithology	Topography & geomorphic processes	Stream flow	Trees	Fish
Lolo NF (USDA Forest Service, 2005)	MT	Mean annual precipitation 127- 152.4 cm Winter snowfall Summer Rain Mean daily temperature is 5.2˚ C.	Large granitic intrusion into local metasedimentary rock Granitic bedrock is highly weathered.	1,341 m to 1,981 m in elevation Glaciers have left the upper elevations steep and dissected Valley bottom deposits of glacial till. Mass wasting is uncommon.	Spring snowmelt Summer thunderstorms are very frequent. Streams rise quickly, but briefly.	western white pine whitebark pine limber pine lodgepole pine ponderosa pine alpine larch western larch mountain hemlock western hemlock Douglas fir grand fir subalpine fir Engelmann spruce western red cedar paper birch water birch aspen	West Slope Cutthroat Trout Rainbow Trout Brown Trout Brook Trout Bull Trout Mountain Whitefish Northern Pikeminnow Longnose Dace Longnose Sucker Largescale Sucker Slimy Sculpin
Green Mountain NF (USDA Forest Service, 2006)	VT	Mean annual precipitation 132 - 117 cm The Gulf of Mexico and the Atlantic Ocean produce frontal summer rainstorms. Snowfall varies around the Forest. Mean annual temp. is 4.3˚ C.	Marble, limestone, dolomite, ultramafic and pematic rocks. Highly metamorphosed. Soils are mostly glacial tills, some calcium rich parent material.	183 m to >1067 m in elevation Valley bottom to alpine Slopes range from 0-70%	Mostly perennial streams Moderate to steep channel gradients	pine hemlock fir spruce maple oak birch beech	Rainbow Trout sea-run Atlantic Salmon Brown Trout Brook Trout Creek Chub Fallfish Common Shiner Blacknose Dace Longnose Dace White Sucker Tessellated Darter Slimy Sculpin

National Forest	State	Climate	Lithology	Topography & geomorphic processes	Stream flow	Trees	Fish
Clearwater NF (Bugosh, 1999; USDA Forest Service, 2005)	ID	Mean annual precipitation 127 - 152.4 cm Winter snowfall Summer Rain Mean annual temperature is 5.9˚ C	Large granitic intrusion into local metasedimentary rock Granitic bedrock is highly weathered.	1,889 m to 1,387 m in elevation (site specific) Glaciers left the upper elevations steep and dissected. Valley bottom deposits of glacial till. Mass wasting is not common.	Spring snowmelt Summer thunderstorms are very frequent. Streams rise quickly, but briefly.	western white pine whitebark pine limber pine lodgepole pine ponderosa pine alpine larch western larch mountain hemlock western hemlock Douglas fir grand fir subalpine fir Engelmann spruce western red cedar paper birch water birch aspen	West Slope Cutthroat Trout Rainbow Trout Brown Trout Brook Trout Bull Trout Mountain Whitefish Northern Pikeminnow Speckled Dace Suckers Sculpins
Monongahela NF (USDA FS, 2011b)	WV	Mean annual precipitation 152 - 76 cm Winter snowfall Summer Rain Prevailing weather is from the west. Mean annual temperature is 9.5˚ C	Sedimentary bedrock: sandstone, siltstone, coal, and limestone	~610 m to 1,482 m in elevation Steep slopes Narrow valleys	Dominant source of stream flow is summer rainstorms. Streams are flashy.	white pine balsam fir red spruce mountain ash sugar maple red oak black cherry	20 fish species including: Brook Trout Creek Chub Mountain Redbelly Dace Blacknose Dace Fantail Darter

National Forest	State	Climate	Lithology	Topography & Geomorphic Processes	Stream flow	Trees	Fish
Daniel Boone NF (USDA Forest Service, 2004)	KY	Mean annual precipitation is 117 cm Influenced by the Gulf of Mexico. Mean annual temperature is 13˚ C Warm summers cool winters Storms between March and September.	Sandstone, shale, siltstone, coal, clay, and limestone Prone to landslides and debris flows (especially in the clay).	396 m to 259 m in elevation	Gravel bed streams, meandering, and narrow flood plains. High gradient, deep pools.	Canadian yew Virginia pine short leaf pine southern yellow pine hemlock hickory sugar maple red maple northern red oak red oak white oak chestnut oak white oak birch beech mountain laurel yellow poplar basswood dogwood black gum rhododendron sourwood	Creek Chub Black-side Dace

National Forest	State	Climate	Lithology	Topography & Geomorphic Processes	Stream flow	Trees	Fish
Siuslaw NF (USDA Forest Service, 1990)	OR	Mean annual precipitation: Coastal areas- 191 to 241.3 cm Interior, west of the coast range summit- >305 cm East of the coast range summit- 127 cm Cool wet winters, relatively warm, dry summers. Mean annual temperature is 10˚ C Occasional snow due to Arctic air masses.	Mostly sedimentary sandstone and siltstone rock Some volcanic flows Scattered intrusive igneous rocks.	457 to 1,219 m in elevation. Rapid uplift, high precipitation, and large frequent landslides give hillslope form.	High winter flows, low summer flow Headwaters are flashy, fast moving, v-shaped canyons Valley bottom streams are gentler gradient, U shaped or flat valleys. Large streams flow into estuaries before they reach the ocean. Dense dendritic drainage patterns.	lodgepole pine (on beach dunes) western hemlock Douglas fir (dominant tree species) Sitka spruce	Sea-Run Cutthroat Trout Steelhead Trout Chinook Salmon Coho Salmon Chum Salmon

INFORMATION LISTED WITHIN TABLE 2 IS LARGELY TAKEN FROM THE LAND AND RESOURCES MANAGEMENT PLAN FOR EACH FOREST. IT IS NOT AN EXHAUSTIVE LIST OF ALL SPECIES WHICH OCCUR ON A FOREST, NOR IS MOST INFORMATION SITE SPECIFIC TO MY STUDY REACHES.

3.2 SITE SELECTION

This thesis is part of a larger Forest Service effort to improve physical monitoring protocols for assessing the effectiveness of channel designs at road-stream crossings. In addition to physical monitoring (the focus of my thesis), the Forest Service is also developing a biologic monitoring protocol for assessing passage. Although the physical and biologic monitoring efforts are managed separately, most sites selected for this thesis are also biologic monitoring sites. The majority of physical monitoring sites were chosen by Dr. Dan Cenderelli (US Forest Service) from the biological monitoring sites that were recently replaced to provide fish and aquatic organism passage. Several other sites, introduced by local Forest Service employees, were also included. Selected sites had (theoretically) experienced at least one high flow season, represented a variety of stream types and hydro-geomorphic settings. Sites on the Green Mountain National Forest in Vermont were included for the above noted reasons, but in addition experienced a 300-500 year flood associated with hurricane Irene during the summer of 2011.

3.3 FIELD PROTOCOL DEVELOPMENT

The first draft of the level II physical effectiveness monitoring field protocol was developed in 2009 by Dan Cenderelli (US Forest Service), Margaret Lang (Humboldt State University), and Mark Weinhold (US Forest Service). The field methods were tested at four sites on or near the Shasta-Trinity National Forest, CA and one site on the White River National Forest, CO. Following these field tests, the level II physical monitoring protocol was revised by the authors, the result of which l used in my study.

A draft of the level I physical monitoring protocol was developed in 2012 by Cenderelli, Lang, and Weinhold. Level I is a simplified subset of the level II physical monitoring protocol. It was purposefully designed to be simple and quick, so that users could semi-quantitatively evaluate the effectiveness of road-stream channel designs at a large number of sites. Most of the sites at which I conducted level II physical effectiveness monitoring were also evaluated by the level I protocol.

Both protocols were refined by me during 2011 and 2012 field testing, as well as through data analysis and subsequent discussions with Cenderelli, Lang, and Weinhold. The protocols detailed within Appendices B [Level II 2013 Field Protocol] and C [Level I 2013 Field Protocol] have been adjusted from what I was originally provided in 2011 (level II) and 2012 (level I); they are the most up-to-date (2013) draft levels I and II field protocols. Adjustments made are presented within section 6.1. I have tried to improve the 2013 field protocols further by using the results of the summary analyses along with site-specific insights to make recommendations for future field data collection methods (see section 6.1). Level I and level II field protocols should be finalized in the near future, although this will likely occur after this thesis is complete.

In order to create a data set which would allow me to make comparisons between levels I and II (objective 3), some sites (initially visited during the 2011 field season) were re-visited by Weinhold and Cenderelli during the summer of 2012. Weinhold (not present during the initial level II field visit in 2011) selected an unbiased level I representative reach. Where he did not select the same representative reach as selected by the level II longitudinal profile analysis, Weinhold took additional level I measurements within the level II representative reach. During the latter part of the 2012 field season, at some sites, I also collected additional level I data within the level II representative reach. Please see able 1 for a list of those seven sites which have both a level I and level II evaluation for the level II representative reach (objective 3 sites).

3.4 OBJECTIVE 1: FIELD TESTING THE LEVELS I AND II PROTOCOLS

Upon arrival at a new site, the applicability of physical effectiveness monitoring was verified by navigating a decision tree: Is there substrate within the structure? Is the structure at least as wide as ¾ the bankfull width? Is there reason to believe the site has experienced sufficiently high flows for adjustment? Are the channel units in the design channel present and similar in dimensions to those in the adjacent natural channel? If the answer to any of these questions was no, effectiveness monitoring at the site is not appropriate. For illustrative purposes, the level I protocol was initiated at some sites which did not meet these criteria.

Once it was determined a particular site was well suited for effectiveness monitoring, I began with the level I evaluation protocol. Level I data collection was ideally completed before level II data at each site in order to avoid potentially biasing how the representative reach was selected (level II offers a surveyed longitudinal profile and quantitative analysis of gradients for representative reach selection).

3.4.1 The Level II Protocol, an Overview

The 2011 draft level II physical effectiveness monitoring protocol was field tested at 14 sites across the US during the 2011 field season. The 2013 level II protocol (presented by the various sections, tables and appendices cited within this section) resulted from both field testing and subsequent data analysis. Suggestions for additional improvements are summarized within section 7: Table 64, Table 65, and 66.

Data collection for level II analysis is extensive; it takes about five, ten-hour days at sites with several channel units. Field time is lengthy because sample sizes for each metric are designed to be large enough for statistical significance. See 3 for a list of level II metrics. A surveyed longitudinal profile is analyzed to determine an appropriate representative reach. Section 3.4.4.1 and Appendix B4 [Longitudinal Profile Analysis] detail the specifics of analyzing a longitudinal profile and provide an example analysis spreadsheet. Data are collected and analyzed by group. See sections 3.4.3 and 3.4.4.2 for a lengthy description of where data are measured. 4 describes the level II method of data collection, measurements collected, sample sizes, data manipulations and the resulting metrics. See Appendix B [Level II Draft Field Protocol] for the 2013 draft protocol and field forms.

The order of level II data collection is somewhat dictated by the need for a complete longitudinal profile analysis, and selected representative reach. Obviously, data can't be measured within the representative reach if the reach has not yet been selected. Metric data are collected first within the design channel. Doing so allows one to continue field work during the day, while analyzing the longitudinal profile in the evening. Once a representative reach is selected, and all metrics within the design channel have been measured, data are collected at the representative reach. The order in which individual metrics are measured does not matter.

A two-person field crew is imperative for surveying and extremely helpful for collecting the other metrics. Equipment used were: a total station, tripod, rod, prism, umbrella, compass, Carlson data logger, two-way radios, whistle, laptop computer, a Leica Disto D330 laser distance meter, stadia rod fit with a bubble level, pocket rod, metric pocket tape, two 100-m plastic rolled measuring tapes, small sledge hammer, 16 pieces of rebar (¼ inch, 4 ft. long), 32 large alligator clips, flagging, sediment sampling frame (1 m x 1 m), bubble level, 20 m of string, clipboard, write-in-the-rain data forms, machete, sandvik brush cutter axe, flagging, knee pads, neoprene gloves, waders, and wading boots. See Figure 427 and Figure 428 within Appendix D [Equipment Used].

3.4.2 THE LEVEL I PROTOCOL, AN OVERVIEW

The level I physical effectiveness monitoring protocol was field tested during the 2012 field season at 16 sites across the US. The 2013 level I protocol (presented within the sections, tables, and appendices cited in section) is the result of field testing and subsequent data analysis. Suggestions for additional improvements are summarized within section 7,Table 64, Table 65, and 66.

The level I protocol is a scaled-down version of the level II protocol. Collecting level I data requires between one and 3 hours, depending on channel complexity. Most, but not all, level II metrics are collected, and many fewer measurements are taken. Observations are predominantly quantitative. Level I metrics are described in section 3.4.4. 5 describes level I measurements, manipulations, metrics, and, sample sizes. See Sections 3.4.3and 3.4.4.2 for a description of where data are collected. A longitudinal profile is not surveyed; instead, the representative reach is selected based on ocular estimates of slope segment gradient and an assessment of similar channel units. Slope segments are also delineated within the design channel by ocular estimate. Similar to level II, level I data are collected and analyzed by group. See section 3.4.4.3 for a description of how data are compared between the design and representative reach. The improved (2013) version of the (draft) level I field protocol and data sheets is located in Appendix C [Level I Draft Field Protocol].

The order of level I data collection is somewhat dictated by the need for a complete long profile analysis, and selected representative reach. Obviously, data can't be measured within the representative reach if the reach has not yet been selected. Metric data are collected first within the design channel. Doing so allows one to continue field work during the day, while analyzing the longitudinal profile in the evening. Once a representative reach is selected, and all metrics within the design channel have been measured, data are collected at the representative reach. The order in which individual metrics are measured does not matter.

It is possible, but would not be easy for a single person to complete the level I protocol. Necessary equipment includes: a cloth or plastic rolled tape measure (50 m length), a pocket rod or full sized rod, bubble, data sheet, clip board, and camera. When selecting the representative reach, a clinometer on a tripod can be helpful for better estimating stream gradient. Figure 428 within Appendix D [Equipment Used] shows the equipment used for level II; level I equipment is a subset of that pictured.

3.4.3 SITE ANATOMY

At each site, a study reach was evaluated. An eligible study reach (for both the levels I and II protocols) is the length of channel which extends 20-30 bankfull widths upstream from the structure inlet and downstream from the structure outlet (including the structure itself). At some sites, the length was extended for two reasons: (i) an appropriate representative reach was not found within the initial study reach, but a good possibility was located just outside the bounds; or, (ii) if the structure length was equal to or more than ten times the bankfull channel width, the study reach was lengthened to five times the culvert length upstream and downstream of the structure.

A study reach is further divided into the design channel and the natural channel. The design channel consists of the inlet transition zone (ITZ), the structure, and the outlet transition zone (OTZ). The structure boundaries are set by its physical upstream and downstream extent (inlet and outlet). The inlet and outlet transition zones will extend upstream from the structure inlet, and downstream from the structure outlet, for a distance between one and three bankfull widths. The boundary can be adjusted within the eligible range to meet the greater of two criteria: 1) the upstream (ITZ) or downstream (OTZ) limit of disturbance from the pre-replacement culvert and/or construction activities, or 2) the upstream (ITZ) or downstream (OTZ) hydraulic influence of the existing culvert during flood conditions (i.e., backwater at inlet, velocity jet at outlet). The ITZ and OTZ boundaries given by criteria 1 or 2 are then adjusted upstream (ITZ) or downstream (OTZ) to the nearest grade control (e.g., pool-tail crest, step crest), if the grade control is within one bankfull width. If a grade control is further, terminate the boundary as dictated by criteria 1 or 2. At riffles, the ITZ and OTZ can be located at a prominent rib immediately beyond the criteria 1 or 2 limit, if a grade control is beyond one bankfull width's distance. Within the natural channel, data are collected within the "representative reach" zone (Figure 11).

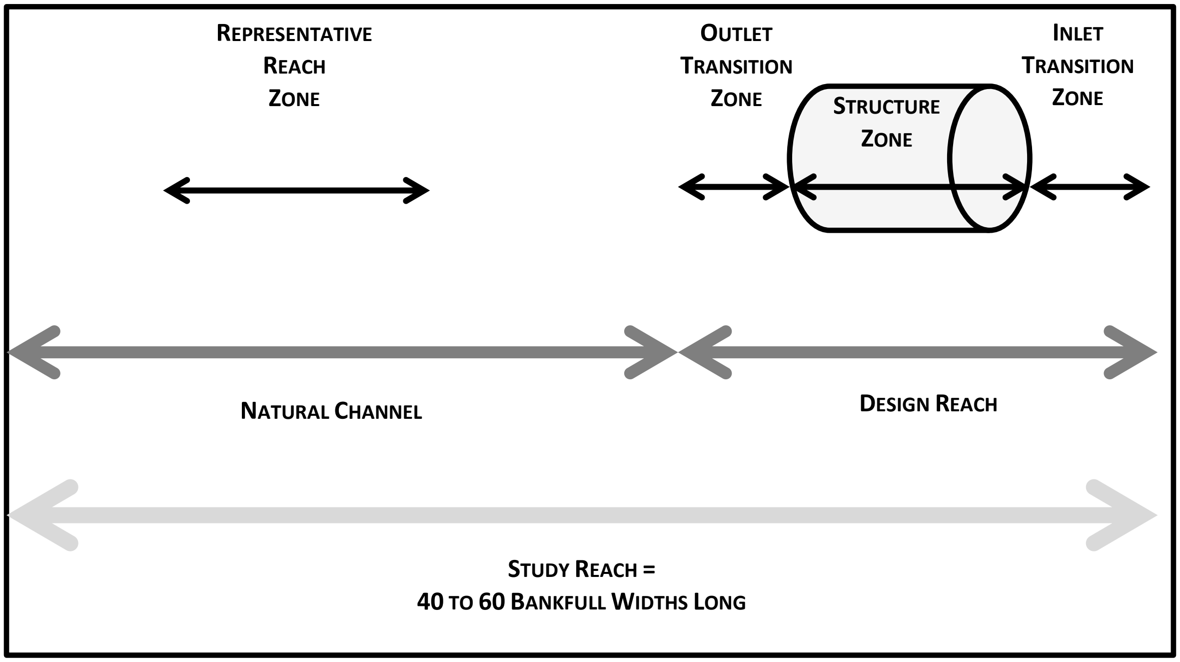


FIGURE 11: SITE ANATOMY

3.4.4 CHANNEL METRICS COLLECTED, FIELD METHODS, AND RATIONALE

Field protocol metrics measure the physical dimensions of the design and representative reach channels. Within the design channel, metrics capture the current form of the stream channel. The current form may represent the original design or the hydraulically adjusted design. Below are synopses of the levels I and II physical effectiveness monitoring protocols. 3 provides a list of metrics by protocol. Please see 4 and 5 within this section for a complete description of the levels I and II metrics, their measurements, manipulations, and approximate sample sizes. See Appendices B [Level II Draft Field Protocol] and C [Level I Draft Field Protocol] for the full 2013 levels I and II protocols.

3.4.4.1 SELECTING A REPRESENTATIVE REACH (ANALYZING CHANNEL BED GRADIENT)

There are nine very specific ways, or “degrees of freedom,” in which a stream channel may adjust to changes in discharge, sediment load, and boundary conditions: bankfull width, mean depth, maximum depth, bedform height, bedform wavelength, slope, velocity, sinuosity, and meander arc length. Slope is the least changeable of these, sometimes acting as a controlling influence on the others (Hey, 1988). It follows that, within the same stream, reaches with similar channel slopes should have similar form (channel units) if all other controlling influences are equal. Physical effectiveness monitoring takes this idea and applies the reverse logic: If one finds two similar channel slopes within the same study reach and compares the other channel dimensions (degrees of freedom), they should be similar. If channel dimensions differ, another factor besides slope is controlling channel form. The levels I and II protocols try to determine whether the crossing structure, or other design element, is influencing form by changing the boundary conditions (discharge and sediment loads are assumed consistent within a study reach).

Level II requires surveying a longitudinal profile for the entire study reach. The profile is used for calculating channel bed gradient and selecting a representative reach. Survey points are generally collected along the channel centerline, except where pools are located near the margins. Survey points should include: riffle crests, prominent ribs in riffles, step crests, the base of steps, the base of riffles/head of pools, maximum pool depths, pool-tail crests, and bend apices. In addition, the channel centerline at the inlet and outlet of the structure, left and right structure footers at the inlet and outlet, top of structure, inlet and outlet transition zone boundaries, the upstream and downstream base of road fill, and the upstream and downstream edges of road are surveyed. Survey points should be no more than one half bankfull width apart.

Similar gradients between stable grade controls (less than 25% different from adjacent gradients) are grouped together into slope segments. The slope segment(s) within the natural channel most similar in gradient(s), channel unit(s), and length(s) (both reach length and channel unit length) to those present within the design channel are selected as the representative reach(es). Of these criteria, gradient is the most important and length the least. Representative reaches do not necessarily have to be located adjacent to one another in the natural channel, nor do channel units have to be in sequence. At some sites, it will be necessary to find individual representative *channel units* within the natural channel for comparison.

Because gradients are rarely exactly equal, some leniency for differences is allowed. Similar slope segments are defined by the following criteria:

- Design channels with gradients greater than 3% should match design and representative reach gradients within ± 25%.
- Design channels with gradients less than 3%, but greater than or equal to 0.5%, should match design and representative reach gradients within ± 50%.
- Design channels with gradients less than 0.5% should match design and representative reach gradients within ± 100%.

The criteria differ by design channel gradient for mathematical reasons. When multiplying by a fraction, larger numbers produce larger numbers. Therefore, ± 25% multiplied by the design gradient produces a greater range of possible gradients for larger slopes than smaller slopes. To correct for this, and help to ensure a representative reach is selected for smaller gradients, a more lenient criterion has been set for gentle slopes. The slope categories of the gradient criteria are meant to group channels which have similar physical characteristics and processes. See section 6.1.2.1 for a discussion of the sliding scale gradient criteria. Also, see the longitudinal profile analysis section within Appendix B4 [Longitudinal Profile Analysis] for more information about selecting the level II representative reach.

The **Level I** protocol does not specify surveying a longitudinal profile, instead slope segments are delineated by ocular estimate and representative reach(es) are selected. Delineating slope segments by eye requires generalizing the channel gradient for 10s of meters. Commonly several channel units are grouped together. Similar to level II, the ideal representative reach(es) are alike in gradient, channel unit(s), and length (both reach length and channel unit length). Representative reaches do not necessarily have to be located adjacent to one another in the natural channel, nor do channel units have to be in sequence. At some sites, it will be necessary to find individual representative *channel units* within the natural channel for comparison.

3.4.4.2 CHANNEL UNITS: DEFINITIONS, COMPARISONS, AND DATA COLLECTION

Pool and riffle channel units shorter than one bankfull width in length may be skipped during data collection, unless they can be analyzed as part of a channel unit sequence (and are cumulatively longer than one bankfull channel width). Pools must have a convex shape and have a maximum depth twice the depth at the pool-tail crest. Steps must have a scour pool beneath them to be considered a step, rather than a prominent rib within a riffle.

Within each zone, measurements are tracked by channel unit and slope segment because metrics are eventually compared by channel unit (or sequence) and slope segment. For example, if the gradient within the structure (zone) is uniform (a single slope segment) and channel units are: step, pool, riffle; metrics are collected within each unit. Associated data are marked with the zone, the channel unit name and a slope segment identifier. This applies to both the **levels I and II** protocols.

Where zone boundaries truncate pools (e.g., a pool within the structure extends beyond the outlet), the entire pool should be considered as part of the zone which has the majority of its length. Where entire zones are represented by a partial segment of a pool unit, comparative analysis by zone becomes meaningless for metrics like depth and wetted width because the head and tail of the pool would be analyzed separately. Further, the portion of the pool within the structure may experience different boundary conditions than the rest of the unit. This situation is relevant to sites on the Daniel Boone NF. Ultimately, the **levels I and II** protocols are not appropriate for assessing such long, zone-spanning units. Riffles truncated by zone boundaries are analyzed separately, per zone. Where the portion of the riffle within a zone is less than one bankfull width in length, it is not analyzed. Steps at zone boundaries are analyzed as part of the zone in which the scour pool is located. This is true for both the **levels I and II** protocols.

By nature, steps are usually few per zone, short in length, and narrow in width. Therefore, sample sizes are small, which prohibits statistical testing between groups. For both the **levels I and II** protocols, data are collected at the tallest step within each design zone slope segment and each representative reach slope segment. The zone and associated slope segment are noted with the step data. Steps which form the boundary between two slope segments may be analyzed as a part of either slope segment (it is best to choose the slope segment which has the best step for comparison within the representative reach). For example, if there are two steps within two slope segments in the structure zone, data would be collected at each step. They would be separately compared with the representative step for each slope segment. See the discussion sections 6.1.1.3 and 6.2.4.

3.4.4.3 APPROPRIATE COMPARISONS: DESIGN VS. NATURAL CHANNEL

For both the **levels I and II** protocols, design zones are never compared with one another. Comparisons are always made between either entire design and representative reach zones, or portions therein (slope segments and channel units). Different design slope segments may be compared with the same representative reach, as long as the gradient criterion is met.

Because there are three variables (zone, slope segment, and channel unit) which affect how design metrics are compared with representative reach metrics, it is helpful to consider the possibilities individually; there are basically four:

A. First, the simplest example; a single slope segment *riffle* passes through all three design zones (ITZ, structure, and OTZ). The selected representative reach should also be a riffle of similar gradient and length as the one that composes the design channel. Because the same slope segment and channel unit is present within each design zone, separately the portion of the riffle within each design zone is compared with the entire representative reach riffle (Figure 12).

B. A slightly more complicated example; a single slope segment passes through all three design zones, but two (or more) channel units repeat themselves in sequence (e.g., pool, riffle, pool, riffle). In this case, a representative reach should be selected which is both similar in gradient and has the same repeating channel unit sequence. Channel units within the representative reach should be of similar lengths and of the same number as those within the design channel. Data for the channel unit sequences within each design zone are separately compared with data for the entire representative reach (Figure 13).

C. A further complicated example; a single slope segment passes through all three design zones, but more than two (non-repetitive) channel units are present within the design channel (e.g., pool, riffle, step, pool). In this case, one should select a representative reach which is similar in gradient and has the same channel unit sequence. Comparisons are made between each design zone channel unit and similar units within the representative reach (Figure 14).

   It may be possible to compare a single design pool-riffle sequence with the same sequence in the representative reach, if zone boundaries do not interrupt the sequence. Also, when the same channel unit (e.g., the pool in the above example) is repeated within a single zone and slope segment, data for that channel unit can be combined. Where repeated channel units are within different design zones or slope segments, their data are not combined.

D. The most complicated example; multiple gradients and channel units compose the design channel. When this occurs, first try to find representative reaches (one for every design slope segment) with a similar gradient sequence and channel unit sequence as present within the design channel. If a similar sequence of slope segments cannot be found, identify a separate representative reach for each gradient. For each design zone, channel units are compared individually (or by sequence when possible) with similar units in each representative reach. For some channels, it may be necessary to find individual, non-adjacent, representative *channel units* to which design channel units are individually compared. Representative channel units must be of similar gradient and length as those units within the design channel (Figure 15)

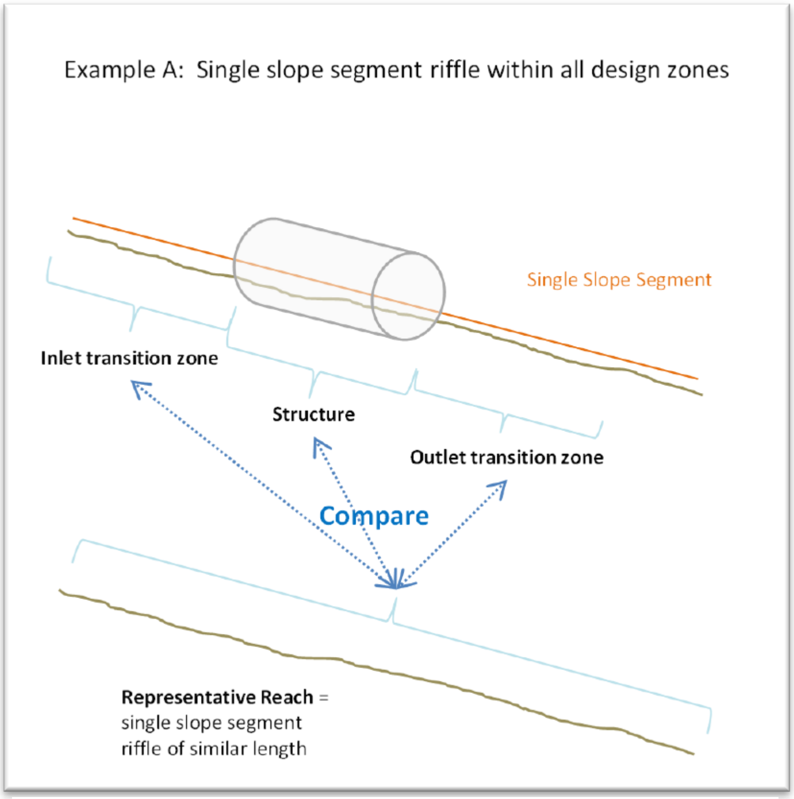


FIGURE 12: EXAMPLE A

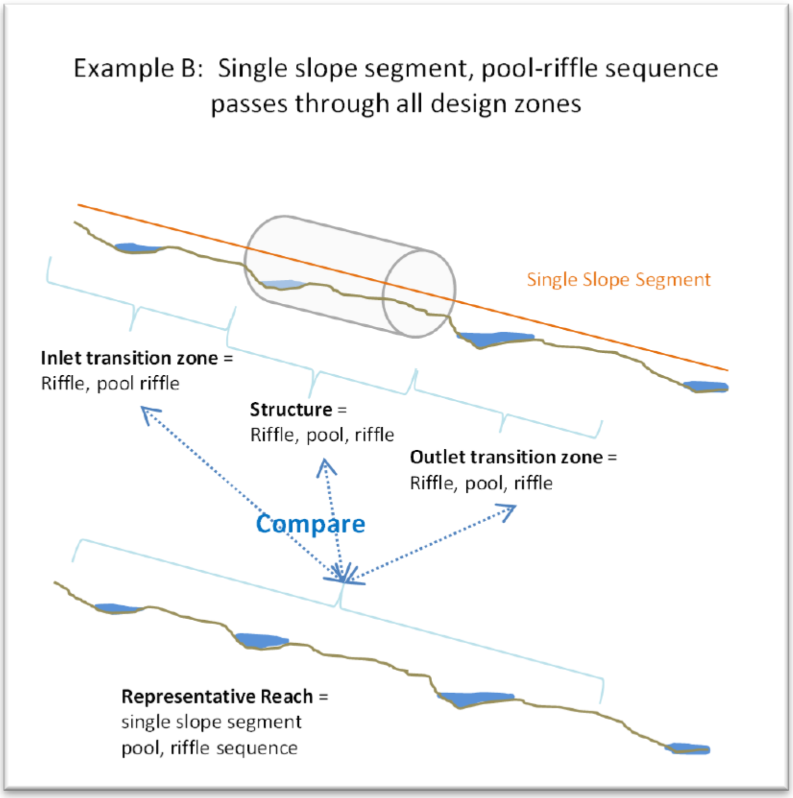


FIGURE 13: EXAMPLE B

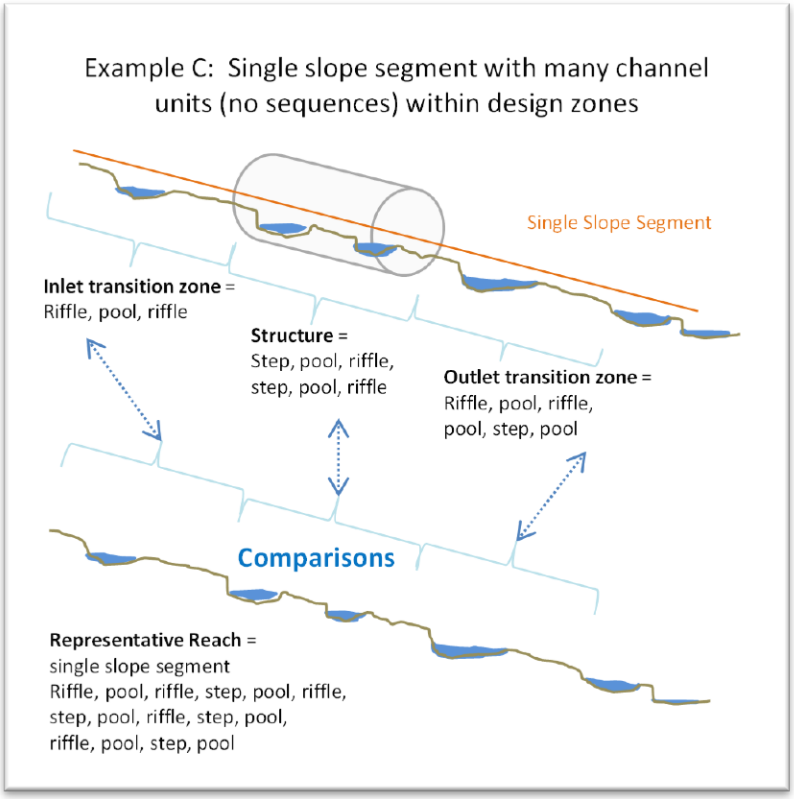


FIGURE 14: EXAMPLE C

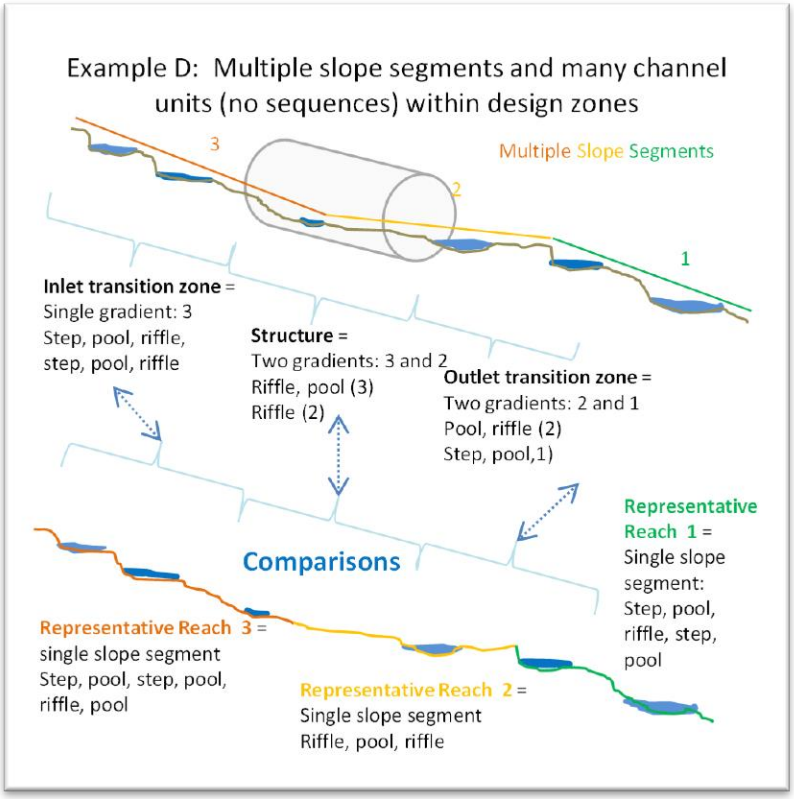


FIGURE 15: EXAMPLE D

3.4.4.4 GROUPS

Because most of the sites I evaluated were too complicated (e.g., example D), to analyze simply by zone or channel unit sequence, I created a unique identifier system which facilitated analysis and alleviated confusion. Group identifiers were essential for evaluating complex channels without immediately comparable representative reaches. I used this identifier system at simple sites as well because it made coding the data for statistical analysis easier. This identifier is called the “group” and consists of the zone, the slope segment (labeled 1, 2, 3 …), and the unit type. For example, the structure (S) riffle (R) within the steep slope segment (2) would be uniquely identified as group SR2. SR2 is then compared with the steep slope segment (2) riffle (R) within the representative reach (RR), or RRR2 group. Analyzing by group can however be a problem when channel units are very short in length because sample sizes become small and statistical tests lose power (discussed further within section 6.2.5.1). I frequently refer to group names at each site within the results and discussion sections of this thesis. The levels I and II metrics are described below by protocol. 3 shows the metrics collected by each protocol. See 4 and 5 for a more complete description of the levels I and II metrics, their measurements, data manipulations, and approximate sample sizes. Appendices B [2013 Level II Field Protocol] and C [2013 Level I Field Protocol] give further details.

3.4.4.4.1 WIDTHS

Because channel width affects flow depth and velocity, width is an indirect assessment of stream energy. These measurements evaluate the design channel width compared with the natural channel width at various stages of flow, indicate the presence/absence of banks, and show width transitions into and out of the structure. Width measurements also indicate whether the effects of an undersized structure were repaired, such as bank erosion at the inlet and outlet. Bankfull stage is an important metric because approximately bankfull flows are thought to be the channel forming, sediment transporting flows. Half bankfull stage is important because those flows are more frequent and are considered the common condition within the design channel. The wetted width should be an expression of channel width and habitat during lower flows.

Level II width measurements are collected at three stages; bankfull, half bankfull, and low flow (wetted width) (Figure 16). They are measured from the channel centerline separately to the right and left banks at each stage, except low flow. The low flow width is measured across the channel. The sampling interval is set to obtain a minimum of 20 measurements within the structure or representative reach, whichever is shorter. First, an interval equal to 20% of bankfull is considered, if the minimum sample size will not be achieved, the interval is decreased until the minimum interval (0.3 m) is reached. Setting the sampling interval this way however does create some issues. Where channel units (instead of sequences) must be compared, sample sizes can be too small for statistical analyses. Small sample size also becomes a problem within the inlet and outlet transition zones. Width measurements at all three stages are collected at riffles and pools (associated with riffles). Only bankfull width is collected at steps.

Level I specifies collecting only bankfull and low flow widths. They are measured across the channel at each stage. The sample size is five for riffle and pool channel units, regardless of zone. These units are sampled at 0%, 25%, 50%, 75% and 100% its length. Width measurements at both stages are collected at riffle and pools (associated with riffles). Only bankfull width is collected at steps.

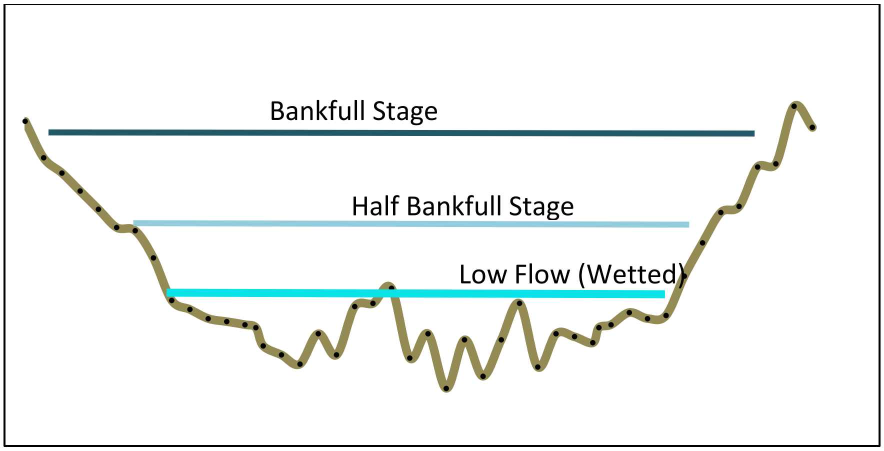


Figure 16: Stages at which Level II Width Measurements are Collected

3.4.4.4.2 Bank Continuity

Banks within the structure are important for creating micro-eddies (resting areas) and edge habitat. Banks also protect the structure foundations and the structure itself (commonly galvanized steel) from corrosion. Banks are evaluated at the half bankfull stage because flows are commonly present at this elevation.

Level II derives a quantitative measurement from the width metric at half bankfull elevation (yellow lines in 17) by counting the number of data points (left and right) *not* coincident with structure walls. Where the percentage of points not coincident with structure walls is greater than 75%, bank continuity is “good”. Where the percentage of points not coincident with structure walls falls between 50-75%, bank continuity is “fair”, and where the percentage of *not* coincident data points is less than 50%, bank continuity is “poor.” 17 shows 35% of the structure has banks at half bankfull elevation; bank continuity is “poor.” Bank continuity is assessed at riffle and pool (those associated with riffles) channel units.

Level I qualitatively estimates bank continuity (good, fair, poor) at the half bankfull elevation within the structure by eye. “Good” irregularity is where more than 75% of the structure walls (left and right) have banks at the half bankfull stage. “Fair” irregularity is where 50-75% of the structure walls have banks, and "poor" irregularity is where less than 50% of the structure walls have banks. Bank continuity is assessed at riffle and pool (those associated with riffles) channel units.

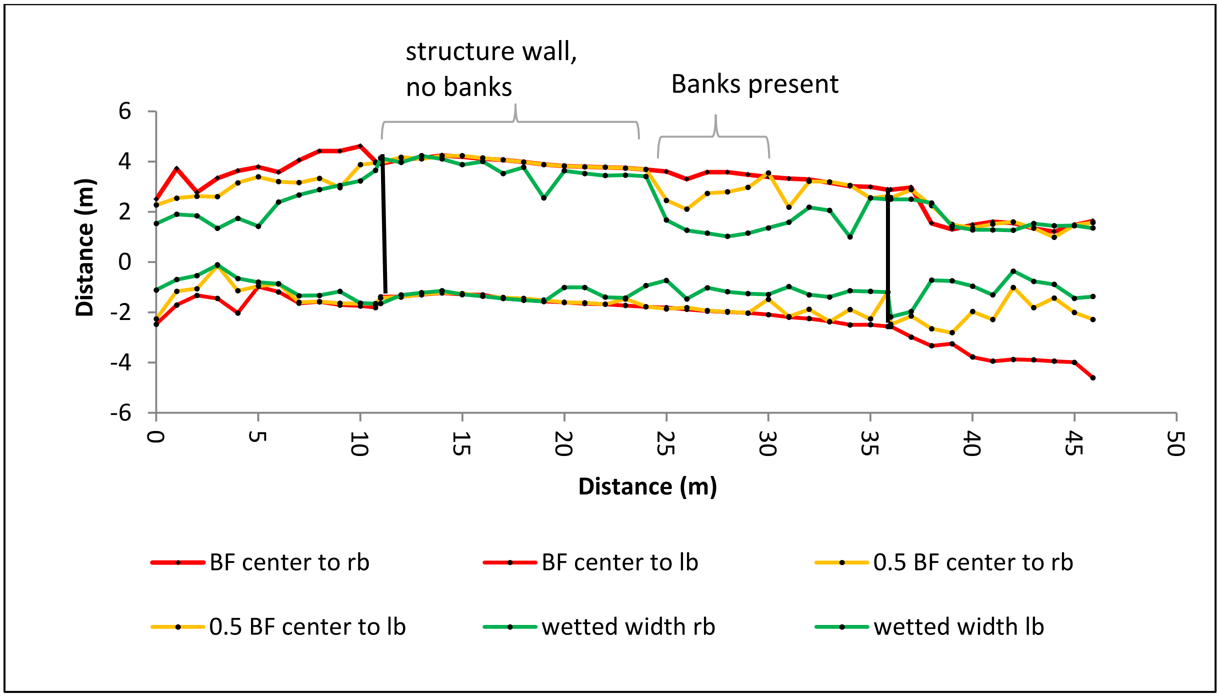


FIGURE 17: PLAN VIEW OF LOWER STILLWELL DESIGN CHANNEL WIDTHS

3.4.4.4.3 BANK IRREGULARITY

Diversity along the stream banks is important for weaker swimming and crawling species because it creates micro-eddies in which these organisms can rest as they travel against the current. Within the design channel, this metric captures both what was built, and what may have developed over time. **Level II** derives bank irregularity, or bank margin diversity, from the width measurements at half bankfull elevation. Bank irregularity is a measure of how far (absolute value) the bank deviates from the median half width (channel centerline to the bank) for the left and right banks separately (Figure 18). The absolute values of the deviations from the median (for the left and right banks) are combined into a single data set for analysis (doubling the sample size). Bank irregularity is assessed at pools (associated with riffles) and riffles.

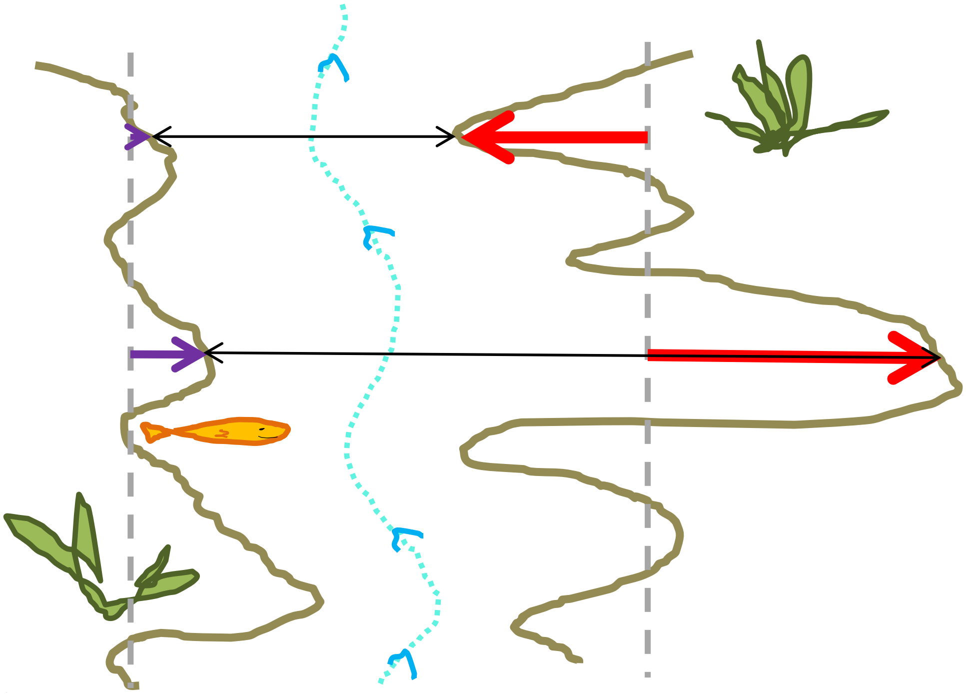


FIGURE 18: PLAN VIEW ILLUSTRATION OF BANK IRREGULARITY MEASUREMENTS

FIGURE 18 THE BROWN LINES SHOW THE LEFT AND RIGHT BANKS. THE CHANNEL CENTERLINE AND THALWEG ARE SHOWN BY THE DASHED BLUE LINE. BLACK ARROWS SHOW THE HALF WIDTH MEASUREMENTS FROM THE CHANNEL CENTERLINE TO THE BANKS. THE DASHED GREY LINES SHOW THE MEDIAN RIGHT AND LEFT BANK HALF WIDTHS. THE RED ARROWS SHOW THE RIGHT BANK DEVIATIONS FROM THE MEDIAN (BANK IRREGULARITY MEASURE). THE PURPLE ARROWS SHOW THE LEFT BANK DEVIATIONS FROM THE MEDIAN. THE ARROWS FACING TOWARDS THE CHANNEL CENTERLINE HAVE NEGATIVE VALUES. THE ARROW FACING TOWARDS THE BANK HAS A POSITIVE VALUE. THE ABSOLUTE VALUES OF THE BANK IRREGULARITY MEASURES ARE USED TO EVALUATE BANK IRREGULARITY. LEFT AND RIGHT BANK IRREGULARITY MEASURES ARE COMBINED INTO A SINGLE DATA SAMPLE.

The level I protocol measures bank margin diversity on a qualitative scale (good, fair, poor), by ocular estimate. “Good” irregularity is where bank undulations or protrusions (0.3 - 0.6 m) are less than 2 channel widths apart (irregular banks) for both banks over the entire zone. “Fair” irregularity is where spacing equals 2 channel widths, and “poor” irregularity is where spacing is greater. The left and right banks are evaluated as if they were a single, continuous bank. Figure 19 depicts categorizing bank irregularity by the level I protocol. Bank irregularity is assessed at pools (associated with riffles) and riffles.

FIGURE 19: CATEGORIZING BANK IRREGULARITY BY THE LEVEL I PROTOCOL METHOD

FIGURE 19 shows Sparks Brook, looking upstream at the left and right banks from the channel centerline. The red dashed line is the approximately the bankfull channel width. The yellow lines highlight bank irregularities at the half bankfull elevation. Bank irregularity is categorized by noting if the majority of the bank protrusions between 0.3 and 0.6 m in size occur within two bankfull widths apart, at two bankfull widths apart, or greater than two bankfull widths apart. The left and right banks are analyzed as if they were connected and continuous over the length of the reach. This channel reach would be categorized as "irregular" because irregularities (highlighted with yellow lines) are spaced closer than two lengths of the red dashed line.

3.4.4.4.4 BED IRREGULARITY

Bed irregularity creates important micro-habitat for bottom dwelling aquatic organisms such as macro-invertebrates and sculpin fishes. The bed irregularity metric is derived from cross section data. A minimum of 20 bed elevations are measured within the wetted width. The sampling interval however, should never be less than 10 cm. Technically, bed irregularity is a measure of how far each measurement deviates from the median bed elevation below bankfull (similar to bank irregularity) (Figure 20). Within the design channel, the measured bed may have adjusted since construction, or may be the original material.   Cross sections also provide a visual indicator of the channel shape, which can be qualitatively compared between the design and natural channels. Bed irregularity is only a **level II** metric. It is assessed at pool (associated with riffles) and riffle channel units.

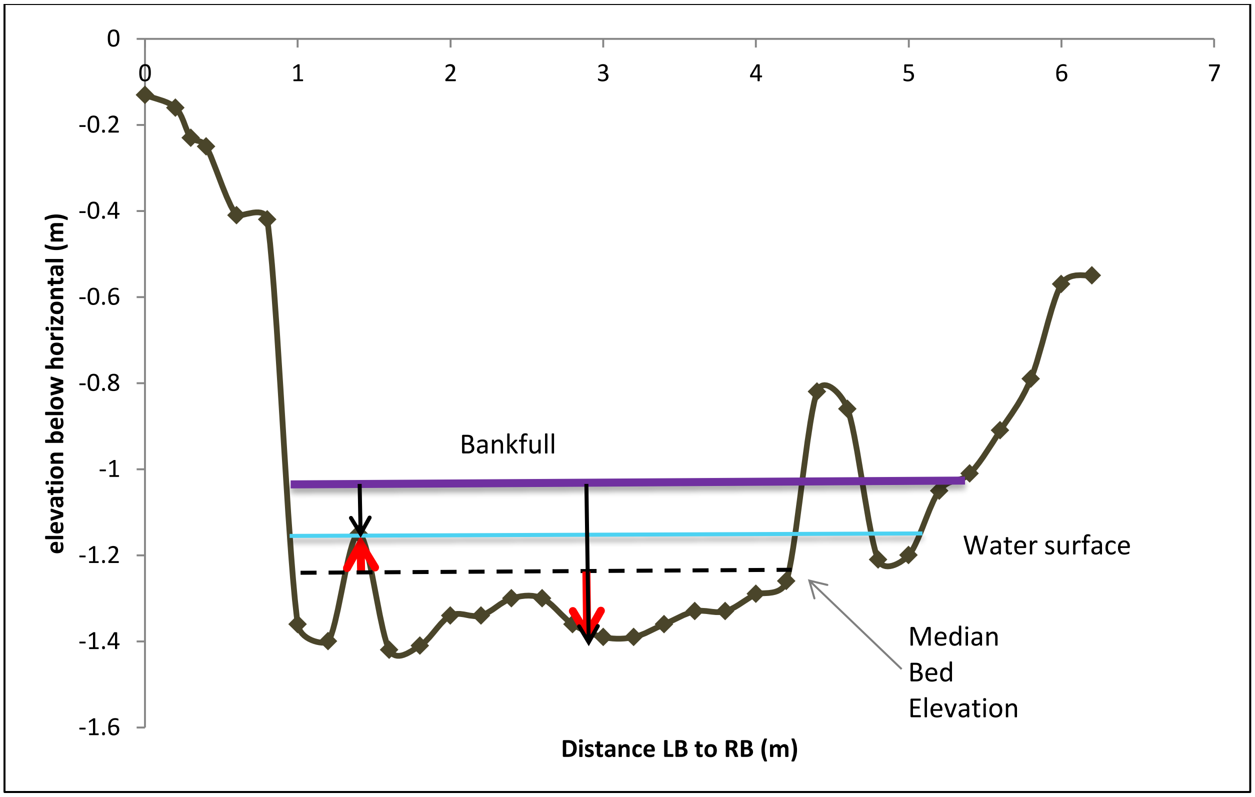


Figure 20: Downstream cross-sectional view of bed irregularity at Lower Stillwell, cross-section 1

15BFigure 20 is a typical channel cross section. The purple line represents bankfull stage. The dashed line is the median bed elevation below bankfull stage; blue line is the water surface; black arrows show the distance from bankfull stage to the bed; red arrows show the distance from the median bed elevation to the bed surface (bed irregularity measure). Arrows which point up have a positive sign. Arrows which point down have a negative sign. The absolute values of the irregularity measures are evaluated.

3.4.4.4.5 Maximum Depths

Stream depth reflects the combined influences of channel width, gradient, large obstructions, and local hydraulics. Stream depth is important because it is related to water velocity as well as habitat. The metric detects both areas of excess scour and insufficient depth. Excess scour may indicate insufficient energy dissipation, which can eventually destabilize the structure and road above. Shallow regions may be indicative of overly permeable substrates or a poorly defined low-flow channel.

Within the **level II** protocol, the maximum depth is collected at every sampling station where width measurements are taken. The sampling interval is set to obtain a minimum of 20 measurements within the structure or representative reach, whichever is shorter. First, an interval equal to 20% of bankfull is considered, if the minimum sample size will not be achieved, the interval is decreased until the minimum interval (0.3 m) is reached. Setting the sampling interval this way however does create some issues. Where channel units (instead of sequences) must be compared, sample sizes can be too small for statistical analyses. Small sample size also becomes a problem within the inlet and outlet transition zones.

The **level I** protocol also specifies collecting a maximum depth measurement at each station where width measurements are collected. The sample size is five for each channel unit, regardless of zone. The channel unit is sampled at 0%, 25%, 50%, 75% and 100% its length.

3.4.4.4.6 Coarse Fraction of the Gradation or Largest Particles

Bed material should be sized within the design channel so as to maintain equal mobility with the representative reach. D50 particles are the median sediment size within the bed. In gravel and cobble bed streams (generally pool-riffle), the D50 should be mobilized during approximately bankfull floods (although this is not always true) (Bunte et al., 2010).

The surface D84 is used to compare the design bed mobility with that in the natural channel. D84 is the size of particle larger than 84% of all particles found on the bed surface, mobile only during larger flood flows. It is assumed that when these particles are mobile, smaller bed particles are also mobile (Stream Simulation Working Group, 2008); thereby assessing the continuity of sediment transport through the design channel for most particle sizes.

Within the **level II** protocol, the D84 is measured by pebble count within riffles. An adjustable vertices sampling frame (Bunte and Abt, 2001) is used to ensure the unbiased selection of particles. The spacing of vertices within the frame is altered so that each particle intersects with only one vertex. The frame is placed on the channel bed and the particle located directly beneath each vertex is measured. The frame is moved along evenly spaced transects oriented perpendicular to the flow. Two hundred fluvially transported particles are measured (b-axis only).

The pebbles greater than the D50 of the full distribution are extracted. This subset is referred to as the "coarse fraction." The D50 of the coarse fraction is approximately equal to the D75 of the full distribution, which is considered (by this study) an acceptable approximation of the D84. D84 was chosen by convention; the D95 could have been assessed instead. The goal is to simply compare some of the largest, least mobile particles in the channel bed. Sub-sampling the full distribution in this way makes statistical analysis easier because the other metrics are scored by comparing medians, and testing specific (non-quartile) percentiles is not commonly done.

The **Level I** protocol approximates the D84 by measuring 9 to 11 of only the largest surface particles per riffle. At random, the largest particles are selected and their b-axes are measured.

3.4.4.4.7 STEP LENGTH

The step length metric is a geometric indicator of how the step dissipates energy. The length of the step is the longitudinal distance from its maximum extent upstream to its maximum extent downstream. Step length is measured in the same way for both the **levels I and II** protocols.

3.4.4.4.8 STEP HEIGHT

The step height metric is a geometric indicator of the potential energy dissipated. It is also an important metric because overly tall features can block aquatic organism passage. Step height is measured from the flat water surface at the step crest to the water surface at the base of the step. Step height is measured in the same way for both the **levels I and II** protocols.

3.4.4.4.9 STEP PARTICLE SIZE

Constructed steps should be immobile. Undersized step particles can be indicative of features at risk of failure. The intermediate axes (b) of the largest step particles are measured in place. Step particle size is measured in the same way for both the **levels I and II** protocols.

3.4.4.4.10 RESIDUAL POOL DEPTH (ASSOCIATED WITH STEPS)

Residual pool depth is an indication of the hydraulic effectiveness of a step. Steps should concentrate flow enough to maintain adequate pool depths for aquatic organism passage. This metric is also indicative of pool habitat during low flow conditions, which is important to pool-dwelling species. The vertical distance from the maximum depth of the pool to the bed at the pool tail crest is calculated by measuring the distance from the maximum depth to the water surface (A), and the distance from the pool tail crest to the water surface (B). A-B = the residual pool depth. The residual pool depth is measured in the same way for both **levels I and II** metrics.

TABLE 3: PHYSICAL MONITORING METRICS BY PROTOCOL

Metrics	Level II	Level I
Width at bankfull stage	xx	x
Width at half bankfull stage	x	
Width at low flow (wetted width)	xx	x
Maximum depth	xx	x
Bank irregularity	x	*
Bed irregularity	x	
Coarse fraction of the gradation (diameter)	x	
Largest particles (diameter)		x
Step height	x	x
Step length	x	x
Step particle size (largest)	x	x
Residual pool depth at steps	x	x
Bank Continuity	x	*
** = ocular estimate, x = measured, xx = level II sample size is much larger than that for level I*		

TABLE 4: LEVEL II METRICS, MEASUREMENT METHODS, MANIPULATIONS, AND SAMPLE SIZES

Measurements and Units	Measurement Method	Data Manipulation for Each Metric		
		Full Widths n= 20 (min) within rep reach or structure	Bank Irregularity n = 40 (min) within rep reach or structure	Bank Continuity n = 40 (min) within rep reach or structure
channel centerline to right bank at bankfull (m)	Place rebar at the channel centerline. At each stake, measure up from the water surface to the bankfull elevation. Use alligator clips to hold two 100 m measuring tapes; clip them at the bankfull and half bankfull elevations. Use laser distance meter at the channel centerline to find the horizontal distance to each bank (ensure the laser target is hitting soil/rock, not vegetation. Measure with a tape from the channel centerline to the edge of water (right and left).	Subtract the measured rocks, logs, and mid-channel bars from each half-width (channel centerline to bank). Combine left and right half-widths.		
channel centerline to left bank at bankfull (m)				
channel centerline to right bank at half bankfull (m)			Using the width data at half bankfull; for each half width (obstructions removed) calculate the median (per group). Subtract the median from the half width measurement (deviation from the median). Take the absolute value of the deviations from the median.	Using the plot of half widths at half bankfull stage, count the data points co-located with the structure wall. Subtract from the total number of measurements within the structure to find the number of measurements at a constructed bank. Calculate the % of measurements at banks.
channel centerline to left bank at half bankfull (m)				
channel centerline to right edge of water (m)				
channel centerline to left edge of water (m)				

Metrics	Measurements and Units	Measurement Method	Data Manipulations	Approximate Sample Size
Maximum Depth	The maximum channel depth (water surface to bed) (m)	At each width measurement station, find the maximum depth at that channel cross section. Use a stadia rod to find the depth.	none	n = minimum of 20 within the structure and representative reaches
Coarse Fraction	Pebble count (mm)	Do a pebble count by using an adjustable vertices sampling frame. Set the vertices wide enough so that a minimal amount of particles intersect multiple vertices. Measure the length of the riffle or cascade unit. Set transects perpendicular to channel flow at the interval necessary to obtain the minimum sample size. Measure the b-axis of each particle beneath a vertex. Relocate the frame until 200 particles are measured.	Calculate the D50 of the pebble count distribution. Subset particles greater than, or equal to the D50; this is the “coarse fraction.” Calculate the median of the coarse fraction (should be about equal to the D75 of the full distribution).	n = minimum of 200 for the full distribution.

Metrics	Measurements and Units	Measurement Method	Data Manipulations	Approximate Sample Size
Bed Irregularity	Cross sections (m)	Place a rebar stake above bankfull elevation on either side of the channel so that a straight line between the stakes is perpendicular to flow. Using alligator clips, fasten the string to each stake. Fasten a metric measuring tape to each stake, near and parallel to the string. Place a bubble level on the string, and level the string. Determine the measuring interval necessary to obtain the minimum sample size within the wetted width. From the left bank stake, measure from the string to the ground. Continue recording the station and distance to ground, on the determined interval, across the channel to the right bank stake. Mark the edges of water and thalweg stations. Complete 2 cross sections for each channel unit. Capture the widest channel at the inlet transition and outlet transition zones.	The distance from the water surface to the bankfull elevation is known; the distance from the horizontal string to the water surface is known. Calculate the elevation of bankfull relative to the string. Transform the measured distance from string to ground into the distance from bankfull to ground. Calculate the median of these distances. Subtract the distance from bankfull to ground from the median (deviations from the median). Take the absolute value of the deviations.	n = minimum of 20 within the wetted width

Metrics	Measurements and Units	Measurement Method	Data Manipulations	Approximate Sample Size
Step Length	Step length (m)	Measure the horizontal distance from the furthest upstream edge of a step particle to the furthest downstream edge.	None	n = 1
Step Height	Step height (m)	Measure the vertical distance from the flat water surface at the step crest to the water surface at the base of the step at 25%, 50%, and 75% the width of the step.	None	n = 3
Step Bankfull Width	Step width (m)	Measure across the channel at the step crest at the bankfull elevation	None	n = 1
Residual Pool Depth	Step pool depth (m)	At the scour pool below the step, measure the distance from the maximum pool depth to the water surface (A). At the pool tail crest, measure the distance from the bed to the water surface (B). A-B = the residual pool depth.	None	n = 1
Maximum Step Particle Size	Step particle size (mm)	Measure (in place) the intermediate (b) axis of 5 to 9 of the largest step particles with a measuring tape.	None	n = 5 to 9

Table 5: Level I metrics, measurements, methods, manipulations, and sample sizes

Metrics	Measurements	Measurement Method	Data Manipulations	Approximate Sample Size
Full Widths At Bankfull Stage	Across the channel at the bankfull stage	Using a pocket rod, measure up from the water surface to the elevation of bankfull stage. Stretch a measuring tape across the channel at this elevation. Record the width at 5 stations, spread evenly along the length of each channel unit. At the same stations, record the wetted width.	Subtract the measured rocks, logs, and mid-channel bars from each width. Calculate quartiles.	n = 5
Full Widths At Low Flow (Wetted) Stage	Across the channel at the low flow (wetted) stage			n = 5
Bank Irregularity	Ocular estimate	Estimate, over the reach (banks assessed together), bank undulations (0.3-0.6 m in size) less than (irregular), exactly (varied), or greater than (regular) Two bankfull channel widths apart.	None	NA
Bank Continuity	Ocular estimate	Categorize the length of the structure walls with banks at the half bankfull elevation (≥ 75% “good,” 50% to 75% “fair,” < 50% “poor”).	None	NA
Maximum Depth	The maximum channel depth (water surface to bed)	For each width measurement station, find the maximum depth at that channel cross section. Use a stadia rod to find the depth.	Calculate quartiles.	n = 5
Largest Particles	Measured particles	Over the length of each riffle and cascade channel unit, measure the intermediate (b) axis of the largest particles until the minimum sample size has been acquired.	Calculate quartiles.	n = 9 to 11

Metrics	Measurements	Measurement Method	Data Manipulations	Approximate Sample Size
Step Length	Step length	Measure the horizontal distance from the furthest upstream edge of a step particle to the furthest downstream edge.	None	n = 1
Step Height	Step height	Measure the vertical distance from the flat water surface at the step crest to the water surface at the base of the step at 25%, 50%, and 75% the width of the step.	Calculate quartiles.	n = 3
Step Bankfull Width	Step width	Measure across the step crest at the bankfull stage	None	n = 1
Residual Pool Depth	Step pool depth	At the scour pool below the step, measure the distance from the maximum pool depth to the water surface (A). At the pool tail crest, measure the distance from the bed to the water surface (B). A-B = the residual pool depth.	None	n = 1
Maximum Step Particle Size	Step particle size	Measure (in place) the intermediate (b) axis of 5 to 9 of the largest step particles with a measuring tape (mm).	Calculate quartiles.	n = 5 to 9

4 ANALYSIS METHODS

The analyses described in the following sections were done in order to create effectiveness summary tools for levels I and II protocols (objective 2) as well as to compare the protocols (objective 3). Analyses associated with testing and improving the levels I and II protocols themselves (objective 1) were described in the field methods section (3) above.

The R version 3.0.0 statistical software (R Core Team, 2013) was used for calculating bootstrapped confidence intervals and executing statistical tests. R and Microsoft® Excel ®were used to plot data. Excel ®was used to manipulate raw data and as a platform for the level I and level II effectiveness summary rubrics.

4.1 ANALYSIS FOR OBJECTIVE 2: CREATE AN EFFECTIVENESS SUMMARY TOOL

Determining the effectiveness of a design requires systematically analyzing the metrics and combining the results into a single assessment. It should be noted that the structure of the summary tools presented below was initially conceptualized by Cenderelli, Lang and Weinhold in 2010, before this study became a thesis project. One of the objectives of this thesis is to develop their concept into functional levels I and II summary tools.

The level I and level II rubrics are fundamentally structured in the same way. Both rubrics compare each design zone with the representative reach (per metric, per group). Groups are evaluated and summarized separately so that specific design flaws can be related to the crossing morphology. Each group comparison is scored based on the degree of similarity. Each metric is weighted so that its influence on the total group score is relative to how important the physical channel dimensions are to maintaining ecological continuity through the crossing. Metric scores are summed and the total group score is compared with the maximum possible number of points. Evaluation scores equal to or greater than 75% of the total possible points are considered “similar” to the representative reach, scores between 50% and 75% are “questionably” similar, and scores less than 50% are “dissimilar.” Mathematically, the rubric evaluation method can be described as follows:

$$\begin{gathered}
\textbf{(score = 5, 3, or 1)(metric weight) = metric score} \\
\boldsymbol{\sum}\ \textbf{metric scores = group score} \\
\boldsymbol{\sum}\ \textbf{(score = 5) (metric weight) = total possible points} \\
\textbf{group score/total possible points = group evaluation score (similar, questionable, dissimilar)}
\end{gathered} \tag{1}$$

During development, metrics were included or removed based on how meaningful they seemed. Different scoring and weighting schemes were explored. Scoring methods and weights (for two metrics) were iteratively adjusted after comparing the rubric effectiveness results with plots, photos and observations at test sites.

4.1.1 Test Sites: Lower Stillwell and Others

The levels I and II rubrics were initially developed by using data from three test sites: Lang’s data from a site in California, Weinhold’s data from a site in Colorado, and my data from the Lower Stillwell site in Oregon (Siuslaw NF). Lower Stillwell was chosen because the design channel is simple; a single gradient, long riffle extends from the top of the inlet transition zone to the bottom of the outlet transition zone. The simple design allowed me to easily compare my observations with rubric results.

When the levels I and II rubrics seemed to perform reasonably well on the three test sites, they were applied to a total of 9 other sites. Although no further changes to the rubric were made based on these results, suggestions for improvements are summarized in Table 64, Table 65, and 66 (section 7) of the thesis. Three additional sites (where the levels I and II protocols were terminated because no representative reach could be identified) are also qualitatively discussed.

4.1.2 Level II

In total, 7 versions of the level II rubric were created. Each version was evaluated with the Lower Stillwell site data. Level II rubric results were compared with boxplots, histograms, site photos and observations. Where rubric results differed from expected results, the rubric was adjusted. Adjustments to the rubric included changing the statistical analysis method, altering metric weights, and removing/adding metrics. The following sections describe the development of the level II rubric (see the level II rubric spreadsheet in Appendix E2 [Level II Summary Rubric]).

4.1.2.1 Metrics Included

4.1.2.1.1 Redundant Metrics

Although field metrics are thought to be meaningful measurements of physical similarity between the design and natural channels, some metrics may be redundant. Metrics which are too similar to one another will effectively penalize, or aid, a site's rubric score twice. For example, do the metrics of width at low flow versus depth, actually provide the same information? Are the coarse fraction of the gradation and bed irregularity really the same characteristic? Potentially redundant metrics were observed across sites to evaluate whether they scored the same for all or most sites.

4.1.2.1.2 The "Short" Rubric

A level II "short" rubric was created in order to evaluate the effect of the wetted width and bed irregularity metrics on the overall evaluation. These metrics are weighted very low (0.25), because they are not considered critical elements of an effective design. Removing them from the protocol would save hours of field time. The "short" rubric results were compared with the full rubric results at several sites.

4.1.2.2 METHODS OF SCORING, STATISTICAL ANALYSES

Most of the level II metrics are scored by statistical comparison. The exceptions are bank continuity and metrics associated with steps (discussed in section 4.1.2.2.4). During development, several different statistical measures were researched and tried before settling on the most appropriate scoring method. They are described in section 4.1.2.2.5.3.

Before applying statistics, data for each metric were first explored by data plots. The plots helped to better understand the data as well as illuminate erroneous values. The following raw data plots were made for each metric by zone:

- width versus distance (at bankfull, half bankfull, and wetted width elevations)
- depth versus distance
- cross sections
- percentile versus sediment size

Boxplots, histograms and qq residual plots (by group) were also created. All metric data appear to be non-parametric, or at least questionably parametric. See data plots for each analyzed site in Appendix A [Site Data].

4.1.2.2.1 QUARTILES FOR ANALYSES; WHICH PART OF THE DISTRIBUTION TO COMPARE?

Data were shown to be non-parametric, sometimes heavily skewed, in histogram plots. Therefore, the quartiles of each metric distribution are better population descriptors than the mean value. In early versions of the level II rubric, for some metrics, it seemed meaningful to focus on the tails of the distribution (the 25th or 75th quartiles). For example, if the 25th quartile of maximum depth data was analyzed, the shallowest depths would be compared. However, statistical tests of distribution tails are less common than those which test central tendency. Statistical tests which compare medians are relatively simple, and by using a single, standard test across metrics, the rubric is most user-friendly. It was decided the median statistic would be a meaningful summary of each metric, and scores should be based around it.

The coarse fraction of the gradation metric is also analyzed by its median, but the full distribution is subsampled in order to test the tails. We are most interested in the gradation tails (specifically the upper tail) because these values (the “coarse fraction”) yield information about sediment continuity for most particles. During the design process, the D84 within the representative reach is used to size the design particles for equal mobility with the natural channel. The coarse fraction is defined as all particles greater than the D50 of the full distribution. When the D50 of the *coarse fraction* is compared between groups, approximately the D75 of the full distribution is actually compared. Because it is statistically practical to compare medians, we consider the D75 to be an acceptable proxy of the D84.

4.1.2.2.2 WILCOXON RANK-SUM TEST

The Wilcoxon Rank-Sum test (a.k.a the Mann-Whitney U) of distributions is a fairly simple procedure which can be done by hand within an Excel workbook, or easily with a statistical software package. The test can be used with non-parametric data, which makes it an appropriate method of scoring the level II metrics. A two-sided Wilcoxon test evaluates the null hypothesis that the medians of both groups compared are equal, meaning the probability of drawing a larger observation from population A is the same as drawing a larger observation from population B. A one-sided Wilcoxon test evaluates the null hypothesis that the medians are shifted from one another by a specified amount (Ott and Longnecker, 2001). For both one and two-sided tests, the Wilcoxon Rank Sum evaluates whether values from one population tend to be smaller or larger than the other (Conover, 1999) (not population shape). The test assumptions are: 1) independent samples, and 2) distribution shapes between samples are the same (Ott and Longnecker, 2001). Based on data collection methods, assumption 1 is most likely met; samples are independent from one another because they are collected in separate zones at meaningful intervals. Distributions are visually evaluated with plotted histograms; assumption 2 is assumed to be met when group distributions (histogram plots) appear similar (both unimodal, skew is acceptable) (B. Bird, pers. comm., 2013). Where distributions are questionably similar, test results are more critically evaluated and may be overridden (see section 0). Because for most metrics, the population median is of interest, the Wilcoxon Rank-Sum test was chosen as the analysis method for scoring the level II metrics. Further, its simple, straight-forward and intuitive nature is appealing.

The Wilcoxon Rank-Sum test transforms non-parametric data into a normal distribution by ranking the data. The test is performed by combining the two groups of data (*X* and *Y*), then ordering and ranking all data values. The data are then separated back into their two groups. When there are few, or no ties, the rank sum of the group with the lesser sum is used as the test statistic. Ranks for tied data are averaged and the remaining data are ranked as if averaged ranks were not given. Let $R(X_i)$ be the rank of the i^{th} sample from group *X*.

$$\boldsymbol{U = \sum_{i=1}^{n} R(X_i)} \tag{2}$$

When many ties exist, the mean is subtracted from the test statistic *U* and the remainder is divided by the standard deviation. Let *n* be the number of samples from group *X*, and *m* be the number of samples from group *Y*. Let $N = n + m$.

$$\boldsymbol{U_1 = \frac{U - n\frac{N+1}{2}}{\sqrt{\frac{nm}{N(N-1)}\sum_{i=1}^{N} R_i^2 - \frac{nm(N+1)^2}{4(N-1)}}}} \tag{3}$$

For large samples (≈ n ≥ 20) U has an approximately Gaussian distribution and,

$$\mathbf{z} = \frac{U - m_U}{\sigma_U}$$

(4)

where $\mathbf{m_u}$ is the mean,

$$m_{U=}\frac{n\,m}{2}$$

(5)

and $\boldsymbol{\sigma_U}$ is the standard deviation (Conover, 1998).

$$\sigma_U = \sqrt{\frac{nm\;(n+m+1)}{12}}$$

(6)

One can look up the probability (p-value) of getting a more extreme U (given the null hypothesis is true) for various significance levels (α) in tables of the normal (z) distribution (Wilcoxon, 1945; Ott and Longnecker, 2001).

For small samples (≈ n < 10) and groups with many ties, the exact U (or W) distribution should be calculated, and exact p-values figured. Exact p-values for the Wilcoxon Rank-Sum test are calculated in R by the Shift Algorithm (Streitberg and Röhmel, 1986). Using the "ExactRankTest" package in R, exact p-values were always calculated for this project, no matter how large the sample size.

At riffles, bank irregularity and maximum depth are tested with a one-sided Wilcoxon Rank-Sum (this does not penalize the design zone if it is more irregular or deeper than the natural channel). For pools associated with riffles, bank irregularity alone is tested with a one-sided test (deeper pools may indicate excessive scour and dissimilar hydraulics). The Wilcoxon Rank-Sum R scripts are included within Appendix G [Wilcoxon Rank-Sum R Code Used].

The p-values are used to score each metric by comparing them with ranges of alpha levels (see section 4.1.2.2.3). Initially, a range of alpha values was subjectively chosen, and the three test sites were analyzed. After evaluating those results, it was clear that adjustments to the range of alpha values might be necessary because evaluation results for the test sites were either “similar” or “dissimilar,” when in reality an effectiveness gradient exists.

A small sample size affects statistical test results because too little information is available for comparing groups. If samples are of inadequate size, the null hypothesis may be falsely accepted (a type II error), leading to an inaccurate interpretation of the effectiveness of the stream-crossing design. Some metrics (width at bankfull stage, width at half bankfull stage, wetted width, depth, and bank irregularity) base a statistically significant sampling interval on the length of the structure or representative reach (whichever is shorter). For these metrics, sample size can be particularly small (less than 10) within the inlet and outlet transition zones, and where channel units are very short in length. Where sample sizes are small, data are evaluated qualitatively and scored. Sampling these metrics by channel unit instead is, however, time prohibitive. Sample size appears to be consistently adequate (n>10) for the coarse fraction of the gradation, bank irregularity, and bed irregularity metrics, because they are sampled by channel unit, or sample sizes are doubled by bank (left and right). The bank continuity metric does not require a statistical test of two data populations.

4.1.2.2.3 SCORING SCHEMES FOR LEVEL II

The level II scoring method was altered to analyze each metric by comparing p-values associated with the Wilcoxon Rank-Sum test with various alpha level intervals (able 6). For the “fair” score of 3, the p-value must fall within the designated alpha interval. P-values which fall below the lower boundary score “poor,” or 1. P-values which fall above the upper boundary will score “good,” or 5. The scoring schemes used for analysis are:

TABLE 6: LEVEL II SCORING SCHEMES APPLIED

Scheme for a score of 3	Notes
$0.001 \le p \le 0.1$	Easy to get a 3, hard to get a 5
$0.001 \le p \le 0.05$	Easy to get a 3, ok to get a 5
$0.01 \le p \le 0.05$	Hard to get a 3, ok to get a 5
$0.01 \le p \le 0.1$	Easy to get a 1, easy to get a 3, hard to get a 5
$0.05 \le p \le 0.1$	Very easy to get a 1, ok to get a 3, hard to get a 5

The summary rubric evaluation results for each scoring scheme were compared between sites. The rubric version with the most consistently reasonable results is the recommended method, presented within the results section (5.2.1.1), along with the level II effectiveness evaluations for each site (5.2.1.2). See Appendix A [Site Data] for level II summary rubric results by all scoring schemes.

4.1.2.2.4 NON-STATISTICAL SCORING METHODS WITHIN THE LEVEL II RUBRIC

Bank continuity is assessed from the plotted width at half bankfull stage. The metric is only relevant to the structure zone. Bank continuity is scored as follows:

- “Good” score of 5 = more than, or equal to 75% of the width measurements at half bankfull stage do not intersect the structure walls.
- “Fair” score of 3 = between 50% and 75% of the width measurements at half bankfull stage do not intersect the structure walls.
- “Poor” score of 1 = Less than 50% of the width measurements at half bankfull stage do not intersect the structure walls.

Steps are not evaluated statistically because sample sizes are small. Instead, where step metrics have only one measurement (channel unit length, bankfull width, and residual pool depth metrics), they are scored by a percent-difference criteria. Specifically, the difference between the design and natural channel measure is divided by the natural channel measure to calculate the percent difference. Then, for each metric scored in this manner, the percent difference is compared with a criterion:

- Where the design *channel unit length* is different from the natural channel by less than 25%, the score is “good” (5), where the percent difference is between 25% and 50%, the score is “fair” (3), and where the percent difference is greater than 50%, the score is “poor” (1).
- Where the design *bankfull width* is different from the natural channel by less than 10%, the score is “good” (5), where the percent difference is between 10% and 30%, the score is “fair” (3), and where the percent difference is greater than 30%, the score is “poor” (1).
- Where the design *residual pool depth* is different from the natural channel by less than 25%, the score is “good” (5), where the percent difference is between 25% and 50%, the score is “fair” (3), and where the percent difference is greater than 50%, the score is “poor” (1).

Where more than one measurement is collected (maximum particle size and step height metrics), the design median is compared with the representative step data range. Similar to how other level I channel units are scored, if the design median falls within the 25th and 75th representative quartiles, the metric is scored 5. If the design median falls within the minimum and maximum values, the metric is scored 3. And, if the design median falls outside of the range of representative data, the metric is scored 1.

4.1.2.2.5 PRIOR DATA EXPLORATION

Before settling on the Wilcoxon Rank-Sum test for scoring metrics, several other statistical scoring methods were tried. I outline them here as a reference, should future editions of the level II summary rubric (or others working on similar projects) consider them.

4.1.2.2.5.1 OVERLAPPING CONFIDENCE INTERVALS

Bootstrapped confidence (90%, 95%, and 99%) intervals were calculated about the 25th, 50th, and 75th quartiles for each metric. These confidence intervals were calculated for both design and representative reach data. Where confidence intervals between a design and a representative group overlapped, “similarity” was inferred. The degree of similarity could be judged by which confidence limits were overlapping. For example, overlapping 90% confidence intervals (most narrow interval) would receive a “similar” rating, while no overlap would receive a “poor” rating.

Bootstrapping allows one to make inferences from data without making distributional assumptions about the data. This is especially helpful for non-parametric data populations (my data). Bootstrapping (“with replacement,” or Monte Carlo resampling) resamples the original data to create m new data sets (I used 10,000). The sample size for each new data set is thereby kept the same as the original. The chosen statistic (e.g., median) is calculated within each new data set. The distribution of the calculated statistics gives the probability of any possible value for that statistic. The distribution of the calculated statistics is used to calculate a confidence interval about the statistic within the original data set (Haukoos and Lewis, 2005). Confidence intervals can be calculated in several ways. I calculated empirical confidence intervals to ensure they did not extend beyond the range of measured data. A basic (empirical) confidence interval is calculated as:

$$\left(2\theta - \theta^*_{(1-\alpha)}\ ;\ 2\theta - \theta^*_{(\alpha)}\right) \tag{7}$$

where θ is the statistic of interest within the original data, θ* is the (1-α), or (α) percentile of the bootstrapped statistics (Davison, 1997).

Where confidence intervals had very small overlaps at only the 99% confidence level (the widest interval), it seemed incorrect to consider the groups at all similar. Confidence intervals were then discarded as a method for scoring metrics. The plots, however, proved somewhat helpful as a visual comparison of metric data between groups. See Appendix A6.5 [Lower Stillwell Site Data, Confidence Interval Plots] for example confidence interval plots.

4.1.2.2.5.2 MULTI RESPONSE PERMUTATION PROCEDURE

Previous research by Cenderelli, Lang, and Weinhold encouraged assessing similarity between groups with a statistical test called the Multi Response Permutation Procedure (MRPP) (D. Cenderelli, pers. comm., 2011). MRPP is a non-parametric procedure for testing the null hypothesis of no distributional difference between two or more groups. MRPP makes both inter-group and intra-group comparisons. It allows different sample sizes between groups and can be used as a multivariate test. It is similar to an F test of variance, but can be applied to non-parametric data. Assumptions of the null hypotheses are 1) the data are a representative sample, 2) each observation belongs to only one group, and 3) all possible permutations among groups have an equal probability of occurrence (Mielke and Berry, 2001). MRPP calculates a weighted mean within-group distance (Euclidean) for each original group (δ). By permutation, data points are then randomly assigned to new groups and the weighted mean within group δ is calculated again. Because permuted groups are composed of random members, distances between values should be large (because data are un-related within the group). The significance test is the fraction of permuted δ that are less than or equal to the observed (original) δ (with a small sample correction). If the fraction is large, groups are similar (Mielke, 1991). When comparing only two groups, the probability (p-value) of finding a δ equally small, or smaller than the observed δ (at some prescribed level of significance) is found by using the Pearson type III distribution (Mielke et al., 1981) for permutations greater than 10,000. Within group homogeneity (A) can also be estimated (McCune et al., 2002).

Although confidence intervals were no longer being considered as a method for scoring the metrics, they were used to help evaluate the accuracy of the MRPP results. The data from the Lower Stillwell site were used. For several metrics, the results were conflicting: overlapping confidence intervals were observed for the 25th and 75th quartiles (at the 95% confidence level), but the MRPP test results indicated the groups were different. As previously noted, assuming similarity based on overlapping confidence intervals is not always correct. Also, MRPP is very sensitive to extreme values beyond the 25th and 75th quartiles. Perhaps if the confidence intervals were built around values more extreme than the 25th and 75th quartiles, the MRPP and confidence interval results would have been more similar. Because the extreme values of each metric are not generally of interest, using a tool so sensitive to them seemed inappropriate.

Subsequent discussions with a Forest Service statistician further discouraged us from using MRPP as an analysis tool because MRPP is best utilized for comparing many groups at a time. Because we are always interested in comparing only two groups, a basic non-parametric test of medians provides a more intuitive analysis. A simple comparison of medians is also more similar to the level I rubric analysis method. MRPP was not further explored as a way to score the level II metrics.

4.1.2.2.5.3 OTHER LEVEL II SCORING METHODS CONSIDERED

Statistical tests briefly considered for scoring groups include the Kruskal-Wallace and the Fligner-Killeen tests for homogeneity of variance. These were not chosen because a comparison of medians (Wilcoxon Rank-Sum test) is more similar to the level I analysis method, which also focuses on the median.

I thought a multivariate method could be a meaningful way to summarize all metrics into one effectiveness result (a possible alternative to a rubric approach). The multivariate PERMANOVA (permutational multivariate analysis of variance) method was considered, but not carried forward because data for all metrics are not available for all channel units (e.g., no gradation data are collected within pools) and sample sizes between metrics are not equal. Blank data fields are problems for multivariate analysis.

4.1.3 LEVEL I

Just as the level I field protocol is designed to be similar to the level II field protocol, the level I summary rubric also mimics level II's; a combination of metric scores and weights provide an effectiveness evaluation by group (a unique zone, channel unit, and slope segment). The level I rubric weights are the same as those in the level II rubric. Level I protocol metrics are similar to those used for level II, but width at half bankfull stage and bed irregularity are not measured. Steps are evaluated in exactly the same way (including scoring methods) between levels I and II.

For riffle and pool channel units, the level I protocol sample sizes are much smaller than those collected for level II (less than 10), which prevents statistical testing. Several different methods of comparing the design zones to the representative reach were considered. In total, nine versions of the level I protocol were created, each one slightly different from the previous one.

As part of development, rubric evaluations at the three test sites were compared with level I data boxplots, histograms, photos and site observations. Results generated by the rubric for those sites seemed reasonable. The 2013 level I summary rubric is located in Appendix E3 [Level I Summary Rubric].

4.1.3.1 METHODS OF SCORING LEVEL I

4.1.3.1.1 QUARTILES, MINIMUM AND MAXIMUM VALUES

The level I rubric scores most metrics by evaluating whether the design median falls within the inner quartile (25th to 75th percentiles), within the minimum and maximum data values, or outside of the range of representative data values. Scores of “good” (5), “fair” (3), or “poor” (1), were assigned, respectively. Similar to level II, riffles are allowed to be deeper than the representative reach where a design median greater than the representative reach 25th percentile scores 5, less than the 25th percentile of the representative reach scores 3, and below the minimum representative reach values scores 1. The same is true for the bank irregularity metric within all zones.

4.1.3.1.2 OTHER SCORING METHODS WITHIN THE LEVEL I RUBRIC

Where metrics are not quantitative, but qualitative, they are scored by categorical comparisons. The level I *bank irregularity* metric compares the bank irregularity rating (irregular (5), varied (3), or regular (1)) for each design zone with that for the representative reach. Where the difference is 0, the metric is scored "good" (5), where the difference is equal to or between 1 and 3, the metric is scored "fair" (3), and where the difference is greater than 3, the metric is scored "poor" (1).

The level I *bank continuity* metric simply categorizes the percent of the structure walls with constructed banks (at half bankfull stage) and scores them: Where more than 75% of the banks are continuous through the structure, the score is "good" (5), where 50% to 75% of the structure walls have banks, the score is "fair" (3), and where less than 50% of the structure walls have banks, the score is "poor" (1).

All step metrics are evaluated and scored by the level I protocol identically to the level II protocol (see section 4.1.3.1).

4.1.3.1.3 OTHER LEVEL I SCORING METHODS CONSIDERED

Level I metrics were initially scored by comparing the design zone median with an allowable percent difference from the representative reach median. I detail the method here as a reference, should future editions of the level I rubric become interested in re-visiting what was already tried.

The percent difference for a "good" (5), "fair" (3), or "poor" (1) score varied by metric. For example, if the median design width at bankfull stage fell within 10% of the median representative width, the metric scored a 5. If the median design width at bankfull stage was within 10%-30% of the median representative channel width, the metric scored a 3, and if the median design width at bankfull stage was more than 30% different from the median representative width, the metric scored a 1. Difference margins were altered several times to assess the effect on rubric results. However, it was observed the allowed percent difference around the representative reach median was sometimes wider than the minimum and maximum measured data values. It became obvious that the spread of representative reach data points should serve as the comparison for the median design value.

4.1.3.2 OTHER CHANGES

Additional small changes to the level I rubric included altering the evaluation scheme for the total group score. The required percent of total possible points necessary for a “similar” effectiveness rating was increased from 70% to 75%. The level I effectiveness evaluation scoring scheme is now identical to the level II scheme. Also, penalties were removed for sites with design steps shorter than those found within the natural channel, and design pools deeper than those within the natural channel. Both of these changes were reversed in the 2013 rubric. Channel unit length was initially included as a level I metric, but was later removed for riffle and pool channel units.

4.1.4 METRIC WEIGHTS

Each metric is weighted so that its influence on the group’s total score is relative to how important the physical channel dimensions are to maintaining geomorphic continuity through the crossing. Weights are the same for the levels I and II protocols. Specifically, weights affect the overall score by multiplying the metric score (5, 3, or 1) by the weight. The maximum weight (reserved for the most important metrics) is 1. The minimum weight is 0.25. Metric weights are listed by channel unit type in able 7. The following paragraphs provide the rationale for the relative weights by metric.

After creating the first version of the level II rubric, weights were subjectively adjusted for two channel metrics in order to produce rubric results that best matched observations and qualitative assessments at the three test sites. Pie charts were created as a visual aid during this process (Appendix E1 [Weights: Pie Charts for Level I and II]). They display the contribution of each metric to the total maximum score.

Channel width (at any stage) is an indirect assessment of stream energy because it affects flow depth and velocity. Bankfull width is an especially meaningful metric and is weighted the highest (1 for pools and riffles) because it is a "master" control (independent degree of freedom) which affects many other physical stream dimensions. At approximately bankfull stage, sediment transport within gravel and cobble channels occurs. Sediment transport creates and maintains the channel's form (cross section and slope), a crucial geomorphic process. Also, when compared with the natural channel, the design width at bankfull stage assesses the (flood stage) flow constriction forced by the unyielding boundary of the structure. The narrower the constriction, the greater the hydraulics (velocity) become within the structure, relative to those found in the natural channel (from the continuity equation Q = VA, volumetric discharge = average velocity * cross sectional area (Knighton, 1998)). For aquatic organisms, floods are often migratory cues during which the higher stages allow them to move up or down the channel. Their physical abilities however, are adapted to a limited range of hydraulics.

The coarse fraction of the gradation (level II) or largest particles (level I) metrics are given the maximum weight (1 for riffles) because it is assumed that if the largest particles are mobile, smaller particles are also mobile. Also, larger particles will be mobilized by greater floods during which the crossing structure is most likely to affect channel hydraulics. By comparing these particles between the design and representative reaches, sediment mobility is most accurately compared.

The *half bankfull stage* metric is weighted significantly (0.75) because it is a high stage which occurs frequently (approximately every year). It is weighted slightly less than the bankfull width metric because it does not strongly affect channel geomorphology. The metric of width at half bankfull stage should indirectly evaluate the hydraulic conditions (depth, velocity, turbulence) commonly experienced by aquatic organisms within the design channel.

The *maximum depth* metric is significantly weighted (0.75) because it is an indirect assessment of channel hydraulics. It is not given the maximum weight because it does not independently control other metrics. Maximum depths greater than those within the natural channel may indicate excessive scour is occurring. Scour within the structure can both undermine the structure's foundation and remove substrate. Further it means inadequate energy dissipation has been incorporated into the design. Maximum depths less than those within the natural channel may indicate insufficient riffle height or permeable substrates. The maximum depth of pools associated with riffles should be equivalent between the natural and design channels. Riffles are not penalized for being deeper. Pools beneath steps are evaluated by a separate metric.

Bank irregularity is moderately weighted (0.5) because it is a geomorphic control (i.e., it influences energy dissipation by creating micro-eddies) as well as a habitat measure (i.e., organisms use the micro eddies as resting areas, feeding areas, etc.). The metric does not carry a greater weight because it does not exert a large control over other channel dimensions.

The *bank continuity* metric (assessed only within the structure) is given a moderate weight (0.5) because it affects the physical stability of the structure. Where banks are absent, scour along the structure walls may undermine the footers, jeopardizing the longevity of the road-stream crossing. Although not a classic control on geomorphology, a stable and intact structure will prevent impacts to a stream by massive introduction of road fill, should the structure fail.

The *low flow width* metric is given the minimum weight (0.25) because it does not measure a control on channel form. It is included as a metric because it is an assessment of (some) physical dimensions important to aquatic organisms. If the design channel is wider than the natural channel at low flow, insufficient depth (a barrier to aquatic movement) may be indicated. Also, where the design channel low flow width and maximum depth are not similar to the natural channel, excess permeability and poor bed construction may be indicated.

Bed irregularity is given the minimum weight (0.25) because it does not control geomorphic processes. One could argue that bed roughness (≈ irregularity) might affect channel width because it is a boundary condition which dissipates energy. The bed within the design channel is however, unlikely to affect the banks because they are commonly un-erodible; constructed of large rock and concrete or metal (e.g., the structure). Instead, bed irregularity is a measure of habitat for bottom dwelling species such as macro-invertebrates and sculpin fishes.

The *step height* metric is given the maximum weight (1) for two reasons: 1) The height of steps within the design channel reflects how well design features are spaced. For example, where design steps are much taller than those found within the natural channel, more steps should have been installed. Where steps are shorter, fewer steps would better mimic the energy dissipation occurring in the natural channel. 2) Step height is also an indicator of barriers to upstream migration. From the basis for physical effectiveness monitoring; constructed steps with heights similar to those found within the natural channel should pose no more of an obstacle to aquatic organisms than natural steps.

The *residual pool depth* metric is given the maximum weight (1) because it is an indicator of dissipated potential energy, a geomorphic control. As flow drops from the step crest to the step base, its potential energy is transformed into work performed on the bed, turbulence (kinetic energy), and heat. The work on the channel bed results in a scoured pool; of which the depth measures how effectively the step's geometry dissipates energy.

The *maximum step particle size* is given a significant weight (0.75) because the stability of steps is critical for maintaining the features and energy dissipation designed through the crossing. The step particle size is not weighted higher because it does not also necessarily affect aquatic organism migration.

The *step length* metric is also weighted significantly (0.75). Step length is a geometric expression of the obstacle to upstream migration; the longer the step length, the further distance an aquatic organism must endure (or leap over) elevated velocities and shallow depths. See the discussion section 6.2.6 for recommendations regarding the weight of this metric.

The *width at bankfull stage* is weighted moderately (0.5). During bankfull flows, the hydraulics at the step are influenced by the degree of flow confinement. Wider steps concentrate the flow less, creating shallower depths at the step crest, slower water velocity, and less bed scour. Narrower steps concentrate the flow more, creating deeper flow across the step crest, faster water velocity, and more bed scour. Because bankfull stage floods only affect the step hydraulics approximately every 1.5 years, the metric is deemed slightly less important than the metrics which capture the common hydraulics, stability, and navigability of steps.

TABLE 7: METRIC WEIGHTS FOR EACH CHANNEL UNIT TYPE

Channel Unit	Metric	Weight
Riffles	Width at Bankfull Stage	1
	Width at Half Bankfull Stage	0.75
	Width at Low Flow (Wetted Width)	0.25
	Maximum Depth	0.75
	Coarse Fraction of the Gradation/Largest Particles	1
	Bank Irregularity	0.5
	Bed Irregularity	0.25
	Bank Continuity	0.5
Pools (Associated with Riffles)	Width at Bankfull Stage	1
	Width at Half Bankfull Stage	0.75
	Width at Low Flow (Wetted Width)	0.25
	Maximum Depth	0.75
	Bank Irregularity	0.5
	Bed Irregularity	0.25
	Bank Continuity	0.5
Steps	Width at Bankfull Stage	0.5
	Maximum Particle Size	0.75
	Step Height	1
	Residual Pool Depth	1
	Step Length	0.75

4.1.5 THE OVERRIDE OPTION

The levels I and II rubrics provide effectiveness evaluations by summing metric scores for each group. The accuracy of each evaluation should be critically considered because the rubrics are simple tools which do not consider overarching factors. Where effectiveness evaluations seem inappropriate, users are asked to use boxplots, histograms, calculated quartiles, photos and site observations to investigate discrepancies. Allowing users to alter an evaluation seems reasonable where (and only where) changes can be justified. This option is termed an “override”.

Both the levels I and II rubrics incorporate a space within the site summary table to display override evaluations. The original group score and evaluation are however still displayed. When overriding a metric score, users enter the override score into the summary rubric worksheet. The worksheet then re-calculates the total group score and provides a new effectiveness evaluation (although categorically, it may not change).

Overrides should be used judiciously. It is important to realize that many factors may influence a particular channel dimension. For example, both slope and channel width will affect the bed gradation. Overriding the gradation metric score simply based on slightly different design and representative reach gradients would be inappropriate without also considering the width metric.

Some metric scores were overridden at sites evaluated by this study. They were most often issued to correct for general issues to be addressed by future versions of the level II summary rubric, such as the method for scoring irregularity metrics. The following is a list of justifications for issuing overrides in this study, and possible justifications (although not exhaustive) for other studies:

- Where p-values are near the boundary between two scores (e.g., 0.049 vs. 0.05)
- Where sample sizes are very small, type II errors are likely. High scores awarded to design groups with small sample sizes were commonly overridden based on data plots.
- Where the bank and bed irregularity metric group comparisons showed similar medians but the histograms appeared to have very different shapes, it seemed irregularity was not effectively assessed. Scores were overridden to evaluate irregularity.
- Where the design and representative reach gradients were different enough to warrant skepticism about the coarse fraction metric score. Where gradients differ, the gradation may also naturally differ.
- Where recent construction may have influenced physical channel dimensions (e.g., the gradation).
- Where the step particle size metric scored poorly because design particles are larger than those within the natural channel.
- Where measurement accuracy is more variable than the level I representative reach quartile intervals (the level I scoring method).
- Where a flood (greater than the design flood) has likely changed channel dimensions.
- Where data were not collected, one might score missing metrics (based on observations) to observe how the overall group evaluation is affected.

See section 6.2.3.2 and 5.2.1.2.2for an example of how an override is used.

4.2 ANALYSIS FOR OBJECTIVE 3: CAN LEVEL I BE USED AS A PROXY FOR LEVEL II DATA? WHAT ARE THE LIMITATIONS OF LEVEL I?

If the level I protocol is designed to be a scaled down, less time intensive version of the level II protocol, then logically, level I results should be reasonably similar to level II results. If not identical, the less sensitive, less informative, level I results should not provide a more favorable effectiveness evaluation than the detailed, presumably more accurate, level II. For many of the sites analyzed, rubric results were not identical, and for several level I evaluations, produced more favorable scores than those provided by level II (see Table 58 and section 5.3.1).

In order to understand why, level I and II Lower Stillwell data were analyzed together in several ways. To help visualize differences, for each level I metric, boxplots of the level I and level II data were graphed together by group. See Figure 233 [Lower Stillwell Levels I and II Bankfull Widths] within Appendix A6.4 [Lower Stillwell Boxplots and Histograms] for an example of this plot with Lower Stillwell data.

4.2.1 LEVEL II DATA ANALYZED BY THE LEVEL I RUBRIC

Differences between the levels I and II rubric results may be either attributed to the data distributions or the rubrics themselves. Theoretically, if levels I and II data have similar distributions, the level II data should provide the same results as the level I data when analyzed by the same method. Because the metrics differ slightly between protocols, level II data had to be made more similar to level I data. For this analysis, modifications to level II data included:

- From each level II gradation data set, the largest 5 or 9 particles were selected for comparison (to be used instead of the coarse fraction data).
- Plots of width at half bankfull stage versus distance were used to visually assign a bank irregularity score to each zone (to be used instead of the absolute value of the irregularity measure.
- Bank continuity was assessed with plots of width at half bankfull stage inside the structure; a visual instead of quantitative assessment.

Level II Lower Stillwell data were then analyzed with the level I rubric. Rubric effectiveness evaluations were compared. Lang and Weinhold also completed this analysis for two of their sites.

4.2.2 COMPARING THE LEVEL I MEDIAN WITH CONFIDENCE INTERVALS AROUND THE LEVEL II MEDIAN

If levels I and II data are collected within the same zone, theoretically, metric distributions should be similar and their medians should be nearly the same. Having similar levels I and II medians is important because both rubrics score metrics based on a comparison of this statistic. Differences between the levels I and II data sets were investigated by comparing the level I median with the empirical bootstrapped 95% and 99% confidence intervals around the level II median. For several metrics, results were quite poor; the level I median did not fall within the level II confidence intervals (specifics are given within section 5.3.3). Differences between data collection methods and sample sizes were then considered.

4.2.3 LEVEL I SAMPLE SIZE INVESTIGATION

For three of the ten level I metrics, the level I sample size is 5 per group, regardless of zone or channel unit size. In contrast, the level II sample size is 20 for these metrics (although it can be less where channel units are short). Level II metrics with only 5 samples are statistically analyzed, but the results are considered very questionable. Is it possible that the 5 level I measurements are not representative of the level II distribution?

If one assumes that the sample collected with the level II protocol represents the “true” distribution, an adequate level I sample size can be assessed. Width at the bankfull stage, wetted width and depth were selected as test metrics because they are spatial data sets common to both protocols (for which the level I sample size is five). A spatial data set enables sub-sampling the level II data by distance along the channel length. This is important because level I measurements are collected spatially, at 0%, 25%, 50%, 75%, and 100% of the channel length. Using the level II data, I first selected the 5 measurements between 0% and 100% of the channel length. Data subsets were systematically (spatially and gradually) created with sample sizes incrementally increased from 5 to 11. Eleven was chosen as the maximum allowable sample size because level I is intended to be a rapid assessment, and each measurement increases the time necessary for data collection (a sample size of 17 was investigated for data exploration purposes, although not seriously considered). For each subset, the quartiles were compared with the “true” quartiles of the full level II data set. Differences less than 5 cm were considered acceptable approximations, exact values were best. The full level II data were also spatially sub-sampled by another method; selecting 50% of the full zone sample size. Quartiles from the 50% subset were calculated and compared with the “true” quartiles from the full data set. Because the Lower Stillwell level II inlet transition zone (n=11), structure (n=27), outlet transition zone (n=11), and representative reach (n=26) have varying sample sizes, subsampling was repeated separately for each zone. Subsets with the best quartile matches were further evaluated by entering them into the level I rubric. Rubric results for the level II data subsets of various sample sizes were then compared.

5 RESULTS

5.1 OBJECTIVE 1 RESULTS: FIELD PROTOCOL TESTING AND REFINEMENT

5.1.1 FIELD TESTING THE LEVEL II PROTOCOL

Over the course of implementing the level II field protocol at 14 different sites, many small changes were made. Some notable changes and improvements are described here, further improvements are suggested within section 7, Table 64, Table 65, and able 66.

Initially, the level II field protocol described collecting width measurements by using a stadia rod outfitted with a bubble level. The distance from the channel centerline to each bank was measured, one side at a time, by sliding the end of the horizontal rod up and down the bank until it was level with a measuring tape (fastened to a stake at the channel centerline) at the elevation equivalent to bankfull stage (See Appendix B1 [Photos of Data Collection Methods]). The same technique was used for collecting width at half bankfull stage. Although this seemed to be an accurate way of measuring width at specified elevations, the method was physically exhausting and extremely slow, especially in very wide channels with lots of vegetation on the banks. During the second field season (2012), I instead used a Leica Disto laser distance meter (Appendix D [Equipment Used], Figure 428). The laser was held at the channel centerline at an elevation even with the fastened tape. The distance to the bank was measured by first removing and flattening vegetation on the banks. Then, while the laser was oriented perpendicular to bankfull flow, it was aimed and fired at the bank. The horizontal distance was recorded. Field tests showed the laser measurements were repeatable and comparable to the rod technique, and the laser method was faster by at least an hour. In areas of dense vegetation, however, the level rod technique is probably more accurate.

The methods for collecting data at steps were really developed in 2012 as part of the level I protocol development. Therefore, at sites with steps visited in 2011 (Haskell Creek), data must be gleaned from the surveyed longitudinal profile.

In 2011, the level II field protocol required selecting a representative reach for only the gradient(s) which extend through the structure; if different, the gradients within the inlet and outlet transition zones were not analyzed. The protocol was altered in 2012 to specify finding representative reaches for each gradient within the entire design channel. For example, if a design channel has four slope segments which break within the inlet transition zone, the structure, and the outlet transition zone, four representative reaches are now identified for comparison.

The draft level II protocol, provided to me at the beginning of the 2011 field season, was not designed to statistically analyze width and depth data by channel unit type (sampling intervals were not set by channel unit length, but instead by zone). In 2012, it became apparent that meaningful comparisons between the design and representative reaches would have to be done more precisely: 1) By group, whereby a unique combination of channel unit, slope segment and zone are compared with a similar representative channel unit. 2) By channel unit sequence (e.g., pool-riffle), whereby a sequence within a single slope segment and design zone is compared with a similar sequence in the appropriate representative reach.

Analyzing with respect to channel unit however, was difficult with 2011 data because the channel units were not specifically recorded at each measurement station. Data collected during 2011 are useful where channel units can be assigned to data values by looking at the longitudinal profile and associated notes. Luckily, metrics were frequently tied in the notes to the longitudinal profile by the location of numbered grade control points.

Because sampling intervals for width and depth metrics were set by zone instead of channel unit length, sample sizes at short units are sometimes too small for meaningful statistical analysis. Test results (p-values) for these units are ignored, and instead the metric data are evaluated qualitatively with site observations.

Where zone boundaries truncate pool units, the site is also analyzed by population (design versus natural). In actuality, however, the levels I and II protocols are awkwardly applied at best. These sites are best evaluated qualitatively. See sections 5.2.1.2.6, 5.2.1.2.7, 6.2.3.6, and 6.2.3.7 for examples of this scenario.

5.1.2 FIELD TESTING THE LEVEL I PROTOCOL

The Level I protocol was created immediately before the summer 2012 field season. It was refined through field testing at 16 sites. For example, the interval and sample size collected at pool and riffle units were determined in the field, as were the methods for measuring step geometry (height, length, and width). After field work was complete, the residual pool depth metric was added to the protocol as a metric for evaluating the hydraulic effectiveness at steps. Although really a field measurement, I gleaned these data in the office from the surveyed longitudinal profile. Suggested improvements to the level I protocol are summarized in section 7, Table 64, Table 65, and Table 66.

5.2 Objective 2 Results: Create Effectiveness Summary Tools

Within this section, the 2013 level II and level I draft summary rubrics are presented. The results from some of the ideas explored during rubric development are given. Finally, the rubrics are used to analyze data from 12 sites (able 8), and the effectiveness evaluations are displayed.

Table 8: Sites and locations evaluated, by protocol

Site Name	Forest	State	Level II	Level I	Stream Simulation?
Lower Stillwell	Siuslaw NF	Oregon	X	X	No
North Fork Indian	Siuslaw NF	Oregon	X	X	Yes
WF01	Monongahela NF	West Virginia	X	X	No
WF02	Monongahela NF	West Virginia	X	X	No
Site 3	Monongahela NF	West Virginia	X	X	No
Dog Slaughter	Daniel Boone	Kentucky	X	X	No
Big Lick	Daniel Boone	Kentucky	X	X	No
Sparks Brook	Green Mountain	Vermont	X	X	Yes
Caney Creek	Daniel Boone	Kentucky		X	No
Utley Brook	Green Mountain	Vermont		X	No
Joe Smith Brook	Green Mountain	Vermont		X	No
Bays Creek	Siuslaw	Oregon		X	No

5.2.1 Level II Summary Rubric

A level II summary effectiveness tool was created. It is basically an Excel workbook in which the user either enters a p-value from a Wilcoxon Rank-Sum test, or the bank continuity measure (see section 3.4.4.4.2). The spreadsheets automatically score the p-values, weight the scores, and summarize the scores to produce an overall effectiveness evaluation for each group.

The summarized score, or "percent total score," is evaluated (for both levels I and II protocols) as follows:

- Similar Attributes/Good Rating: Score between 75 and 100 percent.
- Questionable Attributes/At Risk Rating: Score between 50 and 75 percent.
- Dissimilar Attributes/Poor Rating: Score less than 50 percent.

Each site is summarized by a single table which displays the effectiveness evaluations for every design group. See the level II summary rubric, Appendix E2 [Level II Summary Rubric] and the analyzed site results, section 5.2.1.2 .

Lower Stillwell was used to build and initially test the level II summary rubric tool. Seven other sites were also analyzed with the level II rubric. These sites were chosen because they represent a range of AOP restoration quality. The sites analyzed are listed in abl e 8. For each level II site, see Appendix A [Site Data] for a surveyed longitudinal profile, key photos, and metric data plots.

5.2.1.1 THE CHOSEN SCORING SCHEME

At each site analyzed by the level II summary rubric, a range of scoring schemes were used to score the metrics. Each range of alpha values applied differed in how easy they made scoring 5s or 1s. Evaluations were assessed by comparing scores with data plots and values. Scoring schemes, whereby scores of 5 and 1 were more difficult to obtain, generated too many scores within the “fair” category. Where scores of 5 and 1 were easier to obtain, scores generated were mostly “good” or “poor,” and very few were “fair.” Ultimately, it appears the moderate scheme whereby a p-value between 0.001 and 0.05 scores 3, seems most appropriate because rubric evaluations best reflect the data (see Appendix A [site data]). In an effort to simplify subsequent discussions, detailed results are only presented for the chosen scoring scheme.

5.2.1.2 LEVEL II RESULTS FOR ANALYZED SITES

Because the Lower Stillwell site was central to the creation of the Level II summary rubric, Lower Stillwell site data (photos and plots) are included with the description and rubric results. In order to keep the length of the thesis text reasonable, photos and plots for all other sites are located in Appendix A [Site Data].

5.2.1.2.1 LOWER STILLWELL SITE DESCRIPTION AND RESULTS

The Lower Stillwell road-stream crossing site is located at T 5 S, R 9 W, section 33, lower ½ (on the section line between 33 and 34, or Latitude/Longitude 123° 45’45.88W, 45° 5’16.93 N, within the Siuslaw National Forest (Hebo RD) in Oregon. The road number is Forest road 1201. Stillwell Creek is a direct tributary to the Little Nestucca River, which flows to the Pacific Ocean. The watershed area is 2.97 km^2 and the approximate bankfull discharge is 3.11 m^3/s. Stillwell Creek is habitat for coho salmon, winter steelhead and cutthroat trout. It is also a cold-water refuge for juvenile salmonids (Ellis-Sugai, 2011).

The site experiences heavy precipitation during the winter, and dry summers. Coastal fog is common. The study reach flows through a fairly confined narrow valley. It has pool-riffle morphology with frequent, suspended, channel spanning logs at bankfull or greater elevations. Some wood was present in the channel itself, although wood jams were absent. Landslides which directly deliver sediment and wood to the channel are common, and presumably frequent; the upstream sediment supply is large. A floodplain is present in some places. Riparian vegetation is composed of deciduous trees, coniferous trees, shrubs (largely salmon and thimble berries), grasses and broad leafed vegetation. Lithology is the Tyee Formation, a “very thick sequence of rhythmically bedded, medium to fine-grained micaceous, feldspathic, lithic, or arkosic marine sandstone and micaceous carbonaceous siltstone; contains minor interbeds of dacite tuff in upper part.” (Walker and MacLeod, 1991, USGS Geologic Map Key). Substrate was medium sized cobbles, angular, embedded, sandstone and siltstone. The D50 within the design reach is 64-69 mm. The D50 within the level II representative reach is 72 mm. Average bankfull width is 5 m. The average study reach gradient is 3%.

The project at the Lower Stillwell Creek site was a replacement of a previously existing crossing structure. Prior to replacement, the channel had aggraded upstream of the inlet, and scoured a plunge-pool downstream of the outlet. The new structure is a steel, open-bottomed arch with span 5.4 m, height 3.1 m and length 25.2 m. The inlet is mitered with a concrete slope collar. The outlet is at grade with rock-riffle control. The replacement was completed in 2004. The design channel was built with randomly placed boulders and rock steps spaced 6 m apart (Ellis-Sugai, 2011; Ellis-Sugai, 2012). Today, all design zones are riffles with gradient 3.1%. Banks within the structure are absent and a mid-channel bar has developed. The selected level II representative reach has a gradient of 1.9%. A 50% gradient criterion was used to select the representative reach. Analyzed groups are IR1 (inlet TZ riffle), SR1 (structure riffle), and OR1 (outlet TZ riffle). Long-term monitoring by Forest personnel indicates the bed within the structure has adjusted significantly since implementation. The design channel gradient has decreased over time from 4.4% in 2004 to 3.09% in 2006. The aggraded sediment at the structure inlet has been moved into the structure, deposited as a mid-channel bar and filled the old plunge pool at the outlet. Cross sections upstream of the structure show the channel has widened as the sediment wedge caused by the undersized culvert has been eroded. Within and downstream of the structure, cross sections show only slight changes in elevation (Ellis-Sugai, 2011; Ellis-Sugai, 2012).

A flood (~ 25 year recurrence interval) occurred at Lower Stillwell in January of 2012 and field work was conducted in August 2012. Monitoring at nearby AOP structures before and after the flood showed little change in the longitudinal profiles of those design channels (Siuslaw NF, 2012). Flood effects at the Lower Stillwell design channel were not obvious.

5.2.1.2.1.1 Lower Stillwell Level II Results Table

Table 9: Lower Stillwell level II results for riffle 1, by metric

Zone	Channel unit	Width at bankfull stage			Width at half bankfull stage			Width at low flow (wetted width)			Maximum depth			Coarse fraction			Bank irregularity			Bed irregularity			Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Riffle	🟧 0.009			🟩 0.143			🟧 0.010			🟩 0.556			🟩 0.098			🟩 0.963			na			na	88	Similar
Structure	Riffle	🟥 0.000			🟥 0.000			🟩 0.255			🟩 0.305			🟩 0.764			🟩 1.000			🟩 0.965			🟥 35%	64	Questionable
Outlet TZ	Riffle	🟧 0.011			🟩 0.201			🟩 0.465			🟥 0.000			🟧 0.050			🟩 0.944			🟩 0.419			na	69	Questionable
Data	Quartile	75	50	75	25	50	75	25	50	75	25	50	75	25	50	75	25	50	75	25	50	75			
Rep Reach	Quartile	4.56	4.65	4.86	3.64	4.12	4.27	2.70	3.10	3.49	0.12	0.13	0.15	120	150	160	0.06	0.13	0.40	0.03	0.07	0.11			
Inlet TZ	Quartile	5.19	5.42	5.51	3.04	3.80	4.28	2.09	2.30	2.63	0.12	0.13	0.17	110	140	143	0.13	0.33	0.57	na	na	na			
Structure	Quartile	5.37	5.45	5.48	4.59	4.94	5.37	2.43	2.79	3.57	0.11	0.13	0.15	120	140	145	0.20	0.38	0.66	0.03	0.07	0.11			
Outlet TZ	Quartile	4.78	5.43	5.84	3.89	4.34	4.68	2.39	2.64	3.64	0.08	0.10	0.12	110	130	140	0.12	0.35	0.59	0.04	0.07	0.14			

9Results are color coded so that green cells were scored 5, or “good,” orange cells were scored 3, or “fair,” and red cells were scored 1, or “poor.” The scoring criteria are based on the Wilcoxon rank-sum test p-values:

- $p \geq 0.05$, scores 5
- $0.001 \leq p < 0.05$, scores 3
- $0.001 < p$, scores 1

5.2.1.2.1.2 LOWER STILLWELL PHOTOS

PHOTO CREDIT: SIUSLAW NATIONAL FOREST

PHOTO CREDIT: SIUSLAW NATIONAL FOREST

Example Site:

Lower Stillwell, Siuslaw National Forest, Oregon
barrier culvert replaced in 2004
pre-replacement width = 4', post-replacement width = 18'

FIGURE 21: BEFORE AND AFTER AT LOWER STILLWELL

IN FIGURE 21THE DASHED YELLOW CIRCLE REPRESENTS THE (TO SCALE) PRE-REPLACEMENT CULVERT DIAMETER ON THE POST-REPLACEMENT PHOTOS.

FIGURE 22: LOOKING UPSTREAM WITHIN THE LOWER STILLWELL STRUCTURE

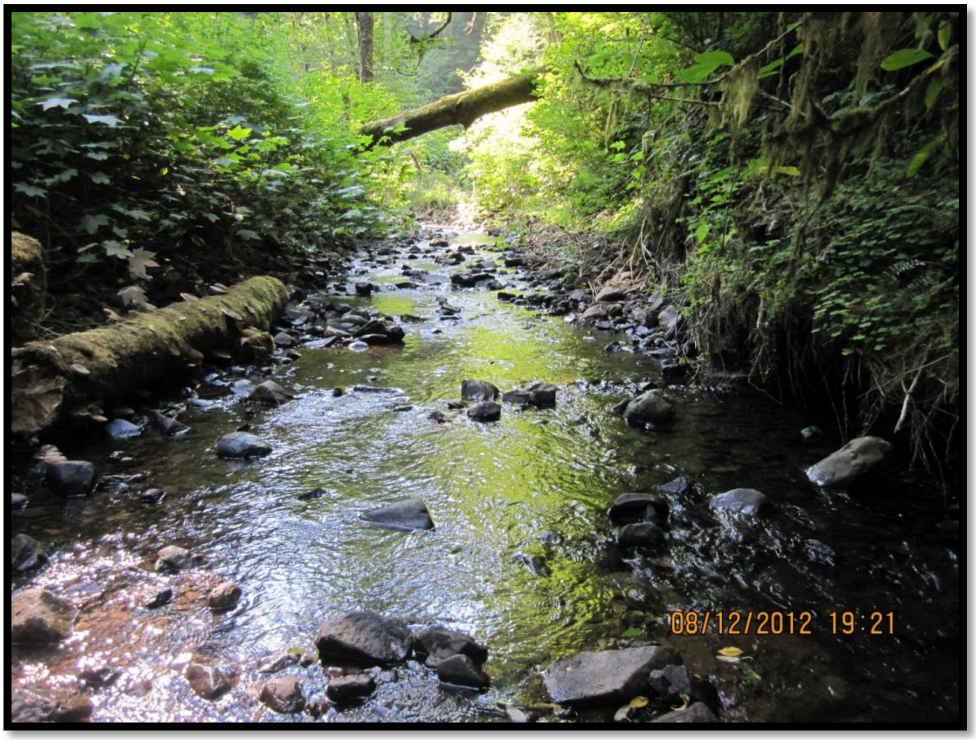


FIGURE 23: LOOKING UPSTREAM WITHIN THE REPRESENTATIVE REACH FOR LOWER STILLWELL

Figure 25: Looking down-stream at the outlet transition zone from the top of the culvert at Lower Stillwell

Figure 24: Looking upstream at the inlet transition zone from the top of the culvert at Lower Stillwell

5.2.1.2.1.3 Lower Stillwell Representative Reach Analysis

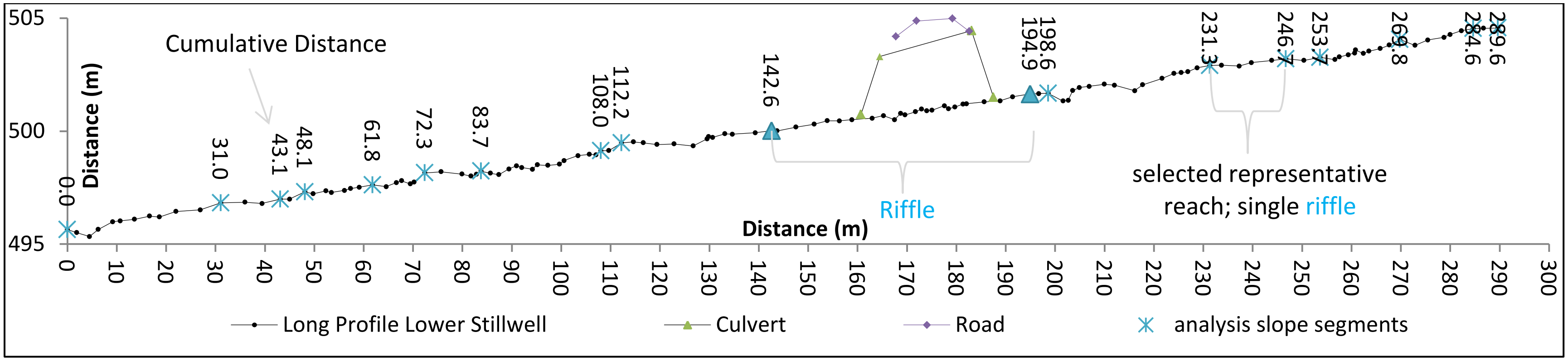


Figure 26: Lower Stillwell Longitudinal Profile

The Lower Stillwell design channel contains a single slope segment riffle in all design zones. The design channel gradient is 3%. The selected representative reach riffle has a 2% gradient. The structure is an open bottom pipe-arch with length 25.7 m, span 5.4 m and height 3.1 m. The blue triangles on the plot above mark the inlet and outlet transition zone boundaries. The Lower Stillwell longitudinal profile has a 5x vertical exaggeration.

Table 10: Design Channel Slope Segment Data

Design Channel Data (Single slope segment riffle)									
N (m)	**E (m)**	**Cumulative Distance (m)**	**Elev (m)**	**Survey Notes**	**Straight line segment length (m)**	**Elev. Diff. (m)**	**Channel Length (m)**	**Gradient**	**Selection Notes**
497.89	494.60	142.57	500.03	gc15	50.71	1.62	52.35	0.03	this is the entire design reach (inlet tz, structure, and outlet trans zone)
484.16	445.79	194.93	501.65						
slope segment length (m)		52.3	Culvert Length (m)		25.71				

TABLE 11: REPRESENTATIVE REACH ANALYSIS

N (m)	E (m)	Cumu-lative Distance (m)	Elev (m)	riffle crest (rc)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn successive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Notes
549.87	603.20	0.00	495.64		816.21	495.64	0.00	#DIV/0!		#DIV/0!	100.00	
530.15	584.39	31.05	496.83		27.25	1.18	31.05	0.04	#DIV/0!	-23.21	40.69	steep riffle, pool
530.98	572.53	43.12	496.99		11.89	0.17	12.07	0.01	-63.70	55.27	76.95	
527.34	569.20	48.10	497.31		4.94	0.32	4.98	0.06	361.96	-106.62	90.48	
515.71	562.34	61.81	497.62		13.49	0.31	13.71	0.02	-64.97	27.62	73.81	riffle, pool, riffle
510.92	554.44	72.34	498.15	gc6	9.24	0.53	10.53	0.05	125.74	-63.40	79.89	
508.15	543.98	83.73	498.23	gc8	10.82	0.08	11.40	0.01	-86.90	78.59	78.23	
503.05	527.14	108.05	499.13		17.59	0.90	24.31	0.04	461.52	-20.20	53.56	steep riffle, pool at bottom, pocket pools in riffle?
503.24	523.13	112.20	499.48		4.02	0.35	4.15	0.08	124.43	-169.76	92.07	

N (m)	E (m)	Cumu-lative Distance (m)	Elev (m)	riffle crest (rc)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Grad-ient	% diff. btwn successive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Notes
497.89	494.60	142.57	500.03	gc15	29.02	0.55	30.37	0.02	-78.34	41.56	41.99	moderate riffle, steep riffle, pool
484.16	445.79	194.93	501.65		50.71	1.62	52.35	0.03	71.12	0.00	0.00	design = long riffle with pocket pools, prominent ribs
484.72	442.15	198.60	501.67	gc22	3.67	0.02	3.67	0.01	-78.39	78.39	92.98	
489.87	413.52	231.32	502.90		29.09	1.23	32.72	0.04	462.99	-21.64	37.49	steep riffle, pool, steep riffle, step, pool
492.45	398.38	246.72	503.20		15.36	0.30	15.39	0.02	-48.45	37.29	70.60	Selected: long straight riffle with transverse ribs
493.84	391.63	253.66	503.26	gc27	6.90	0.06	6.95	0.01	-52.80	70.41	86.73	
494.93	377.18	269.81	504.06	gc30	14.49	0.80	16.15	0.05	438.34	-59.32	69.15	
499.79	363.70	284.65	504.54		14.33	0.48	14.83	0.03	-34.68	-4.06	71.67	steep riffle with pool at bottom
498.45	358.89	289.64	504.56		4.99	0.02	4.99	0.00	-84.99	84.38	90.47	

5.2.1.2.1.4 LOWER STILLWELL DATA-BY-DISTANCE PLOTS

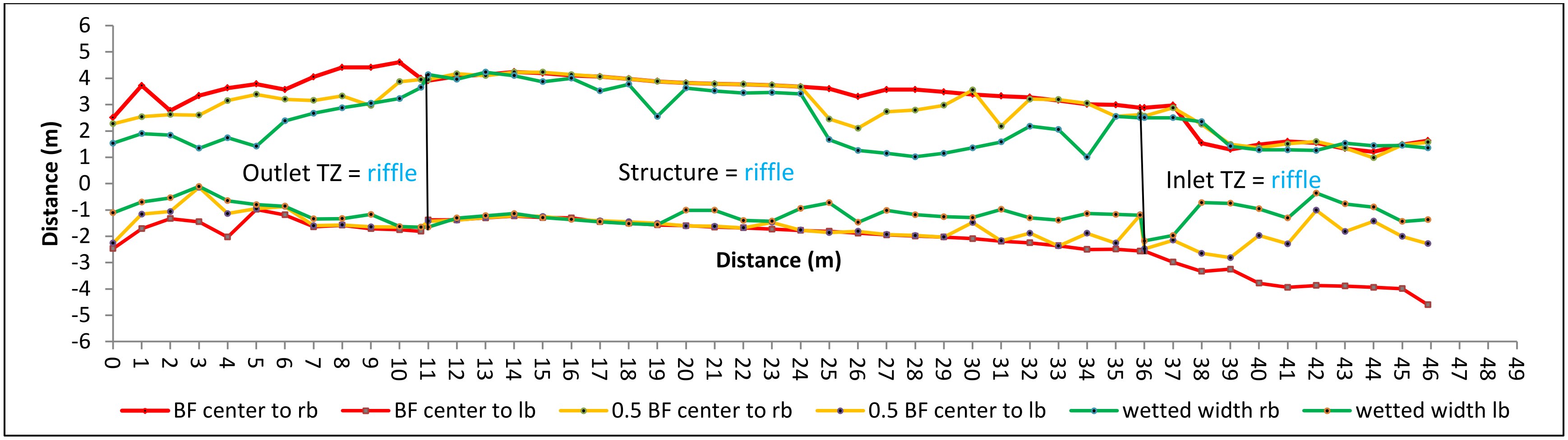


FIGURE 27: LOWER STILLWELL DESIGN CHANNEL WIDTHS

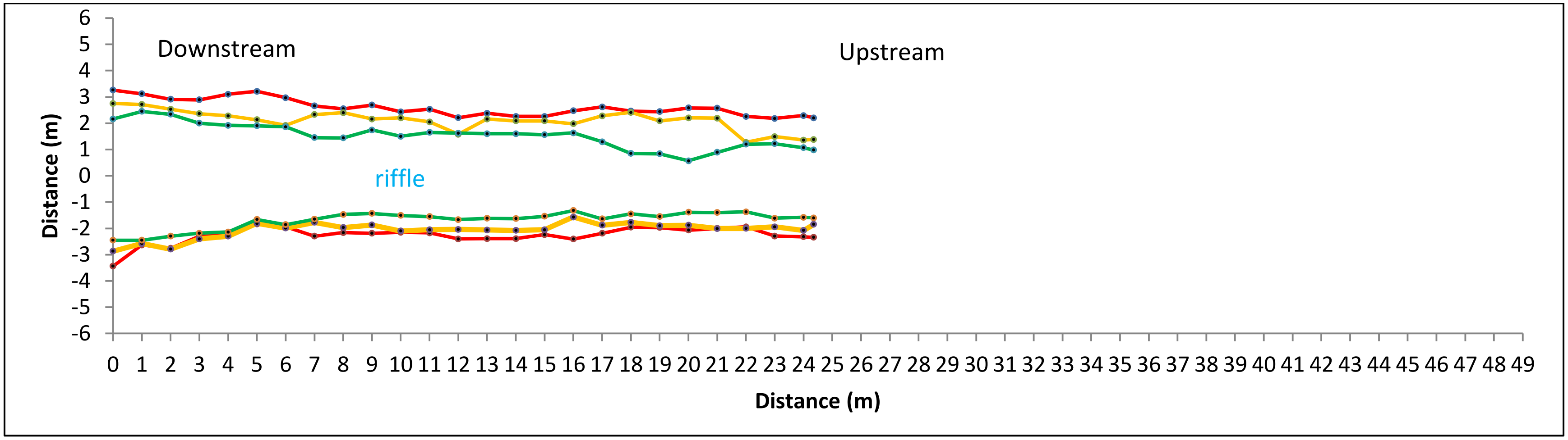


FIGURE 28: LOWER STILLWELL REPRESENTATIVE REACH WIDTHS

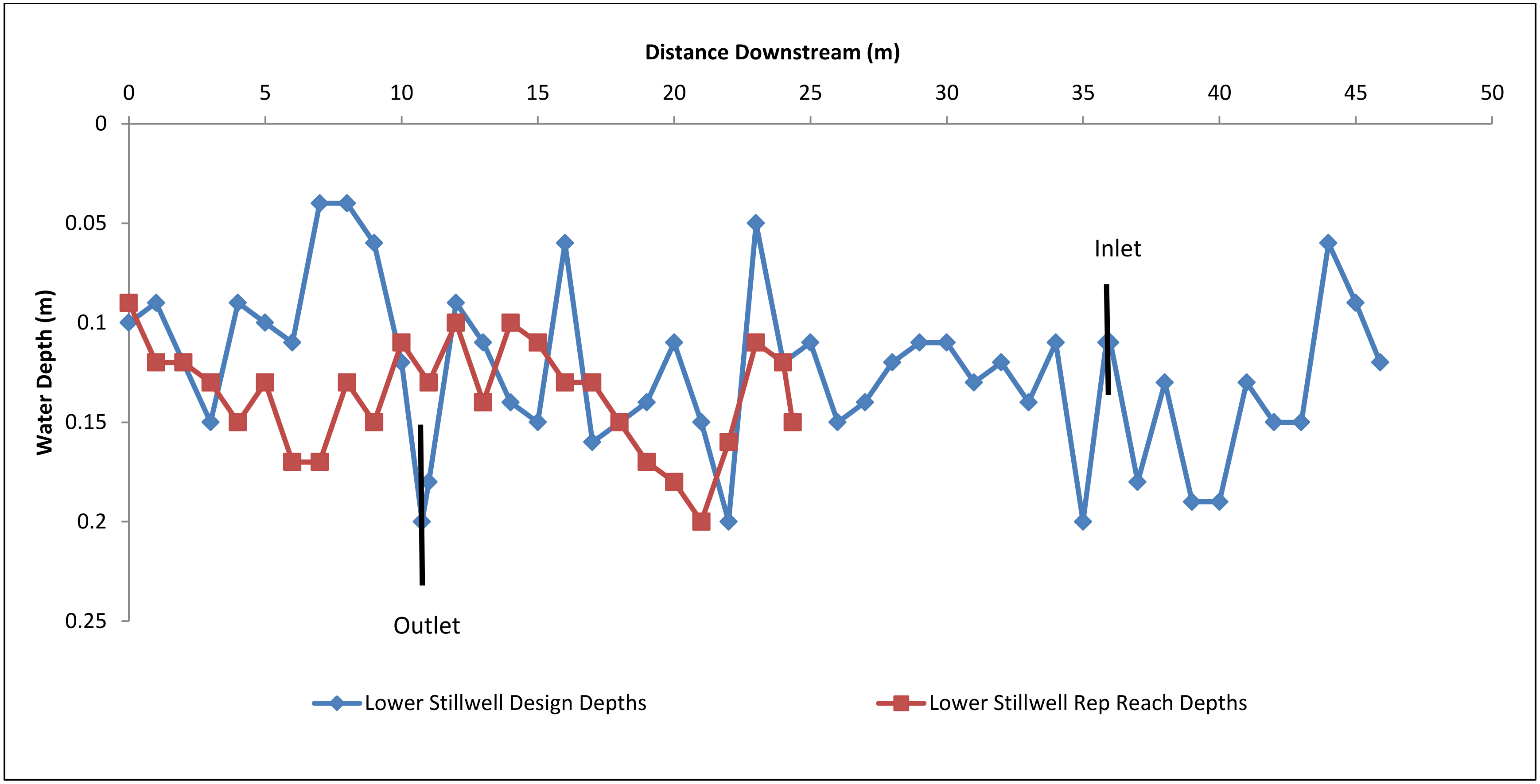


Figure 29: Lower Stillwell Maximum Depths

Lower Stillwell maximum depths- all zones are riffles of a single slope segment.

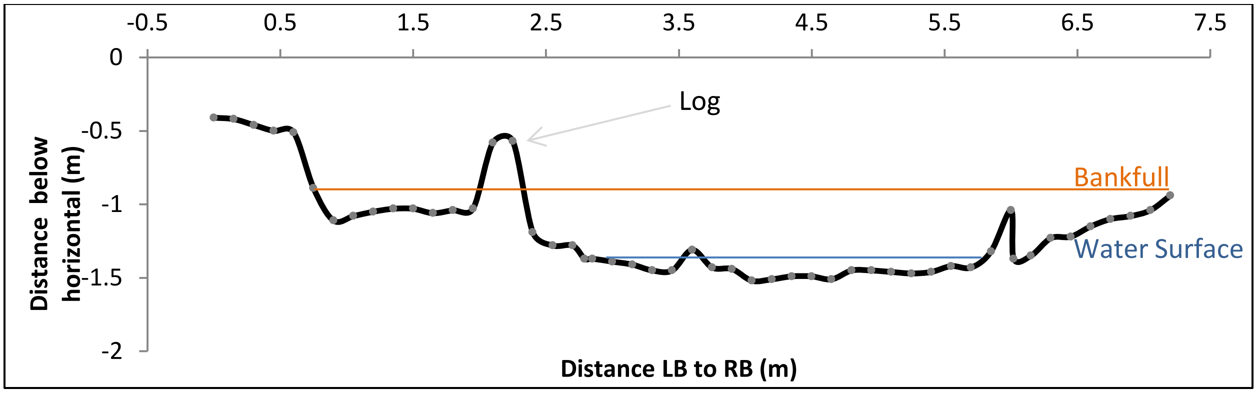


FIGURE 30: LOWER STILLWELL CROSS SECTION 1; OUTLET TRANSITION; RIFFLE

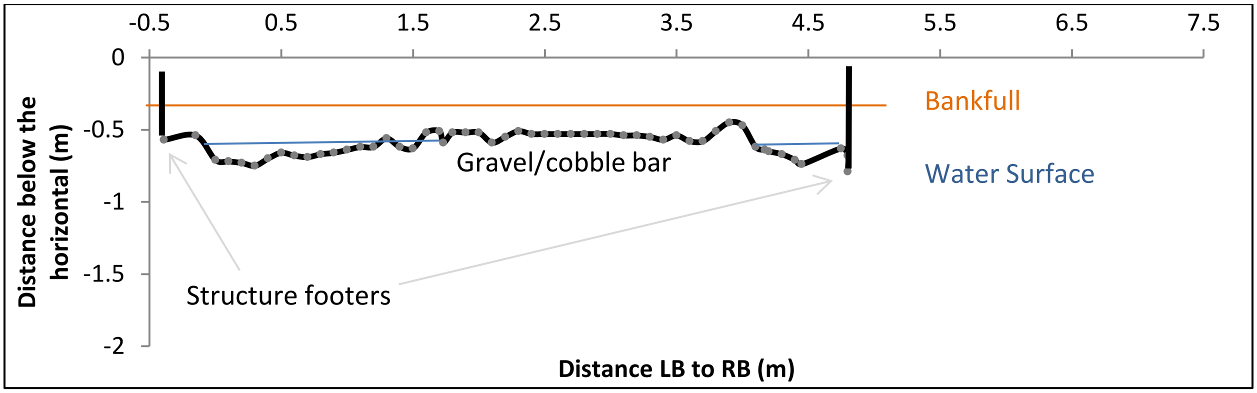


FIGURE 31: LOWER STILLWELL CROSS SECTION 2; LOWER CULVERT, ACROSS BAR

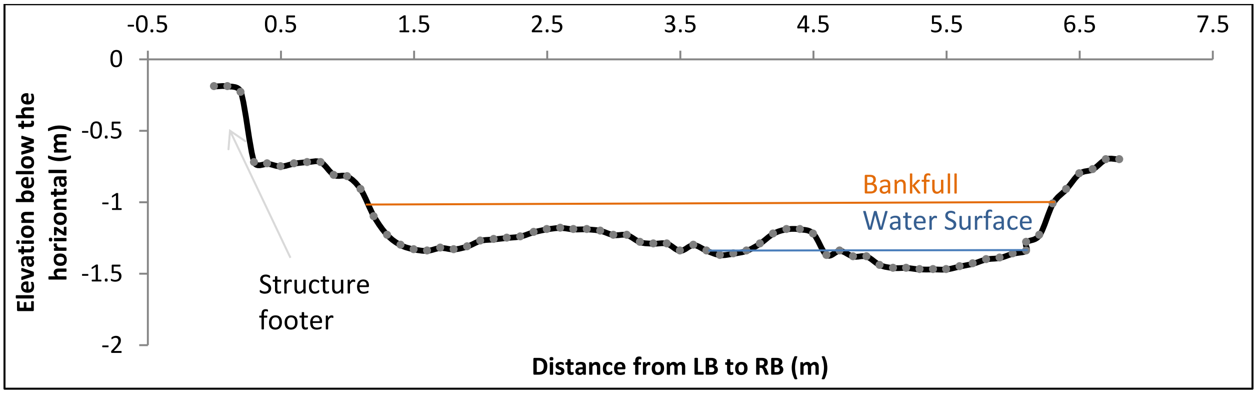


FIGURE 32: LOWER STILLWELL CROSS SECTION 3; RIFFLE IN CULVERT NEAR INLET

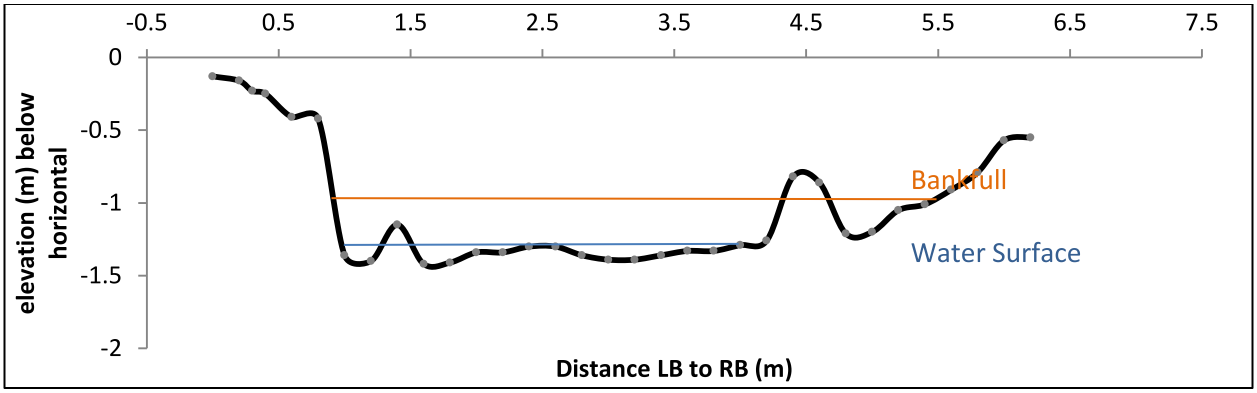


Figure 33: Lower Stillwell Cross Section RR1; Lower 1/2 Riffle

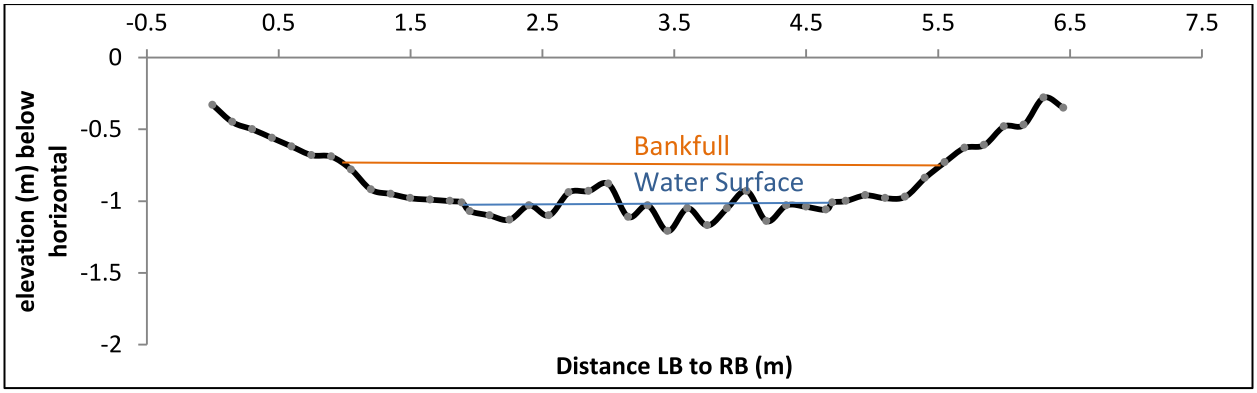


Figure 34: Lower Stillwell Cross Section RR2; Riffle and Pocket Pool

5.2.1.2.1.5 LOWER STILLWELL GRADATION

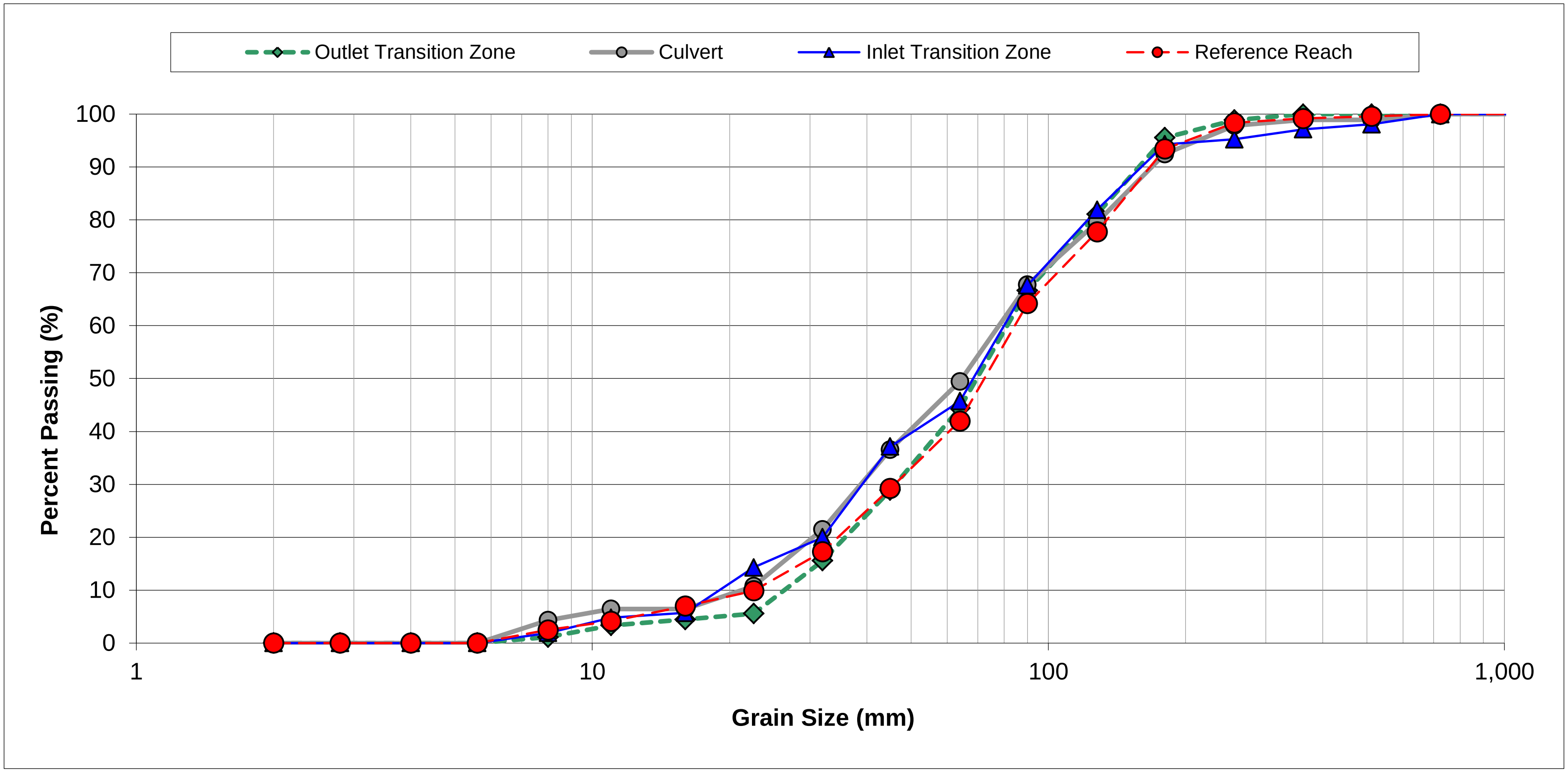


FIGURE 35: LOWER STILLWELL GRADATION

5.2.1.2.1.6 Lower Stillwell Boxplots and Histograms

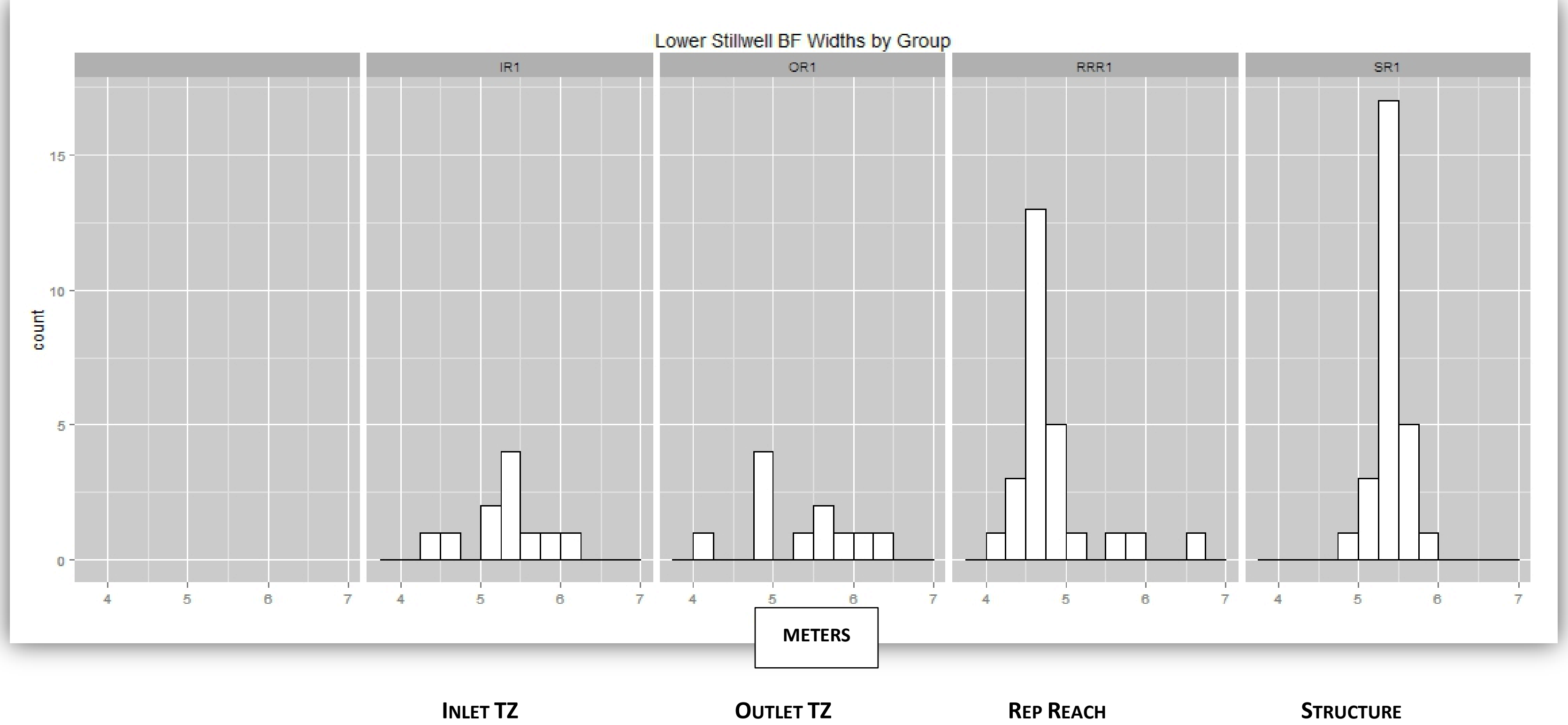


Figure 36: Lower Stillwell width at bankfull stage histogram

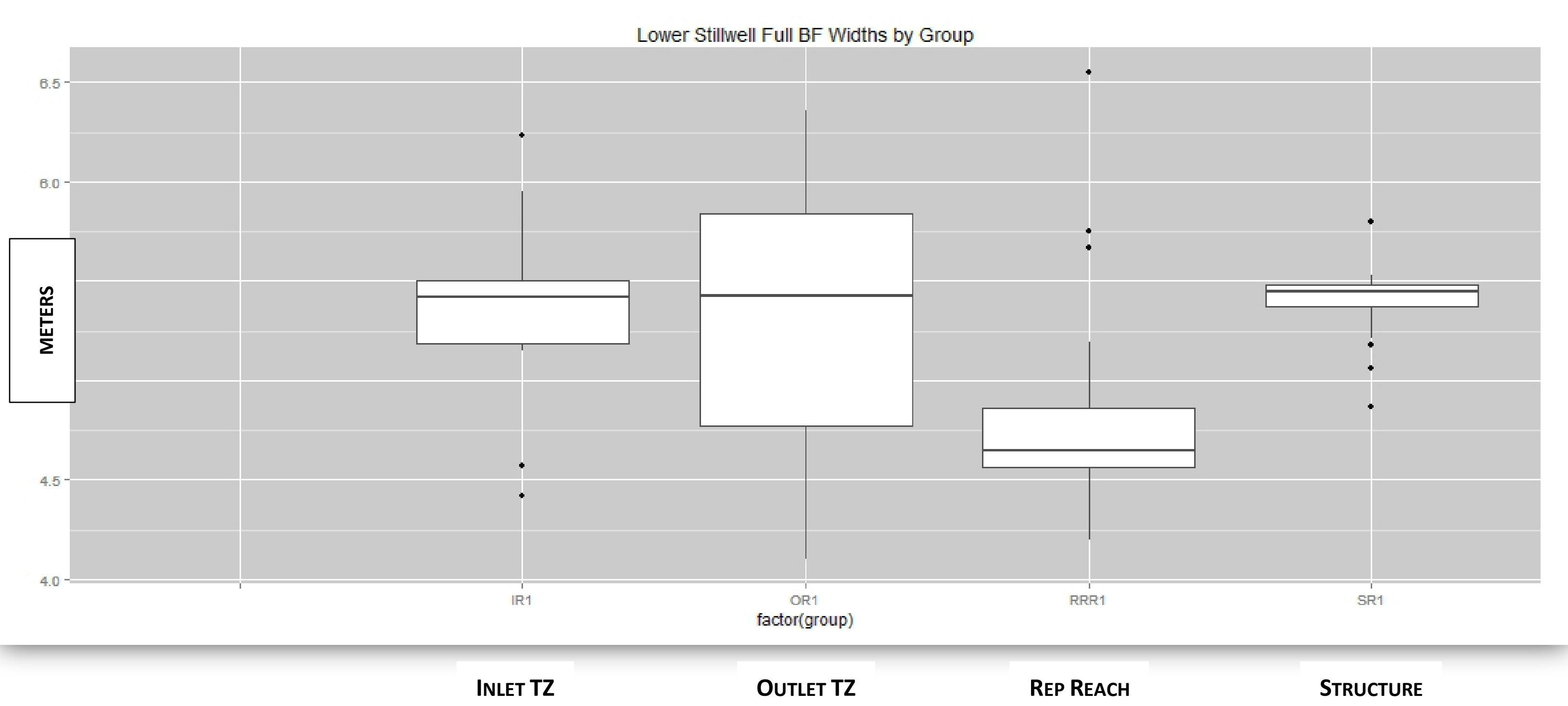


FIGURE 37: LOWER STILLWELL WIDTH AT BANKFULL STAGE BOXPLOT

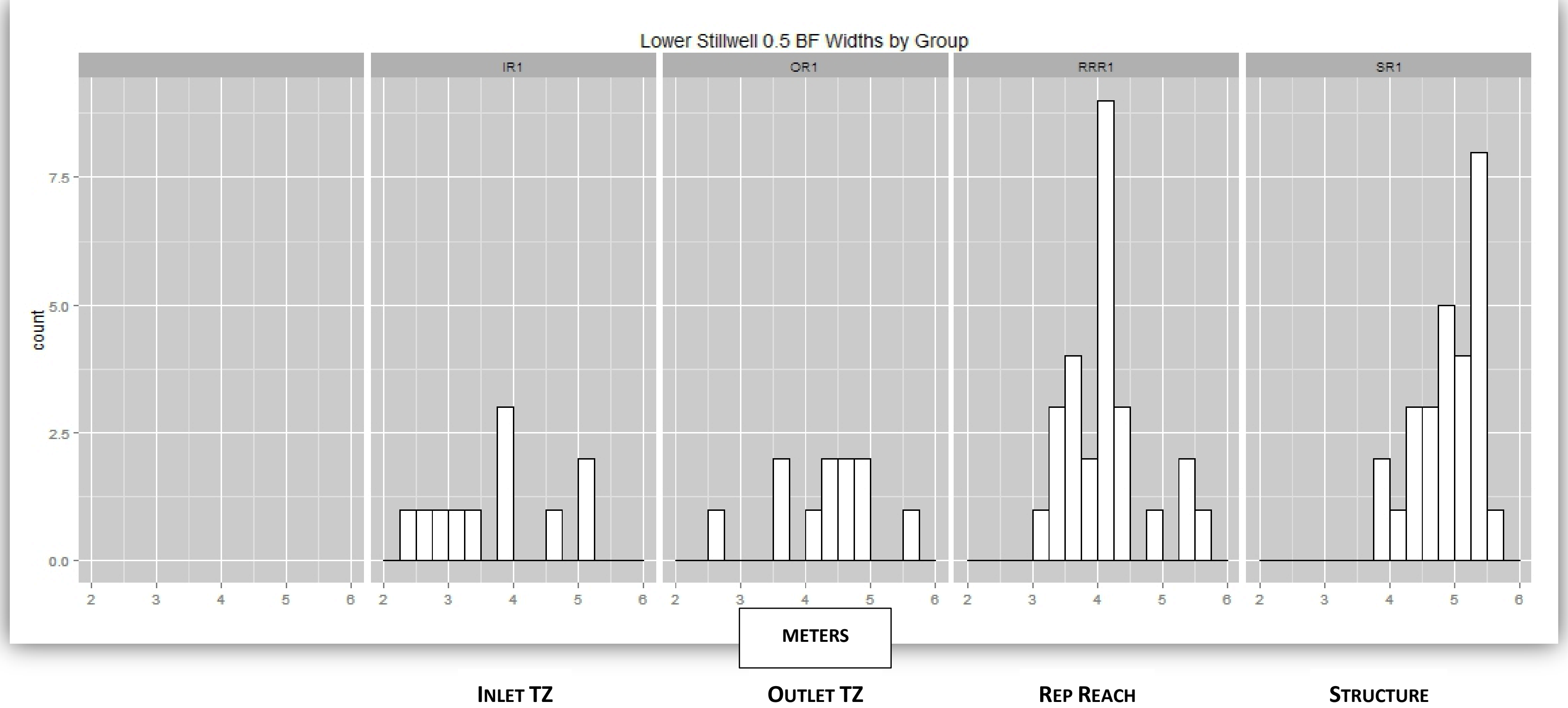


FIGURE 38: LOWER STILLWELL WIDTH AT HALF BANKFULL STAGE HISTOGRAM

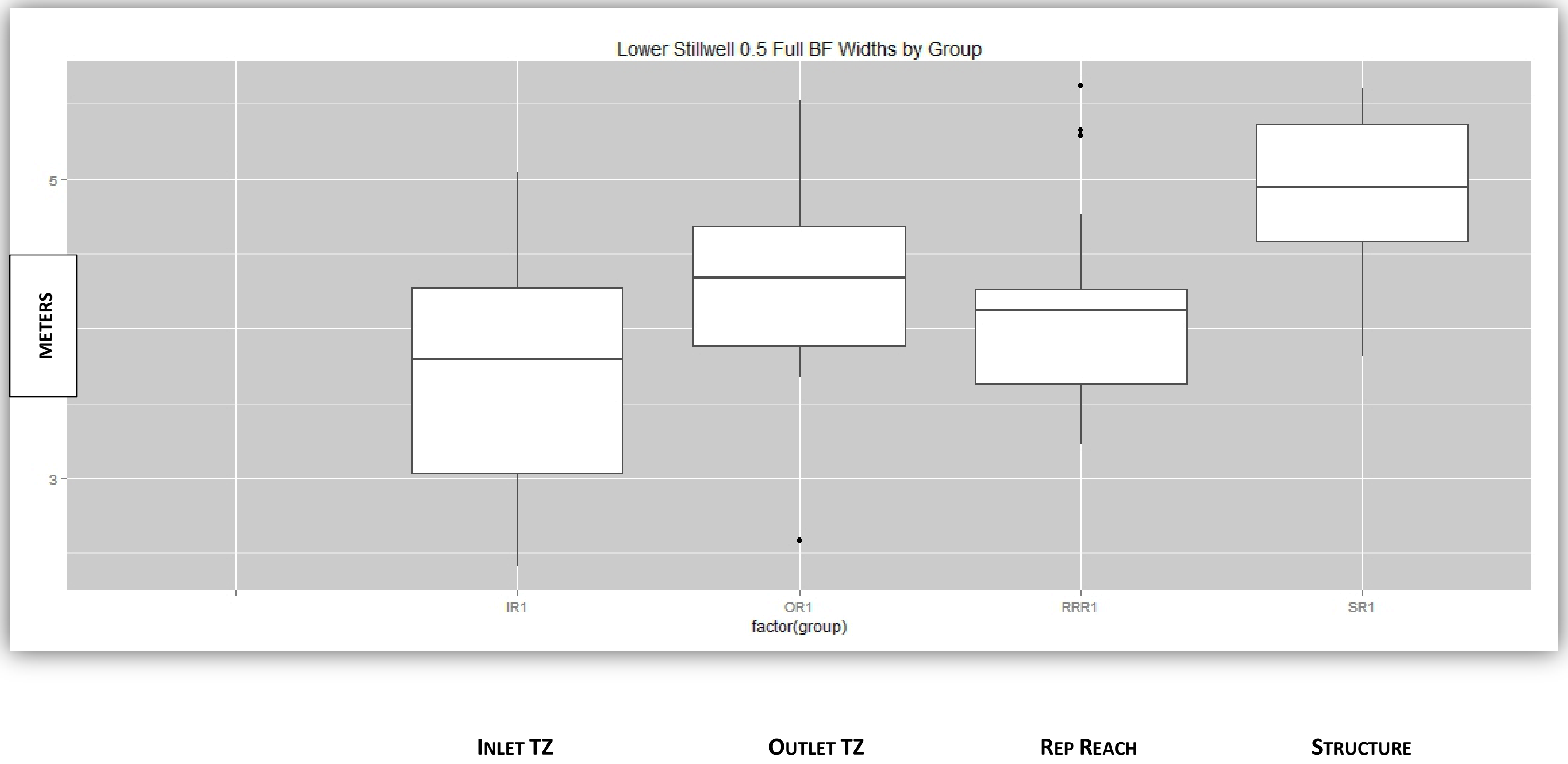


Figure 39: Lower Stillwell width at half bankfull stage boxplot

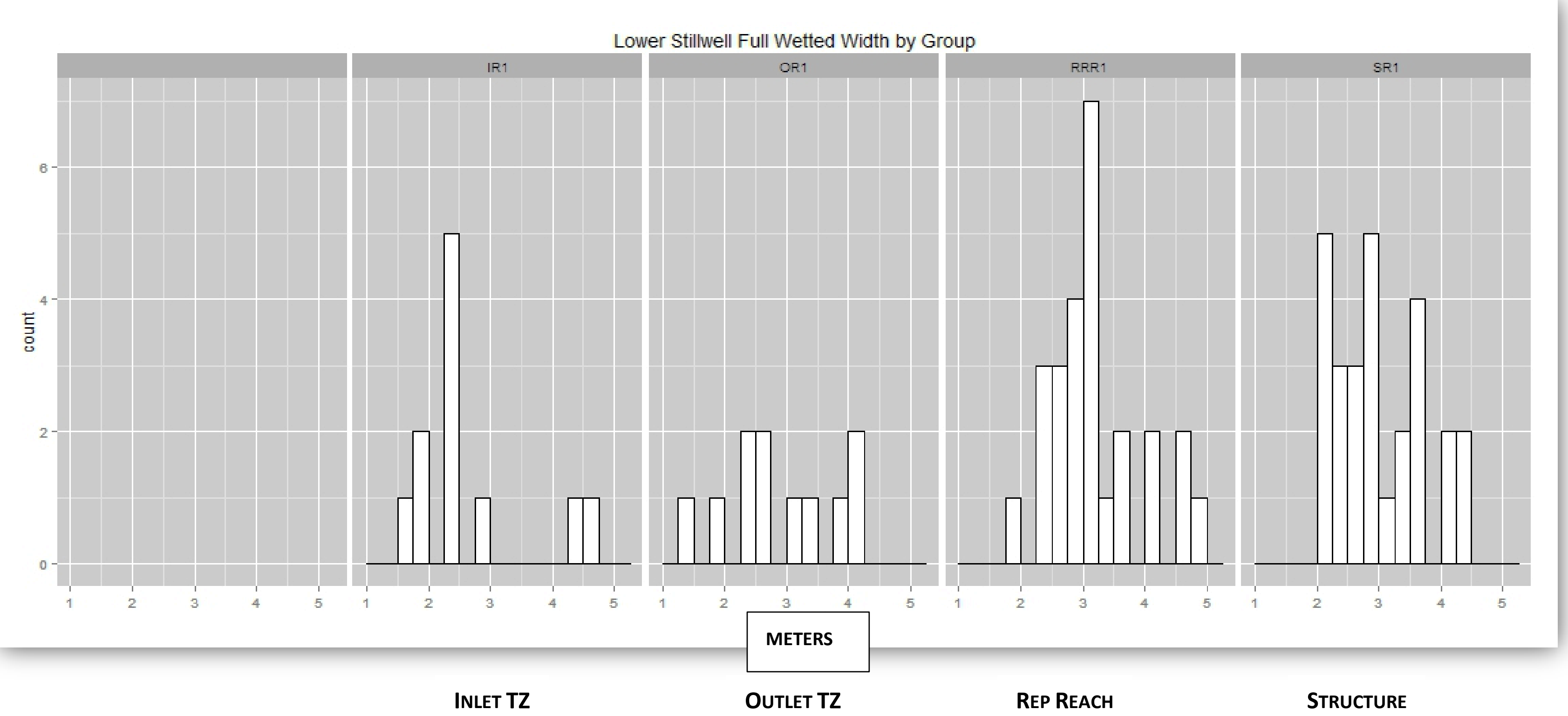


FIGURE 40: LOWER STILLWELL WIDTH AT LOW FLOW HISTOGRAM

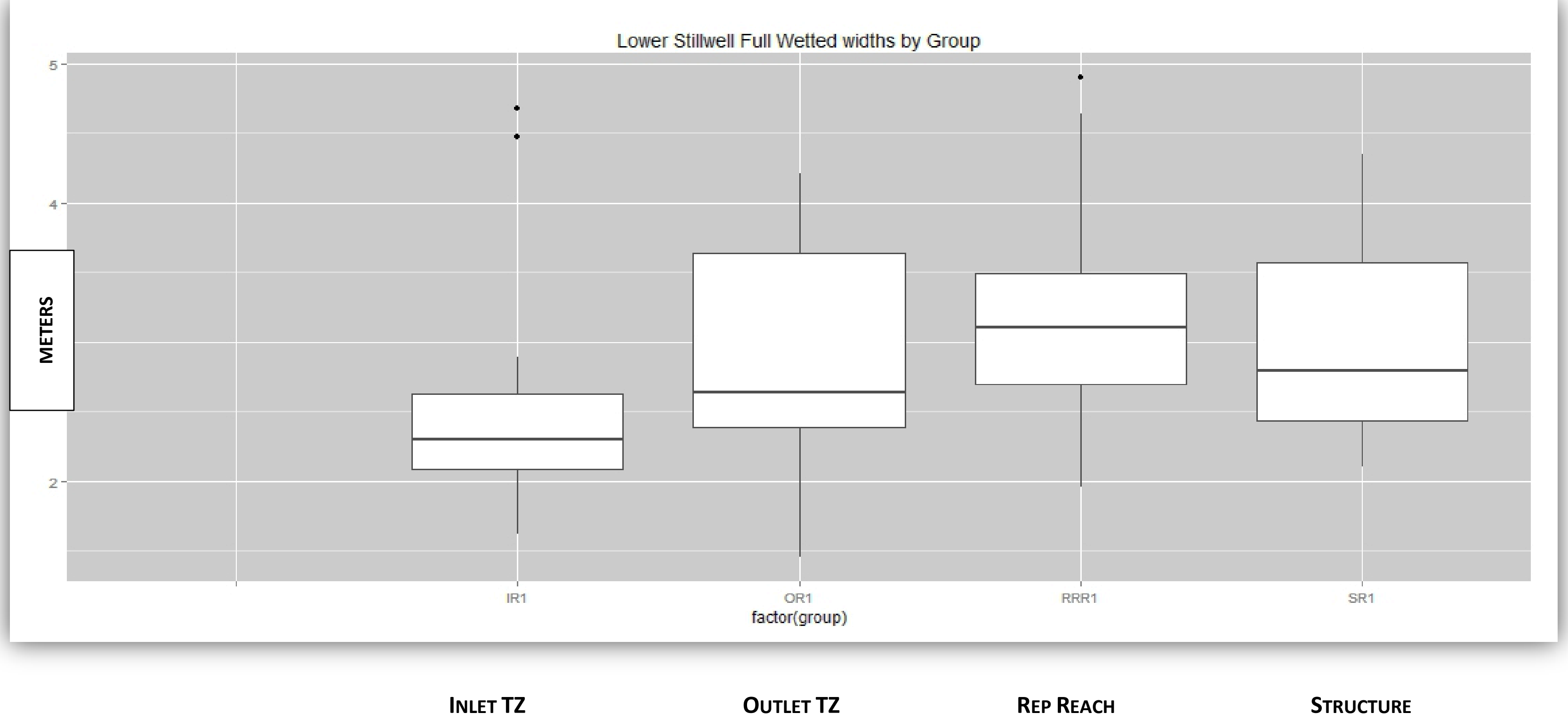


FIGURE 41: LOWER STILLWELL WIDTH AT LOW FLOW BOXPLOT

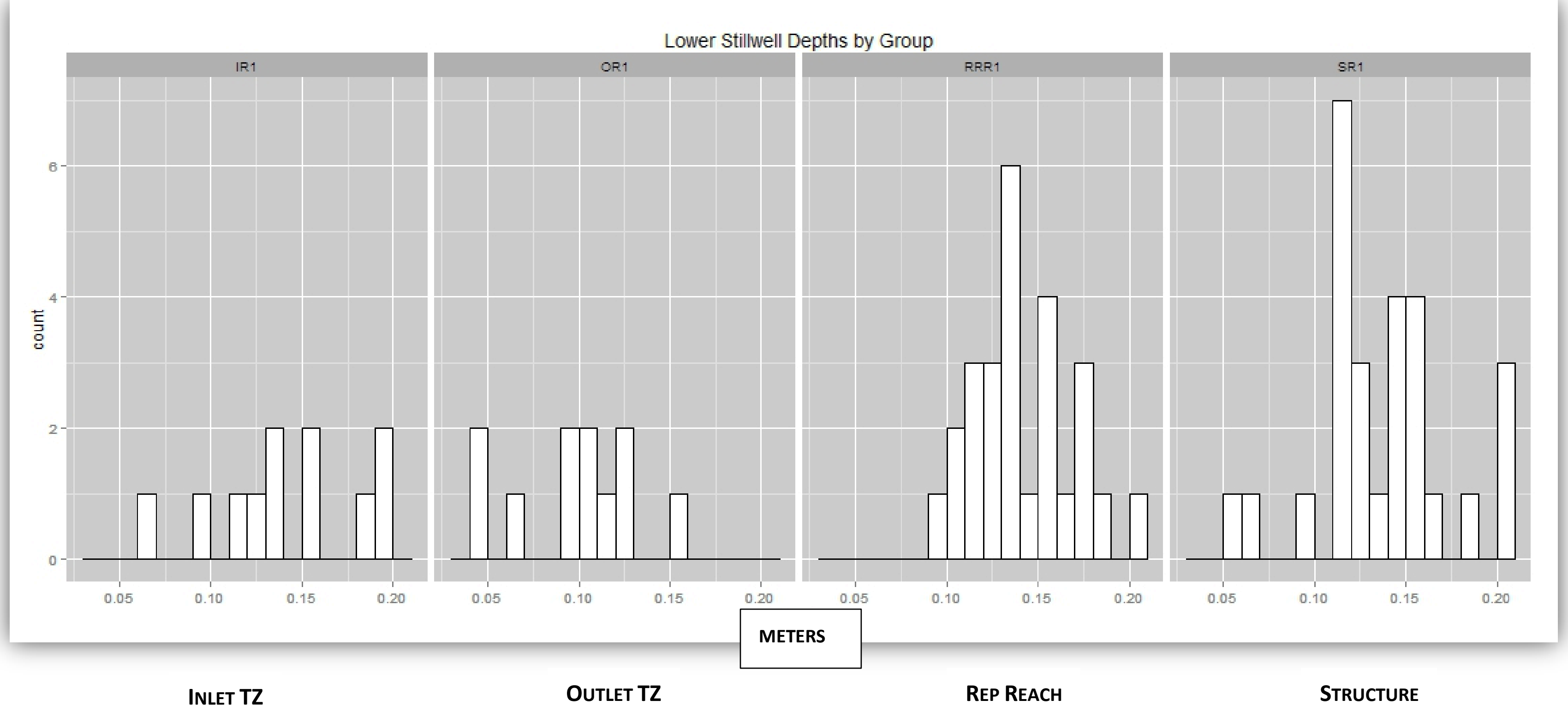


FIGURE 42: LOWER STILLWELL MAXIMUM DEPTH HISTOGRAM

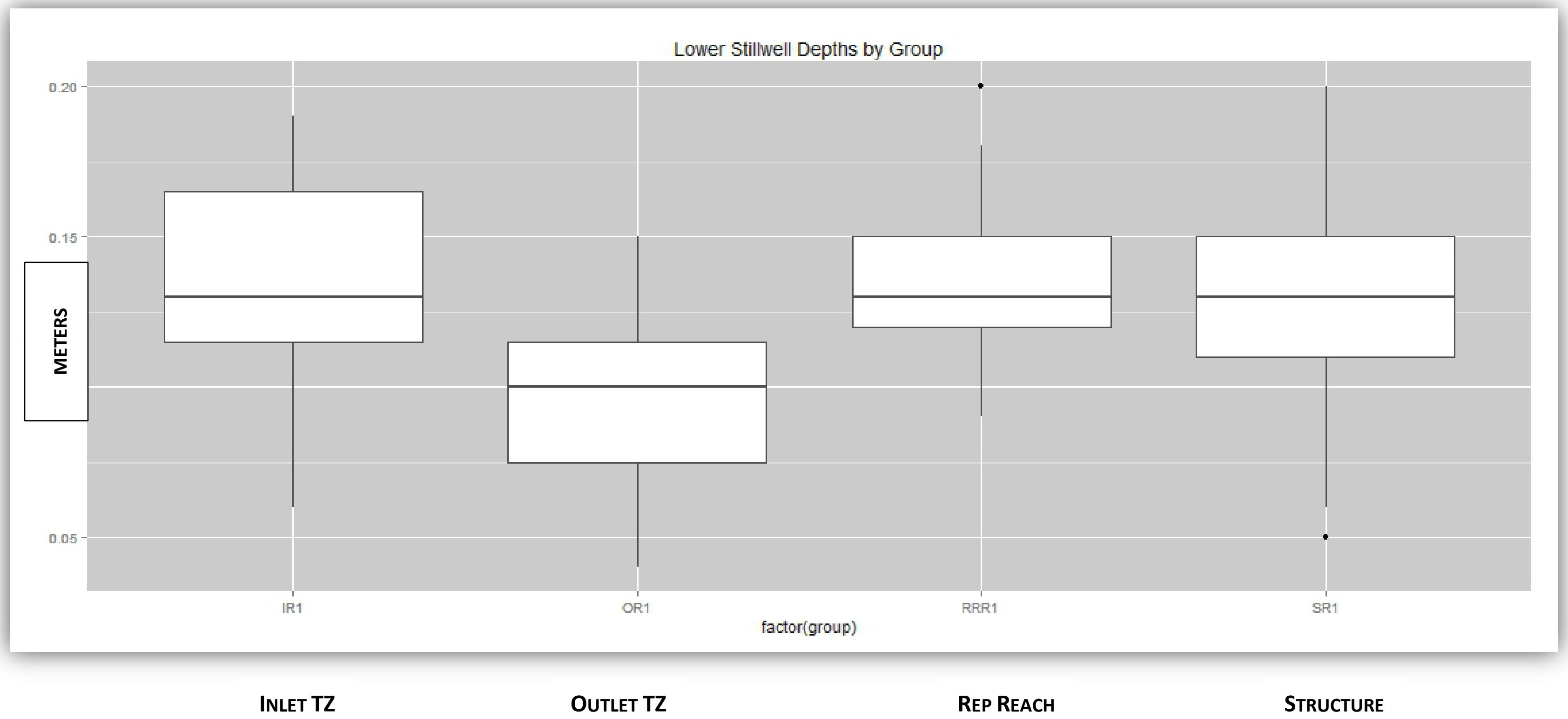


Figure 43: Lower Stillwell maximum depth boxplot

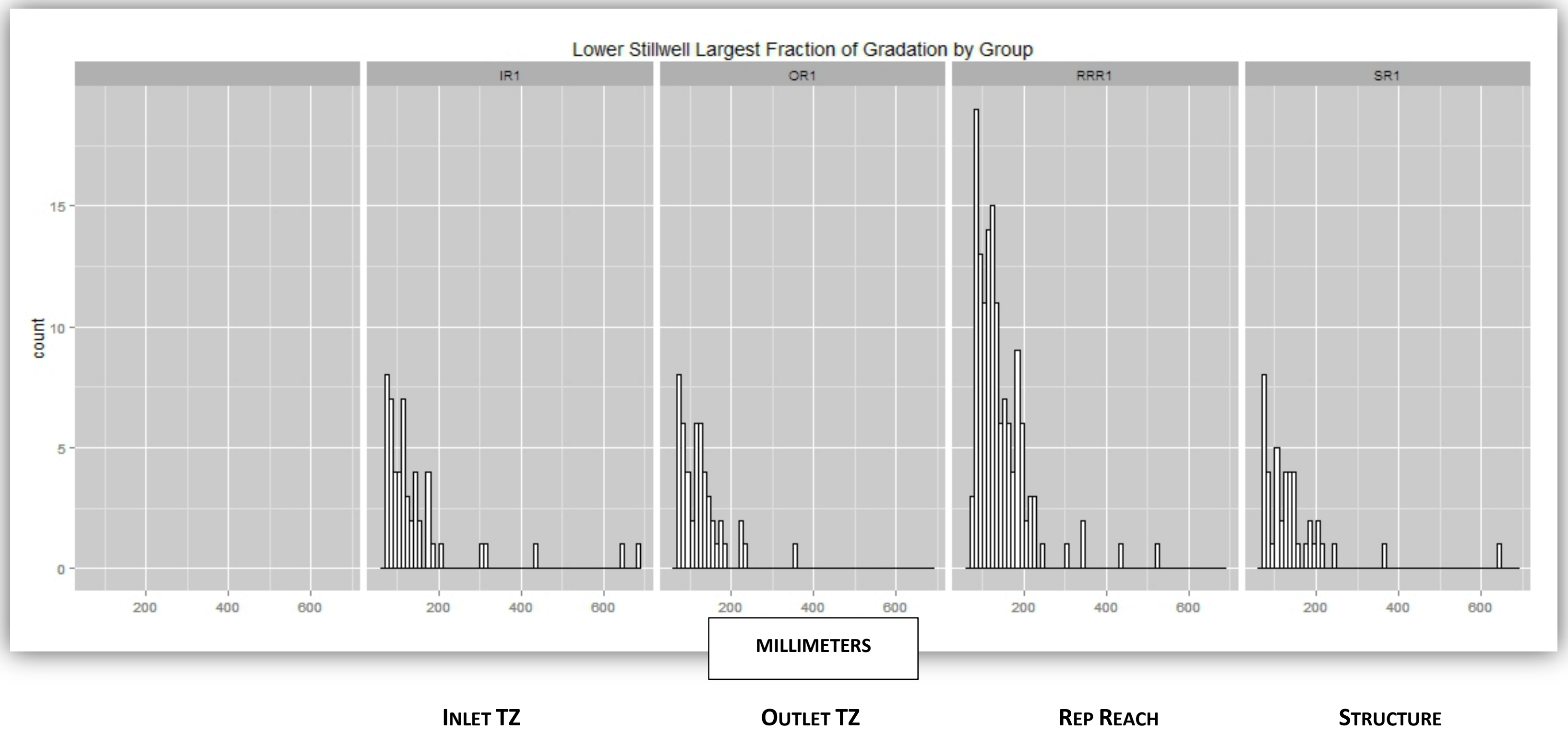


Figure 44: Lower Stillwell coarse fraction histogram

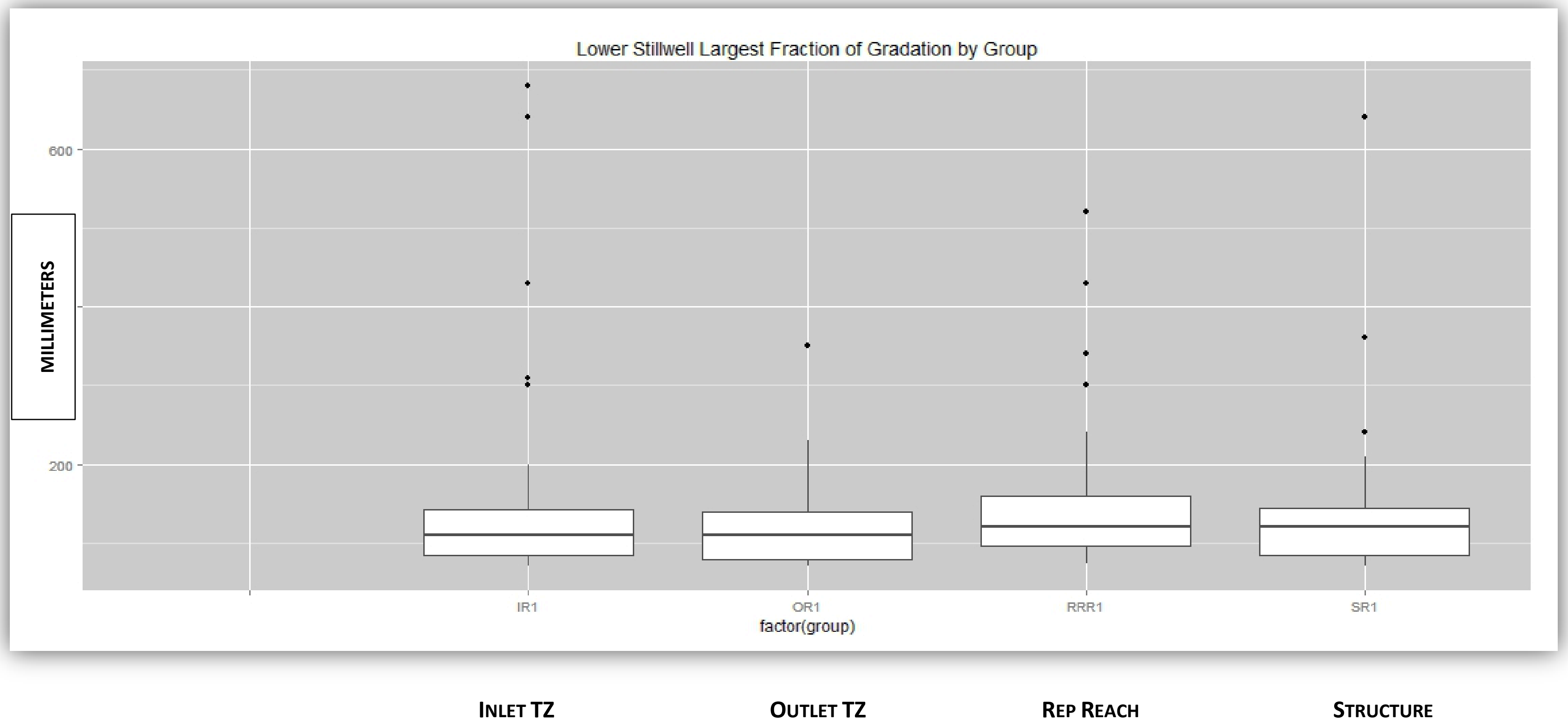


Figure 45: Lower Stillwell coarse fraction boxplot

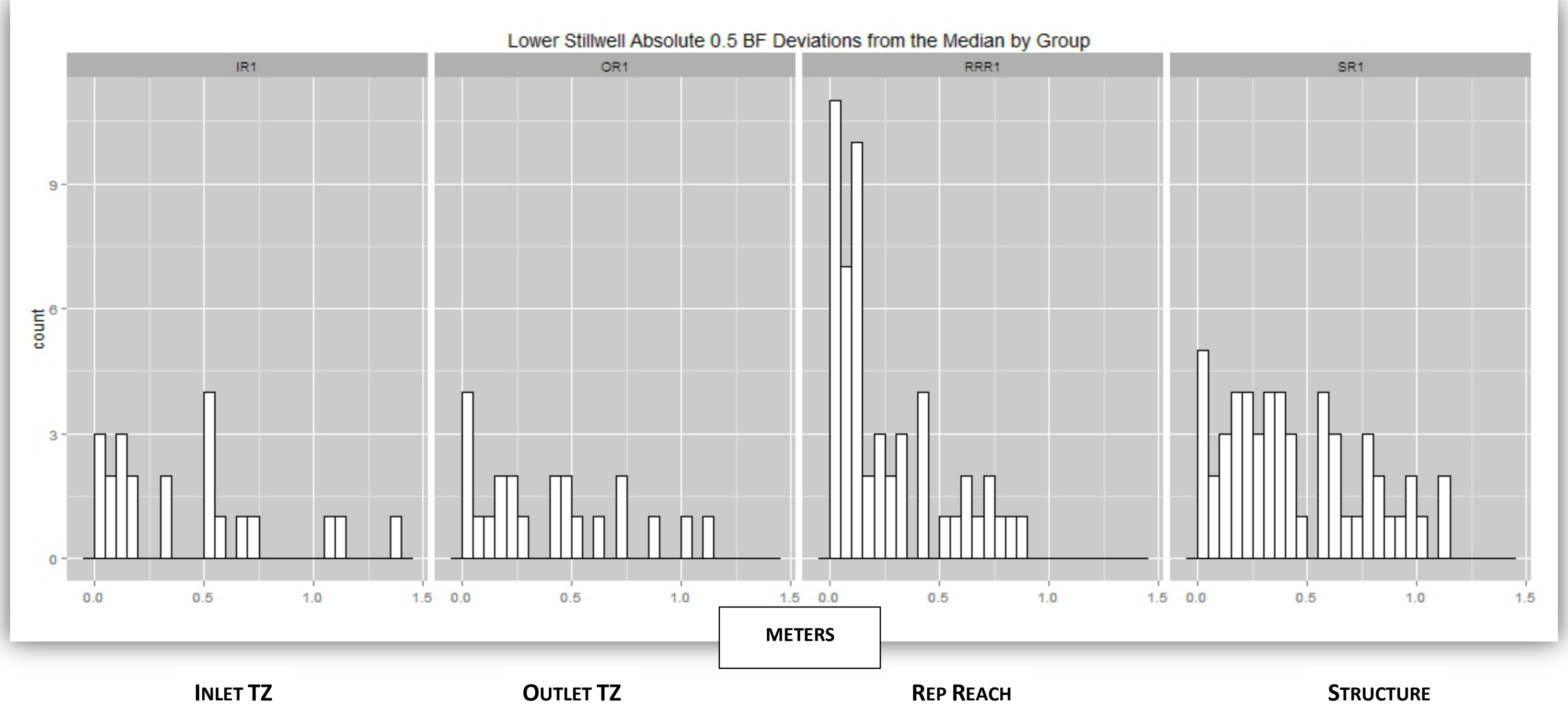


Figure 46: Lower Stillwell bank irregularity histogram

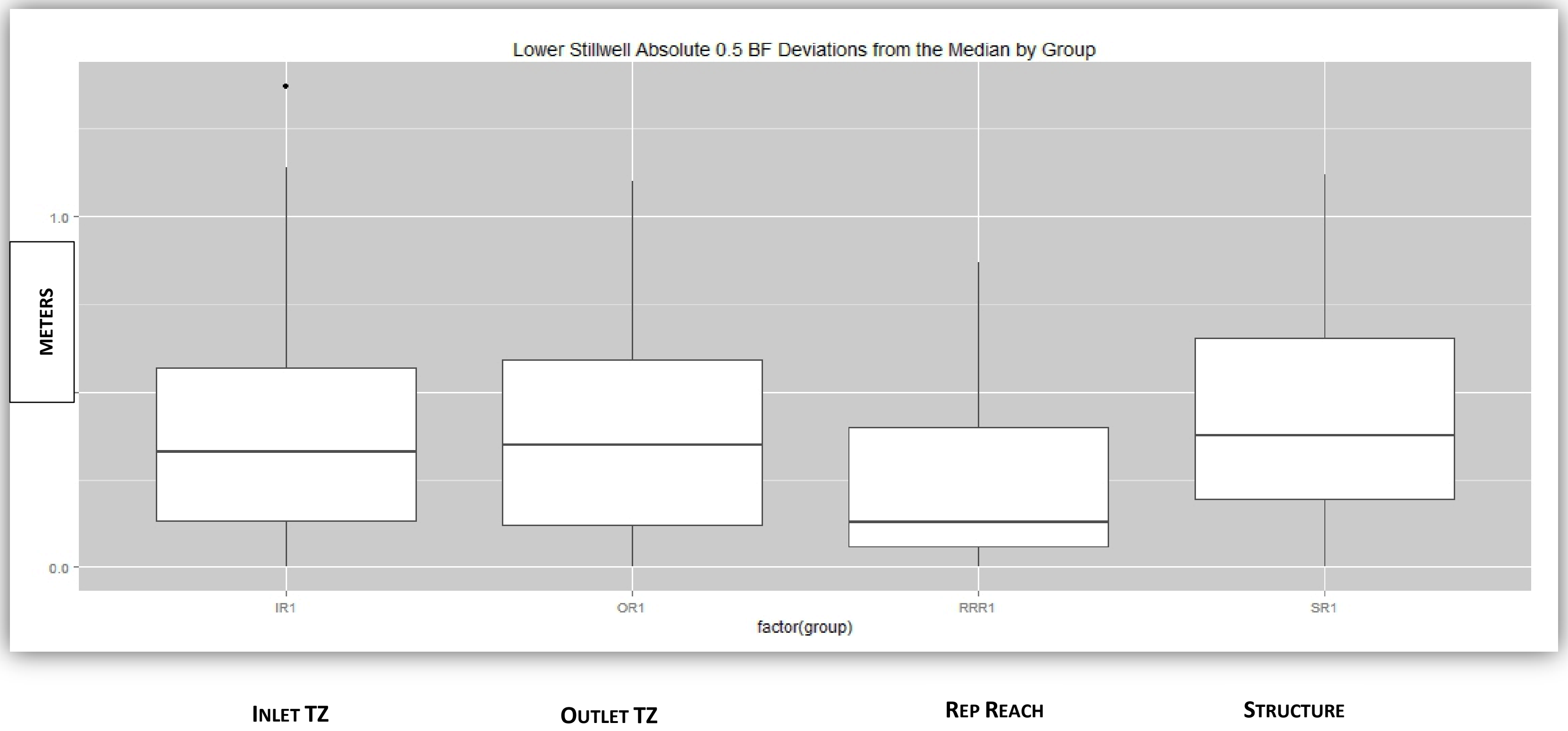


FIGURE 47: LOWER STILLWELL BANK IRREGULARITY BOXPLOT

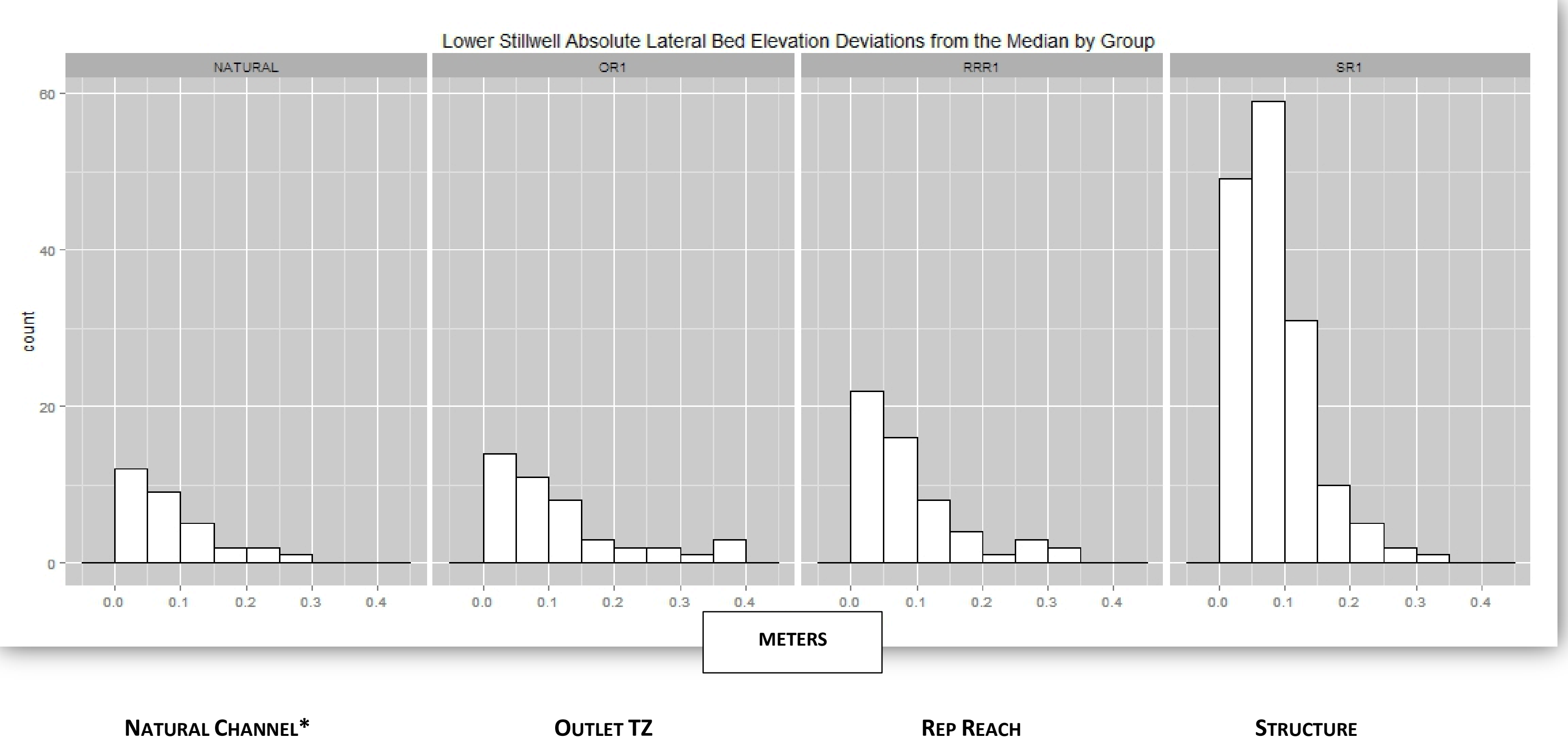


FIGURE 48: LOWER STILLWELL BED IRREGULARITY HISTOGRAM

*ERRONEOUSLY, CROSS SECTIONS WERE NOT COLLECTED WITHIN THE INLET TRANSITION ZONE, BUT INSTEAD SLIGHTLY UPSTREAM OF THE BOUNDARY WITHIN THE NATURAL CHANNEL. BED IRREGULARITY IS NOT EVALUATED FOR THE INLET TRANSITION ZONE.

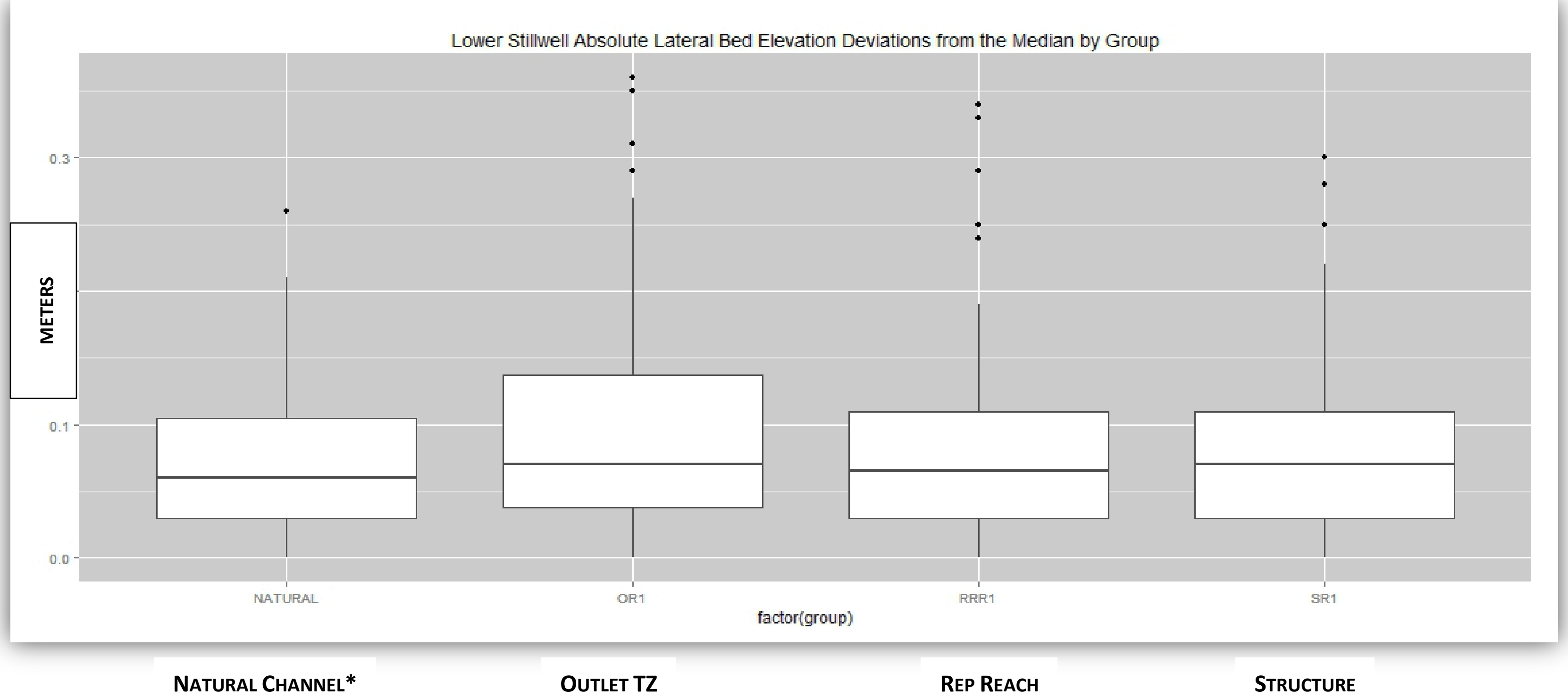


Figure 49: Lower Stillwell bed irregularity boxplot

*Erroneously, cross sections were not collected within the inlet transition zone, but instead slightly upstream of the boundary within the natural channel. Bed irregularity is not evaluated for the inlet transition zone.

5.2.1.2.2 NORTH FORK INDIAN SITE DESCRIPTION AND RESULTS

The North Fork Indian (a.k.a. Mann) Creek road-stream crossing site is located at T 16 S, R 9 W, section 2, NE ¼ of the E ½ on the Siuslaw National Forest (Central Coast RD) in Oregon. The road is Forest road 2116. North Fork Indian Creek is a direct tributary to Indian Creek within the Siuslaw River Basin (which empties into the Pacific Ocean). Its watershed area is 1.97 km^2 and the bankfull flow is approximately 1.86 m^3/s (Ellis-Sugai, 2011). The study reach flows through a fairly confined valley bottom, although a floodplain is present in some places. The channel has pool-riffle morphology. Some large wood is present in the channel, but large log jams and steps were not observed. Riparian vegetation is composed of deciduous trees and shrubs (predominantly salmon berry), grasses and broad leafed flora. Lithology is the Tyee Formation, a “very thick sequence of rhythmically bedded, medium- to fine-grained micaceous, feldspathic, lithic, or arkosic marine sandstone and micaceous carbonaceous siltstone; contains minor interbeds of dacite tuff in the upper part (Walker and MacLeod, 1991, USGS Geologic Map Key). The channel bed substrate is not embedded; particles are rounded to sub-rounded sedimentary, small to medium sized cobbles and gravels. Pebble counts were done within two design riffles; the D50s are 47.1 mm and 55.7 mm. Pebble counts were also done at two representative riffles; the D50s are 52.9 mm and 64 mm (level II data). The average study reach gradient is 1.6%. The average bankfull width is 3 m. Recently, a road which crossed North Fork Indian upstream of the structure (but within the study reach) was decommissioned. See Appendix A [North Fork Indian Site Data] for photos and data plots. Data quartiles for each metric can be found within Table 16.

The new structure at the NF Indian site was a replacement (2003) of a previously existing crossing structure that was “undersized by half” (Ellis-Sugai, 2012b). The new structure is an aluminum, open-bottom pipe arch. It has a span of 3.9 m, height 1.3 m and length 11.6 m. The inlet is projecting and the outlet is at-grade with a rock riffle control. The stream gradient breaks mid-way through the structure. The inlet transition zone and upper half of the structure have a gradient of 1.4% (gradient 1). The outlet transition zone and lower half of the structure have a gradient of 2.6% (gradient 2). Two representative reaches were selected for comparison; representative reach 1 has a gradient of 1.4%, representative reach 2 has a gradient of 1.6%. A 50% gradient criterion was used to select each representative reach. Long term monitoring by Forest personnel indicates that, since replacement, the design channel gradient has increased in slope from 1.93% in 2004 to 3.35% in 2011. Significant aggradation (0.6 m) has occurred upstream of the structure inlet. Stream-banks became well formed, and significant sand deposits formed along the right bank within the structure. A scour pool present at the previous structure outlet filled after replacement and a new pool formed just upstream of the structure outlet (Ellis-Sugai, 2012b). An approximately 25 year recurrence interval flood occurred in January of 2012 (Siuslaw NF, 2012). Significant adjustments to the design channel bed are not apparent when 2011 and 2012 photos are compared.

The inlet transition zone unit is composed of a long riffle (IR1). The unit within the upstream half of the structure is also a riffle (SR1). The units within the downstream half of the structure are a short steep riffle (SSR2), a moderately steep riffle (SR2), and a small pool (SP2). The pool is approximately half within and half outside of the structure (but is analyzed as if it were entirely within the structure). The outlet transition zone unit is a moderately steep riffle (OR2). A comparable sequence for the steep riffle, moderately steep riffle and pool design channel units was not identified within the natural channel. Instead, individual channel units were compared.

Table 12: North Fork Indian level II results for riffle 1, by metric

Zone	Channel unit	Width at bankfull stage	Width at half bankfull stage	Width at low flow (wetted width)	Maximum depth	Coarse fraction	Bank irregularity	Bed irregularity	Bank continuity	Percent Total Score	Evaluation	Override
Inlet TZ	Riffle 1	0.003	0.252	0.062	0.510	0.000	0.001	0.246	na	69	Questionable	Similar
Structure	Riffle 1	0.001	0.028	0.034	0.727	na	0.252	0.506	96%	80	Similar	Questionable
Outlet TZ	Riffle 1										Not Applicable	

Table 13: North Fork Indian level II results for riffle 2, by metric

Zone	Channel unit	Width at bankfull stage	Width at half bankfull stage	Width at low flow (wetted width)	Maximum depth	Coarse fraction	Bank irregularity	Bed irregularity	Bank continuity	Percent Total Score	Evaluation	Override
Inlet TZ	Riffle 2										Not Applicable	
Structure	Riffle 2	0.764	0.019	0.000	0.994	na	0.008	0.615	96%	83	Similar	Questionable
Outlet TZ	Riffle 2	0.000	0.269	0.004	0.786	0.691	0.008	0.746	na	76	Similar	

Table 14: North Fork Indian level II results for Steep Riffle 2, by metric

Zone	Channel unit	Width at bankfull stage	Width at half bankfull stage	Width at low flow (wetted width)	Maximum depth	Coarse fraction	Bank irregularity	Bed irregularity	Bank continuity	Percent Total Score	Evaluation	Override
Inlet TZ	Steep Riffle 2										Not Applicable	
Structure	Steep Riffle 2	0.000	0.629	0.000	0.857	na	0.615	na	96%	73	Questionable	→Similar
Outlet TZ	Steep Riffle 2										Not Applicable	

Table 15: North Fork Indian level II results for Pools 2, by metric

Zone	Channel unit	Width at bankfull stage	Width at half bankfull stage	Width at low flow (wetted width)	Maximum depth	Coarse fraction	Bank irregularity	Bed irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Pools 2										Not Applicable
Structure	Pools 2	0.234	0.191	0.560	0.273	na	0.000	0.000	96%	85	Similar
Outlet TZ	Pools 2										Not Applicable

Evaluations within the override column are discussed and justified within section 6.2.3.2. Overrides in general are explained within section 0.

12, 13, 14, and Table 15 results are color coded so that green cells were scored 5, or "good," orange cells were scored 3, or "fair," and red cells were scored 1, or "poor." The scoring criteria are based on the Wilcoxon Rank-Sum test p-values:

- $p \geq 0.05$, score 5
- $\leq p < 0.05$, score 3
- $0.001 < p$, score 1

Table 16: North Fork Indian Level II Metric Data Quartiles

Zone and Metric	riffle 1			riffle 2			steep riffle 2			pools 2		
Width at Bankfull Stage	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	4.06	4.49	4.81	4.48	4.77	4.99	3.06	3.66	4.39	3.62	4.37	4.58
Inlet Transition	3.41	3.64	3.97									
Structure	3.46	3.57	3.65	2.97	3.13	3.34	3.30	3.35	3.52	3.42	3.80	4.03
Outlet Transition				4.33	4.51	5.95						
Width at 1/2 Bankfull Stage	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	2.87	3.24	4.02	2.64	3.06	3.35	2.26	2.27	2.77	2.70	2.80	2.84
Inlet Transition	2.96	3.16	3.21									
Structure	2.60	2.84	2.89	1.88	2.04	2.36	2.02	2.34	2.48	1.98	2.45	2.69
Outlet Transition				3.16	3.51	3.85						
Wetted Width	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	2.05	2.45	2.72	1.98	2.42	2.53	1.42	1.47	1.50	2.01	2.12	2.17
Inlet Transition	1.79	1.79	1.79									
Structure	1.99	2.13	2.29	1.33	1.41	1.57	0.78	1.01	1.28	1.99	2.14	2.26
Outlet Transition				1.65	1.73	1.79						

Zone and Metric	Riffle 1			Riffle 2			Steep riffle 2			Pool 2		
Maximum Depth at Low Flow	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	0.06	0.08	0.09	0.08	0.10	0.11	0.06	0.06	0.07	0.14	0.21	0.26
Inlet Transition	0.06	0.08	0.10									
Structure	0.07	0.08	0.10	0.14	0.15	0.16	0.06	0.08	0.09	0.15	0.18	0.20
Outlet Transition				0.09	0.10	0.13						
Coarse Fraction (>d50) Gradation	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**			
rep reach	72.50	90.00	118.00	65.00	80.00	107.50						
Inlet Transition	60.00	75.00	100.00									
Structure	na	na	na	na	na	na						
Outlet Transition				65.00	77.50	100.00						

Zone and Metric	Riffle 1			Riffle 2			Steep riffle 2			Pool 2		
Bank Irregularity	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	0.08	0.20	0.50	0.22	0.39	1.74	0.05	0.09	0.89	0.47	0.84	1.26
Inlet Transition	0.04	0.09	0.14									
Structure	0.10	0.15	0.34	0.07	0.15	0.29	0.09	0.16	0.30	0.08	0.28	0.41
Outlet Transition				0.05	0.20	0.48						
Bed Irregularity	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	0.02	0.06	0.10	0.04	0.06	0.12	na	na	na	0.12	0.16	0.20
Inlet Transition	0.02	0.05	0.15									
Structure	0.03	0.06	0.07	0.03	0.08	0.15	0.05	0.08	0.11	0.03	0.07	0.14
Outlet Transition				0.02	0.06	0.14						

5.2.1.2.3 WEST FORK GREENBRIER 01 SITE DESCRIPTION AND RESULTS

The WF01 (West Fork 1) road-stream crossing site is located at 38˚38’00’’ and 79˚48’00’’ at Cove Run, on the Monongahela National Forest in West Virginia (Forest Road number 44). Although the site should have been named Cove Run 1, I believe I called it West Fork 1 to remain consistent with Forest Service documentation.

Cove Run is a direct tributary to the West Fork Greenbrier River within the New River and Ohio River basins. The channel has pool-riffle morphology, with steps occasionally created by large wood and tree roots. The creek flows within a valley bottom wide enough to include a floodplain for most of its length. Terraces are occasionally present. Vegetation on the floodplain is predominantly deciduous trees, grasses and broad leafed vegetation. The substrate is sandstone and siltstone, poorly to moderately embedded, and moderately imbricated. Coal was also found within the substrate. Particles are angular and planar. The study reach gradient is 3.7%. The average bankfull width is 5 m. See Appendix A11 [WF01 Site Data] for photos and data plots. Data quartiles for each metric can be found within Table 19.

The project at the WF01 road-stream crossing was the replacement of an existing structure for the purpose of improving aquatic organism passage. It was completed in 2010. Field work was done shortly after, in August 2011. The installed structure is a pre-cast concrete box with rock constructed wing walls (~30˚) at the inlet and outlet. The outlet is at stream grade, with no designed control features. The structure spans 3.66 m, is 2.44 m high and 17.28 m long. At the inlet, the streambed is 2.05 m below the structure, 2.12 m halfway through the structure, and 2.2 m at the outlet. The design channel is a long riffle unit, with a significant gradient break at the structure outlet. The inlet transition zone and structure have a gradient of 4%; the outlet transition zone has a gradient of 3%. A 25% gradient criterion was used to select the representative reach, which has a gradient of 3.5%. The same representative reach is used for both slope segments (1 steeper and 2 gentler). A small scour pool has developed along the right bank at the inlet. Analyzed groups are IR1 (inlet TZ riffle), SR1 (structure riffle), and OR2. WF01 is 47 m upstream from a second structure, WF02. WF02 is a bike trail-stream crossing which was completed at the same time as WF01.

When field work began at WF01, Cove Run was a dry channel. Rain did occur while field work was in progress, and the natural channel began to flow. Many salamanders, fish and crawdads appeared after significant surface water was present. The riffle within the inlet transition zone was flowing, while the substrate within the structure and the outlet transition zone remained dry. At some distance downstream of WF01, surface flow again emerged. At the inlet, surface water could be heard pouring into a vertical hole, suggesting water was piping around or under the structure.

Table 17: WF01 level II results for riffle 1, by metric

Zone	Channel unit	Width at bankfull stage	Width at half bankfull stage	Width at low flow (wetted width)	Maximum depth	Coarse fraction	Bank irregularity	Bed irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Riffle 1	0.019	0.001			0.000	0.093	0.932	na	57	Questionable
Structure	Riffle 1	0.000	0.312			0.000	0.000	0.000	0%	35	Dissimilar
Outlet TZ	Riffle 1								na		Not Applicable

Table 18: WF01 level II results for riffle 2, by metric

Zone	Channel unit	Width at bankfull stage	Width at half bankfull stage	Width at low flow (wetted width)	Maximum depth	Coarse fraction	Bank irregularity	Bed irregularity	Bank continuity	Total Score	Evaluation
Inlet TZ	Riffle 2								na		Not Applicable
Structure	Riffle 2										Not Applicable
Outlet TZ	Riffle 2	0.000	0.000			0.000	0.830	0.350	na	37	Dissimilar

17and 18 results are color coded so that green cells were scored 5, or "good," orange cells were scored 3, or "fair," and red cells were scored 1, or "poor." The scoring criteria are based on the Wilcoxon Rank-Sum test p-values:

- $p \geq 0.05$, score 5
- $\leq p < 0.05$, score 3
- $< p$, score 1

TABLE 19: WF01 LEVEL II METRIC DATA QUARTILES

Zone and Metric	riffle 1		
Width at Bankfull Stage	**25th quartile**	**Median**	**75th quartile**
rep reach	5.59	5.63	5.73
Inlet Transition	4.07	4.65	5.88
Structure	3.65	3.66	3.66
Outlet Transition	8.59	8.75	9.17
Width at 1/2 Bankfull Stage	**25th quartile**	**Median**	**75th quartile**
rep reach	3.49	3.93	4.47
Inlet Transition	2.75	3.06	3.82
Structure	3.65	3.65	3.66
Outlet Transition	6.36	8.75	9.17
Wetted Width (50th Quartile)	**25th quartile**	**Median**	**75th quartile**
rep reach	NA	NA	NA
Inlet Transition	NA	NA	NA
Structure	NA	NA	NA
Outlet Transition	NA	NA	NA
Maximum Depth at Low Flow 50th Quartile	**25th quartile**	**Median**	**75th quartile**
rep reach	NA	NA	NA
Inlet Transition	NA	NA	NA
Structure	NA	NA	NA
Outlet Transition	NA	NA	NA
Coarse Fraction (>d50) Gradation	**25th quartile**	**Median**	**75th quartile**
rep reach	150	190	280
Inlet Transition	100	130	180
Structure	75	100	140
Outlet Transition	70	100	160
Bank Irregularity	**25th quartile**	**Median**	**75th quartile**
rep reach	0.12	0.35	0.61
Inlet Transition	0.09	0.20	0.46
Structure	0.00	0.02	0.03
Outlet Transition	0.13	0.36	0.73
Bed Irregularity	**25th quartile**	**Median**	**75th quartile**
rep reach	0.03	0.08	0.20
Inlet Transition	0.02	0.06	0.22
Structure	0.00	0.01	0.04
Outlet Transition	0.03	0.06	0.09

5.2.1.2.4 WEST FORK GREENBRIER 02 SITE DESCRIPTION AND RESULTS

The WF02 (West Fork site 2) bike path-stream crossing site is located at 38˚38’00’’ and 79˚48’00’’ at Cove Run. WF02 is on the Monongahela National Forest in West Virginia (Forest Trail 312). Although the site should have been named Cove Run 2, I believe I called it West Fork 2 to remain consistent with Forest Service documentation.

Cove Run is a direct tributary to the West Fork Greenbrier River within the New River and Ohio River basins. The channel has pool-riffle morphology, with steps occasionally created by large wood and tree roots. The creek flows within a valley bottom wide enough for a flood plain along most of its length. Terraces are occasionally present. Vegetation on the floodplain is predominantly deciduous trees, grasses and broad leafed vegetation. Substrate is sandstone and siltstone, poorly to moderately embedded, and moderately imbricated. Coal was also found within the substrate. Particles are angular and planar. The study reach gradient is 3.7%. The average bankfull width is 5 m. See Appendix A12 [WF02 Site Data] for photos and data plots. Data quartiles for each metric can be found within Table 21.

The project at WF02 was the replacement of an existing crossing for the purpose of improving aquatic organism passage. It was completed recently, in 2010. Field work occurred shortly after, in August 2011. The installed structure is a pre-cast concrete box with rock constructed wing walls (30˚) at the inlet and outlet. The outlet is at stream grade, with no designed control features. The WF02 structure outlet is located 11.6 m upstream from the confluence of Cove Run and the West Fork Greenbrier River. The structure spans 3.65 m, is 2.44 m high and 11 m long. At the inlet, the streambed is 2.04 m below the structure, 2.14 m halfway through the structure, and 2.02 m at the outlet. The inlet transition, structure and outlet transition zones were all designed as a single gradient riffle. The design reach has a gradient of 4.8% and the representative reach has gradient 3.5%. Analyzed groups are IR1 (inlet TZ riffle), SR1 (structure riffle), OR1 (outlet TZ riffle). A 50% gradient criterion was used to find a representative reach. WF02 is 46 m downstream from a second structure, WF01. WF01 is a road-stream crossing completed at the same time as WF02.

The channel at WF02 was dry upon arrival and for most of the level II data collection. After significant precipitation, flow within the natural channel began. After some time, a small trickle could be seen flowing through the structure.

Table 20: WF02 level II results for riffle 1, by metric

Zone	Channel unit	Width at bankfull stage	Width at half bankfull stage	Width at low flow (wetted width)	Maximum depth	Coarse fraction	Bank irregularity	Bed irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Riffle 1	0.048	0.009	na	na	0.000	0.605	0.355	na	57	Questionable
Structure	Riffle 1	0.000	0.041	na	na	0.000	0.000	0.885	0%	33	Dissimilar
Outlet TZ	Riffle 1	0.000	0.000	na	na	0.000	0.002	0.388	na	31	Dissimilar

Table 20 results are color coded so that green cells were scored 5, or "good," orange cells were scored 3, or "fair," and red cells were scored 1, or "poor." The scoring criteria are based on the Wilcoxon Rank-Sum test p-values:

- $p \geq 0.05$, score 5
- $\leq p < 0.05$, score 3
- $< p$, score 1

TABLE 21: WF02 LEVEL II METRIC DATA QUARTILES

Zone and Metric	riffle 1		
Width at Bankfull Stage	**25th quartile**	**Median**	**75th quartile**
rep reach	5.59	5.63	5.73
Inlet Transition	5.48	6.42	6.91
Structure	3.66	3.68	3.81
Outlet Transition	6.28	6.48	6.76
Width at 1/2 Bankfull Stage	**25th quartile**	**Median**	**75th quartile**
rep reach	3.49	3.93	4.47
Inlet Transition	4.01	5.17	5.60
Structure	3.46	3.54	3.65
Outlet Transition	5.45	5.61	5.83
Wetted Width	**25th quartile**	**Median**	**75th quartile**
rep reach	NA	NA	NA
Inlet Transition	NA	NA	NA
Structure	NA	NA	NA
Outlet Transition	NA	NA	NA
Maximum Depth at Low Flow	**25th quartile**	**Median**	**75th quartile**
rep reach	NA	NA	NA
Inlet Transition	NA	NA	NA
Structure	NA	NA	NA
Outlet Transition	NA	NA	NA
Coarse Fraction (>d50) Gradation	**25th quartile**	**Median**	**75th quartile**
rep reach	150	190	280
Inlet Transition	110	150	190
Structure	80	110	153
Outlet Transition	40	55	84
Bank Irregularity	**25th quartile**	**Median**	**75th quartile**
rep reach	0.12	0.35	0.61
Inlet Transition	0.17	0.29	0.79
Structure	0.00	0.00	0.08
Outlet Transition	0.06	0.10	0.19
Bed Irregularity	**25th quartile**	**Median**	**75th quartile**
rep reach	0.03	0.08	0.20
Inlet Transition	0.02	0.06	0.11
Structure	0.05	0.08	0.13
Outlet Transition	0.02	0.05	0.08

5.2.1.2.5 SITE 3 DESCRIPTION AND RESULTS

The road-stream crossing called “Site 3” is located on an un-named tributary to the West Fork Greenbrier River in West Virginia. The crossing is on the Monongahela National Forest at approximately 38˚42’N and 79˚47’W. The road is Forest Road 44. The channel flows through a fairly narrow valley, although flood plains and terraces surround the stream for most of the study reach. The channel morphology is pool-riffle with occasional large wood-forced steps. Pools are shallow. The study reach is moderately sinuous and has a gradient of 5%. The average bankfull width is 2.62 m. Thick, predominantly deciduous riparian vegetation surrounds the channel. The understory is composed of grass and broad leafy plants. The channel substrate is planar and angular sedimentary gravels and cobbles. Particles are poorly embedded and somewhat imbricated. See Appendix A8 [Site 3 Site Data] for photos and data plots. Data quartiles for each metric can be found within Table 23.

The road-stream crossing structure is the replacement of a previously undersized culvert. The new structure is a circular concrete pipe with concrete wing walls at the inlet and outlet. The structure width is 1.73 m and is 13.25 m long. The design channel is a long riffle which extends from the inlet transition zone through the outlet transition zone. The replacement was completed in 2010. Level II monitoring field work was completed in August of 2011; level I monitoring occurred in October 2012. The design gradient is 9% within the inlet transition zone and 4.5% within the structure and outlet transition zones. The structure and outlet transition zone were compared with a representative reach of 5% gradient. A 25% gradient criterion was used to select the representative reach. No representative reach was identified for the steeper inlet transition zone, which was therefore not analyzed. The study reach was extended beyond the normal 20-30 bankfull widths upstream and downstream of the structure because of the long structure length.

At the time of data collection (August 2011), the channel was predominantly dry. After significant precipitation, water began to flow on the surface within the natural channel. The bed within the structure remained mostly dry. Flow could be seen bubbling up from the bed with pressure, just downstream of the structure.

Table 22: Site 3 Level II results for riffle 1, by metric

Zone	Channel unit	Width at bankfull stage	Width at half bankfull stage	Width at low flow (wetted width)	Maximum depth	Coarse fraction	Bank irregularity	Bed irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Riffle 1										Not Applicable
Structure	Riffle 1	0.000	0.000	na	na	0.010	0.000	0.000	13%	30	Dissimilar
Outlet TZ	Riffle 1	0.000	0.000	na	na	0.000	0.959	0.698	na	37	Dissimilar

22 results are color coded so that green cells were scored 5, or “good,” orange cells were scored 3, or “fair,” and red cells were scored 1, or “poor.” The scoring criteria are based on the Wilcoxon Rank-Sum test p-values:

- $p \geq 0.05$, score 5
- $\leq p < 0.05$, score 3
- $< p$, score 1

TABLE 23: SITE 3 LEVEL II METRIC DATA QUARTILES

Zone and Metric	riffle 1		
Width at Bankfull Stage	**25th quartile**	**Median**	**75th quartile**
rep reach	1.91	2.45	3.41
Inlet Transition	5.80	6.44	6.63
Structure	1.69	1.70	1.71
Outlet Transition	4.12	5.95	6.35
Width at 1/2 Bankfull Stage	**25th quartile**	**Median**	**75th quartile**
rep reach	1.13	1.30	1.50
Inlet Transition	3.35	4.70	5.10
Structure	1.52	1.63	1.63
Outlet Transition	3.68	4.29	4.76
Wetted Width	**25th quartile**	**Median**	**75th quartile**
rep reach	na	na	na
Inlet Transition	na	na	na
Structure	na	na	na
Outlet Transition	na	na	na
Maximum Depth at Low Flow	**25th quartile**	**Median**	**75th quartile**
rep reach	na	na	na
Inlet Transition	na	na	na
Structure	na	na	na
Outlet Transition	na	na	na
Coarse Fraction (>d50) Gradation	**25th quartile**	**Median**	**75th quartile**
rep reach	50	80	120
Inlet Transition	60	40	80
Structure	45	65	90
Outlet Transition	25	45	60
Bank Irregularity	**25th quartile**	**Median**	**75th quartile**
rep reach	0.05	0.10	0.24
Inlet Transition	0.18	0.44	0.86
Structure	0.01	0.02	0.03
Outlet Transition	0.05	0.22	0.71
Bed Irregularity	**25th quartile**	**Median**	**75th quartile**
rep reach	0.02	0.03	0.06
Inlet Transition	0.02	0.03	0.07
Structure	0.01	0.01	0.02
Outlet Transition	0.02	0.04	0.06

5.2.1.2.6 DOG SLAUGHTER CREEK SITE DESCRIPTION AND RESULTS

The Dog Slaughter Creek road-stream crossing site is located at 84˚18’30’’ and 36˚51’30’’, on the Daniel Boone National Forest, Kentucky. The crossing is on Forest Road 195, at mile-post 3. The site is located just downstream of the North Fork Gulf Branch and Dog Slaughter Creek (for consistency with the biological monitoring group, I refer to the site as Dog Slaughter, although some Forest Service documents refer to it as North Fork Gulf Branch). The creek is a tributary to the Cumberland River within the Ohio River Basin. Dog Slaughter Creek is home to the federally threatened blackside dace, among many other species of aquatic organisms. The channel flows through a narrow valley, frequently bounded by sandstone bedrock cliffs. The creek has pool-riffle morphology and pools are frequent, long and deep. The channel bed is bedrock completely covered with a thin veneer of substrate. Where bedrock-dominated hillslopes are coupled with the channel, small and large boulders are common. Substrate is generally coarse, with sand deposited in the pools. Where the valley widens, floodplains are present. The floodplain and hillslopes are densely vegetated with trees, especially rhododendrons. The average bankfull channel width is 5 m. The creek plunges over an approximately 10 m high waterfall (Dog Slaughter Falls), about 5.6 km downstream from the road-stream crossing site. See Appendix A4 [Dog Slaughter Site Data] for photos and data plots. Data quartiles for each metric can be found within Table 28.

The project was the replacement of a previously undersized road-stream crossing structure. The project was completed in September 2011. Monitoring field work was completed shortly after, in October 2012. The new structure is a steel, open-bottom pipe arch on concrete footers. As one would expect from a new structure, no rust or leaks were observed. Banks surrounding the inlet and outlet transition zones were covered with a geotextile mesh and planted with grass. No shrubby vegetation was yet present on the banks. The culvert inlet and outlet project just beyond the road fill. The fill around the culvert inlet is armored with small stacked boulders to approximately bankfull elevation.

The structure has a span of 3.7 m, a height of 1.8 m (measured from the top of the footers), and a length of 25.9 m. The design channel gradient is 0.6%. A 50% gradient criterion was used to select the representative reach, which has a gradient of 0.8%. The slope segment which contains the constructed coarse riffle downstream of the outlet transition zone has a gradient of 2.9%. The representative riffle slope segment to which it was compared has a gradient of 4.1%. A 50% gradient criterion was used to select the representative reach for the constructed riffle. The inlet transition zone design units are the lower portion of a riffle (IR1) and the head of a long pool (IP1). The pool continues through the structure (SP1) to the bottom of the outlet transition zone (OP1). The upper portion of the pool within the structure has a bed of bedrock, the lower portion is covered by a veneer of sand and finer sediments. Below the outlet transition zone, a coarse riffle was constructed (CR2) which backwaters the pool through the structure. The gradient of the constructed riffle was analyzed and a representative riffle was selected, independent of the design reach analysis. Because the pool extends beyond the structure zone, and analyzing the head and tail of the pool separately is not meaningful, the design channel was analyzed not just by group, but also by population; design versus natural.

Table 24: Dog Slaughter level II results for riffle 1, by metric

Zone	Channel unit	Width at bankfull stage	Width at half bankfull stage	Width at low flow (wetted width)	Maximum depth	Coarse fraction	Bank irregularity	Bed irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Riffle 1	0.000	0.034	0.000	0.000	0.000	0.030	0.765	na	36	Dissimilar
Structure	Riffle 1										Not Applicable
Outlet TZ	Riffle 1										Not Applicable

TABLE 25: DOG SLAUGHTER LEVEL II RESULTS FOR POOL 1, BY METRIC

Zone	Channel unit	Width at bankfull stage	Width at half bankfull stage	Width at low flow (wetted width)	Maximum depth	Coarse fraction	Bank irregularity	Bed irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Pools 1										Not Applicable
Structure	Pools 1	0.000	0.000	0.000	0.004	na	0.000	0.000	0%	28	Dissimilar
Outlet TZ	Pools 1	0.117	0.002	0.007	0.012	na	0.000	0.010	na	66	Questionable

TABLE 26: DOG SLAUGHTER LEVEL II RESULTS FOR THE CONSTRUCTED RIFFLE, BY METRIC

Channel Unit/Zone	Width at bankfull stage	Width at half bankfull stage	Width at low flow (wetted width)	Maximum depth	Coarse fraction	Bank irregularity	Bed irregularity	Bank continuity	Percent Total Score	Evaluation
Constructed Riffle	0.000	0.011	0.000	0.000	0.399	0.718	0.682	na	58	Questionable

TABLE 27: DOG SLAUGHTER LEVEL II RESULTS FOR THE DESIGN CHANNEL, BY METRIC

Population	Width at bankfull stage	Width at half bankfull stage	Width at low flow (wetted width)	Maximum depth	Coarse fraction	Bank irregularity	Bed irregularity	Bank continuity	Percent Total Score	Evaluation
Design	0.000	0.040	0.003	0.497	0.000	0.000	0.002	0%	42	Dissimilar

24, 25, 26, AND TABLE 27 RESULTS ARE COLOR CODED SO THAT GREEN CELLS WERE SCORED 5, OR "GOOD," ORANGE CELLS WERE SCORED 3, OR "FAIR," AND RED CELLS WERE SCORED 1, OR "POOR." THE SCORING CRITERIA ARE BASED ON THE WILCOXON RANK-SUM TEST P-VALUES:

- P ≥ 0.05, SCORE 5
- ≤ P < 0.05, SCORE 3
- < P, SCORE 1

TABLE 28: DOG SLAUGHTER LEVEL II METRIC DATA QUARTILES

Zone and Metric	riffle 1			pools 1		
Width at Bankfull Stage	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	5.87	8.15	8.86	6.09	6.53	7.73
Inlet Transition	6.45	6.89	7.12	5.76	6.10	6.10
Structure				2.91	3.61	3.69
Outlet Transition				7.33	7.62	7.93
Width at 1/2 Bankfull Stage	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	5.30	5.75	6.19	3.70	4.83	5.94
Inlet Transition	4.16	4.74	5.65	5.25	5.25	5.85
Structure				2.89	2.91	3.65
Outlet Transition				6.50	7.03	7.25
Wetted Width	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	4.87	5.31	6.02	3.54	4.69	5.79
Inlet Transition	3.66	3.93	4.21	4.64	4.64	4.64
Structure				2.86	2.88	2.90
Outlet Transition				5.88	6.75	7.01
Maximum Depth at Low Flow	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	0.15	0.16	0.22	0.50	0.82	1.07
Inlet Transition	0.06	0.09	0.13	0.19	0.20	0.25
Structure				0.35	0.50	0.52
Outlet Transition				0.41	0.52	0.55
Coarse Fraction (>d50) Gradation	**25th quartile**	**Median**	**75th quartile**			
rep reach	190	230	310			
Inlet Transition	125	150	180			
Structure						
Outlet Transition						
Bank Irregularity	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	0.50	0.83	1.24	0.44	0.90	1.23
Inlet Transition	0.19	0.45	0.84	0.04	0.08	0.27
Structure				0.04	0.10	0.17
Outlet Transition				0.10	0.25	0.47
Bed Irregularity	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	0.03	0.07	0.11	0.10	0.20	0.34
Inlet Transition	0.03	0.07	0.11			
Structure				0.01	0.04	0.18
Outlet Transition				0.06	0.11	0.30

TABLE 29: DOG SLAUGHTER LEVEL II CONSTRUCTED RIFFLE METRIC DATA

Zone and Metric	Con Riff 2
Width at Bankfull Stage	**Median**
rep reach	8.27
Constructed Riffle	6.72
Width at 1/2 Bankfull Stage	**Median**
rep reach	5.53
Constructed Riffle	5.24
Wetted Width	**Median**
rep reach	5.35
Constructed Riffle	4.34
Maximum Depth at Low Flow	**Median**
rep reach	0.11
Constructed Riffle	0.06
Coarse Fraction (>d50) Gradation	**Median**
rep reach	200
Constructed Riffle	190
Bank Irregularity	**Median**
rep reach	0.75
Constructed Riffle	0.35
Bed Irregularity	**Median**
rep reach	0.05
Constructed Riffle	0.05

5.2.1.2.7 BIG LICK BROOK SITE DESCRIPTION AND RESULTS

Big Lick Brook is located at 84˚ 18’30’’ and 36˚51’30’’ on the Daniel Boone National Forest, Kentucky. It is a direct tributary to the Cumberland River, within the Ohio River Basin. The road is Forest Road 272; the crossing is at mile post 1.7. The site is not a recent replacement (circa 1960’s?), as evidenced by the significant rust line within the structure. The site is monitored by the biological monitoring group and was therefore included in this study. Physical effectiveness monitoring field work was completed in October 2012. Big Lick Creek is home to the federally threatened blackside dace, among many other species of aquatic organisms. See Appendix A2 [Big Lick Site Data] for photos and data plots. Data quartiles for each metric can be found within Table 33.

The channel is a sinuous pool-riffle stream incised into fine grained sandy banks. Bedrock outcrops are occasionally present. The stream plunges over a large waterfall about 0.4 km downstream from the road-stream crossing. Channel bed particles are sedimentary. Substrate is coarse cobble with small, hard pebbles of quartz eroded from the conglomerate bedrock. Pools have significant sand deposits. Tributaries truncate the study reach at the upstream and downstream ends. The average bankfull width within the natural channel is 5 m.

The structure is a squashed (oval) steel CMP. It has a span of 3.9 m, is 2.1 m high and 12.3 m long. The inlet is mitered and the outlet is at stream grade with no control. There is a rust line along the structure walls about 0.3 m above the bed. The roof at the outlet has partially collapsed under the weight of fill. Substrate has been scoured from the upper third of the culvert because the pipe is located at a natural bend in the stream. Road fill to the right of the culvert inlet has also been scoured by flood flows.

The design reach is composed of a riffle and pool (head) within the inlet transition zone (IR1 and IP1). The pool extends through the structure (SP1), for the entire length of the outlet transition zone, and beyond (OP1). The inlet and outlet transition zones are truncated mid-unit at artificial grade controls (riffle rib and submerged wood). A single slope segment represents the design channel with gradient

0.39%. The gradient of the design reach is 0.4%; the gradient of the representative reach is 0.2%. The study reach gradient is 0.9%. The representative reach was chosen by a 100% gradient criterion. It has a gradient of 0.21%. Big Lick was analyzed both by group and by population; design versus natural.

TABLE 30: BIG LICK LEVEL II RESULTS FOR RIFFLE 1, BY METRIC

Zone	Channel unit	Width at bankfull stage	Width at half bankfull stage	Width at low flow (wetted width)	Maximum depth	Coarse fraction	Bank irregularity	Bed irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Riffle 1	0.001	0.014	0.001	0.634	0.000	1.000	0.115	na	64	Questionable
Structure	Riffle 1										Not Applicable
Outlet TZ	Riffle 1										Not Applicable

TABLE 31: BIG LICK LEVEL II RESULTS FOR POOL 1, BY METRIC

Zone	Channel unit	Width at bankfull stage	Width at half bankfull stage	Width at low flow (wetted width)	Maximum depth	Coarse fraction	Bank irregularity	Bed irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Pool 1	0.001	0.038	0.005	0.318	na	0.003	0.121	na	60	Questionable
Structure	Pool 1	0.000	0.410	0.017	0.061	na	0.000	0.005	0%	55	Questionable
Outlet TZ	Pool 1	0.002	0.024	0.292	0.200	na	0.969	0.072	na	80	Similar

Table 32: Big Lick level II results for the design channel, by metric

By Population (Design vs. Natural)	Width at bankfull stage	Width at half bankfull stage	Width at low flow (wetted width)	Maximum depth	Coarse fraction	Bank irregularity	Bed irregularity	Bank continuity	Percent Total Score	Evaluation
Design	0.293	0.891	0.809	0.004	0.000	0.000	0.046	0%	58	Questionable

30, Table 31, and 32 results are color coded so that green cells were scored 5, or “good,” orange cells were scored 3, or “fair,” and red cells were scored 1, or “poor.” The scoring criteria are based on the Wilcoxon Rank-Sum test p-values:

- $p \geq 0.05$, score 5
- $\leq p < 0.05$, score 3
- $< p$, score 1

TABLE 33: BIG LICK LEVEL II METRIC DATA QUARTILES

Zone and Metric	riffle 1			pools 1		
Width at Bankfull Stage	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	5.35	5.59	6.23	4.24	4.88	5.30
Inlet Transition	4.45	4.59	4.61	5.39	5.57	5.92
Structure				3.88	3.89	3.90
Outlet Transition				4.89	5.71	6.14
Width at 1/2 Bankfull Stage	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	4.25	5.29	6.01	3.63	4.03	4.72
Inlet Transition	3.14	3.35	3.71	4.64	4.84	4.95
Structure				3.88	3.88	3.89
Outlet Transition				4.31	4.66	5.15
Wetted Width	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	4.33	4.75	5.18	2.46	3.12	3.57
Inlet Transition	1.56	1.72	1.84	3.95	4.18	4.23
Structure				3.64	3.64	3.80
Outlet Transition				2.97	3.62	4.31
Maximum Depth at Low Flow	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	0.06	0.07	0.08	0.15	0.19	0.25
Inlet Transition	0.07	0.07	0.07	0.20	0.25	0.28
Structure				0.21	0.23	0.27
Outlet Transition				0.15	0.25	0.37
Coarse Fraction (>d50) Gradation	**25th quartile**	**Median**	**75th quartile**			
rep reach	55.0	70.0	90.0			
Inlet Transition	90.0	110.0	137.5			
Structure						
Outlet Transition						
Bank Irregularity	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	0.19	0.35	0.50	0.14	0.37	0.55
Inlet Transition	0.10	0.21	0.48	0.05	0.16	0.26
Structure				0.03	0.04	0.06
Outlet Transition				0.14	0.53	0.88
Bed Irregularity	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	0.02	0.04	0.10	0.04	0.08	0.12
Inlet Transition	0.04	0.08	0.16	0.06	0.11	0.15
Structure				0.03	0.05	0.08
Outlet Transition				0.03	0.10	0.20

5.2.1.2.8 SPARKS BROOK SITE DESCRIPTION AND RESULTS

The Sparks Brook road-stream crossing is located on the Middlebury Ranger District of the Green Mountain National Forest in Vermont. The crossing site is on Forest road 59. The lat/long coordinates are approximately 44˚60’N, 72˚59’W. The replacement design was implemented in 2010. Field work was completed in June 2012. See Appendix A9 [Sparks Brook Site Data] for photos and data plots. Data quartiles for each metric can be found within Table 37.

The study reach is steep, with an overall gradient of 4.8%. The Sparks Brook natural channel has step-pool morphology within a confined valley. Most steps are made of medium to large boulders, but some incorporate large wood. Mosses and leafy plants cover the banks and terraces (where present). A granitic bedrock outcrop, approximately 30 m downstream from the structure, forms a small waterfall. Although 1.2 m high, Forest fisheries biologists do not believe it is a barrier to fish passage during higher flows. In 2011, high flows associated with hurricane Irene formed a large log jam and associated avulsion near the top of the study reach. Traditional bankfull indicators are few or absent because of that recent flood. Conifers and deciduous trees are the dominant riparian vegetation.

The design structure at the road-stream crossing is an open bottomed pipe arch. At the inlet, the steel pipe has partially caved in where it projects beyond the road fill. The structure has a length of 28.3 m, height of 2.82 m, and width of 4.4 m. The average bankfull channel width is 6 m. The design channel bed is composed of several slope segments and channel units. A single gradient riffle (2.79%) extends from the top of the inlet transition zone midway through the structure (IR1 and SR1). The gradient then steepens, extending just beyond the structure outlet (5.1%). Channel units within the steeper segment are riffle (SR2), step (SS2), and step pool (SSP2). Most of the data were collected within the longer riffle units (IR1, SR1, and SR2). The gradient becomes gentle within the outlet transition zone (1%); channel units measured are a step (OS0) and pool (OP0). A 50% gradient criterion was used to select the representative reach for slope segment 1 (although they are actually different by 57%). A 25% gradient criterion was used to select the representative reach for slope segment 2. They differ by 4.8%.

More data were collected than are analyzed. Data were accidentally collected upstream of the present inlet transition boundary. Also in error, no representative reach was selected for the outlet transition zone slope segment (0), and therefore the Outlet TZ is not analyzed quantitatively (except for the step at the structure outlet).

There are two major steps within the design channel: one is located mid-way through the structure, the other at the structure outlet. The steps are analyzed separately from one another, but are compared with the same representative step. The step at the outlet (analyzed as if it were in the outlet transition zone) forms the gradient break between slope segments 2 and 0. This means it can be compared with the representative reach for either slope segment. Because no representative reach was selected for slope segment 0, this step is compared with the representative step for slope segment 2. The step-pool unit below that step is analyzed as part of the step analysis. Data were collected at only the tallest design steps. Within the representative channel, only the most "representative" step was measured. There are two steps just below the analyzed step at the structure outlet (within slope segment 0). Of these, the upstream step appears to have been mobilized since it was first installed, probably by high flows during hurricane Irene. The step is no longer hydraulically effective and is now nearly submerged within a unit which I consider to be a pool run. The step at the downstream boundary of slope segment 0 (bottom of the outlet transition zone) is a linear feature with equal-sized step blocks. It looks similar to a constructed wall. No pool is scoured below this step; the step appears to be hydraulically ineffective.

Table 34: Sparks Brook level II results for riffle 1, by metric

Zone	Channel unit	Width at bankfull stage	Width at half bankfull stage	Width at low flow (wetted width)	Maximum depth	Coarse fraction	Bank irregularity	Bed irregularity	Bank continuity	Total Score	Evaluation
Inlet TZ	Riffle 1	0.007	0.417	0.006	1.000	0.011	0.451	na	na	79	Similar
Structure	Riffle 1	0.005	0.190	0.162	0.998	0.282	0.810	0.336	70%	88	Similar
Outlet TZ	Riffle 1										Not Applicable

Table 35: Sparks Brook level II results for riffle 2, by metric

Zone	Channel unit	Width at bankfull stage	Width at half bankfull stage	Width at low flow (wetted width)	Maximum depth	Coarse fraction	Bank irregularity	Bed irregularity	Bank continuity	Percent Total Score	Evaluation	Override
Inlet TZ	Riffle 2								NA		Not Applicable	
Structure	Riffle 2	0.134	0.024	0.454	0.571	na	0.97	na	70%	87	Similar	→Question-able
Outlet TZ	Riffle 2								NA		Not Applicable	

Table 36: Sparks Brook level II results for steps 2, by metric

Zone	Channel unit	Channel Unit Length	Width at Bankfull Stage	Maximum Particle Size	Step Height	Residual Pool Depth	Percent Total Score	Evaluation	Override
Inlet TZ	Steps 2							Not Applicable	
Structure	Steps 2	5	5	3	1	5	73	Questionable	→Similar
Outlet TZ	Steps 2	3	1	3	1	1	35	Dissimilar	

34, Table 35, and Table 36 results are color coded so that green cells were scored 5, or "good," orange cells were scored 3, or "fair," and red cells were scored 1, or "poor." The scoring criteria are based on the Wilcoxon Rank-Sum test p-values:

- $p \geq 0.05$, score 5
- $\leq p < 0.05$, score 3
- $< p$, score 1

Table 36 results are based on the identical level I and II protocol methods of scoring steps. For the metrics of step height and maximum particle size, a score of 5 indicates the median design measurement falls between the 25th and 75th quartile of the representative reach data. A score of 3 means the median design measurement falls outside of the inner quartile interval, but within the range of representative reach data. A score of 1 means the median design measurement falls outside the range of representative reach data. The metrics of channel unit length, width at bankfull stage, and residual pool depth have only 1 to 5 measurements each. Therefore, scoring is based on a comparison of distributions or percent difference tolerance. Evaluations within the override column are discussed and justified within section 6.2.3.8. Overrides in general are explained within section 0.

TABLE 37: SPARKS BROOK LEVEL II METRIC DATA QUARTILES

Zone and Metric	riffle 1			riffle 2		
Width at Bankfull Stage	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	5.16	5.74	5.89	4.53	5.66	8.71
Inlet Transition	4.51	4.86	4.98			
Structure	4.56	4.81	4.91	4.15	4.52	4.53
Outlet Transition						
Width at 1/2 Bankfull Stage	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	4.12	4.54	5.08	4.02	4.48	5.32
Inlet Transition	3.86	4.24	4.56			
Structure	3.49	4.42	4.43	2.28	2.95	3.70
Outlet Transition						
Wetted Width	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	3.18	3.79	4.33	2.57	2.91	3.44
Inlet Transition	2.30	2.73	2.92			
Structure	2.83	3.15	3.52	1.41	2.40	3.32
Outlet Transition						
Maximum Depth at Low Flow	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	0.16	0.18	0.20	0.14	0.21	0.28
Inlet Transition	0.23	0.26	0.29			
Structure	0.20	0.22	0.27	0.20	0.22	0.24
Outlet Transition						
Coarse Fraction (>d50) Gradation	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	70	95	120			
Inlet Transition	50	75	138			
Structure	70	95	150			
Outlet Transition						
Bank Irregularity	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	0.12	0.27	0.49	0.12	0.31	1.00
Inlet Transition	0.07	0.16	0.43			
Structure	0.16	0.39	0.46	0.21	0.33	0.51
Outlet Transition						
Bed Irregularity	**25th quartile**	**Median**	**75th quartile**	**25th quartile**	**Median**	**75th quartile**
rep reach	0.04	0.11	0.16			
Inlet Transition						
Structure	0.05	0.08	0.12			
Outlet Transition						

LEVELS I AND II PROTOCOLS ARE IDENTICAL FOR STEP METRICS; STEP DATA ARE OMITTED FROM TABLE 37, SEE LEVEL I DATA QUARTILES, TABLE 54

5.2.1.3 Metric Redundancy Results

There was concern that some metrics could be redundant with one another (i.e., they provide the summary rubric with the same information about the design). Metric scores were monitored across sites in order to determine if they were providing the same information. It was assumed that if some metrics consistently score the same, they are likely redundant. The metric scores for low flow width versus depth, and bed irregularity versus the coarse fraction of the gradation are summarized in 38. Group scores for the metrics considered are listed left to right in the wetted width, depth, bed irregularity and coarse fraction columns. Compare the pattern of group scores between cells (e.g., 3,3,5,1 vs. 5,5,3,5) and track consistencies across sites. For example, the level II protocol scored the wetted width metric for the three groups at Lower Stillwell 3, 5, and 5. The depth metric was scored for those same three groups 5, 5, and 3. The only consistent score is the score for the group listed in the middle (5). Across sites, the low flow width and depth score patterns are not similar; only occasionally do the metrics score a group the same. By this method, bed irregularity and the coarse fraction metrics were also examined. Neither pair of potentially redundant metrics however, appears to provide consistent scores between them.

TABLE 38: TRACKING POTENTIALLY REDUNDANT LEVEL II METRICS

		Scores by Group			
Site	Protocol	Low Flow Width vs.	Depth	Bed Irregularity vs.	Coarse Fraction
Lower Stillwell	Level II	3,5,5	5,5,3	na, 5,5	5,5,3
NF Indian	Level II	5,3,1,3,1,5	5,5,5,5,5,5	5,5,5,5,na,1	1,na,na,5,na,na
WF01	Level II	na	na	5,1	1,1
WF02	Level II	na	na	5,5,5	1,1,1
Site 3	Level II	na	na	1,5	3,1
Dog Slaughter	Level II	1,1,3,1,3	1,3,3,5,1	5,1,3,5,3	1,na,na,5,1
Big Lick	Level II	3,3,3,5,5	5,5,5,5,3	5,5,3,5,3	1,na,na,na,1
Sparks Brook	Level II	3,5,5	5,5,5	na,5,na	3,5,na

WITHIN 38 "NA" INDICATES THE METRIC WAS NOT COLLECTED AT THE SITE OR FOR THAT GROUP.

5.2.1.4 THE "SHORT" RUBRIC RESULTS

The level II "short" rubrics were created in order to evaluate the effect of the wetted width and bed irregularity metrics on the overall evaluation. These metrics are weighted very low (0.25), because they are not considered critical elements (geomorphic controls) for an effective design. We became interested in potentially removing them from the protocol entirely because doing so would save hours of field time. The "short" rubric results were compared with the rubric results for all metrics at several sites. Removing the wetted width and bed irregularity metrics did not change the effectiveness evaluation (similar, questionable, or dissimilar) for any groups at the 6 sites where "short" rubrics were evaluated.

5.2.2 LEVEL I SUMMARY RUBRIC

A summary effectiveness tool for level I data was created. It is basically an Excel workbook in which one can enter the field data. Quartiles are automatically calculated by the workbook and then users enter them into group scoring spreadsheets. The design median value is compared with the inner-quartile interval as well as the full range of representative data. The spreadsheet then automatically scores the comparisons, weights the scores, and summarizes the scores to produce an overall effectiveness evaluation for each group. The summarized score, or “percent total score,” is evaluated as follows:

- Similar Attributes/Good Rating: Score between 75 and 100 percent.
- Questionable Attributes/At Risk Rating: Score between 50 and 75 percent.
- Dissimilar Attributes/Poor Rating: Score less than 50 percent.

Within this section, results by the level I summary rubric are presented for each site by a single table which displays the effectiveness evaluations for each group. For sites not also evaluated by the level II protocol, both level I evaluations as well as site descriptions are given here. See the level I summary rubric in Appendix E2 [Level II Summary Rubric]. See Appendix A [Site Data] for surveyed longitudinal profiles, data plots, and photos of each site (Lower Stillwell photos and plots are however included within section 5.2.1.2.1).

5.2.2.1 Level I Results for Analyzed Sites

5.2.2.1.1 Lower Stillwell Results

Table 39: Lower Stillwell level I results for riffle 1, by metric

Zone	Channel unit	Width at bankfull stage	Width at low flow (wetted width)	Maximum depth	Largest particles	Bank irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Riffle	3	1	5	3	5	na	71	Questionable
Structure	Riffle	3	5	5	3	5	1	70	Questionable
Outlet TZ	Riffle	1	5	5	5	5	na	77	Similar

5.2.2.1.2 North Fork Indian Results

Table 40: North Fork Indian level I results for gentle riffle 1, by metric

Zone	Channel unit	Width at bankfull stage	Width at low flow (wetted width)	Maximum depth	Largest particles	Bank irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Gentle Riffle 1	1	3	5	5	5	na	74	Questionable
Structure	Gentle Riffle 1								Not Applicable
Outlet TZ	Gentle Riffle 1								Not Applicable

TABLE 41: NORTH FORK INDIAN LEVEL I RESULTS FOR STEEP RIFFLE 2, BY METRIC

Zone	Channel unit	Width at bankfull stage	Width at low flow (wetted width)	Maximum depth	Largest particles	Bank irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Steep Riffle 2								Not Applicable
Structure	Steep Riffle 2	1	3	5	3	5	5	68	Questionable
Outlet TZ	Steep Riffle 2								Not Applicable

TABLE 42: NORTH FORK INDIAN LEVEL I RESULTS FOR POOLS 2, BY METRIC

Zone	Channel unit	Width at bankfull stage	Width at low flow (wetted width)	Maximum depth	Largest particles	Bank irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Pools 2								Not Applicable
Structure	Pools 2								Not Applicable
Outlet TZ	Pools 2	5	5	3	na	5	na	88	Similar

TABLE 43: NORTH FORK INDIAN LEVEL I RESULTS FOR MODERATELY STEEP RIFFLE 2, BY METRIC

Zone	Channel unit	Width at bankfull stage	Width at low flow (wetted width)	Maximum depth	Largest particles	Bank irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Moderate Steep Riffle 2								Not Applicable
Structure	Moderate Steep Riffle 2	1	1	5	1	5	5	55	Questionable
Outlet TZ	Moderate Steep Riffle 2								Not Applicable

5.2.2.1.3 West Fork Greenbrier 01 Results

Table 44: WF01 level I results for riffle 3, by metric

Zone	Channel unit	Width at bankfull stage	Width at low flow (wetted width)	Maximum depth	Largest particles	Bank irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Riffle 1	5	3	3	1	3	Na	60	Questionable
Structure	Riffle 1	1	1	3	1	1	1	28	Dissimilar
Outlet TZ	Riffle 2	1	1	3	1	3	na	34	Dissimilar

5.2.2.1.4 West Fork Greenbrier 02 Results

Table 45: WF02 level I results for riffle 1, by metric

Zone	Channel unit	Width at bankfull stage	Width at low flow (wetted width)	Maximum depth	Largest particles	Bank irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Riffle 1	1	1	3	3	3	na	46	Dissimilar
Structure	Riffle 1	1	1	1	3	3	1	35	Dissimilar
Outlet TZ	Riffle 1	1	5	1	1	3	na	31	Dissimilar

5.2.2.1.5 Site 3 (Unnamed Tributary to the West Fork Greenbrier) Results

Table 46: Site 3 level I results for riffle 1, by metric

Zone	Channel unit	Width at bankfull stage	Width at low flow (wetted width)	Maximum depth	Largest particles	Bank irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Riffle 1	1	1	3	1	3	na	34	Dissimilar
Structure	Riffle 1	5	1	3	3	3	1	63	Questionable
Outlet TZ	Riffle 1	1	1	3	1	3	na	34	Dissimilar

5.2.2.1.6 Dog Slaughter Creek Results

Table 47: Dog Slaughter level I results for riffle 1, by metric

Zone	Channel unit	Width at bankfull stage	Width at low flow (wetted width)	Maximum depth	Largest particles	Bank irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Riffle 1	5	5	3	1	3	na	63	Questionable
Structure	Riffle 1								Not Applicable
Outlet TZ	Riffle 1								Not Applicable
Constructed Riffle	Riffle 1	5	3	3	1	1	na	54	Questionable

Table 48: Dog Slaughter level I results for pools 1, by metric

Zone	Channel unit	Width at bankfull stage	Width at low flow (wetted width)	Maximum depth	Largest particles	Bank irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Pools 1	3	5	1	na	3	na	52	Questionable
Structure	Pools 1	1	1	3	na	1	1	30	Dissimilar
Outlet TZ	Pools 1	5	3	3	na	1	na	68	Questionable

5.2.2.1.7 Big Lick Creek Results

Table 49: Big Lick level I results for riffle 1, by metric

Zone	Channel unit	Width at bankfull stage	Width at low flow (wetted width)	Maximum depth	Largest particles	Bank irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Riffle 1	5	1	5	1	5	na	71	Questionable
Structure	Riffle 1								Not Applicable
Outlet TZ	Riffle 1								Not Applicable

Table 50: Big Lick level I results for pool 1, by metric

Zone	Channel unit	Width at bankfull stage	Width at low flow (wetted width)	Maximum depth	Largest particles	Bank irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Pool 1	3	5	5	na	5	na	84	Similar
Structure	Pool 1	1	5	5	na	3	1	53	Questionable
Outlet TZ	Pool 1	3	5	5	na	3	na	76	Similar

5.2.2.1.8 Sparks Brook Results

Table 51: Sparks Brook Level I results for riffle 1, by metric

Zone	Channel unit	Width at bankfull stage	Width at low flow (wetted width)	Maximum depth	Largest particles	Bank irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Riffle 1	5	3	5	1	3	na	69	Questionable
Structure	Riffle 1	5	5	1	3	5	5	75	Similar
Outlet TZ	Riffle 1								Not Applicable

Table 52: Sparks Brook Level I results for pool run 1 and pool 4, by metric

Zone	Channel unit	Width at bankfull stage	Width at low flow (wetted width)	Maximum depth	Largest particles	Bank irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ									Not Applicable
Structure	Pool Run 1 (level II SR1)	1	1	3	na	5	5	57	Questionable
Outlet TZ	Pool 4	1	3	5	na	3	na	56	Questionable

Table 53: Sparks Brook Level I results for steps 2, by metric

Zone	Channel unit	Step Length	Width at Bankfull Stage	Maximum Particle Size	Step Height	Residual Pool Depth	Percent Total Score	Evaluation
Inlet TZ	Steps 2							Not Applicable
Structure	Steps 2	5	5	3	1	5	73	Questionable
Outlet TZ	Steps 2	3	1	3	1	1	35	Dissimilar

TABLE 54: SPARKS BROOK LEVEL I METRIC DATA QUARTILES

Bankfull Width	**Riffle**					**Pool**					**Step**				
Zone	**Min (m)**	**25th (m)**	**50th (m)**	**75th (m)**	**Max (m)**	**Min (m)**	**25th (m)**	**50th (m)**	**75th (m)**	**Max (m)**	**Min (m)**	**25th (m)**	**50th (m)**	**75th (m)**	**Max (m)**
Representative	4.50	4.60	4.60	5.40	5.50	4.20	4.20	4.60	4.80	5.50	na	na	na	na	na
Inlet Transition	2.95	3.80	5.05	5.30	5.40						na	na	na	na	na
Structure	3.73	4.66	4.66	4.66	4.67	3.57	3.8	4.1	4.1	4.42	na	na	na	na	na
Outlet Transition						4.7	5.9	6.65	7	7.40	na	na	na	na	na
Wetted Width	**Riffle**					**Pool**					**Step**				
Zone	**Min (m)**	**25th (m)**	**50th (m)**	**75th (m)**	**Max (m)**	**Min (m)**	**25th (m)**	**50th (m)**	**75th (m)**	**Max (m)**	**Min (m)**	**25th (m)**	**50th (m)**	**75th (m)**	**Max (m)**
Representative	1.70	2.70	4.30	4.40	5.00	3.80	4.00	4.00	4.70	5.20	na	na	na	na	na
Inlet Transition	1.75	2.00	2.40	2.95	4.20						na	na	na	na	na
Structure	2.33	2.56	2.80	3.15	3.50	2.10	2.22	2.60	2.80	3.80	na	na	na	na	na
Outlet Transition						3.85	4.26	4.91	5.00	5.03	na	na	na	na	na
Maximum Depth	**Riffle**					**Pool**					**Step**				
Zone	**Min (m)**	**25th (m)**	**50th (m)**	**75th (m)**	**Max (m)**	**Min (m)**	**25th (m)**	**50th (m)**	**75th (m)**	**Max (m)**	**Min (m)**	**25th (m)**	**50th (m)**	**75th (m)**	**Max (m)**
Representative	0.21	0.23	0.25	0.34	0.53	0.17	0.31	0.32	0.39	0.61	na	na	na	na	na
Inlet Transition	0.16	0.20	0.24	0.27	0.27						na	na	na	na	na
Structure	0.15	0.17	0.19	0.25	0.25	0.19	0.19	0.20	0.29	0.30	na	na	na	na	na
Outlet Transition						0.3	0.31	0.32	0.35	0.40	na	na	na	na	na

Maximum Particle Size	**Riffle**					**Pool**	**Step**				
Zone	**Min (mm)**	**25th (mm)**	**50th (mm)**	**75th (mm)**	**Max (mm)**		**Min (mm)**	**25th (mm)**	**50th (mm)**	**75th (mm)**	**Max (mm)**
Representative	610	720	920	980	1310		450	460	540	620	920
Inlet Transition	440	440	500	600	730		420	450	570	570	640
Structure	530	570	640	720	730		540	620	650	690	830
Outlet Transition							700	870	900	910	910

Step Height	**Riffle**					**Pool**	**Step**				
Zone							**Min (m)**	**25th (m)**	**50th (m)**	**75th (m)**	**Max (m)**
Representative							0.23	0.265	0.3	0.31	0.32
Inlet Transition							0.24	0.245	0.25	0.27	0.29
Structure							0.39	0.39	0.39	0.39	0.39
Outlet Transition							0.32	0.335	0.35	0.365	0.38

5.2.2.1.9 JOE SMITH BROOK SITE DESCRIPTION AND RESULTS

Joe Smith Brook road-stream crossing is located on the Green Mountain National Forest in Vermont. The site is on Forest road 45 at approximately 43˚50’30’’N, 72˚53’30’’W. Joe Smith Brook is a step-pool channel, with frequent steps formed by small to medium boulders and logs. The channel flows within a valley wide enough to contain terraces (20 m across). Riparian vegetation is a mixture of coniferous and deciduous trees, with broad leafy vegetation in the understory. The site is on the east side of a prominent ridge within the Green Mountains, where the effects of hurricane Irene were much more intense than those on the west side (e.g., at Sparks Brook). Upstream and downstream of the crossing, enormous log jams and avulsions were observed. Because of the flood associated with Irene, bankfull indicators are absent, and the elevation at bankfull stage was estimated.

The road-stream crossing structure at Joe Smith Brook is an open bottomed pipe-arch. The structure has a width of 3.1 m, a length of 12.3 m, and a height (top of footers to structure roof) of 1.6 m. The average channel width at the estimated bankfull stage is 6.8 m. The channel bed through the crossing is composed of three slope segments: a step (IS1) and short cascade within the inlet transition zone, an extremely gentle gradient riffle (SR1) through the structure, and a very steep cascade (OSR1) within the outlet transition zone. Exact gradients are not known because a level II longitudinal profile was not surveyed at the site. There is evidence of fill erosion all the way around the structure inlet, suggesting high flows overtopped, or nearly overtopped, the road although no excessive scour was observed within the structure itself. The road is currently closed to motor vehicles just beyond the crossing by a barrier and thick vegetation. The crossing was recently replaced because the road has been retained for future resource and fire access.

TABLE 55: JOE SMITH BROOK LEVEL I RESULTS FOR RIFFLE 1, BY METRIC

Zone	Channel unit	Width at bankfull stage	Width at low flow (wetted width)	Maximum depth	Largest particles	Bank irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Riffle 1								Not Applicable
Structure	Riffle 1	1	1	5	1	3	1	40	Dissimilar
Outlet TZ	Riffle 1								Not Applicable

TABLE 56: JOE SMITH BROOK LEVEL I RESULTS FOR STEEP RIFFLE, BY METRIC

Zone	Channel unit	Width at bankfull stage	Width at low flow (wetted width)	Maximum depth	Largest particles	Bank irregularity	Bank continuity	Percent Total Score	Evaluation
Inlet TZ	Steep Riffle								Not Applicable
Structure	Steep Riffle								Not Applicable
Outlet TZ	Steep Riffle	1	3	5	3	5	na	63	Questionable

TABLE 57: JOE SMITH BROOK LEVEL I RESULTS FOR STEPS, BY METRIC

Zone	Channel unit	Step Length	Width at Bankfull Stage	Maximum Particle Size	Step Height	Residual Pool Depth	Percent Total Score	Evaluation
Inlet TZ	Steps	3	3	1	1	na	37	Dissimilar
Structure	Steps							Not Applicable
Outlet TZ	Steps							Not Applicable

5.2.2.1.10 CANEY CREEK SITE DESCRIPTION AND RESULTS

Caney Creek road-stream crossing is on Forest road 105 in the Daniel Boone National Forest, Kentucky. The site is at approximately 38˚6'0''N, 83˚35'30''W. The previously undersized culvert was replaced with the current structure in 2012. The stream channel is incised within platy bedrock, possibly slate. A thin layer of mobile and platy alluvium is deposited on top of the bedrock to form short riffles and pools. This sediment accumulates in wider areas where the bedrock is not as confining. Caney Creek flows within a fairly broad valley (~100 m). A floodplain has developed where bedrock is not limiting. Vegetation is a dense mixture of coniferous and deciduous trees, with a broad-leafy understory. At the time of the field visit (October 2012) it was raining. The natural channel was dry in the morning, but began to flow in the afternoon.

The road-stream crossing structure is an open bottom galvanized steel pipe-arch. Rock wing-walls surround the structure inlet. The structure width is 2.82 m, the length is 30.6 m, and the height is 1.3 m to the top of the structure footers. The average bankfull channel width is 6.01 m. The design channel bed within the inlet transition zone is a riffle and head of a pool. The pool extends through the structure with the pool tail crest at the downstream outlet transition zone boundary. Immediately downstream, a constructed riffle backwaters the structure. The constructed riffle remained mostly dry throughout the rainy field day. The design channel width is hour-glass shaped; wide within the inlet transition zone, narrow within the structure, and wide again through the outlet transition zone and constructed riffle. Immediately upstream of the inlet transition zone, a significant tributary joins the channel. Because of this confluence, a representative reach was only sought downstream of the crossing. See photo Figure 120 through Figure 128 in Appendix A3.1 [Caney Creek Photos].

A decision tree was followed to determine if physical effectiveness monitoring was appropriate at Caney Creek:

- Is there substrate within the structure? Yes.
- Is the structure at least as wide as ¾ the bankfull width? No, at Caney Creek, the structure is less than half the average bankfull width (the level I protocol was terminated here, but for illustrative purposes, I complete the decision criteria).
- Is there reason to believe the site has experienced sufficiently high flows for adjustment? Probably.
- Are the channel units in the design channel present and similar in dimensions to those in the adjacent natural channel? No. A suitable representative reach was not found within approximately 180 m downstream of the structure outlet. No natural pools were as long and narrow as that constructed within the structure and outlet transition zone. No natural riffles were as long, steep, or coarse as the constructed riffle which backwaters the structure.

Together with site observations, the initial decision tree for physical effectiveness monitoring helped to determine the design at Caney Creek is dissimilar from the natural channel.

5.2.2.1.11 UTLEY BROOK SITE DESCRIPTION AND RESULTS

Utley Brook is located on the Green Mountain National Forest in Vermont. The road-stream crossing is on Forest road 279 at approximately 43◦18’30’’N, 72◦53’30’’W. Utley brook has pool-riffle morphology with a boulder and large cobble bed. It flows within a fairly broad valley. A floodplain is present at many places along the creek. The natural channel bankfull width is approximately 10 m.

The structure is a galvanized steel, open-bottomed pipe-arch, with dimensions 2.74 m wide, 7.01 m long, and 6 m high. The pipe-arch is surrounded by a concrete collar and wing-walls. Boulders armor the banks upstream of the structure inlet. The inlet is not projecting and it is even with the footers. The upstream end of the inlet transition zone is the head of a large pool. The pool extends through the structure to the downstream end of the outlet transition zone. A boulder cascade backwaters the structure. The crossing is older, built circa 1965. See Figure 356 through Figure 362 in Appendix A10.1 [Utley Brook Photos].

A decision tree was followed to determine if physical effectiveness monitoring was appropriate at Utley Brook:

- Is there substrate within the structure? Yes.
- Is the structure at least as wide as ¾ the bankfull width? No (the level I protocol was terminated here, but for illustrative purposes, I complete the decision criteria).
- Is there reason to believe the site has experienced sufficiently high flows for adjustment? Yes, the structure survived hurricane Irene one year prior to field work.
- Are the channel units in the design channel present and similar in dimensions to those in the adjacent natural channel? No. A distance of approximately 200 bankfull channel widths upstream and downstream of the structure was walked while searching for an appropriate representative reach. No natural pools were found with length and depth similar to that within the structure. No boulder riffles or cascades were found with length and gradient similar to that which backwaters the structure.

Together with site observations, the initial decision tree for physical effectiveness monitoring helped to determine the design at Utley Brook is dissimilar from the natural channel.

5.2.2.1.12 BAYS CREEK SITE DESCRIPTION AND RESULTS

Bays Creek is located on the Siuslaw National Forest in Oregon. The road-stream crossing is on Forest road 8573. The crossing is located at T3S, R9W, SW ¼ section 13. Bays Creek is a tributary to the Nestucca River, within the Pacific Ocean basin. Data were collected in August of 2012.

Bays Creek is a predominantly pool-riffle channel, with short sections of bedrock chutes and pools. The creek flows within a very broad valley (~300 m); a floodplain has developed where bedrock does not prevent it. Riparian vegetation is a mixture of deciduous and coniferous tree species, with thick berry bushes and ferns lining most banks. The channel substrate is predominantly large cobble and small boulder, with places of exposed bedrock. A significant tributary joins Bays Creek at the right bank roughly 15 m below the structure outlet.

The road-stream crossing at Bays Creek is a replacement of a previously undersized culvert. The crossing structure is a channel-spanning, galvanized steel, pipe-arch. The structure has a span of 3.6 m, a length of 18.3 m, and a height of 2.1 m. The average width at bankfull stage within the natural channel near the crossing is 7.7 m. Channel units within the inlet transition zone are a steep riffle and cascade. The structure bed has a pool near the inlet and a very gentle riffle. The gentle riffle extends through the structure to the bottom of the outlet transition zone. See photo Figure 55 through Figure 65 in Appendix A1.1 [Bays Creek Photos].

A decision tree was followed to determine if physical effectiveness monitoring was appropriate at Bays Creek:

- Is there substrate within the structure? Yes.
- Is the structure at least as wide as ¾ the bankfull width? No (the level I protocol was terminated here, but for illustrative purposes, I complete the decision criteria).
- Is there reason to believe the site has experienced sufficiently high flows for adjustment? Yes, during January of 2012, an approximately 25 year event was documented at the nearby Lower Stillwell site (Siuslaw NF, 2012).
- Are the channel units in the design channel present and similar in dimensions to those in the adjacent natural channel? No. The gentle riffle within the structure is flatter in gradient (and finer in substrate) than any riffle encountered within the natural channel. Because of the tributary confluence downstream of the structure, the search for a representative reach was only appropriate upstream of the crossing. The level I protocol failed to find a reach within the natural channel which appeared similar enough to the design channel (in gradient and channel units).

Together with site observations, the initial decision tree for physical effectiveness monitoring helped to determine the design at Bays Creek is dissimilar from the natural channel.

The crossing at Bays Creek however, presented an opportunity to show that one can adequately determine the presence/absence of a suitable representative reach by ocular estimate. To do so, a longitudinal profile was surveyed and analyzed, as if the level II protocol had been initiated.

The level II longitudinal profile (see Appendix 0 [Bays Creek Long Pro]) analysis showed that the entire study reach has a gradient of 2.4%. The gradient within the inlet transition and the upper half of the structure (steep riffle, cascade, pool) is 4.1%. The gradient within the lower half of the structure and the outlet transition (gentle riffle) is 0.5%. An adequate representative reach was identified for the steeper design slope segment (the segment which extends from the top of the inlet transition zone midway through the structure). The selected steep representative reach has a gradient of 4.1%, only 2%

different from the design gradient, and well within the 25% selection criteria. Channel units within this representative reach are similar to those within the design channel: steep riffle, bedrock chute, cascade, pool, steep riffle, riffle run, bedrock chute, pool, and step. Within the design channel, “key pieces” mimic bedrock.

The only suitable reach (within a 100% difference criterion) for the gentle gradient design slope segment was predominantly a pool unit (the gradients were 40% different). The riffle within the slope segment is only 7.3 m long, which is less than the average bankfull width. According to the level II protocol rules, this channel unit would not be analyzed (due to the short length and small sample size). Without a suitable representative riffle for comparison, this gentle slope segment would not be a reasonable representative reach.

In conclusion, the level II longitudinal profile analysis confirmed that the level I ocular estimate method can effectively identify the absence of a suitable representative reach.   See the longitudinal profile and figures within Appendix A1.1 [Bays Creek Photos].

5.3 Objective 3 Results: Can Level I Be Used as a Proxy for Level II? What are the Limitations of Level I?

5.3.1 Levels I And II Results Compared: Does Level I Positively Skew Effectiveness Evaluations?

The level I protocol is intended to be a simplified, less time intensive version of the level II protocol. It therefore ought to evaluate a site similarly to level II. If protocol results are not identical, at a minimum, level I should not skew effectiveness evaluations in the positive direction. The levels I and II results, presented in detail above, are summarized in 58. Columns indicate positively skewed level I results with a “Y.” Of particular concern are groups which have entirely different effectiveness ratings (e.g., similar versus questionable) because there are especially large differences between levels I and II scores. These differences are explored in section 6.3.4 of the discussion.

At some sites, where data were collected, and how groups were labeled, is slightly different between levels I and II protocols. Within 58, groups which are the same (regardless of group labels) are shown side-by-side within level I and II columns. Differences are described below, and are denoted in 58, by “na” within the comparison columns:

- **North Fork Indian:** The pool unit (SP2 or OP2) is actually half within the structure and half outside of the structure. It was arbitrarily analyzed as completely within the structure for the level II protocol, but completely outside of the structure for the level I protocol. Level I data were not collected within the upper structure riffle of slope segment 1 (SR1). The unit was not recognized as an independent unit because it was perceived to be truncated by a break in gradient and therefore too short; I later found this not to be a significant slope segment division, according to the level II analysis. During level I data collection, the outlet transition zone boundary was not extended as far as indicated by the level II longitudinal profile analysis. Therefore, no level I data were collected within the level II outlet transition zone riffle (OR2).

- **Site 3:** Site 3 was visited twice: first in 2011 for level II data collection and again in 2012 for level I data collection. In 2011, the level II protocol had not yet evolved to analyze and select a representative reach for each slope segment present within the design channel. Instead, a single representative reach was selected only for the gradient(s) which pass through the structure. The inlet transition zone at Site 3 is entirely within a different slope segment from that within the structure (as indicated by the longitudinal profile analysis). Therefore, no representative reach was selected to which the inlet transition zone could be compared. In 2012, Weinhold and Cenderelli revisited the site in order to collect level I data. The gradient break at the structure inlet was not considered significantly different (by ocular estimate) from the gradient which passes through the rest of the design channel. Therefore, level I data *were collected* within the inlet transition zone (IR1) and compared with the representative reach.
- **Dog Slaughter:** The portion of the pool within the inlet transition zone (IP1) was not analyzed separately for the level II protocol because the sample size was too small. During level I, however, data were collected within this pool segment and compared with the representative pool.
- **Sparks Brook:** SR1 for level II is a single riffle within the structure; slope segment 1. Level I breaks up this riffle into a riffle (SR1) and a pool run (SP1). SR2 was not evaluated during level I data collection because the short, steep riffle was considered to be too short. Also, before the level II longitudinal profile was collected, it was not recognized that a significant break in slope, separating two slope segments, was present at the structure outlet. Therefore, level I data *were collected* at the pool within the outlet transition zone (OP4) and compared with the most similar channel unit within the representative reach. Erroneously, during level II data collection, no representative reach was selected for the gentle gradient slope segment within the outlet transition zone. Level II data were collected within OP4, but not analyzed. Level II data were

collected within the structure pool, but the sample size was too small for statistical analysis. Level II SP2 data were therefore not analyzed.

TABLE 58: LEVEL I AND II RESULTS COMPARED

Site	Group	Level II Score	Level II Evaluation	Level I Score	Level I Evaluation	SCORES: Is level I higher than level II?	EVALUATIONS: Is level I better than level II?
Lower Stillwell	IR1	88	Similar	71	Questionable	N	N
	SR1	64	Questionable	70	Questionable	Y	N
	OR1	69	Questionable	77	Similar	Y	Y
North Fork Indian	IR1	69	Similar*	74	Questionable	Y	N
	SR1	80	Questionable*	na	na	na	na
	SR2	83	Questionable*	55	Questionable	N	N
	OR2	76	Similar	na	na	na	na
	SSR2	73	Similar*	68	Questionable	N	N
	SP2/OP2	85	Similar	88	Similar	Y	N
WF01	IR1	57	Questionable	60	Questionable	Y	N
	SR1	35	Dissimilar	28	Dissimilar	N	N
	OR2	na	na	34	Dissimilar	na	na
WF02	IR1	57	Questionable	46	Dissimilar	N	N
	SR1	33	Dissimilar	35	Dissimilar	Y	N
	OR1	31	Dissimilar	31	Dissimilar	N	N
Site 3	IR1	na	na	34	Dissimilar	na	na
	SR1	30	Dissimilar	63	Questionable	Y	Y
	OR1	37	Dissimilar	34	Dissimilar	N	N
Dog Slaughter	IR1	36	Dissimilar	63	Questionable	Y	Y
	IP1	na	na	52	Questionable	na	na
	SP1	28	Dissimilar	30	Dissimilar	Y	N
	OP1	66	Questionable	68	Questionable	Y	N
	Conn. Riff. 2	58	Questionable	54	Questionable	N	N
Big Lick	IR1	64	Questionable	71	Questionable	Y	N
	IP1	60	Questionable	84	Similar	Y	Y
	SP1	55	Questionable	53	Questionable	N	N
	OP1	80	Similar	76	Similar	N	N
Sparks Brook	IR1	79	Similar	69	Questionable	N	N
	SR1	88	Similar	75	Similar	N	N
	SR2	87	Questionable*	na	na	N	N
	OP4	na	na	56	Questionable	na	na
	SP1/SR1	88	Similar	57	Questionable	N	N
	SS2	73	Similar?*	73	Questionable	N	N
	OS2	35	Dissimilar	35	Dissimilar	N	N

* = override result

58 RESULTS ARE BASED ON THE SCORING CRITERIA WHICH RATES P-VALUES FROM 0.001 TO 0.05 “FAIR,” WITH A SCORE OF 3.

5.3.2 LEVEL II DATA ANALYZED BY THE LEVEL I RUBRIC, RESULTS

Level II Lower Stillwell data, evaluated with the level I rubric, produced different results than level I data evaluated by the same method. Level II results were not systematically different. Level II data scored lower than level I data within the structure and outlet transition zones, but not within the inlet transition zone (able 59 and able 60). Clearly, the level I Lower Stillwell data is different from the level II data.

TABLE 59: SUMMARY OF LOWER STILLWELL LEVEL II DATA ANALYZED BY LEVEL I (V5B) RUBRIC

Channel Unit	Inlet Transition Zone			Structure Zone			Outlet Transition Zone		
	% Score	Rating[a]	Override	% Score	Rating[a]	Override	% Score	Rating[a]	override
Riffle	84	Similar		73	Questionable		62	Questionable	

TABLE 60: SUMMARY OF LOWER STILLWELL LEVEL I DATA ANALYZED BY LEVEL I (V5B) RUBRIC

Channel Unit	Inlet Transition Zone			Structure Zone			Outlet Transition Zone		
	% Score	Rating[a]	override	% Score	Rating[a]	override	% Score	Rating[a]	override
Riffle	71	Questionable		70	Questionable		77	Similar	

a)

SIMILAR ATTRIBUTES/GOOD RATING: SCORE BETWEEN 75 AND 100 PERCENT.

QUESTIONABLE ATTRIBUTES/FAIR RATING: SCORE BETWEEN 50 AND 75 PERCENT.

DISSIMILAR ATTRIBUTES/POOR RATING: SCORE LESS THAN 50 PERCENT.

5.3.3 COMPARING THE LEVEL I MEDIAN WITH CONFIDENCE INTERVALS AROUND THE LEVEL II MEDIAN, RESULTS

The level I median was compared with the 90%, 95%, and 99% confidence intervals around the level II median. The level I median frequently fell outside of the broadest (99%) confidence interval, suggesting the differences between the level I and II rubric results may not be related to the rubrics themselves, but to the data. able 61 summarizes which metrics, for different confidence intervals, have similar levels I and II medians (at Lower Stillwell).

TABLE 61: LOWER STILLWELL LEVEL I MEDIAN COMPARED WITH CONFIDENCE INTERVALS AROUND THE LEVEL II MEDIAN

Metric	Group	Level I Median	Level II Median	95% CI min	95% CI max	Level I median falls within 95%CI?	99% CI min	99% CI max	Level I median falls within 99% CI?
BF Width	**IR1**	5.80	5.42	5.23	5.72	no	5.15	5.80	yes
	SR1	5.45	5.45	5.41	5.48	yes	5.40	5.49	yes
	OR1	4.64	5.43	4.80	6.30	no	4.56	6.53	yes
	RRR1	5.00	4.65	4.55	4.75	no	4.52	4.78	no
Low Flow Width	**IR1**	2.61	2.30	1.73	2.80	yes	1.56	2.97	yes
	SR1	3.35	2.79	2.33	3.15	no	2.20	3.28	no
	OR1	3.32	2.64	1.52	3.27	no	1.24	3.54	yes
	RRR1	3.40	3.10	2.89	3.35	no	2.81	3.42	yes
Max Depth	**IR1**	0.14	0.13	0.09	0.16	yes	0.08	0.17	yes
	SR1	0.12	0.13	0.11	0.15	yes	0.10	0.16	yes
	OR1	0.11	0.10	0.08	0.13	yes	0.07	0.13	yes
	RRR1	0.13	0.13	0.11	0.14	yes	0.11	0.14	yes
Max Particle Size	**IR1**	430	250	67	406	no	14	459	yes
	SR1	395	200	144	246	no	128	261	no
	OR1	345	175	127	204	no	115	216	no
	RRR1	330	300	206	408	yes	175	440	yes

5.3.4 LEVEL I SAMPLE SIZE INVESTIGATION, RESULTS

Boxplots of Lower Stillwell data show the level I data poorly approximates the level II data when compared by group (Figure 233). In an effort to understand why, the accuracy of the level I protocol small sample size was investigated by sub-sampling the level II data (assuming level II data are accurate) for these metrics. Quartile values were calculated for each subsample. The difference between the "true" quartile value and the subsample value was used as a way to evaluate the performance of a subset sample size. A difference of 0 cm was considered excellent, a difference between 0 and 5 cm was acceptable, and greater than 5 cm was poor. The sample size investigation results clearly indicate that a sample size of five is inadequate for representing the "true" level II distribution. In general, a sample size of nine had acceptable to excellent performance, especially within the representative reach. Figure 38 through Figure 41 show how the quartiles change (for each metric and zone) as sample size increases.

Weinhold also tested the level I sample size at his site on the White River National Forest. He similarly found n = 9 adequately represented the "true" sample size for all zones. When the n = 9 subset (at Lower Stillwell) was evaluated by the level I rubric, the results produced were compared with the "full" level II data results (Table 51).

TABLE 62: LEVEL I SCORE AND EVALUATIONS FOR SUBSET LEVEL II DATA

Zone	Inlet TZ	Structure	Outlet TZ
N = 9	84%, Similar	64%, Questionable	62%, Similar
The "truth": Full level II dataset	84%, Similar	73%, Questionable	62%, Similar

When 50% of the "true" population was used as a rule to subsample data: sample sizes became n = 6 for the inlet and outlet transition zones and n = 13 for the structure. These subsets were also evaluated with the level I rubric. These rubric results were compared with the "true" (full level II distribution) results. The n = 50% results were identical to those for n = 9 in all zones.

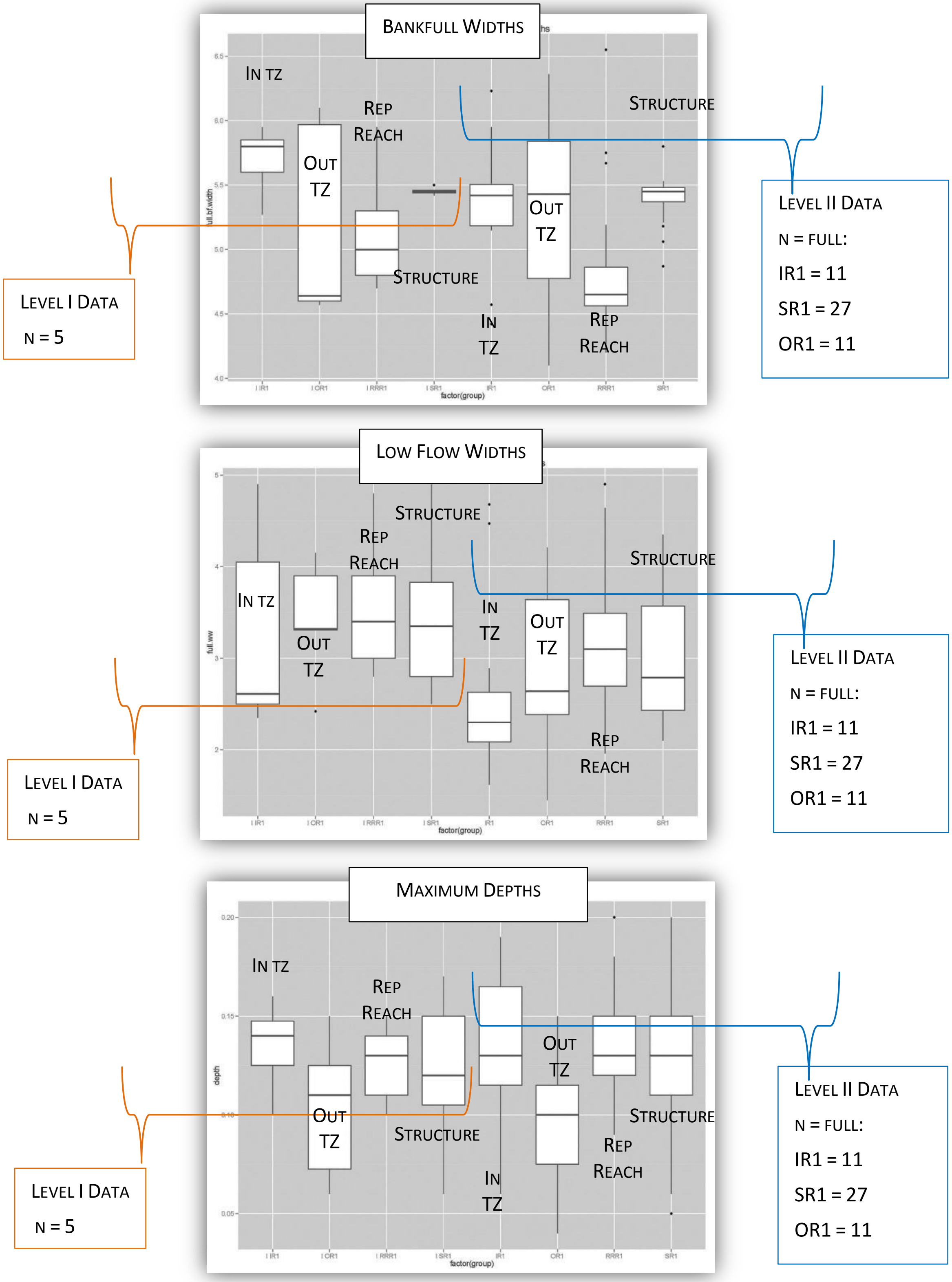


Figure 50: Lower Stillwell level I N = 5 data compared with Lower Stillwell level II N = full sample size data

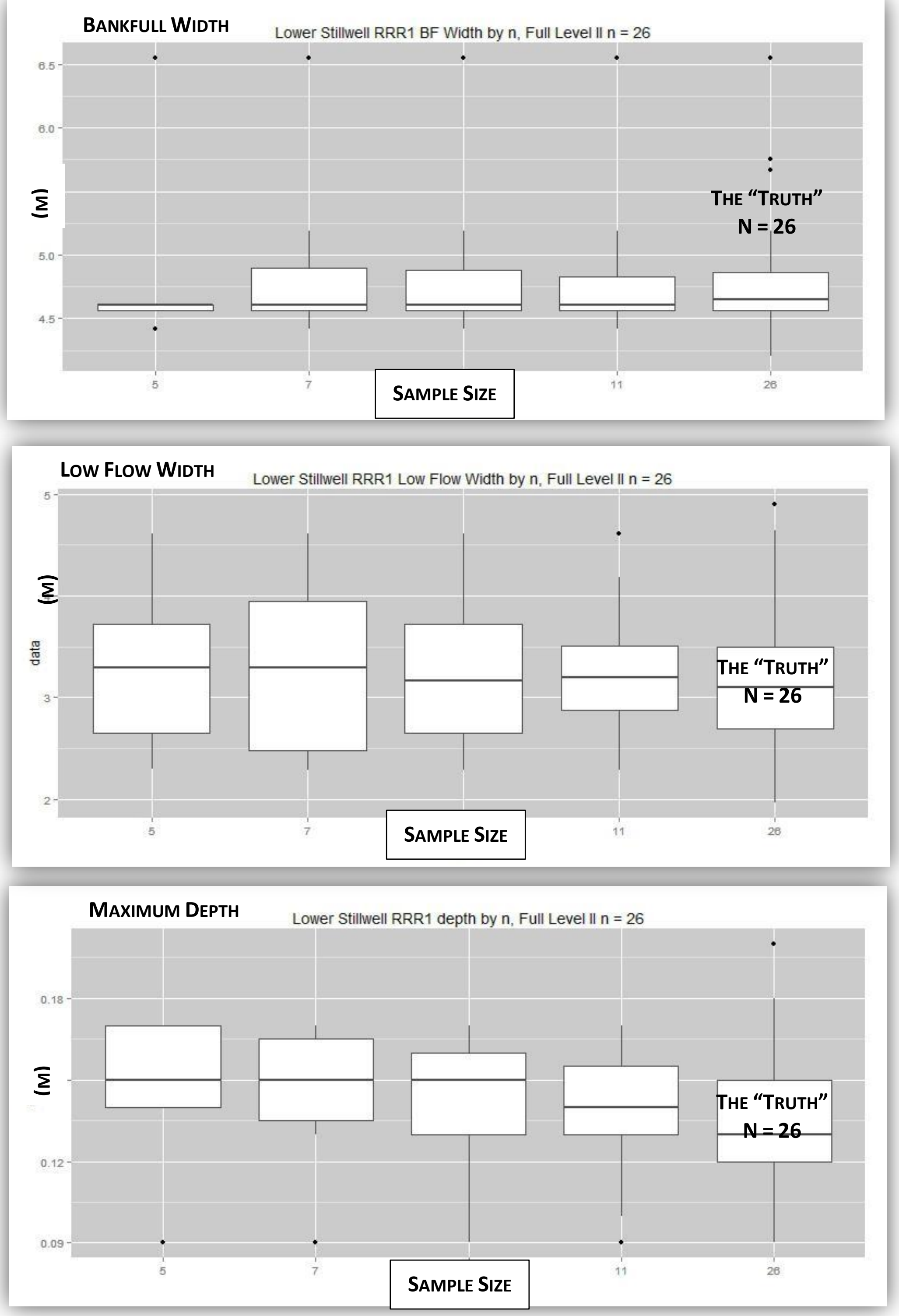


FIGURE 51: LOWER STILLWELL BANKFULL, LOW FLOW, AND MAXIMUM DEPTH DATA WITHIN *THE REPRESENTATIVE REACH* AS SAMPLE SIZE CHANGES

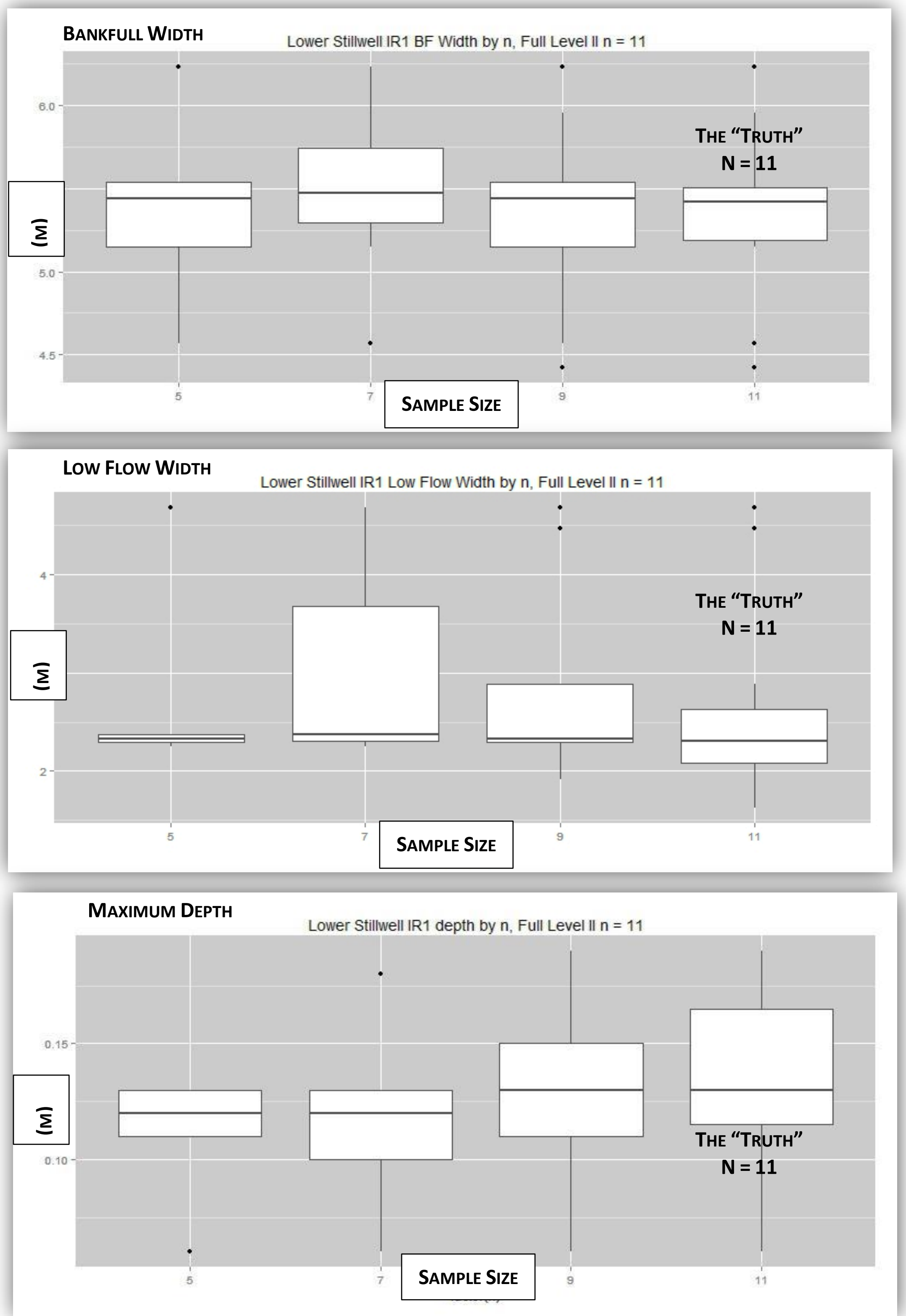


FIGURE 52: LOWER STILLWELL BANKFULL, LOW FLOW, AND MAXIMUM DEPTH DATA WITHIN THE *INLET TRANSITION ZONE* AS SAMPLE SIZE CHANGES

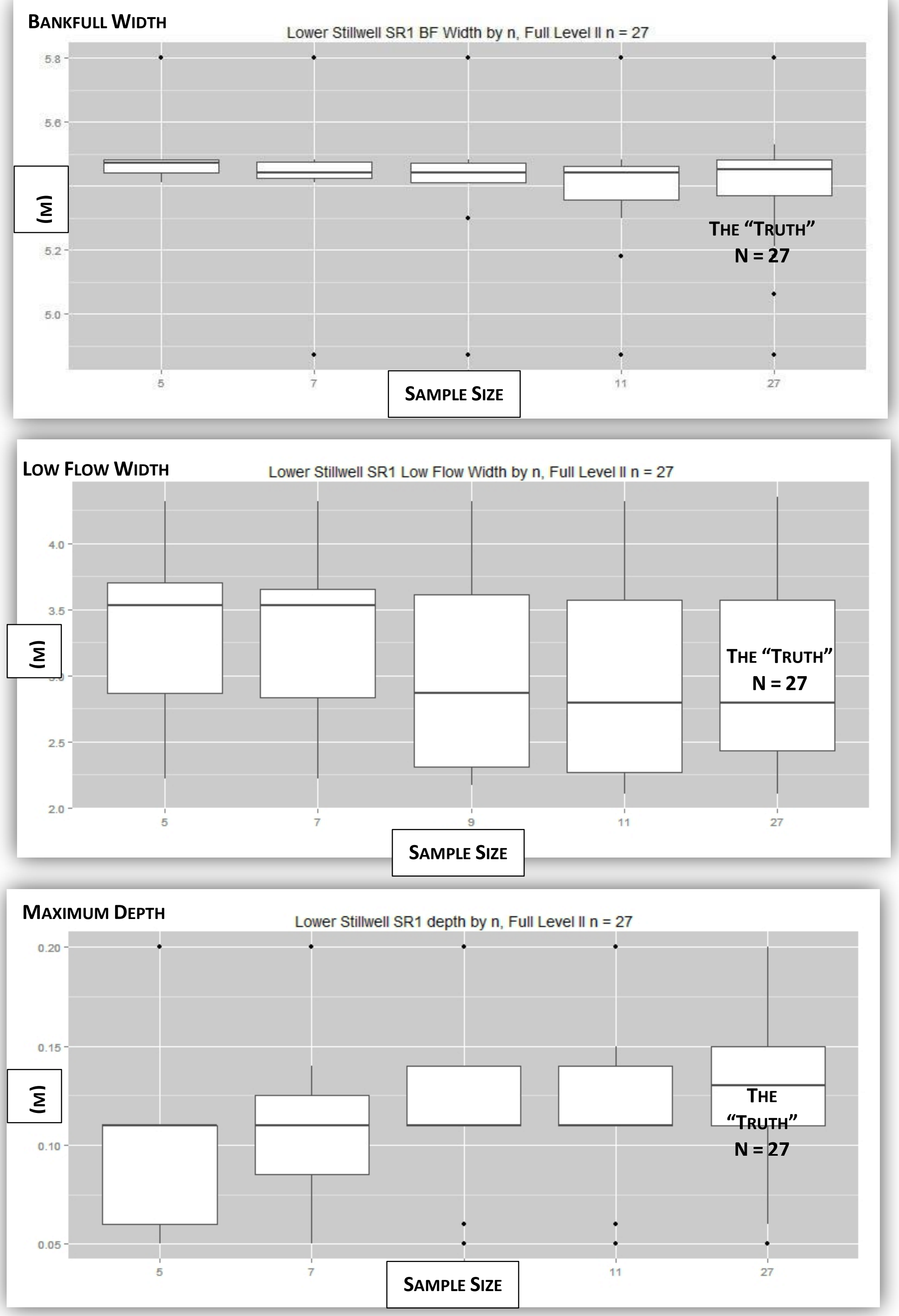


FIGURE 53: LOWER STILLWELL BANKFULL, LOW FLOW, AND MAXIMUM DEPTH DATA WITHIN THE *STRUCTURE* AS SAMPLE SIZE CHANGES

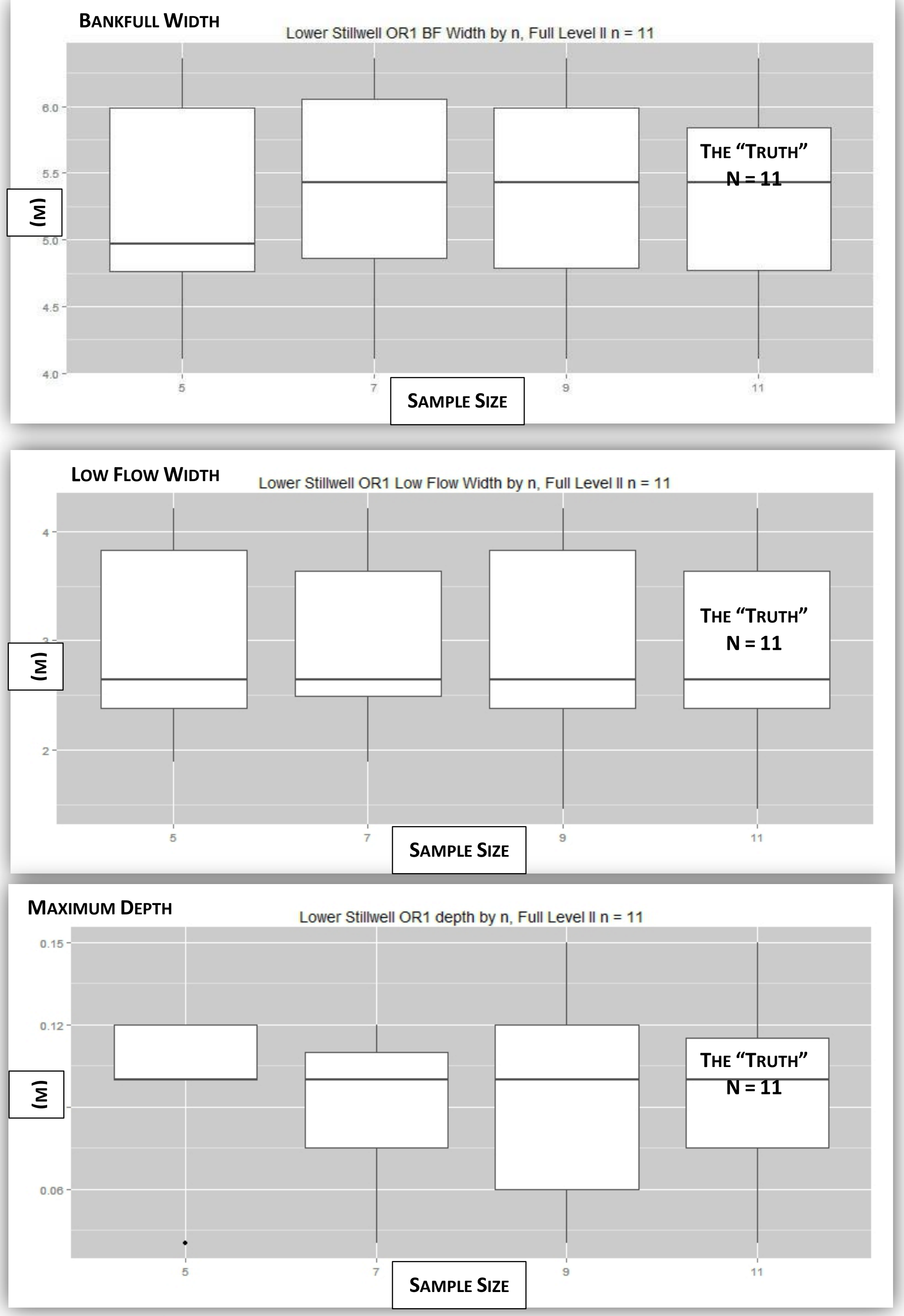


FIGURE 54: LOWER STILLWELL BANKFULL, LOW FLOW, AND MAXIMUM DEPTH DATA WITHIN THE *OUTLET TRANSITION ZONE* AS SAMPLE SIZE CHANGES

5.3.5 LEVELS I AND II METRIC SCORES COMPARED

Here, the level I summary rubric scores for each evaluated site are compared directly with those same metric scores by the level II summary rubric. Where group scores *differ*, the levels I and II protocol data are consulted and described (section 5.3.5.1 through 5.3.5.7). Ultimately, these comparisons are summarized in able 63. Knowing that level I sample sizes and methodologies need to be adjusted (as shown by the studies of Lower Stillwell data), some differences between the level I and II evaluations are expected. It was hoped more could be learned by comparing levels I and II scores at many sites. These results are discussed within the Objective 3 Discussion, Sections 6.3.2 and 6.3.3.

5.3.5.1 LOWER STILLWELL

Although the levels I and II rubric evaluations seem to generally agree, metrics were not always scored identically. Below, by group, the metrics which scored differently are presented. Specific differences between the level I and II design group data medians are provided. At Lower Stillwell, the selected representative reach is the same for levels I and II. The data values for the representative reach as measured by the level I and II protocols are also provided.

IR1

The riffle within the inlet transition zone at Lower Stillwell was evaluated as 71%, “questionable” by level I, and 88%, “similar” by level II.

- The level I IR1 group was rated lower than the level II IR1 group for several metrics. Width at low flow was rated “poor” (1) rather than “fair” (3). The level I design median is wider than that measured during level II by 31 cm. The level I representative reach median is wider than that measured during level II by 30 cm.

- The level I largest particles were scored “fair” (3) while the level II coarse fraction scored “good” (5). The level I median largest particle size is 288 mm greater than that for level II. The representative reach median largest particle size is 170 mm greater than that for level II.

SR1

The riffle within the Lower Stillwell structure scored 70%, “questionable” by level I, and 64%, “questionable” by level II.

- The level I width at bankfull stage metric scored higher (3) than the level II metric (1). The level I design median is equal to the level II median, but the representative reach according to level I is 35 cm wider than that by level II.

OR1

The riffle within the outlet transition zone scored 77%, “similar” by level I, and 69%, “questionable” by level II. Level I has positively skewed the effectiveness evaluation, an occurrence it was hoped would not occur. Reasons for the skew are discussed in section 6.3.4.

- The level I width at bankfull stage metric scored “poor” (1), while the level II metric scored “fair” (3). The level I median is 79 cm narrower than that measured during level II. And the level I representative reach median is 35 cm wider than that measured during level II.
- The level I outlet transition zone riffle scored much better than level II for the metric of maximum depth (5 versus 1). The level I maximum depth is 1 cm greater than that measured during level II. The representative reach depths are the same.
- Level I also scored better (5) for the largest particles metric than the level II coarse fraction (3). Level I data show the design median depth is greater than the representative median by 15 mm. The level I largest particles at OR1 are 205 mm larger than those measured during level II. The representative reach particles are larger by 170 mm for level II.

5.3.5.2 NORTH FORK INDIAN

Below, by group, the metrics which scored differently between levels I and II protocols are presented. Specific differences between the levels I and II design group data medians are provided. The North Fork Indian representative reach for levels I and II is not the same; representative reach data are not directly comparable and are therefore not listed.

IR1

The level I summary rubric evaluated IR1 at North Fork Indian as 74%, “questionable,” while it is 69%, “questionable” by the level II rubric. With overrides, the evaluation became “similar” (73%). For the original scores, a similar proportion of the metrics (40%) were penalized within both rubrics I and II, but they were largely different metrics.

- IR1 scored “poor” (1) for the level I metric of width at bankfull stage. This metric scored “fair” (3) by level II. The level I median width is 39 cm wider than that measured during level II.
- The low flow (wetted) width metric scored “fair” (3) by level I, but “good” (5) by level II. The median design low flow width is 41 cm wider than that measured during level II. The level II rubric overrode this score and lowered it from 5 to 3 (based on a p-value at the score boundary between 5 and 3). The level II group evaluation remained “questionable,” with a score of 67%.
- The largest particles metric scored “good” (5) by level I, but “poor” (1) by the level II coarse fraction. The median largest particle by level I is 95 mm larger than that measured by the level II coarse fraction. The level II coarse fraction was overridden from 1 to 3 and the evaluation became “similar,” with a score of 78%. The override was issued based on recent construction at the site.

- Bank irregularity scored 5 by level I, but 3 by level II. The level I inlet transition zone was rated 5 (irregular), while the level I representative reach was rated 1 (regular). The level II data show the median irregularity measure within IR1 is less than that within the representative reach by 11 cm. A level II override was issued for this metric based on the histogram and boxplot. The score was lowered from 5 to 3, and the evaluation again became "questionable," with a score of 73%.
- **SR1** was not evaluated by level I. This riffle was overridden by level II from "similar" to "questionable" (score became 70%) based on a bank irregularity score which was not well supported by the data.

SR2

Level I scored SR2 as 55%, "questionable," while level II scored SR2 as 83%, "similar." After an override, the level II score became 73%.

- The bankfull width metric scored 1 by level I, and 5 by level II. The level I median bankfull width is wider than that according to level II by 25 cm. The level II score was overrode from 5 to 3 based on a small sample size. The override dropped the group evaluation to "questionable," and the score to 73%.
- The bank irregularity metric scored 5 by level I, and 3 by level II. Level I rated both the SR1 and representative banks as being regular (1), and therefore the score is 5, "good". Level II shows the median bank irregularity measure is 24 cm less within SR2 than the representative reach.
- The coarse fraction metric was not evaluated by level II.

OR2

During level I data collection, the outlet transition zone boundary was not extended as far as indicated by the level II longitudinal profile analysis. Therefore, no level I data were collected within the level II outlet transition zone riffle.

SSR2

SSR2 is 68% “questionable” by level I, but 73% “questionable” by level II. The level II evaluation was later overridden from “questionable” to “similar” (score 84%) based on small sample sizes for the metrics of bankfull and low flow widths

- The low flow width metric score by level I is 3; it is 1 by level II. The level I design median low flow width is 50 cm wider than that measured during level II. The median representative level I low flow width is 53 cm wider than that measured during level II. A level II override was issued for this metric. The score was changed from 1 to 3, and the evaluation became “similar.” The override was based on data plots and small sample sizes.
- The coarse fraction and bed irregularity metrics were not evaluated by level II.

SP2/OP2

These units are actually the same pool. It spans the structure outlet evenly, and was evaluated as within different zones by each protocol. The pool was evaluated as 88% “similar” by level I, and 85% “similar” by level II.

- The maximum depth metric scored a 3 by level I, and a 5 by level II. The level I median maximum depth is 2 cm shallower than that measured by level II.
- Bank irregularity by level I scored 5, while it scored 1 by level II. Level I rated the pool as “regular” (1), the same irregularity as the representative reach. Level II rated the pool as having lower irregularity than the representative reach.

- Bank continuity was not evaluated by the level I protocol, because the pool was considered to be outside of the structure.

5.3.5.3 WF01

Although the evaluations seem to generally agree, metrics were not always scored identically. Below, by group, the metrics which scored differently between level I and II protocols are presented. Specific differences between the level I and II design group data medians are provided. At WF01, the selected representative reach should be the same for levels I and II. The data values for the representative reach as measured by the level I and II protocols are also provided. Level I data were collected one year after level II data by Cenderelli and Weinhold.

Level I did not recognize 2 different slope segments within the design channel, where level II did. Therefore, riffle 3 (combined slope segments for level I) is compared with riffles 1 and 2 (separate slope segments for level II).

IR1

This group scored 60% of the total possible points and was evaluated “questionable” by level I, and 57% “questionable” by level II.

- Width at bankfull stage scored 5 by level I, but 3 by level II. The level I median IR1 bankfull width is 45 cm wider than that measured during level II. The median representative reach is 28 cm narrower.
- Bank Irregularity scored 3 by level I, and 5 by level II. Level I evaluated the IR1 riffle as “varied” and the representative reach as “irregular.” Level II shows the median design irregularity measure is 15 cm less than that within the representative reach.

- The low flow width and maximum depth metrics were not evaluated during the level II protocol data collection (2011) because of the dry channel, but were evaluated in 2012 by level I.

SR1

The riffle within the structure was evaluated by level I as 28%, “dissimilar” while level II determined it 35%, “dissimilar.”

- All evaluated metrics scored the same by levels I and II.
- The low flow width and maximum depth metrics were not evaluated during the level II protocol data collection (2011) because of the dry channel, but were evaluated in 2012 by level I.

OR2

The level II riffle within the outlet transition has the same representative reach as that selected for the inlet and structure slope segment. Level I evaluated this group as 34% “dissimilar,” while level II evaluated it as 37% “dissimilar.”

- Bank irregularity scored 3 for level I, and 5 for level II. Level I rated the irregularity within the outlet transition zone riffle “varied” and the irregularity within the representative reach “irregular”. The level II median bank irregularity measure is 33 cm less than that within the representative reach.
- The low flow width and maximum depth metrics were not evaluated during level II protocol data collection (2011) because of the dry channel, but were evaluated in 2012 by level I.

5.3.5.4 WF02

Although the evaluations seem to generally agree, metrics were not always scored identically. Below, by group, the metrics which scored differently between level I and II protocols are presented. Specific differences between the level I and II design group data medians are provided. At WF02, the selected representative reach is the same for levels I and II. The data values for the representative reach as measured by the level I and II protocols are also provided. Level I data were collected one year after level II data, by Cenderelli and Weinhold.

IR1

Level I evaluated the riffle within the inlet transition zone as 46%, “dissimilar.” Level II evaluated the riffle within the inlet transition zone 57%, “questionable.”

- The width at bankfull stage was scored 1 by level I, and 3 by level II. The median level I design width is 8 cm wider than that within level II. The median representative reach measured by the level I protocol is 13 cm narrower than that by level II.
- The largest particles were scored 3 by level I, but 1 by the level II coarse fraction metric. The median largest particle within IR1 is 230 mm larger than that measured by the level II coarse fraction. The largest particles within the representative reach (level I) are 210 mm larger than the coarse fraction median (level II).
- Bank irregularity scored 3 by level I, but 5 by level II. The level I protocol rated the IR1 banks “regular” and the representative reach banks “varied.” The level II protocol shows the median bank irregularity measure is 7 cm less than that within the representative reach.
- The low flow width and maximum depth metrics were not evaluated during the level II protocol data collection (2011) because of the dry channel, but were evaluated in 2012 by level I.

SR1

SR1 was evaluated by level I as 35%, “dissimilar” and 33%, “dissimilar” by level II.

- The level I largest particle metric scored 3, while the level II coarse fraction scored 1. The median design largest level I particles are 230 mm greater than those within the representative reach. The median representative reach level I particle is 210 mm larger than the median coarse fraction particle.

- The low flow width and maximum depth metrics were not evaluated during the level II protocol data collection (2011) because of the dry channel, but were evaluated in 2012 by level I.

OR1

The riffle within the outlet transition zone scored 31% of the total possible points and was evaluated as "dissimilar" by level I. Level II evaluated it as 31%, "dissimilar."

- All evaluated metrics scored the same.
- The low flow width and maximum depth metrics were not evaluated during the level II protocol data collection (2011) because of the dry channel, but were evaluated in 2012 by level I.

5.3.5.5 SITE 3

Below, by group, the metrics which scored differently between level I and II protocols are presented. Specific differences between the level I and II design group data medians are provided. Level II data were collected at the site in 2011, level I data were collected in 2012 by Cenderelli and Weinhold. It was thought the representative reaches for level I and II protocols were the same, but metric score comparisons have created some uncertainty about this. Regardless, the data values for the representative reach as measured by the level I and II protocols are also provided.

IR1

The level I evaluation at Site 3 did not recognize the inlet transition zone was a different slope segment from the rest of the design channel. The level II analysis showed this, but selecting a representative reach for non-structure gradients was not part of the protocol at the time of data collection (2011). The inlet transition was therefore not analyzed by level II.

SR1

The level I rubric evaluated the riffle within the structure as 63%, “questionable.” The level II rubric evaluated this riffle as 30%, “dissimilar.” Level I has positively skewed the effectiveness evaluation for this group. Reasons for the skew are discussed in section 6.3.4.

- Level I scored the bankfull width as 5, while level II scored it as 1. The level I median design width is 7 cm narrower than that measured during level II. The median representative reach width is 70 cm narrower than that measured during level II.
- Level I evaluated the bank irregularity metric as 3, while level II evaluated it as 1. Level I rated the irregularity within the structure as “regular” and the representative reach as “varied.” Level II shows the median irregularity measure is 8 cm less than that within the representative reach.
- The low flow width and maximum depth metrics were not evaluated during the level II protocol data collection (2011) because of the dry channel, but were evaluated in 2012 by level I.

OR1

The level I rubric evaluated the riffle within the outlet transition zone as 34% “dissimilar”; the same group was evaluated by the level II rubric as 37%, “dissimilar.”

- Level I scored the bank irregularity metric 3; level II scored the metric 5. Level I rates the irregularity within the outlet transition zone riffle as “regular” and that within the representative reach as “varied.” Level II shows the median design irregularity measure is 12 cm greater than that within the representative reach.

- The low flow width and maximum depth metrics were not evaluated during the level II protocol data collection (2011) because of the dry channel, but were evaluated in 2012 by level I.

5.3.5.6 DOG SLAUGHTER

Below, by group, the metrics which scored differently between level I and II protocols are presented. Specific differences between the level I and II design group data medians are provided. The representative reach for the levels I and II protocols are the same. The data values for the representative reach as measured by the level I and II protocols are also provided.

IR1

Level I scored the riffle within the inlet transition zone as 63%, "questionable." Level II scored the same riffle 36%, "dissimilar." Level I positively skewed the effectiveness evaluation at this site. Reasons for the skew are discussed in section 6.3.4.

- The bankfull width metric scored 5 by level I, and 1 by level II. The median level I design width is 21 cm greater than that measured during level II. The median representative reach bankfull width by level I is 1.67 m narrower than that measured during level II.
- The low flow (wetted) width metric scored 5 by level I, and 1 by level II. The level I low flow design median is 7 cm wider than that measured by level II. The representative reach level I median is 1.98 m narrower than that measured by level II.
- The maximum depth metric scored 3 by level I, and 1 by level II. The level I median design depth is 1 cm shallower than that measured by level II. And the representative reach median design depth is 1 cm deeper than that measured by level II. The level II metric would have scored the same as level I, if it had been scored by the level I summary rubric.

This indicates there must be a distributional difference between depth populations; small sample size is likely causing the difference between scores.

IP1

The portion (head) of the pool within the inlet transition zone was not evaluated by level II, because it is too short. Level I however did evaluate IP1.

SP1

Level I evaluated the pool within the structure as 30% “dissimilar,” and level II evaluated the pool within the structure as 28%, “dissimilar.”

- All metrics scored the same by level I and II protocols.

OP1

Level I scored the portion of the pool within the outlet transition zone as 68%, “questionable.” Level II scored the same group; as 66% “questionable.”

- All metrics were scored the same by the level I and II protocols.

Constructed Riffle

Level I evaluated the constructed riffle as 54%, “questionable.” Level II evaluated it as 58%, “questionable.”

- Level I scored the bankfull width metric 5, while level II scored it 1. The median level I design bankfull width is greater than the median level II bankfull width by 8 cm. The median representative reach width for level I is 1.79 m narrower than that measured during level II.
- Level I scored the low flow width metric 3, while level II scored it 1. The median design wetted width measured by level I is 0.14 cm narrower than that measured during level II. The median representative reach wetted width is 2.02 m narrower than that measured during level II.

- Level I scored the maximum depth 3, while level II scored it 1. The median design maximum depth measured by level I is 2 cm deeper than that measured during level II. The median maximum depth within the representative reach is 6 cm deeper by level I than level II.
- The largest particles metric scored 1 by level I, while level II scored the coarse fraction metric 5. The largest median design particles measured by level I are 140 mm larger than the median design coarse fraction. The median largest representative reach particle is 510 mm larger than the median representative coarse fraction particle.
- Level I scored bank irregularity 1, while level II scored bank irregularity 5. Level I rated the bank irregularity within the outlet transition zone 1 (regular) and that within the representative reach 5 (irregular). The level I median bank irregularity measure is 40 cm less than that within the representative reach.
- Big Lick
- Below, by group, the metrics which scored differently between level I and II protocols are presented. Specific differences between the level I and II design group data medians are provided. The representative reach is the same for both the levels I and II protocols. The data values for the representative reach as measured by the level I and II protocols are also provided.

IR1

The level I protocol scored the riffle within the inlet transition zone 71%, “questionable.” Level II scored the riffle 64%, “questionable.” After overrides, the level II score became 53%, and the evaluation remained “questionable.”

- Level I scored the width at bankfull stage metric 5; level II scored it 3. The level I median design width is 76 cm wider than that measured by level II. The level I median representative reach is 19 cm narrower than that measured by level II. A level II override was issued for this metric. The score was changed from 3 to 1 based on sample sizes too small for reliable statistical testing. The evaluation remained questionable, and the score was lowered to 56%.

- Level I scored the low flow width 1; level II scored it 3. The level I median low flow width is 12 cm narrower than that measured during level II. The median level I representative reach width is 5 cm wider than that measured by level II. The level II low flow metric was overridden and the score changed from 3 to 1 because the sample sizes are very small and statistical test results are questionable. The score was lowered to 53%, but the evaluation remains "questionable."

IP1

The level I protocol scored the portion of the pool within the inlet transition zone 84%, "similar." Level II scored IP1 60%, "questionable." Level I positively skewed the effectiveness evaluation for this group. Reasons for the skew are discussed in section 6.3.4.

- Level I scored the width at bankfull stage metric 3, while level II scored it 1. The level I width at bankfull stage is 67 cm narrower than that measured during level II. The representative reach level I median width is 47 cm wider by level I than it is by level II.
- Level I scored the low flow width metric 5, while level II scored it 3. The median design low flow width as measured by level I is 8 cm narrower than that measured by level II. The median representative reach width by level I is 13 cm wider than that measured by level II.
- Level I scored bank irregularity 5, while level II scored it 3. Level I rated the bank irregularity at the pool within the inlet transition zone "regular" and the representative reach banks "varied". The median level II bank irregularity measure within IP1 is 21 cm less than that within the representative reach.

SP1

The Level I protocol scored the portion of the pool within the structure 53%, “questionable.” Level II scored the portion of the pool within the structure 55%, “questionable.”

- The low flow width metric was scored 5 by level I, 3 by level II. The design low flow width measured by level I is 11 cm wider than that measured by level II. The representative reach width is 13 cm wider when measured by level I.
- The bank irregularity metric scored 3 by level I, 1 by level II. Level I rated the bank irregularity within the structure as “regular”, and that within the representative reach as “varied.” The median level II bank irregularity measure is 33 cm less than that within the representative reach.

OP1

The level I protocol evaluated the pool within the outlet transition zone as 76%, “similar.” Level II evaluated the same pool as 80%, “similar.”

- Level I scored the bank irregularity metric 3; level II scored it 5. The level I protocol evaluated the pool within the outlet transition zone as “regular,” and the representative reach as “varied.” The level II median bank irregularity measure is 16 cm greater than that within the representative reach. The test is 1-sided, yielding a high score.

5.3.5.7 SPARKS BROOK

Below, by group, the metrics which scored differently between levels I and II protocols are presented. Specific differences between the level I and II design group data medians are provided. The representative reach is the same for both the levels I and II protocols. The data values for the representative reach as measured by the levels I and II protocols are also given.

IR1

The riffle within the inlet transition zone was evaluated as 69%, “questionable” by level I. The same riffle was evaluated as 79%, “similar” by level II.

- The width at bankfull stage scored 1 by level I, but 3 by level II. The level I median bankfull width is 19 cm less than that measured by the level II protocol. The representative reach median width is 1.14 m narrower than that measured during level II.
- The level I largest particles scored 1; while the level II coarse fraction scored 3. The level I median maximum particle size is 425 mm larger than that measured by the level II coarse fraction. The median level I maximum particle size within the representative reach is 825 mm larger than that measured during level II.
- The bank irregularity metric scored 3 by level 1 and 5 by level II. Level I rated the IR1 banks “varied” and the representative reach banks “irregular.” The level II median bank irregularity measure is 10 cm less than that within the representative reach.

SR1

Level I considered SR1 to be only the upper half of the level II riffle; the other half is called SP1, because it is a riffle run. For this reason, comparing level I to level II scores for this unit may not be very meaningful. The riffle within the upper part of the structure was evaluated 75%, “similar” by level I, and 88%, “similar” by level II.

- The width at the bankfull stage metric scored 5 by level I, and 3 by level II. The level I design bankfull width is 15 cm narrower than that measured during level II. The representative reach bankfull width is 1.14 m narrower by level I.
- The maximum depth metric scored 1 by level I, 5 by level II. The level I median design maximum depth is 3 cm shallower than that measured by level II. The representative reach is 7 cm deeper by level I.

- The largest particles scored 3 by level I, and 5 by the level II coarse fraction metric. The level I design median maximum particle size is 545 mm larger than that measured by the level II coarse fraction. Within the representative reach, the level I maximum particle size is 825 mm larger than that measured by the level II coarse fraction.

SP1

This unit is also called pool-run, or riffle-run 1 by level I. It is the lower part of the level II SR1 riffle. For this reason, the level I scores compared to level II scores may not be very meaningful. SR1 was evaluated as 57%, "questionable" by level I, and 88% "similar" by level II.

- The bankfull width metric scored 1 by level I and 3 by level II. The level I median design bankfull width is 71 cm narrower than that measured by level II. The representative reach is 1.14 m narrower.
- The low flow width (wetted) scored 1 by level I and 5 by level II. The level I median design low flow width is 55 cm narrower than that measured by level II. The representative reach median width is 21 cm wider by level I.
- The maximum depth metric scored 3 by level I and 5 by level II. The level I median design maximum depth is 2 cm shallower than that measured by level II. The representative reach is 14 cm deeper by level I.
- The largest particles were not measured during the level I protocol. This channel unit was classified as a pool run, and particles are not measured at pool units.

SR2

This unit was not evaluated by level I because it was thought to be too short (it is the short riffle between steps in the structure). The unit was overridden in level II from "similar" to "questionable" based on a low sample size for the low flow width metric. The score dropped from 76% to 73%.

SS2

SS2 is the step approximately half way through the structure. Steps are also evaluated (scored) in the same way between level I and II. The level I and II rubrics show SS2 is 73%, “questionable.” SS2 was overrode in level II from “questionable” to “similar” based on the method of scoring the particle size metric. The step evaluation improved to 80%.

OS2

OS2 is the step at the structure outlet. It is at the gradient break between the steep structure gradient 2, and the gentle gradient 0 within the outlet transition zone. It is compared with the same representative step as that used to evaluate SS2. At the time of level II data collection, it was unclear which step metrics would be collected. After spending time at the site, the step protocol was developed for level II. The level I data collected at steps was later used as part of the level II protocol. Steps are also evaluated (scored) in the same way between level I and II. SS2 was evaluated by the level I and II rubrics to be 35%, “dissimilar.”

Table 63: Differences between levels I and II results by metric scores; looking for patterns

Site	Group	Score %		Evaluation		Bankfull Width		Low Flow Width		Maximum Depth		Max Particle or Coarse Fraction		Bank Irregularity	
		I	II	I	II	I vs. II		I vs. II		I vs. II		I vs. II		I	II
						rep reach	design	rep reach	design	rep reach	design	rep reach	design	RR>design	RR median > design median
Lower Stillwell	IR1	71	88	Questionable	Similar			>	>			>	>		
	SR1	70	64	Questionable	Questionable	>	=								
	OR1	77	69	Similar	Questionable	>	<			=	>	>	>		
NF Indian	IR1	74	69	Questionable	Questionable	na	>	na	>			na	>	N	N
	SR2	55	83	Questionable	Similar	na	>							=	Y
	SSR2	68	73	Questionable	Questionable			>	>						
	SP2/OP2	88	86	Similar	Similar					na	<			=	Y
WF01	IR1/IR3	60	57	Questionable	Questionable	<	>							Y	Y
	OR2/OR3	34	37	Dissimilar	Dissimilar									Y	Y
WF02	IR1	46	57	Dissimilar	Questionable	<	>					>	>	N	Y
	SR1	35	33	Dissimilar	Dissimilar							>	>		

Site	Group	Score %		Evaluation		Bankfull Width		Low Flow Width		Maximum Depth		Max Particle or Coarse Fraction		Bank Irregularity	
		I	II	I	II	I vs. II		I vs. II		I vs. II		I vs. II		I	II
						rep reach	design	rep reach	design	rep reach	design	rep reach	design	RR > design	RR median > design median
Site 3	SR1	63	30	Questionable	Dissimilar	<	<							Y	Y
	OR1	34	37	Dissimilar	Dissimilar									Y	N
Dog Slaughter	IR1	63	36	Dissimilar	Dissimilar	<	>	<	>	>	<				
	Cons. Riffle	54	58	Questionable	Questionable	<	>	<	<	>	>	>	>	Y	Y
Big Lick	IR1	71	64	Questionable	Questionable	<	>	>	<						
	IP1	84	60	Similar	Questionable	>	<	>	<					Y	Y
	SP1	53	55	Questionable	Questionable			>	>					Y	Y
	OP1	76	80	Similar	Similar									Y	N
Sparks Brook	IR1	69	79	Questionable	Similar	<	<					>	>	Y	Y
	SR1	75	88	Similar	Similar	<	<			>	<	>	>		
	SP1	57	88	Questionable	Similar	<	<	>	<	>	<				

*ALL LEVEL II SCORES ARE LISTED PRE-OVERRIDES

6 DISCUSSION

Similar to other sections, the discussion section is also organized by objective. Within each objective's sub-sections, I address results previously presented as well as assess the performance of the levels I and II summary rubrics at evaluated sites. Perhaps most important, improvements to the levels I and II protocols and summary rubrics, both implemented and suggested, are presented. Many of these improvements are related to more than one objective, and are therefore referred to in more than one place. These changes are summarized within tables located in the Summary and Conclusions section (7) of this thesis.

6.1 OBJECTIVE 1: FIELD TESTING THE LEVEL I AND II DRAFT PROTOCOLS

The levels I and II draft field protocols were tested over the course of two field seasons. Most improvements to the protocols were made while in the field. Further changes were made, or are suggested, as the result of data analysis (addressed under Objectives 2 and 3). This section highlights some of the improvements to field methods which were made, or that I suggest could be made. They are summarized within Table 64, Table 65, and Table 66 (section 7).

6.1.1 DATA COLLECTION

6.1.1.1 FIELD LOGISTICS

Level II data collection logistics are challenging because of the significant field time required (about five days). Camping at the site would have been the most efficient use of field time, but the Total Station, Carlson data logger, two-way radios, and laptop computer required a power source for charging. Travel between the site and a Forest Service station was generally necessary until the long profile analysis was complete. This added to the time required for level II data collection. Some description of these logistics should be included within the final level II field protocol. Perhaps a solar-charged battery system would be worth carrying if one were to do level II monitoring at several remote sites.

6.1.1.2 IMPROVING MEASUREMENT ACCURACY

Precipitation during data collection may have affected the accuracy of measurement at several of my sites. The distance from water surface to bankfull elevation is measured within the *natural* channel where bankfull indicators are present. The elevation at bankfull stage within the *design* channel is then estimated by measuring up from the water surface. If significant rains occur between the time the distance to bankfull is measured within the *natural* channel and data are collected within the *design* channel, width, bank irregularity, and bank continuity metrics will be measured at the wrong height. Should this occur, I recommend that either the bankfull elevation be re-measured within the natural channel, and/or measurements be taken again within the design channel. Some description of this problem should be added to the final field protocol.

The effect of measurement accuracy on summary rubric scores should be considered and discussed within the finalized summary rubric instructions. The issue is particularly relevant to data distributions which are not variable (e.g., depth). Level I effects are especially obvious because the scores are based on the range of data within the representative reach. For example, at Lower Stillwell, the difference between the level I representative reach minimum riffle depth and the 25th percentile is 1 cm. This centimeter is the difference between a metric score of 1 and 3. How accurate are depth measurements taken with a stadia rod in flowing water? It seems likely that depth measurements could vary by at least 2 cm in swift flow. I recommend that a discussion of measurement accuracy be included as part of the instructions for using the override option. For example, evaluators might justify an override based on scores for metrics with narrow scoring intervals when compared with accuracy expectations.

The accuracy of channel width measurements may have been affected by the method used to collect these data. The laser distance meter replaced the level stadia rod technique at the start of the 2012 field season. The laser method improved efficiency and decreased the physical stress of collecting the width measurements, but in some environments it may be less accurate. In particular, accuracy is likely affected by extremely vegetated banks. The laser was field tested and compared with stadia rod measurements at a boulder lined bank and it performed well. However, some erroneous data values call this technique into question. Further accuracy testing of the laser distance meter is warranted because inaccurate width measurements affect the width at bankfull stage, width at half bankfull stage, bank irregularity and bank continuity metrics.

The accuracy of width measurements is certainly affected by the number of obstructions encountered in a single measurement. For example, when a large boulder extends above the bankfull elevation, one must measure from the channel centerline to the boulder's edge, mark the location of intersection on the boulder, measure the width of the boulder at that elevation, and then the distance from the boulder's far edge to the bank. It is reasonable to say that whenever an obstruction is encountered, the measured width becomes a good estimate at best. Perhaps a more accurate technique for capturing channel width at obstructions could be incorporated into the protocol. Obstructions were most frequently encountered at the half bankfull stage and wetted width.

During the 2011 field season and beginning of the 2012 field season, measurements were not specifically collected by channel unit. This may mean data have been assigned to inaccurate groups, which would alter summary rubric evaluations. Channel units were assigned to data values by comparing the measurement station with the surveyed distance on the long profile. It is possible my results would be more accurate if the protocol had initially specified collecting data by channel unit. I recommend that the final protocols specify that a channel unit and slope segment are noted for each metric collected.

Perhaps the level I data population would be more similar to the level II data population (and assumed accurate) if the minimum, maximum, and median values were visually determined and measurements were specifically collected at these locations. The level I sample size for width and depth metrics is currently small (n=5) and data are collected by dividing the channel unit length into five equal segments.

A width and depth measurement is taken at each segment division. Future field research could test this idea by comparing both methods of stationing the level I data collection, and comparing the results to the level II data populations.

6.1.1.3 METRICS

Metrics included in the levels I and II protocols should offer clues which help to assess geomorphological processes. Within this section, data collection methods, measurements, and scoring methods are discussed for some level II metrics; improvements are suggested. Level I metrics have been studied in the context of the level II protocol; issues are therefore presented throughout the Objective 3 discussion.

Table 64 summarizes suggested changes to the level I protocol. Table 65 summarizes suggested changes to the level II protocol. 66 summarizes suggested changes applicable to both the levels I and II protocols.

More step-pool channels should be analyzed in order to further develop the step metrics. The field protocol for steps was minimally tested during this study. Only two sites with steps in the design channel were analyzed and only one of them by the level II protocol. Data were actually collected at four step-pool channels; the other sites with steps (Haskell Creek and Jenny Coolidge) were not analyzed because the data are questionable. At Haskell Creek, data have different sampling intervals between the representative reach and the design channel, creating statistical uncertainty. Jenny Coolidge experienced hurricane Irene in 2011. This approximately 500-year storm event (B. Gubernick, pers. comm., 2013) had a dramatic effect on channel geometry, making it difficult to interpret culvert effects at flows near bankfull.

The protocol for collecting data at steps was developed in 2012, after level I was created. It could be improved upon. Steps are difficult to assess because of their small size and linear dimensions. Further studies, which address the following questions, seem necessary: Do the metrics collected adequately capture the geometry which controls the hydraulics created by steps? Are single measurements at a step adequate, or should the median value of at least 3 measurements be used? Should more steps within the representative reach be measured and their data pooled in order to better represent the full range of natural variability? Should all steps within the design zone be measured and compared with the representative step(s)?

Close-up photographs of each measured and compared step would have been very useful for assessing the performance of the rubrics. Unfortunately, I did not collect these images. Specifically, photos which capture each measured dimension: height, length, and width, would be helpful. I recommend adding directions for capturing these photos to the levels I and II protocols.

Originally, cross sections were included in the level II protocol for comparing (at-a-station) hydraulic geometry coefficients and exponents. It was time prohibitive, however, to measure enough cross sections to obtain a statistically significant sample. Instead, it was thought bed irregularity would be a meaningful way to use the cross section data. Bed irregularity is derived from a cross section by finding the median distance from bankfull stage to the bed. The changes in bed elevation (deviations) above and below the median bed are then calculated. The absolute values of the deviations are the bed irregularity measures. It seems bed irregularity might be better assessed by statistically testing distributions, whereby a population of irregularity measures would be analyzed (e.g., the K-S test).

An entirely different data collection method however, may prove more representative of bed irregularity. As is, I wonder whether a single cross section, or at most two per channel unit, adequately represents bed irregularity within the entire channel unit. Instead of directly measuring irregularity, perhaps by assessing the sorting of a streambed, sediment continuity and hydraulic differences would be portrayed. Design representative zones should be similarly sorted. Folk (1974) created the “inclusive graphic standard deviation” as a measure of sorting. The inclusive graphic standard deviation is calculated as follows:

$$\boldsymbol{\sigma_1 = \frac{\Phi 84 - \Phi 16}{4} + \frac{\Phi 95 - \Phi 5}{6.6}} \tag{8}$$

Where ϕ84, ϕ16, ϕ95, and ϕ5 are the phi values at the 84th, 16th, 95th, and 5th percentiles of the gradation distribution. Folk (1974) also created a sorting classification scale:

- <0.350: very well sorted;
- 0.35-0.500: well sorted;
- 0.5-0.710: moderately well sorted;
- 0.71-1.00: moderately sorted;
- 1.00-2.00: poorly sorted;
- 2.00-4.00: very poorly sorted;
- >4.00: extremely poorly sorted.

The bed irregularity metric might be scored by assessing the percent difference between the design and representative reach zones. Or, scores could be assigned according to Folk’s classification scale in which groups with the same classification are scored 5, those with one classification different are scored 3, and more than 1 classification different are scored 1. If bed irregularity were evaluated by sorting classification, the pebble counts collected for the coarse fraction metric could be utilized, thereby making data collection more time efficient than measuring irregularity by cross section.

Given that bed irregularity does not control channel morphology, but instead is affected by design elements, it could arguably be removed from the level II protocol. This is reflected by the metric weight, which is so low, a group evaluation is hardly affected by bed irregularity. As the protocol is now, this would mean cross sections would no longer be collected nor analyzed, thereby eliminating several hours of field and office work. Cross sections do, however, offer a nice visual comparison of channel geometries (design versus representative reach). In addition, some hydraulic modeling is made possible by the collected cross sections.

As an alternative to the current method of measuring channel width, more cross sections could be collected, from which bankfull, half bankfull, wetted widths, and maximum depth metrics could be extracted. This would mean measuring at least 20 cross sections within each zone. The width and bank irregularity metrics would be compared with a representative reach by group. Hydraulic geometry exponents and coefficients could be calculated and statistically compared by zone. The bed irregularity metric would be improved because more cross sections would be collected per channel unit. More field research would show whether this approach was more time and labor efficient than the current method of measuring widths and cross sections.

The coarse fraction of the gradation metric is especially sensitive to channel gradient. Where design and representative reach slope segments have slightly different gradients, it may be unreasonable to expect the coarse fraction medians to be equivalent (especially at steeper gradients). By altering the method of scoring this metric, un-fairly penalizing for minor differences in gradation might be avoided. Scores could be generated by graphing the sample fraction (per phi size class) versus the particle size in phi units (creates an approximately Gaussian distribution), and then comparing the design mode to phi intervals around the representative reach mode. A "good" score (5) would be within the proximal ± 0.5 phi bin from the mode, a "fair" (3) score would be within the ± 1 phi bin from the mode, and a "poor" (1) score would be beyond a 1 phi bin interval from the mode. Scoring gradation in this manner is more lenient than simply testing for similar medians because phi is scaled by $-\log_2$(particle diameter in mm). Originally, I believe the intention of the level II coarse fraction of the gradation metric was to compare the stability of the largest design particles with those in the representative reach (the "key pieces"). Key pieces are important because they maintain the design gradient, bed features, and protect the structure. They should be sized to remain stationary during the structural design flood (an event with a ~50 to 100 year recurrence interval). I don't believe the coarse fraction of the gradation is adequately assessing particle stability; instead it evaluates particle mobility by comparing approximately the surface

D84 between the design and the natural channel. When the D84 is transported, most of the particles on the bed will also mobilize. The problem occurs because the adjustable vertices sampling frame is most easily placed on the channel bed, over particles smaller than it. The largest (stable) particles are rarely found under the frame. To ensure the “key pieces” are measured, the protocol should specify measuring all particles, including those which may be rarely mobilized (likely particles much larger than the frame).

6.1.2 IDENTIFYING THE REPRESENTATIVE REACH

6.1.2.1 LEVEL II: LONGITUDINAL PROFILE ANALYSIS

The longitudinal profile analysis is a critical part of the level II protocol because it is the method by which the representative reach is selected. Within this section, implemented changes, and suggestions for further changes to the longitudinal profile analysis procedure are discussed.

Longitudinal profile analysis proved to be more time-consuming and frustrating than seemed necessary. At times it appeared to be a subjective analysis, whereby myself and Dr. Cenderelli would arrive at very different interpretations given the same data. Over the course of both field seasons, several techniques seemed to improve the interpretations, removing the subjectivity. I highly recommended they are both incorporated into the final level II protocol instructions. The first recommendation is to emphasize limiting the vertical exaggeration of the longitudinal profile during analysis. An exaggeration between 2 and 10 will prevent too many slope segments from being identified. For channels with gradients greater than 6 percent, a smaller exaggeration should be used. Setting the vertical and horizontal scales equal and then using a box “shape” on the profile to visualize the difference is helpful.

The second recommendation is a method for delineating slope segments. Rather than relying on a spreadsheet to mathematically arrange and then combine line segments which differ in gradient by less than 25%, one initially uses line “shapes” on the plotted long profile to connect grade controls. After slope segment boundaries are visually selected, they can be mathematically analyzed to ensure they have a gradient difference greater than or equal to 25% for adjacent segments. When this technique was employed, the long profile analysis method gave more reproducible results.

A third recommendation, although a simple one, is to encourage evaluators to enter the field note associated with each survey point into the longitudinal profile spreadsheet. Having these notes available for easy reference was very helpful during survey interpretation.

A representative reach is selected based on a sliding scale gradient criterion. The difference in gradient between design slope segments and potential representative reaches is evaluated. The tolerable difference changes depending on steepness of the design gradient. Steep design channels must be very similar (within 25%) in gradient to the natural channel segment, while gentle gradient design channels can be quite different (100%). Given that channel gradient has a large effect on channel form, how similar do gradients need to be to create the same hydraulics? Differences in gradient will have an effect on metric scores (i.e., coarse fraction of the gradation).

Future work might explore a more stringent gradient criterion for selecting the representative reach for steeper design channels. Moderately steep and gentle gradient channels have larger tolerance criterion because a small range of gradients is made available when a small number is multiplied by a fraction. Perhaps if design channels greater than 5-6% slope were within 10% (or less) of the representative reach gradient, channel metrics within steep channels (especially gradation) would be more fairly compared.

Possibly the most significant change to the draft level II protocol during field testing was allowing for more than one representative reach when multiple design slope segments are present. Initially, a representative reach was selected only for the gradient which passes through the structure. If different gradients composed the inlet and outlet transition zones, no representative reach was chosen to which these zones could be compared. The inlet and outlet transition zones are influenced by the structure and are part of the crossing design. It is therefore important to also determine whether these zones affect stream continuity by comparing them with the natural channel. Because this change was made during the second field season, some design zones are not analyzed even though data were collected there.

6.1.2.2 Level I: Ocular Estimate of Slope Segments

Instead of surveying a longitudinal profile, the current level I protocol requires the evaluator to identify similar channel gradients (by ocular estimate). The method proved possible at Bays Creek where a level I representative reach was not identified in the natural channel by ocular estimate, nor was an appropriate representative reach identified by the level II survey. Ocular estimate may not, however, be consistent, and certainly leaves room for subjectivity.

The level I method of selecting a representative reach could be improved by using a survey level and rod. For the distance of the study reach, major breaks in slope (assumed slope segments) would be surveyed and later analyzed. Gradients within 25% would be combined into single slope segments. Potential representative reaches would first be identified through numerical analysis, and then later verified in the field. Measuring channel gradient by level and rod would certainly lengthen the time required beyond that necessary for the current ocular estimate, but a coarse survey would still be much faster than the level II survey by total station.

Level I sites evaluated by this study used an ocular estimate of each *channel unit's* gradient within a design zone. To be consistent with the level II protocol, it is recommended instead that similar channel gradients between grade controls (<25% different from one another) are grouped together into slope segments. The same channel units within slope segments (e.g., riffles) are evaluated together (data are combined) and compared with data from that channel unit in the representative reach. Wherever possible, channel unit sequences should be analyzed by the level I protocol, just as they are within the level II protocol. In addition, the level I criteria for defining channel units and selecting the representative reach should be identical to the level II criteria.

6.1.3 PROTOCOL APPLICABILITY

This section highlights situations where the levels I and II protocols either do not lend themselves well to analyzing the design, or have not been well tested. Specifically, long pools, short channel units, basin setting, large wood loads, and recent, very large floods make the protocol results difficult to interpret. These limitations were illuminated by issues at several of my field sites. The levels I and II protocols were not field tested at designs with sand beds, although it should be noted that they would also be applicable to those channels.

The levels I and II protocols may not be applicable to sites with exceptionally long pools which span multiple design zones. Segmenting the pool by analyzing the head, body and tail separately makes little sense for two reasons. First, the hydraulic influence and boundary conditions imposed by the structure are different than conditions at the inlet and outlet transition zones. Hydraulics may be especially different during floods if the structure width is much narrower than either the inlet or outlet transition zones. Second, comparing design depth data for only a portion of the pool to the entire pool within the representative reach is meaningless. This is especially true for the maximum depth metric.

Dog Slaughter and Big Lick both have long pools which extend beyond the structure into the inlet and outlet transition zones. These sites were analyzed both by group (segmented by zone) and by population (design versus natural channel). For the two reasons described, neither approach is valid. The levels I and II protocols are not really applicable at sites with these designs. The best method of analysis at these sites is a qualitative assessment, where few, simple measurements are collected (i.e. structure width versus natural channel width at the bankfull stage). Long pools which occupy the entire design channel are not common, nor would they typically pass as stream simulation design.

The levels I and II protocols are most applicable to simple designs with few long channel units. Channels with complicated designs that include many short units (e.g., steep short riffle, short pool, short riffle) may present a challenge for both protocols because per group sample sizes will be small. When evaluating channels with short units, one should first try to find channel sequences (riffle, pool) with similar lengths as those in the representative reach. If comparable channel sequences can be identified, sampling intervals can be set by unit sequence instead of zone (structure or representative reach) length. For the level II protocol, statistically significant sample sizes are necessary. If most units are less than one bankfull channel width in length, neither the levels I or II protocols apply. These designs must be qualitatively evaluated. If no comparable sequences composed of short units are found, the level II protocol may not apply because statistical testing won't be possible. Setting sampling intervals based on the length of individual channel units is not feasible because, for shorter units, tight intervals may not be obtaining "new" information at each sampling location (violates the statistical assumption of independence). Sampling accuracy and precision become more important as sampling intervals become smaller. Further, setting sampling intervals by channel unit would make the level II protocol very time consuming and altering the interval between groups would create problems for statistical testing.

The basin setting at some road-stream crossing sites may influence the effectiveness of the design. Although an evaluator should be aware of basin scale effects, capturing them within notes, the levels I and II protocols do not account for large-scale factors influencing the channel. For example, where the crossing is located at a basin-scale gradient inflection, either concave, convex, or a combination of the two, the stream may naturally aggrade or incise. Because a design at an inflection point will have a significantly different gradient than the majority of the natural channel, an appropriate representative reach may not be identified, making both protocols inapplicable. In these circumstances, it is important to recognize the presence of the inflection point and consider its effect on the channel. The design may instead be qualitatively assessed (compare bankfull dimensions to those in the natural channel, channel unit types, channel unit lengths, etc.). Where road-stream crossings have been replaced at inflection points, impacts from construction, such as headcuts, may travel upstream. An effectiveness evaluation should also check for these channel changes.

At streams with large wood loads, physical effectiveness monitoring may not apply because the channel's morphology is largely controlled by the wood. Many large wood pieces which fall into a channel eventually find a stable position which allows them to influence local hydraulics. These pieces may form steps (mimicked in a crossing structure with large stable rocks). Wood also forms log and debris jams, which can pond water behind them. At high flows, the jams may re-route the stream onto the floodplain, carving new channels, and entraining more wood. Or, the stream may find a way through the jam, re-establishing its gradient before the jam was formed. The dynamic nature of these wood jams is impossible to mimic within a road-stream crossing structure. Frequent wood jams in the natural channels above and below the design structure may alter the stream gradient enough to prevent one from finding a suitable representative reach. These designs should be qualitatively assessed.

At sites where large floods (i.e., greater than the approximately bankfull discharge) have recently occurred (e.g., at Jenny Coolidge), channel dimensions within the design and the natural channels will have both been dramatically altered. Comparing the design channel to the natural channel before several, or many, moderate flows (approximately bankfull discharge) have re-adjusted the channel won't yield information about how the design channel affects geomorphology at the design discharge because the structure likely constricted the flow. Monitoring activities after extremely large floods (greater than bankfull) should focus simply on how well the structure passed the flood. Long-term monitoring should then track channel adjustments over time.

The levels I and II protocols were generally tested and developed around designs with gravel, cobble and boulder beds. This does not imply the protocols are not applicable to sand bed channels. The main difference is the lack of stable grade controls used to delineate slope segments and zone boundaries.

Instead, somewhat mobile features (i.e., point bars) may be used. In addition, some metrics (i.e., the coarse fraction) may not be measured. Further study might try to identify the best way to compare mobile bed features such as ripples and anti-dunes.

6.1.4 UTILITY OF LEVEL I AND II PROTOCOLS

The level of physical effectiveness monitoring (I or II) used at a design site should reflect how critical monitoring geomorphic continuity is at that stream. Because level II is detailed and statistically significant, it is most appropriate at a small number of sites. It is both financially and temporally demanding because it requires meticulously collecting abundant data, but, because it is detailed, those who design road stream crossings may improve their skills by identifying specific mistakes. The level II protocol requires about 5 field days to complete, not including data analysis (other than the longitudinal profile). Level II should be implemented by experienced hydrologists, geomorphologists, geotechnical engineers, and physically trained fisheries biologists.

The level I protocol should be used to monitor a large number of road-stream crossing sites. Many sites are appropriate for this protocol because it only requires about 3 hours of field time per site. Although not likely to provide enough information to improve design skills, it should identify crossings which interrupt geomorphic continuity. Where continuity is critical, level I sites evaluated as “fair” should be followed up with a level II evaluation. In this way, level I can be used as a screening tool for the application of the level II protocol. Level I can be implemented by well-trained crews of physically oriented technicians.

Both levels I and II protocols were designed to be implemented by applied scientists. To ensure the protocols are utilizable by this audience, field equipment, software, and statistical knowledge have been kept as simple as possible. The most expensive piece of equipment specified is a total station, and if necessary, a survey level could be used instead.

6.2 OBJECTIVE 2 DISCUSSION: CREATE SUMMARY RUBRICS FOR LEVELS I AND II PROTOCOLS (RUBRIC PERFORMANCE AT EVALUATED SITES)

Summary rubrics were developed for levels I and II. A total of twelve sites were evaluated by either the levels I or II summary rubrics. Results from these sites are used to assess the performance of these tools. At three of these sites, discussed within this section, physical effectiveness monitoring was terminated because the sites did not meet the basic criteria for monitoring. Eight sites, also discussed in this section, were evaluated by the level II protocol and summary rubric. The results for these level II sites are discussed here in the context of their data plots, photos and site observations. These same eight sites were also evaluated by the level I protocol and summary rubric. They are evaluated within the Objective 3 discussion (section 6.3.2), in the context of the level II results. A single level I site not also evaluated by level II is discussed here. The results are evaluated qualitatively with photos and observations. The overall performance of the levels I and II rubrics are summarized at the end of this section (Sections 6.2.8 and 6.2.9). The data plots and photos referred to can be found in Appendix A [Site Data] organized alphabetically by site.

6.2.1 SITES WHERE THE LEVEL I PROTOCOL WAS TERMINATED

Physical effectiveness monitoring was stopped at the sites discussed within this section because they did not meet the basic criteria for monitoring. These sites are included within this study for two reasons: they are examples of sites where the physical effectiveness monitoring protocols do not apply and they offer an opportunity to show that evaluating potential representative reaches by eye (as in level I) is possible (but may not be the best approach). See Sections 6.1.2.2 and 5.2.2.1.12.

6.2.1.1 CANEY CREEK

Although the level I protocol was terminated (the structure is too narrow and no representative reach was identified within the natural channel), the qualitative data collected at Caney Creek are enough to evaluate the site. An obvious problem is the dry constructed riffle that backwaters the design pool. Although at higher flows the constructed riffle may be wet enough to allow for aquatic organism passage, clearly at lower flows, the dry riffle is a barrier. The design could be improved by lowering the riffle crest elevation.

Another obvious problem at Caney Creek is the narrow structure. It is less than half the bankfull width of the natural channel. A narrow structure will affect the design channel within and around it. The inlet transition pool may aggrade over time as sediment and wood are deposited within this low gradient, backwatered area. During high flows, the narrow structure will increase the depth and velocity of water, scouring any accumulated sediment within the structure pool. Edge habitat and bed irregularity will not develop over time. The stability of the structure footings, however, will not likely be compromised, given that the design channel bed is solid bedrock. Given these qualitative observations, the Caney Creek road-stream crossing design is dissimilar from the natural channel. It is interrupting geomorphic and likely ecologic continuity.

6.2.1.2 UTLEY BROOK

The level I physical monitoring protocol was terminated at Utley Brook for two reasons: the structure is too narrow, and no representative reach was identified within the natural channel. Because Utley Brook was recently disturbed by high flows associated with hurricane Irene, it is difficult to say how the road-stream crossing has affected geomorphic continuity within the natural channel. The structure is much narrower than the natural bankfull channel width, which surely creates stronger hydraulics within the culvert during floods. The inlet and outlet transition zones are both wider than the natural channel. The fines present in these zones are likely evidence of sediment accumulated as a result of the increased width and low gradient. Prior to the Irene flood, these zones may have been more aggraded.

It seems likely the Utley Brook design is passable by many aquatic organisms at low flows. Certainly, many fish were observed within the structure pool, and the steep riffle/cascade at the downstream outlet transition zone boundary did not appear exceptionally treacherous. At higher flows, the narrow structure width could elevate velocities beyond the swimming abilities of many organisms.

6.2.1.3 BAYS CREEK

Both the levels I and II protocols were terminated at Bays Creek for two reasons: the structure is too narrow, and a representative reach was not identified for the gentle gradient riffle present within the structure and outlet transition zones. Observations at the site can, however, be interpreted to yield a meaningful assessment of geomorphic continuity through the design. The longitudinal profile and photos are located within Appendix A1 [Bays Creek Site Data].

The Bays Creek road-stream crossing is located at an abrupt change in geomorphic setting; the boundary between a bedrock confined and an alluvial unconfined channel. Immediately upstream of the structure inlet, the channel emerges from a section of bedrock into which it has incised. The confined, channel flows from chute to pool, with some riffles present in the wider portions of the channel. At the inlet transition zone boundary, the bedrock disappears and the stream channel width expands dramatically. The bedrock, present upstream, remains absent downstream of the culvert and the channel is generally wide, alternating between pools and riffles. As the boundary condition changes the gradient also changes; the channel is generally steeper within the bedrock and gentler downstream. The break in gradient occurs within the structure (see Figure 75 [Bays Creek Longitudinal Profile], Appendix A1 [Bays Creek Site Data]).

The geomorphic setting is further complicated by a large tributary which enters Bays Creek at the outlet transition zone boundary. The increased discharge from the tributary changes the channel dimensions, making any comparison of the design channel with reaches downstream inappropriate. This is problematic for both the levels I and II protocols because the low gradient slope segment within the structure and outlet transition zone is more closely related in boundary condition to reaches downstream.

The significant break in gradient (4.1% to 0.5%) within the structure may cause aggradation within the low gradient riffle at the structure outlet over time. Aggradation at the outlet might backwater the structure, temporarily causing aggradation within the structure until the next sediment transporting flow.

Another obvious design flaw is the narrow width of the structure when compared with the natural channel at bankfull stage (3.6 m versus 7.7 m). Although the narrow width will help scour aggraded sediment during floods, the depth and therefore velocity within the structure are elevated by the confinement, especially for the steeper gradient segment. High velocities can be problematic for weaker swimming species and may scour the bed near the structure foundation, eventually undermining the crossing.

The crossing design could be improved if it were moved slightly upstream so that the gradient break was downstream of the crossing. This would require re-aligning the road, curving it before and after the structure, so as to cross Bays Creek perpendicular to the channel. The structure should also be sized at least as wide as the natural channel bankfull width. The design bed within the structure would likely be a steep, coarse riffle.

Given the unique geomorphic setting, dissimilarities between the constructed channel and the natural channel are difficult to blame entirely on the design. Given the undersized structure however, the design is certainly no better than “fair.” Fish passage studies have shown that Bays Creek is not a barrier to the fish species studied (J. Speece, pers. comm., 2013), although other aquatic organisms were not specifically evaluated.

6.2.2 SITES EVALUATED BY THE LEVEL I SUMMARY RUBRIC: RESULTS DISCUSSION

Level I data were collected at only one site where level II data were not; this site alone is discussed here. The other level I sites are discussed as part of Objective 3 (section 6.3.2).

6.2.2.1 JOE SMITH BROOK

The road-stream crossing at Joe Smith Brook is an open bottom pipe arch structure. The design channel contains a step just upstream of the structure inlet, a very gentle gradient riffle through the structure, and a steep riffle/cascade just downstream of the structure outlet. The site experienced a flood associated with hurricane Irene in 2011, approximately one year prior to level I data collection. The accuracy of scores for the structure riffle is assessed with photographs (Figure 202 through Figure 212 within Appendix A5.1) [Joe Smith Brook Photos]. Where metrics cannot be assessed by photos, the score is not discussed and is assumed to be reasonable.

IS1

The step at the structure inlet scored 37% of the total possible points and was evaluated as “dissimilar.” The step scored poorly (1) because it is shorter than the representative step by 4 cm. The data however show that only one measurement at the design step was compared with a single measurement at the representative reach step. Were more measurements taken, the representative reach height distribution would be better defined, and the design step may not have lost as many points. If this metric were to score a 3, the step scores 50% of the total possible points and becomes “questionable.” The step also scored poorly (1) because it is built of larger particles than the representative step. I think this metric should be a one-sided evaluation of stability and larger particles should not be penalized. Were the step to score a 3 for this metric, the score becomes 60% “questionable” (this score includes the override described above for step height). If only this override is executed, the step score is 47% and the evaluation remains "questionable."

SR1

The riffle within the structure has an extremely gentle gradient, not common within the natural channel. The selected representative reach has the most similar gradient encountered within the study reach, although it is likely steeper. The level I summary rubric evaluated the riffle as "dissimilar"; it scored only 40% of the total possible points. The structure riffle scored highly (5) for the maximum depth metric. The median design was found to be slightly deeper than the median representative reach. The widths at bankfull and low flow stages scored poorly (1). Data show both metrics are much narrower than those encountered within the natural channel. Photos show these scores to be reasonable. The largest particle metric also scored poorly (1). Data show the largest particles within the structure are much larger than those found within the natural channel. This is believable given the narrow structure width, which creates faster velocities and higher shear stress along the bed. Bank irregularity was rated "fair" (3). The representative reach was categorized as "varied" and the structure "regular." Photos support this evaluation. Banks are absent within the structure; bank continuity is reasonably scored poorly (1).

OSR1

The gentle gradient riffle extends from the structure a short distance into the outlet transition zone. The gradient then breaks sharply into a steep riffle/cascade below. The steep riffle scored 63% of the total possible points and was evaluated as "questionable." The steep riffle scored highly (5) for the maximum depth metric. Data show the design depth is nearly equal to the median representative depth. The steep riffle also scored highly (5) for the metric of bank irregularity. The representative reach was rated "varied" while the outlet transition zone was rated "irregular." Photos support this score. The low flow width metric scored “fair” (3). Data show the design cascade is narrower than that within the representative reach. The cascade also scored “fair” (3) for the maximum particle size metric. The median design maximum particle size is slightly narrower than the 25th percentile of that within the representative reach. The width at bankfull stage scored poorly (1). The maximum design width is narrower than the minimum width within the natural channel.

SUMMARY

Based on the structure dimensions alone, one can assume that velocities are elevated at bankfull stage. Banks within the structure are absent; bank margin diversity is low, and the stability of the structure may be compromised over time as the culvert walls are scoured during floods. The low gradient and narrow width of the structure will counter-act each other; the structure will aggrade until a flood flow creates enough shear stress to scour the bed within the structure. The stability of the structure really depends on the stability of the steep riffle/cascade crest just downstream of the outlet. It is difficult to know if this crest was constructed as part of the design, or was self-formed during hurricane Irene. Were the riffle crest to mobilize, a headcut may travel upstream through the low gradient structure, undermining the structure support footers.   Given that the structure survived hurricane Irene, the risk of this occurring seems low.

Assessing the accuracy of the level I summary rubric at the Joe Smith Brook road-stream crossing is difficult given the small sample size collected. Further, hurricane Irene had recently radically altered the channel. Evidence for how the structure affects the channel at the design discharge is gone. Generally, it seems reasonable to say the crossing design is “dissimilar” from the natural channel and the level I evaluation is accurate based on the overly gentle gradient and narrow width. The step within the inlet transition zone, and the steep riffle within the outlet transition zone, are more difficult to assess.

“Questionable,” an assessment which warrants further study, may be the best evaluation for these groups.

6.2.3 SITES EVALUATED BY THE LEVEL II SUMMARY RUBRIC: RESULTS DISCUSSION

The level II summary rubric was used to evaluate data from eight sites as a way to test its performance. The effectiveness results for each site are discussed, metric by metric, group by group, in the context of data and observations collected. Specifically, a general site description which gives information about how the design channel was compared with the natural channel is provided. Each metric score is then presented with its associated p-value. The sample size for each group is noted, and data plots and photos are used to evaluate the accuracy of the score (we are assuming the data are accurate). I state whether each metric score is reasonable. If not, the score is overridden, with described justification. The group effectiveness evaluations are then discussed. The entire design channel is described within the context of geomorphic processes and changes through time. Finally, improvements to each design are suggested. Other evaluators using the level II protocol and summary rubrics might assess and report their results in a similar way.

It is important to remember that the level II summary rubric scores level II data by p-value. The p-values result from the Wilcoxon Rank-Sum test, which assesses the null hypotheses that the medians of two groups are co-located (2-sided test), or they are shifted from one-another (1-sided test). All metrics, except bank irregularity (for all channel unit types) and maximum depth (at riffles) are tested with 2-sided tests. The excepted metrics do not penalize design groups for having more irregular banks, or greater depths than the representative reach.

Where sample sizes are small, it is possible a type II error will occur because the Wilcoxon Rank-Sum test does not have enough information with which to reject the null hypothesis (H_0: the compared groups have coincident medians). The literature is vague regarding minimum sample size for the Wilcoxon Rank

Sum test. The necessary sample size is relative to data variability; the more variable the data, the larger the required sample. Level II sample sizes are sometimes less than five for short channel units, which seems too small for meaningful statistical testing. Generally, I assume n = 10 to be adequate, but without specifically studying the distribution of each metric, it is not possible to conclusively know (see section 6.2.5.1).

It was thought a type II error might be avoided by switching the null and alternative hypotheses, but I was advised against this by a Forest Service statistician (B. Bird, pers. comm., 2013), presumably because "no effect" is typically the null hypothesis and switching them might be confusing to others (and difficult to re-program within statistical software). P-values associated with small sample size tests are therefore discounted, and the groups are scored by assessing boxplots, histograms, "data-by-distance" plots, and photographs. "Data-by-distance" plots show data plotted spatially (e.g., cross sections). Scores for groups with larger sample sizes are also critically assessed with data plots and site observations.

The scoring scheme which seems to best represent field observations is the most moderate one. It awards a "fair" score (3) for p-values between 0.001 and 0.05. A "good" score of 5 is given for p-values greater than or equal to 0.05, and a "poor" score (1) is given for p-values less than 0.001. For each site, group evaluations by this scoring scheme are discussed in detail below.

6.2.3.1 LOWER STILLWELL

The lower Stillwell road-stream crossing design is a long, single gradient riffle which extends from the top of the inlet transition zone (IR1), through the structure (SR1), to the bottom of the outlet transition zone (OR1). The design slope segment gradient is 3.1%, the representative reach gradient is 1.9%. For all scoring schemes, the site scored fairly well. Summary rubric results indicate the inlet transition zone is "similar" to the representative reach, the structure is "questionable," and the outlet transition zone is "questionable." Data referred to by figure number below can be found in the level II summary rubric Lower Stillwell results, section 5.2.1.2.1.

IR1

The riffle within the inlet transition zone (IR1) scored 88% of the total possible points and was evaluated as "similar" to the representative reach. The group scored "good" (5) for the width at half bankfull stage metric. The p-value is 0.143, and sample sizes should be adequate (n = 11 at IR1 and n = 26 at RRR1). The data show the design median is 77 cm wider than the representative reach median (Figure 38 and Figure 37). The high score for this metric seems reasonable.

IR1 scored 5 for the metric of maximum depth. The p-value is 0.556, and sample sizes should be adequate (they are the same as those for the width metrics). Data show the design median is equal to the representative reach median (Figure 42 and Figure 43). The high score for this metric is reasonable.

IR1 scored 5 for the coarse fraction of the gradation metric. The p-value is 0.098 and sample sizes are large (n = 52 at IR1 and n = 138 at RRR1). Data show the design median is only 1.8 cm less that that within the representative reach (Figure 44 and Figure 45). The high score for this metric is reasonable.

IR1 also scored high (5) for the metric of bank irregularity. The p-value is 0.963, and sample sizes are large (n = 22 at IR1 and n = 52 at RRR1). Data show the median design irregularity measure is 25 cm greater than that within the representative reach. Figure 46 is, however, difficult to interpret given the difference in sample sizes. IR1 has several irregularities larger in size than any within RRR1. But RRR1 has more, smaller irregularities. In general, from Figure 46, it seems IR1 is more irregular than RRR1. Because bank irregularity is a one-sided test which does not penalize a more irregular design, the metric scored highly. The high score seems reasonable for this metric.

The metric of width at bankfull stage scored "fair" (3). The p-value is 0.009, and the sample sizes should be adequate (the same as those for the width at half bankfull metric). Data show the median design width is 77 cm larger than that within the representative reach (36 and 37). 37 shows the central halves of data do not overlap, but the extent of data does. The “fair” score seems reasonable for this metric.

The width at low flow (wetted) metric also scored “fair” (3). The p-value is 0.01, and sample sizes should be adequate (the same as those for width at half bankfull stage). Data show the median wetted width is narrower than that within the representative reach by 80 cm. 40 and 41 show the central halves of data do not overlap, but the extent of data does. The “fair” score for this metric seems reasonable.

It is interesting that the wetted width is narrower than the representative reach in this zone, but the depth is nearly equal. A cobble bar extends from the left bank just upstream of the culvert inlet. Likely, flow is travelling through the bar, decreasing the depth and narrowing the wetted width. Because the depth is similar, the flow velocity should not be affected by the width constriction. Should the effectiveness evaluation in this zone be inconsistent with expert opinion, one might consider overriding the wetted width score from 3 to 5, to see if this improves the evaluation. Because the effectiveness evaluation for the riffle within the inlet transition zone is reasonable, an override is not necessary.

By mistake, cross sections were not collected within the inlet transition zone, therefore, the bed irregularity metric is not evaluated (nor is it part of the total score) within this zone.

SR1

The structure riffle (SR1) scored 64% of the total possible points and was evaluated as “questionable.” The structure riffle scored highly (5) for most metrics.

SR1 scored “good” (5) for the metric of width at low flow (wetted). The p-value is 0.255, and sample sizes should be adequate (n = 27 at SR1 and n = 26 at RRR1). Data show the median design low flow width is 31 cm narrower than that within the representative reach. 41 and 40 show strong data distribution overlap, supporting the high score.

SR1 also scored 5 for the maximum depth metric. The p-value is 0.305 and sample sizes should be adequate (the same as those for the low flow width metric). Data show the median design maximum depth is equal to that within the representative reach. 42 and 43 support the high score; the data populations overlap well.

SR1 scored 5 for the coarse fraction metric. The p-value is 0.764 and sample sizes are large (n=43 at SR1 and n = 138 at RRR1). Data show the median design coarse fraction particle is only 1.5 cm smaller than that within the representative reach. 45 shows the central halves of the data overlap well. The high score seems reasonable for this metric.

The bank irregularity metric also scored high (5) at SR1. The p-value is 1, and sample sizes are large (n = 54 at SR1 and n = 52 at RRR1). Data show the median design irregularity measure is 25 cm greater than that within the representative reach. 46 shows SR1 has more, larger irregularities, and RRR1 has many irregularities of the same size. Given the histogram it seems reasonable to say that SR1 is more irregular than RRR1. Because the bank irregularity score is based on a one-sided test which allows the design to be more irregular than the representative reach, the high score seems reasonable.

Bed irregularity also scored 5 at SR1. The p-value is 0.965 and the sample sizes are large (n = 157 at SR1 and n = 57 at RRR1). Data show the median design bed irregularity measure is equal to that within the representative reach. 48 shows the size of irregularity values is similar between groups. The high score for this metric seems reasonable.

The structure riffle scored “poor” (1) for the metrics of width at bankfull stage. The p-value is 0.000 and sample sizes should be adequate (n = 27 at SR1 and n = 26 at RRR1). The boxplot of bankfull width data shows the median structure width is wider than the representative reach by almost 75 cm. A low score seems reasonable for this metric.

The metric for width at half bankfull stage also scored 1. The p-value is 0.000 and sample sizes should be adequate (the same as those for the bankfull width metric). The boxplot of width at half bankfull stage shows the median structure width is greater than that within the representative reach by 82 cm. The low score for this metric seems reasonable.

The plot of the design widths at half bankfull stage (17) were used to calculate the bank continuity metric (35%). When Figure 22 and boxplots of the full width at half bankfull stage (36) are consulted, the (1) low bank continuity score is supported. It is apparent the design did not incorporate stable banks into the structure.

OR1

The riffle within the outlet transition zone (OR1) scored 69% of the total possible points and was evaluated as “questionable.”

The group scored highly (5) for the metric of width at half bankfull stage. The p-value is 0.201 and sample sizes should be adequate (n = 11 at OR1 and n = 26 at RRR1). Data show the median design width at half bankfull stage is 22 cm wider than that within the representative reach (38 and 39). The high score for this metric seems reasonable.

The width at low flow (wetted) metric also scored 5 at OR1. The p-value is 0.465, and sample sizes should be adequate (the same as those for width at half bankfull stage). Data show the median design low flow width is 46 cm narrower than that within the representative reach. 40 and 41 show the central halves of the data overlap well. The high score for this metric seems reasonable.

OR1 also scored highly (5) for the metric of bank irregularity. The p-value is 0.944, and sample sizes are large (n = 22 at OR1 and n = 52 at RRR1). Data show the median design irregularity measure is 23 cm greater than that within the representative reach, and 46 shows OR1 also has a greater variety of irregularity sizes. A high score is reasonable because the one-sided statistical test does not penalize the design zone for being more irregular than the representative reach.

OR1 also scored 5 for the bed irregularity metric. The p-value is 0.419 and sample sizes are large (n = 44 at OR1 and n = 56 at RRR1). Data show the median design irregularity measure is equal to that within the representative reach. 48shows the variety of irregularity sizes between OR1 and RRR1 are very similar. The high score seems warranted for this metric.

The riffle within OR1 scored “fair” (3) for the width at bankfull stage metric. The p-value is 0.011 and sample sizes should be adequate (n = 11 at OR1 and n = 26 at RRR1). 37 shows the outlet transition zone is much wider than the representative reach (by about 75 cm). The central halves of the data barely overlap, but the extent of the data overlap well. When the photos are consulted, the discontinuity of the natural channel bank-line, immediately downstream from the culvert outlet, is apparent (Figure 217). The “fair” score for this metric seems reasonable.

OR1 also scored “fair” for the coarse fraction metric. The p-value connected to this score is 0.049, very nearly 0.05, which is the boundary between a score of 3 and a score of 5. Sample sizes are large (n = 49 at OR1 and n = 138 at RRR1). The coarse fraction boxplot and histograms (44 and 45) show the outlet transition zone median is very slightly (2 cm) less coarse than the representative reach. The difference is so slight, that a “fair” score seems un-warranted. When considering the plotted data and site observations, it seems reasonable to override the coarse fraction score from 3 to 5. If the score is a 5, the entire group evaluation becomes “similar.”

The riffle within the outlet transition zone scored “poor” (1) for the maximum depth metric. The p-value is 0.000 and sample sizes should be adequate (the same as those for the bankfull width metric). The zone appears shallower (~3 cm) than the representative reach. There is a mid-channel bar which extends out of the structure into the outlet transition zone (Figure 217). Because the wetted width is actually narrower, and the depth is shallower, I believe some water is flowing through the mid-channel bar. If one expanded the wetted width to include the mid-channel bar, the score might change from 5 to 1. If this change were made, in addition to changing the coarse fraction score from 3 to 5 (described above), the group evaluation returns to “questionable” with a total score of 73%.

SUMMARY

The level II summary rubric effectiveness evaluations seem to agree with data, photos, and field observations at the Lower Stillwell road-stream crossing; the level II summary rubric tool evaluations are therefore considered meaningful. They are general assessments of the design channel function over a range of flows. The data can also be separated to understand the flow hydraulics and ecological implications within each design zone at several stages.

At low flows (< half bankfull stage), every design zone should hydraulically be very similar to the representative reach. At this stage, differences between design zone and representative reach metrics can be attributed to planform geometry and the previously undersized structure. The inlet transition zone contains a point bar which is the most probable explanation for a narrower width yet similar depth (at low flow) to those within the representative reach. Within the structure and outlet transition zones, the sediment accumulated upstream of the previously undersized structure has been mobilized and deposited, forming a mid-channel bar. At the outlet transition zone, flow within the bar is the best explanation for a narrower yet shallower (at low flow) channel than the representative reach. In addition, the difference in bed material is likely related to the fine sediments composing the bar. Over time, the design channel is likely to coarsen as this finer bar material is mobilized downstream. Overall, at low flow, hydraulically there are few differences between the representative and design channels. Ecologically, aquatic organisms are not likely affected by the design at this stage.

At the half bankfull stage, the major difference between the design channel and the representative reach is the lack of banks within the structure. Bank margin diversity is therefore low, yet is not unlike the natural channel. The representative reach also has very straight banks. At this stage, the absence of banks may not affect organism passage, but will likely decrease the lifespan of the structure as the galvanization is scoured away and the steel is exposed to rust. Without constructed banks, the structure and outlet transition zones are slightly wider than the natural channel. Hydraulically, the extra width may slightly decrease shear stress within these design zones, but at this stage, sediment transport is not likely affected.

At bankfull stage the entire design channel is wider than the representative reach (by ~ 1 m). This will decrease the bed shear stress, possibly enough to cause the deposition and accumulation of sediment. Because the widths are not drastically different, and all other metrics are fairly similar to one another, the design channel at this stage should function hydraulically, and therefore ecologically, similarly to the natural channel.

At flows much greater than bankfull, the design channel will differ the most from the natural channel. The representative reach has a floodplain along its left bank and a nearly vertical hillslope wall along its right bank. Neither the inlet transition zone, nor the structure channel, has access to a floodplain. Flows within these zones will be concentrated, creating stronger hydraulics. Any sediments deposited within these zones during bankfull flows will be mobilized downstream. The outlet transition zone is wider than the natural channel at bankfull stage, and has access to a floodplain along its left bank. This zone may continue to be a depositional area, accumulating the bed material transported from the inlet transition zone and structure. Alternatively, during large enough floods, the concentrated flow emerging from the structure may scour the bed within the outlet transition zone. This would both maintain a narrow and deep channel as well as build up the right bank. Because the design channel hydraulics will differ from those within the natural channel, upstream migration may be impeded, especially for weaker swimming or crawling species.

Evaluators can use the level II summary rubric results to both fix the existing design and improve their skills. Although it may not be a barrier to aquatic organisms (Bair and Robertson, 2010), the road-stream crossing replacement at Lower Stillwell Creek could be improved to also ensure geomorphic continuity at bankfull and greater than bankfull flows. The implemented design failed to narrow the banks to match the natural channel width at the inlet and outlet transition zones; constructing banks and floodplains in these zones would better mimic the natural channel hydraulics. Without banks in the structure, the longevity of the structure itself is compromised. Already, the high sediment load in Stillwell Creek has scoured the galvanization off the culvert steel, allowing rust to form within a very young structure (less than 10 years old); a consequence of this design mistake (Figure 219). This problem might be corrected were the existing design retrofitted with bank material.

6.2.3.2 NORTH FORK INDIAN

The North Fork Indian road-stream crossing site has two slope segments which break approximately mid-way through the structure. Within the upper, gentler gradient (1.4%), a long riffle (IR1) extends from the top of the inlet transition zone to the slope segment break within the structure. Within the steeper gradient of the structure and outlet transition zones (2.6%), a short riffle/cascade channel unit (SSR2) flows into a moderately steep riffle (SR2). A pool (SP2) extends from the base of this riffle within the structure through the outlet (it is analyzed by level II as if it were entirely within the structure). The outlet transition zone is otherwise composed of a long riffle (OR2). Two representative reaches were selected, a steeper gradient reach (1.6%) to compare with SSR2, SR2, SP2, and OP2, as well as a gentler gradient reach (1.4%) to compare to IR1 and SR1. The majority of the design groups (4 of 6) were evaluated (before overrides) as being "similar" to the natural channel. The other groups were evaluated as "questionable." Data referred to by figure number below can be found in the North Fork Indian Appendix, Appendix A [North Fork Indian Site Data].

It should be noted that were this site evaluated as described by the 2013 protocol, the SSR2, SR2, and SP2 groups would be analyzed together as a single riffle-pool unit sequence. Data for the SSR2 and SR2 riffles would be combined. Analyzing in this way would have allowed selecting a representative reach with a gradient more similar to the steeper gradient within the structure; resulting in more accurate results.

IR1

The riffle within the inlet transition zone (IR1) scored 69% of the total possible points. It scored “good” (5) for the metric of width at half bankfull stage. The p-value is 0.252 and sample sizes should be adequate (n = 14 at IR1 and n = 21 at RRR1). Data show the median design width is 8 cm narrower than that within the representative reach. Figure 276 [Full Width at Half Bankfull Stage Boxplot] shows the central halves of the data overlap well. The high score for this metric seems reasonable.

IR1 also scored high for the metric of width at low flow (wetted). The p-value is 0.062 and the sample sizes should be adequate (the same as those for the width at half bankfull stage). Figure 278 [Width at Low Flow Boxplot] shows the central halves of the data have significant overlap, but data show the median design width is 66 cm narrower than that within the representative reach. The p-value is fairly low for a score of 5, and close to the boundary between 3 and 5. One could consider overriding the wetted width score. If the score was changed to a 3, the group evaluation remains questionable, with a total score of 67%.

IR1 scored 5 for the maximum depth metric. The p-value is 0.510 and the sample sizes should be adequate (the same as those for the width metrics). Data show the median design maximum depth is equivalent to that in the representative reach. Figure 280 [Maximum Depth Boxplot] shows the central halves of the data strongly overlap. The high score for this metric seems reasonable.

IR1 scored highly for the metric of bed irregularity. The p-value is 0.246 and sample sizes are large (n = 95 at IR1 and n = 114 at RRR1). Data show the median design irregularity measure is equivalent with that at the representative reach. Figure 285 [Bed Irregularity Histogram] shows the distributions are similar given the difference in sample size, and the high score seems reasonable.

The riffle within the inlet transition zone (IR1) scored “fair” (3) for the metric of width at bankfull stage. The p-value is 0.003, and sample sizes should be adequate (the same as those for the other width metrics). The boxplot of bankfull width confirms the design median is lower (narrower) than that of the representative reach by about 80 cm. The p-value associated with the score is seemingly not low enough to justify an override. A group score of 3 seems reasonable for this metric.

IR1 also scored 3 for the bank irregularity metric. The p-value is 0.001 and sample sizes should be adequate (n = 28 at IR1 and n = 42 at RRR1). The design median bank irregularity measure is less than that at the representative reach by 11 cm. Figure 283 [Bank Irregularity Histogram] shows the variety of data values within IR1 is less than that within the representative reach. The score of 3 for this metric is supported by the data.

The riffle within the inlet transition zone (IR1) scored poorly (1) for the coarse fraction metric. The coarse fraction design median is 15 cm less than the representative reach median and the p-value associated with the test is very small (0.000009206). I have confidence in the test results, because the sample sizes associated with the coarse fraction metric is large (~50). The riffle gradients within the inlet transition zone and the gentle gradient representative reach are nearly the same, 1.4% versus 1.38%. Given the similarity in gradient and slightly narrow width, I am puzzled as to why the coarse fraction would be finer than the representative reach. Recent road decommissioning just upstream of both the culvert and the representative reach, may have introduced finer sediment into the channel. Perhaps the finer material is a slug of sediment which has migrated past the representative reach, but was deposited within the inlet transition zone.

If this is true, the design channel should coarsen as the fine material is transported downstream. If the coarse fraction is actually more similar to that within the representative reach, the score for this metric may be changed from 1 to 3, or even 5. Given that there is no other physical reason why the coarse fraction should be different from that within the representative reach; I am inclined to override the score. With the override, the riffle within the inlet transition zone scores 78% of the total possible points, and the evaluation changes to become “similar.” Long-term monitoring would help determine whether this is appropriate.

SR1

The same riffle extends into the upper portion of the structure and is analyzed as group SR1. SR1 scored 80% of the total possible points and is considered similar to the representative reach by the level II summary rubric.

The riffle within the structure scored highly (5) for the maximum depth metric. The p-value is 0.727; sample sizes are smaller, but are probably adequate (n = 9 at SR1 and n = 21 at RRR1). Data show the median design maximum depth is equivalent to that within the representative reach. Figure 280 [Maximum Depth Boxplot] shows the central halves of the data have strong overlap. The high score for this metric seems reasonable.

SR1 scored highly for the bank irregularity metric. The p-value is 0.252, and sample sizes should be adequate (n = 18 at SR1 and n = 42 at RRR1). The score, however, is not justified. The boxplot (Figure 284) shows the median bank irregularity measures are nearly equal (they differ by 4 cm), but the variety of irregularity values is greater for the representative reach [Bank Irregularity Histogram].

Bed irregularity also scored highly. The p-value is 0.506 and sample sizes are large (n = 37 at SR1 and n = 114 at RRR1). Figure 286 [Bed Irregularity Boxplot] shows the medians are nearly equal between SR1 and the representative reach, but Figure 285 [Bed Irregularity Histogram] shows the variety of bed irregularity values is greater for the representative reach.

For both of these metrics, the appearance of more variety in representative reach irregularity values might actually result only from the larger sample size, which complicates how this metric is interpreted. To be conservative, It seems scores of 3 might better reflect the design bank and bed irregularity comparisons. If these scores are changed from 5 to 3, the SR1 group score becomes 73%, and the evaluation becomes "questionable." A comparison of distributions would more accurately assess irregularity for these metrics.

SR1 also scored 5 for the bank continuity metric. Bank continuity is extracted from the width measurements at the half bankfull stage within the structure. The structure had banks for 96% of its length, and was therefore scored "good" (5). On the plot of design widths (Figure 257 [North Fork Indian Design Widths]) the banks are clearly delineated by the measurements of width at half bankfull stage. These highly scoring metrics appear to be well supported by the data.

SR1 scored "fair" (3) for the width at bankfull stage metric. The p-value associated with this score is 0.001371; it is on the boundary between a score of 3 and 1. Sample sizes are smaller, but are probably adequate (n = 9 at SR1 and n = 21 at RRR1). The boxplot and width plots (Figure 274, Figure 258, and Figure 257 [Width at Bankfull Stage Boxplot, NF Indian Steep Representative Reach Widths, and NF Indian Design Widths]) show the median structure bankfull width at SR1 is much narrower (by 0.92 m) than the median width within the representative reach. If the score were lowered to a 1, the group score for this riffle drops to 70% and would be evaluated as "questionable."

The SR1 width at the half bankfull stage also scored 3. The p-value (0.03) is well within the range of a "fair" score. The sample sizes are smaller but are probably adequate (the same as those for the width at bankfull stage). Figure 276 [Width at Half Bankfull Stage Boxplot] shows the median riffle width is narrower than the median representative width at half bankfull stage by 40 cm. The "fair" score is reasonable for this metric.

SR1 also scored 3 for the low flow (wetted) width metric. The p-value is 0.034, and sample sizes are smaller but are probably adequate (the same as those for the other width metrics). The p-value is well within the range of a “fair” score. The data show the median wetted width within SR1 is 32 cm narrower than the wetted width within the representative reach. Figure 278 [Width at Low Flow Boxplot] shows the central halves of the data overlap. The evaluation for this metric seems reasonable. The coarse fraction metric is not included in the SR1 evaluation because erroneously, a pebble count was not conducted there. Were this metric available, it would likely show SR1 is coarser than the representative riffle, given the constricted width imposed by the structure.

In summary, a “questionable” effectiveness evaluation (override) seems appropriate for SR1 given that all three full width metrics (bankfull, half bankfull, and low flow) are narrower than the representative reach riffle.

SSR2

Just downstream of SR1 is a short steep riffle/cascade (SSR2), the crest of which is the boundary between the gentle and steeper slope segments. It is important to remember that SSR2 has a different representative reach than SR1, and therefore the scores for width at half bankfull stage can be different from SR1’s, even though they are both within a confined structure. It is also important to note the short unit length (approximately 5.3 m). The sampling interval for all width metrics and the maximum depth metric is set by the length of the structure, or the representative reach, whichever is shorter. This means, very few measurements were taken within this steep riffle. In fact, only 4 width/depth measurement stations were set within the SSR2, while 3 stations were set within the representative steep riffle unit. Given the small sample size, the p-values are ignored and plots of the data as well as photographs and observations are instead relied upon to validate SSR2 group scores.

SSR2 scored high (5) for the metrics of width at half bankfull stage. The boxplot of width at half bankfull stage (Figure 276) shows the median width of the steep riffle unit within the structure is only slightly wider (by 6 cm) than the median of the representative reach for this unit. Figure 276[Width at Half Bankfull Stage Boxplot] also shows the central halves of the data overlap well. The plotted data support the high score for this metric.

SSR2 also scored 5 for the maximum depth metric. The median maximum depth within the boxplot of depths (Figure 280) for the steep riffle unit shows SSR2 is nearly equal to the representative reach median depth (it is deeper by 2 cm). Figure 280 [Maximum Depth Boxplot] supports the high score for this metric; the central halves of the data overlap well.

SSR2 also scored 5 for the bank irregularity metric. The boxplot (Figure 284 [Bank Irregularity Boxplot]) shows the median irregularity measure is only 8 cm greater within the structure than the representative reach. The boxplot also shows the variety of bank irregularity values within the representative reach is much greater than that within SSR2. The difference in data spread is because the representative reach has a single very large irregularity. A single irregularity will not affect the median value, nor does it create the overall bank margin diversity a design is trying to mimic. Therefore, overriding the score for bank irregularity is not appropriate where the spread of data is solely because of one measurement. The data plots of bank irregularity support the high scores for the bank irregularity metric; the central halves of data overlap well.

SSR2 bank continuity scored high (5) because 96% of the structure had banks at the half bankfull stage. Plots of the design widths (Figure 257 [NF Indian Design Widths]) support the high score. Were banks at this elevation not present, the straight structure boundary would be evident.

The metric of width at bankfull stage scored poorly (1). The p-value is 0.000, but the sample sizes are very small (n = 4 at SSR2 and n = 3 at RRSR2). The bankfull width boxplot shows the median structure width at SSR2 is narrower than the median bankfull width within the representative reach for this unit (by only 31 cm). Given the small difference, perhaps a score of 3 is more reasonable for this metric. If the score were overridden to 3, the group evaluation becomes “similar” with a total score of 84%.

The low flow metric also scored poorly at SSR2. The p-value is 0.000, but sample sizes are very small (the same as those for the width at bankfull stage). The boxplot of the low flow within the steep riffle/cascade structure unit shows the wetted width is much narrower, and more variable, than that within the representative reach. Figure 253 and Figure 255 show the difference in width and substrate size. Within the structure, large boulders (“key pieces”) confine the flow at the steep riffle. This confinement is absent in the natural channel. The low score of 1 seems warranted for the low flow metric.

SR2

Below the steep riffle/cascade within the structure, is a lower gradient riffle (SR2). SR2 scored 83% of the total possible points; the effectiveness evaluation is “similar.” Only four width and depth measurement were taken within SR2, while 13 were taken within the representative reach for this unit. Given the small sample size within the structure riffle, p-values associated with the tests are discounted; instead, data plots, photos, and site observations are used to evaluate the scores.

SR2 scored highly (5) for the metric of width at bankfull stage. Figure 274 [Bankfull Width Boxplot] shows the bankfull width within SR2 is narrower than the representative width by 1.65 m. Surely, the high p-value is the result of a lack of data with which to reject the null hypotheses (groups are similar). The unit would be better represented by changing the score from 5 to at least a 3, if not a 1. If the score is changed from 5 to 3 for the bankfull width metric, the evaluation becomes “questionable” with a total score of 73%.

A high score (5) was also given for the metric of maximum depth. The maximum depth data (Figure 280 [Maximum Depth Boxplot]) show the median depth at SR2 is deeper than that within the representative reach riffle by 5 cm. Deeper riffles do not pose a depth obstacle to aquatic organisms, nor are they signs of excessive scour. A high score seems reasonable for this metric.

Bed irregularity scored 5 at SR2. The boxplot and histogram (Figure 285 and Figure 286) show the design and representative medians, as well as the variety of irregularity sizes, are nearly equal. The high score is reasonable.

Bank continuity, as discussed above for the SSR2 and SR1 groups scored reasonably high when compared with the plots and photos of width at half bankfull stage (Figure 257 [NF Indian Design Widths] and Figure 253 [photos within the structure]).

SR2 scored "fair" (3) for the width at half bankfull stage metric. Data (Figure 275 and Figure 276 [Width at Half Bankfull Stage Boxplot and Histogram]) show the median width at the half bankfull stage is 1.03 m narrower than that within the representative reach. The central halves of the data groups do not overlap, but the extent of data does. Given the small sample size at SR2, it is difficult to say the score should be lower than 3. Therefore, the moderate "fair" score seems reasonable.

SR2 scored "poor" (1) for the metric of width at low flow. Data (Figure 277 and Figure 278 [Width at Low Flow Boxplot and Histogram]) show the median width at low flow (wetted) is 1.02 m narrower than that within the representative reach. Neither the central halves of the data groups, nor the extent of data overlap. The poor score for this metric seems reasonable.

SP2

The pool within the structure (SP2) scored 85% of the total possible points and was evaluated as "similar." Sample sizes for the width and depth metrics are 6 within the structure pool and 7 within the representative reach pool. The small sample size warrants critically evaluating the p-value generated scores, and overriding scores which do not agree with data and observations.

The width at bankfull stage metric scored highly (5). The bankfull width data (Figure 274 [Width at Bankfull Stage Boxplot]) show the median representative pool width is wider than that within the structure by 58 cm. The spread of both distributions however have significant overlap. The high score for this metric is reasonable.

SP2 scored highly (5) for the width at the half bankfull stage metric. Figure 276 [Width at Half Bankfull Stage Boxplot] shows the channel widths at half bankfull are similar, differing by only 36 cm (the representative reach being wider) and the data distributions have a strong overlap. The high score is also reasonable for this metric.

SP2 also scored 5 for the low flow width metric. Figure 278 [Width at Low Flow Boxplot] indicates the median wetted width for RRP2 and SP2 are nearly equal, differing by only 2 cm. In addition, the spread of the data populations are very similar. A high score for this metric is reasonable.

SP2 scored 5 for the maximum depth metric. The maximum depth boxplot (Figure 280) shows the median depths between RRP2 and SP2 are very similar, differing by only 4 cm. The spread of data are also well overlapped. The high score is reasonable for this metric.

Bank continuity, as discussed above for the SR2, SSR2 and SR1 groups is scored justifiably high, when compared with the plots of width at half bankfull stage and photos (Figure 257 [NF Indian Design Widths] and Figure 253 [photo within structure]).

The bank irregularity metric scored poorly (1). The p-value is very small (0.0004), but may be un-reliable because sample sizes for this metric are small (n = 8 at SSR2 and n = 6 at RRSR2). Figure 284 [Bank Irregularity Boxplot] shows the representative pool has a larger median irregularity measure (by 55 cm). Figure 285 [Bank Irregularity Histogram] shows the variety of irregularity data is much greater within the representative reach than the structure pool. The poor score seems reasonable, and appears to be verified by the data.

Bed irregularity also scored poorly. The p-value is 0.000 and the sample sizes are large (~40). Figure 286 [Bed Irregularity Boxplot] indicates the representative pool median irregularity measure is larger by 9 cm. The bed irregularity boxplot (Figure 286) shows the 25th and 75th percentiles of the data barely overlap. Figure 285 [Bed Irregularity Histogram] shows the distributions have different shapes, but the variety of irregularity sizes are similar between groups. The low score for this metric would be better supported by a test of distributions. Given this uncertainty, an override cannot be justified for this metric.

Overall, the high score and "similar" evaluation of the structure pool unit (SP2) agree with the data and observations at the site.

OR2

The riffle within the outlet transition zone (OR2) scored 76% of the total possible points and was evaluated as "similar" to the representative reach. The sample size at OR2 was 8 for the width and depth metrics, while it was 13 within the representative reach riffle (RRR2). P-values should be fairly reliable, but will be evaluated critically against the data.

OR2 scored high (5) for the half bankfull width metric. The p-value is 0.269. The median half bankfull width within OR2 is 45 cm less than the median half bankfull width at the representative reach riffle. Yet, the boxplot for width at half bankfull stage (Figure 276) shows strong overlap between the data design and representative reach groups. Because of the significant data overlap, it seems the high p-value and the high score are valid.

The maximum depth metric also scored highly at OR2. The p-value is 0.786. In Figure 280 [Maximum Depth Boxplot], the median maximum depths are exactly equal and the distributions have large overlaps. The high score and p-value seem appropriate for this metric.

The coarse fraction metric also scored 5. The p-value is 0.691. The coarse fraction distributions look very similar to one another in the histogram (Figure 281), and the boxplot (Figure 282) shows the medians are nearly equal (they differ by 2.5 cm). The high score for this metric also seems reasonable.

Bed irregularity scored highly at OR2. The bed irregularity data (Figure 286 [Bed Irregularity Boxplot]) show the median irregularity measure at OR2 and RRR2 are equivalent. The p-value is 0.746 and the sample sizes are large (n = 54 at OR2 and n = 52 at RRR2). The distributions have similar diversity in size of irregularity measures (Figure 285 [Bed Irregularity Histogram]). The high score for this metric seems supported by the data.

The outlet transition zone riffle lost points for the width at low flow metric (scored 3). The p-value is 0.004. The width at low flow boxplot (Figure 278) shows two very different data populations; the design riffle at OR2 has a narrow data distribution around the median, while the representative reach riffle, RRR2, has a much greater spread of values. The median low flow RRR2 width is larger than OR2's by 70 cm. The score of 3 seems appropriate for this moderate width discrepancy.

Bank irregularity also scored 3. The p-value is 0.008, and sample sizes should be adequate (n = 16 at OR2 and n = 26 at RRR2). Figure 284 [Bank Irregularity Boxplot] shows the median bank irregularity measure at OR2 is less than that within RRR2 by 19 cm. Figure 283 [Bank Irregularity Histogram] shows both populations are bimodal, and the representative reach population has more irregularities of larger size. A score of 3 is well supported by the data.

Overall, the “similar” evaluation and high score for the riffle within the outlet transition zone (OR2) seems appropriate and well supported by the data.

SUMMARY

After comparing the summary rubric results with data and site observations, the North Fork Indian assessment seems reasonable. Several overrides were issued to correct for p-values associated with small sample sizes and recent disturbance (construction) at the site. With these overrides, four of the six design groups received “similar” effectiveness evaluations; the others (both within the structure) are “questionable.”

The metrics can also be separated to evaluate different flow stages within each zone. At low flow, all three design zones are narrower and generally deeper than the natural channel. The slightly greater depths (the largest being only 5 cm) theoretically will create stronger hydraulics, but at this stage, are likely to impact none but the weakest swimming/crawling species, if any. Despite a narrower channel, it seems unreasonable to consider the design channel geomorphically dissimilar from the natural channel at this stage.

At the half bankfull stage, the inlet transition zone is similar in width to the representative reach. Banks are present and of similar irregularity as those within the natural channel. Geomorphically and hydraulically the zone is functioning similarly to the natural channel. The structure, however, is narrower (by about 1 m). The flow at this stage will be deeper than the natural channel, creating stronger hydraulics within most channel units. Banks at this stage are present along the left wall of the structure and for some of the right wall. The banks were not constructed, but are actually only deposits formed in the eddies created by large boulders (key pieces). At flows near and above bankfull, the eddies are likely to become smaller, and the current bank deposits are likely to erode. Given less bank margin diversity and elevated hydraulics, it may become increasingly more difficult for aquatic organisms to migrate upstream through the structure at the half bankfull stage. Were a wider structure installed, bank irregularity might also be improved. A structure with a broader span would provide the space necessary to construct banks along the entire structure length. The outlet transition zone is slightly wider (by ~0.5 m) than the representative reach, yet the median depth is similar to that within the representative reach. Therefore, hydraulics are also thought to be similar and aquatic organism passage through this zone is not likely affected at this flow stage.

At bankfull stage, the entire design channel is narrower than the natural channel by approximately 0.75 to 1 m. Although not an extreme difference, the constricted flow will create stronger hydraulics, which could affect the passage of aquatic organisms, especially the weaker swimming and crawling species. The constricted flow would be expected to scour deeper pools. The large rock incorporated into the design and steep riffle (SSR2) however, is probably providing enough roughness so as to diminish this energy, preventing scour. It is possible the constricted flow hydraulics during higher stages have scoured the narrow low flow channel. Interestingly, the inlet transition zone is both narrower and significantly less coarse than the representative reach at the bankfull stage, while the structure and outlet transition zones have particles similar to those within the natural channel. The most logical explanation is related to a recent road-stream crossing decommissioning project (located approximately 110 m upstream from the structure inlet). It seems likely that finer particles could have been introduced into the stream channel as heavy equipment (tracks still visible) removed road fill at the decommissioned crossing. These particles might have since been transported downstream into the inlet transition zone. During the next flood, they are likely to mobilize through the design channel.

At flows above bankfull, the hydraulics within the inlet and outlet transition zones are likely to remain similar to those within the representative reach. This is because a floodplain (similar to that present at both representative reaches) is available to overbank flows at these zones. Within the structure, however, flow dispersed across the floodplain will be forced to travel through the structure. The concentrated flow will increase the depth, elevating velocities and hydraulics. The constricted flow emerging from the narrow structure should maintain the pool at the structure outlet by scouring the bed.

The North Fork Indian structure may still be a barrier to upstream aquatic organism passage during large floods, perhaps even to the strongest swimming species (adult salmonids migrating upstream to spawn).

Should this be a realistic problem, the best solution is to replace the structure with a much wider one; a project made most cost effective at the end of the current structure's lifespan.

Returning to North Fork Indian to repeat levels I and II monitoring would be worthwhile for two reasons. First, the site provides an opportunity to analyze by channel unit sequence; a situation not common amongst the pool of study sites. The longitudinal profile at North Fork Indian shows slope segments with similar channel unit sequences and gradients as those within the design channel do exist within the natural channel. Also, the road decommissioning impacts should diminish over time and more accurate particle size data might be collected.

6.2.3.3 WF01

The WF01 structure is a box culvert. The design channel is a long riffle which extends from the top of the inlet transition zone to the bottom of the outlet transition zone. The design is composed of two slope segments which break gradient at the structure outlet. Slopes are 4% and 3% respectively. Analyzed units are IR1, SR1, and OR2. The representative reach has a gradient of 3.5%. The same representative reach was used for both slope segment gradients 1 and 2 because it met the 25% difference criteria for both of them.

WF01 groups (all zones) were evaluated with the level II protocol as "dissimilar" or "questionable" by all scoring schemes. IR1 scored 57% of the total possible points (questionable), SR1 scored 35% (dissimilar) of the total possible points, and OR2 scored 37% (dissimilar) of the total possible points. Data referred to by figure number below can be found in the WF01 Appendix, Appendix A11 [WF01 Site Data].

IR1

The riffle within the inlet transition zone scored "good" (5) for the bank irregularity metric. Although the p-value associated with the Wilcoxon Rank-Sum test is not extremely high, 0.09. Sample sizes are large, nearly 90 within the inlet transition zone riffle and more than 20 within the representative reach. Data show the median IR1 bank irregularity measure is less than that within the representative reach by 15 cm. The data populations show strong overlap in Figure 389 [Bank Irregularity Boxplot]. Figure 388 [Bank Irregularity Histogram] shows the groups have a similar variety of irregularity sizes. The data support the high score for this metric.

Bed irregularity also scored high (5). The p-value associated with the metric score is very high 0.93, and sample sizes for both groups are large (>20). The median IR1 bed irregularity measure is only 2 cm less than that within the representative reach. The data populations show strong overlap in Figure 391 [Bed Irregularity Boxplot]. Figure 390 [Bed Irregularity Histogram] shows IR1 has a greater variety of irregularity sizes. If the high score is overridden from a 5 to a 3, the group evaluation score becomes 54%. If it is lowered from 5 to 1, the group evaluation score becomes 51%. Regardless of the metric score, the evaluation remains “questionable” with overrides.

IR1 scored “fair” (3) for the metric of width at bankfull stage. The p-value associated with the score (0.019) should be reliable because sample sizes are very large within the inlet transition zone (more than 40) and probably adequate (more than 10) within the representative reach. The p-value is near the upper end of the “fair” score range. Data show the median bankfull width of IR1 is narrower than the median representative reach riffle width by 98 cm Figure 382 and Figure 383 [WF01 Full Bankfull Widths Boxplot and Histogram). But, the representative reach distribution overlaps well with the IR1 distribution at its lower end. The data support the “fair” score for this metric.

IR1 also scored “fair” (3) for the width at half bankfull stage metric. The p-value associated with the score is 0.001, on the border with a lower score of 1. Sample sizes are the same as those for the width at bankfull stage and are adequate for a statistical test. The median width at half bankfull is 87 cm narrower than that within the representative reach. Figure 384 and Figure 385 [Full Half Bankfull

Widths Boxplot and Histogram] show the data distributions overlap well in extent, but the central halves of measurements barely overlap. The score of 3 for this metric is appropriate.

The riffle within the inlet transition zone scored poorly (1) for the coarse fraction metric. The p-value associated with the test is very low (2.69e-11), and sample sizes are large (~100 for each group). The median of the coarse fraction within the inlet transition riffle is 60 mm less coarse than that within the representative reach. Figure 381, Figure 386 and Figure 387 [WF01 Gradation, WF01 Coarse Fraction Boxplot and Histogram] support the low score. The central halves of measurements for the two groups barely overlap. The low score is warranted for this metric.

Together, the score assessments indicate the "questionable" effectiveness evaluation is appropriate for the riffle within the inlet transition zone (IR1). However, because the channel was mostly dry during the field visit, widths at low flow (wetted) and maximum depths were not collected. These metrics do not count against the score because they are not included in the total possible points. Were these metrics collected, given the "fair" scores for width at bankfull and half bankfull stages, it is likely the wetted width and depth metrics would also score "fair". However, including moderate scores for these metrics does not result in a total score less than the required 50% for a "questionable" effectiveness evaluation.

SR1

The riffle within the structure (SR1) scored only 35% of the total possible points and is considered by the level II rubric to be "dissimilar" from the representative reach riffle.

It scored 5 for the metric of width at half bankfull stage. The p-value associated with this score is high, 0.312, and sample sizes should be adequate for a fair statistical test (~40 within the structure, and ~10 within the representative reach riffle). Data in Figure 384 and Figure 385 [WF01 Full Half Bankfull Widths Boxplot and Histogram] show the median width at the half bankfull stage within the structure is only 28 cm less than that within the representative reach. The high score for the width at half bankfull stage seems appropriate.

SR1 scored poorly (1) for most metrics. The width at bankfull stage metric had an extremely small p-value, 2.28e-12. Sample sizes should be adequate. The median structure width at bankfull is less than that within the representative reach by 1.97 m. The ranges of data for the groups don't overlap (Figure 382 and Figure 383 [WF01 Full Bankfull Widths Boxplot and Histogram]). The poor score is well supported by the data.

The riffle within the structure also scored poorly (1) for the coarse fraction metric. The p-value associated with the score is very small, 2.2e-16, and sample sizes are adequate (>100 per group). Figure 381, Figure 387 and Figure 386 [WF01 Gradation, WF01 Coarse Fraction Boxplot and Histograms] show the median of the coarse fraction is less than that within the representative reach by 100 mm, and the central halves of the data do not overlap. The poor score for this metric is reasonable.

SR1 also scored poorly (1) for the bank irregularity metric. The p-value associated with this metric is extremely small, 2.2e-16, and sample sizes are large. Figure 388 and Figure 389 [WF01 Bank Irregularity Boxplot and Histogram] show the median irregularity measure for SR1 is 33 cm less than that within the representative reach, and is nearly equal to zero. In addition, the spread of data around the median SR1 bank irregularity measure is extremely narrow, indicating poor variation in the size of irregularities. Figure 373 [Design Channel Widths] supports this showing the irregularity at the half bankfull elevation (yellow line) is effectively zero; as does photo Figure 368 [photo within structure]. The poor score for this metric is well supported by the data.

SR1 scored poorly (1) for the bed irregularity metric. The p-value associated with the score (0.0001214) is very small. Sample sizes are adequate (~ 20 for both groups). Plots of the data (Figure 390 and Figure 391 [WF01 Bed Irregularity Boxplot and Histogram]) show the median bed irregularity measure is less than that within the representative reach (by 7 cm). The variability of data values within SR1 is also low.

The central halves of the data for each group barely overlap. The low score for this metric is supported by the data.

Bank Continuity within the structure scored poorly because 0% of the structure banks are present at the half bankfull stage. Figure 368[photo within the structure], and Figure 373 [Design Channel Widths] support this low score.

The wetted width and maximum depth metrics were not collected because the channel was dry at the time of data collection. I argue these metrics should receive a poor score (1) because over the course of field work, with adequate precipitation, the natural channel and inlet transition zones carried flowing water but the structure remained dry. Water was audibly pouring into a hole at the structure inlet. Some distance downstream of the outlet, water emerged from the channel bed. If these metrics, with scores of 1, are included in the level II protocol for the SR1 evaluation, the total SR1 score becomes 38% and the evaluation remains "dissimilar" from the natural channel.

OR2

The riffle within the outlet transition zone is downstream of a significant break in slope located at the structure outlet. The gradient of OR2 (3%) is within the gradient criteria (±25%) to be compared with the representative reach gradient (3.5%) used for slope segment 1 comparisons. OR2 scored 37% of the total possible points and was evaluated as "dissimilar" to the natural channel.

OR2 scored "good" (5) for the bank irregularity metric. The p-value associated with the test was high (0.830), and the sample sizes are large enough to be adequate (~60 within OR2, and ~20 within RRR1&2). Data show the median irregularity measures are nearly equal (they differ by 0.5 cm), and Figure 388 and Figure 389 [WF01 Bank Irregularity Boxplot and Histogram] show the spread of data are similar. The high score for this metric is reasonable.

OR2 also scored “good” (5) for the bed irregularity metric. The p-value associated with the test is high, 0.35, and sample sizes (~20 for both groups) should be adequate. The median irregularity measures differ by only 2 cm. However, the spread of data around the OR2 median is much narrower, indicating less diversity in irregularity size, and smaller deviations from the median depth (Figure 390 and Figure 391 [WF01 Bed Irregularity Boxplot and Histogram]). Therefore, it seems most appropriate to override this metric. Based on the difference between bed irregularity data spread, a score of 1 seems appropriate. When the bed irregularity metric score is changed from 5 to 1, the group evaluation score for OR2 becomes 31%, but the evaluation remains “dissimilar.”

OR2 scored “poor” (1) for most metrics. The statistical test for width at bankfull stage gave a very small p-value, 5.73e-08. Sample sizes should be adequate (~ 30 within OR2 and ~10 within RRR1&2). Data (Figure 382 and Figure 383 [WF01 Full Bankfull Width Boxplot and Histogram]) indicate the median bankfull width at OR2 is 3.12 m wider than that within the representative reach. The distributions overlap only by outliers. The data are supported by photos (Figure 368 and Figure 371), and the poor score for this metric is reasonable.

OR2 also scored poorly (1) for the metric of width at half bankfull stage. The p-value associated with the test is extremely small, 5.14e-11. Sample sizes should be adequate (~ 30 within OR2 and ~10 within RRR1&2). The OR2 median width at half bankfull stage is wider than that within the representative reach by 4.82 m. Figure 385 [Width at Half Bankfull Stage Boxplot] shows the ranges of OR2 and RRR1&2 data do not overlap at all. Figure 373 and Figure 374 [Design Channel Widths and WF01, WF02 Rep. Reach Widths] also show the difference between the group half bankfull widths. The poor score for this metric is well supported by the data.

OR2 scored poorly (1) for the coarse fraction metric. The p-value associated with the statistical test was extremely small, 2.2e-16. The median coarse fraction within OR2 is 90 mm smaller than that within the representative reach. Figure 381, Figure 386, and Figure 387[WF01 Gradation, WF01 Coarse Fraction

Boxplot and Histogram] show this. The central halves of the data for OR2 and RRR1&2 barely, if at all, overlap one another. The poor score for this metric is reasonable.

SUMMARY

WF01 was evaluated by the level II rubric as “questionable” within the inlet transition zone, “dissimilar” within the structure, and “dissimilar” within the outlet transition zone. These effectiveness evaluations do not change when the overrides for bed irregularity, wetted width and maximum depth are included. Scores were generally well supported by data and observations at the site, and the effectiveness evaluations seem to be valid assessments of the WF01 design. If the data are separated by flow stage, hydraulic conditions can be interpreted.

A low flow width was not measured within the design channel because the channel was mostly dry during the field visit. Site observations indicate the inlet transition zone would have a similar low flow width to the natural channel, while the outlet transition zone would likely be wider.

Although not directly measured, it is apparent the structure design does not provide adequate wetted width or depth during low flow periods. Because flow was observed percolating into the bed at the inlet and later emerging from the bed downstream from the outlet, it is thought the structure was poorly installed. It is likely the material beneath the structure was incorrectly sized and sorted, creating a porous environment through which stream flow preferentially travels. The design might be improved if the culvert was removed, the culvert pad was made less permeable to flow, and the structure set deeper within the design bed. Extra precaution might include a vertical wall buried within the bed at the structure inlet. This wall would help force water traveling through the stream bed to the surface and through the structure. In addition, a low flow channel should be constructed within the structure around which adequately sized and stable, “key pieces” would help to create and maintain the thalweg.

Given the difference in thalweg width and depth through the majority of the design channel, it is assumed to be very hydraulically different from the natural channel. The design is likely a barrier to most aquatic organisms migrating both up and downstream through the design channel.

At the half bankfull stage, flow is slightly constricted within the inlet transition zone, passes through the structure and dramatically expands as it exits the structure outlet. The riffle within the inlet transition zone is narrower (by ~ 1 m) at the half bankfull stage. Flow depth and hydraulics within this zone will be slightly elevated above those within the representative reach.

At the half bankfull stage, the structure is nearly equal to the natural channel width. Were flows not passing beneath the structure, hydraulic conditions within the structure might be similar to the natural channel. As is, the diminished discharge within the structure will likely be shallower and slower moving than flow within the representative reach. Constructed banks at the half bankfull stage are completely absent within the structure. At flows greater than the half bankfull stage, aquatic organisms may have a difficult time moving upstream through the structure because, without bank irregularity, resting areas are largely eliminated. If banks were built, the structure would become much narrower than the natural channel at the half bankfull stage.

Banks continuous with the natural channel were not constructed, resulting in an outlet transition zone much wider than the natural channel at the half bankfull stage (by ~5 m). Flow will spread out and slow down.

At the bankfull stage, both the inlet transition zone and structure are narrower than the natural channel (by about 1 to 2 m). Flow velocities and depths within these zones will be elevated, creating stronger hydraulics.

Interestingly, both the inlet transition zone and structure are also less coarse than the natural channel (for both the full distribution and the coarse fraction). Given how similar the inlet transition zone and structure gradient is to the representative reach gradient (4% versus 3.5%), the difference in sediment size is odd. If anything, one would expect the steeper, confined, inlet transition zone and structure to be coarser than the representative reach because shear stress on the bed should be higher.

A possible explanation is that the finer inlet transition zone and structure bed is composed of the particles placed during construction. Perhaps sediment mobilizing flows had not yet occurred in August 2011. Were adequate flow to have occurred, the ~D50 (of the full distribution) sized material within the design would have been transported downstream. Those particles would have been replaced by the ~D50 sized particles from upstream, coarsening the bed. The data within the inlet transition zone and structure suggest this had not yet occurred. One alternate theory is that a fine sediment slug is passing through the design reach. This, however, is not likely because landslides or roads within the upper watershed were not observed. Another theory is that enough flow travels through the design bed and beneath the structure that deposition of finer particles occurs within the inlet transition zone and structure. Once flows adequate for mobilizing the D50 at these zones occur, significant scouring and bed degradation are likely if the D50 within the natural channel is not also mobilized. Channel bed diversity within the structure is also low; by increasing the variety of sediment sizes within the structure, bed habitat would be created. This condition may improve on its own if natural sediment is mobilized into the structure from upstream.

The riffle within the outlet transition zone is “dissimilar” from the natural channel. The main problem is that banks continuous with the natural channel were not constructed. The design is much wider at bankfull stage (by more than 3 meters). Similar to the rest of the design channel, the bed is composed of much finer particles. The gentle slope at OR2 and the extreme width make this zone susceptible to aggradation over time. A low flow channel may not be maintained as the stream disperses across the wide channel, and will likely be a barrier to larger swimming organisms.

At several places along the Cove Run study site, the stream clearly accesses its floodplain somewhat frequently, indicating the structure should also be sized to pass overbank flows. The installed structures are, however, narrower than the channel width at bankfull stage. During discharges equal to and greater than bankfull, flow depths and velocities will be significantly elevated. These conditions may create a barrier to aquatic organisms migrating upstream during large floods.

It is possible a headcut is travelling up the channel between WF02 and WF01. A sharp break in slope occurs at the WF01 outlet transition zone downstream boundary. Two steep steps are located before the gradient which passes through WF02 is reached (Figure 372 [WF01 and WF02 Long Profile], Figure 369 and Figure 370). Each step is composed entirely of a mélange of large and small imbricated particles. The drops, or steps, don’t appear to be composed of stable material. Roots are exposed and the left bank is undercut; seemingly evidence of rapid incision.

If the previous WF02 structure downstream of WF01 was grossly undersized, sediment may have accumulated at the inlet, decreasing the channel gradient between WF01 and WF02. Now that WF02 has been enlarged, the accumulated sediment is travelling downslope. If this hypothesis is correct, WF01 may be in danger of being undermined as the headcut moves upstream.

An alternative hypothesis is that the steps, now composed solely of cobbles, are what remains of two wood-forced steps. The wood could have accumulated sediment behind it. After passing downstream, or having been removed during construction at WF01 and WF02, the sediment is now slowly eroding back to the original channel gradient. Previously, an overflow channel on the left bank re-routed the channel around these steps; a common feature at large log jams.

In summary, the WF01 structure is likely interrupting both ecological and geomorphic continuity at the road-stream crossing. Further, the current structure and road may be at risk because of channel incision associated with the possible headcut moving upstream.

To fix the problem, the WF01 road-stream crossing would need to be replaced and entirely redesigned to correct for the short-comings described above. Preferably, a wider open-bottom pipe arch would be installed at WF01; one which would incorporate banks, with enough span to prevent flow constriction during overbank flows. Additionally, footers should be placed deep enough to avoid destabilizing the structure if the potential head-cut does travel upstream.

6.2.3.4 WF02

The WF02 structure is a box culvert. The design channel is a long riffle which extends from the top of the inlet transition zone to the bottom of the outlet transition zone. The design is composed of a single slope segment. The design gradient is 4.8% and the representative reach is 3.5%; it meets the 25% gradient difference criteria. The same representative reach was chosen to be compared with the design channels at WF01 and WF02.

Analyzed groups are IR1, SR1, and OR1. WF02 groups were evaluated with the level II protocol as "dissimilar" or "questionable" by all scoring schemes. IR1 scored 57% of the total possible points (Questionable), SR1 scored 33% (Dissimilar), and OR1 scored 31% (Dissimilar). Data referred to by figure number below can be found in the WF02 Appendix, Appendix A12 [WF02 Site Data].

IR1

IR1 scored highly (5) for the bed irregularity metric. The p-value associated with the test is 0.355, and sample sizes are assumed adequate (~20 within the representative reach riffle, and ~40 within the inlet transition zone). Data show that the median IR1 bed irregularity measure is larger than that within the representative reach by 2cm. Figure 417 and Figure 416 [WF02 Bed Irregularity Boxplot and Histogram] show the central halves of the data overlap well, and the variety in size of irregularities is similar. The high score for this metric seems reasonable.

IR1 also scored high (5) for the bank irregularity metric. The p-value associated with the test is 0.605. Sample sizes should be adequate (~60 in the inlet transition zone and ~25 in the representative reach riffle). Figure 415 and Figure 414 [WF02 Bank Irregularity Boxplot and Histogram] show the data at IR1 and RRR1 are very similar to one another. The median bank irregularity measures differ by only 7 cm. The central halves of the data values are well overlapped. The inlet transition zone has more, irregularities larger in size than the representative reach. The test is one sided and the design channel is not penalized for banks more irregular than the representative reach. A score of 5 is reasonable and well supported by the data.

IR1 scored “fair” for the width at bankfull stage metric. The p-value from the Wilcoxon Rank-Sum test is very high, 0.048. Sample sizes should be adequate (~25 in the inlet transition zone, and 12 within the representative reach). Figure 408 and Figure 409 [WF02 Full Bankfull Widths Boxplot and Histogram] show the median width at bankfull stage within the representative reach is narrower than the inlet transition zone (by 79 cm). The spread of data around the inlet transition zone median value is much greater than that within the representative reach. Although not an evaluated metric, higher bank irregularity within the design channel (at bankfull width) is good. The hour-glass shape within the design channel plan-view plot (characteristic of undersized culverts) is still present because the banks were not re-constructed. The score of 3 seems reasonable (and supported by the data) given IR1 is slightly wider than the representative reach.

IR1 also scored “fair” for the metric of width at half bankfull stage. The p-value of the test is 0.009; Sample sizes should be adequate (they are the same as those for the bankfull width metric). The median design width at the half bankfull stage is 1.24 m larger than that within the representative reach. Figure 410 and Figure 411[WF02 Full Half Bankfull Widths Boxplot and Histogram] show the central halves of the data barely overlap. The hour-glass shape (plan-view of widths within the design channel) is present at the half bankfull stage. The 3 score for this metric is supported by the data and is reasonable.

IR1 scored poorly (1) for the coarse fraction of the gradation metric. The p-value of the test is 6.17e-09. Samples are very large (~100 for both groups). The median of the IR1 coarse fraction is less than that within the representative reach by 40 mm. Figure 412 and Figure 413 [WF02 Coarse Fraction Boxplot and Histogram] show the central halves of the data barely overlap. The low score is supported by the data.

The wetted width and depth metrics were not collected because the channel was dry when data collection began in 2011. After significant rains, the channel did begin to flow, but there was not time to return to the design channel to collect these metrics. Given that both the bankfull and half bankfull width metrics were scored “fair” (3), it seems reasonable to assume wetted width and depth might also score 3. If they had and were included in the evaluation, the overall group score would not change from 57%, “questionable.”

SR1

The riffle within the structure (SR1) scored only 33% of the total possible points and was evaluated as “dissimilar” from the natural channel. The structure scored “good” (5) for the metric of bed irregularity. The p-value from the test was very high, 0.885. Sample sizes are adequate (~20 within the representative reach and ~25 within the structure). The difference between the SR1 and RRR1 bed irregularity deviation medians is very small, only 0.5 cm. Figure 416 and Figure 417 [WF02 Bed Irregularity Boxplot and Histogram] show the central halves of the data for each group are well overlapped, and the variety of irregularity sizes are similar between groups. The score of 5 is well supported by the data.

SR1 scored “fair’ for the metric of width at half bankfull stage. The p-value is 0.041 and the sample sizes should be adequate for a fair test (~10 within the representative reach and ~20 within SR1). The median representative reach width is 39 cm larger than the half bankfull width at SR1. Figure 410 and Figure 411 [WF02 Full Half Bankfull Widths Boxplot and Histogram] support this, showing a much greater spread of data values around the representative reach median. The central halves of the data overlap well. The 3 score for this metric is well supported by the data.

SR1 scored poorly (1) for the width at bankfull flow metric. The p-value associated with the metric is 3.69e-10. Sample sizes are adequate (equal to those for the half bankfull width metric). Data show the median structure width is narrower than that within the representative reach at bankfull stage by 1.96 m. Figure 398, Figure 399, Figure 408, and Figure 409 [WF02 Design Widths, WF01 and WF02 Representative Reach Widths, WF02 Full Bankfull Widths Boxplot and Histogram] show the large difference in width. The data distributions do not overlap with one another. The score of 1 is reasonable for this metric.

SR1 also scored “poor” (1) for the coarse fraction of the gradation metric. The p-value is extremely small, 2.2e-16. Sample sizes should be large enough (~100 per group). Data show the representative reach median of the coarse fraction is coarser than that within the structure by 80 mm. Figure 407, Figure 412, and Figure 413 [WF02 Gradation, WF02 Coarse Fraction Boxplot and Histogram] support this. Further, the central halves of the data for each group do not overlap. The poor score for this metric is warranted.

SR1 scored “poor” for the bank irregularity metric. The p-value from the statistical test is very small, 4.9e-11, and sample sizes should be large enough (~20 within the representative reach and ~40 within the structure). Figure 414 and Figure 415 [WF02 Bank Irregularity Boxplot and Histogram] show the median irregularity measure is less than that within the representative reach by 35 cm. The central halves of the data do not overlap, and the variety of irregularity values is very different. The poor score for this metric is reasonable.

The structure riffle also scored poorly (1) for the bank continuity metric because 0% of the structure length (left and right walls) had banks at the half bankfull stage. The “poor” score is supported by Figure 398[Design Channel Widths] and Figure 395 [photo within structure].

OR1

The riffle within the outlet transition zone (OR1) scored only 31% of the total possible points and was evaluated as “dissimilar.” The group scored highly (5) for the metric of bed irregularity, with a p-value of 0.388. Sample sizes should be large enough (~20 per group). Data show the median bed irregularity within OR2 is 3 cm less than that within the representative reach. Figure 416 and Figure 417 [WF02 Bed Irregularity Boxplot and Histogram] show the medians are nearly equal, and the central halves of the data overlap well. The variety of irregularity values appears similar between groups in Figure 416 [Bed Irregularity Histogram]. The high score seems appropriate for this metric.

OR1 scored “fair” (3) for the bank irregularity metric. The p-value is 0.002, and the sample sizes are large (~20 within the representative reach and 50 within the outlet transition zone). The data show the median bank irregularity measure is 10 cm less than that within the representative reach. Figure 415 [Bank Irregularity Boxplot] shows the central halves of the data for each group only somewhat overlap. Figure 414 [Bank Irregularity Histogram] shows the variety of irregularity values is greater within the representative reach than the outlet transition zone, even when considering the difference in sample size between groups. However, given the irregularity difference between groups is not extreme, the score of 3 seems reasonable.

OR1 scored “poor” (1) for the metric of width at bankfull stage. The p-value is extremely small, 6.84e-06. Sample sizes are adequate (~10 within the representative reach and ~25 within the outlet transition zone). Data show the median bankfull width at OR1 is 85 cm wider than that within the representative reach. Figure 398, Figure 399, Figure 408, and Figure 409[WF02 Design Widths, WF01 and WF02 Representative Reach Widths, WF02 Full Bankfull Widths Boxplot and Histogram] support this; they also show the ranges of data for each group do not overlap. The low score is well supported by the data for this metric.

OR1 also scored “poor” (1) for the width metric at half bankfull. The p-value associated with the test is extremely small, 4.75e-08. The sample sizes should be adequate (the same as those for the bankfull width metric). Data show the median design width at half bankfull stage is 1.69 m wider than that within the representative reach. Figure 398, Figure 399, Figure 410, and Figure 411 [WF02 Design Widths, WF01 and WF02 Representative Reach Widths, WF02 Full Half Bankfull Widths Boxplot and Histogram] support this; they show the ranges of data for each group do not overlap. The low metric score is well supported by the data.

OR1 scored “poor” (1) for the coarse fraction metric. The p-value associated with the statistical test is extremely small, 2.2e-16. Sample sizes are large (~150 within OR1, and ~90 within the representative reach). The representative reach median is 135 mm coarser than that within the outlet transition zone. Figure 407, Figure 412, and Figure 413 [WF02 Gradation, WF02 Coarse Fraction Boxplot and Histogram] support this. Figure 413[Coarse Fraction Boxplot] also shows that the central halves of the data do not overlap. The low score for this metric is well supported by the data.

SUMMARY

The level II rubric evaluations of the WF02 design groups generally appear to be well supported by the data and site observations. The effectiveness evaluations are reasonable assessments of the geomorphic continuity provided by the design channel; within all zones, geomorphic processes are affected by the crossing. When one separates the metrics by flow stage, an understanding of the design and resulting hydraulics is gained, allowing potential improvements to be identified.

Cove Run and the WF02 design channel were dry at the beginning of the 2011 field visit. After significant rains, the natural channel began to flow. The structure was slower to carry water, but eventually a continuous surface stream could be seen. Compaction beneath the structure and within the design bed may be diminishing the volume of surface flow. In this regard, WF02 is, however, an improvement over WF01.

Although measured low flow width data were not collected at WF02, observations indicate a low flow channel is only somewhat defined. Formed low flow channels help to ensure aquatic organisms have enough depth for locomotion. The design would be improved if large key pieces (boulders) were installed to help guide and concentrate discharge. In addition, narrowing both the inlet and outlet transition zones would prevent these areas from aggrading and further spreading the flow.

The inlet transition zone is hydraulically different from the natural channel at the half bankfull stage because of its excessive width (greater by more than 1 m). Conversely, the structure at half bankfull stage is nearly equal to the representative reach width. Although the hydraulics at half bankfull stage are likely similar to the natural channel, the lack of constructed banks along the culvert walls may affect passability. Banks would create channel margin diversity. Channel margin diversity causes micro-eddies within the current, creating resting areas important to weaker swimming species. Channel banks are also important habitat for some small organisms. Were a wider structure incorporated into the design, room for incorporating banks would be allowed.

At the bankfull stage, both the inlet and outlet transition zones are wider than the natural channel (by about 1 m). A coarser bed is expected within the inlet transition zone because its gradient is steeper than that within the representative reach. Oddly, the coarse fraction at the inlet transition zone riffle is finer. It seems likely the broad width has caused smaller particles to deposit. Similarly, the excess width at the outlet transition zone, and the immediate proximity to the confluence with the West Fork Greenbrier River, make the outlet transition zone prone to aggradation. Were the crossing to be re-designed, the transition zones should be narrowed to match the width of the natural channel.

At bankfull stage the structure is nearly 2 m narrower than the natural channel. Water depths and velocities will be elevated because of the narrow width, creating a challenging environment for weaker swimmers migrating upstream.

It is surprising the substrate within the structure is less coarse than that within the representative reach, given a steeper gradient and confined width. Similar to WF01, perhaps the substrate observed within the structure is the same bed material installed during construction. Alternatively, it is possible flows large enough for sediment transport have not yet occurred. If a discharge large enough to move particles within the structure bed, but not large enough to transport particles within the natural channel were to occur, one would expect to see signs of scour or bed degradation within the structure. None were observed, supporting the idea that the design bed has not yet adjusted. During high flows, natural sediment should be transported into the structure, coarsening the bed over time.

In several areas along the natural channel, Cove Run accesses its floodplain somewhat frequently, indicating a structure wider than bankfull (or additional floodplain relief) should have been installed. Were the floodplain considered, hydraulics during larger flood flows would be similar to those within the natural channel. During large floods, however, the West Fork of the Greenbrier River will likely backwater the WF02 outlet transition zone and possibly the structure. Any resulting aggradation within the structure should be scoured by subsequent bankfull floods. Within the much wider outlet transition zone, it is unclear if a bankfull channel will be maintained, or if flow will always spread across a backwater deposit.

6.2.3.5 SITE 3

The site 3 structure is an especially long (13.6 m), round concrete culvert. The design channel within the inlet transition zone is a steep riffle (9%). The gradient breaks at the structure inlet. A long riffle extends through the structure (SR1) to the bottom of the outlet transition zone (OR1) (4.5% gradient).

The representative reach is also a riffle with 5% gradient. No representative reach was selected for the steep riffle within the inlet transition zone; it is therefore not analyzed. The structure scored 30% of the total possible points and is considered "dissimilar." The outlet transition zone scored 37% of the total possible points and is considered "dissimilar." All photos and plots for Site 3 are found in Appendix A8 [Site 3 Site Data].

At the time of data collection, the stream channel at Site 3 was dry; the wetted width and maximum depth metrics were not collected. After significant rains, the channel began to flow.

IR1

The inlet transition zone at Site 3 is part of a unique slope segment, different than the one present within the structure and outlet transition zone. At the time of data collection, the protocol specified selecting a representative reach only for the slope segment present within the structure. Therefore, the inlet transition zone was not evaluated quantitatively; instead it is discussed qualitatively within the discussion summary below.

SR1

The coarse fraction of the gradation within the structure riffle received a "fair" score of 3. The p-value associated with the Wilcoxon Rank-Sum Test is fairly high, 0.01. Sample sizes should be adequate (>100 for both groups). The median of the coarse fraction within SR1 is 15 mm less than that within the representative reach. The data plots (Figure 299, Figure 304, and Figure 305) support this. The fair score seems reasonable for this metric.

SR1 received poor scores (1) for all other metrics. The statistical test of widths at bankfull stage gave a p-value of 4.68e-10. Sample sizes are large and should be adequate (~70 within the representative reach and ~40 within the structure).

Figure 301and Figure 300 show the median bankfull width at SR1 is 75 cm narrower than that within the representative reach.

Figure 301 [Full Bankfull Widths Boxplot] shows the central halves of the data do not overlap. The metric seems appropriately scored.

SR1 also scored poorly for the metric of width at half bankfull stage. The p-value is 5.24e-10 and the sample sizes are large (the same as those for the bankfull width metric). Data show the half bankfull width within the structure is 33 cm wider than that within the representative reach; Figure 293, Figure 294, Figure 302 and Figure 303 [Site 3 Design Reach Widths, Site 3 Representative Reach Widths, Site 3 Full Half Bankfull Widths Boxplot and Histogram] support this. The central halves of the data for each group do not overlap. The low score is reasonable for this metric.

SR1 scored poorly for the metric of bank irregularity. The p-value is very small, 2.20e-16, and sample sizes are large (~70 within the structure and ~140 within the representative reach). Data show the median irregularity measure is 8 cm less than that within the representative reach. Figure 307[Bank Irregularity Boxplot] shows the central halves of the data don’t overlap. Figure 306 [Bank Irregularity Histogram] shows the variety in irregularity size is much greater for the representative reach than SR1. Figure 293 [Design Reach Widths] and Figure 290 [photos within structure] show that banks which create irregularity are nearly absent within the structure. This metric is scored appropriately low.

SR1 also scored 1 for the bed irregularity metric. The p-value is very small, 2.61e-04, and the sample sizes should be adequate (n = 18 at SR1 and n = 50 at RRR1). Data show the median irregularity measure for SR1 is 2 cm less than that within the representative reach. Figure 309 [Bed Irregularity Boxplot] shows the central halves of the data groups do not overlap. Figure 308 [Bed Irregularity Histogram] shows the representative reach has a greater diversity of irregularity sizes than SR1. The low score for this metric is reasonable.

SR1 scored poorly for the bank continuity metric because only 13% of the structure had “banks”. The photo shows the “banks” are piles of likely mobile particles set against the pipe wall. Designed banks should be immobile “key pieces”. Figure 293 [Design Reach Widths] and Figure 290 [photo within structure] support the low score for this metric.

OR1

The riffle within the outlet transition zone (OR1) scored well (5) for the metric of bank irregularity. The p-value is high, 0.959, and the sample sizes are large (~25 within OR1, and ~140 within the representative reach). Data show the median irregularity measure is 12 cm more irregular within the outlet transition zone riffle. Figure 307 [Bank Irregularity Boxplot] shows the central halves of the data overlap well. Figure 306 [Bank Irregularity Histogram] shows the diversity of irregularity values is similar between groups, although the sample sizes are very different. Were the sample sizes more similar, or a test of distributional shapes used, evaluating this metric score would be more conclusive. Without more evidence against the finding of similar irregularity, the high score for this metric cannot be overridden. OR1 also scored highly (5) for the bed irregularity metric. The p-value is 0.698 and the sample sizes should be adequate (~25 for each group). The data show the outlet transition zone median bed irregularity is only 1 cm greater than that within the representative reach. Figure 309 [Bed Irregularity Boxplot] shows the central halves of the data groups overlap well, and Figure 308 [Bed Irregularity Histogram] shows the diversity of irregularity values are very similar. The high score for this metric is reasonable.

The riffle within the outlet transition zone scored poorly for the width at bankfull stage metric. The p-value is very small 1.28e-07, and the sample sizes should be adequate (~10 within the OR1, and ~80 within the representative reach). Data show the median OR1 bankfull width is 3.5 m wider than that within the representative reach channel.

Figure 301 and Figure 300 [Site 3 Design Reach Widths, Site 3 Representative Reach Widths, Site 3 Full Bankfull Widths Boxplot and Histogram] support this. Figure 301 [Full Bankfull Widths Boxplot] also shows the central halves of the data do not overlap. The low score for this metric seems valid.

OR1 scored poorly (1) for the metric of width at half bankfull stage. The p-value is very small, 4.02e-12. The sample sizes are large (the same as those for the bankfull width metric). Data show the median width at half bankfull stage is 2.99 m wider than that within the representative reach. Figure 293, Figure 294, Figure 302, and Figure 303 [Site 3 Design Reach Widths, Site 3 Representative Reach Widths, Site 3 Full Half Bankfull Widths Boxplot and Histogram] support this; Figure 303 [Full Half Bankfull Widths Boxplot] shows the central halves of the data groups do not overlap. The low score for this metric is reasonable.

The riffle within the outlet transition zone scored poorly (1) for the coarse fraction metric. The p-value is very small, 3.99e-12. Sample sizes are large (110 within OR1 and ~90 within the representative reach). Data show the median of the coarse fraction within the representative reach is 80 mm larger than that within the outlet transition zone. Figure 299, Figure 305 and Figure 304 [Site 3 Gradation, Site 3 Coarse Fraction Boxplot and Histogram] support this. The low score for this metric seems reasonable.

SUMMARY

All metric scores seem to be well supported by data and observations at Site 3. The structure and outlet transition zones are dissimilar from the natural channel and are affecting geomorphic continuity. If one considers the design channel at different flow stages, its effect on geomorphic process and channel form are best understood. In addition, design improvements are most easily identified.

During the 2011 field visit the channel was initially dry. After substantial precipitation, both the natural and design channels carried water. Flow within the structure, however, appeared diminished. At the outlet transition zone, a significant spring was found emerging at noticeable pressure out of the bed, indicating water is also passing underneath or around the structure. This problem is likely related to poor compaction of the substrate upon which the structure rests. During low flow periods, reduced flow and shallow depth through the structure likely create a migration barrier for larger bodied aquatic organisms. The wide, gentle gradient area at the inlet transition zone probably exacerbates the problem by allowing still water to percolate into the bed. The inlet transition zone is wider than the natural channel at low flow, bankfull and half bankfull widths (Appendix A8.3, Figure 293and Figure 294) because banks were not constructed; instead, concrete wingwalls, road fill and the eroded hillslope define the channel. Banks would both help to route more of the surface flow into the structure, as well as maintain a low flow channel. The outlet transition zone is similarly wide at all flow stages. During low flow periods, the discharge emerging from the structure disperses within this gentle gradient. Here, too, constructed banks would help to maintain a low flow channel.

The structure is fairly similar to the width of the natural channel at the half bankfull stage (slightly wider). Banks are, however, absent and bank margin diversity at the half bankfull stage is low. Were banks constructed, aquatic organisms would benefit from the resting areas and habitat created by the hydraulic diversity. Banks, however, would require installing a much wider structure.

In addition to being wider than the natural channel, the inlet transition zone is also much steeper. Two factors steepen the gradient at the inlet transition zone: an eroding sediment deposit and the convex profile of the stream's basin (which breaks gradient just upstream of the inlet transition zone). The erosion is occurring because a wooden step at the upstream boundary of the inlet transition zone was recently undermined (possibly by construction activities). A small headcut now has the potential to travel upstream. Because this headcut is upstream of the structure, it is unlikely to critically impact the design, although greater sediment loads will travel through the crossing for some time.

Sediments within the inlet transition zone are surprisingly (given the steep gradient) less coarse than the representative reach. Because the current structure is narrower than the representative reach at the bankfull stage, it is possible flow is somewhat backwatered, causing finer particles to deposit. Alternatively, the fine bed material within the inlet transition zone may be a lingering deposit caused by the previously undersized structure. If large enough flows have not yet adjusted the design channel, the channel bed may be what was placed, or left undisturbed during construction (similar to what might have occurred at WF01 and WF02, located nearby within the same river basin). In either case, constructing narrower banks within this zone will help to prevent aggradation at the structure inlet.

The crossing design would be improved were the structure replaced with a wider one (at least as wide as the natural channel at bankfull width). A structure wider than bankfull would allow enough space to construct stable banks along the structure walls. It is possible banks had been constructed, but constricted flows mobilized the rocks downstream.

A wider structure would also ensure flow velocities (and therefore shear stresses) are similar to those within the natural channel, at least up to the bankfull stage. The coarse fraction metric is most similar to the natural channel within the structure, not necessarily because natural sediments have been transported into the structure, but because elevated shear stresses have caused fines to be transported downstream.

As constricted bankfull flow exits the structure outlet, it spreads to fill the excessively wide outlet transition zone. As the flow slows, both fine and coarse particles are deposited; the zone may aggrade over time. The bed particles within the outlet transition zone are much less coarse than those within the representative reach. Were banks to confine the channel, concentrated flow would maintain a coarser channel and steeper gradient.

It is possible an aggradation and erosion cycle will occur within the outlet transition zone. Concentrated bankfull floods emerging from the structure outlet may scour a channel into the sediment deposit. Then, over time and during lesser floods, the eroded channel may fill with finer material.

The natural channel at Site 3 had a developed floodplain along the majority of the study reach; ideally, the Site 3 design would incorporate a structure much wider than the natural channel at bankfull stage. During overbank flows, the structure is likely to reach capacity as the water carried on the floodplain is also forced through the structure. These floods will create a backwater condition upstream of the structure inlet, causing sediment to deposit within the inlet transition zone. Inside the structure, the concentrated, possibly pressurized flows will have greater erosive power than the natural channel, possibly scouring the channel bed to the concrete culvert bottom. During floods greater than bankfull, the pressurized flow emerging from the structure outlet is likely to scour the channel bed within the outlet transition zone. A pool may eventually form near the structure outlet. Its presence may be cyclical, as lesser floods deposit sediments within it.

6.2.3.6 DOG SLAUGHTER

The Dog Slaughter road-stream crossing design is basically a riffle (IR1) and long pool within the inlet transition zone (IP1), structure (SP1), and outlet transition zone (OP1). The pool is backwatered by a constructed riffle downstream of the outlet transition zone (CR2). The design reach is a single slope segment (0.6%). The representative reach gradient is 0.8%. The constructed riffle is within a separate slope segment (2.9%) which has its own representative reach (4.1%). A 50% gradient difference criterion was used to select both representative reaches. Figures referred to are located within Appendix A4 [Dog Slaughter Site Data].

The level II rubric evaluated the inlet transition zone riffle as “dissimilar,” the structure pool as “dissimilar,” and the pool within the outlet transition zone as “questionable.” Sample sizes within the inlet transition zone pool are too small for statistical analysis, and therefore the group is instead qualitatively discussed as part of the design channel. The constructed riffle was evaluated as “questionable.”

IR1

The riffle within the inlet transition zone scored 36% of the total possible points, and was evaluated as “dissimilar” from the natural channel. It scored “good” (5) for the metric of bed irregularity. The p-value associated with the test is high, and sample sizes are large (~80 within IR1 and ~110 within RRR1). Data show the medians are exactly equal. Figure 173 [Dog Slaughter Bed Irregularity Boxplot] shows the data extent around each median is very similar, and Figure 172 [Dog Slaughter Bed Irregularity Histogram] shows the variety of irregularity values is nearly identical. The high score for this metric is reasonable.

IR1 scored “fair” (3) for the metric of width at half bankfull stage. The p-value is 0.034, and the sample sizes are large (~10 within IR1 and ~30 within RRR1). Data show the design median at IR1 is 1.01 meters narrower than that within the representative reach. Figure 163 [Full Half Bankfull Widths Boxplot] shows the central half of IR1 data do overlap with the central half of RRR1 data. Given the overlap, a score of 3 seems reasonable for this metric.

IR1 also scored “fair” for the metric of bank irregularity. The p-value is fairly high, 0.03. Sample sizes are large. Data show the median irregularity measures differ by 38 cm (RRR1 is greater). Figure 171 [Bank Irregularity Boxplot] shows the central halves of the data groups overlap, and Figure 170 [Bank Irregularity Histogram] shows the variety of irregularity values within the representative reach are slightly greater than the variety within IR1 (although this may be partly because RRR1 has a larger sample size). Together, the data suggest a score of 3 is reasonable for this metric.

The riffle within the inlet transition zone scored poorly for most metrics. IR1 scored a 1 for the metric of width at bankfull stage. The p-value is extremely small, 2.14e-10. Sample sizes should be adequate (~10 for IR1 and ~30 for RRR1). Data show the median bankfull width at IR1 is 1.26 m narrower than that within the representative reach. Figure 160 and Figure 161 [Dog Slaughter Full Bankfull Widths] show the data distributions are very different from one another. The poor score for this metric seems reasonable.

IR1 scored “poor” for the width at low flow metric. The p-value is very small, 1.49e-04. Sample sizes should be adequate (the same as those for the bankfull width metric). Data show the low flow (wetted) width is 1.38 m narrower at IR1 than at RRR1. Figure 165[Dog Slaughter Full Low Flow Widths Boxplot] shows the central halves of data for each group do not overlap. The poor score for this metric is reasonable.

IR1 scored “poor” for the maximum depth metric. The p-value is 4.69e-04. Sample sizes should be adequate (the same as those for the bankfull width metric). Data show the median maximum depth within IR1 is 7 cm less than that within the representative riffle. Figure 167 [Dog Slaughter Maximum Depths Boxplot] shows the central halves of data for each group do not overlap. The poor score for this metric is reasonable.

IR1 scored “poor” for the coarse fraction metric. The p-value is very small, 2.20e-16, and sample sizes are large (~90 at IR1, and ~75 at RRR1). Data show the median coarse fraction value is 80 mm larger within the representative reach than within IR1. Figure 169 [Dog Slaughter Coarse Fraction Boxplot] shows the central halves of each data group do not overlap. Given that the representative reach is steeper than the inlet transition zone (by 0.2%) one would expect IR1 to be slightly less coarse. 80 mm however seems like a large size discrepancy for such a small difference in gradient. If one were to override this metric (increase the score from 1 to 3) in order to factor in the difference in gradient, the evaluation remains “dissimilar.”

IP1 AND OP1

The long pool which extends from the inlet transition zone (IP1) through the structure (SP1) to the bottom of the outlet transition zone (OP1) is a challenge to analyze because it spans analysis zones. It is not meaningful to compare just the head or tail-out of the design pool to the entire representative pool. However, to consistently apply the level II rubric, I did analyze the long design pool by group (segments the pool by zones). As expected, the design pool scores poorly for most metrics, but scores are not very informative.

In an effort to avoid analyzing the pool unit in segments, I also tried analyzing the pool by unit sequence. I compared the riffle-pool sequence within the design channel with the riffle-pool sequence within the representative channel. However, this approach at Dog Slaughter is also problematic because the unit lengths between the design and representative reach pools are not similar (51.3 m design versus 20.3 m), and the hydraulics inside and out of the structure might differ at flood flows. The results show the design is “dissimilar,” a reasonable conclusion, even though the analysis is flawed. The best approach for assessing the effectiveness of this design is qualitative, because the protocols are not easily applied and the site’s design flaws are fairly apparent. The site was included in this study because it is an example of a road-stream crossing design where neither the level I nor II protocols apply. Qualitatively, the poor scores are reasonable evaluations, given that the structure is narrower than the bankfull width (by 2.92 m), bed particles within the structure are solely fines (the footers sit on bedrock), and no banks were constructed within the structure. The median maximum depth is much shallower within the structure than in the design channel. It is reasonable to consider the pool unit “dissimilar.”

CONSTRUCTED RIFFLE

The constructed riffle, immediately downstream of the outlet transition zone lower boundary, backwaters the structure. This channel unit was analyzed separately (as its own zone) by the level II rubric analysis. It scored 71% of the total possible points and was evaluated as “questionable.”

The constructed riffle scored highly (5) for most metrics. The p-value for the coarse fraction metric is very high, 0.399. Sample sizes are large (~100 within the constructed riffle and ~80 within the representative reach). Figure 182 and Figure 183 [Dog Slaughter Coarse Fraction Boxplot and Histogram] show the data populations are very similar. The high score for this metric seems reasonable.

The constructed riffle scored highly (5) for the metric of bank irregularity. The p-value is 0.718. Sample sizes should be adequate (~30 within the constructed riffle and ~20 within the representative reach). Data show the median irregularity measure within the representative reach is 41 cm greater than that within the constructed riffle. However, Figure 185 [Dog Slaughter Bank Irregularity Boxplot] shows the central halves of the data overlap well. And, Figure 184 [Dog Slaughter Bank Irregularity Histogram] shows the variety in size of irregularities is similar between the two groups. The high score for this metric seems reasonable.

The constructed riffle also scored highly for the bed irregularity metric. The p-value is very high 0.68, and sample sizes should be adequate (~50 per group). Data show the median bed irregularity measures are equivalent. Figure 187 [Dog Slaughter Bed Irregularity Boxplot] shows the extent of data around each median is very similar and the central halves of data overlap well. However, Figure 186 [Dog Slaughter Bed Irregularity Histogram] shows the variety of irregularity sizes between groups is slightly greater for the representative reach. If the score for this metric was downgraded (overridden) from 5 to 3, the evaluation remains “questionable.”

The constructed riffle was evaluated as “fair” for the width at half bankfull metric. The p-value is 0.01, and the sample sizes should be adequate (~20 within the constructed riffle and ~15 within the representative reach). Data show the representative reach is wider than the constructed riffle at half bankfull stage by 30 cm. Figure 177 [Dog Slaughter Full Half Bankfull Widths Boxplot] shows the central halves of the data have some overlap. A score of 3 seems reasonable for this metric.

The constructed riffle scored poorly (1) for the metric of width at bankfull stage. The p-value is very small, 9.93e-06. Sample sizes should be adequate (~20 within the constructed riffle and ~15 within the representative reach). Data show the median representative bankfull width is 1.55 m wider than the width at the constructed riffle. Figure 175 [Dog Slaughter Full Bankfull Widths Boxplot] show the central halves of the data do not overlap. The low score for this metric seems reasonable.

The constructed riffle scored poorly (1) for the metric of low flow (wetted) width. The p-value is very small, 1.39e-09. Sample sizes should be adequate (the same size as those for bankfull and half bankfull widths). Data show the median representative riffle is 1.02 m wider than the constructed riffle at wetted width. Figure 179 [Dog Slaughter Full Low Flow Widths Boxplot] shows the central halves of the data do not overlap. The low score for this metric seems reasonable.

The constructed riffle also scored poorly (1) for the maximum depth metric. The p-value is very small, 0.927e-05. Sample sizes are large (~20 within the constructed riffle and ~15 within the representative reach). Figure 180 and Figure 181 [Dog Slaughter Maximum Depth Metric] show the median constructed riffle depth is 5 cm shallower. The low score for this metric seems reasonable.

SUMMARY

The road-stream crossing design channel at Dog Slaughter Creek does not simulate the natural channel. The inlet transition zone is narrower at bankfull, half bankfull and low flow stages. Interestingly, the inlet transition zone is also shallower at low flow and less coarse (discussed below) than the natural channel. The banks of the inlet transition zone are less irregular. Bed irregularity is the only way it is similar to the natural channel. The inlet transition zone was reasonably evaluated as “dissimilar.” Although the summary rubric analysis did not lend itself well to analyzing designs with long, channel spanning units, the evaluations themselves are appropriate. The pool which extends from the inlet transition zone to the bottom of the outlet transition zone is reasonably “dissimilar” from the natural channel. No other pools in the Dog Slaughter Creek study reach are as long and straight as the design pool. Nor are natural pools as consistently narrow. Constructed banks are also absent within the structure.

At low flow, the structure is narrower than the natural channel by nearly two meters. At half bankfull, it is narrower by nearly 1 m, and at bankfull, the structure is narrower by nearly 3 meters. During floods, the structure will be deeper with greater velocity (and shear stresses) than pools within the natural channel. Were the channel bed within the structure not bed rock, it would be at risk of undercutting the structure's support footers. Further, the structure may become a barrier to aquatic organisms migrating upstream during floods, as they struggle to maintain a swimming speed greater than the water velocity for the long length of the structure.

The "dissimilar" evaluation of the structure pool is accurate. The "questionable" evaluation of the portion of the pool within the outlet transition zone should also be "dissimilar," based on the pool's extreme length and excessive width. During floods, the concentrated flow emerging from the narrow structure will scour any accumulated sediment within the outlet transition zone, effectively maintaining the pool depth over time.

The constructed riffle, located just downstream of the outlet transition zone boundary, is considered "questionably" similar to the natural channel. The riffle is oddly both narrower (at low flow, half bankfull and bankfull stages) and shallower than steep riffles within the natural channel. Likely fine material was not included in the riffle particle mixture, increasing the permeability. Flow travels through the riffle, rather than over its surface. The level II summary rubric evaluation of the constructed riffle is reasonable.

It is possible high flows have not yet adjusted the design channel and what I measured is simply what was installed. The previously undersized structure was replaced in 2011. I collected data at the site approximately one year later in October of 2012. The coarse fraction metric at the constructed riffle supports this idea. The similarity in particle size between the constructed riffle and the natural channel is surprising given the 1.2% difference in channel gradient. One would expect the less steep design riffle to also be less coarse. With significant flows, it might aggrade and become less coarse.

The idea the design is yet to adjust to its hydro-geomorphic setting is also supported by the riffle within the inlet transition zone. As described above, the bed at IR1 is both significantly less coarse (for nearly equal gradients) and shallower than the representative reach. Perhaps the surface substrate at IR1 is the same as that present before the undersized structure was replaced. Without significant flows to mobilize the sediment into the now wider structure, the smaller particles are still in place. The aggraded bed at the inlet transition zone might also allow more flow to permeate into the bed, causing the riffle to be shallower.

If the design has not yet been adjusted by floods, one might ask, why was it selected as a site for effectiveness monitoring? How can one assess if geomorphic continuity has been restored when the geomorphic driver, discharge, hasn't been present? Frankly, if Dog Slaughter was not also monitored by the biological effectiveness monitoring group, it would not have been selected as a physical effectiveness monitoring site. The design problems are apparent enough that the detailed and time consuming level II protocol is not necessary to point them out.

6.2.3.7 BIG LICK

The road-stream crossing structure at Big Lick Creek is a squashed (oval) corrugated metal pipe. It is an older structure, installed circa 1960, and is not a replacement of a previously undersized structure. It was chosen for physical monitoring because the biological group is also monitoring the site.

The design reach is composed of a riffle and pool. Within the inlet transition zone is a riffle and the head of a long pool (IR1 and IP1). The pool continues through the structure (SP1) and extends past the downstream boundary of the outlet transition zone (OP1). The inlet and outlet transition zones are truncated mid-unit at artificial grade “controls”, features not actually controlling the channel gradient (riffle rib and submerged wood). A single slope segment makes up the design channel; it has gradient 0.39%. The representative reach has a gradient of 0.21%; it was chosen by a 100% gradient criterion. Figures referred to are located in Appendix A2 [Big Lick Site Data]. The inlet transition zone riffle and pool-head is evaluated by the level II summary rubric as “questionable.” The pool segment within the structure is evaluated as “questionable” and the pool segment within the outlet transition zone is evaluated as “similar.”

IR1

The riffle within the inlet transition zone (IR1) is the tail end of a much longer, natural riffle upstream of the design crossing. IR1 scored highly (5) for the metric of maximum depth. The p-value is 0.634, but the sample size within IR1 (n = 5) is small. Data show the median maximum depths are equivalent for the IR1 and the RRR1. Figure 99 [Big Lick Depths Boxplot] shows the central halves of data for each group overlap, and Figure 98 [Big Lick Depths Histogram] shows the distribution shapes are very similar. The high score for this metric seems reasonable, despite the small sample size.

IR1 scored “good” (5) for the metric of bank irregularity. The p-value is high, 1, and the sample size should be adequate (~30 within IR1 and ~20 within the representative riffle). Data show the median irregularity measure within the representative reach is 14 cm larger than that within IR1. Figure 103 [Big Lick Bank Irregularity Boxplot] shows the central halves of the data overlap well. Figure 102 [Big Lick Bank Irregularity Histogram] shows the variety of irregularity sizes is similar between groups. The high score for this metric seems reasonable.

IR1 scored “good” (5) for the bed irregularity metric. The p-value is 0.115, and sample sizes are large (~40 within IR1, and ~50 within RRR1). Data show the median irregularity measure within IR1 is 4 cm larger than that within the representative riffle. Figure 105 [Big Lick Bed Irregularity Boxplot] shows the central halves of the data for each group overlap well. Figure 104 [Big Lick Bed Irregularity Histogram] shows the variety of irregularity sizes is similar between groups. The high score for this metric seems reasonable.

The riffle within the inlet transition zone scored “fair” (3) for the width at bankfull stage metric. The p-value is 0.001, but the sample sizes within IR1 are small (n = 5 at IR1 and n = 12 within the representative reach riffle). Data show the bankfull width at IR1 is 1 m narrower than that within RRR1. Figure 93 [Big Lick Full Bankfull Width Boxplot] shows the central halves of the data do not overlap. Figure 93 and Figure 92 [Big Lick Full Width at Bankfull Stage Boxplot and Histogram] show the group medians are coincident but the distributions appear different from one another. Given the small sample size might not provide enough information to reject the null hypothesis, a lower score for this metric is reasonable. If an override lowers the score from 3 to 1, the group evaluation of IR1 remains “questionable” (56%).

IR1 also scored “fair” for the metric of width at half bankfull stage. The p-value is 0.014, but sample sizes are small (the same as those for the bankfull width metric). Data show the design median width at half bankfull is 1.94 m narrower than that within the representative reach. Figure 95 [Big Lick Half Bankfull Widths Boxplot] shows the central halves of data do not overlap, but the extent of data does. The “fair” score for this metric is reasonable.

The riffle within the inlet transition zone scored “fair” (3) for the metric of low flow width. The p-value is 0.01, but sample sizes are small (the same as those for the bankfull and half bankfull width metrics). Data show the median low flow (wetted) width at IR1 is 3.03 m narrower than that within the representative reach. Figure 97 [Big Lick Full Low Flow Width Boxplot] shows the data populations do not overlap at all between groups and Figure 96 [Big Lick Full Low Flow Width Histogram] shows they have different skews. An override for this metric might be justified, but if the score were downgraded from 3 to 1 (poor), the group evaluation remains “questionable” (53%).

IR1 scored “poor” (1) for the metric of the coarse fraction. The p-value is very small 2.20e-16, and sample sizes are large (~90 within IR1 and RRR1). Data show the median of the coarse fraction within IR1 is 40 mm more coarse than that within the representative reach. Figure 100 and Figure 101 [Big Lick Coarse Fraction Boxplot and Histogram] support this. The poor score seems reasonable for this metric. The level II evaluation showed the inlet transition zone maximum depth, bank irregularity, and bed irregularity are similar to the representative reach. IR1 is narrower than the representative reach at bankfull, half bankfull and low flow stages. It is coarser and less steep than the representative reach (which makes sense given the narrow width).

IP1, SP1, AND OP1

Analyzing the pool unit which extends through all design zones (IP1, SP1, and OP1) is problematic for the level II (and level I) protocols. It makes no sense to compare the head or tail of the design pool with an entire pool in the natural channel. The design pool at Big Lick was analyzed in this manner only as an example of a design channel where the protocols do not apply; the scores for IP1, SP1, and OP1 are therefore not meaningful alone.

In an effort to obtain more meaningful results, the design channel at Big Lick was also analyzed by channel unit sequence. At Big Lick, a single riffle-pool sequence makes up the entire design channel. Therefore, the design population was compared with the “natural” population. Though not preventative of this analysis, the representative reach is composed of separate channel units and is not a sequence, Figure 75 [Big Lick Longitudinal Profile]. When analyzed by population, the design channel scores 58% of the total possible points and is considered “questionably” similar to the natural channel. Comparing channel unit sequences is however not an entirely appropriate comparison. Matched channel units should be of similar lengths, otherwise data populations are skewed by the predominate channel unit type. At Big lick, the design sequence (riffle-pool) is 12% riffle, while the representative natural channel sequence is 41% riffle.

SUMMARY

The road-stream crossing design at Big Lick is difficult to summarize by zone because the pool unit spans the entire design channel. Here it is most meaningful to summarize the design not strictly by zone or channel unit, but in terms of hydraulics during various flow stages, impacts to aquatic organism passage, and how the design might be improved.

One of the major design flaws at Big Lick is the crossing alignment to the natural stream channel. The problem is especially evident within the inlet transition zone. The road forces the stream channel into a tighter bend than its natural course had followed. The bend has caused scour around the culvert inlet at the right bank, and bed scour (down to metal) immediately inside the culvert. Over time, the road fill will continue to erode and the integrity of the structure will be compromised.

Within the portion of the inlet transition zone composed of the pool unit (nearest the inlet), the channel width (at bankfull, half bankfull, and wetted width) is significantly greater than that within the natural channel. During smaller floods, fine particles will tend to deposit within this wide area. Spreading flow will exacerbate erosion of the road fill along the right bank at the structure inlet.

The pool within the structure is much narrower than the natural channel at bankfull width. It is similar (slightly narrower) at the half bankfull width, and slightly wider at the low flow width. During low flow periods, because the wetted width it is slightly wider, the structure may be shallower than the natural channel, creating a barrier to aquatic organism migration. During floods at and above half bankfull stage, flows will be concentrated through the structure, and flow velocity will be greater than that found within the natural channel. Substrate within the structure will be mobilized downstream; fines may gradually accumulate again during lower flows. Banks within the structure are absent, and bank irregularity is missing. The strong hydraulics and lack of bed and bank margin diversity within the structure likely make it a barrier to aquatic organisms migrating upstream during flood flows.

The pool within the outlet transition zone is significantly wider at bankfull, half bankfull and low flow stages. During lesser floods, flow will spread within this wide zone and particles will tend to deposit. Large floods will maintain the pool within the outlet transition zone as concentrated flood waters exit the structure outlet, scouring the bed.

Although some metrics were numerically similar enough to the natural channel to yield “questionable” and “similar” evaluations for the design channel, the *total* length of the pool is far longer than any pool observed within the natural channel. Further, the structure alignment with the natural channel is poor, forever requiring maintenance. Qualitatively, one should conclude the road-stream crossing design is “dissimilar” from the natural channel. The difference between the level II summary rubric evaluation and a qualitative evaluation can be attributed to the design-zone-spanning pool unit, which makes assessing the channel design by the level II summary rubric difficult (inappropriate for some metrics).

The quantitative and qualitative observations gained from monitoring at Big Lick might help inform structure replacement plans. The structure is obviously older (as evidenced by the 0.3 m high, well developed rust line, Figure 69) and is near the end of its life-span. Aligning the structure with the natural meander would prevent the erosion issues at the inlet and would help maintain the substrate by preventing excessive scouring within the structure. To do this, the road would have to be moved, for which there is ample room. Ideally, the replacement structure would be an open bottomed pipe arch; a superior structure to the current one because an open-bottom design bed is guaranteed to be natural substrate. Finally, a short riffle downstream of the outlet transition zone would help maintain the stability of the design, creating channel units more similar in length to those in the natural channel.

6.2.3.8 SPARKS BROOK

The design structure at the Sparks Brook road-stream crossing is an open bottomed pipe arch. The structure has a length of 28.3 m and width of 9 m. The average natural channel bankfull width is 6 m. The design channel bed is composed of several slope segments and channel units; a single gradient riffle (2.79%) extends from the top of the inlet transition zone midway through the structure. Channel units within this slope segment are a riffle within the inlet transition zone (IR1) and a riffle within the structure (SR1). The gradient then steepens, extending just beyond the structure outlet (5.1%). Channel units within the steeper segment are riffle (SR2), step (SS2), and step pool (SSP2). Most of the data were collected within the longer *riffle* units (IR1, SR1, and SR2). The gradient becomes gentle within the outlet transition zone (1%); outlet transition zone channel units are a step (OS0) and pool (OP0).

A representative reach was not selected for the low gradient within the outlet transition zone. Most channel units at this design zone were therefore not analyzed, although data were collected there. The step at the structure outlet is the exception. Two representative reaches were selected; one for comparison with channel units within the inlet transition zone and upper half of the structure, and one for comparison with channel units within the lower half of the structure. The gentle representative reach has a gradient of 2%, the steeper representative reach has a gradient of 5%.

The design steps are analyzed separately from one-another, but are compared with the same representative step. The step within the structure is in slope segment 2. The step at the outlet forms the gradient break between slope segments 2 and 0. Because no representative reach was selected for slope segment 0, this step is compared with the representative step for slope segment 2. Figures for the site can be found in Appendix A9[Sparks Brook Site Data].

IR1

The riffle within the inlet transition zone scored 79% of the possible points and was evaluated as “similar.” It scored high (5) for the metric of width at half bankfull stage. The p-value is 0.417. The IR1 sample size is small (n=7), and the representative reach sample is larger (n=16). Data show the median representative reach is wider than that at IR1 by 30 cm. Figure 345 [Sparks Brook Full Half Bankfull Width Boxplot] supports the high score; it shows the central halves of the data overlap well. Figure 323 and Figure 324 [Big Lick Design Widths and Big Lick Representative Riffle Reach Widths] also support the high score.

IR1 scored “good” (5) for the metric of maximum depth. The p-value is very high (1), but the design sample size is small (the same as those for width at half bankfull stage). Data show the median maximum depth within IR1 is 8 cm deeper than that within the representative reach. Figure 349 [Sparks Brook Depths Boxplot] shows the central halves of data for both groups do not overlap. However, the test is one-sided; design riffles are not penalized for being deeper than the representative group. The high score (5) is therefore reasonable.

IR1 also scored highly (5) for the bank irregularity metric. The p-value is 0.451 and sample sizes should be adequate (~15 at IR1 and ~ 30 at RRR1). Data show the median irregularity measure is 10 cm larger within the representative reach than within IR1. Figure 323 and Figure 324 [Sparks Brook Design Widths and Sparks Brook Representative Riffle Reach Widths] show group irregularities appear similar to one another. Figure 352 [Sparks Brook Bank Irregularity Histogram] shows the variety of irregularity sizes is similar between groups, although RRR1 has more samples. The high score for this metric is reasonable.

IR1 scored “fair” (3) for the width at bankfull stage metric. The p-value is 0.007, but sample sizes are small (n=7 within IR1 and n=16 within RRR1). Data show the median bankfull width within the representative reach is 87 cm wider than that within the inlet transition zone riffle. Figure 342 and Figure 343 [Sparks Brook Full Bankfull Width Boxplot and Histogram] show the full range of data for each group overlap well, but the central halves of data do not. Figure 342 [Sparks Brook Full Bankfull Width Histogram] shows the representative reach bankfull widths are generally wider. The “fair” score for this metric seems reasonable.

IR1 also scored “fair” (3) for the low flow width metric. The p-value is 0.006, but sample sizes are small; they are the same size as those for the bankfull width metric. Data show the median representative reach low flow (wetted) width is 1.06 m wider than that within IR1. Figure 347 [Sparks Brook Full Low Flow Widths Boxplot] shows the ranges of data for each group overlap with one another but the central halves of data do not. The “fair” score for this metric seems reasonable.

IR1 scored “fair” (3) for the coarse fraction metric. The p-value is 0.011 and sample sizes are large (~130 within the inlet transition zone riffle and ~90 at RRR1). Data show the median of the coarse fraction is 20 mm coarser within the representative riffle than within the inlet transition zone. Figure 350 and Figure 351 [Sparks Brook Coarse Fraction Boxplot and Histogram] show IR1 has larger particles, and more variety of large particle sizes. Figure 351 [Sparks Brook Coarse Fraction Boxplot] shows the central halves of the data values for each group overlap well. Together the data and observations show the “similar” evaluation is a reasonable assessment of the inlet transition zone riffle.

SR1

The riffle just downstream of the structure inlet (SR1) scored 88% of the possible points, and was evaluated as “similar” to the natural channel. SR1 scored highly (5) for the metric of width at half bankfull stage. The p-value is 0.19 and sample sizes should be adequate for a fair test (n=11 at SR1 and n=16 at RRR1). Data show the representative riffle at half bankfull stage is 12 cm wider than that at SR1. Figure 345 [Sparks Brook Full Half Bankfull Width Boxplot] shows the central halves of data overlap well. The high score for this metric is reasonable.

SR1 scored “good” (5) for the low flow width metric. The p-value is 0.162 and sample sizes should be adequate (they are the same as those for the width at half bankfull stage metric). Data show the median low flow width at SR1 is 64 cm narrower than that within the representative reach. Figure 347 [Sparks Brook Full Low Flow Boxplot] shows the central halves of the data at each group, as well as the data extent overlap well. The high score for this metric seems reasonable.

SR1 scored “good” (5) for the metric of maximum depth. The p-value is high, 0.998 and the sample sizes should be adequate (they are the same as those for the width metrics). Data show the median maximum depth at SR1 is 4 cm deeper than that within the representative reach. Figure 349 [Sparks Brook Depths Boxplot] shows the central halves of the data do not overlap, but the test is 1-sided and deeper design riffles are not penalized. The high score for this metric is warranted.

SR1 also scored “good” (5) for the coarse fraction metric. The p-value is 0.282 and sample sizes are large (~200 within SR1 and ~90 at RRR1). Level II gradation data for the upper half of the structure (SR1) were collected twice; once for each riffle above and below a slight break in gradient. Slope segment analysis showed the break in gradient was not significant enough to consider the riffles different from one another. Therefore, Figure 341 [Sparks Brook Gradation] shows two separate plots for SR1 riffles; the data were combined and statistically compared however, with the representative reach riffle as one data set.

Figure 341 [Sparks Brook Gradation] shows that the riffle closer to the structure inlet is coarser (at D50 and D75) than the riffle immediately downstream. However, when the structure riffle data are combined (SR1 group), the design and representative reach medians are equivalent (Figure 351) [Sparks Brook Coarse Fraction Boxplot]. Figure 351 [Sparks Brook Coarse Fraction Boxplot] shows the central halves of the data overlap well. The high score for this metric seems reasonable.

SR1 scored highly (5) for the metric of bank irregularity. The p-value is 0.336 and sample sizes are large (~30 within RRR1 and ~20 within SR1). Data show the median irregularity measure within SR1 is 12 cm greater than that within the representative reach. Figure 353 [Sparks Brook Bank Irregularity Boxplot] shows the central halves of the data overlap well, and Figure 352[Sparks Brook Bank Irregularity Histogram] shows the variety of irregularity values is similar between groups. Figure 323 and Figure 324 [Sparks Brook Design Widths and Sparks Brook Representative Reach Widths] show the irregularities for the design and representative channels. The high score for this metric seems reasonable.

SR1 also scored highly (5) for the metric of bed irregularity. The p-value is 0.336 and sample sizes are large (n=~40 within RRR1 and n=~60 within SR1). Data show the median bed irregularity measure is only 3 cm larger within the representative reach. Figure 355 [Sparks Brook Bed Irregularity Boxplot] shows the central halves of the data overlap well. Most importantly, Figure 354 [Sparks Brook Bed Irregularity Histogram] shows similar variability in the size of irregularities between groups. A high score for this metric seems reasonable.

SR1 scored “fair” for the width at bankfull stage metric. The p-value is 0.005 and sample sizes should be adequate (n=11 at SR1, and n=16 at RRR1). Data show the median bankfull width within the representative reach is 93 cm wider than that within SR1. Figure 323 shows the structure walls at the bankfull elevation, for much of the structure length. Figure 343 [Sparks Brook Full Bankfull Widths Boxplot] shows the central halves of the data do not overlap, but the ranges of data do. A “fair” score for this metric seems reasonable.

SR1 scored “good” (5) for the bank continuity metric. 70% of the structure’s walls (left and right) have banks, as represented by Figure 323 [Sparks Brook Design Widths and Figure 317 [photo within structure]. The high score for this metric is reasonable. The “similar” evaluation of the gentle gradient riffle within the structure is a fair assessment, well supported by data and observations.

SR2

The structure riffle within the steeper slope segment (SR2) scored 87% of the possible points and is evaluated as “similar” to the natural channel. SR2 scored highly (5) for most metrics. The p-value associated with the test for width at bankfull stage is 0.134, but sample sizes are small (n = 4 within SR2, and n = 11 within RRR2). Data indicate the median representative width value is 1.14 m wider than that at SR2. Given that the 75th percentile of the SR2 bankfull width is only equivalent to the 25th percentile of the representative reach widths, it seems the metric score is artificially high because of the small sample sizes. If the score were overridden from 5 to 3, the total group score becomes 76% and the evaluation remains “similar.”

SR2 also scored highly (5) for the low flow width metric. The p-value is 0.454, but again, the sample sizes are small (they are the same as those for the bankfull width metric). The data show that the SR2 riffle low flow median is 51 cm narrower than that at RRR2. The quartiles show the median SR2 depth is less than the 25th percentile of RRR2. Yet the 75th quartile values are similar (they differ by 12 cm). Figure 347 [Sparks Brook Full Low Flow Widths Boxplot] shows the central halves of the data for each group overlap well. The score for this metric is probably reasonable; but if the low flow score were overridden and lowered from 5 to 3 (based on small sample size), the total score (accounting for other overrides) drops from 76% to 73% and becomes “questionable.”

SR2 scored highly (5) for the maximum depth metric. The p-value is 0.571, but sample sizes are small (the same size as those for the bankfull width metric). Data show the median SR2 depth is greater than that within the representative reach by 2 cm. The quartiles of the groups are similar. Figure 349 [Sparks Brook Maximum Depths Boxplot] shows the central halves of the data, and the extent of data for each group, overlap well. The high score for this metric seems reasonable.

Bank irregularity at SR2 also scored highly (5). The p-value is very large, 0.970, but the design sample size is small (n=8 at SR2 and n=20 at RRR2). Data show the median irregularity measure within SR1 is 2 cm larger than that within the representative reach. Figure 353 [Sparks Brook Bank Irregularity Boxplot] shows the central halves of the data overlap well, as do the data extents for each group. Figure 352 [Sparks Brook Bank Irregularity Histogram] shows the variability of irregularity sizes. It appears RRR2 has a greater variety of irregularities than SR2; this however may be influenced by the larger sample size within RRR2. Given the data overlap, the high score for this metric seems reasonable.

SR2 scored high (5) for the bank continuity metric. 70% of the structure has banks composed of stable "key pieces" (boulders). Figure 323 [Sparks Brook Design Widths], and Figure 317 [photo within the structure] support the high score for this metric.

SR2 scored "fair" (3) for the width at half bankfull stage metric. The p-value is 0.024, but the design sample size is small (n = 4 within SR2, and n = 11 within RRR2). Data show the SR2 median is 1.53 m narrower than the representative riffle median, and the 75th quartile SR2 width is narrower than the 25th quartile RRR2 width. Figure 345 [Sparks Brook Full Half Bankfull Width Boxplot] shows the central halves of the data do not overlap, although the extent of data for each group does. The "fair" score for this metric is reasonable.

It seems the small sample size may have prevented rejecting the null hypothesis and a type II error could have been made for the metrics of bankfull and low flow width. If both scores are lowered from 5 to 3, the SR2 group evaluation becomes "questionable," a reasonable assessment given the structure width is narrower than the median representative channel width at bankfull and low flow stages.

SS2

The step within the structure is located approximately at the structure mid-point, and is within slope segment 2. The step scored 73% of the total possible points and is evaluated as "questionable."

The structure step scored “good” (5) for the channel unit length metric (n=1). Data show the structure step and representative step have only a 14% length difference. The high score seems reasonable for this metric.

The structure step also scored “good” (5) for the width at bankfull stage metric (n=1). The structure and representative step differ by only 5.2%. The high score for this metric seems reasonable.

The structure step scored “good” (5) for the residual pool depth metric. The design step pool is 25% shallower than the representative pool, differing by 10 cm. The high score seems reasonable for this metric.

The structure step scored “fair” (3) for the metric of maximum particle size. Particle size data show the median particle size within the structure step is 110 mm larger than that within the representative reach (n=5). In fact, all quartiles, as well as the minimum and maximum particle sizes are larger for the constructed step. The median design step particle is similar in size to the 75th quartile representative step particle.

The method for evaluating the particle size at steps is not entirely reasonable. In steeper channels, steps hold the channel gradient. Step particles (the “key pieces” of the design) should be stable enough to not move during large floods. Designers may over-size these particles to ensure the design is stable. As long as the step height is not also increased, it does not seem appropriate to penalize design steps for being extra stout. The group comparison should be a 1-sided evaluation, awarding poor scores only if particles are smaller than those found within the representative steps. If the metric score is improved from 3 to 5 based on a one-sided assessment, the structure step evaluation becomes “similar” with a total score of (80%).

The structure step scored “poor” (1) for the step height metric (n=3). The median design step height is uniform (39 cm) across the step (or possibly only one measurement was actually collected). It is 9 cm greater than the median representative reach step height, and is 16 cm greater than the minimum representative value. The step height is 7 cm greater than the maximum representative step value. The poor score for this metric seems reasonable.

Steps higher than those within the natural channel, could pose significant passage problems for aquatic organisms. Data show the step within the structure has uniform height. This is likely only a reflection of where (or possibly how few) measurements were collected. Photos suggest it has some irregularity, especially at bankfull stage.

To summarize, the step within the structure is taller and built of slightly larger particles than the representative step, but is similar in length and width. Hydraulically, it is similarly effective, as shown by the comparable scour pool depths. When the particle size score is changed to a one-sided assessment (does not penalize for larger particles), and the step length weight is adjusted to 0.25 (see section 6.2.4), the evaluation remains “similar.”

OS2

The step at the structure outlet scored only 35% of the total possible points and was evaluated as “dissimilar” from steps within the natural channel. The step scored “fair” (3) for the step length metric. The design step is shorter than the representative step by 47%. The “fair” score is reasonable for this metric.

The outlet step scored “fair” (3) for the metric of maximum particle size. The median particle size is 360 mm larger than that at the representative step. It is 20 mm smaller than the representative maximum particle size. The minimum design particle is larger than the representative 75th percentile. Again, the step seems to have been built extra stout. The score of 3 seems adequate. If this metric were scored by a 1-sided test (to penalize only for smaller particles) the metric score would become a 5, and the overall score would remain “dissimilar” (43%).

The outlet step scored poorly (1) for the metric of width at bankfull stage. The outlet transition step is much wider than the comparative step within the natural channel (by 95%). The poor score for this metric is reasonable.

The step scored poorly (1) for the metric of step height. The median design height is greater than the median representative height by 5 cm. It is greater than the representative maximum height by 3 cm. The minimum design height is equal to the maximum representative height, and greater than the minimum representative height by 9 cm. The “poor” score for this metric seems reasonable.

The outlet step scored poorly for the residual pool depth metric. The depth is different from the design depth by 30 cm (75% difference). The poor score for this metric seems reasonable.

To summarize, the step at the structure outlet is apparently wider, taller, shorter in length, and built of larger particles. Hydraulically, it is less effective at maintaining a pool beneath it, as evidenced by the shallower residual pool depth. The “dissimilar” evaluation seems reasonable, given the data.

The validity of the step effectiveness evaluations is however difficult to assess because the data are limited; sample sizes are small and photos are poor. If compared with a different step within slope segment 2, would the outlet step score any higher? Perhaps a better approach would be to measure every step within the representative slope segment(s), thereby defining the range of variability found within the natural channel.

SUMMARY

Overall, the Sparks Brook road stream crossing seems to allow geomorphic continuity through the structure. The inlet transition zone and upper structure riffle are similar to the natural channel for most metrics. The design could be improved by slightly increasing the width of both the inlet transition zone and structure at bankfull, half bankfull and low flow stages. Bankfull floods will be constricted within the structure (by about 1 m), increasing the depth and elevating the velocity. Aquatic organisms may find the structure more difficult to navigate than the natural channel during bankfull stage.

The Sparks Brook study reach has an active floodplain along some of its length. During floods greater than bankfull stage, flows within the natural channel are able to spread across these areas, maintaining near bankfull hydraulics within the active channel. Within the design channel, however, floods greater than bankfull stage will be concentrated, creating stronger hydraulics than those in the natural channel. It is likely the design channel at floods greater than bankfull is a barrier to upstream aquatic organism passage.

Differences in the coarse fraction of the gradation metric (the design is less coarse) within the inlet and upper structure zones could be related to the hurricane Irene flood, during which ponded water at the inlet might have allowed finer particles to deposit. Long term monitoring would probably show the design substrate is not actually that different in size from the natural channel.

The steeper downstream riffle within the channel originally scored very high and was evaluated as “similar” to the natural channel. I believe this is probably a statistical bias due to small sample size. The structure is narrow compared with the natural channel and “good” scores for the width metrics seem too high. If the bankfull and low flow width metrics are scored “fair”, the evaluation becomes “questionable,” a more appropriate evaluation. The step within the structure is fairly similar to a step within the natural channel, although it is slightly taller and constructed of larger material. One could argue that a “similar” evaluation is reasonable for this step if the particle size comparison were altered to become 1-sided. The step could be improved by decreasing its height and adding more irregularity to its geometry. The step at the outlet is much less similar to the representative step. It is taller, wider, shorter in length, and larger in particle size. The “dissimilar” evaluation seems appropriate because the difference in residual pool depths shows it is not hydraulically effective (too shallow). The step might perform better (if re-built) by narrowing it and decreasing the height. Aquatic organism passage may be hindered by the step at the outlet (especially during low flows), given a significant pool downstream is absent. In summary, the Sparks Brook road-stream crossing could be improved; a wider structure would ensure flow hydraulics remain similar to those within the natural channel during bankfull floods. In general however, the design appears to be functioning fairly similarly to the natural channel.

6.2.4 METRICS

6.2.4.1 REDUNDANCY

If one compares the level II scores in Table 38, section 5.2.1.3, (read left to right by protocol), neither pair of potentially redundant metrics appears to provide consistent group scores. It seems reasonable to assume that all four of these metrics (low flow width versus depth and bed irregularity versus the coarse fraction) provide different information about a stream channel. This does not, however, indicate all four metrics should be included within the protocol. The meaningfulness of the low flow width and bed irregularity metrics is still questioned (see section 6.2.4.2).

If bed irregularity were scored by a different method (see section 6.2.5.1), the scores might reflect *irregularity* more accurately. Were that to happen, it is possible redundancy with the coarse fraction metric would become apparent. If so, bed irregularity, a less critical metric, might be removed from the level II protocol.

Through data analysis, redundancy for step metrics was also questioned. Some designs with steps seem to have been constructed under the adage “when in doubt, build it stout” and step particles are sized extra-large to ensure design stability. This is not a design problem, as long as step height is consistent with the natural channel. Penalizing steps for having larger particles and greater height seems redundant. It would make more sense to use particle size to evaluate design stability, and step height to evaluate aquatic organism passage and hydraulic effectiveness. If the step particle size metric evaluation was changed to a one-sided assessment, redundancy would be avoided. A one-sided assessment would only penalize steps with smaller particles. Steps are evaluated identically within the levels I and II protocols.

6.2.4.2 The "Short" Rubric

Although the level II low flow width and bed irregularity metrics appear to provide unique information about the stream channel, they do not seem to have a large effect on the group effectiveness evaluation. This is because the metrics are weighted very low in the overall scoring scheme. The low weights show these channel dimensions are relatively unimportant influences on geomorphic continuity through a crossing. Removing the wetted width and bed irregularity metrics did not change the effectiveness evaluation (similar, questionable, or dissimilar) for any groups at the 6 sites where "short" rubrics were evaluated.

Although biologically these physical channel characteristics may be important habitat components, should they be included in either physical effectiveness monitoring protocol? If low flow width and bed irregularity metrics were removed from the level II protocol, several hours of field work would be saved (not to mention the office time necessary to convert the raw measurements into metrics). Or, if just cross sections were measured, a low flow channel could be extracted from those plots; bed irregularity would still be measured. This option would save at least one hour of level II field work. As discussed under Objective 1, the method of assessing bed irregularity may not be meaningful.

6.2.5 Scoring Methods

6.2.5.1 Level II Scoring Methods

The level II summary rubric is scored based on exact (necessary for small sample sizes) p-values associated with the Wilcoxon Rank-Sum test results. A p-value is the probability of obtaining a test statistic (Wilcoxon *W*, or Mann-Whitney *U*) more extreme than that observed, given the null hypothesis is true (groups are similar). We compare this p-value to ranges of alpha values as a way to differentiate between scores. Several ranges, or scoring schemes, were tried (able 6 in section 4.1.2.2.3). For schemes where scores of 3 are difficult to obtain (3 = p-values between 0.01 and 0.05), groups are easily scored “poor” (1). This seems unnecessarily stringent. Schemes where scores of 5 are very difficult to achieve (5 = p-values ≥ 0.1) also seem unnecessarily stringent. The moderate scheme, where scores of 3 are easy to obtain, but scores of 5 and 1 are not (3 = p-values between 0.001 and 0.05), makes the most sense because this interval ensures groups are very different, or very similar, if they are to be evaluated as such. When the level II site results by each scoring scheme are compared, results by the moderate scheme are generally reasonable. At least, the more extreme schemes do not seem to agree better with site observations and data.

For statistical simplicity and a user-friendly application, only one statistical test was incorporated into the level II rubric. For some metrics (the coarse fraction, bank irregularity, and bed irregularity), the data median is not a statistic of interest, and the data were transformed to lend themselves better to the test. There are no known statistical consequences of these data manipulations, but there may be. Further, it is arguable that the ~D75 of the full gradation distribution is not an appropriate proxy of the D84. Instead of altering the data to fit the statistical test, it might be worth finding an alternative way to score the coarse fraction metric (see section 6.1.1.3).

The Wilcoxon Rank-Sum test is really an assessment of medians and may not detect other differences, like variance (Conover, 1998). Variance is the spread of any set of numbers. When thinking about irregularity, the spread of numbers represents the many sizes, or variety, of irregularity measures. And, in a way, *irregularity* can be defined by variety. Therefore, the characteristic of interest for bank and bed irregularity comparisons is not the median measure, but the similarity or difference in distribution shape. This is important, because for several sites, the Wilcoxon Rank-Sum p-values for bank and bed irregularity metrics are very high. When the boxplots are studied, the medians do appear very similar.

Yet the distributions, as shown by the histograms, are not similar and one group clearly shows greater variability or irregularity in the data. It seems we are not actually testing irregularity with the Wilcoxon Rank Sum Test.

A Kolgmorov-Smirnov (K-S) two-sample test (a.k.a. Smirnov Test) would be a better way to score the bank and bed irregularity metrics because it evaluates the equality of distributions (shape and variance). The test is nonparametric, but assumes the observations within each group are random, independent, and identically distributed. Measurements must be ordinal and continuous (for an exact test). Sample sizes do not need to be equal between groups, nor do they need to be large. The null hypothesis for a two sided test is that samples are drawn from the same distribution; the alternative hypothesis is that they are not. The test is sensitive to shifts in location and distributional shape. The K-S test uses the maximum vertical distance between empirical distribution functions to assess how similar they are (Conover, 1998).

The test statistic for a two sided test is the greatest vertical distance between the two empirical distribution functions $S_1(x)$ and $S_2(x)$, where $S_1(x)$ is based on the random samples of group X, and $S_2(x)$ is based on the random samples from group Y:

$$\boldsymbol{T_1 = sup_x|S_1(x) - S_2(x)|} \tag{9}$$

The test statistic for a one-sided test is given by T_1^+, which is equal to the greatest vertical distance achieved by $S_1(x)$ above $S_2(x)$:

$$\boldsymbol{T_1^+ = sup_x[S_1(x) - S_2(x)]} \tag{10}$$

The null hypothesis is rejected when the p-value is less than the α level of significance, or when the test statistic is greater than the critical value (Conover, 1998). The bed irregularity metric, however, might alternatively be measured by the “inclusive graphic standard deviation” and scored according to its classification scale. See section 6.1.1.3.

The level II summary rubric would be more robust if one could be sure a type II error (falsely accepting a null hypothesis) would not be committed. A type II error is more likely with smaller sample sizes. Type II errors are particularly problematic for level II physical effectiveness monitoring because falsely accepting the null hypothesis means the design channel is more favorably evaluated than it should be. Nothing is ever learned or improved when one is ignorant of their mistakes.

Calculating the necessary sample size to avoid committing a type II error can be done for each metric with a power test. Power is the probability of finding a difference (effect size) that does exist. Because data are nonparametric, two general distributions must be created which describe the design and natural channels for each metric. One could use the 14 sites where level II data were collected to create these general distributions. It seems likely however, that bank and bed irregularity varies by hydro-geomorphic region. For example, vegetated sandy banks might be less irregular than boulder and bedrock banks; platy sedimentary particles might create a less irregular bed than round metamorphic particles. It might be necessary to field test more sites with the level II protocol, specifically targeting hydro-geomorphic settings in order to create reasonable general distributions for each bed and bank type.

The next step in calculating the minimum necessary sample size is binning the generalized distributions to create relative frequency histograms (design and natural) for each metric. The two distributions, design versus natural, are then compared. To calculate the minimum required sample size for the Wilcoxon Rank-Sum test, the generalized medians are compared. To calculate the minimum required sample size for the K-S test, each bin is compared. One must subjectively decide on an appropriate effect size (i.e., how different should the distributions be, to be considered different?). After this decision has been made for each metric, the minimum necessary sample size can be calculated by specifying the desired power, the test, and the effect size.

6.2.5.2 LEVEL I SCORING METHODS

The level I summary rubric method of scoring compares the design median with the range of measured representative reach data. The method is transparent because data values are visible, making scores easy to interpret and simple mistakes easy to find. The level I method makes logical sense for scoring small sample sizes.

Assessing the validity of level I scores, however, requires greater critical thinking skills than assessing level II scores. Without the power of probability behind each score, the chance of misinterpretation is increased. One should have an understanding of measurement accuracy, the ability to identify erroneous data values, and keen field observation skills with which to later compare scores.

6.2.6 WEIGHTS

Weights are used within the levels I and II summary rubrics to ensure the channel dimensions most critical for maintaining geomorphic continuity have the most influence on the group effectiveness evaluation. This is accomplished by multiplying each metric score by its weight, then summing the scores to produce a total score. Levels I and II summary rubric weights are identical. The maximum weight is 1, the minimum weight is 0.25. The most heavily weighted metrics (weights = 1) are bankfull width at riffles and pools, the coarse fraction, residual pool depth at steps, and step height. The least weighted metrics (weights = 0.25) are wetted width and bed irregularity.

In general, the level II site results (section 5.2.1.2) show reasonable effectiveness evaluations. I interpret this to mean most metrics have been weighted appropriately; metrics influence the evaluation proportionately to the control they exert on channel form.

The weight for the step length metric is the exception. As it is now, step length is weighted 0.75. Step length is really a measure of the distance an organism needs to clear during an upstream jump. This metric is not very important geomorphically, and should therefore have the least influence on the evaluation. It is seems reasonable to decrease the weight to 0.25 for this metric. Relative to the other step metrics it would then carry the least weight.

6.2.7 SUMMARY OF RUBRIC UTILITY

The levels I and II summary rubrics have been designed to be utilized by physical scientists on National Forests throughout the US. Because the summary rubrics are simply Microsoft® Excel® workbooks, the rubrics are practical in that they are easily distributable and immediately familiar to most Forest Service employees.

The levels I and II protocols are particularly useful because one can follow each evaluation back to the metric scores for each group. This allows the evaluator to focus on problems within a particular area of the design. The individual metric scores offer clues as to which geomorphic processes have been affected by the crossing. In this way, the summary rubrics are transparent and evaluators can identify ways to improve each design for better effectiveness. Maintaining transparency, however, makes the protocol somewhat cumbersome to use because each group is analyzed separately. This is especially true for complicated channels with many slope sections and channel units/sequences. Thankfully, it is not likely that complicated channels are common designs (although simple designs may adjust to become more complicated).

6.2.8 SUMMARY OF THE LEVEL II RUBRIC PERFORMANCE

Overall, the level II protocol and summary rubric evaluations seemed to agree with collected data and critical qualitative assessments at each site. It proved easy to relate the rubric evaluation to design elements. Ways to improve the design (and perhaps one's skills) are made apparent because geomorphic processes can be related to physical channel dimensions at specific locations.

The "nuts and bolts" of the level II rubric (metrics, weights, and scoring methods) generally seem appropriate because they provided reasonable evaluations which agreed with site observations. The majority of metrics included captured the critical controls on channel form. It seems excluding the bed irregularity metric would save the most field time without losing much data.

The weights for pool and riffle channel units appear to appropriately affect the group effectiveness evaluations. The step length metric weight should be decreased from 0.75 to 0.25. The Wilcoxon Rank-Sum test of medians is an appropriate way to score most metrics. Bank and bed irregularity metrics, however, should be evaluated instead by a test of distributions (i.e., a K-S test).

Overrides were used for several groups at the eight level II evaluated sites, but were not applied in excessive amounts (which might have indicated the scoring scheme and weights are inappropriate). Overrides were especially employed to correct for small sample size and poor assessments of bed and bank irregularity (the Wilcoxon Rank-Sum test seems inappropriate). Using an override seemed to facilitate thinking critically about the effectiveness evaluations because justifications backed by data are required. Leaving the original rubric score and evaluation for each group, but listing the override evaluation within the override column, is the most honest, transparent way to display changes to the results. I recommend the final summary rubric includes instructions which describe this.

I believe the level II summary rubric was reasonably tested because it was applied to sites which represent a wide variety of design quality. Unfortunately, only two of the nine sites evaluated, and the eighteen sites visited, were considered stream simulation designs, a technique which is quickly becoming the national standard. Further, some of the sites I evaluated (Dog Slaughter, Big Lick) were not very appropriate subjects because they are undersized structures, with excessively long units. Were the protocol to undergo further field testing, visiting more high quality and complicated stream simulation sites, would help ensure it will also provide reasonable evaluations at the upper end of the quality spectrum.

It seems that where design groups are not obviously similar or dissimilar to the natural channel, they are evaluated as “questionable.” “Questionable” evaluations generally mean the design is “good” in a few areas, but “poor” or “fair” in several others. The meaning behind such an evaluation can be difficult to assess. A “questionable” evaluation requires thinking beyond the study reach. For instance, perhaps the design is well done, but the stream channel is going through an adjustment period because of land-use change upstream. Given a “questionable” evaluation, one should begin thinking of long-term changes which would indicate the design is affecting geomorphic processes and continuity through the structure. It should be made explicit within rubric instructions that these sites warrant long-term monitoring, perhaps biological monitoring, and further interpretation by skilled geomorphologists.

Several of the sites analyzed may not have been adequately evaluated because the channels need to adjust (or readjust) to the hydro-geomorphic setting. For example, design channels at WF01, WF02, and Site 3 in West Virginia seemed to still contain the substrate placed during construction. It would be interesting to re-visit WF01, WF02, and Site 3 in the future in order to truly assess how the design is performing. In Vermont, Sparks Brook had only recently (1 year prior to data collection) experienced hurricane Irene. It seems likely the channel had not yet been readjusted by moderate flows near bankfull stage. Similar to the West Virginia sites, returning to Sparks Brook after several years have passed might yield a better assessment of how the design affects the channel at design flows.

Results for steps were difficult to interpret because only one evaluated site had steps. The level II protocol and summary rubric could be improved by field testing and summarizing more step-pool channels. The Sparks Brook analysis brought up questions about weights and scoring methods for some of the step metrics. In particular, the step particle size should be assessed with a one-sided instead of two-sided evaluation, to avoid effectively penalizing design steps twice for excessive height. In addition, it seems more steps should be measured within the natural channel in order to better define the true range of natural step dimensions. Additional field testing might indicate if these, or other changes, would better evaluate designed steps.

Evaluating the level II summary rubric results against site data and photos (at 8 sites) suggested n = 10 provides meaningful test results, but this should really be determined statistically (See Discussion section 6.2.5.1). Results by samples with n < 10 were viewed as questionable in this study. For several sites, tests on metrics with small sample sizes gave suspiciously high p-values, which, when compared with data plots, were unreasonable. The concern is that users won't take sample size into account when reviewing their evaluation results. Or worse, they won't review the results. An explicit discussion of the potential for a type II error needs to be included in the level II rubric discussion.

It should be noted that for two metrics, systematic measurement error may have affected the conclusions drawn about the performance of the level II protocol. Where the very largest bed particles were not measured (because the sampling frame "avoided" these particles), the D84 may actually be larger than that measured. Also, the accuracy of channel width measurements by the laser distance meter (2012 field season only) is somewhat questionable at sites with heavily vegetated stream banks. It is possible the tool may have affected the level II metrics (width at bankfull, width at half bankfull, and bank irregularity), yielding erroneous site evaluations. Because evaluations generally seemed to agree with site observations and photographs, errors are not thought to be large. The impacts on interpretations and conclusions are probably minimal.

6.2.9 Summary of the Level I Rubric Performance

Nine sites were evaluated by the level I summary rubric. Eight of them were also evaluated by the level II rubric. The level II evaluation is considered a "standard" to which the level I results can be compared.

Because comparing the levels I and II evaluations is really the focus of Objective 3, those eight sites are discussed in section 6.3.2. The remaining level I site, Joe Smith Brook is discussed in section 6.2.2.1. It was discovered that levels I and II do not provide acceptably similar effectiveness evaluations. The differences are clearly related to sample size and data collection methods (discussed in depth in section 6.3). If the level I protocol is further developed and field tested, it can be altered to produce evaluations more similar to those by level II. At this time, therefore, it is premature to evaluate the performance of the level I rubric because it still needs significant development.

6.3 OBJECTIVE 3: EVALUATE, CAN LEVEL I BE USED AS A PROXY FOR LEVEL II? WHAT ARE THE LIMITATIONS OF LEVEL I?

Level I is likely to become the most commonly used physical effectiveness monitoring tool. Therefore, it is important to understand the capabilities of this simplified, less informative instrument. In this section, I test level I by comparing it with level II data and results: First, the Lower Stillwell levels I and II data are studied in depth. Next, the levels I and II metric scores comparison is discussed and patterns are identified. Patterns help to show how the level I protocol can be improved to become more similar to level II. Next, the reasons level I has provided more favorable evaluations at several sites are explored. And finally, the lessons learned about the level I protocol are summarized.

6.3.1 THE LOWER STILLWELL LEVELS I AND II SIMILARITY TESTS, DISCUSSION

Lower Stillwell was used as a test site, around which the levels I and II summary rubrics were built. Lower Stillwell was then studied in some detail to better understand the evaluation differences between the two protocols. When the assessment method (the summary rubric) was held constant, differences in data distributions became clear (Sections 4.2.1, 5.3.2, and 6.3.1.1). When distributions were compared with confidence intervals, factors causing differences between levels I and II data became clear (Sections 4.2.2, 5.3.3, and 6.3.1.2). One such reason, sample size, was further investigated using the Lower Stillwell level II data (Sections 4.2.3, 5.3.4, and 6.3.1.3).

6.3.1.1 ASSESSING LEVEL II LOWER STILLWELL DATA BY THE LEVEL I SUMMARY RUBRIC

If the level I protocol is to be used as a proxy for level II, the data should be similar. Theoretically, if two data populations are similar, they will provide the same answers when assessed by the same tool. The Lower Stillwell site was used to test for differences between the level I and II data. The level I summary rubric was chosen as the assessment tool because it is not possible to analyze level I data meaningfully by the level II rubric (statistical tests need larger sample sizes). Level II data were made more similar to level I data for this comparison. See section 4.2.1 for more information.

The results are conflicting; although groups by both protocols scored fairly high, all scores were above 50%. The rubric evaluations agree the structure riffle is “questionable,” but disagree on the inlet and outlet transition zones. The level II data within the inlet transition zone are evaluated as “similar,” while the level I data are “questionable.” The outlet transition zone riffle is evaluated as “questionable” with level II data, but “similar” with level I data. Interestingly, scores were not systematically higher by one protocol. See section 5.3.2, able 59 and able 60.

I concluded the data themselves are different between protocols. This study, however, did not show where, or how, the distributions differed. Further investigation was necessary.

6.3.1.2 ASSESSING THE LEVEL I DATA BY CONFIDENCE INTERVALS AROUND THE LEVEL II MEDIAN

To better understand how the level I and level II data differ for several metrics, I compared the level I Lower Stillwell medians with bootstrapped empirical confidence intervals built around the level II Lower Stillwell medians. Confidence intervals were calculated for the 90% (narrowest interval), 95%, and 99% (widest interval) confidence levels. Many level I medians did not fall within the 95% confidence interval around the level II median; some not even within the wider, 99% confidence interval (See Table 61, section 5.3.3). The worst agreement between levels I and II protocol data were for the metrics of bankfull width, low flow (wetted) width, and maximum particle size. Maximum depth data seemed to be similar between protocols. Several factors could be controlling for which metrics and why data differ:

- sampling technique,
- the degree of physical variability within the channel,
- changes in flow between collecting levels I and II data, and
- sample size.

These factors are discussed in more detail in the context of level II analyses at eight sites, including Lower Stillwell (section 6.3.2). Sample size was studied independently (section 6.3.1.3).

6.3.1.3 ASSESSING THE LEVEL I SAMPLE SIZE

The two previous studies on Lower Stillwell data suggest (for some metrics) the level I data distribution does not approximate the level II distribution well (Figure 50); protocol data provided different evaluations by the same tool, and the level I median is commonly not contained within a confidence interval around the level II median.

The sample size test results at Lower Stillwell show a sample of five is clearly inadequate for capturing the level II distribution (Figure 51 through Figure 54). In general, a sample size of nine had acceptable to excellent performance (< 5 cm difference between quartile values), especially within the representative reach. Luckily, n=9 is still fairly time efficient, an important quality for a protocol designed to be practical.

The n=9 subsample, however, did not capture the low flow width quartiles within the representative reach very well. For all subsamples of this metric (even n = 17), the quartiles of the “true” population were poorly approximated, suggesting chance plays a role in quartile values when a small sample of highly variable data is taken. Conversely, the depth metric is not very variable within Lower Stillwell riffles. For depth subsets of n = 5 through n = 17, the quartiles were well captured.

When the n = 9 subsample was evaluated by the level I summary rubric, the results produced were compared with those using the “full” level II data (able 62). The structure n=9 subsample lost points for the maximum depth metric because the median fell outside the 25th quartile of the representative reach. However, the difference between the n =9 median and the “true” depth median is only 2 cm, which is very hard to measure accurately in the field. In a real evaluation, one might override the depth metric. The level I results show the n=9 subsample performs well when compared with those using the full data set.

The level I rubric results for n = 50% of the full sample size were compared with the “true” (full level II distribution) results. The n = 50% results were identical to those for n = 9 in all zones. Without a marked improvement in performance, the larger sample size generated by the n = 50% criteria is not recommended (for time efficiency) over a sample size of 9.

6.3.2 LEVEL I SUMMARY RUBRIC SITE RESULTS, DISCUSSED IN THE CONTEXT OF LEVEL II RESULTS

The level I protocol is meant to be a simplified version of the level II protocol. Because level I sample sizes are small, scores are directly generated from the quartiles of the level I data. Therefore, simply assessing the level I results by looking at the level I data is not meaningful. Instead, the level I results are compared with level II results to assess the level I protocol and rubric performance. This method assumes the level II results are a truthful standard, which, after review of the level II site evaluations, generally seems reasonable for the metrics levels I and II have in common. Knowing that level I sample sizes and methodologies need to be adjusted (as shown by the studies of Lower Stillwell data), some differences between the level I and II evaluations are expected.

In the Objective 3 Results section (5.3.5), the level I summary rubric scores are compared directly with scores of those same metrics by the level II summary rubric. Where group scores differ, the levels I and II protocol data are consulted and described. Ultimately, these comparisons are summarized in Table 63. Patterns are identified and discussed within the Objective 3 Discussion section (6.3.3). Together with the Lower Stillwell studies, this information helps to make recommendations for improving the Level I protocol (see section 7, Table 64).

6.3.2.1 LOWER STILLWELL LEVEL I DISCUSSION

The level II evaluation of the Lower Stillwell site indicates several problems with the design. The banks within the inlet and outlet transition zones were not rebuilt at the natural channel bankfull width; they remain wider. The structure is also wider than the natural channel width and lacks banks at the half bankfull stage.

The level I evaluation seems to have generally captured these problems, which are reflected by metric scores. The riffle within the inlet transition zone lost points for both width metrics (too wide). The riffle within the structure also lost points for the width at bankfull stage (too wide) and bank continuity metrics (no banks).

The riffle within the outlet transition zone, however, lost points for the width at bankfull stage, not because it is too wide, but the level I data show the median width is too narrow. When one looks at level I and II boxplots side-by-side (Figure 233), it becomes apparent that a single measurement has pulled the level I median value below that of the representative reach. The Lower Stillwell width at bankfull stage example is why the level I sample size (n = 5) for widths and depths was originally questioned. Were more samples collected, the level I median value might be more similar to that measured by level II, and the level I evaluation would not evaluate the site more favorably than level II.

6.3.2.2 NORTH FORK INDIAN LEVEL I DISCUSSION

The level II North Fork Indian summary rubric indicates the road-stream crossing design is generally functioning “similarly” to the natural channel. After overrides (associated with small sample sizes and recent construction at the site) were applied, only two of the 6 groups were evaluated as “questionable.” The groups are the gentle gradient riffle near the structure inlet, (SR1), and the moderately steep riffle (SR2) towards the outlet.

Levels I and II group scores are generally similar, and total score differences between protocols are less than 10% for all groups, except one; the moderately steep riffle within the structure (SR2) scored 73% by level II, but only 55% by level I (after overrides). The large difference in SR2 group scores appears to be caused by a single metric. Level I scored the SR2 group poorly (1) for width at bankfull stage, while level II scored that metric highly (5). The difference in scores for this metric can likely be attributed to sample size. Level I also scored the coarse fraction poorly (1); it was not evaluated by level II (not long enough for a 200 sample pebble count). Other groups appear to have been evaluated by level I more cautiously than level II, as “questionable” instead of “similar.”

Unfortunately, the level I protocol did not evaluate the SR1 group. The unit was not recognized as an independent unit because it was perceived to be truncated by a break in gradient and therefore too short. Level II longitudinal profile analysis showed the break in gradient was not significant.

6.3.2.3 WF01LEVEL I DISCUSSION

The level II summary rubric evaluated most WF01 groups as “dissimilar” from the natural crossing. One group, the riffle within the inlet transition zone, was evaluated as “questionable.” Several overrides were issued (for bed irregularity, low flow width, and maximum depth) but none changed the evaluations. The level II evaluation indicated that there are many problems with the WF01 design: The entire design channel (all zones) appears to be less coarse than the representative reach, and it seems likely the original bed material placed during construction is still present within the structure and inlet transition zones. The inlet transition and structure are much narrower than the natural channel at bankfull stage. The structure lacks banks, and the channel bed is dry because water is flowing underneath the structure. The outlet transition zone is much wider than the natural channel at bankfull and low flow stages. It is also less coarse. Finally, the structure truncates a meander bend, creating scour along the right bank.

The Level I evaluation agrees with the level II evaluation: The inlet transition zone is “questionable,” the structure and outlet transition zones are “dissimilar.” In general, the level I evaluations and metric scores are similar to those by level II. For width at bankfull stage and bank irregularity, scores differ slightly, “good” (5) vs. “fair” (3). The agreement between protocols is encouraging, but should not be taken as evidence of real similarity between data and summary rubrics because, at the very poor end of the design spectrum, it isn’t necessary to make sensitive scoring distinctions.

6.3.2.4 WF02 LEVEL I DISCUSSION

The level II protocol summary rubric evaluated the inlet transition zone as “questionable,” the structure and outlet transition zones as “dissimilar.” Many problems with the design were identified: The inlet transition zone lacks constructed banks at bankfull and half bankfull stages. The bed is less coarse than the representative reach even though it is steeper. The design bed lacks “key pieces” for stability. The structure is much narrower at bankfull stage. Banks are absent and the substrate is less coarse than that found within the representative reach. Bank irregularity is non-existent. The inlet and structure are at risk of scouring over time. It seems likely the channel bed has yet to adjust and the bed particles observed were placed during construction. The outlet transition is much wider than the natural channel at bankfull and half bankfull stages because it lacks constructed banks. It may aggrade over time, especially if high stages of the West Fork Greenbrier deposit sediment within the WF02 outlet transition zone.

In general, the level I protocol evaluated WF02 similarly to the level II evaluation. The level I protocol rated all zones “dissimilar.” Metric scores are commonly the same between protocols. The level I protocol was more critical of the inlet transition zone than level II for the metrics of width at bankfull stage and bank irregularity. The agreement between protocols is encouraging, but should not be taken as evidence of real similarity between data and summary rubrics because, at the very poor end of the design spectrum, it isn’t necessary to make sensitive scoring distinctions.

6.3.2.5 SITE 3 LEVEL I DISCUSSION

The level II protocol evaluated the Site 3 structure and outlet transition zones as “dissimilar.” The inlet transition zone was not evaluated quantitatively because a representative reach was not selected. Qualitatively evaluated, the inlet transition zone lacks banks; it is wider than the natural channel at bankfull and half bankfull stages. The bed particles within the structure and outlet transition zones are much finer than the natural channel. The structure is slightly narrower than the width of the natural channel at the bankfull stage. The channel bed within the structure lacks “key pieces” and constructed banks. The outlet transition zone also lacks banks and is much wider at bankfull and half bankfull flows. Perhaps the greatest design issue is that the flow bypasses the structure, emerging downstream within the outlet transition zone.

In general, the level I protocol evaluated Site 3 similarly to level II. The level I protocol evaluated the inlet transition zone as “dissimilar,” the structure as “questionable,” and the outlet transition zone as “dissimilar.” Of some concern, the level I protocol has evaluated the structure more favorably than the level II protocol. The difference is likely the heavily weighted bankfull width metric; it scored 5 by level I, but 1 by level II. Although the level I sample size is small, there should be no width variability within a structure which lacks banks (the Lower Stillwell data studies indicated that more variable metrics need larger sample sizes). Therefore, the level I sample size should not have caused the score discrepancy between levels I and II. More likely, the selected representative reaches, or portions measured, are slightly different between levels I and II. This seems possible, given that Site 3 was re-visited in 2012 by Cenderelli and Weinhold for the purpose of collecting level I data. They believed they had selected the same representative reach as I had in 2011, but there is potential for error. The level I maximum particle size also scored bank irregularity more favorably than level II. Given the differences in measurement technique, variable scores between protocols are expected for this metric.

6.3.2.6 DOG SLAUGHTER LEVEL I DISCUSSION

The road-stream crossing at Dog Slaughter is basically a short riffle and extremely long pool which extends from the inlet transition zone to the bottom of the outlet transition zone. A constructed riffle backwaters the design pool. Assessing long, zone-spanning, channel units by the level II protocol is not meaningful because boundary conditions change inside of the structure. Further, separately measuring and comparing the head and tail of a pool does not make geomorphic sense. For these reasons, level II also tried to analyze the road-stream crossing at Dog Slaughter by population. Level I did not; the site was only analyzed by group. Realistically, neither analyzing by group nor by population is recommended at sites with long, zone-spanning pools. Qualitatively assessing a site like Dog Slaughter should be enough to identify design problems, as they are not minor. Level I group results are compared with those by level II only as a way of better understanding the level I protocol and summary rubric. Although analyzing by group is not appropriate at sites like Dog Slaughter, it is reasonable to compare levels I and II evaluations because data were collected at the same locations. At Dog Slaughter, the levels I and II representative reaches are the same.

The level II summary rubric (analyzed by group) evaluated the inlet transition zone riffle as “dissimilar,” the structure pool as “dissimilar,” and the pool within the outlet transition zone as “questionable.” The level II protocol (also analyzed by group) shows the inlet transition zone is narrower than the natural channel at bankfull, half bankfull, and low flow stages. The banks are more regular and the substrate is less coarse. The pool within the structure and outlet transition zones is excessively long. The portion within the structure is much narrower than the representative pool at bankfull, half bankfull, and low flow stages. Banks are absent within the structure, and the substrate is bedrock. The outlet transition zone lacks banks, the pool is too wide at the half bankfull and low flow stages, and bank margin diversity is low.

The constructed riffle located at the downstream outlet transition zone boundary, was evaluated as “questionable” by the level II protocol. The riffle is narrower than the steep riffle within the representative reach, and shallower. It is likely fine material was not included in the riffle particle mixture, causing the riffle to be more permeable than natural riffles in the adjacent channel. Flow travels through the riffle, rather than on its surface, decreasing the flow depth.

The level I protocol and summary rubric evaluated the riffle within the inlet transition zone as “questionable,” the structure pool as “dissimilar,” and the outlet transition zone pool as “questionable.” The protocol seems to have rated the inlet transition zone more favorably, based on the bankfull and low flow width metrics (both scored 5 by the level I protocol, and 1 by the level II protocol). The maximum depth metric also scored better; 3 by level I and 1 by level II. It seems likely the discrepancy in scores (and evaluations) can be attributed to the level I sample size. If more samples were collected, the level I distribution might be more similar to that measured during level II.

Level I metrics within the structure and outlet transition zones scored the same as those by level II. Given that differences in sampling methodology and sample size affect the level I scores, it seems probable that these zones scored the same as level II because the channel width is not variable within these zones.

The constructed riffle was evaluated as “questionable” by level I, and the percent total score is nearly equal that of level II. Metrics scores however are almost opposite of level II scores. I think sample size and methodology are partly responsible, as is precipitation between level I and II. Comparing level I and II scores for this group shows the percent total score and evaluation do not necessarily mean the level I and II data are similar.

6.3.2.7 BIG LICK LEVEL I DISCUSSION

The road-stream crossing at Big Lick is basically a short riffle and an extremely long pool which extends from the inlet transition through the outlet transition zone. Assessing long, zone-spanning, channel units by the level II protocol is not meaningful because boundary conditions change inside of the structure. Further, separately measuring and comparing just the head and tail of a pool does not geomorphically make sense. For these reasons, level II also tried to analyze the road-stream crossing at Big Lick by population. Level I did not; the site was only analyzed by group. Realistically, neither by group, nor by population is a recommended approach. Qualitatively assessing a site like Big Lick should be enough to identify design problems because they are major. Level I group results are compared with those by level II only as a way of better understanding the level I protocol and summary rubric. Scores should be directly comparable because data were collected at the same locations. At Big Lick, the level I and II representative reaches are the same.

The level II protocol evaluated the road-stream crossing at Big Lick “questionable” within the inlet transition zone and structure, and “similar” within the outlet transition zone. The level II evaluation showed the inlet transition zone is narrower than the representative reach at bankfull, half bankfull and wetted widths. It is coarser, yet less steep than the representative reach. The structure truncates a natural channel meander bend and forces a sharp bend at the structure inlet. Scour is evident along the right bank at the inlet and within the upper third of the structure. The pool within the structure is much narrower at bankfull width than that within the natural channel. Banks within the structure are absent, as is bank margin diversity. The maximum depth is similar to the pool within the representative reach. The same pool within the outlet transition zone is wider than the representative pool at bankfull, half bankfull and low flow stages. To summarize, the major problems at the Big Lick road-stream crossing design are the road-structure alignment, the narrow width of the structure, the lack of banks within the structure, and the extreme length of the pool unit.

The level I protocol results assessed the Big Lick site as “questionable” within the inlet transition zone riffle, “similar” within the inlet transition zone pool, “questionable” within the structure pool, and “similar” within the outlet transition zone pool. The metrics which differed most commonly between protocols are the width metrics (bankfull and low flow stages). Differences are likely related to sample size and measurement technique.

6.3.2.8 SPARKS BROOK LEVEL I DISCUSSION

Sparks Brook is a step pool channel. Three of the five evaluated groups are “similar” by the level II protocol. The riffle within the inlet transition zone and upper part of the structure are considered “similar” and the riffle within the lower part of the structure is evaluated as “questionable” (after overrides). The evaluated step within the structure is considered “similar” (after overrides), and the step at the structure outlet is “dissimilar.”

The level II protocol identified several ways the crossing design might be improved: the width through the inlet transition zone and structure could be increased. The step within the structure is slightly taller and constructed of larger material than those within the natural channel, but it seems to be hydraulically effective and stable. The step at the structure outlet however, is dissimilar to the representative step within the natural channel; it is taller, wider, shorter in length and larger in particle size. The scour pool below it is very shallow, indicating it may not be hydraulically effective. It might be improved by re-building it shorter.

The level I protocol and summary rubric scored many metrics differently from those scored by level II, although metrics generally scored positively or negatively by both protocols. Issues of sample size and sampling methodology are likely the cause of some differences. Another problem, particularly for comparing levels I and II SR1 evaluations, is that level I analyzed the level II riffle as two separate groups, the SR1 riffle and a pool run riffle, PR1. Therefore, when level I and II scores are matched for these units, only half the data are actually compared. The steep riffle (SR2) within the structure was not evaluated by level I because it was thought to be too short.

The step data and evaluation methods are identical between levels I and II. At the time of level II data collection, it was unclear which step metrics would be collected. After spending time at Sparks Brook, the step protocol was developed for level II. The level I data collected at steps were later used as part of the level II protocol. See section 6.2.4 for recommended improvements to the protocols for step metrics.

6.3.3 Protocol Levels I and II, Comparison of Evaluations: Summary of Patterns Found Across Sites

For each group where levels I and II metrics scored differently from one another, the levels I and II data were compared. 63 was created to summarize the comparisons in the hope that some patterns would emerge. Patterns might illuminate ways in which the level I protocol should be altered to produce results more similar to those by level II. Specific differences between metric scores are given by site within the objective 3 results section (5.3.5). Site by site results comparisons are discussed within section 6.3.2. Some of the issues described here were studied in-depth for the Lower Stillwell Site and are discussed in section 6.3.1.

able 63 shows only those metrics whose scores differed between levels I and II. The greater-than and less-than symbols indicate the relationship of level I data to level II data (by comparing medians). For example, a “>” symbol indicates the level I median data value for a particular metric and group is greater than that measured for the same level II metric and group. The relationship is described specifically for the design group, as well as the representative reach group, because data from both zones affect a metric’s score. The level I largest particles median is compared directly with the level II median of the coarse fraction. Bank irregularity is represented differently because it is qualitative by level I, but quantitative by level II. The “Y” symbols are described below within the bank irregularity discussion.

able 63 shows the bankfull width metric scores differently between levels I and II most often (it has the most occupied rows). This may reflect changes in measuring technique between levels I and II. Level II uses tapes fastened to stakes along the channel centerline at the bankfull stage. A laser distance meter is used to measure from the tapes to each bank. The tapes indicate both measurement station and the elevation at which to measure the width. In contrast, for each level I measurement, the evaluator measures up from the water surface to the bankfull elevation by holding a pocket rod at the water’s edge. With the other hand, a flexible measuring tape is extended to the bank at the bankfull elevation. A field partner extends their end of the measuring tape to the other bank. The tape is then adjusted if it does not seem to be level. Finally, the measurement is read. Error is more likely in this level I measurement because it is difficult to ensure the width is perpendicular to bankfull flow and the tape is level. It is easier to ensure the measurement is perpendicular to flow and at the correct elevation when taken by laser level (or rod) from an elevation indicator (tape) at the channel centerline.

There does not appear to be a pattern, however, in the direction of error (i.e., level I measurements are always greater than those by level II). Therefore, systematic differences in data collection are not occurring; instead, random errors are contributing to the problem. Nor is it clear that level II sites measured by the laser distance meter more frequently disagree with level I data than level II sites measured by the rod technique. Further testing the accuracy of the laser distance meter is, however, warranted (see section 6.1.1.2).

Differences between levels I and II bankfull width scores most probably have to do with sample size (n = 5 for level I versus n ≈ 10 for level II). When side-by-side Lower Stillwell boxplots of levels I and II bankfull widths (Figure 50 are examined, one can see that were more measurements collected by level I, the median value may have increased to become more similar to that measured by level II. The effect of sample size was studied with Lower Stillwell bankfull width, low flow width and maximum depth data. The results are presented in section 5.3.4 and discussed in section 6.3.1.3. It is probable that sample size has affected not only the level I width and depth scores at Lower Stillwell, but also the scores at many of the other evaluated sites as well.

Many of the width at low flow scores also differed between levels I and II. These differences are likely primarily because of sample size. It was observed with Lower Stillwell data that adequate sample size is particularly important for metrics with high variability, such as low flow (wetted) width.

Low flow width, as well as maximum depth scores may have been affected by precipitation events between levels I and II data collection. Should the stage have elevated or decreased, the levels I and II data would be affected. Precipitation occurred between levels I and II at Dog Slaughter, Big Lick and Sparks Brook. Stage was surely different at WF01, WF02, and Site 3 because the channels were dry during level II data collection (2011), but were flowing during level I data collection (2012) (these metrics, however, were not included in the level II scores).

Systematic differences between protocols are not observed for the low flow or maximum depth metrics. They would be apparent if all group inequality signs were pointing in the same direction (able 63).

The maximum particle size (level I) and coarse fraction (level II) metrics are directly compared. Clearly, the metrics are not capturing the same information, because every level I measurement is larger than its corresponding level II measurement (all inequality signs point to the right). Level I requires estimating the largest 9 to 11 particles per group and then measuring their b axes. The level II metric uses an adjustable vertices grid sampling frame to collect a pebble count. All particles greater than the D50 of the distribution are subsampled (termed the “coarse fraction”). The sampling frame rarely lands on particles larger than it (500 mm across), whereas the level I protocol targets these particles. able 63 and related data (section 5.3.5) show the median level I largest particle is consistently much larger than the median of the coarse fraction. Within the level II protocol, I suggest particle mobility is measured by the sampling frame method, while a separate (new) level II metric measures only the particles which are rarely, if ever, transported fluvially (key pieces). Altering the level II protocol in this way might make the levels I and II protocols more similar for this metric.

The bank irregularity metric commonly scores differently between levels I and II (it occupies many rows within able 63). When comparing results, however, the scores do not seem to systematically differ (i.e., level I always indicates irregularity is more similar than level II). For the level I protocol, the evaluator is asked to rate bank irregularity within a design group and compare it with the rated bank irregularity at the representative reach. Where the rating categories agree with one another, the group is scored highly. For the level II protocol, a distribution of the absolute values of the deviations from the median half width (at the half bankfull stage) is analyzed by statistical test. Here, the table simply compares the median irregularity measure within the design to that within the representative reach. Where “Y” is marked, either the representative reach was visually determined to be more irregular, or the representative reach median irregularity measure is greater than that within the design zone. Given the frequency of disagreements between levels I and II scores, perhaps the evaluation method for this metric should be altered. I believe the ocular assessment of bank irregularity is a better judge of bank margin diversity than simply comparing median deviation values (as tested by the Wilcoxon Rank-Sum). A statistical test which compares more than just median values, but instead compares entire distributions, might be a better assessment of irregularity. Were the level II method of scoring bank irregularity improved, levels I and II scores might agree better.

Finally, the Dog Slaughter constructed riffle group was evaluated similarly between levels I and II protocols, but all metrics between protocols scored differently. Clearly, the difference in the number of metrics evaluated by each protocol plays into the final group evaluation. Level I scored well for the metric weighted heaviest, while level II scored well for more of the lesser weighted metrics. The similarity of scores here must be thought of as a fluke.

In summary, the patterns found (or lack thereof) show the protocols and summary rubrics could be improved to become more similar to one another. The level I sample size for the width and depth metrics needs to be increased. Levels I and II gradation data should be collected in a more similar manner. Gradation metrics might be made more similar to one another if transects were used to sample the level I 11 largest stable particles. The level II protocol might measure particle mobility and stability separately, or simply specify measuring the largest stable particles during the pebble count, even if they do not land beneath the sampling frame. The level II coarse fraction metric needs to take small differences in gradient between the design and representative reaches into account when scoring. Instead of statistically testing for similar medians, the coarse fraction could be scored instead by similarity of phi classes. Also, if the level II bank irregularity metric were scored by a statistical comparison of entire *distributions*, the scores might better capture the irregularity of each bank, and agree with the level I ocular estimate.

6.3.4 Assessing, Does Level I Positively Skew Results?

The level I protocol is intended to be a simplified, less time intensive version of the level II protocol. It should therefore evaluate a site similarly to level II. If protocol results are not identical, at a minimum, level I should not skew effectiveness evaluations in the positive direction.

58 displays the levels I and II site evaluations side by side. Columns indicate where the level I group score is greater than that for level II and where the level I group evaluation is better than that by level II. For almost half of the groups compared, the level I group score is higher than that by level II. Given the discovered discrepancies between levels I and II data distributions, differences between scores are expected and understandable.

Only 4 of the 29 groups evaluated by levels I and II had level I evaluations more favorable (“positively skewed”) than those by level II The riffle within the outlet transition zone at Lower Stillwell is one of these groups. It scored 77% by level I “similar,” but only 69% “questionable” by level II. There were large differences between the level I and II measures of width at bankfull stage, maximum depth, and the largest particles; all metrics which proved problematic within the level I protocol because of sensitivity to sample size, and sampling methodology. The scores, however, are not that different from one another and, given the known issues with level I data, this group does not reveal any new issues. The level II evaluation seems more reasonable given the excess width and poor bank continuity at the outlet transition zone.

The riffle within the structure (SR1) at Site 3 was evaluated as 63%, “questionable,” by level I and 30%, “dissimilar” by level II. The large difference in total group scores seems odd. At the time level II data were collected, the Site 3 channel was dry, preventing the measurement of maximum depth and low flow width metrics. Therefore, there are only 6 level II metrics with which to assess the group, and all but one of them scored 1. Level I also has just 6 metrics within the protocol, but one of the most highly weighted metrics (bankfull width) scored 5, which was enough to drastically boost the total group score. The data show the level I design median is only 7 cm narrower than that measured during level II, and the median representative reach width is 70 cm narrower than that measured by level II. It seems the representative reaches (measured by myself in 2011, and Weinhold in 2012) are probably different. Bankfull stage may also have been estimated differently. To summarize the positive skew at this site, it can be attributed to measurement inconsistencies between protocols, perhaps sample size, and possibly different representative reaches. It's hard to say which evaluation is more accurate without revisiting the site to evaluate the bankfull width at the natural channel.

The riffle within the inlet transition zone at Dog Slaughter was scored 63%, "questionable" by level I, and only 36% "dissimilar" by level II. The metrics which scored differently are width at bankfull stage, wetted width, and maximum depth. Sample size is likely part of the evaluation discrepancy because for all of these metrics only 5 level I data points are collected. Differences between the levels I and II protocol maximum depths were very small, only 1 cm. The protocols would have scored this metric similarly if evaluated by the same method; this supports the need for increasing the level I sample size. When more samples are collected, the level I quartiles should be better defined and more similar to those calculated by level II. Data show the levels I and II bankfull and low flow width metrics have very similar values for the design channel, but very different values for the representative reach. Bank irregularity is larger within the representative reach than the design channel. Greater disagreement within the representative reach supports the idea that large sample size is most important when physical channel variability is high. Given the lack of constructed banks, and low bank irregularity, the level II evaluation of this group seems most reasonable.

The portion of the long pool within the inlet transition zone at Big Lick scored 84%, "similar," by level I, and 60%, "questionable," by level II. It is important to remember, that ordinarily, comparing only the head of a pool channel unit does not make sense, but in this case, we are simply interested in comparing sets of data. Since levels I and II data were both collected within this area, a comparison is reasonable. The bankfull and low flow width metrics scored differently, likely indicating sample size is part of the large score discrepancy problem. Bank irregularity also scored differently. The level I protocol shows the design group is less irregular than the representative reach. The level II protocol, however, scored the bank irregularity comparison high, meaning groups are similar, or the design is more irregular than the representative reach. When the bank irregularity histograms are inspected, however, the representative reach appears more irregular than the design. This highlights the need for altering how the irregularity metrics are scored (see section 6.2.5.1).

Given that so many of the metrics scored differently by levels I and II, it is surprising that half of the levels I and II total group scores *are* similar to one another. Metrics scored differently between levels I and II make sense given the results of the studies at the Lower Stillwell site (and other site results); the level I sample size is too small, differences in sampling methodologies affect data distributions, and scoring systems are not comparable for all metrics (bank irregularity) (discussed in more detail in section 6.3.1). For at least one group (the constructed riffle at Dog Slaughter), all metrics scored differently, but the groups were evaluated nearly equivalently between levels I and II (54% vs. 58%). Certainly, the proximity of group scores is not necessarily a real indication that the level I protocol and summary rubric is functioning similarly to level II.

In Summary, level I does not seem to positively skew results consistently, but given the shortcomings of the current level I protocol, it is really too soon to know. The level I protocol needs to first address the issues discovered by this study and undergo more field testing, after which the question of positive skew might be undertaken.

6.3.5 OBJECTIVE 3: SUMMARY OF FINDINGS

Studies on Lower Stillwell data showed the rubrics might provide different evaluations because levels I and II data distributions differ from one another. Differences can be attributed to data collection methodology, scoring technique, and sample size.

Differences between levels I and II scores were further explored when seven other sites were analyzed by the levels I and II protocols. The summary rubric evaluations were compared; the findings of the Lower Stillwell studies were supported by these site comparisons. Specifically, the levels I and II gradation metrics are not comparable; results consistently differ. If the level I data collection method and the level II scoring method were altered, levels I and II scores might become more similar. Site comparisons also show the level II method of scoring bank irregularity is not really assessing *irregularity*. Were the method changed to better assess irregularity (possibly by a K-S test), the levels I and II metric scores might become consistent. When all eight sites analyzed by levels I and II were compared, scores for the width at bankfull and low flow metrics frequently differed. As the Lower Stillwell study results indicate, increasing the sample size would help these scores agree. A level I sample size of 9 (for width and depth metrics) should provide data distributions more similar to those measured by level II. Adequate sample size is especially important for highly variable metrics like low flow width.

It should be noted that for four level II metrics, systematic measurement error may have affected the level II evaluations, thereby also affecting the levels I and II comparisons. The metrics are: the coarse fraction of the gradation, width at bankfull, width at half bankfull, and bank irregularity. Because evaluations generally seemed to agree with site observations and photographs, errors are not thought to be large. The impacts on interpretations and conclusions are therefore probably minimal.

Because of the problems listed here, drawing conclusions about using level I as a proxy for level II, or positively skewed results by level I, are premature. The level I protocol issues need to first be addressed. The protocol should undergo more field testing, after which level I protocol evaluations may be again compared with those by level II. The questions posed by Objective 3 might then be answered. Assessing the limitations of the level I protocol is an important subject for future study because it is expected that level I will be the most commonly used physical monitoring protocol at aquatic organism passage sites. Table 64 summarizes suggested improvements to the level I protocol and summary rubric.

7 SUMMARY AND CONCLUSIONS

Monitoring is critical to ensuring restoration methods are effective and improving. The restoration of aquatic organism passage at road-stream crossings is a common practice on US National Forests, and one to which significant resources are dedicated. The main goal of this research was to develop the physical effectiveness monitoring protocols initially drafted by the Forest Service (and others) through field testing at selected sites. The products are two separate, improved protocols (one more detailed than the other) and two corresponding summary tools ("rubrics") which provide effectiveness evaluations (Appendices **B**, **C**, and E [Level II Draft Field Protocol, Level I Draft Field Protocol, and Summary Rubrics]). Although the protocols are not yet finalized, the practicalities of implementation and specifics of data analysis are much better understood. Once finalized, the protocols can be distributed throughout the Forest Service for use at aquatic organism passage restoration sites across the US.

Developing the draft physical effectiveness monitoring protocols was accomplished by addressing three identified objectives: 1) field test the levels I and II draft protocols and make recommendations to improve them, 2) separately, for each protocol, find a meaningful way to combine the metric data into effectiveness evaluations, and 3) evaluate whether level I can be used as a proxy for the more detailed level II protocol (and in doing so, evaluate the limitations of the level I protocol).

My three objectives were addressed by field testing the levels I and II physical effectiveness monitoring protocols during 2011 and 2012 at eighteen sites, on six National Forests across the US. Specifically, the level II protocol was field tested at fourteen sites while the level I protocol was tested at sixteen sites (objective 1). One site, Lower Stillwell, was used to develop the levels I and II summary rubrics (two other sites, not part of this study, also helped to develop the protocols). Twelve of the eighteen sites were then used to test the levels I and II summary rubrics (objective 2). By comparing the levels I and II analysis results at eight of those sites, along with more detailed studies of Lower Stillwell data, objective 3 was addressed.

The three objectives are inter-related, whereby together the insights gleaned from each have resulted in suggested improvements to the levels I and II protocols and summary rubrics. Further, the results of the first two objectives allowed me to address the third. Within the body of the thesis, I addressed the results of each objective separately, sometimes resulting in redundancy. Here, I summarize the results regardless of objective.

Field work and subsequent analysis identified several issues with the levels I and II protocols. In general, problems can be categorized by data collection methodology, scoring procedure, and sample size. Many improvements to data collection methods were discovered while in the field and through data analysis; they are summarized (along with other suggestions) within Table 64, Table 65, and 66 below.

For most level II metrics, the method of scoring within the summary rubric seems to be appropriate. There are, however, some exceptions. The coarse fraction of the gradation is affected by channel gradient. Where a design riffle and representative riffle have slightly different slopes, it may not be reasonable to expect the D84 to be exactly the same. Were this method scored by a measure other than the Wilcoxon Rank-Sum test, the gradient problem, as well as any statistical bias created by subsampling all particles larger than the D50, might be avoided. An alternative method might compare the modes for the design and representative reach particle size distributions (in phi units) by using intervals to generate scores.

The level II metrics of bank and bed irregularity are currently also evaluated by the Wilcoxon Rank-Sum test of medians. Data at many of the level II evaluated sites show similar medians between design and representative reach groups, but very different variability (a measure of irregularity). A Kolgmorov-Smirnov (K-S) test of distributions (shape and variance) would be a more appropriate test for similarity in irregularity. If a K-S test were employed, the calculated p-values could be scored by the existing criteria.

Within the summary rubric tools, weights (identical for levels I and II) are applied to each score. Summary rubric results confirmed most metric weights are reasonable. They seem to reflect the control each metric exerts on geomorphic processes. For one of the metrics associated with steps however, the weight should be slightly adjusted.

Sample size is certainly the greatest problem for both protocols. Addressing the problem will require further revision of both levels I and II. The issue was demonstrated by level I when study results showed a sample size of five (specified by the draft protocol for width and depth metrics) is clearly too small to accurately mimic the more detailed (larger sample) level II data distributions. Further study indicated a level I sample size of nine both acceptably mimics the level II data distribution and is still time efficient. The level I protocol with an increased sample size should be field tested further to ensure it is a meaningful simplification of the level II protocol.

The draft level II protocol specifies setting the sampling interval for width and depth metrics by zone (either the representative reach or the structure, whichever is shorter). Yet, the summary rubric evolved to analyze by group (a zone, channel unit or sequence, and slope segment combination). Analyzing by group seems to be the most appropriate method because different metrics are collected for each channel unit type. Also, hydraulics vary by channel unit, gradient, and zone. For a meaningful comparison between the design and natural channels, these variables must not be combined unless consistently done so for both compared zones.

As a result of analyzing designs by group however, the level II samples at complicated sites (many slope segments and channel units) are sometimes smaller than necessary for an accurate statistical test. When sample sizes are too small, the test cannot reject the null hypothesis that groups are similar and the summary rubric erroneously provides favorable scores (a type II error). Where my sites have small samples, I ignored the statistical test results and evaluated the data independently.

The minimum sample size for each level II metric could be calculated by studying the distributions of each metric, specifying an appropriate “effect” size, power, and statistical test. If the minimum sampling interval (to maintain observation independence) was also specified, the minimum channel unit length could be determined. Only channel units of adequate length would then be sampled. A separate qualitative protocol, or level I assessment, might be used to assess shorter channel units.

The levels I and II protocols and summary rubrics have been designed to be utilized by physical scientists on National Forests throughout the US. The physical protocols do not require complicated equipment, and the summary rubrics are basically Microsoft® Excel® workbooks, which should be easily distributable and immediately familiar to most Forest Service employees. The summary rubrics are particularly useful because one can see how each metric score, for every area of the design, affects the evaluation. This allows an evaluator to focus on specific design problems and geomorphic processes interrupted by the crossing.

The 2013 levels I and II protocols (the results of this research) are, however, still works in progress. Given the issues summarized in the preceding paragraphs, the protocols should be further revised. Because the 2013 protocols need significant adjustment, it is premature to definitively answer the questions posed by objective 3. I can say that, as is, the level I protocol is not a proxy for level II because it is limited by an insufficient sample size. Also, the level II protocol is not yet the ultimate standard; after the issues of sample size and scoring are resolved, comparisons between the levels I and II results will be more appropriate.

After revision, the levels I and II protocols should be field tested again. Sites visited should be of various quality, but especially at well-designed stream simulations (lacking in this study). Future sites should incorporate more step-pool channels; the 2013 protocol at steps was poorly tested because few step-pool channels were visited, and fewer evaluated. The protocols should be tested at sand bed channels to demonstrate protocol applicability and discover any field methodologies which might need to be adjusted for a mobile bed.

If level I becomes a good proxy for level II, it might be utilized exclusively because it is more time efficient. Without the statistical power offered by level II, however, results from level I remain questionable. Ultimately, levels I and II might morph into a single protocol (level 1.5), especially if the statistically significant level II sample sizes are found to be close to nine (the maximum allowable within the level I protocol).

Level 1.5 might specify surveying a longitudinal profile in which only grade controls for field identified slope segments are collected. Feasibly, only slope segments with similar units to those within the design channel would be surveyed. Ideally, the profile data would require no more than half a day to collect. The most geomorphically important level II metrics would be measured, but perhaps only at the channel units long enough to be statistically tested. The sampling interval (for each metric) would be determined by the shortest statistically significant channel unit. At units too short to be statistically tested, level 1.5 might specify a qualitative protocol, or semi-quantitative method similar to the 2013 level I protocol. For very complicated design zones (many slope segments and many short channel units), level 1.5 might simply measure the most critical metrics (e.g., bankfull channel width within the structure relative to that in the natural channel and the largest particles which compose the design grade controls).

The 2011 level II and 2012 level I draft field protocols have been significantly improved through field testing by this research project. I have identified shortcomings and avenues for improvement which should guide future protocol development. In addition, meaningful and transparent summary evaluation tools were developed for both the levels I and II protocols. These tools should enable practitioners to learn from past mistakes, improving the effectiveness of future AOP restoration efforts at road-stream crossings.

TABLE 64: RECOMMENDATIONS FOR IMPROVING THE *LEVEL I* PROTOCOL AND SUMMARY RUBRIC

Level I
Increase the sample size from 5 to 9 for the metrics of bankfull width, low flow width and maximum depth
Give clear directions for defining level I channel units, sequences, and slope segments. They should be defined (and assessed) similarly to level II.
Consider changing the way the level I width and depth metrics are stationed: by ocular estimate, identify the 25th, 50th, 75th, minimum and maximum widths. Take width and depth measurements at those locations.
Consider changing the way the level I widths at bankfull stage are measured: Pound stakes at the left and right edges of water, oriented perpendicular to flow. Measure up from the water surface and mark the bankfull elevation on the stakes with flagging. Measure the width at this elevation across the channel.
Consider eliminating the low flow (wetted) width metric.
Consider changing the way the level I largest particles metric is measured to become more similar to level II, and more accurate: Set up 9 – 11 evenly spaced transects perpendicular to flow along the channel unit. Measure the largest particle within each transect.
Consider identifying slope segments with a survey level and rod. Survey only the most prominent grade controls for the entire study reach. Quantitatively analyze the slope segments to combine them (according to the level II method). Quantitatively select a representative reach. Compare channel units, or channel unit sequences per slope segment and design zone.
Describe within the level I instructions that "questionable" evaluations might indicate the need for level II monitoring.

TABLE 65: RECOMMENDATIONS FOR IMPROVING THE *LEVEL II* PROTOCOL AND SUMMARY RUBRIC

Level II
Consider suggesting (within protocol instructions) a solar powered battery charging system for remote sites.
Further test the accuracy/applicability of the laser distance meter.
Use the Kolmogorov-Smirnov test to score bank and bed irregularity metrics.
Consider eliminating the bed irregularity and low flow width metrics.
Consider using many cross sections to assess width at bankfull, half bankfull and low flow stages, as well as maximum depth. They could also be used for hydrologic modeling and at-a-station hydraulic geometry.
Emphasize limiting the vertical exaggeration for longitudinal profile analysis within instructions.
Include instructions for delineating slope segments by “drawing” lines on the longitudinal profile.
Encourage evaluators to enter field notes into spreadsheets with survey point data (facilitates analysis).
Consider using a more stringent gradient criterion for steeper channels, e.g., ± 10%.
Select a representative reach for each slope segment *within the design channel*.
Statistically determine the minimum necessary sample size (power calculation) for each metric and each test employed. Given a minimum meaningful sampling interval, ignore shorter channel units.
Consider an alternative method of scoring the coarse fraction metric; scoring intervals built around the particle size (in phi units) distribution instead of the Wilcoxon Rank-Sum test might be more lenient, given slight differences in gradient between the design and representative reach slope segments.
Ensure the largest particles are measured during the pebble count, even if they do not fall beneath the sampling frame.
Describe within the instructions that a “questionable” evaluation might indicate the need for long-term and/or biological monitoring.
Ensure an explicit discussion of sample size and the potential for type II error is included within protocol instructions. It should instruct evaluators to ignore p-values when sample sizes are small and instead rely on data and observations to validate scores.
Consider an alternative field method for assessing bed irregularity, e.g. Folk’s inclusive graphic standard deviation.

TABLE 66: RECOMMENDATIONS FOR IMPROVING *BOTH THE LEVELS* **I** *AND* **II** PROTOCOLS AND SUMMARY RUBRICS

Both Levels I and II
Describe what to do if precipitation occurs between collecting measurements at the design and representative channels.
Set minimum sampling intervals for each metric to maintain independent samples (a statistical assumption).
Discuss measurement accuracy within the finalized levels I and II protocol instructions.
Record channel units and slope segments for each metric collected.
Field test the protocols at more step pool channels.
Consider field testing the protocols at mobile-bed channels.
Consider measuring more steps (all?) within the representative reach. Clearly state which steps should be measured within the design channel.
Consider specifying photographs of analyzed design steps to help verify step geometry.
Within the protocol instructions, discuss circumstances where the protocols are not applicable or where over-arching factors exist which may influence effectiveness interpretations (e.g., zone spanning pools, short channel units, basin setting, large wood loads, and recent very large floods).
Within the protocol directions, specifically address what might be different for sand-bed channels (e.g., stable grade controls).
Consider decreasing the step length metric weight from 0.75 to 0.25.
Consider using a one-sided assessment to score design steps with larger particles than those within the representative reach (larger is acceptable). This effectively avoids penalizing step height twice.
Give clear direction regarding the use of overrides. Evaluators should leave the original scores visible, but indicate which metric was overridden, why it was overridden, and how the scores changed.
Consider exploring an alternative way to capture channel width when obstructions to the measurement are present.
Consider assessing bank irregularity by zone as opposed to group (similar to the bank continuity metric).
The method by which the levels I and II protocols compare channel units (or channel unit sequences) between the design and representative reach should be equivalent, as should the rules by which slope segments and channel units are defined.

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9 APPENDICES

A SITE DATA

A1 BAYS CREEK SITE DATA

A1.1 BAYS CREEK PHOTOS


08/06/2012 18:52

FIGURE 55: LOOKING AT THE BAYS CREEK INLET TRANSITION ZONE FROM THE TOP OF THE STRUCTURE

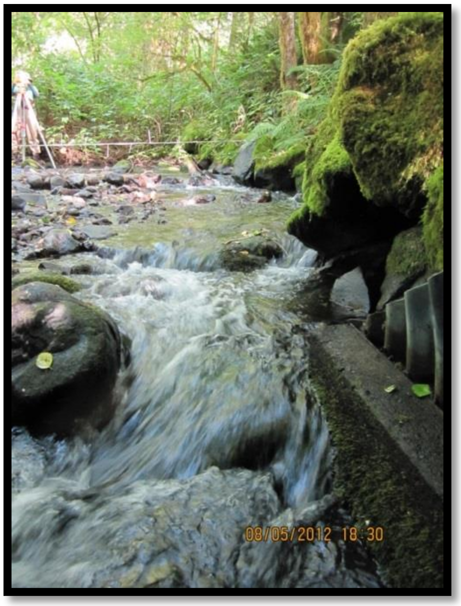
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FIGURE 56: STEEP CASCADE AT THE BAYS CREEK STRUCTURE INLET

FIGURE 57: BAYS CREEK INLET

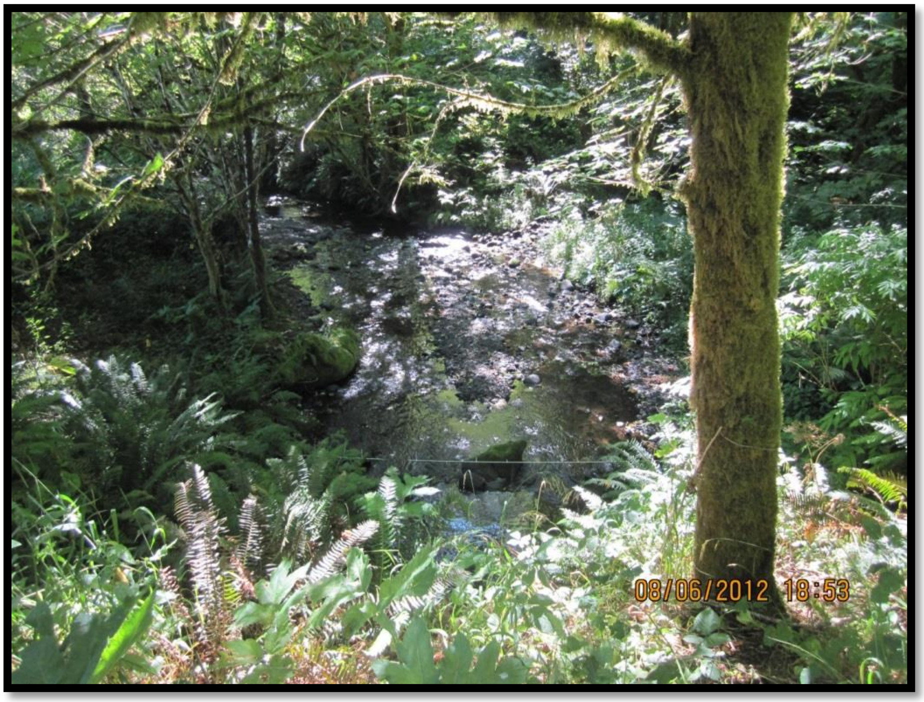

FIGURE 58: LOOKING DOWNSTREAM, FROM THE TOP OF THE STRUCTURE, AT THE BAYS CREEK OUTLET TRANSITION ZONE

FIGURE 59: BAYS CREEK OUTLET TRANSITION ZONE

FIGURE 60: THE DOWNSTREAM BOUNDARY FOR THE OUTLET TRANSITION ZONE AT BAYS CREEK. TRIBUTARY CONFLUENCE AT THE RIGHT BANK. STRUCTURE OUTLET VISIBLE UPSTREAM.

FIGURE 61: LOOKING DOWNSTREAM THROUGH THE BAYS CREEK STRUCTURE

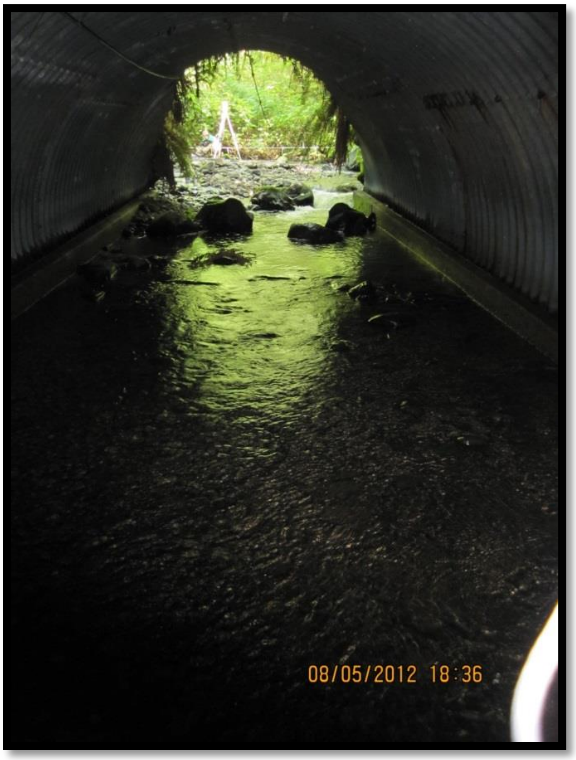

FIGURE 62: LOOKING UPSTREAM AT THE BAYS CREEK GENTLE GRADIENT RIFFLE WITHIN THE STRUCTURE (NO REPRESENTATIVE REACH WAS FOUND FOR THIS GROUP

FIGURE 63: TYPICAL RIFFLE IN THE NATURAL CHANNEL (UPSTREAM OF THE BAYS CREEK STRUCTURE)

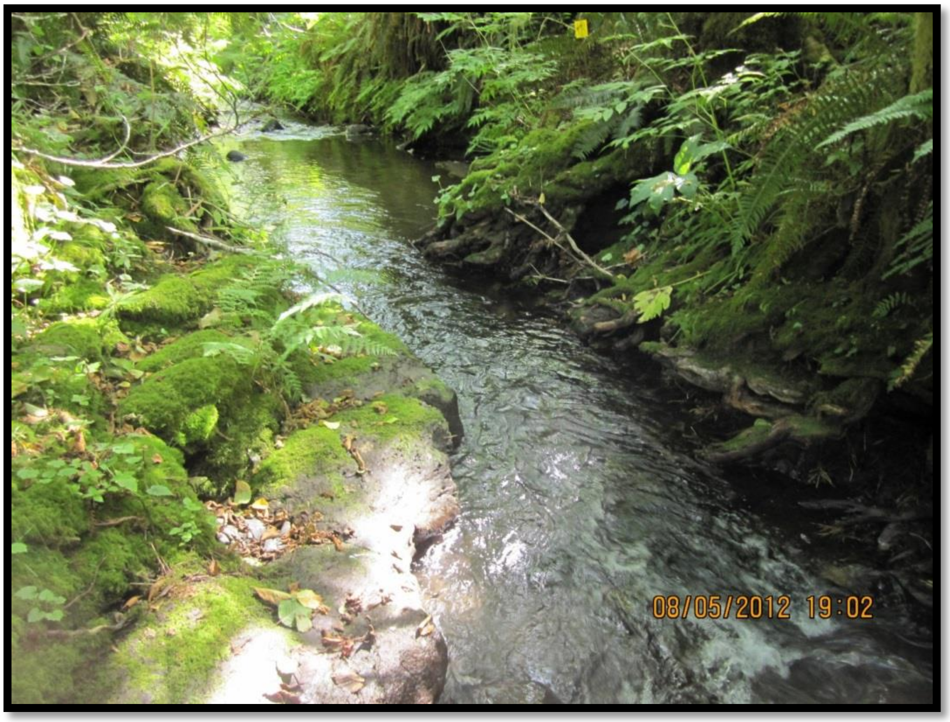

FIGURE 64: TYPICAL NATURAL CHANNEL UPSTREAM OF THE BAYS CREEK STRUCTURE (CHUTE-POOL-CHUTE IN BEDROCK)

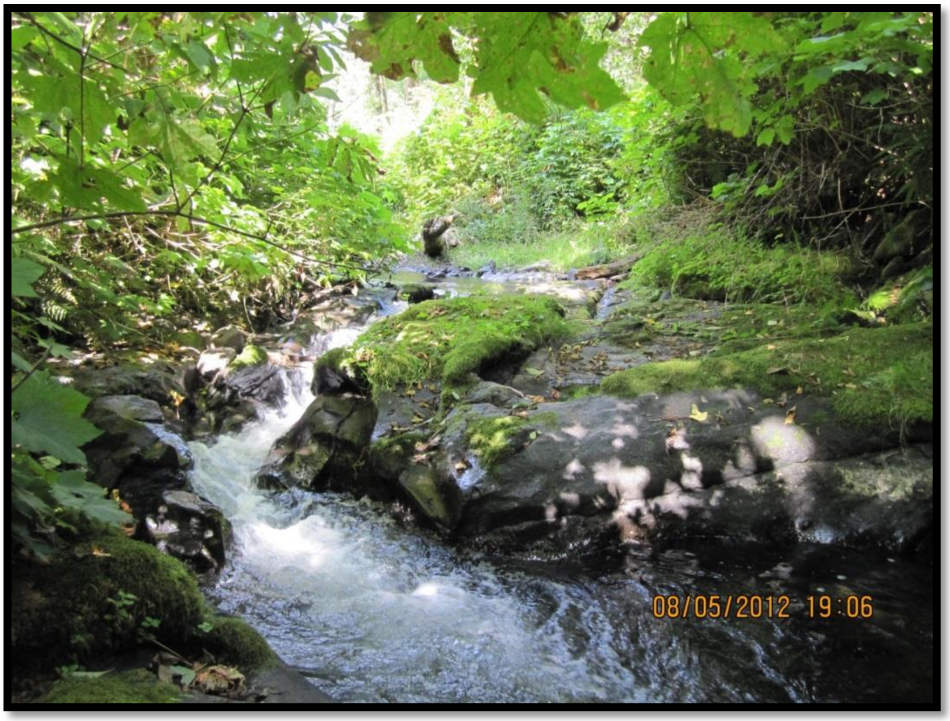

FIGURE 65: BAYS CREEK NATURAL CHANNEL BEDROCK CHUTE

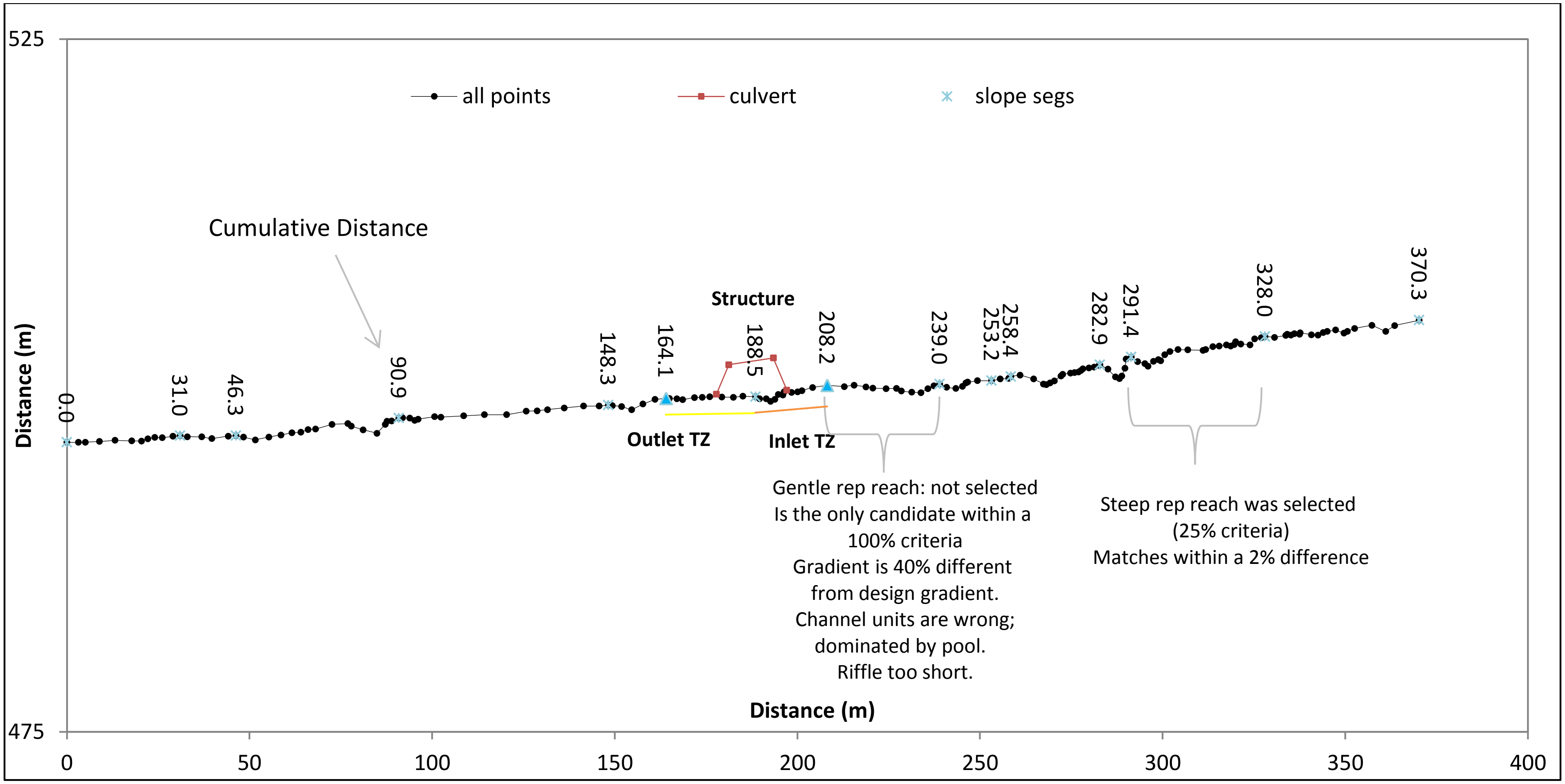

FIGURE 66: BAYS CREEK LONGITUDINAL PROFILE

THE STRUCTURE AT BAYS CREEK IS AN OPEN BOTTOM PIPE ARCH WITH LENGTH 18.3 M, HEIGHT 2.1 M, AND SPAN 3.6 M. AT BAYS CREEK, TWO SLOPE SEGMENTS WITH GRADIENTS 0.5% (YELLOW LINE) AND 4.1% (ORANGE LINE) COMPOSE THE DESIGN CHANNEL. THE INLET AND OUTLET TRANSITION ZONES ARE MARKED BY BLUE TRIANGLES. CHANNEL UNITS ARE A STEEP RIFFLE AND CASCADE WITHIN THE INLET TRANSITION ZONE, A POOL AND GENTLE RIFFLE WITHIN THE STRUCTURE, AND A GENTLE RIFFLE WITHIN THE OUTLET TRANSITION ZONE. A REPRESENTATIVE REACH WAS IDENTIFIED FOR THE STEEPER SLOPE SEGMENT; NO REPRESENTATIVE REACH WAS IDENTIFIED FOR THE GENTLE GRADIENT DESIGN SLOPE. THE MOST SIMILAR SLOPE SEGMENT IS ANNOTATED ON THE PLOT ABOVE. THE PROFILE ABOVE HAS A 4X VERTICAL EXAGGERATION.

TABLE 67: BAYS CREEK GENTLE DESIGN SLOPE SEGMENT DATA

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn successive slope segments	% diff. between Sdc and Snc	% diff. between Ldc and Lnc	Notes
480.34	467.88	164.07	499.07								crest of steep riffle section at end of outlet transition
493.25	488.19	188.52	499.20	24.06	0.12	24.45	0.01	#DIV/0!			riffle-run crest

TABLE 68: BAYS CREEK STEEP DESIGN SLOPE SEGMENT DATA

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn successive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Notes
493.25	488.19	188.52	499.20	15.38	0.82	19.67	0.04				riffle-run crest
504.00	499.18	208.19	500.01								riffle CL
					riffle cascade Length (m)	19.67					25% criteria

TABLE 69: BAYS CREEK REPRESENTATIVE REACH ANALYSIS FOR THE GENTLE DESIGN SLOPE SEGMENT

N (m)	E (m)	Cumu-lative Distance (m)	Elev (m)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Notes
344.84	417.26	0.00	495.90	0.00	495.90	0.00	#DIV/0!		#REF!	100.00	begin very steep riffle; rib; lg cob; M stability
369.29	433.44	31.02	496.38	29.32	0.48	31.02	0.02	#DIV/0!	-202.95	-26.87	PTC; begin steep riffle
379.05	444.57	46.30	496.38	14.81	0.00	15.27	0.00	-100.99	102.99	37.53	PTC?
415.16	463.33	90.91	497.65	40.69	1.28	44.62	0.03	-18928.90	-463.55	-82.47	riffle steepens through wood jam
468.93	458.95	148.26	498.59	53.95	0.93	57.35	0.02	-43.39	-219.04	-134.54	rib in riffle
480.34	467.88	164.07	499.07	14.49	0.49	15.81	0.03	89.37	-504.17	35.34	crest of steep riffle section at end of outlet transition

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn successive slope segments	% diff. between Sdc and Snc	% diff. between Ldc and Lnc	Notes
493.25	488.19	188.52	499.20	24.06	0.12	24.45	0.01	-83.45	0.00	0.00	riffle-run crest
504.00	499.18	208.19	500.01	15.38	0.82	19.67	0.04	718.19	-718.19	19.56	riffle CL
533.72	493.22	238.98	500.11	30.31	0.09	30.79	0.00	-92.67	40.01	-25.92	PTC/RC, CL, High stability not selected; gentle gradient reach dominated by pool; riffle too short.
547.57	491.64	253.20	500.35	13.94	0.24	14.21	0.02	459.25	-235.49	41.86	RC of riffle-run
552.76	491.33	258.42	500.65	5.20	0.30	5.23	0.06	231.96	-1013.71	78.62	step crest at end of steep riffle
576.29	494.91	282.85	501.50	23.79	0.85	24.43	0.03	-38.68	-582.94	0.08	RC of steep riffle, cob-bldr; bedrock LB and RB
584.34	497.48	291.42	502.05	8.45	0.56	8.57	0.06	86.66	-1174.76	64.96	US crest of bedrock step
614.74	512.60	328.04	503.54	33.96	1.49	36.62	0.04	-37.16	-701.04	-49.77	
645.29	536.12	370.27	504.72	38.55	1.17	42.22	0.03	-31.81	-446.20	-72.68	crest of steep riffle; c grav-sm cob; bar deposit LB

TABLE 70: BAYS CREEK REPRESENTATIVE REACH ANALYSIS FOR THE STEEP DESIGN SLOPE SEGMENT

N (m)	E (m)	Cumu-lative Distance (m)	Elev (m)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Notes	Notes
344.84	417.26	0.00	495.90	0.00	495.90	0.00	#DIV/0!		#DIV/0!	100.00	begin very steep riffle; rib; lg cob; M stability	
369.29	433.44	31.02	496.38	29.32	0.48	31.02	0.02	#DIV/0!	62.97	-57.71	PTC; begin steep riffle	
379.05	444.57	46.30	496.38	14.81	0.00	15.27	0.00	-100.99	100.37	22.34	PTC?	
415.16	463.33	90.91	497.65	40.69	1.28	44.62	0.03	-18928.90	31.12	-126.82	riffle steepens through wood jam	not selected; downstream of tributary
468.93	458.95	148.26	498.59	53.95	0.93	57.35	0.02	-43.39	61.01	-191.57	rib in riffle	
480.34	467.88	164.07	499.07	14.49	0.49	15.81	0.03	89.37	26.16	19.62	crest of steep riffle section at end of outlet transition	not selected; downstream of tributary
493.25	488.19	188.52	499.20	24.06	0.12	24.45	0.01	-83.45	87.78	-24.31	riffle-run crest	
504.00	499.18	208.19	500.01	15.38	0.82	19.67	0.04	718.19	0.00	0.00	riffle CL	
533.72	493.22	238.98	500.11	30.31	0.09	30.79	0.00	-92.67	92.67	-56.53	PTC/RC, CL, High stability	

N (m)	E (m)	Cumu-lative Distance (m)	Elev (m)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn successive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Notes
547.57	491.64	253.20	500.35	13.94	0.24	14.21	0.02	459.25	59.00	27.73	RC of riffle-run
552.76	491.33	258.42	500.65	5.20	0.30	5.23	0.06	231.96	-36.12	73.42	step crest at end of steep riffle
576.29	494.91	282.85	501.50	23.79	0.85	24.43	0.03	-38.68	16.53	-24.21	RC of steep riffle, cob-bldr; bedrock LB and RB
584.34	497.48	291.42	502.05	8.45	0.56	8.57	0.06	86.66	-55.80	56.44	US crest of bedrock step
614.74	512.60	328.04	503.54	33.96	1.49	36.62	0.04	-37.16	2.10	-86.18	Selected for steep rep reach; units match, but length is much longer than design; steep riffle into bedrock chute and cascade
645.29	536.12	370.27	504.72	38.55	1.17	42.22	0.03	-31.81	33.24	-114.66	crest of steep riffle; c grav-sm cob; bar deposit LB

A2 BIG LICK SITE DATA

A2.1 BIG LICK PHOTOS

FIGURE 67: LOOKING DOWNSTREAM AT THE BIG LICK INLET TRANSITION ZONE RIFFLE (PORTION MEASURED IS IN THE DISTANCE)

FIGURE 68: LOOKING DOWNSTREAM AT THE BIG LICK STRUCTURE INLET

FIGURE 69: LOOKING DOWNSTREAM WITHIN THE BIG LICK STRUCTURE

FIGURE 70: WITHIN THE BIG LICK STRUCTURE, LOOKING DOWNSTREAM AT THE OUTLET TRANSITION ZONE

FIGURE 71: LOOKING DOWNSTREAM AT THE CONTINUATION OF THE BIG LICK DESIGN POOL. THE OUTLET TRANSITION ZONE WAS TRUNCATED AT THE SUBMERGED LOG IN THE FOREGROUND.

Figure 72: Looking downstream at the Big Lick representative riffle reach (RRR1)

Figure 73: Looking downstream from the top of the Big Lick representative pool reach (RRP1)

FIGURE 74: STANDING WITHIN THE BIG LICK REPRESENTATIVE POOL REACH (RRP1), LOOKING DOWNSTREAM

A2.2 Big Lick Representative Reach Analysis

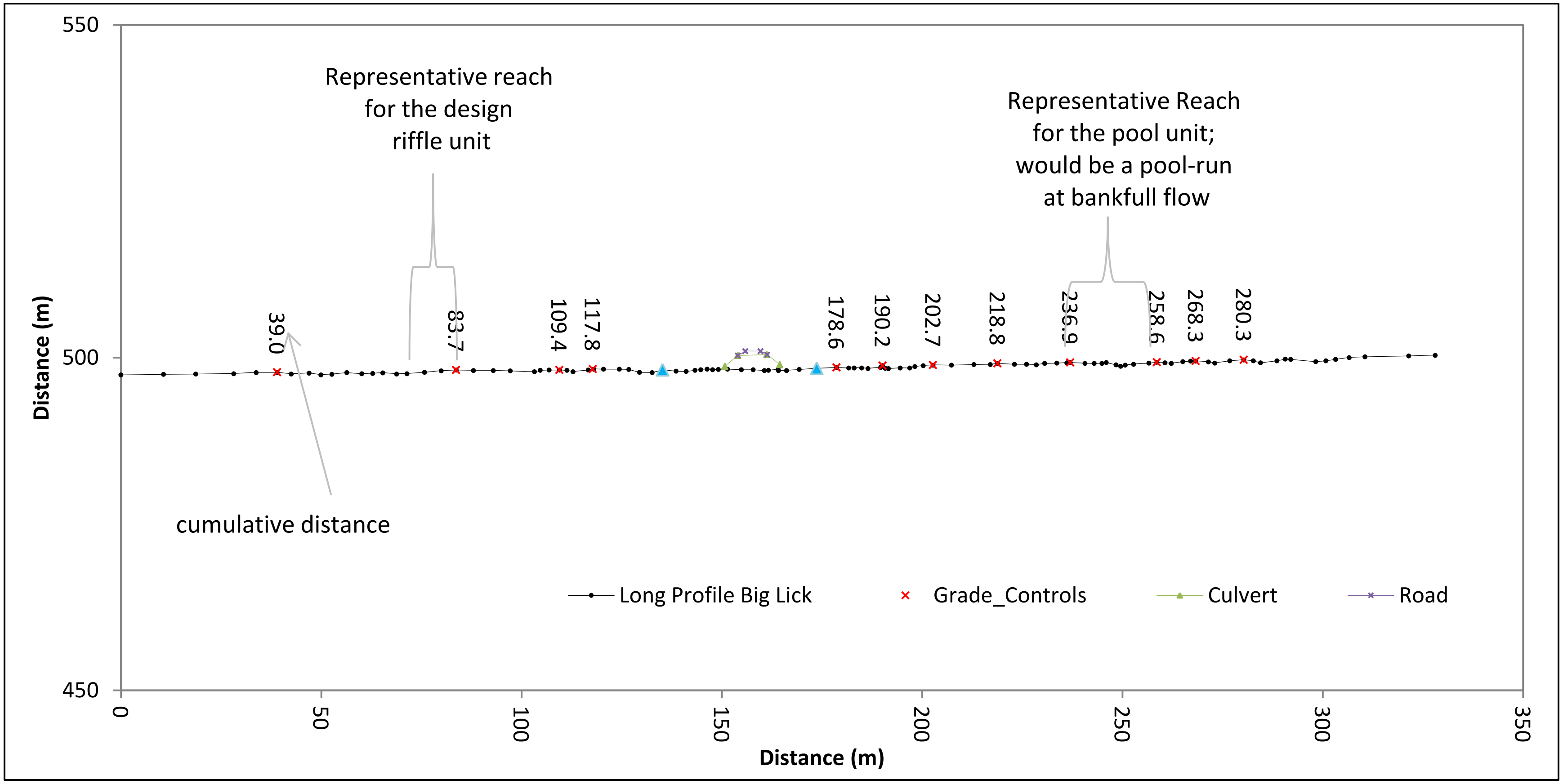

Figure 75: Big Lick Longitudinal Profile

Big Lick longitudinal profile vertical exaggeration is 4 x horizontal. The structure is a squashed (oval) culvert with length 12.3 m, height 2.1 m and span 3.9 m. A single slope segment extends through the design channel, but channel units were analyzed separately (0.4% pool unit and 3.2% riffle unit). The channel units within the design zones are: a riffle and head section of a pool within the inlet transition zone, the mid-section of a pool within the structure, and another section of the pool within the outlet transition zone. The pool-tail-crest is beyond the outlet transition zone boundary. Separate representative riffle and pool channel units were selected within the natural channel with gradients 0.2% (pool unit) and 4.3% (riffle unit).

TABLE 71: BIG LICK DESIGN SLOPE SEGMENT DATA

Design Slope Segment (Riffle, Pool Sequence)								
N (m)	**E (m)**	**Cumulative Distance (m)**	**Elev (m)**	**Straight line segment length (m)**	**El. Diff. (m)**	**Channel Length (m)**	**Gradient**	
471.33	454.90	117.77	498.29					
490.21	500.09	178.62	498.52	48.98	0.24	60.85	0.00	
					Culvert Length (m)	12.63		

TABLE 72: BIG LICK DESIGN CHANNEL SLOPE SEGMENT ANALYSIS

Point Num	N (m)	E (m)	Cumu-lative Distance (m)	Elev (m)	riffle crest (rc)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Notes
106.00	419.70	427.63	39.00	497.80	GC1								
93.00	441.22	440.07	83.70	498.14	GC2	24.86	0.34	44.70	0.01	#DIV/0!	-96.04	-253.97	
86.00	463.22	452.93	109.43	498.14	GC3	25.48	0.00	25.73	0.00	-100.14	100.28	-103.71	
82.00	471.33	454.90	117.77	498.29	FL	8.34	0.15	8.34	0.02	-159984.98	-351.00	33.97	
7.00	490.21	500.09	178.62	498.52	6.00	48.98	0.24	60.85	0.00	-77.83	0.00	-381.84	
14.00	493.90	508.07	190.16	498.79	FL	8.79	0.26	11.54	0.02	483.61	-483.61	8.63	
21.00	503.81	505.08	202.74	498.89	FL	10.35	0.11	12.58	0.01	-62.64	-118.05	0.41	
25.00	516.29	495.49	218.82	499.13	9.00	15.74	0.24	16.08	0.01	74.58	-280.67	-27.34	
32.00	532.20	489.66	236.94	499.27	GC10	16.95	0.13	18.12	0.01	-50.42	-88.72	-43.52	
43.00	552.01	482.28	258.62	499.31	12.00	21.14	0.05	21.68	0.00	-71.46	46.14	-71.67	Selected. Is long pool (separated by small rise) on bend. Gradient is best match. Short riffle above. Is below confluence of dry trib at lb
48.00	560.59	486.24	268.32	499.51	13.00	9.45	0.20	9.70	0.02	871.58	-423.30	23.22	
52.00	571.61	487.54	280.29	499.67	GC14	11.09	0.16	11.97	0.01	-36.02	-234.83	5.18	

Table 73: Big Lick Separate Riffle Analysis

Elevation	Cumulative Distance	Gradient
level II selected rep reach riffle		
499.1887	256.5534	0.06
499.3123	258.6228	
inlet trans riffle		
498.2283	169.3296	0.03
498.5239	178.6196	
riffle sampled for level I try 1		
497.7964	75.74601	0.04
498.1397	83.70168	

Because the representative reach selected contains a very short riffle, another representative riffle (with a better gradient and length match) was also evaluated within the natural channel.

A2.3 BIG LICK DATA-BY-DISTANCE PLOTS

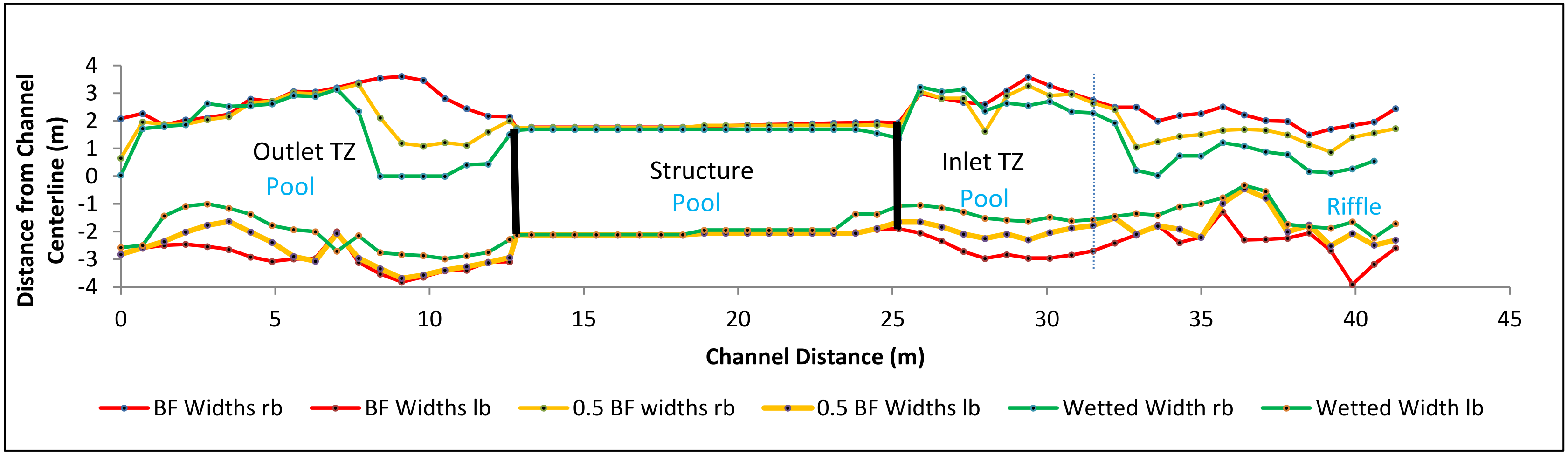

FIGURE 76 : BIG LICK DESIGN WIDTHS

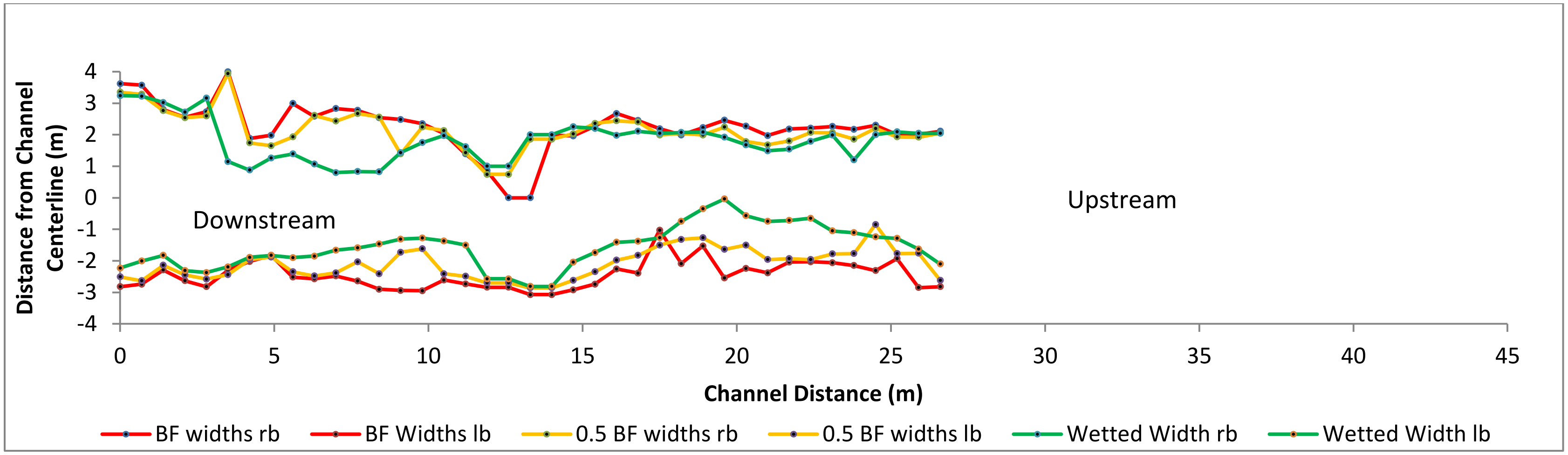

FIGURE 77: BIG LICK REPRESENTATIVE REACH (POOL UNIT) WIDTHS

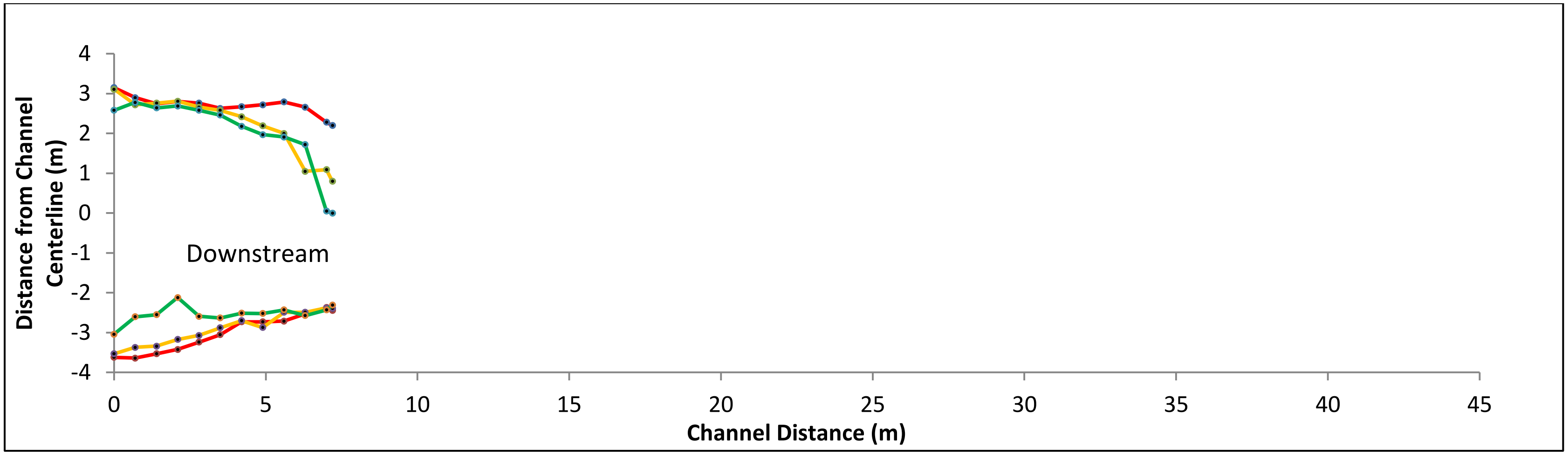

FIGURE 78: BIG LICK REPRESENTATIVE RIFFLE REACH WIDTHS

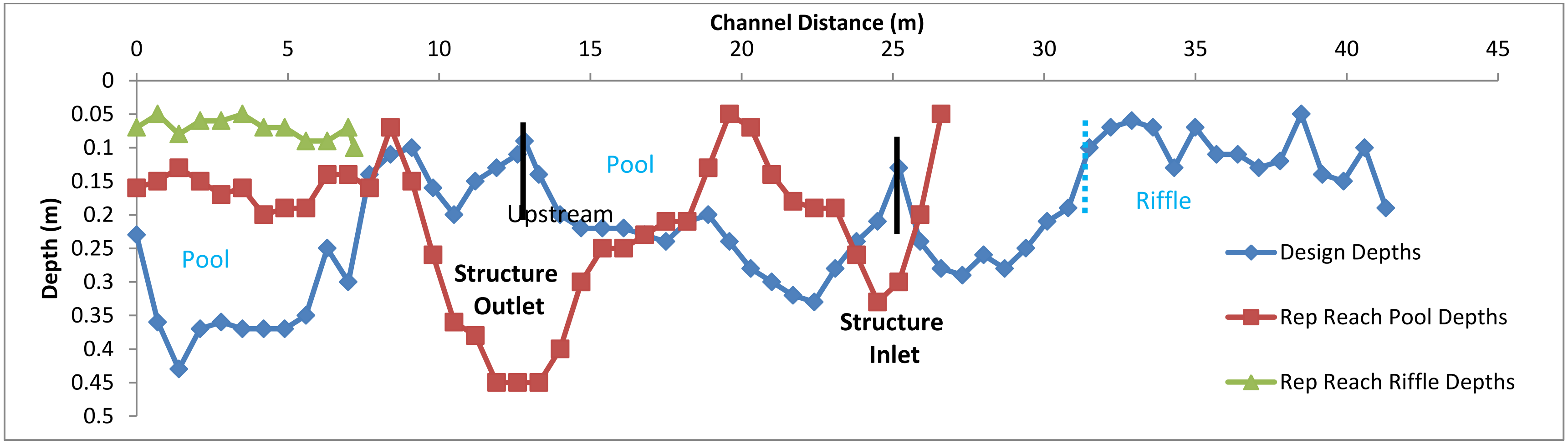

FIGURE 79: BIG LICK DEPTHS

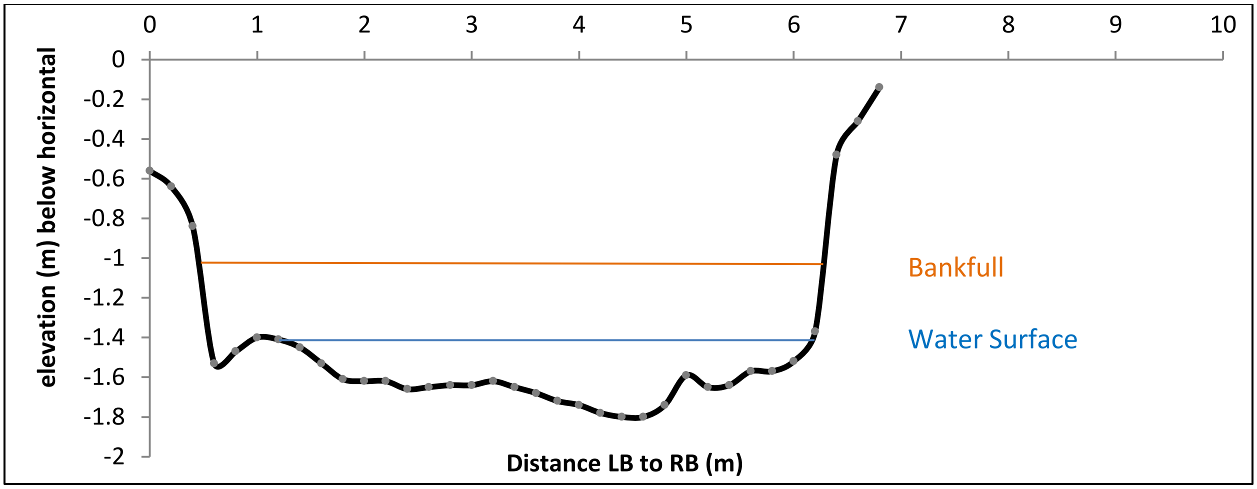

FIGURE 80: BIG LICK CROSS SECTION 1; OUTLET TRANSITION ZONE POOL

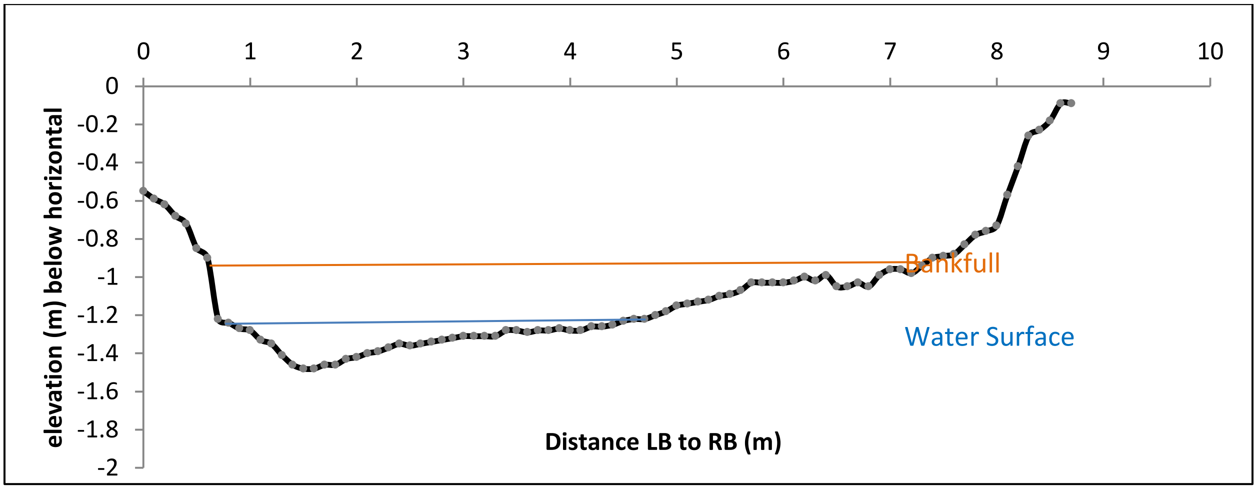

FIGURE 81: BIG LICK CROSS SECTION 2; OUTLET TRANSITION ZONE POOL

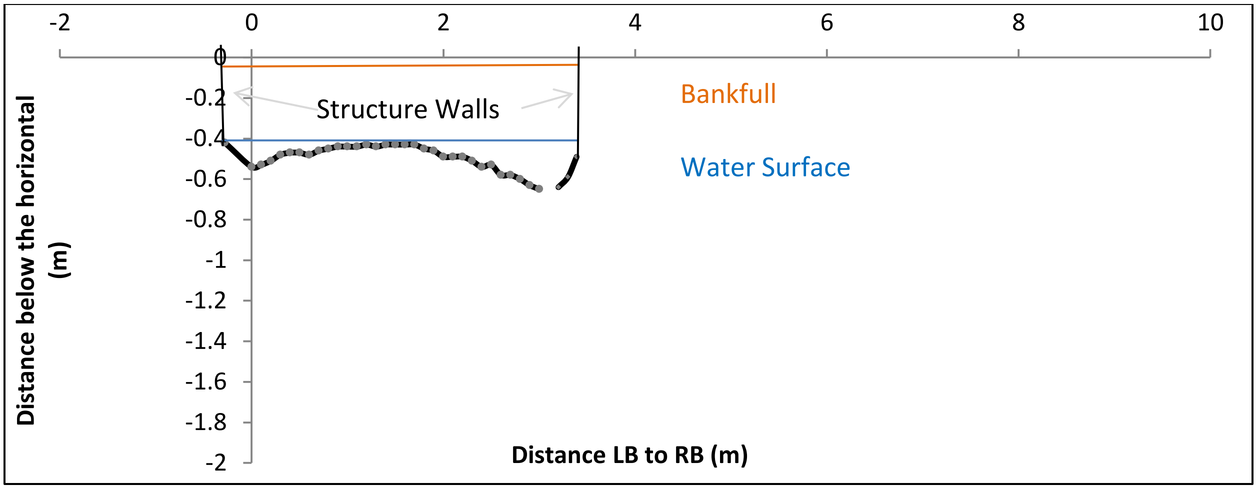

FIGURE 82: BIG LICK CROSS SECTION 3; LOWER THIRD OF STRUCTURE; POOL

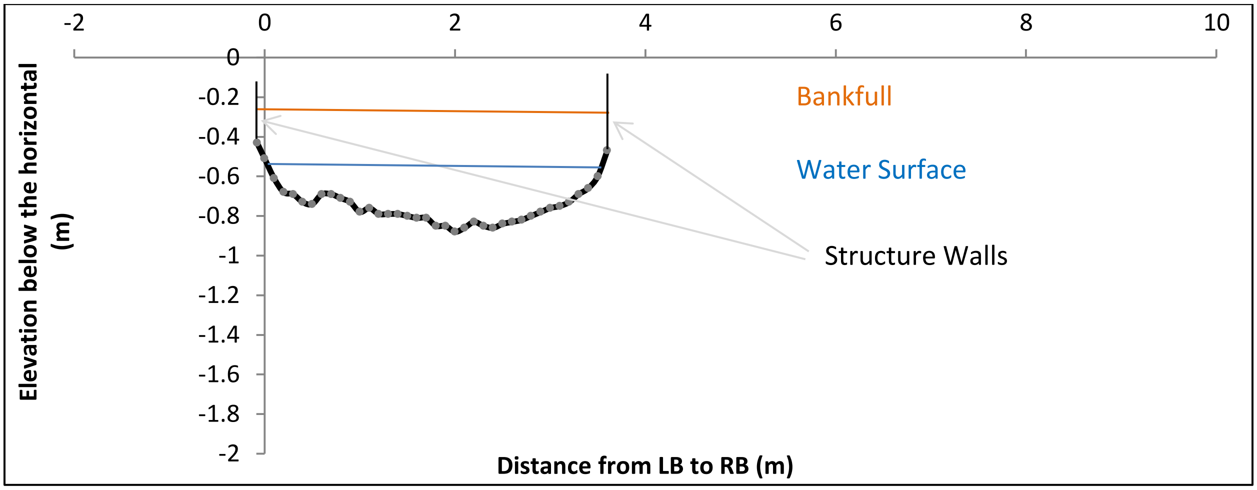

FIGURE 83: BIG LICK CROSS SECTION 4; UPPER THIRD OF STRUCTURE; 2M DOWNSTREAM OF INLET; POOL

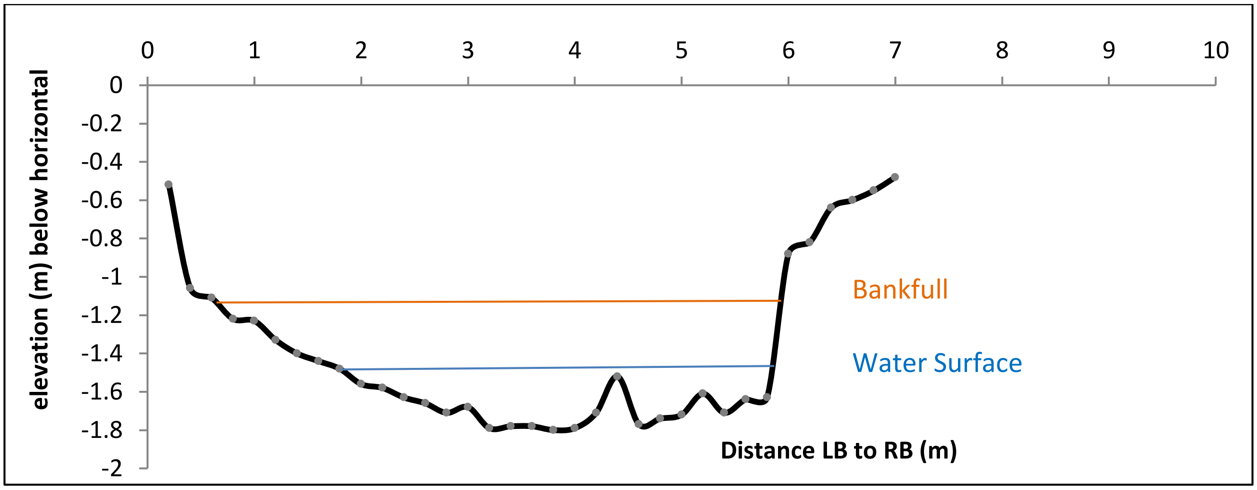

FIGURE 84: BIG LICK CROSS SECTION 5; INLET TRANSITION ZONE; POOL

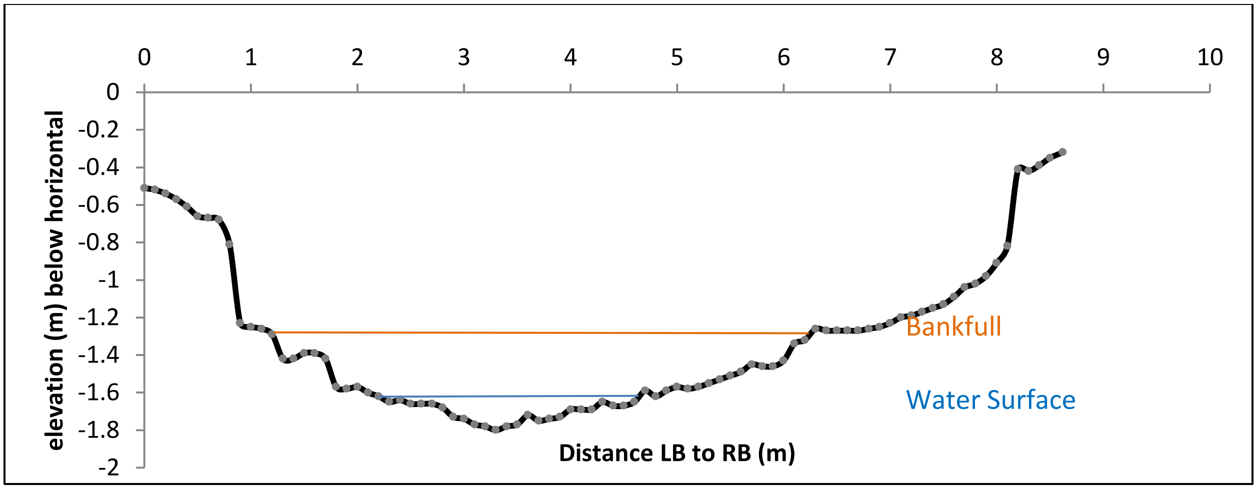

Figure 85: Big Lick Cross Section 6; Inlet Transition Zone; Riffle

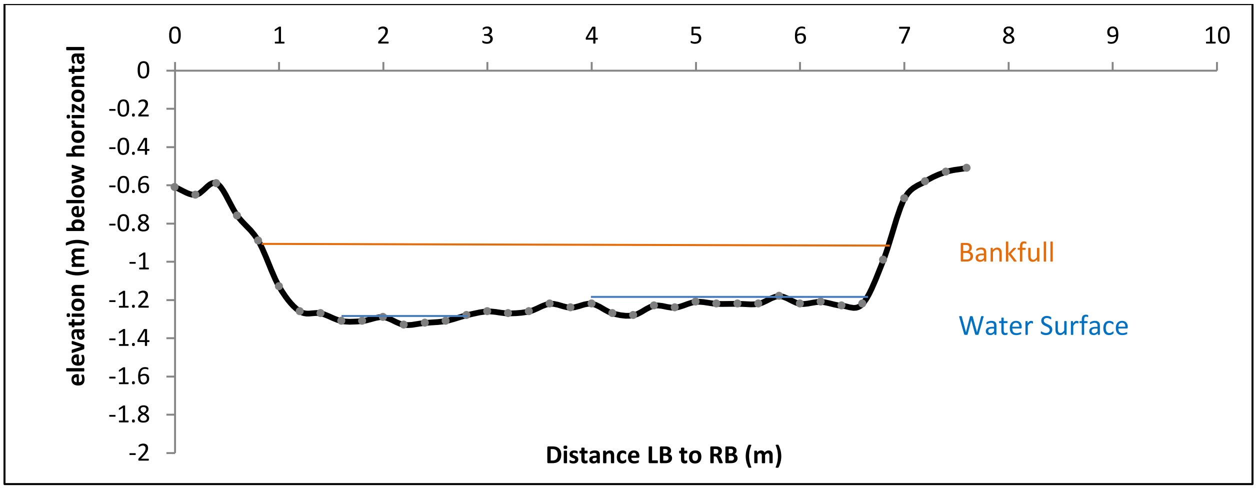

Figure 86: Big Lick Cross Section 7; Representative Reach Riffle; near Riffle Crest

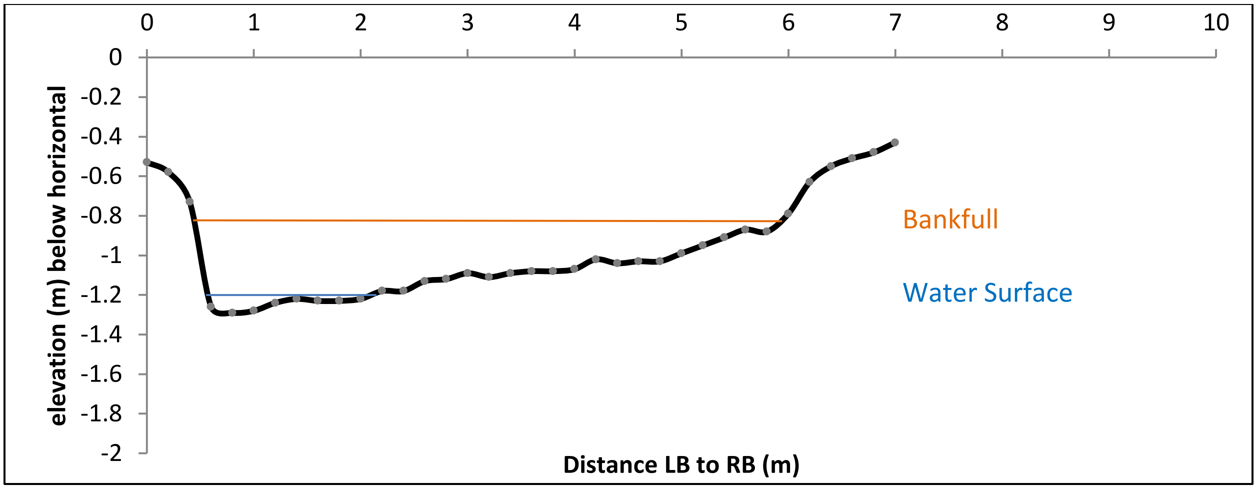

FIGURE 87: BIG LICK CROSS SECTION 8; INLET TRANSITION ZONE REPRESENTATIVE REACH; RIFFLE

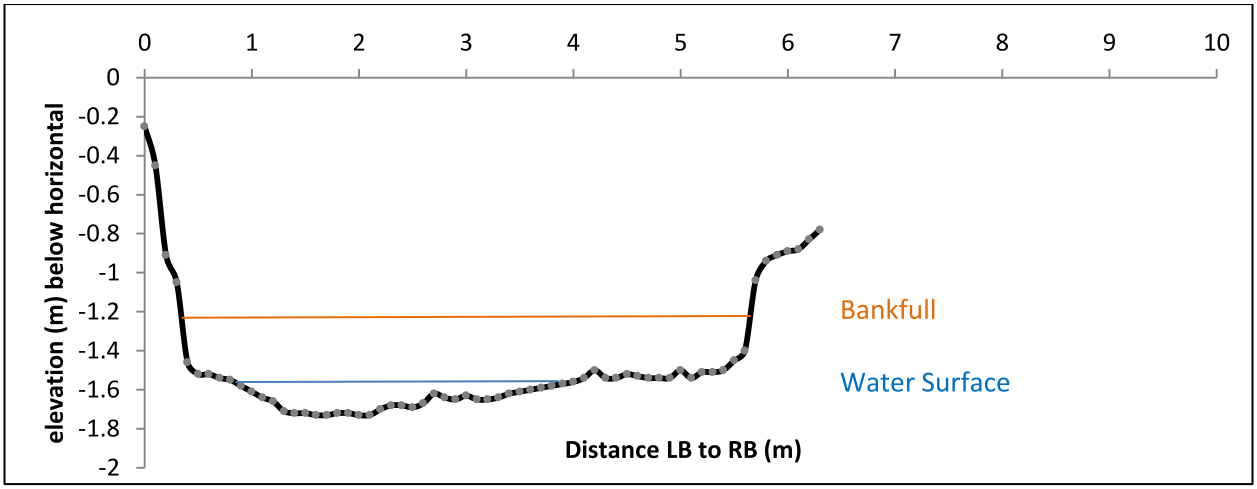

FIGURE 88: BIG LICK CROSS SECTION 9; REPRESENTATIVE REACH POOL

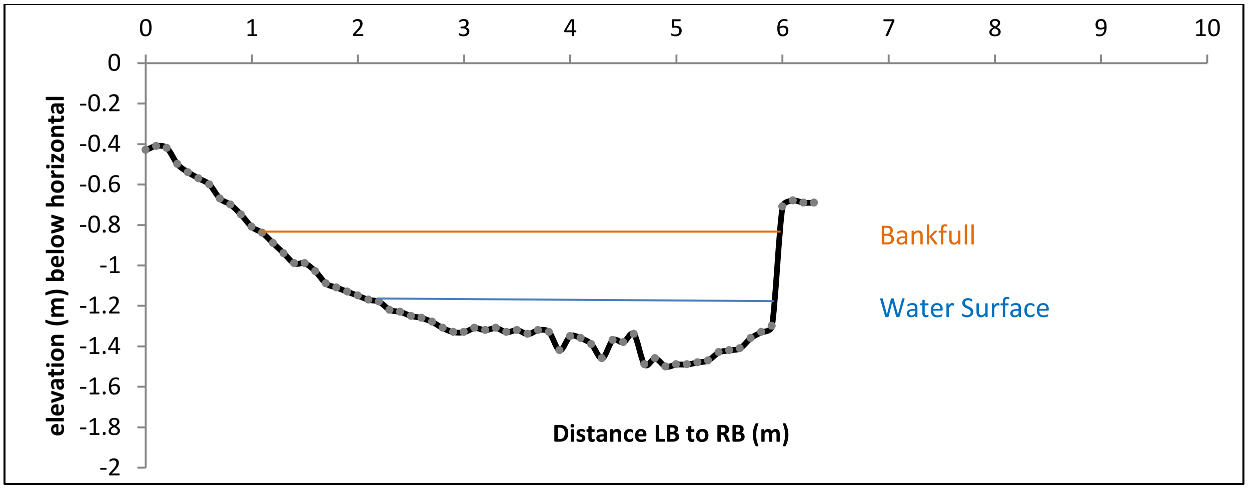

Figure 89: Big Lick Cross Section 10; Representative Reach Pool

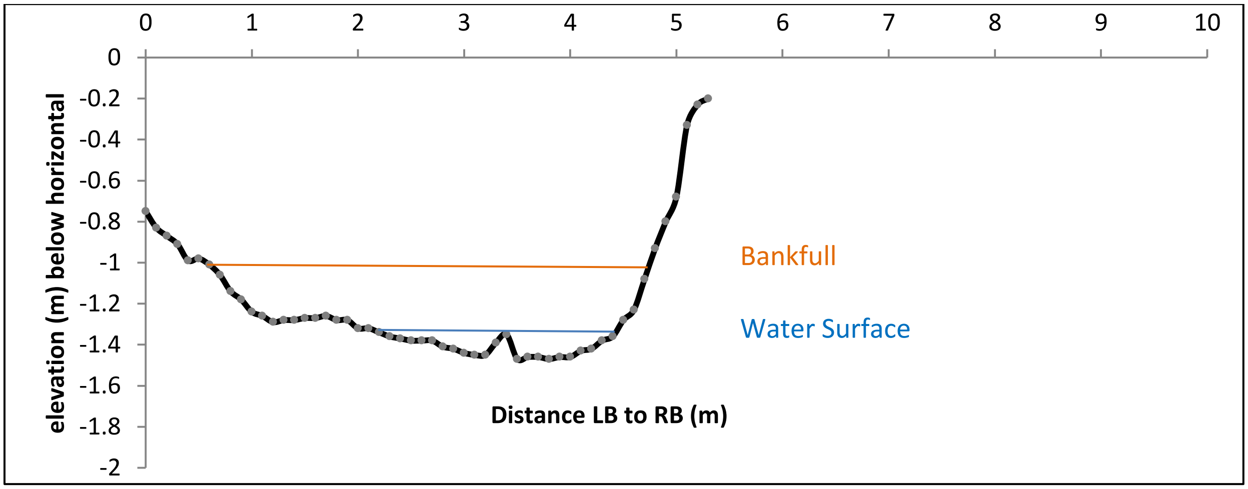

Figure 90: Big Lick Cross Section 11; Representative Reach Pool

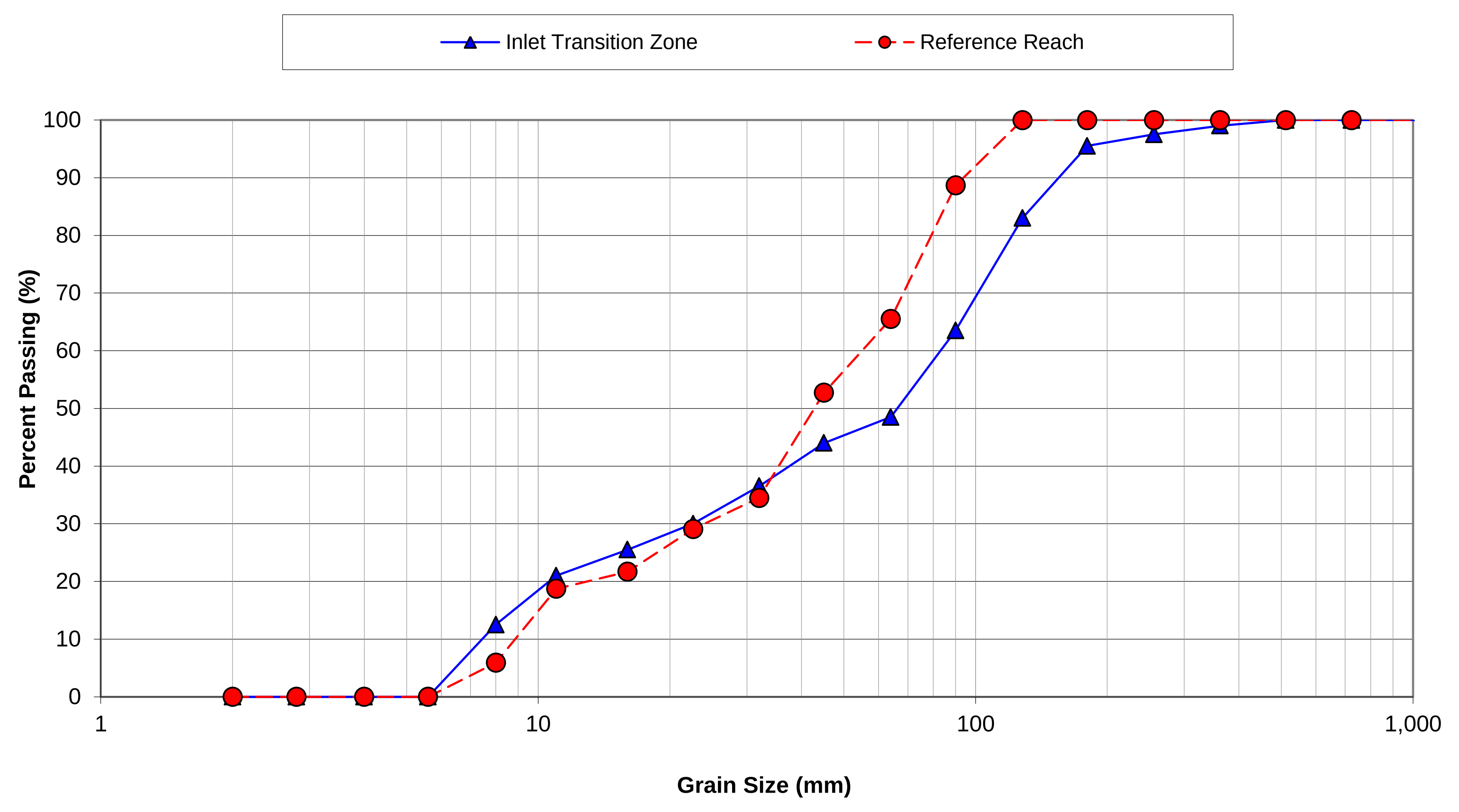

FIGURE 91: BIG LICK GRADATION

A2.4 BIG LICK BOXPLOTS AND HISTOGRAMS BY GROUP

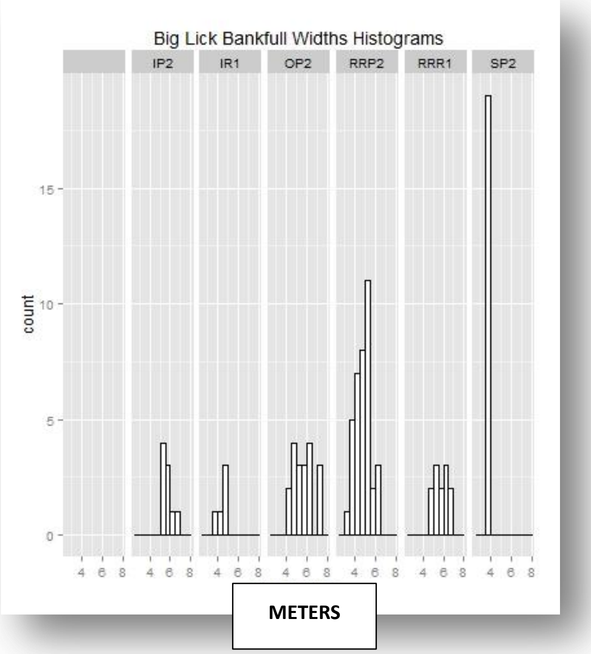

FIGURE 92: BIG LICK WIDTH AT BANKFULL STAGE; HISTOGRAM

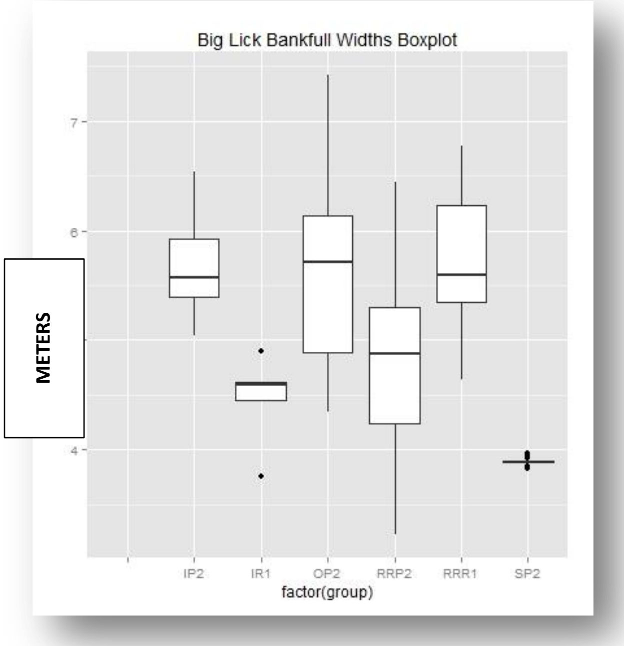

FIGURE 93: BIG LICK WIDTH AT BANKFULL STAGE; BOXPLOT

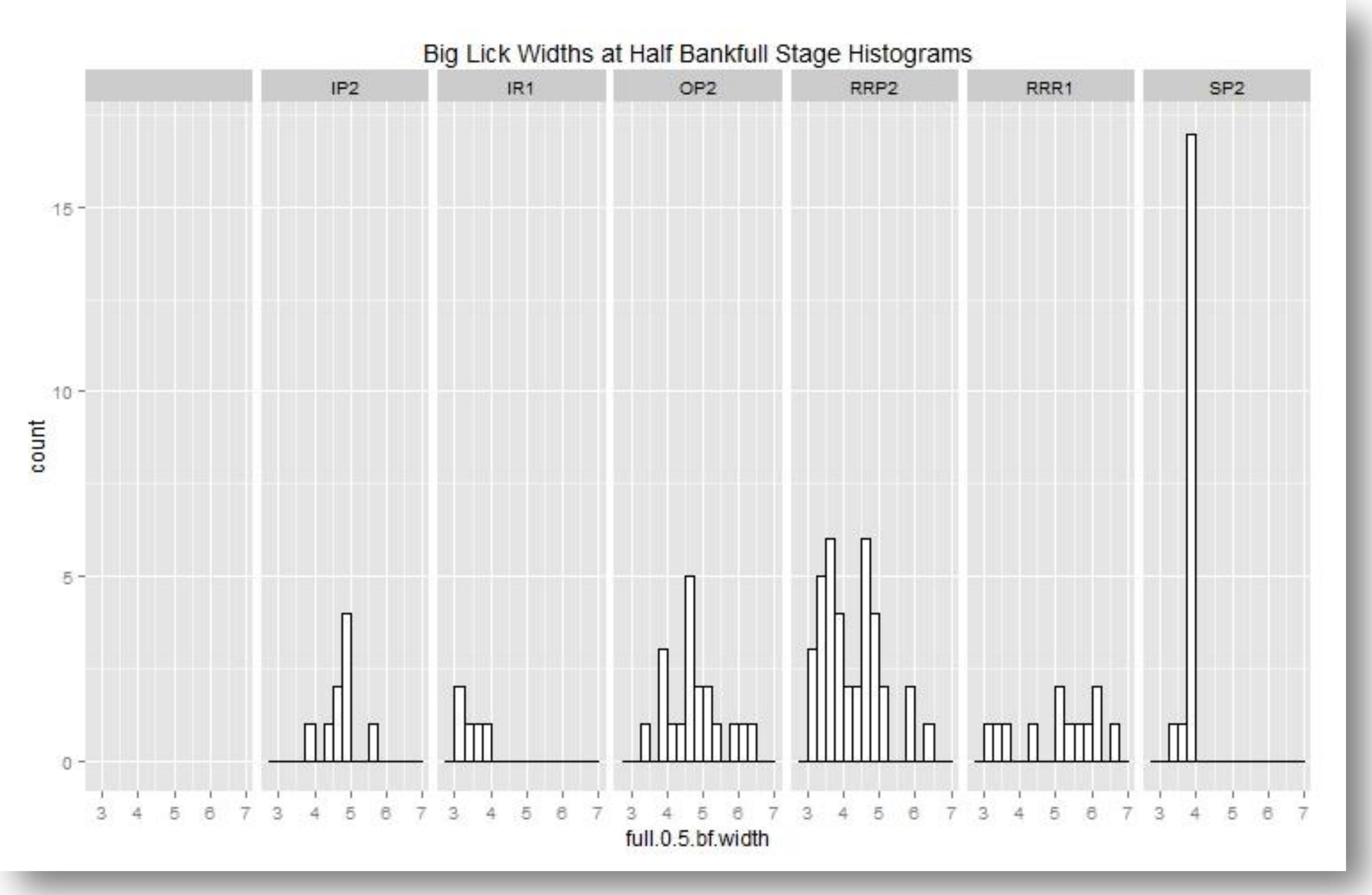

Figure 94: Big Lick Widths at Half Bankfull Stage; Histogram

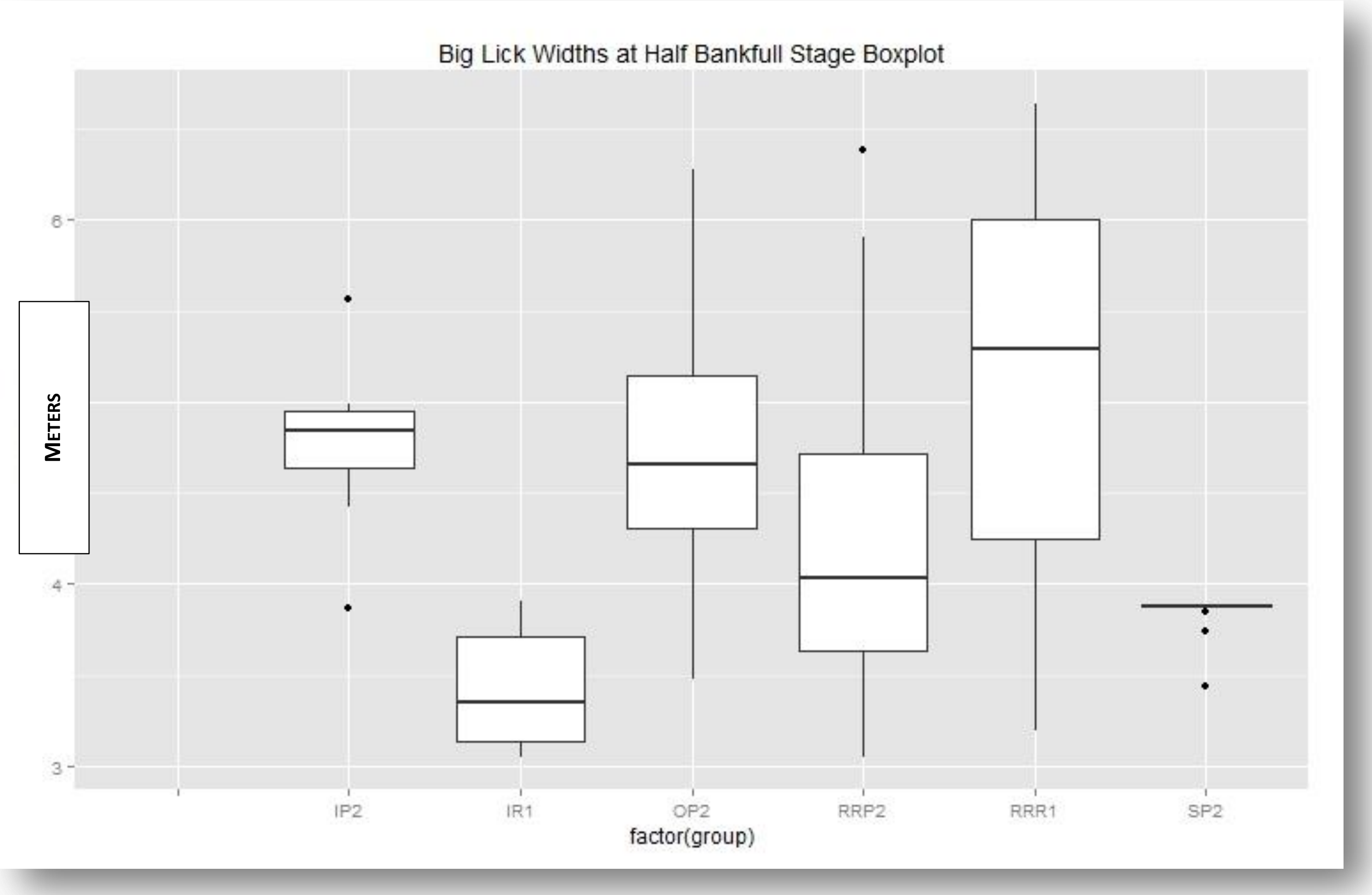

FIGURE 95: BIG LICK WIDTHS AT HALF BANKFULL STAGE; BOXPLOT

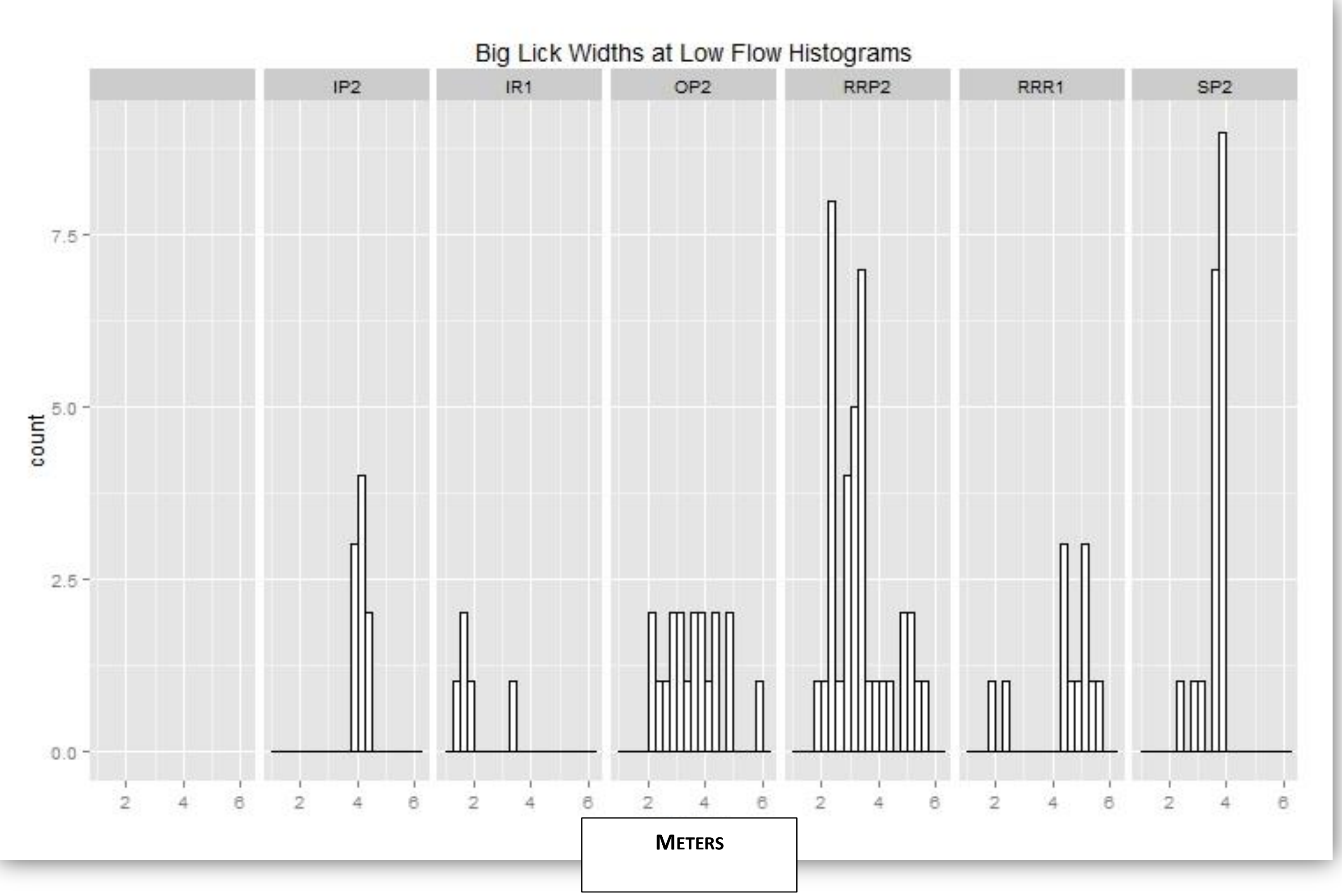

FIGURE 96: BIG LICK LOW FLOW WIDTHS; HISTOGRAM

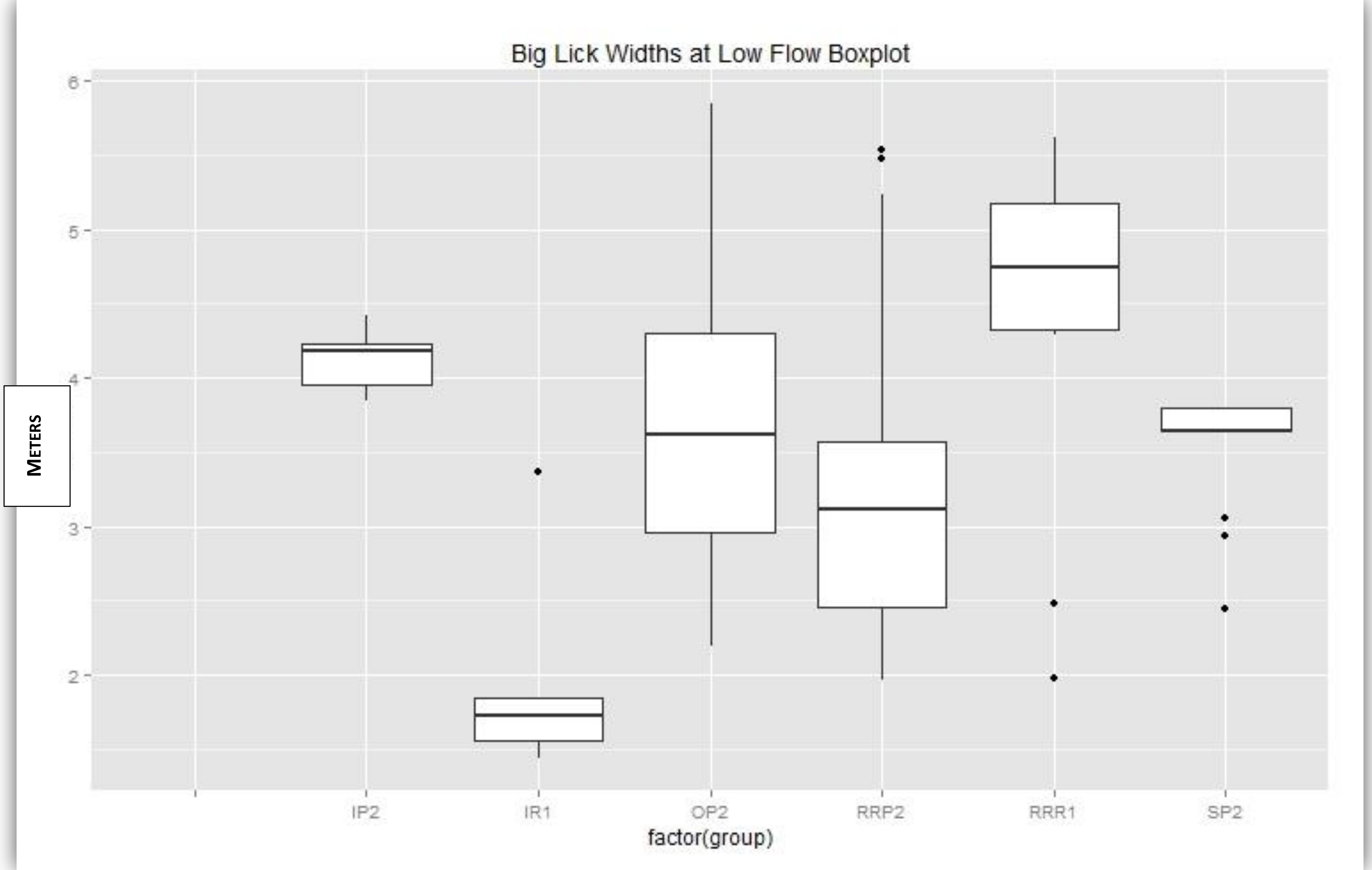

FIGURE 97: BIG LICK LOW FLOW WIDTHS; BOXPLOT

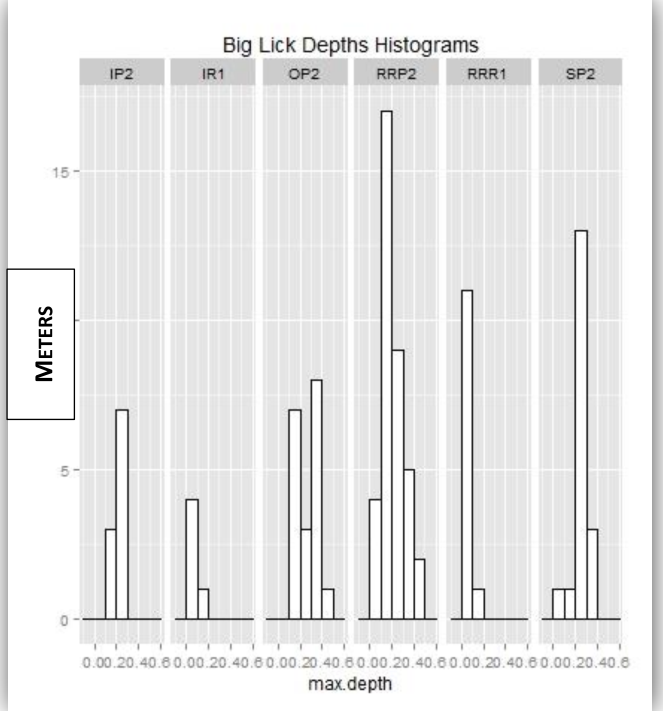

FIGURE 98: BIG LICK MAXIMUM DEPTHS; HISTOGRAM

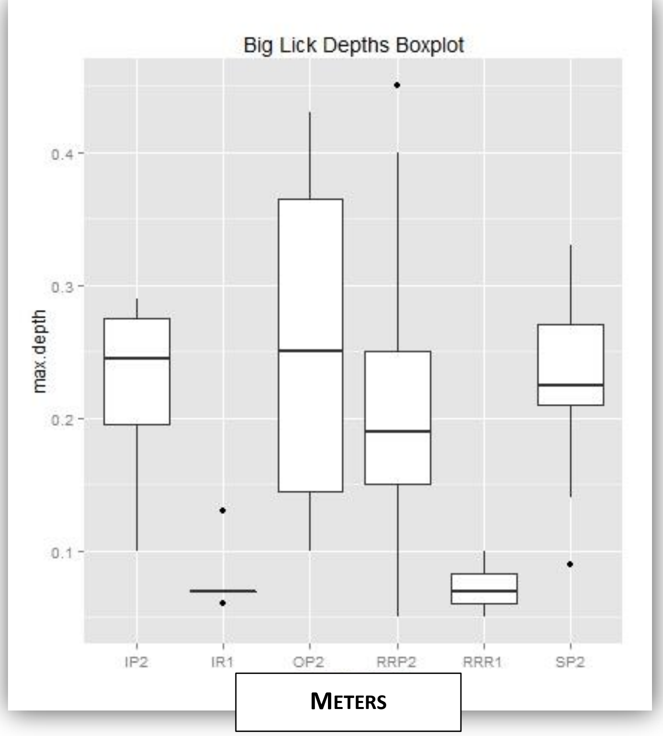

FIGURE 99: BIG LICK MAXIMUM DEPTHS; BOXPLOT

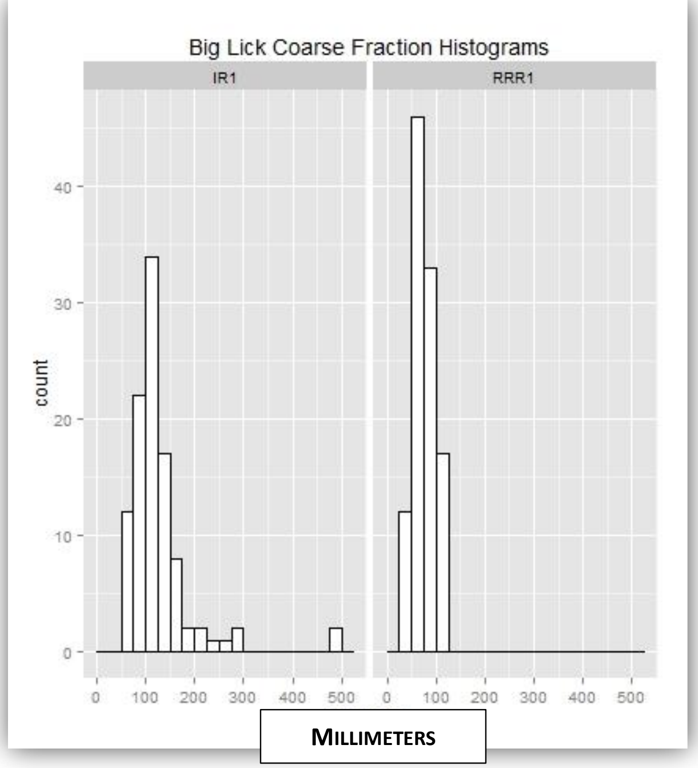

FIGURE 100: BIG LICK COARSE FRACTION OF THE GRADATION; HISTOGRAM

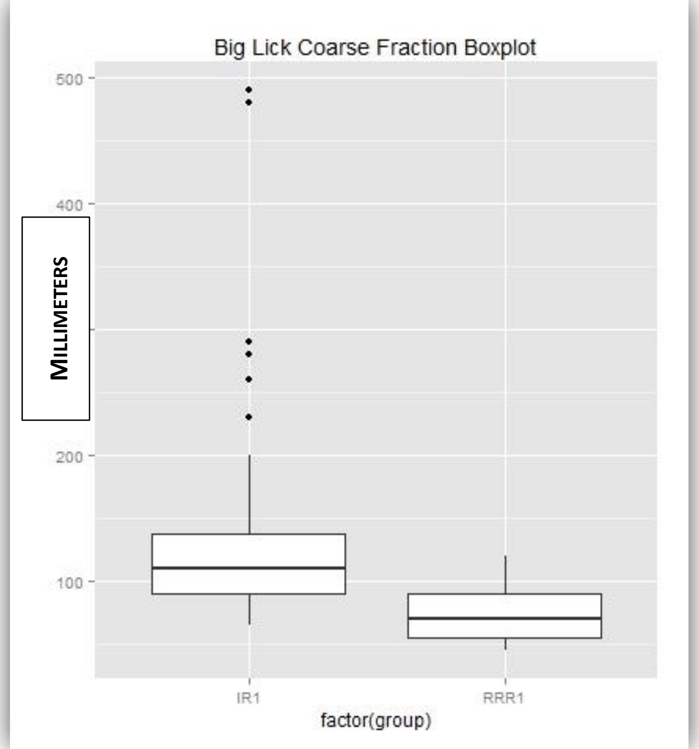

FIGURE 101: BIG LICK COARSE FRACTION OF THE GRADATION; BOXPLOT

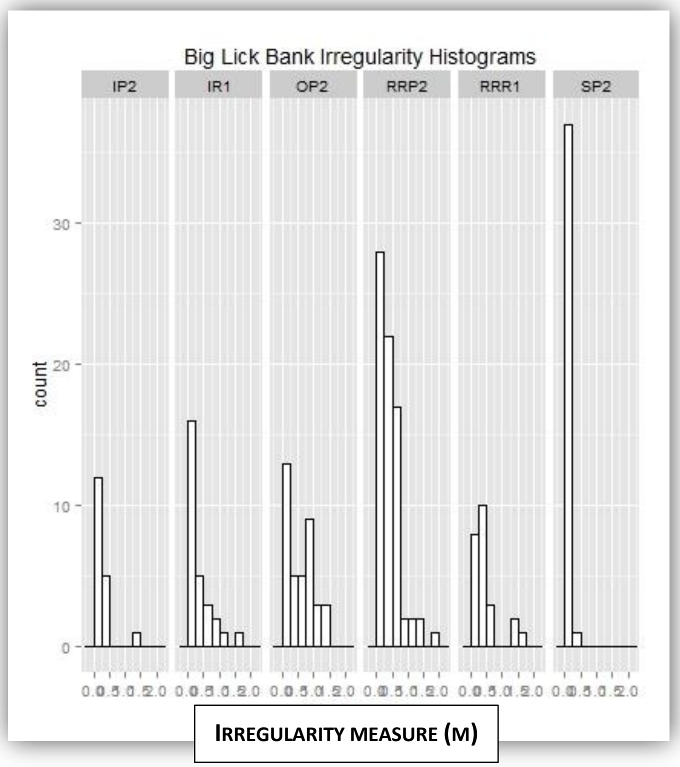

FIGURE 102: BIG LICK BANK IRREGULARITY; HISTOGRAM

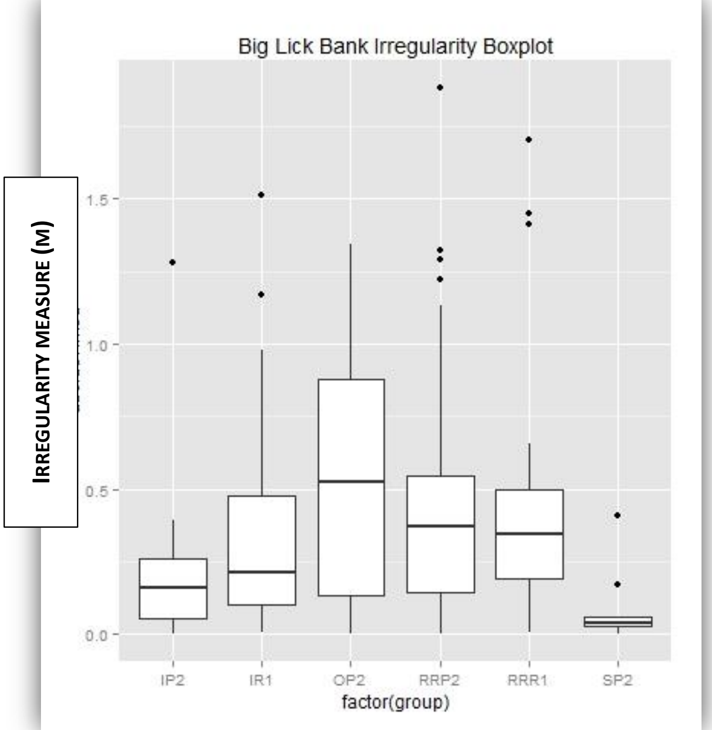

FIGURE 103: BIG LICK BANK IRREGULARITY; BOXPLOT

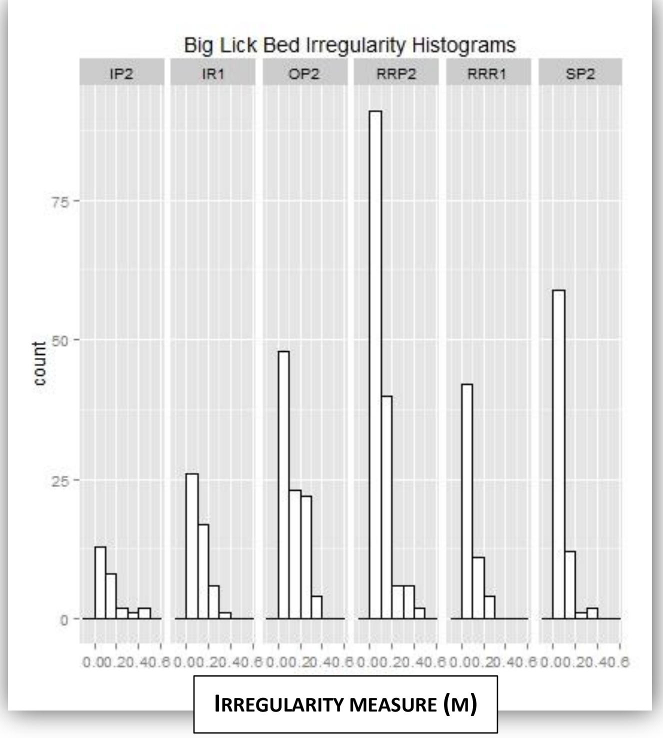

FIGURE 104: BIG LICK BED IRREGULARITY; HISTOGRAM

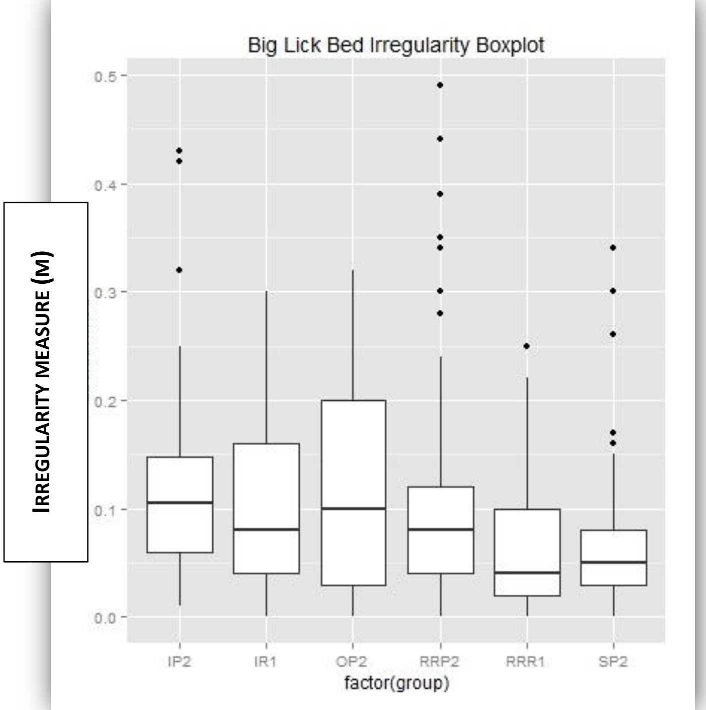

FIGURE 105: BIG LICK BIG LICK BED IRREGULARITY; BOXPLOT

A2.5 BIG LICK BOXPLOTS AND HISTOGRAMS BY POPULATION

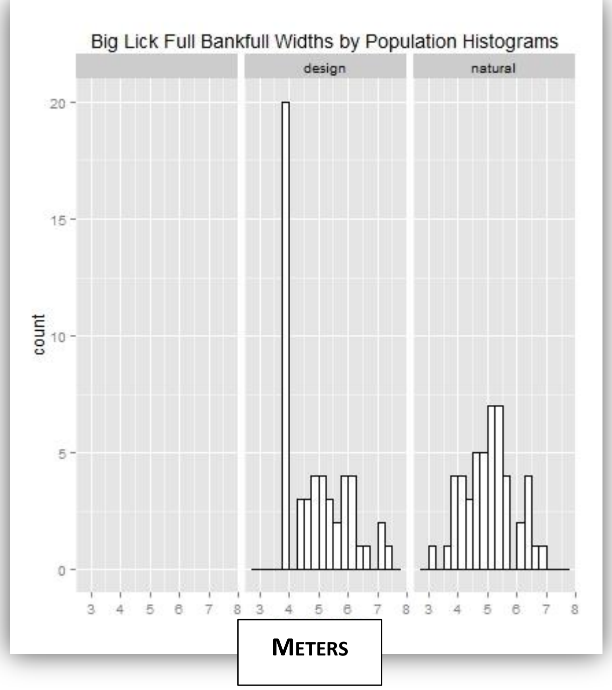

FIGURE 106: BIG LICK BANKFULL WIDTH BY POPULATION; HISTOGRAM

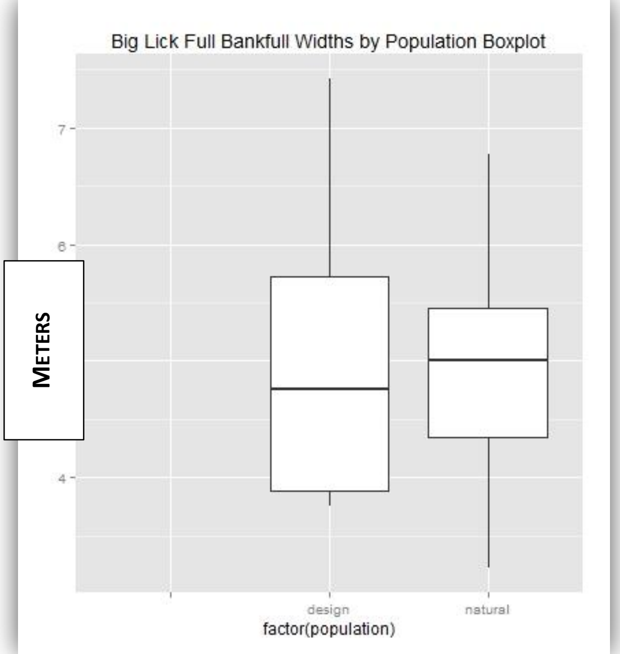

FIGURE 107: BIG LICK BANKFULL WIDTH BY POPULATION BOXPLOT

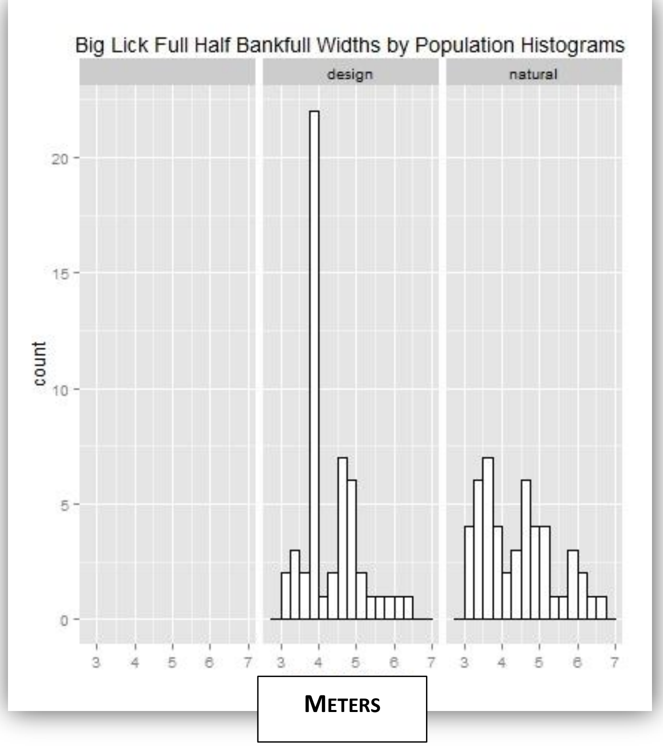

FIGURE 108: BIG LICK HALF BANKFULL WIDTH BY POPULATION; HISTOGRAM

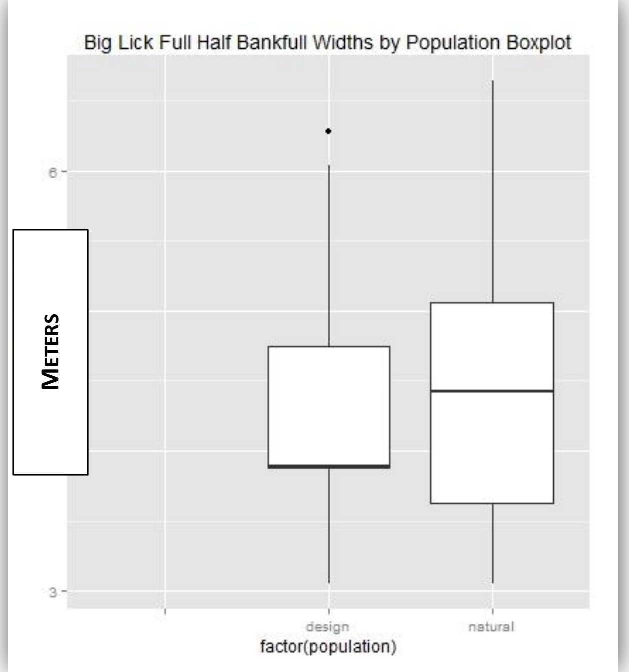

FIGURE 109: BIG LICK HALF BANKFULL WIDTH BY POPULATION; BOXPLOT

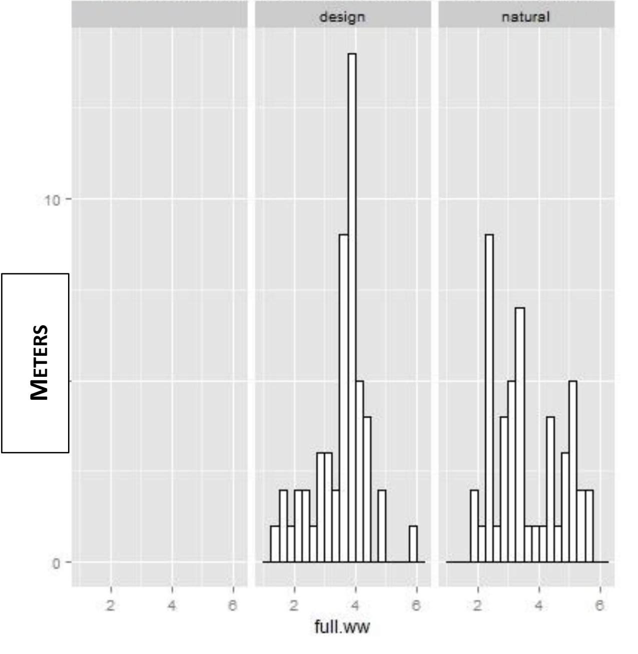

FIGURE 110: BIG LICK LOW FLOW WIDTH BY POPULATION; HISTOGRAM

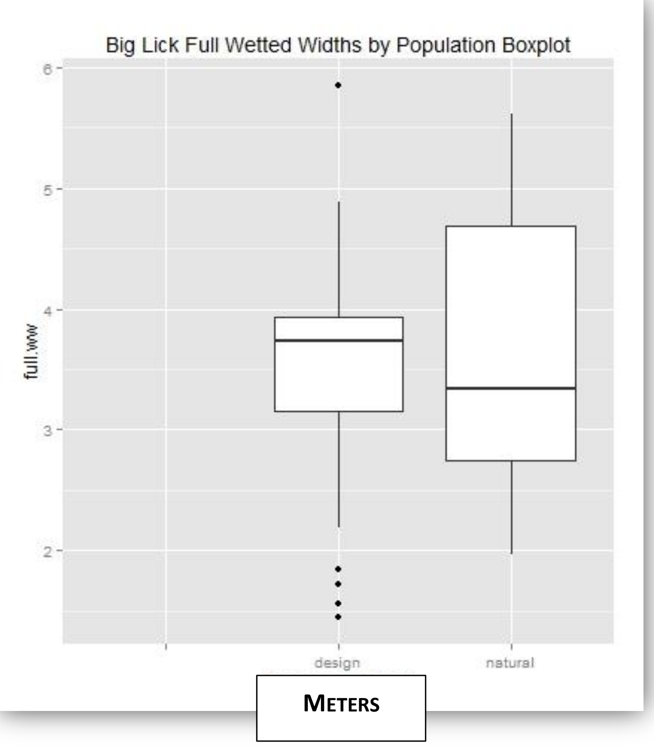

FIGURE 111: BIG LICK LOW FLOW WIDTH BY POPULATION; BOXPLOT

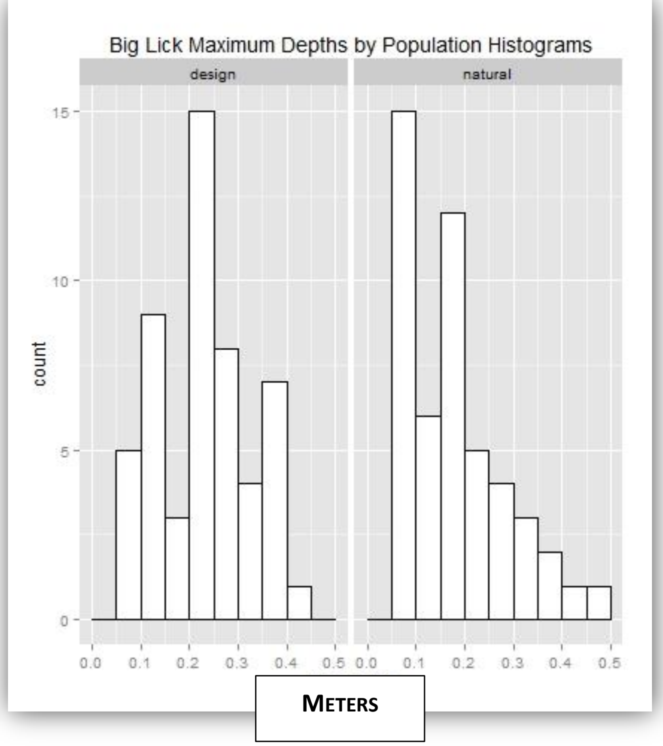

FIGURE 112: BIG LICK MAXIMUM DEPTHS BY POPULATION; HISTOGRAM

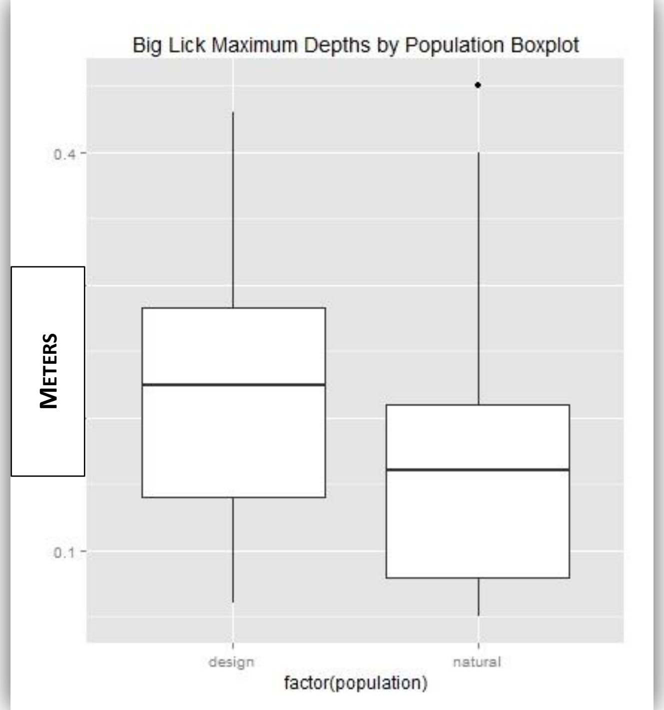

FIGURE 113: BIG LICK MAXIMUM DEPTHS BY POPULATION; BOXPLOT

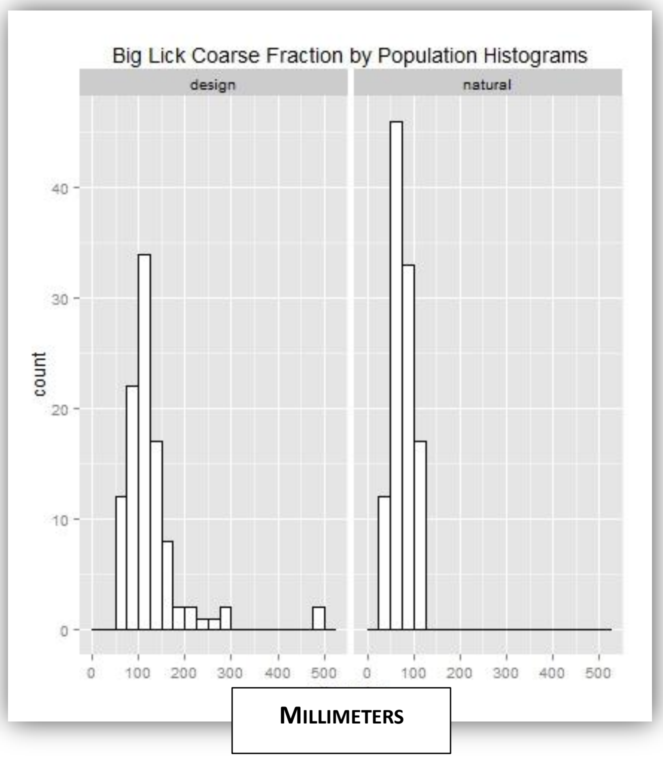

FIGURE 114: BIG LICK COARSE FRACTION BY POPULATION; HISTOGRAM

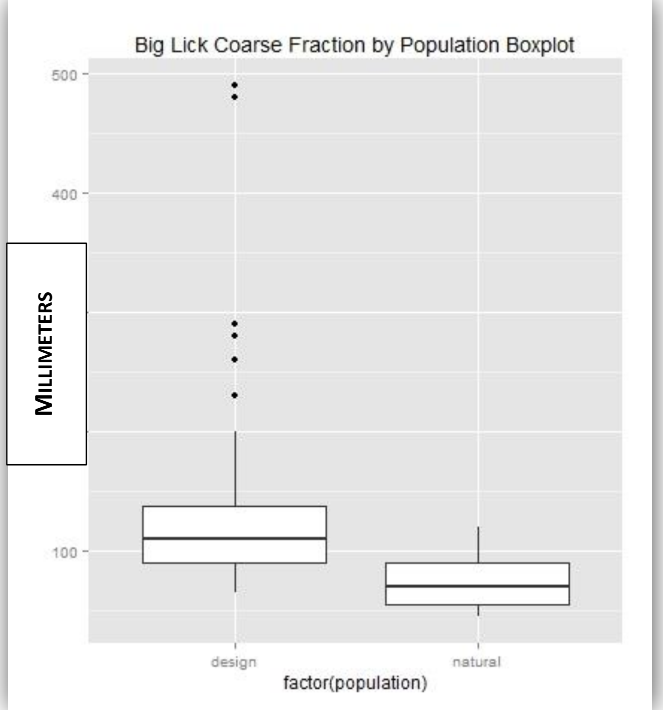

FIGURE 115: BIG LICK COARSE FRACTION BY POPULATION; BOXPLOT

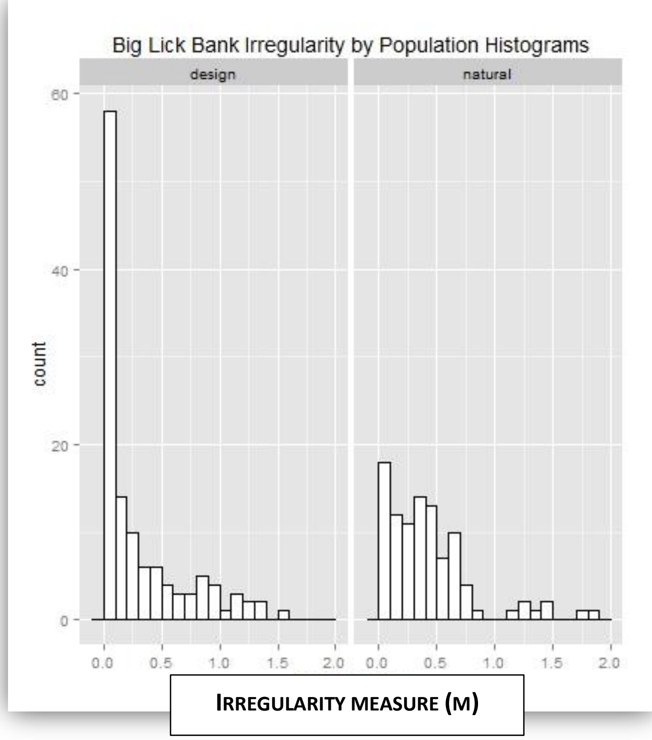

Figure 116: Big Lick Bank Irregularity by Population; Histogram

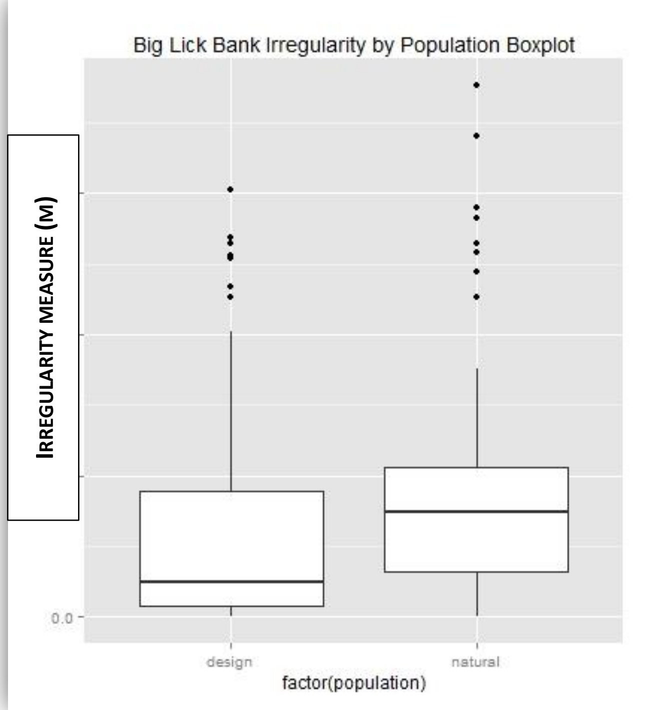

Figure 117: Big Lick Bank Irregularity by Population; Boxplot

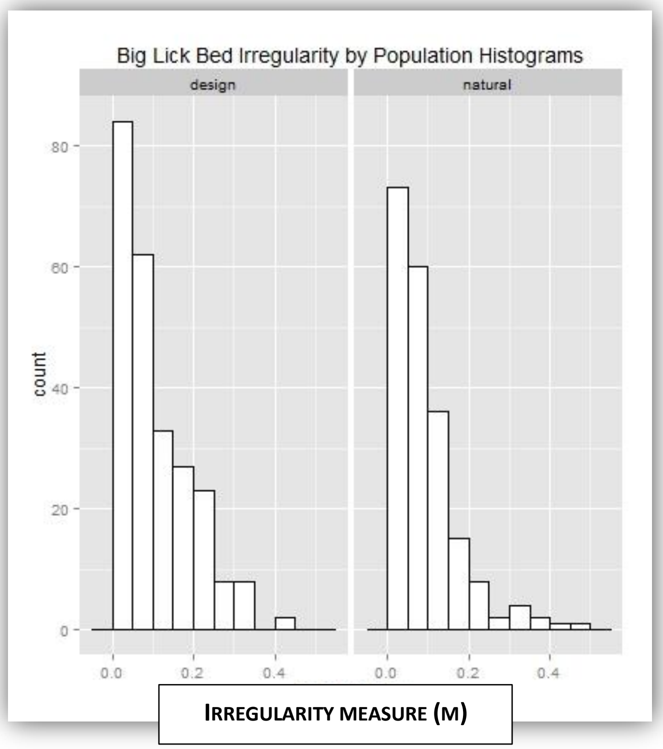

FIGURE 118: BIG LICK BED IRREGULARITY BY POPULATION; HISTOGRAM

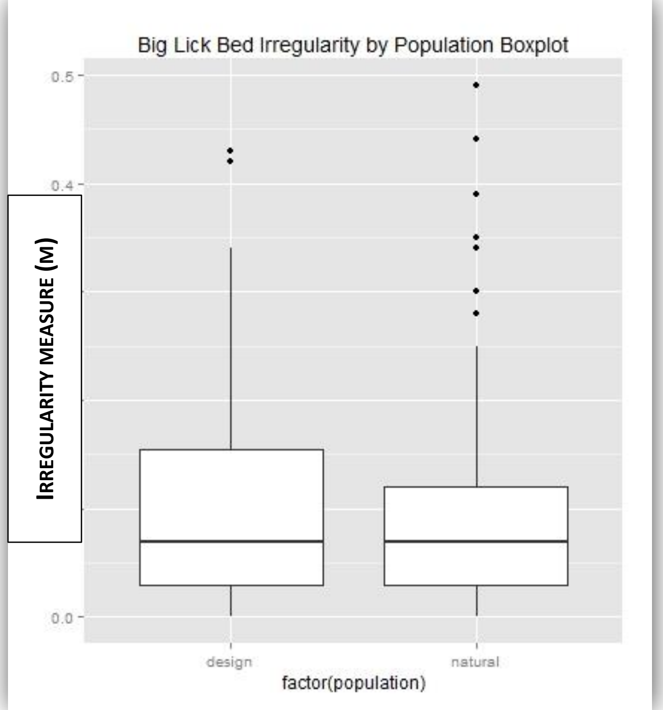

FIGURE 119: BIG LICK BED IRREGULARITY BY POPULATION; BOXPLOT

TABLE 74: BIG LICK LEVEL II SCORING SENSITIVITY ANALYSIS

Channel Unit	Inlet Transition Zone			Structure Zone			Outlet Transition Zone		
	% Score	Rating	Over-ride	% Score	Rating	Over-ride	% Score	Rating	Override
Riffle 0.01 to 0.05	53	Questionable			Not Applicable			Not Applicable	
Riffle 0.001 to 0.05	64	Questionable			Not Applicable			Not Applicable	
Riffle 0.001 to 0.05 short	63	Questionable			Not Applicable			Not Applicable	
Riffle 0.001 to 0.1	64	Questionable			Not Applicable			Not Applicable	
Riffle 0.01 to 0.1	53	Questionable			Not Applicable			Not Applicable	
Pool 0.01 to 0.05	51	Questionable		53	Questionable		69	Questionable	
Pools 0.001 to 0.05	60	Questionable		55	Questionable		80	Similar	
Pools 0.001 to 0.05 short	57	Questionable		54	Questionable		77	Similar	
Pools 0.001 to 0.1	60	Questionable		48	Dissimilar		77	Similar	
Pools 0.01 to 0.1	51	Questionable		45	Dissimilar		66	Questionable	

TABLE 75: BIG LICK LEVEL II SCORING SENSITIVITY ANALYSIS

Channel Units and Criteria for a Score of 3	Design		
	% Score	Evaluation	Override
Design 0.01 to 0.05	52	Questionable	
Design 0.001 to 0.05	58	Questionable	
Design 0.001 to 0.05 SHORT	56	Questionable	
Design 0.001 to 0.1	58	Questionable	
Design 0.01 to 0.1	36	Dissimilar	

A3 CANEY CREEK SITE DATA

A3.1 CANEY CREEK PHOTOS

FIGURE 120: LOOKING UPSTREAM AT THE CANEY CREEK INLET TRANSITION ZONE (HEAD OF POOL AND RIFFLE)

FIGURE 121: LOOKING DOWNSTREAM AT THE CANEY CREEK STRUCTURE INLET

Figure 122: Looking downstream at the outlet transition zone and constructed riffle from the top of the Caney Creek structure

Figure 123: Looking upstream at the Caney Creek structure outlet and pool within the outlet transition zone

FIGURE 124: PEOPLE STANDING ON THE CONSTRUCTED RIFFLE CREST WHICH BACKWATERS THE CANEY CREEK DESIGN POOL

FIGURE 125: THE DRY CONSTRUCTED RIFFLE AT CANEY CREEK

Figure 126: Looking downstream within the Caney Creek Structure

Figure 127: A typical pool and riffle within the Caney Creek natural channel

FIGURE 128: CANEY CREEK NATURAL CHANNEL REACH MOST SIMILAR TO DESIGN REACH

A4 DOG SLAUGHTER SITE DATA

A4.1 DOG SLAUGHTER PHOTOS

FIGURE 129: LOOKING DOWNSTREAM AT THE DOG SLAUGHTER STRUCTURE INLET TRANSITION ZONE AND INLET

FIGURE 130: LOOKING DOWNSTREAM FROM THE DOG SLAUGHTER STRUCTURE INLET

Figure 131: Looking downstream through the Dog Slaughter structure outlet

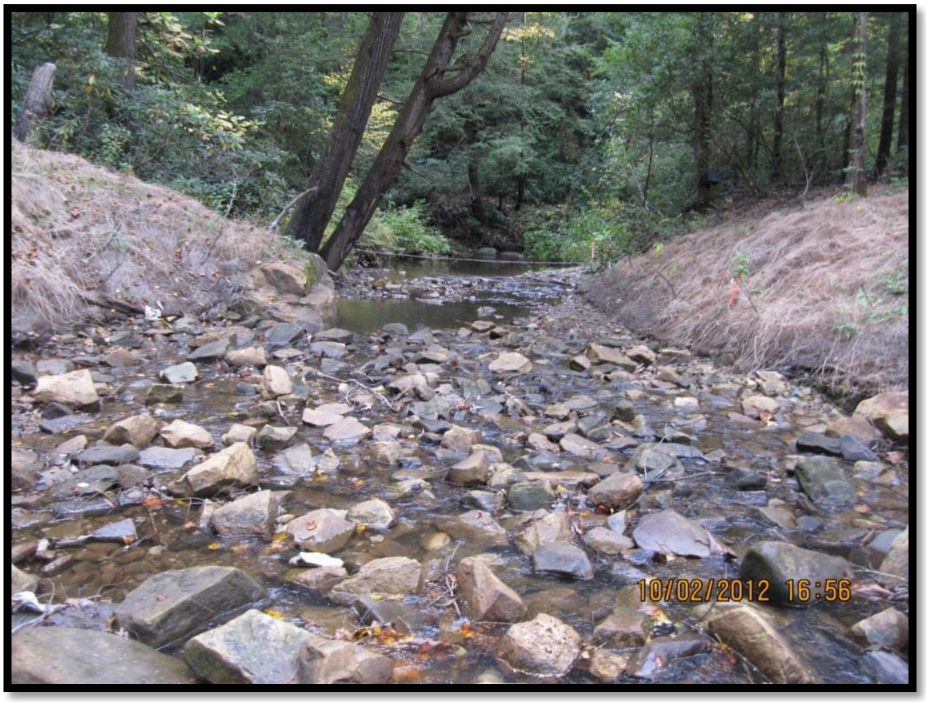

Figure 132: Within the constructed riffle which backwaters the Dog Slaughter structure; downstream of the outlet transition zone

FIGURE 133: STANDING ON ROAD, LOOKING DOWNSTREAM AT THE DOG SLAUGHTER OUTLET TRANSITION ZONE AND CONSTRUCTED RIFFLE

FIGURE 134: LOOKING UPSTREAM AT THE DOG SLAUGHTER REPRESENTATIVE REACH FOR THE DESIGN CHANNEL RIFFLE

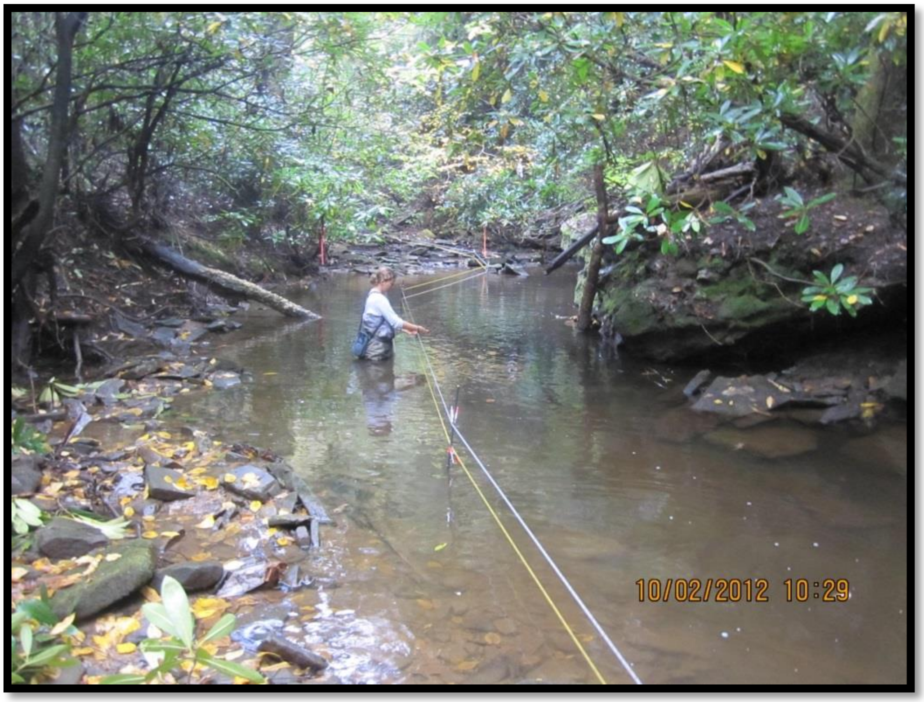

FIGURE 135: LOOKING UPSTREAM AT THE DOG SLAUGHTER REPRESENTATIVE REACH POOL AND RIFFLE (TAKING WIDTH MEASUREMENTS)

FIGURE 136: LOOKING UPSTREAM AT THE DOG SLAUGHTER REPRESENTATIVE REACH FOR THE CONSTRUCTED RIFFLE (AUTHOR STANDING AT THE UPSTREAM BOUNDARY OF THE REACH)

A4.2 DOG SLAUGHTER REPRESENTATIVE REACH ANALYSIS

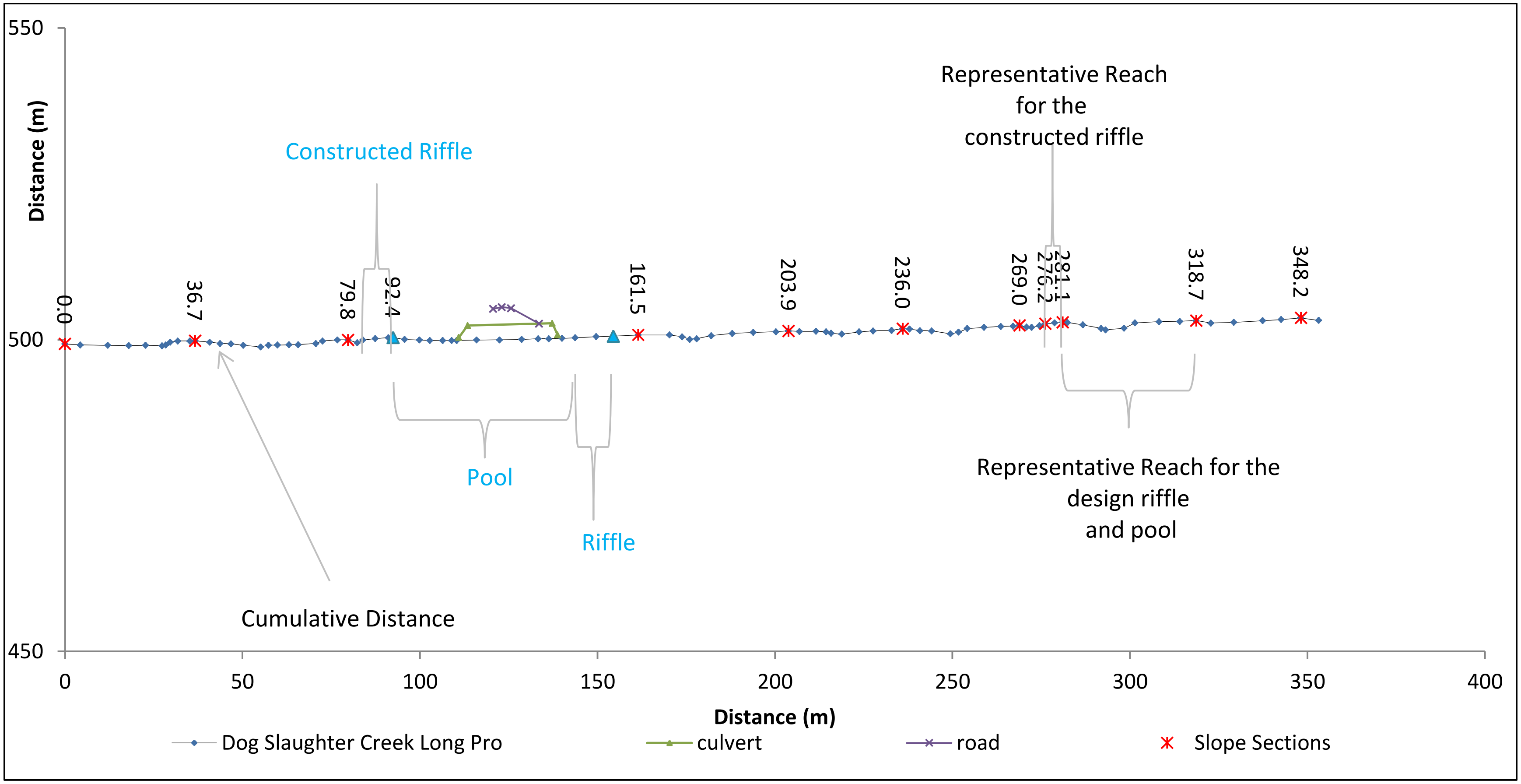

FIGURE 137: DOG SLAUGHTER CREEK LONGITUDINAL PROFILE

THE DESIGN CHANNEL AT DOG SLAUGHTER CONSISTS OF A RIFFLE AND LONG POOL. IN ADDITION, A CONSTRUCTED RIFFLE BACKWATERS THE STRUCTURE. THE GRADIENT OF THE SLOPE SEGMENT WHICH PASSES FROM THE TOP OF THE INLET TRANSITION ZONE TO THE POOL-TAIL CREST IS 0.6%. THE SLOPE SEGMENT WHICH PASSES THROUGH THE CONSTRUCTED RIFFLE HAS A 3% GRADIENT. THE REPRESENTATIVE REACH (RIFFLE AND POOL) FOR THE DESIGN CHANNEL HAS GRADIENT 0.8%. THE REPRESENTATIVE REACH FOR THE CONSTRUCTED RIFFLE HAS A 4% GRADIENT. THE LONGITUDINAL PROFILE ABOVE IS SHOWN WITH 2X VERTICAL EXAGGERATION. THE BLUE TRIANGLES REPRESENT THE INLET AND OUTLET TRANSITION ZONE BOUNDARIES. THE STRUCTURE IS AN OPEN BOTTOM PIPE-ARCH.

TABLE 76: DOG SLAUGHTER DESIGN CHANNEL (RIFFLE AND POOL) SLOPE SEGMENT DATA

N (m)	E (m)	Distance (m)	Elev (m)	riffle crest (rc)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc}	% diff. be-tween L_{dc} and L_{nc}	Notes
518.02	522.94	92.43	500.36	gc4								
565.31	571.42	161.48	500.77	GC5	67.73	0.41	69.05	0.006				
						Culvert Length (m)	25.97	50% similarity criteria				

TABLE 77: DOG SLAUGHTER DESIGN CHANNEL (CONSTRUCTED RIFFLE) SLOPE SEGMENT DATA

N (m)	E (m)	Distance (m)	Elev (m)	riffle crest (rc)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Notes
512.32	512.64	79.78	499.98	gc3								
518.02	522.94	92.43	500.36	gc4	11.77	0.37	12.64	0.03				
						Culvert Length (m)	8.52					

TABLE 78: DOG SLAUGHTER (RIFFLE AND POOL) REPRESENTATIVE REACH ANALYSIS

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	riffle crest (rc)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Notes
552.86	456.84	0.00	499.32	gc1								
525.16	477.98	36.68	499.81	gc2 ptc	34.85	0.49	36.68	0.01	#DIV/0!	-125.14	-41.26	
512.32	512.64	79.78	499.98	gc3	36.96	0.17	43.10	0.00	-69.82	32.05	-65.98	is below tributary confluence; not applicable
518.02	522.94	92.43	500.36	gc4	11.77	0.37	12.64	0.03	630.19	-396.15	51.31	
565.31	571.42	161.48	500.77	GC5	67.73	0.41	69.05	0.01	-79.84	0.00	-165.91	
582.36	605.53	203.88	501.42	FL	38.13	0.65	42.40	0.02	158.80	-158.80	-63.28	
581.60	637.40	236.02	501.78	GC8	31.88	0.36	32.14	0.01	-28.43	-85.22	-23.78	
584.59	668.04	268.97	502.28	GC9	30.78	0.50	32.95	0.02	38.72	-156.94	-26.88	
580.00	679.07	281.08	502.78	FL	11.95	0.49	12.10	0.04	166.51	-584.77	53.40	
583.62	714.96	318.74	503.08	GC11	36.08	0.30	37.67	0.008	-80.41	-34.15	-45.05	selected; is riffle into large deep pool
598.49	739.29	348.21	503.50	GC12	28.52	0.42	29.47	0.01	79.86	-141.28	-13.49	

TABLE 79: DOG SLAUGHTER (CONSTRUCTED RIFFLE) REPRESENTATIVE REACH ANALYSIS

N (m)	E (m)	Distance (m)	Elev (m)	riffle crest (rc)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Notes
552.86	456.84	0.00	499.32	gc1								
525.16	477.98	36.68	499.81	gc2 ptc	34.85	0.49	36.68	0.01	#DIV/0!	54.62	-330.55	
512.32	512.64	79.78	499.98	gc3	36.96	0.17	43.10	0.00	-69.82	86.30	-405.90	
518.02	522.94	92.43	500.36	gc4	11.77	0.37	12.64	0.03	630.19	0.00	-48.41	
565.31	571.42	161.48	500.77	GC5	67.73	0.41	69.05	0.01	-79.84	79.84	-710.50	
582.36	605.53	203.88	501.42	FL	38.13	0.65	42.40	0.02	158.80	47.84	-397.66	
581.60	637.40	236.02	501.78	GC8	31.88	0.36	32.14	0.01	-28.43	62.67	-277.27	
584.59	668.04	268.97	502.28	GC9	30.78	0.50	32.95	0.02	38.72	48.21	-286.74	
580.00	679.07	281.08	502.78	FL	11.95	0.49	12.10	0.04	166.51	-38.02	-42.04	selected; will use portion which is short riffle above step pool
583.62	714.96	318.74	503.08	GC11	36.08	0.30	37.67	0.01	-80.41	72.96	-342.11	
598.49	739.29	348.21	503.50	GC12	28.52	0.42	29.47	0.01	79.86	51.37	-245.92	

A4.3 DOG SLAUGHTER DATA-BY-DISTANCE-PLOTS

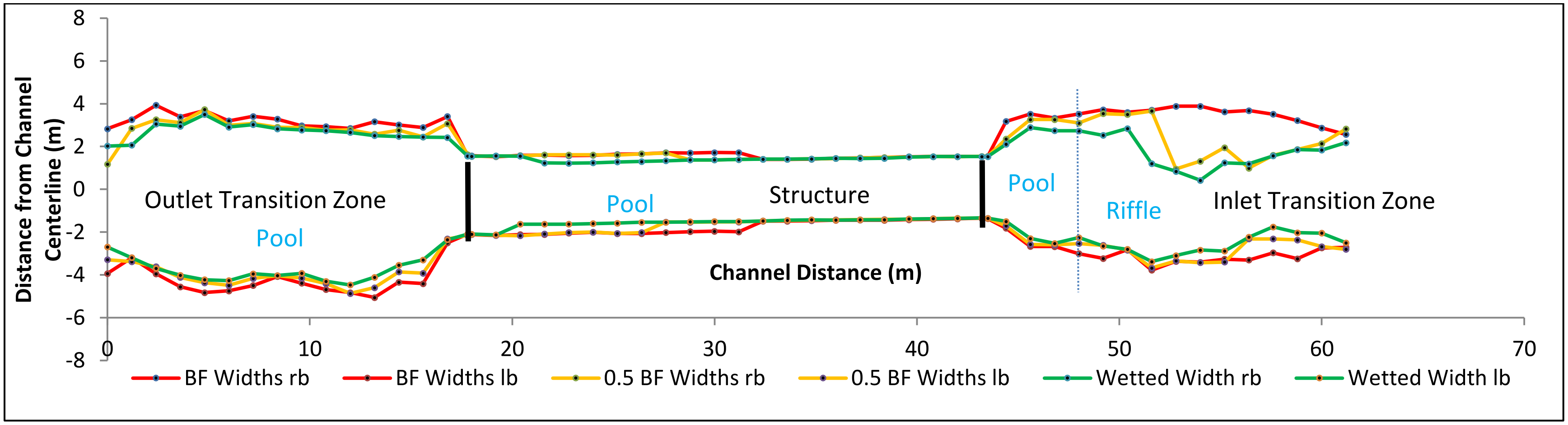

FIGURE 138: DOG SLAUGHTER DESIGN WIDTHS (RIFFLE AND POOL)

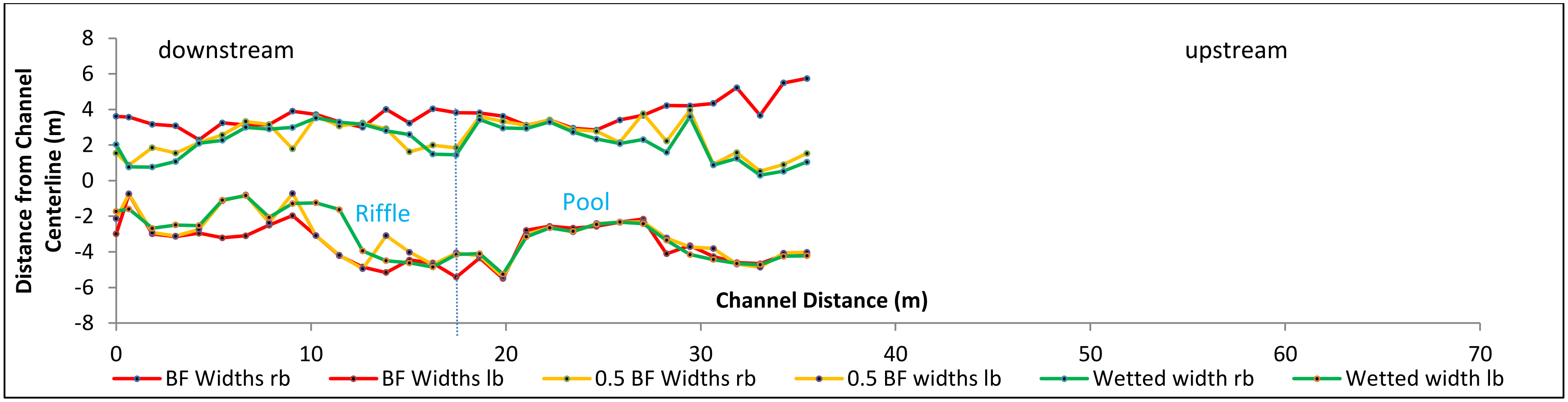

FIGURE 139: DOG SLAUGHTER REPRESENTATIVE REACH WIDTHS (POOL AND RIFFLE)

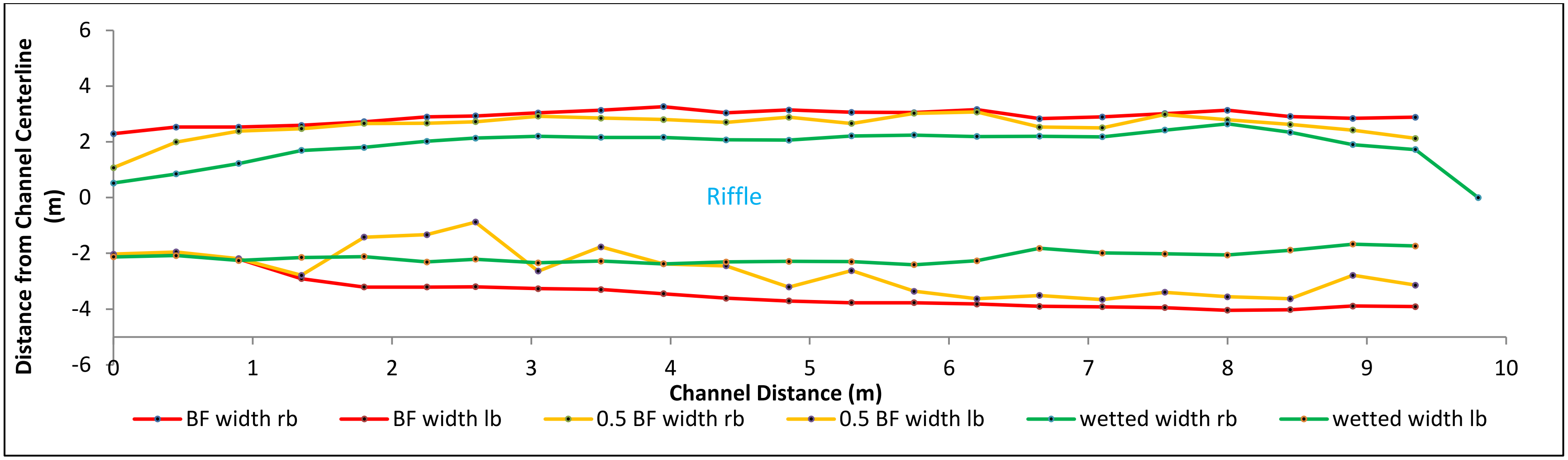

FIGURE 140: DOG SLAUGHTER CONSTRUCTED RIFFLE WIDTHS

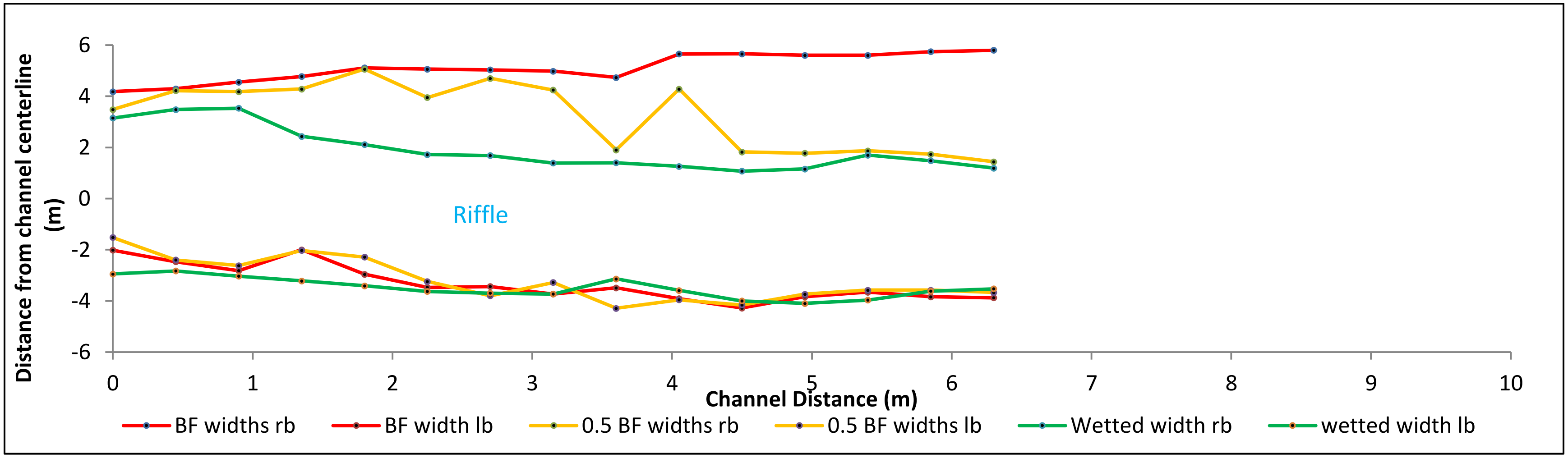

FIGURE 141: DOG SLAUGHTER CONSTRUCTED RIFFLE REPRESENTATIVE REACH WIDTHS

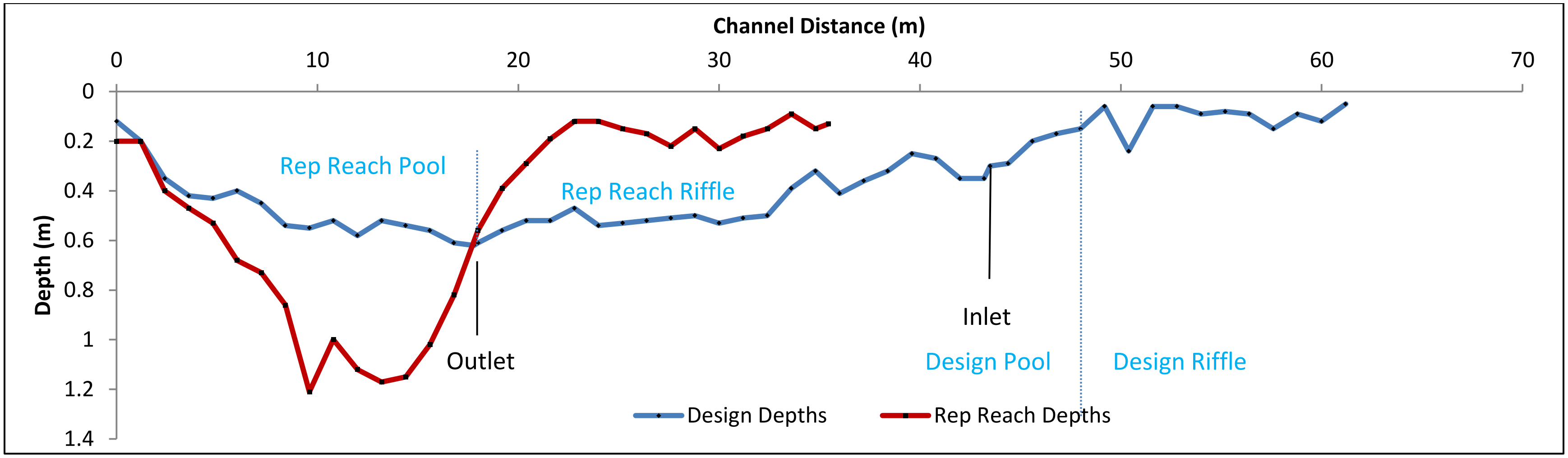

FIGURE 142: DOG SLAUGHTER DEPTHS

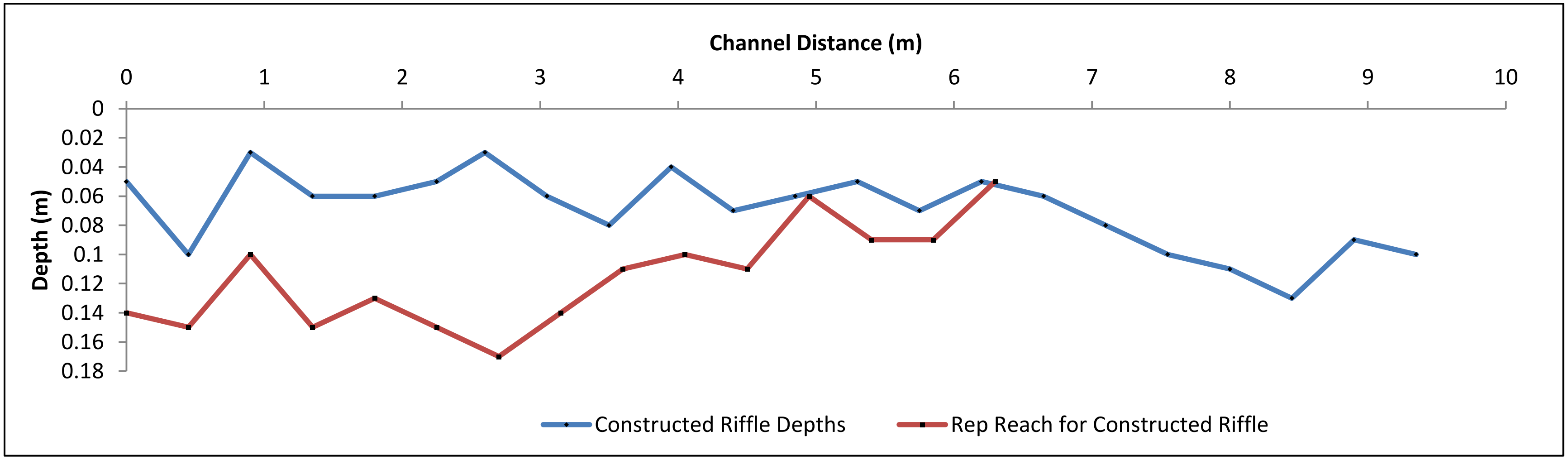

FIGURE 143: DOG SLAUGHTER CREEK CONSTRUCTED RIFFLE DEPTHS

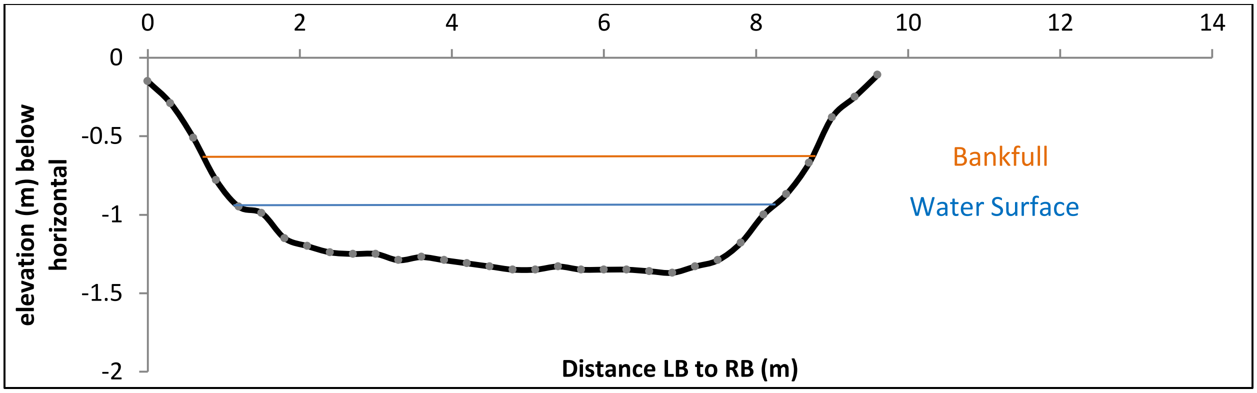

FIGURE 144: DOG SLAUGHTER CROSS SECTION 1; OUTLET TRANSITION ZONE; POOL

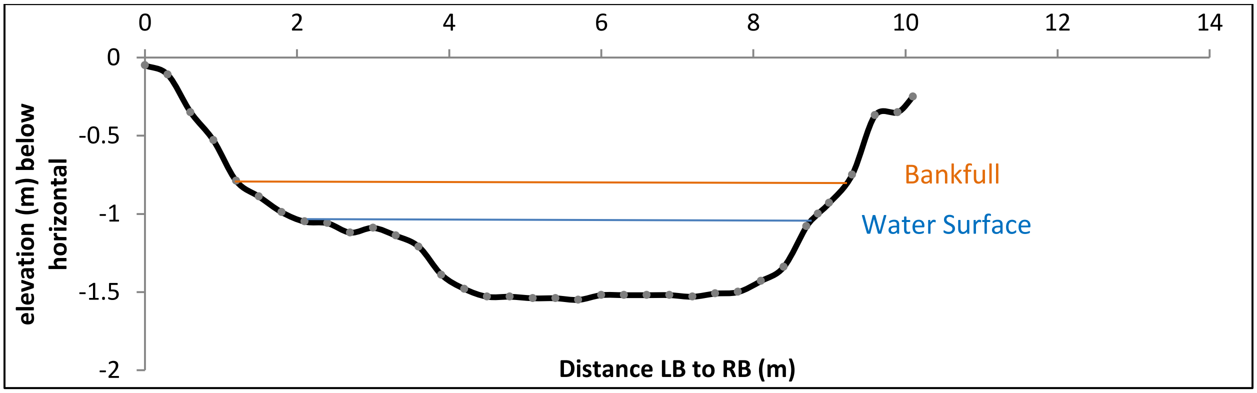

FIGURE 145: DOG SLAUGHTER CROSS SECTION 2; OUTLET TRANSITION ZONE; POOL

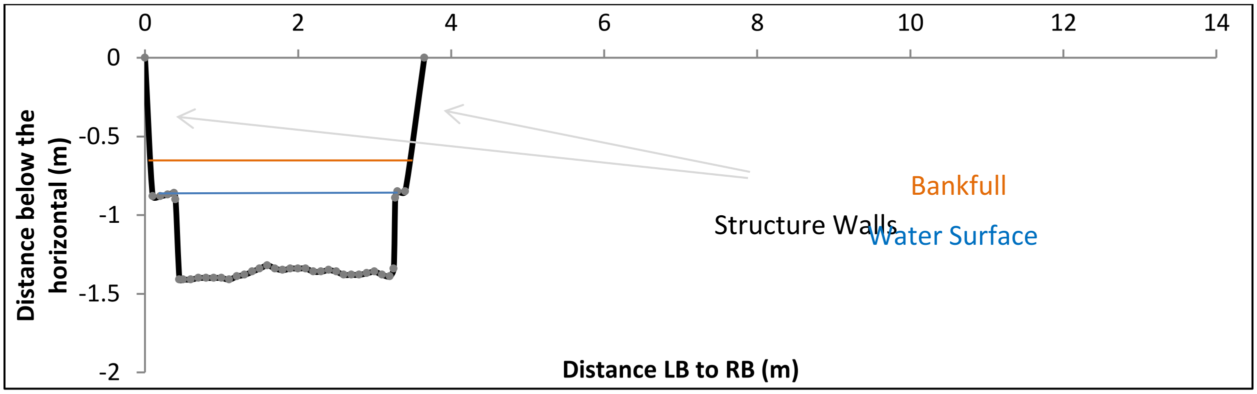

FIGURE 146: DOG SLAUGHTER CROSS SECTION 3; LOWER 1/3 OF STRUCTURE; POOL

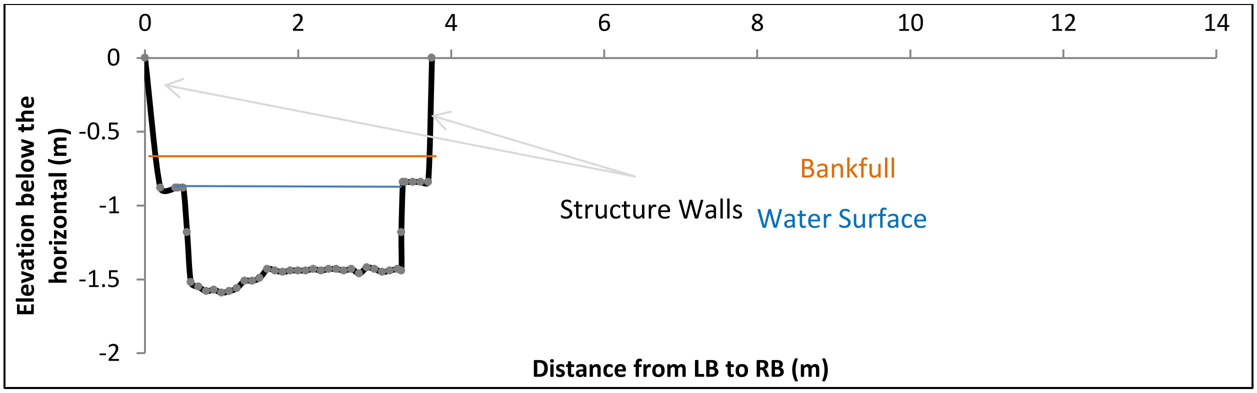

FIGURE 147: DOG SLAUGHTER CROSS SECTION 4; UPPER 1/3 OF STRUCTURE; 3 M DOWNSTREAM OF INLET; POOL

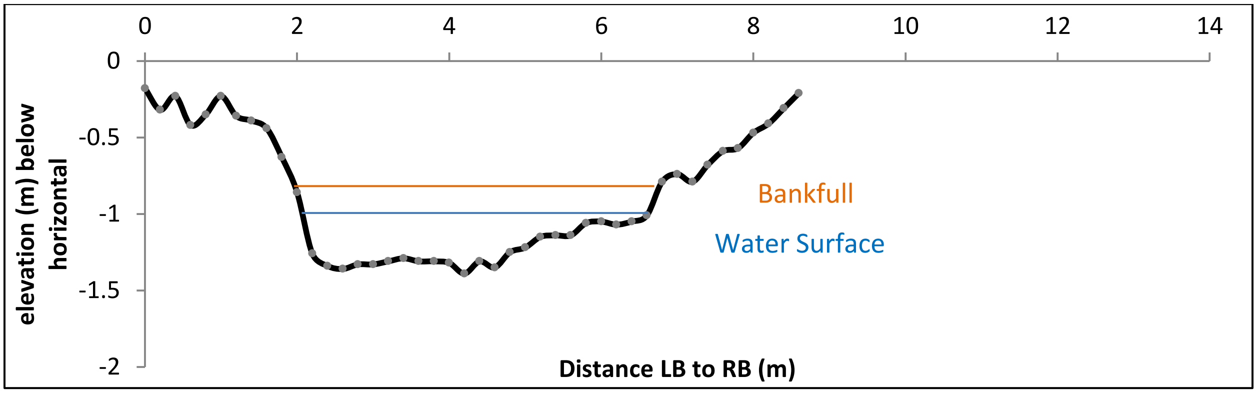

FIGURE 148: DOG SLAUGHTER CROSS SECTION 5; INLET TRANSITION ZONE; POOL

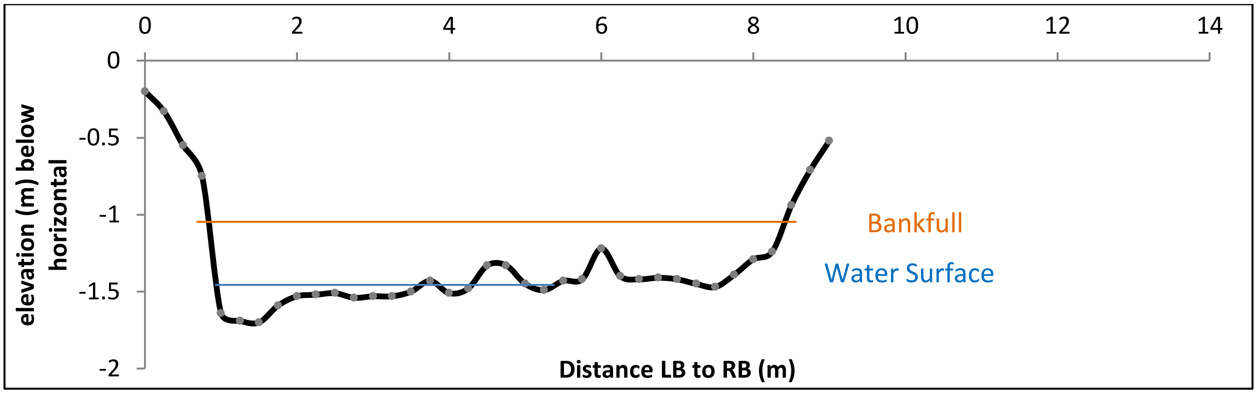

FIGURE 149: DOG SLAUGHTER CROSS SECTION 6; INLET TRANSITION ZONE; RIFFLE

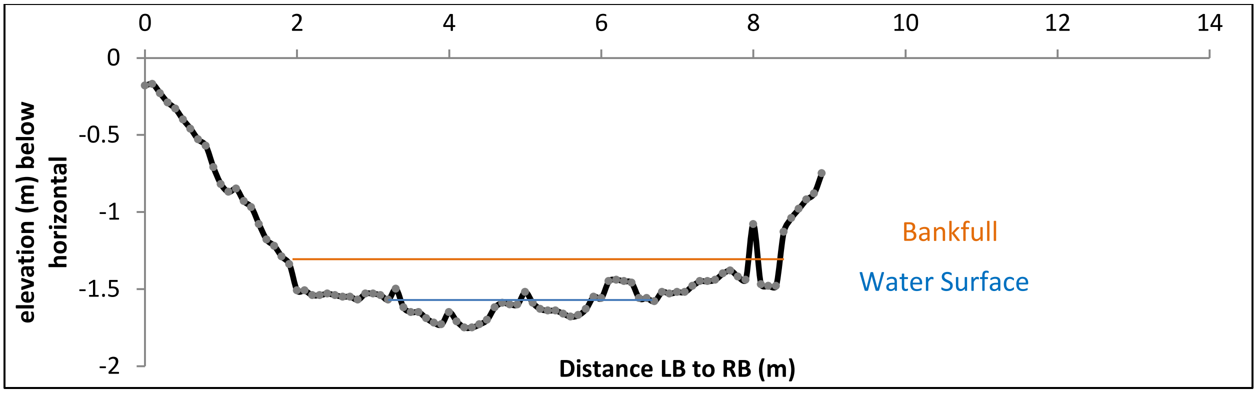

Figure 150: Dog Slaughter Cross Section 7; Inlet Transition Zone; Riffle

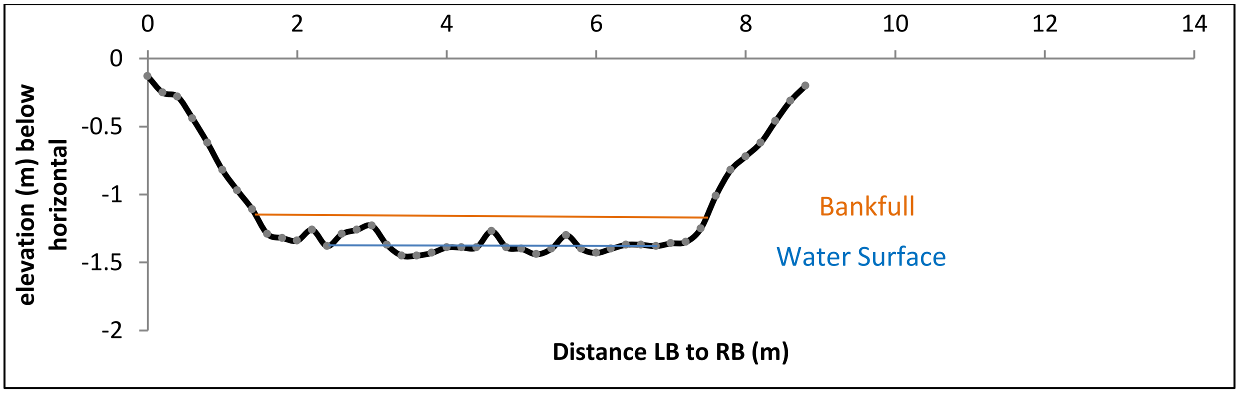

Figure 151: Dog Slaughter Cross Section 8; Constructed Riffle below Outlet Transition Zone

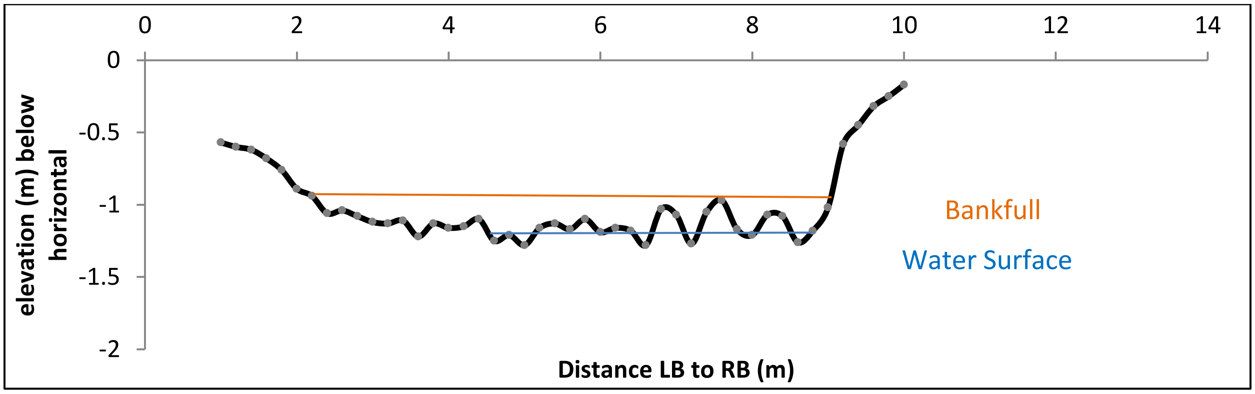

Figure 152: Dog Slaughter Cross Section 9; Representative Reach; Pool

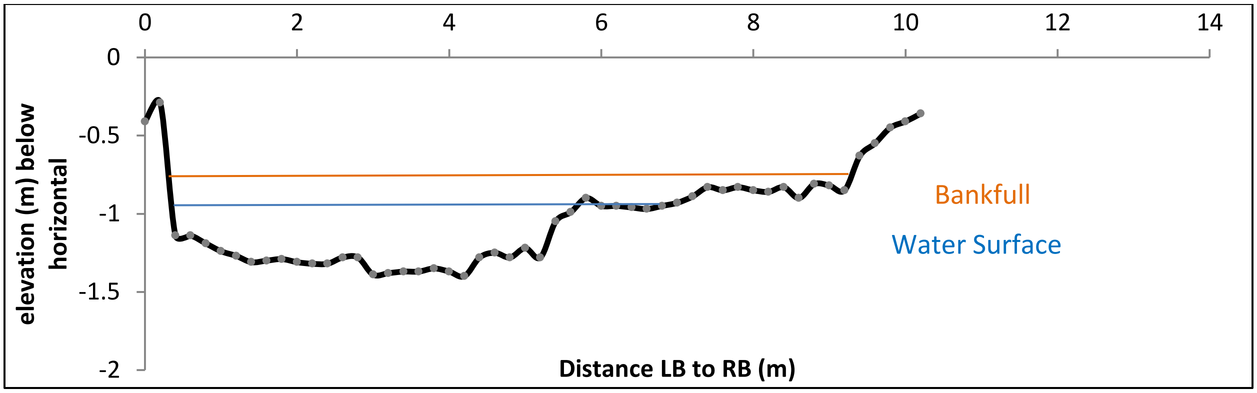

FIGURE 153: DOG SLAUGHTER CROSS SECTION 10; REPRESENTATIVE REACH; POOL

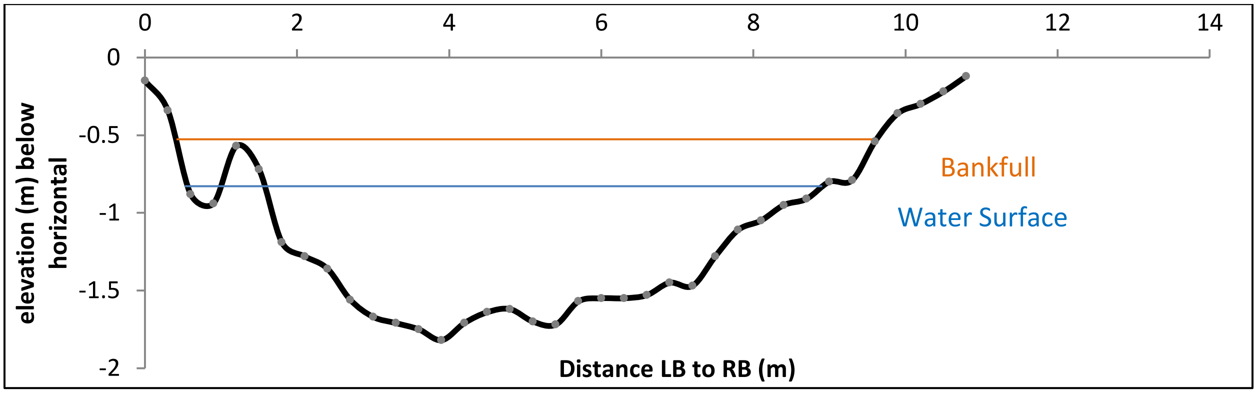

FIGURE 154: DOG SLAUGHTER CROSS SECTION 11; REPRESENTATIVE REACH; POOL

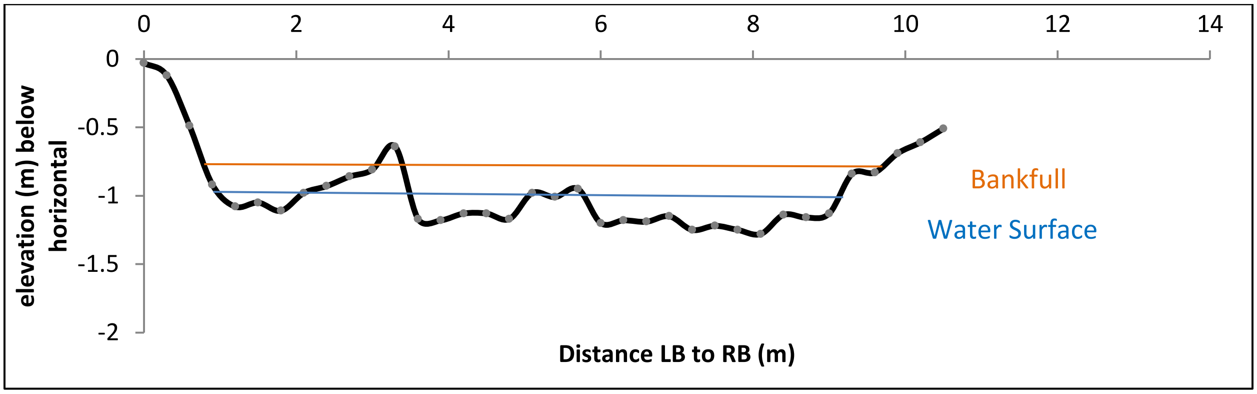

FIGURE 155: DOG SLAUGHTER CROSS SECTION 12; REPRESENTATIVE REACH FOR THE CONSTRUCTED RIFFLE

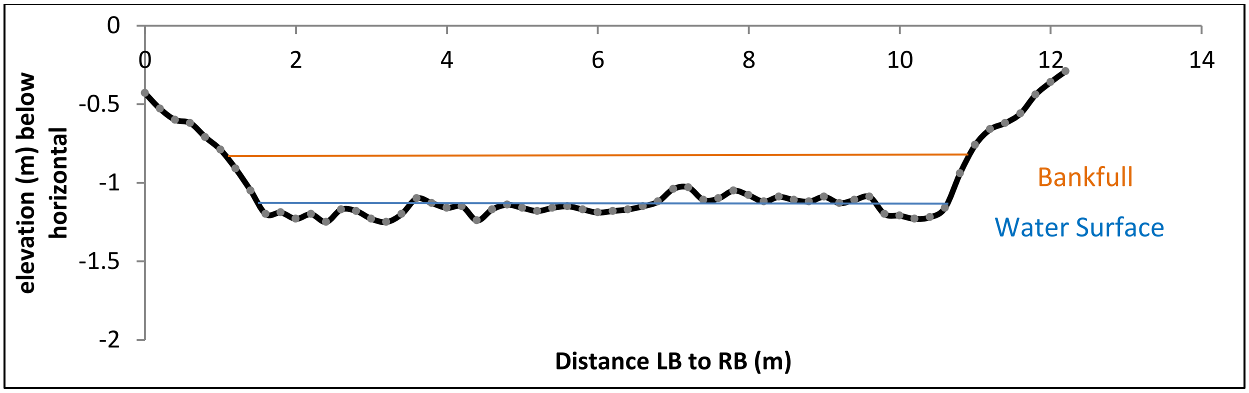

FIGURE 156: DOG SLAUGHTER CROSS SECTION 13; REPRESENTATIVE REACH FOR THE CONSTRUCTED RIFFLE

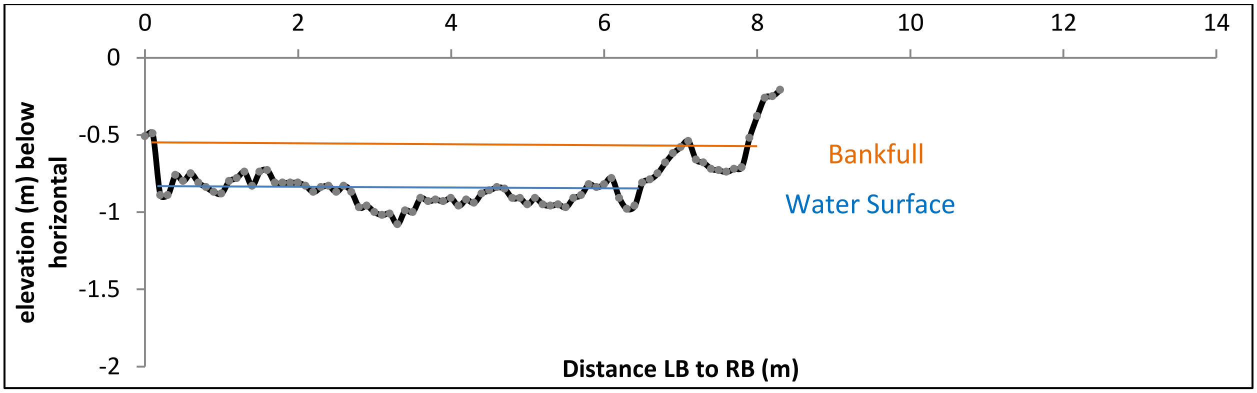

FIGURE 157: DOG SLAUGHTER CROSS SECTION 14; REPRESENTATIVE REACH FOR THE INLET TRANS ZONE; RIFFLE

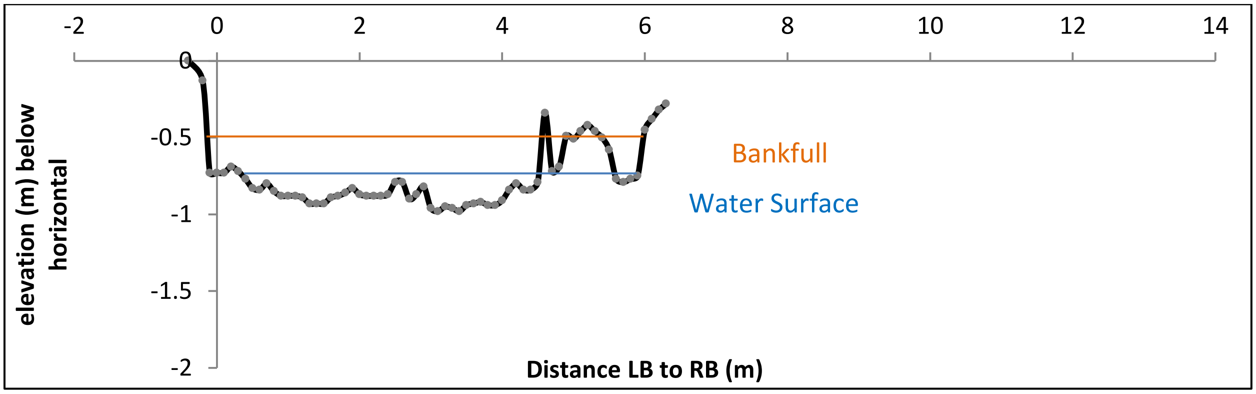

FIGURE 158: DOG SLAUGHTER CROSS SECTION 15; REPRESENTATIVE REACH FOR THE INLET TRANSITION ZONE; RIFFLE

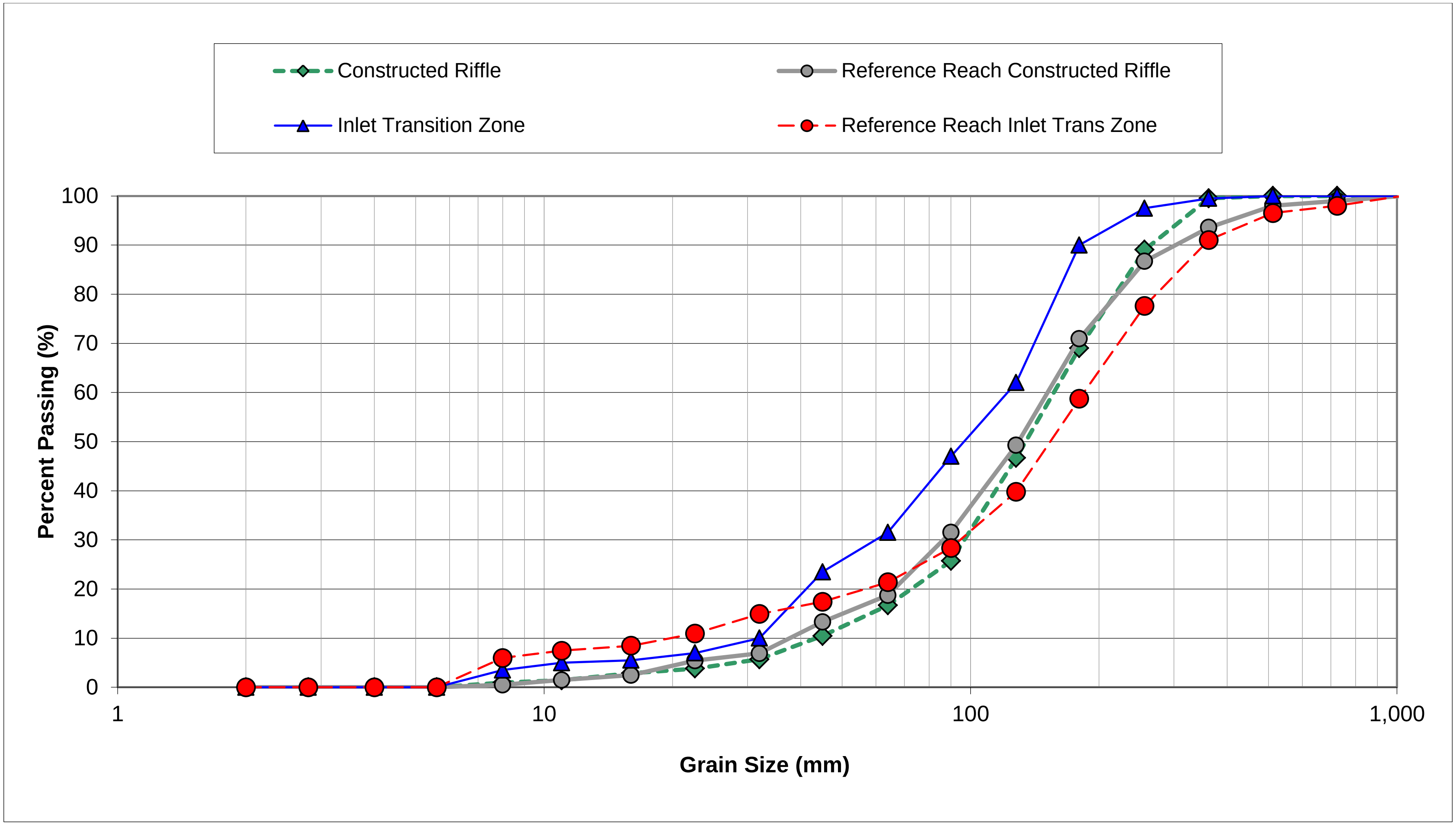

FIGURE 159: DOG SLAUGHTER GRADATION

A4.4 DOG SLAUGHTER BOXPLOTS AND HISTOGRAMS BY GROUP

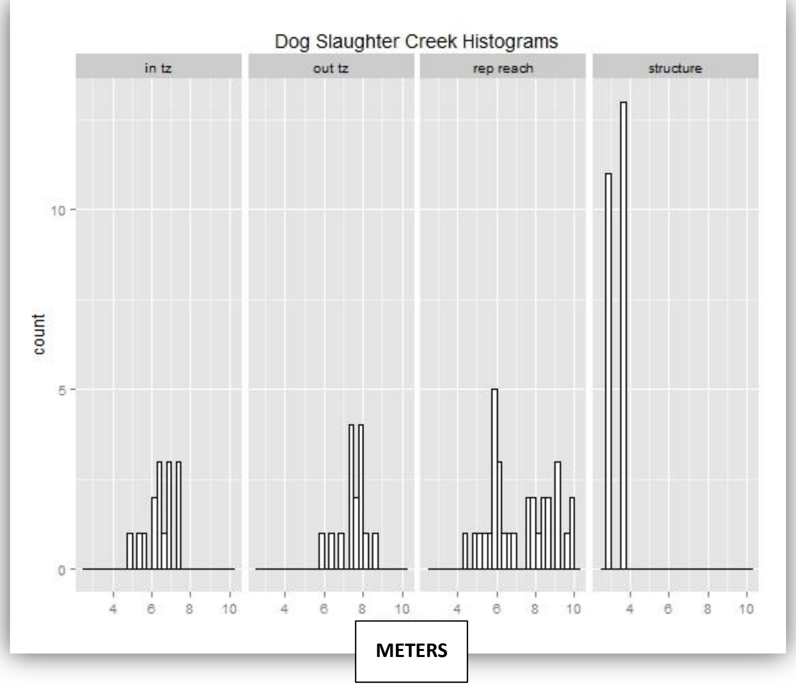

FIGURE 160: DOG SLAUGHTER WIDTH AT BANKFULL STAGE; HISTOGRAM

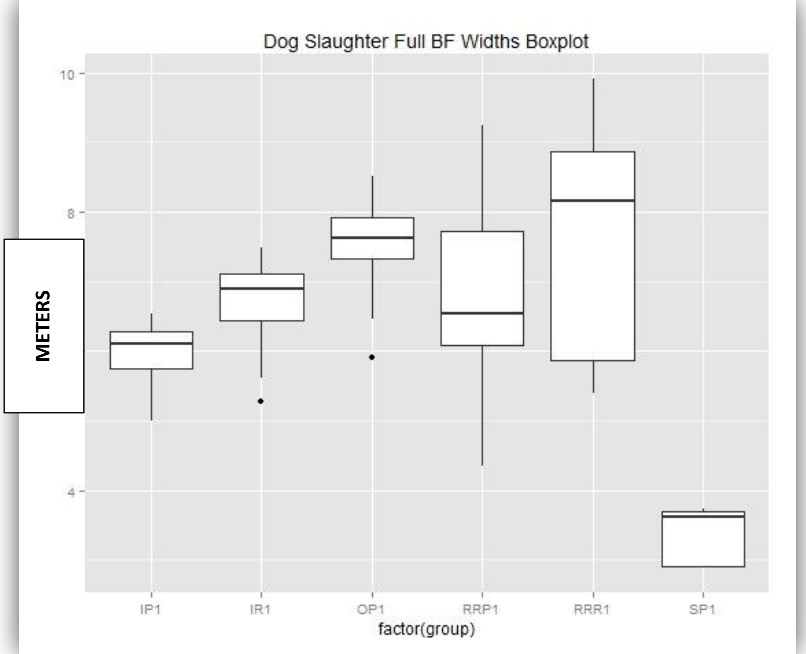

FIGURE 161: DOG SLAUGHTER WIDTHS AT BANKFULL STAGE; BOXPLOT

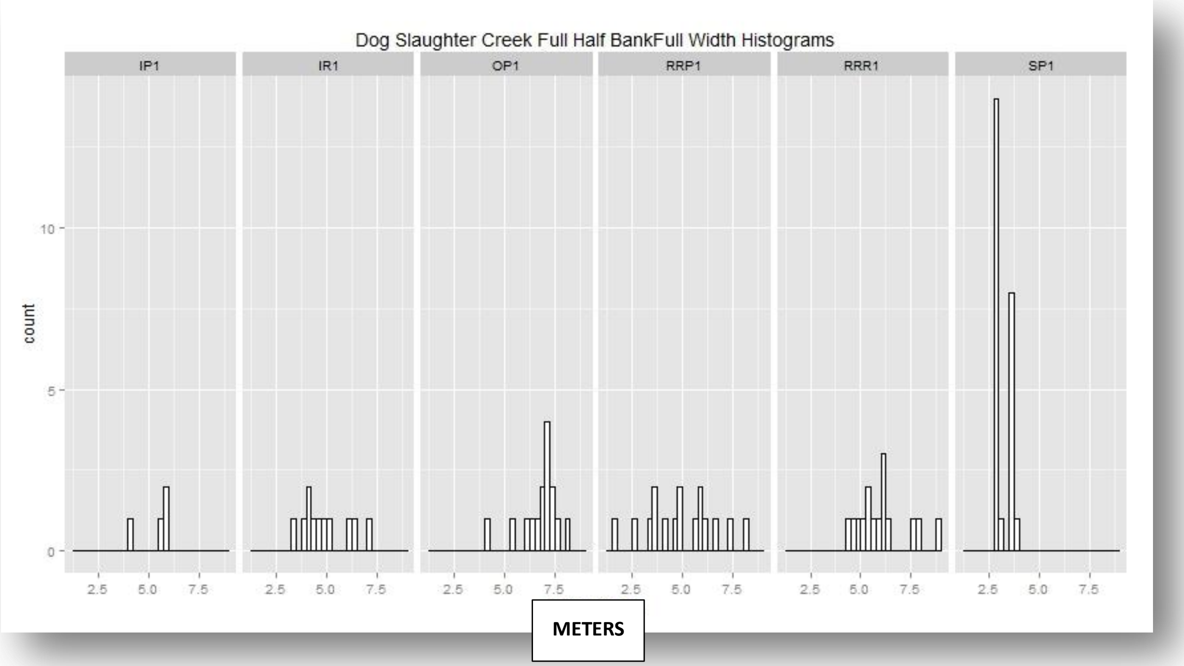

FIGURE 162: DOG SLAUGHTER WIDTH AT HALF BANKFULL STAGE; HISTOGRAM

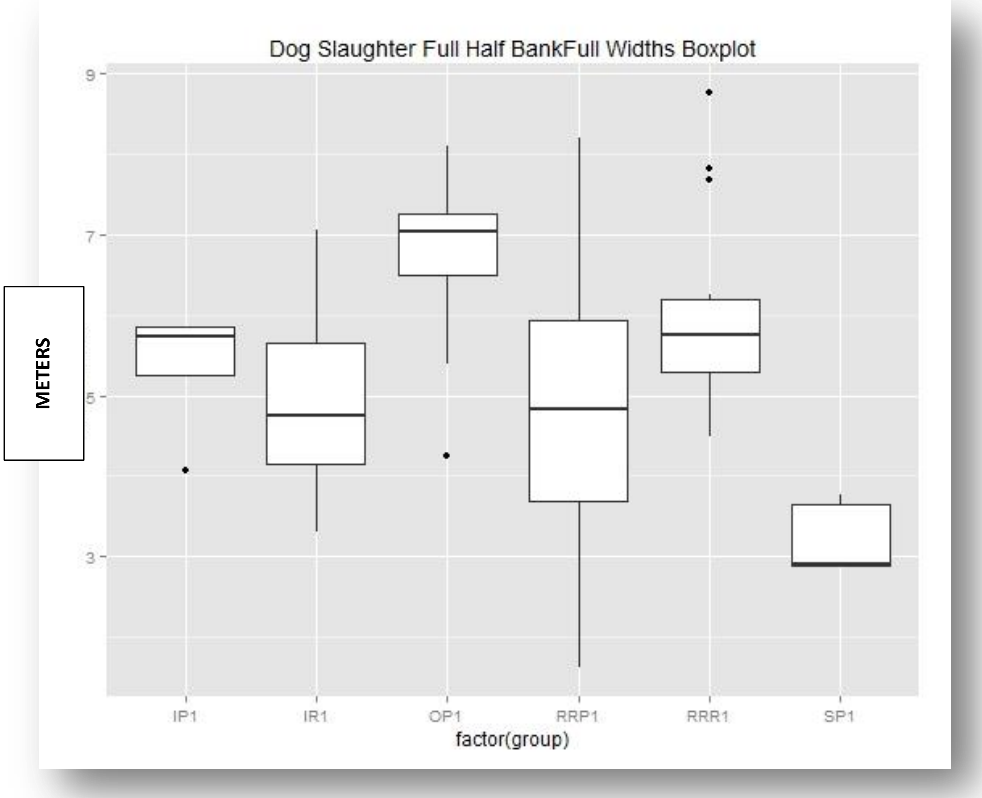

FIGURE 163: DOG SLAUGHTER WIDTH AT HALF BANKFULL STAGE; BOXPLOT

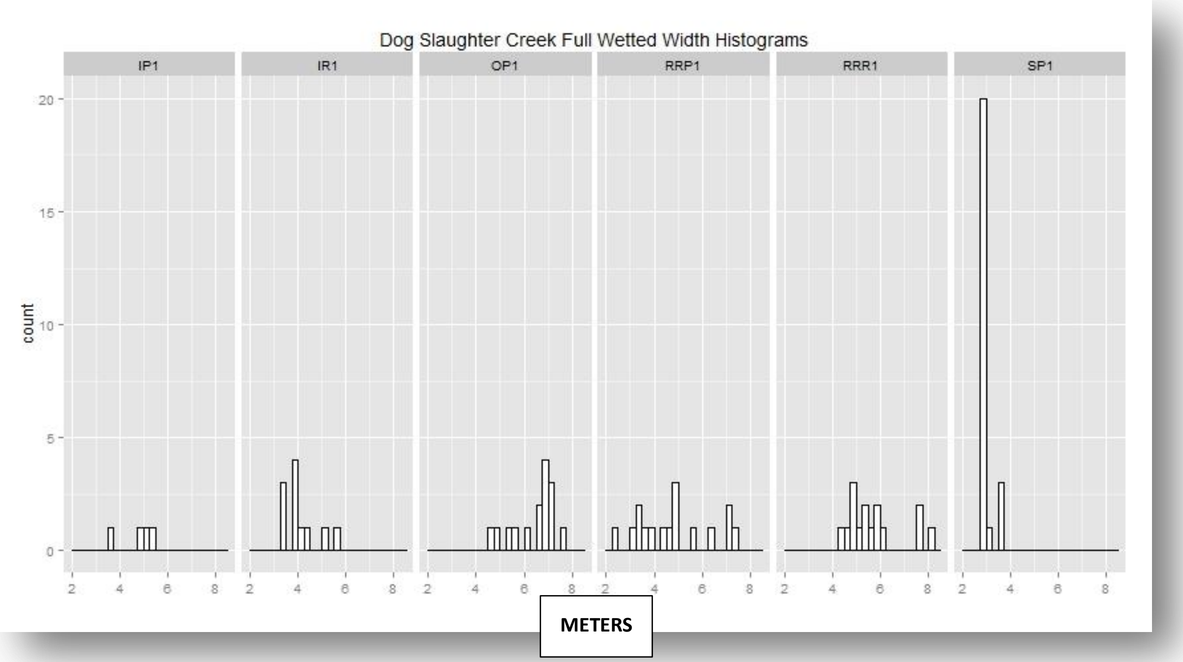

FIGURE 164: DOG SLAUGHTER LOW FLOW WIDTHS; HISTOGRAM

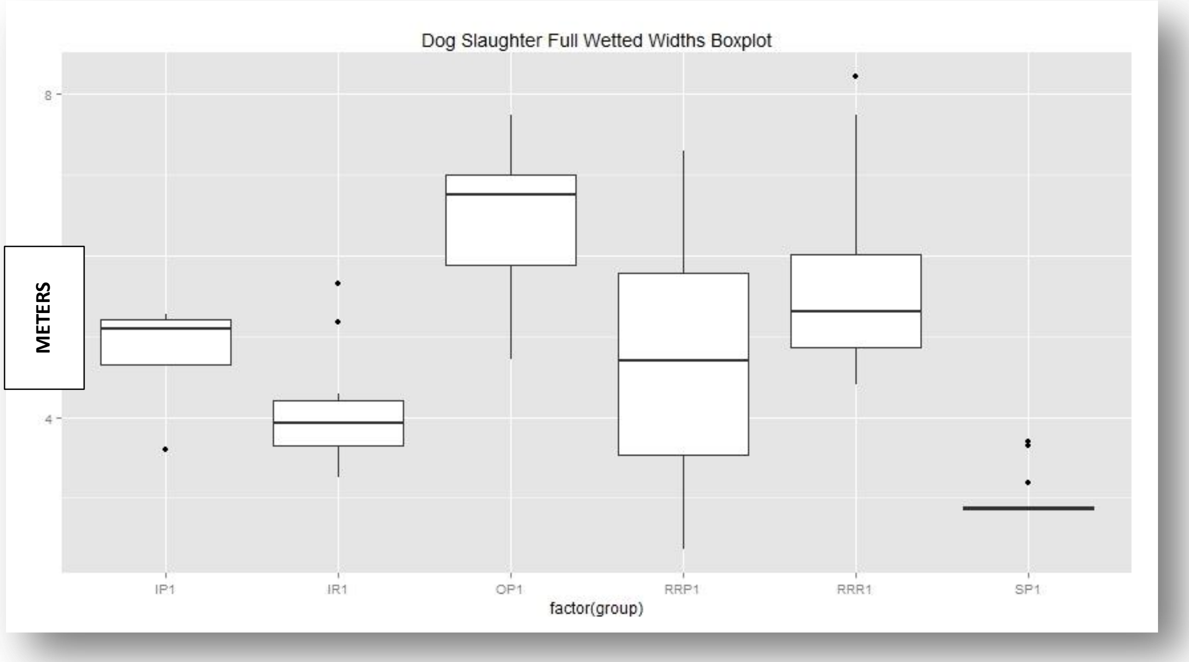

FIGURE 165: DOG SLAUGHTER LOW FLOW WIDTHS; BOXPLOT

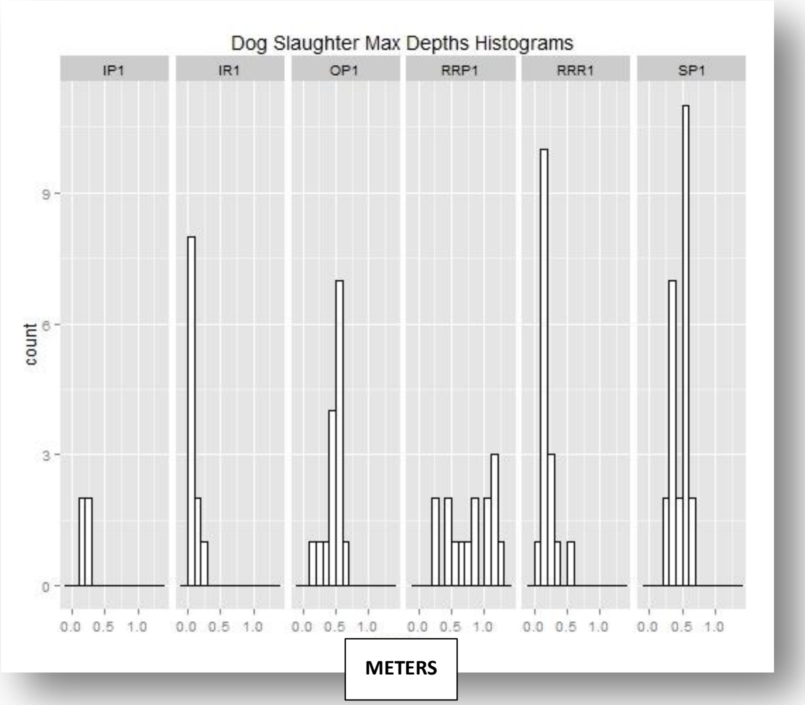

FIGURE 166: DOG SLAUGHTER MAXIMUM DEPTHS; HISTOGRAM

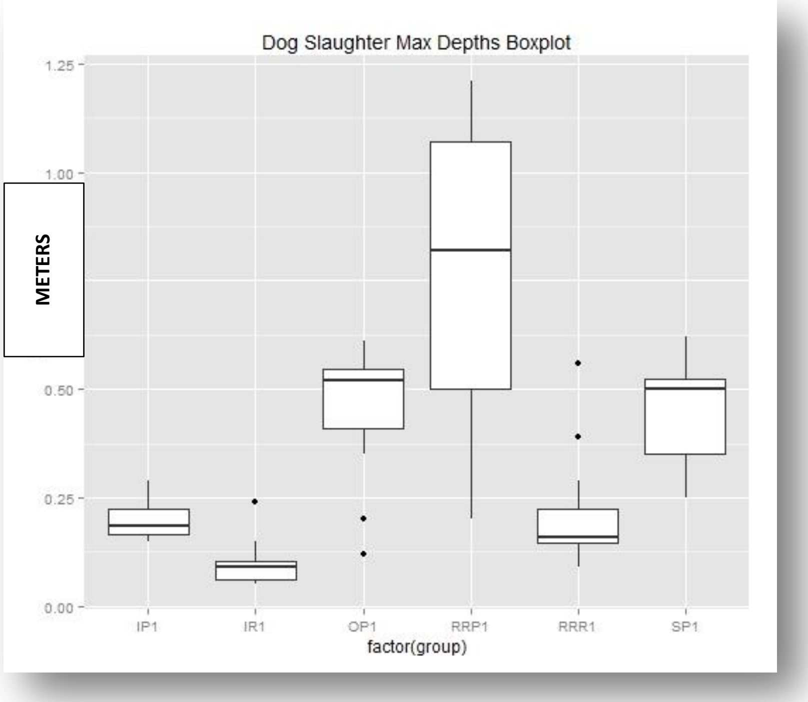

FIGURE 167: DOG SLAUGHTER MAXIMUM DEPTHS; BOXPLOT

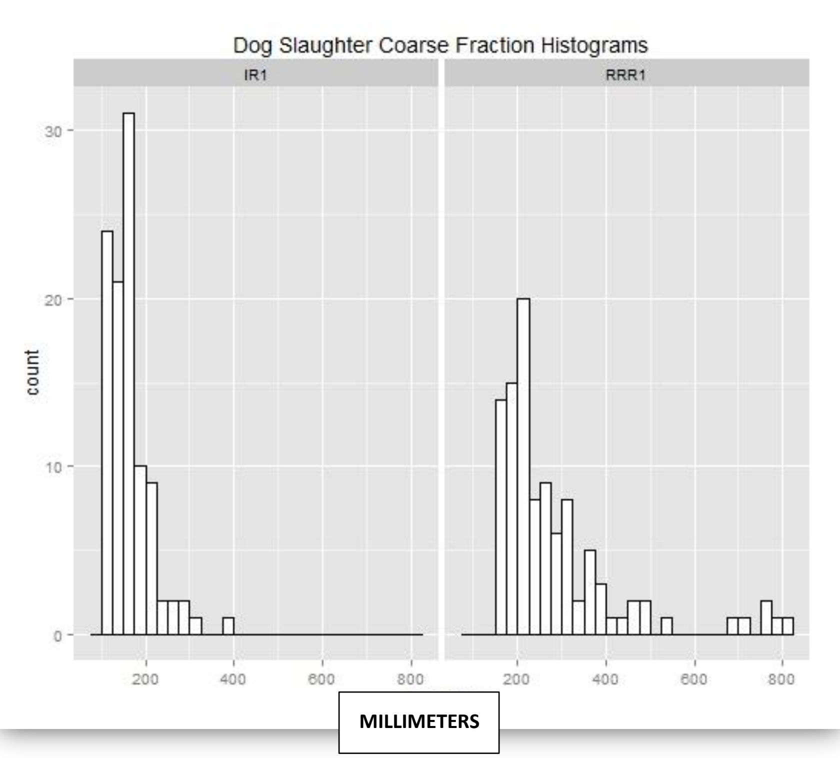

FIGURE 168: DOG SLAUGHTER COARSE FRACTION OF THE GRADATION; HISTOGRAM

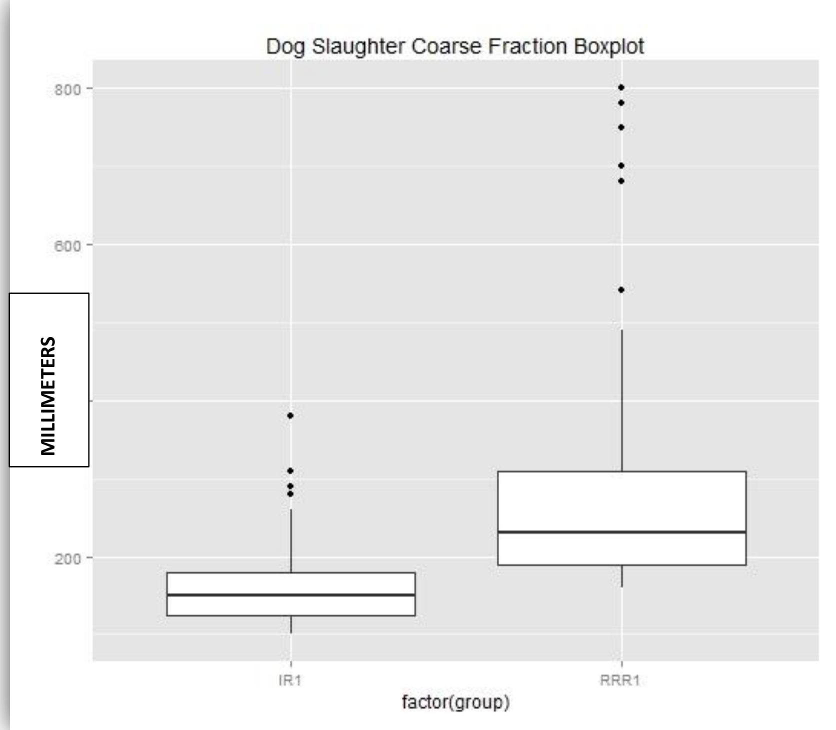

FIGURE 169: DOG SLAUGHTER COARSE FRACTION; BOXPLOT

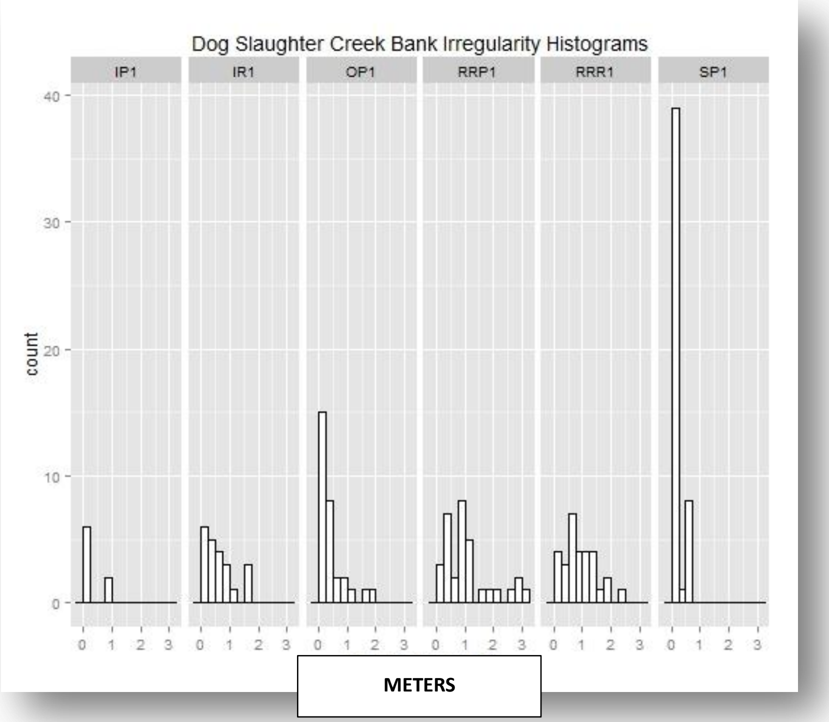

FIGURE 170: DOG SLAUGHTER BANK IRREGULARITY; HISTOGRAM

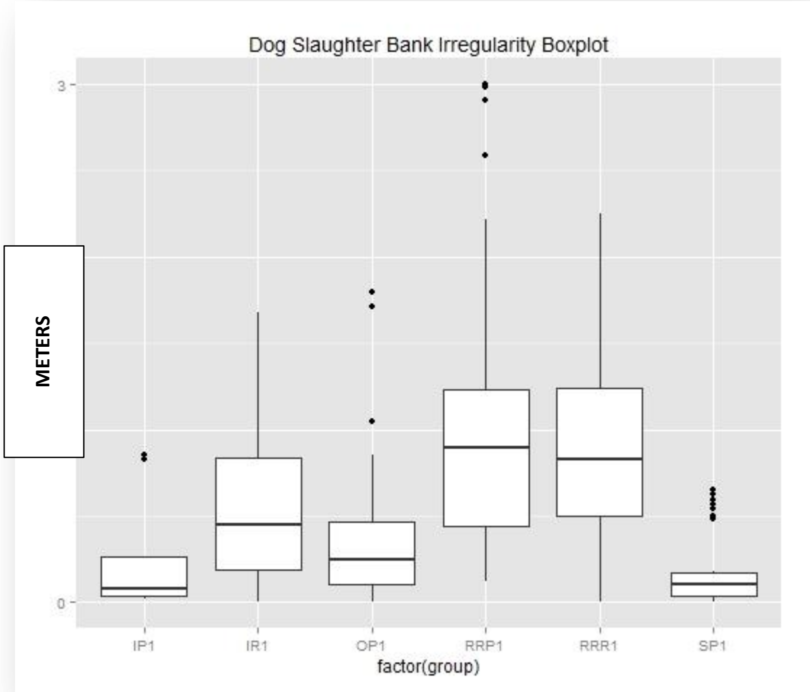

FIGURE 171: DOG SLAUGHTER BANK IRREGULARITY; BOXPLOT

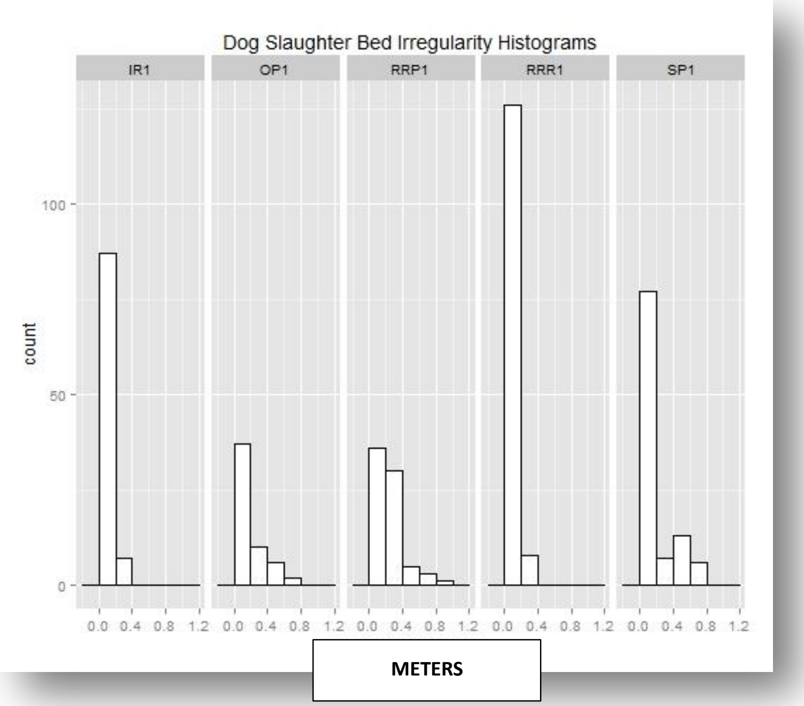

FIGURE 172: DOG SLAUGHTER BED IRREGULARITY; HISTOGRAM

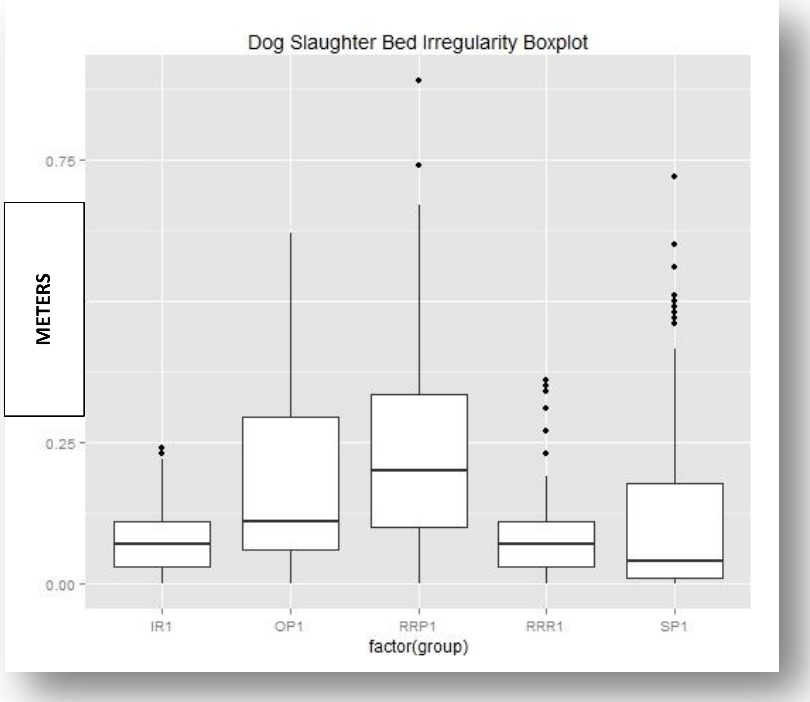

FIGURE 173: DOG SLAUGHTER BED IRREGULARITY

A4.5 DOG SLAUGHTER BOXPLOTS AND HISTOGRAMS FOR THE CONSTRUCTED RIFFLE

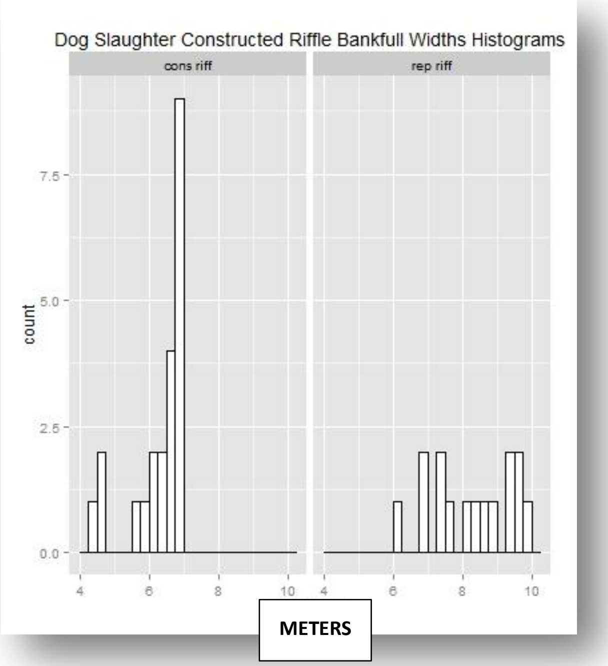

FIGURE 174: DOG SLAUGHTER CONSTRUCTED RIFFLE WIDTHS AT BANKFULL STAGE; HISTOGRAM

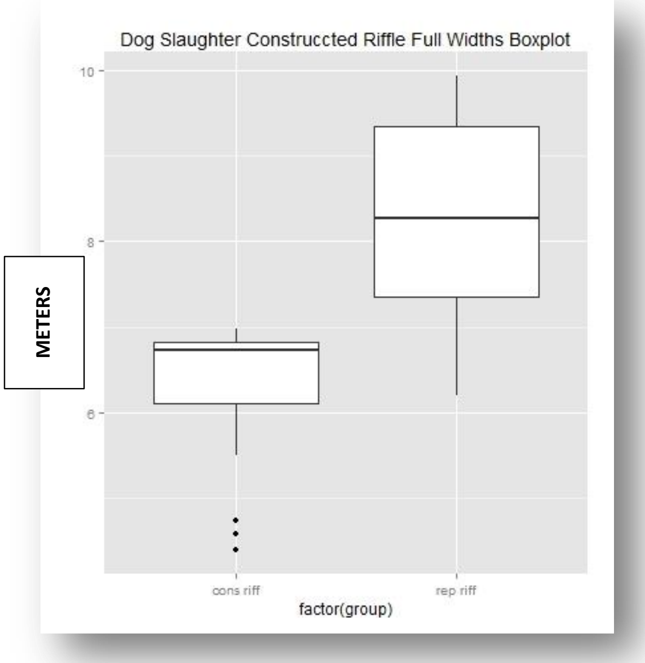

FIGURE 175: DOG SLAUGHTER CONSTRUCTED RIFFLE WIDTH AT BANKFULL STAGE; BOXPLOT

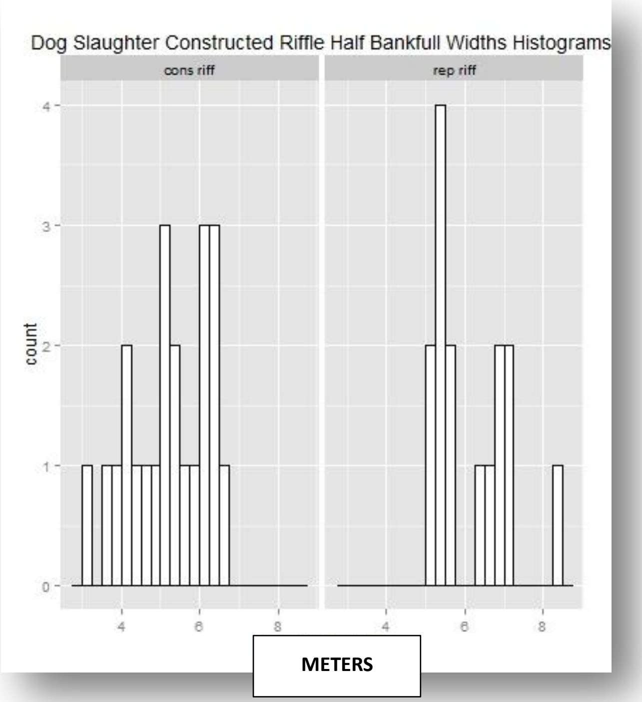

FIGURE 176: DOG SLAUGHTER CONSTRUCTED RIFFLE WIDTHS AT HALF BANKFULL STAGE; HISTOGRAM

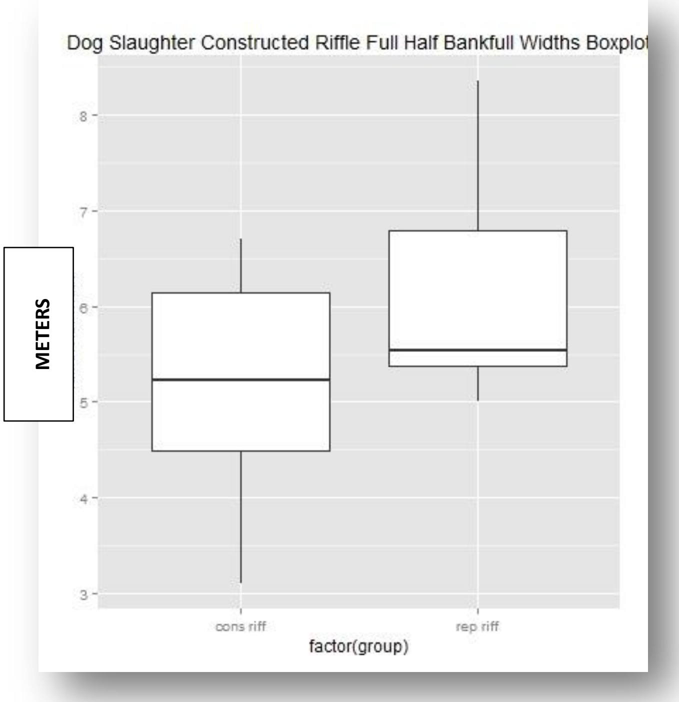

FIGURE 177: DOG SLAUGHTER CONSTRUCTED RIFFLE WIDTH AT HALF BANKFULL STAGE; BOXPLOT

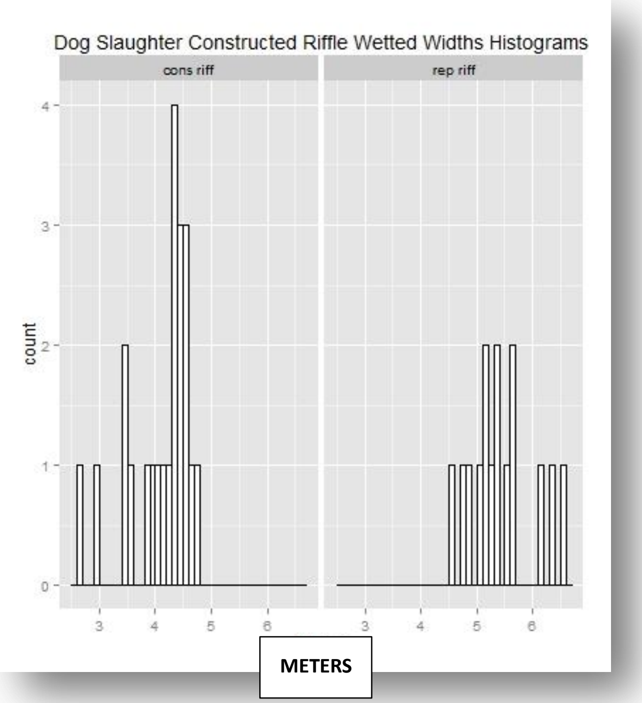

FIGURE 178: DOG SLAUGHTER CONSTRUCTED RIFFLE LOW FLOW WIDTH; HISTOGRAM

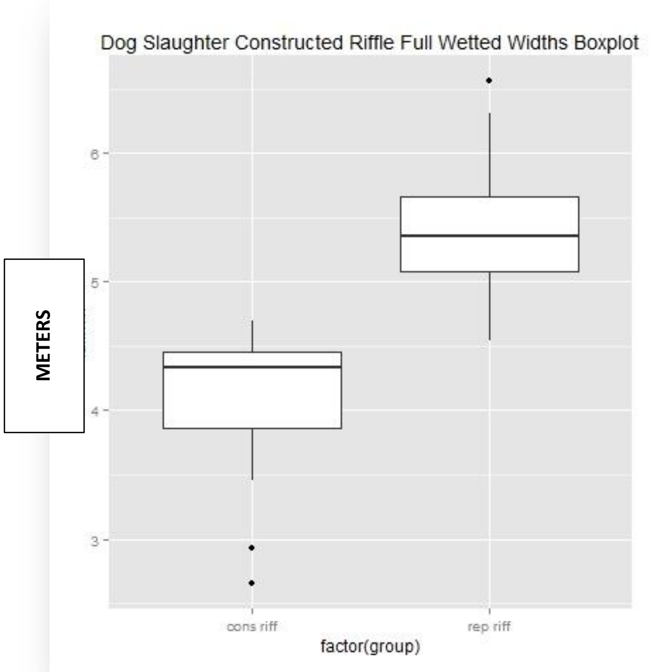

FIGURE 179: DOG SLAUGHTER CONSTRUCTED RIFFLE LOW FLOW WIDTH; BOXPLOT

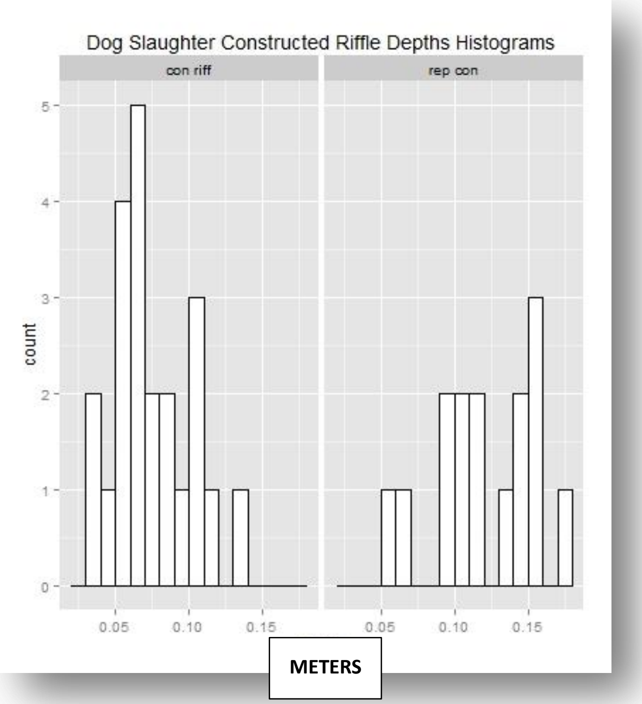

FIGURE 180: DOG SLAUGHTER CONSTRUCTED RIFFLE MAXIMUM DEPTH; HISTOGRAM

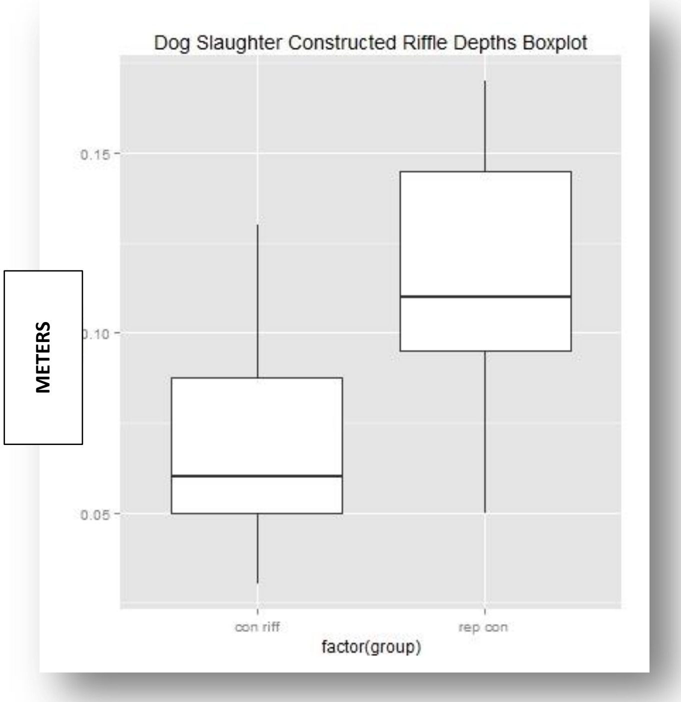

FIGURE 181: DOG SLAUGHTER CONSTRUCTED RIFFLE MAXIMUM DEPTHS; BOXPLOT

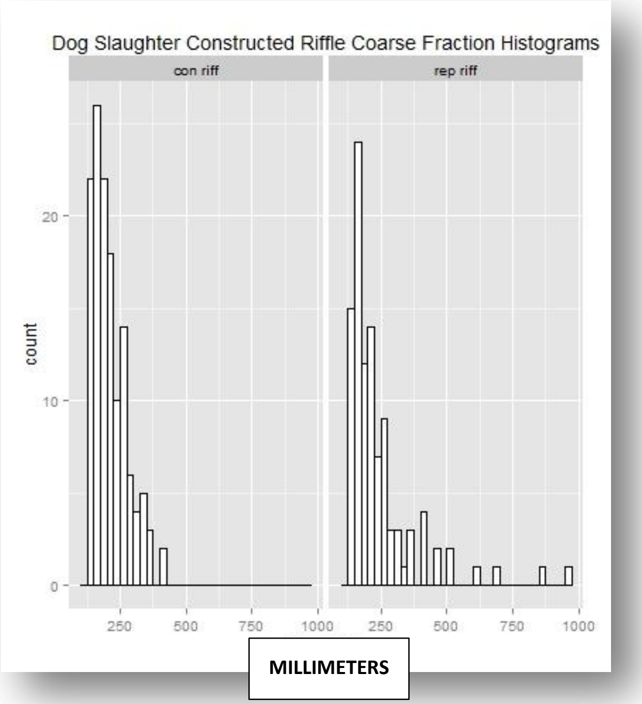

FIGURE 182: DOG SLAUGHTER CONSTRUCTED RIFFLE COARSE FRACTION; HISTOGRAM

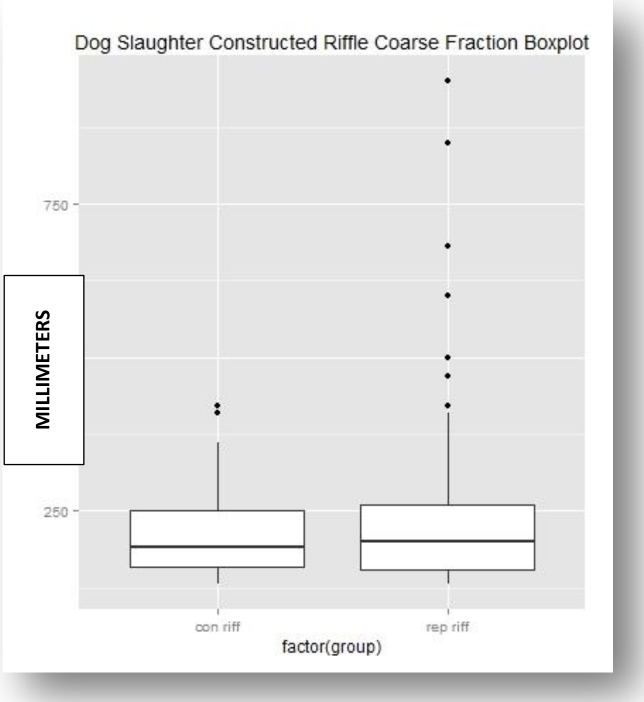

FIGURE 183: DOG SLAUGHTER CONSTRUCTED RIFFLE COARSE FRACTION OF THE GRADATION; BOXPLOT

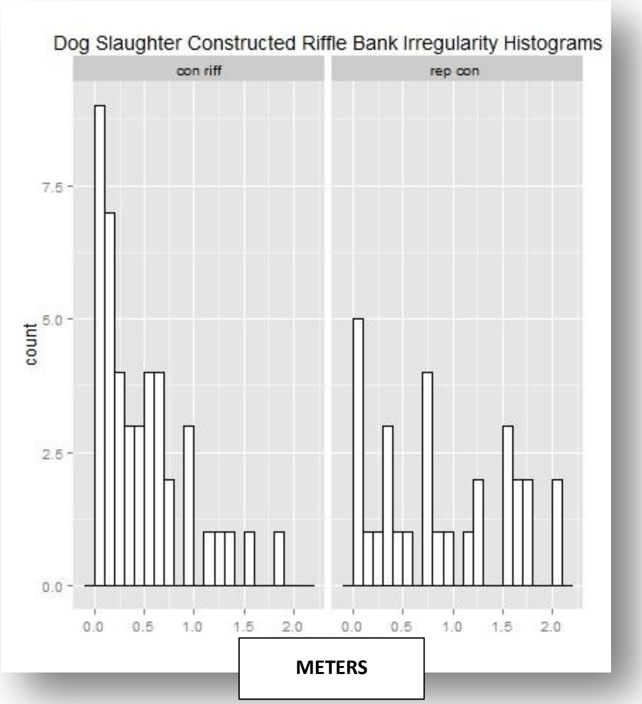

FIGURE 184: DOG SLAUGHTER CONSTRUCTED RIFFLE; BANK IRREGULARITY HISTOGRAM

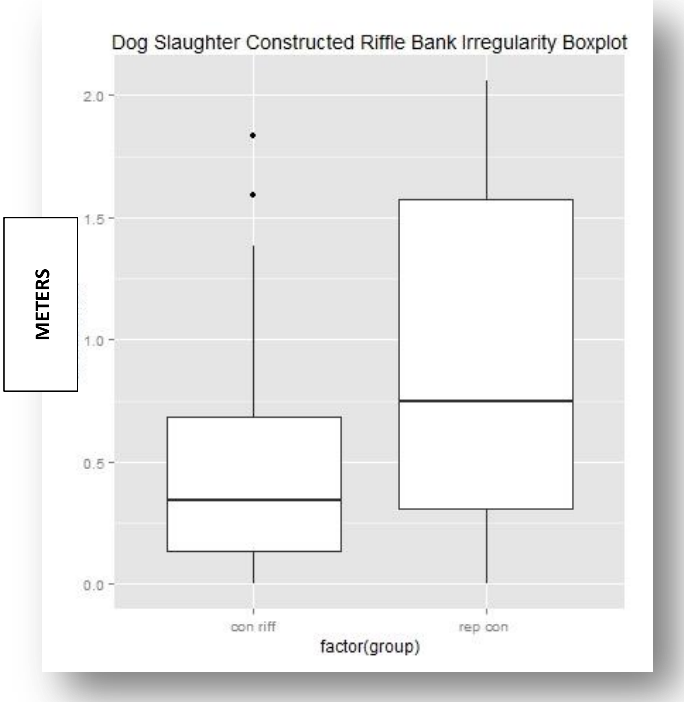

FIGURE 185: DOG SLAUGHTER CONSTRUCTED RIFFLE BANK IRREGULARITY; BOXPLOT

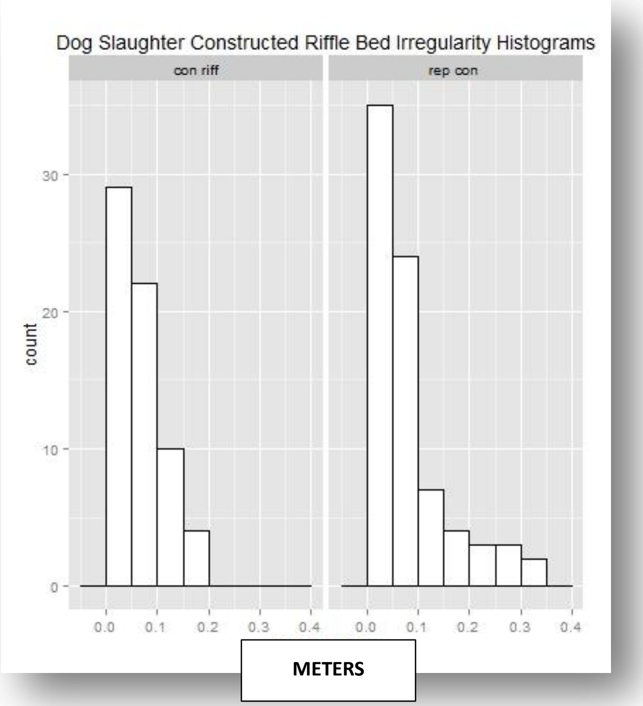

FIGURE 186: DOG SLAUGHTER CONSTRUCTED RIFFLE BED IRREGULARITY; HISTOGRAM

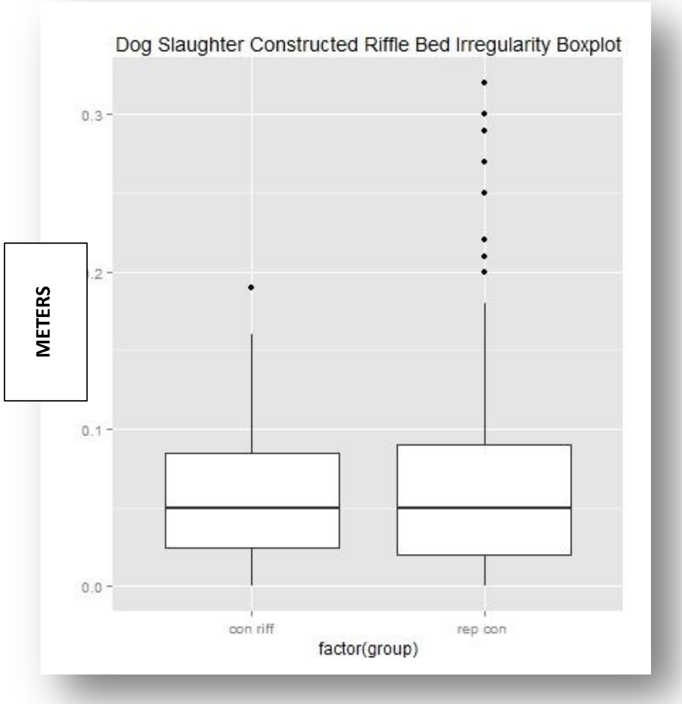

FIGURE 187: DOG SLAUGHTER CONSTRUCTED RIFFLE BED IRREGULARITY; BOXPLOT

A4.6 DOG SLAUGHTER BOXPLOTS AND HISTOGRAMS BY POPULATION

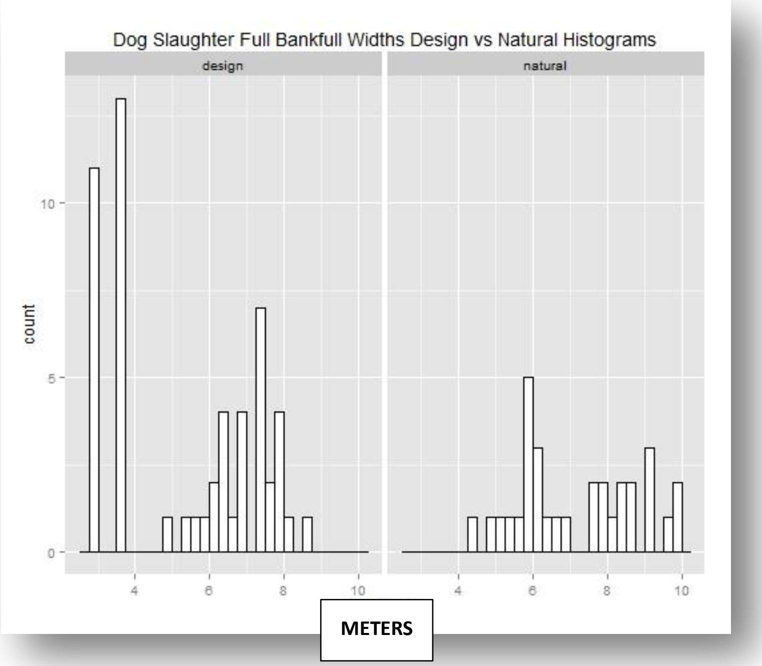

FIGURE 188: WIDTH AT BANKFULL STAGE BY POPULATION; HISTOGRAM

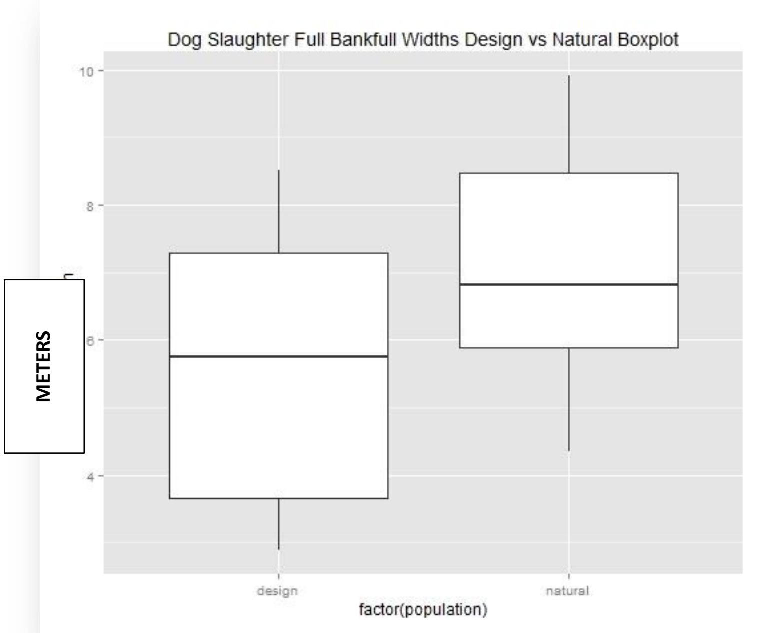

FIGURE 189: DOG SLAUGHTER WIDTH AT BANKFULL STAGE BY POPULATION; BOXPLOT

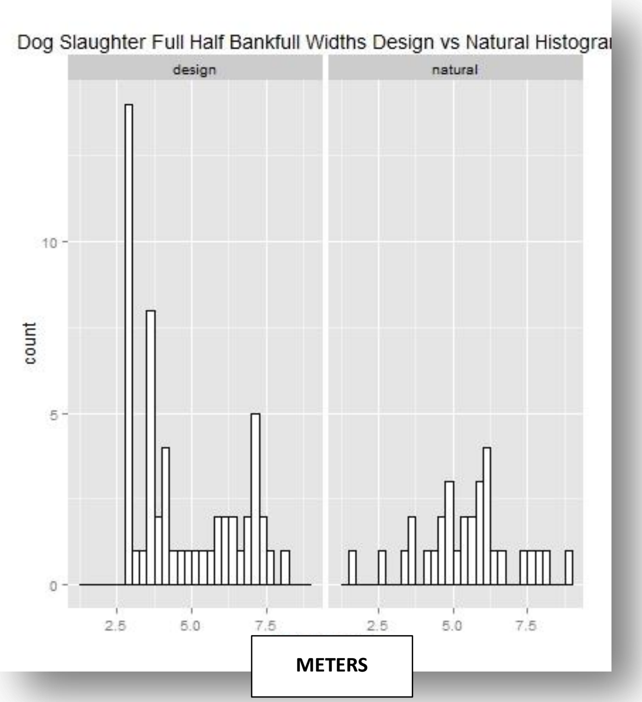

FIGURE 190: DOG SLAUGHTER WIDTHS AT HALF BANKFULL STAGE BY POPULATION; HISTOGRAM

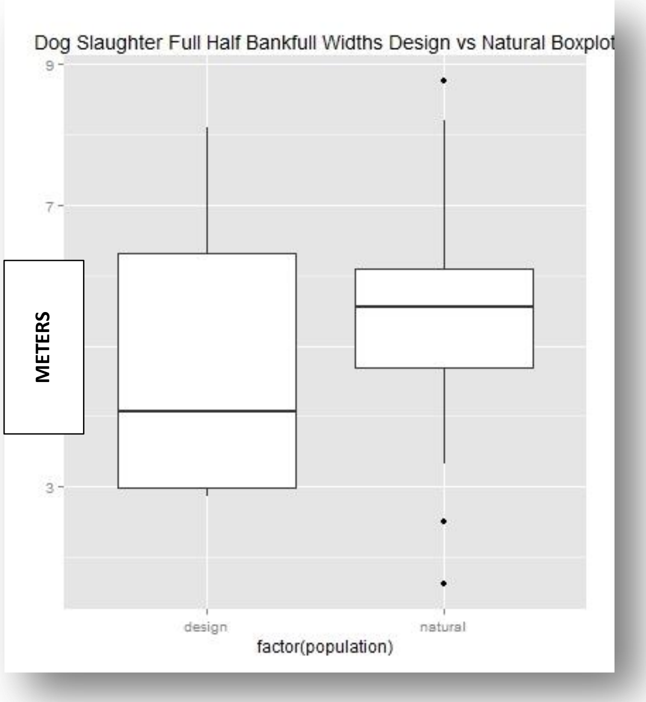

FIGURE 191: DOG SLAUGHTER WIDTH AT HALF BANKFULL STAGE BY POPULATION; BOXPLOT

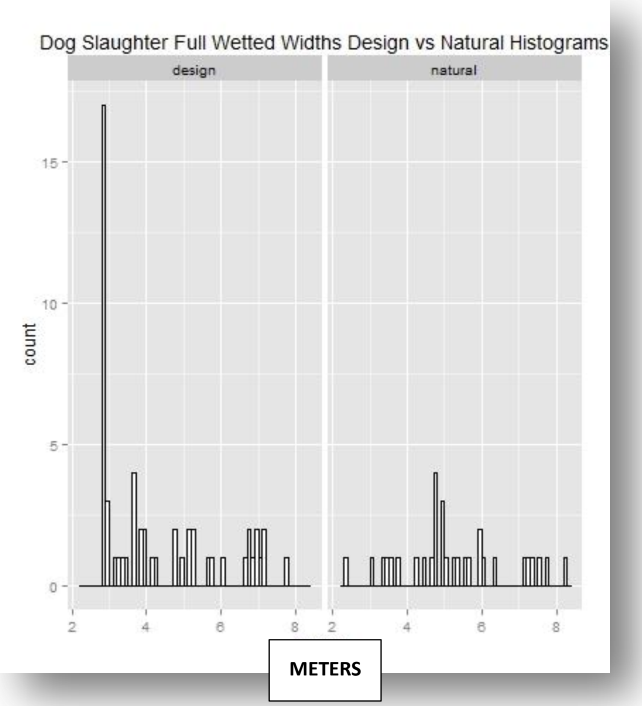

FIGURE 192: DOG SLAUGHTER WIDTH AT LOW FLOW BY POPULATION; HISTOGRAM

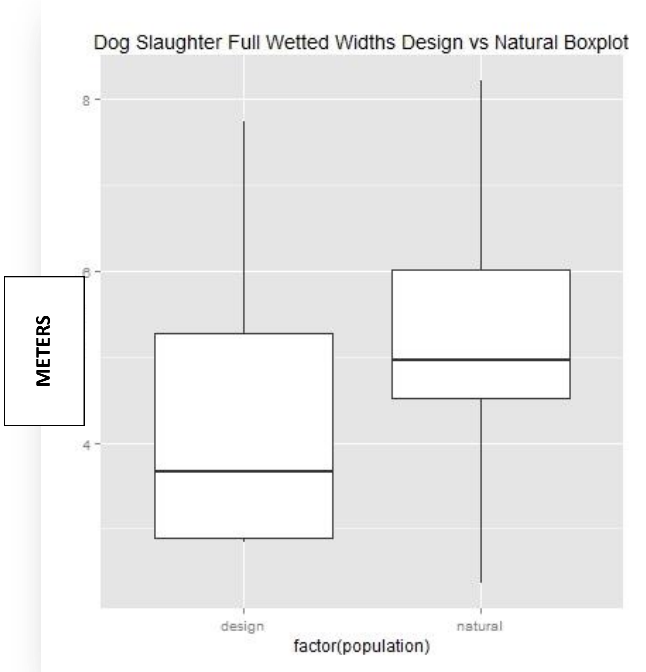

FIGURE 193: DOG SLAUGHTER WIDTH AT LOW FLOW BY POPULATION; BOXPLOT

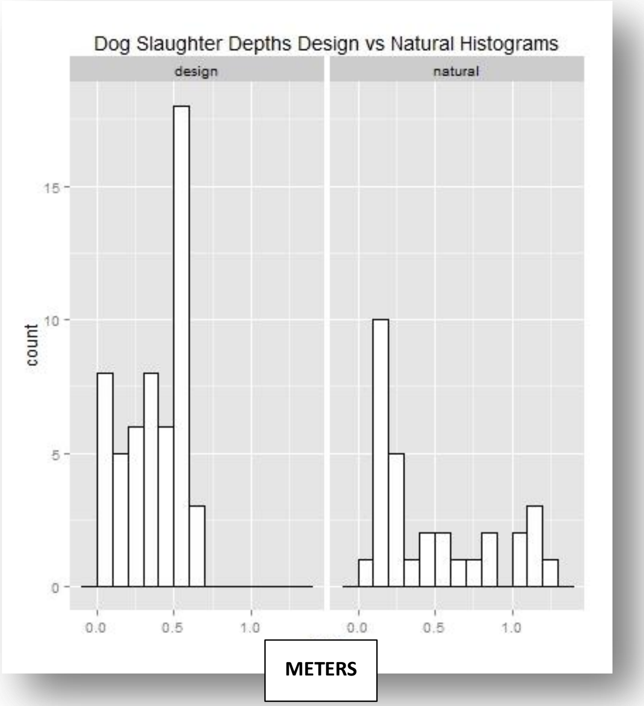

FIGURE 194: DOG SLAUGHTER MAXIMUM DEPTH BY POPULATION; HISTOGRAM

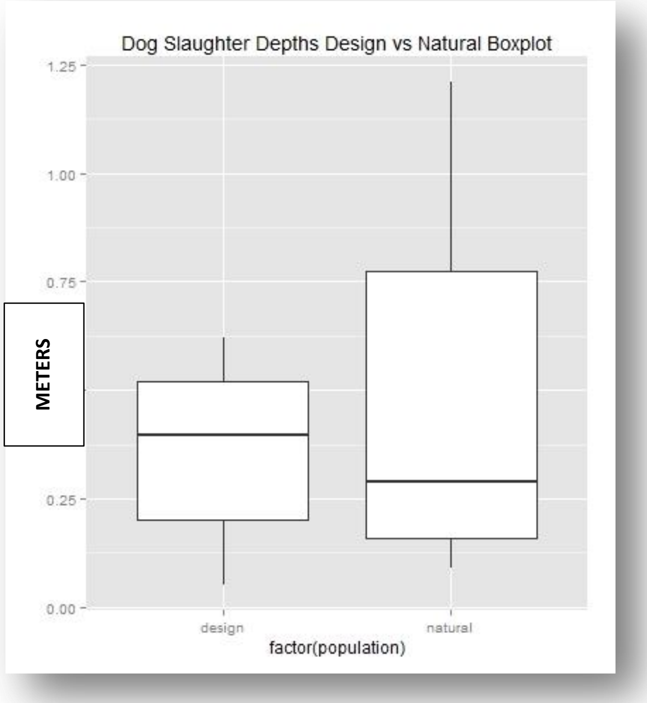

FIGURE 195: DOG SLAUGHTER MAXIMUM DEPTHS BY POPULATION; BOXPLOT

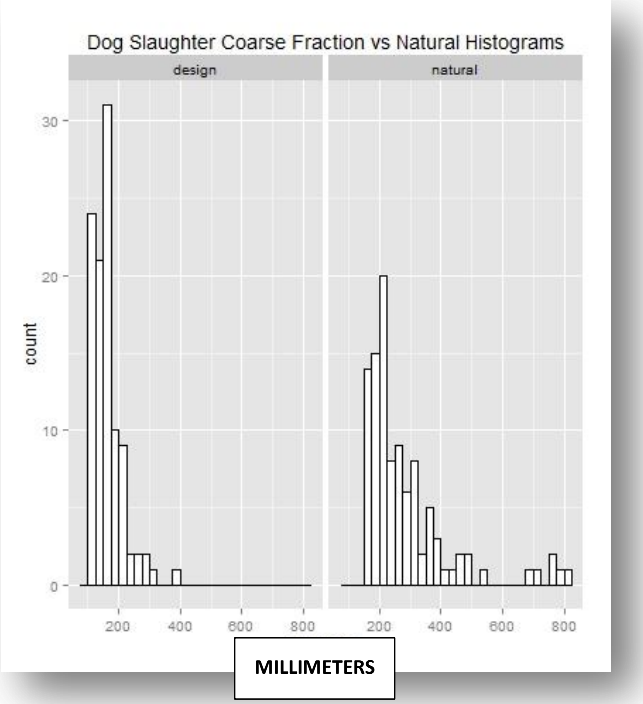

FIGURE 196: DOG SLAUGHTER COARSE FRACTION BY POPULATION; HISTOGRAM

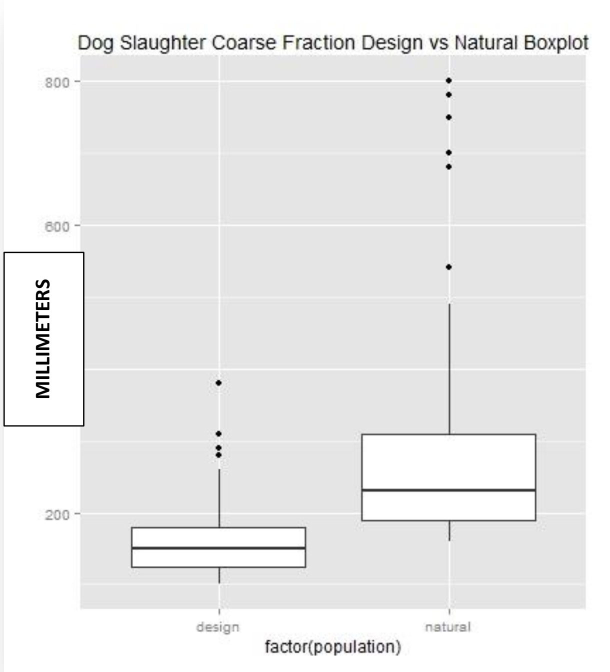

FIGURE 197: DOG SLAUGHTER COARSE FRACTION OF THE GRADATION BY POPULATION; BOXPLOT

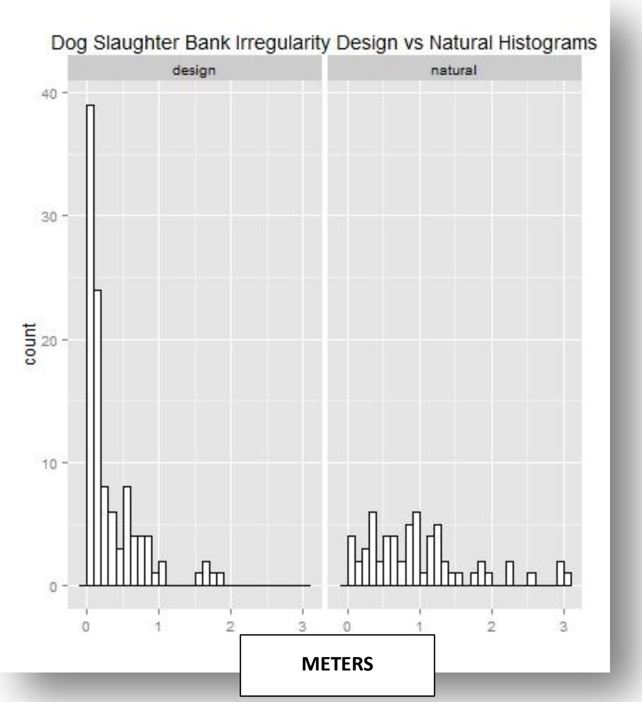

Figure 198: Dog Slaughter Bank Irregularity by Population; Histogram

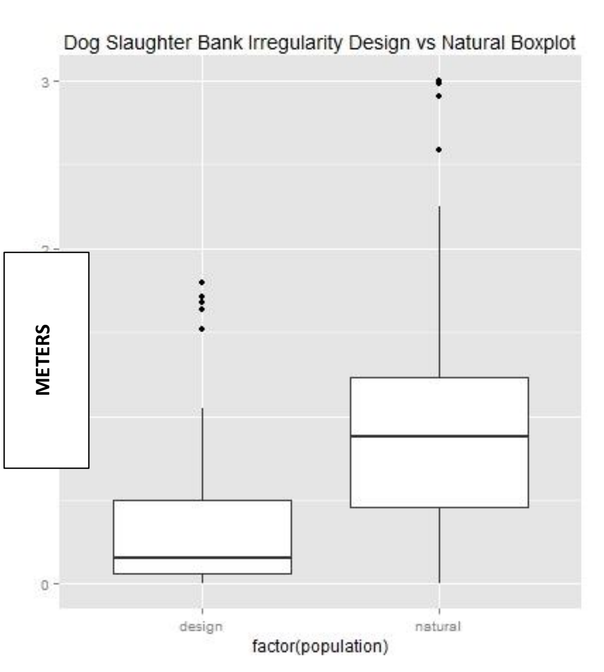

Figure 199: Dog Slaughter Bank Irregularity by Population; Boxplot

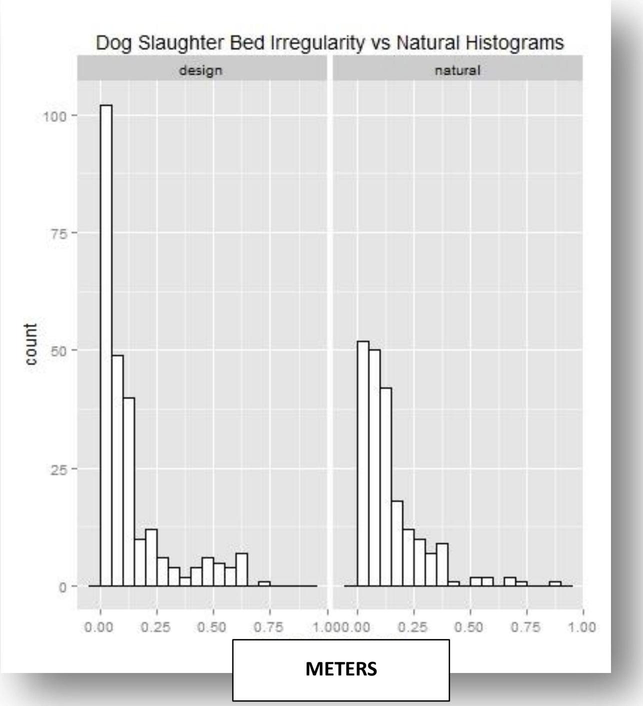

FIGURE 200: DOG SLAUGHTER BED IRREGULARITY BY POPULATION; HISTOGRAM

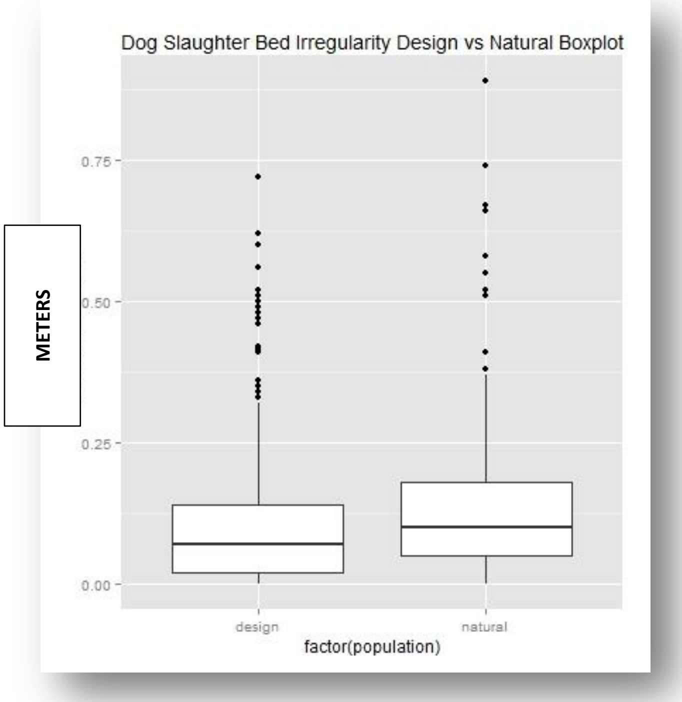

FIGURE 201: DOG SLAUGHTER BED IRREGULARITY BY POPULATION

A4.7 Dog Slaughter Scoring Sensitivity Analysis

Table 80: Dog Slaughter Level II Scoring Sensitivity Analysis

Channel Unit And Criteria for a Score of 3	Inlet Transition Zone			Structure Zone			Outlet Transition Zone		
	% Score	Evaluation	Override	% Score	Evaluation	Override	% Score	Evaluation	Override
Riffle 0.01 to 0.05	36	Dissimilar			NA			NA	
Riffle 0.001 to 0.1	36	Dissimilar			NA			NA	
Riffle 0.001 to 0.05	36	Dissimilar			NA			NA	
Riffle 0.001 to 0.05 short	33	Dissimilar			NA			NA	
Riffle 0.01 to 0.1	36	Dissimilar			NA			NA	
Pool 0.01 to 0.05		NA		20	Dissimilar		51	Questionable	
Pool 0.001 to 0.1		NA		28	Dissimilar		66	Questionable	
Pool 0.001 to 0.05		NA		28	Dissimilar		66	Questionable	
Pool 0.001 to 0.05 short		NA		31	Dissimilar		67	Questionable	
Pool 0.01 to 0.1		NA		20	Dissimilar		51	Questionable	
	Downstream of the Outlet Transition Zone								
Constructed Riffle 0.001 to 0.05	58%				Questionable				

TABLE 81: DOG SLAUGHTER BY POPULATION; LEVEL II SCORING SENSITIVITY ANALYSIS

Channel Units and Criteria for a Score of 3	Design		
	% Score	Evaluation	Override
Design 0.01 to 0.05	38	Dissimilar	
Design 0.001 to 0.05	42	Dissimilar	
Design 0.001 to 0.05 SHORT	40	Dissimilar	
Design 0.001 to 0.1	42	Dissimilar	
Design 0.01 to 0.1	36	Dissimilar	
Constructed Riffle 0.001 to 0.05	58	Questionable	

A5 JOE SMITH BROOK SITE DATA

A5.1 JOE SMITH BROOK SITE PHOTOS

FIGURE 202: LOOKING AT THE JOE SMITH INLET TRANSITION ZONE FROM THE TOP OF THE STRUCTURE

FIGURE 203: LOOKING DOWNSTREAM AT THE JOE SMITH STRUCTURE INLET


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FIGURE 204: LOOKING DOWNSTREAM AT THE JOE SMITH OUTLET TRANSITION ZONE FROM THE ROAD


06/15/2012 15:17

FIGURE 205: LOOKING UPSTREAM AT THE JOE SMITH STRUCTURE OUTLET

FIGURE 206: LOOKING UPSTREAM AT THE INLET TRANSITION ZONE FROM WITHIN THE JOE SMITH STRUCTURE

FIGURE 207: LOOKING DOWNSTREAM WITHIN THE JOE SMITH STRUCTURE

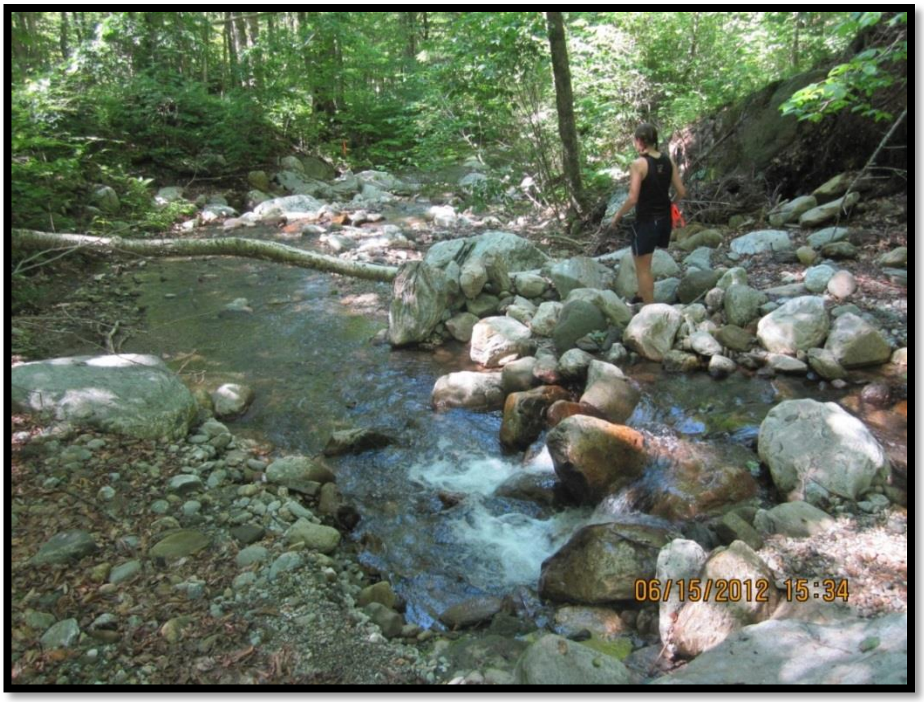


FIGURE 208: LOOKING DOWNSTREAM FROM THE TOP OF THE JOE SMITH REPRESENTATIVE REACH

FIGURE 209: LOOKING UPSTREAM AT THE STEP WHICH MARKS THE UPSTREAM BOUNDARY OF THE JOE SMITH REPRESENTATIVE REACH

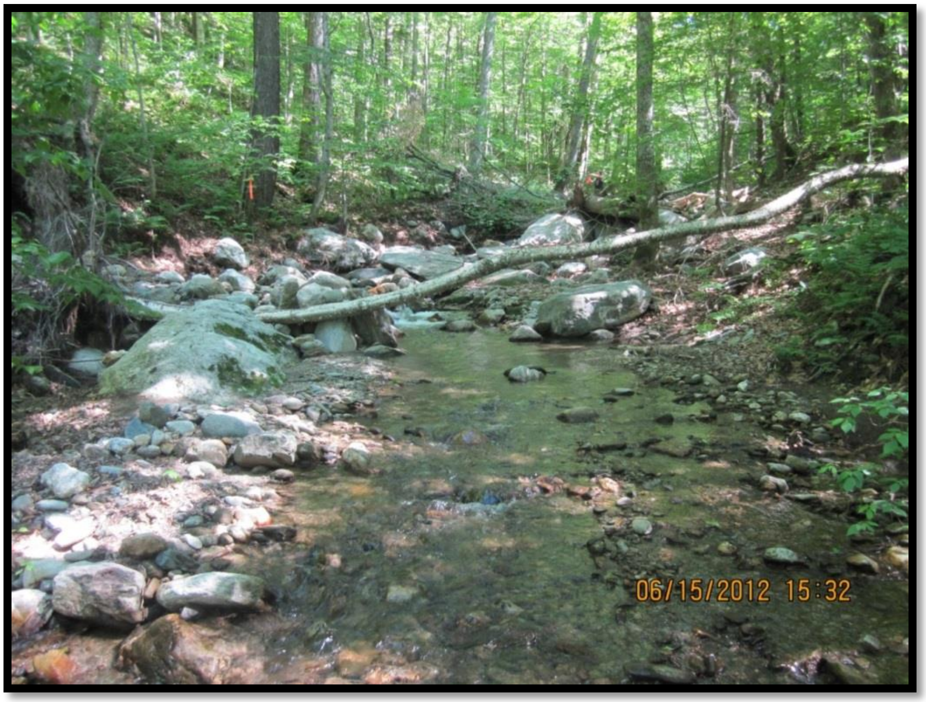


FIGURE 210: LOOKING UPSTREAM WITHIN THE JOE SMITH REPRESENTATIVE REACH (GENTLE RIFFLE)

FIGURE 211: LOOKING UPSTREAM (AT THE GENTLE RIFFLE) WITHIN THE JOE SMITH REPRESENTATIVE REACH

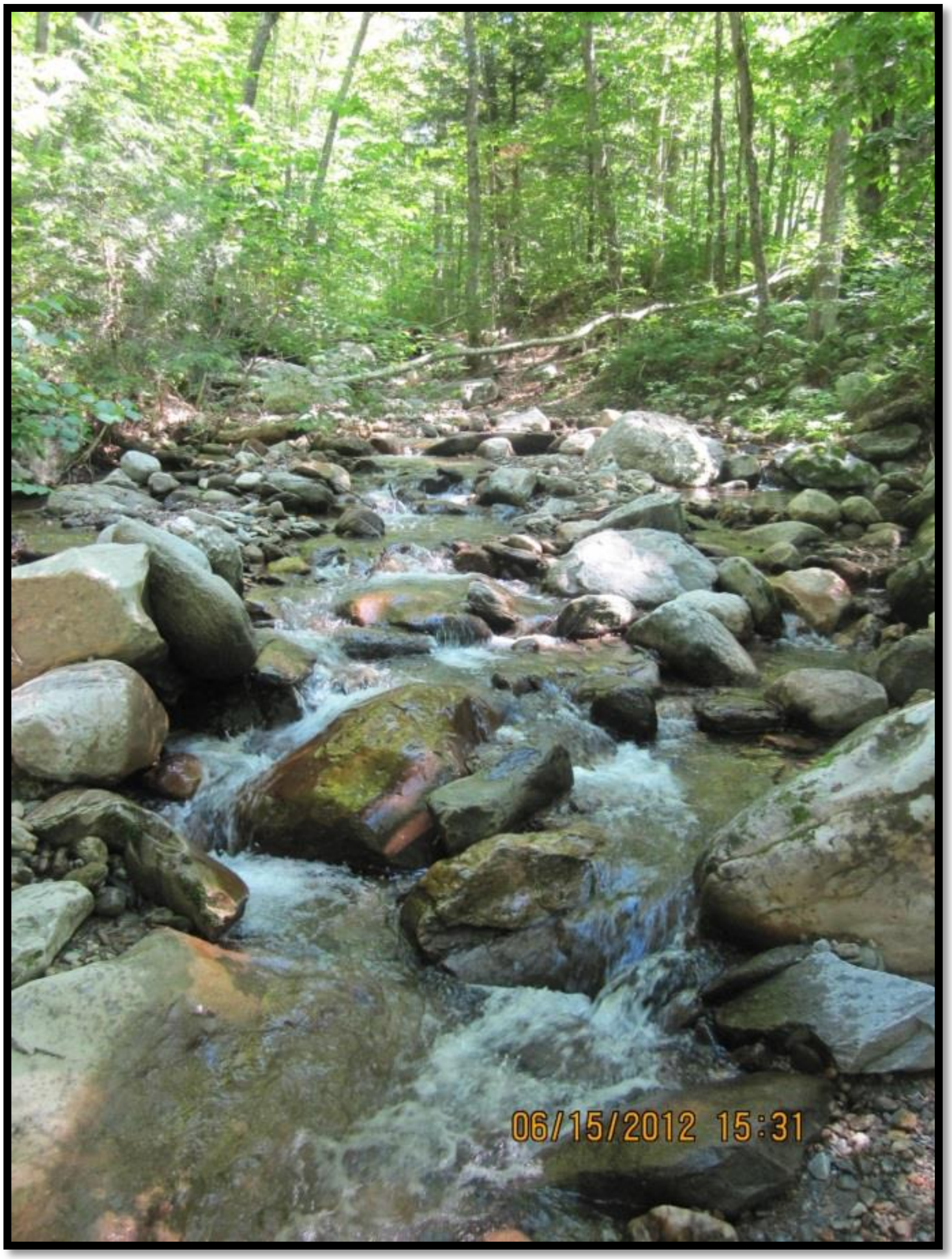


FIGURE 212: LOOKING UPSTREAM (AT THE CASCADE) FROM THE BOTTOM OF THE JOE SMITH REPRESENTATIVE REACH

A6 Lower Stillwell Site Data

A6.1 Lower Stillwell Photos

Photo Credit: Siuslaw National Forest

Photo Credit: Siuslaw National Forest

Lower Stillwell, Siuslaw National Forest, Oregon
barrier culvert replaced in 2004
pre-replacement width = 4’, post-replacement width = 18’

Figure 213: Before and after at Lower Stillwell

FIGURE 214: **LOOKING DOWNSTREAM AT THE STRUCTURE INLET AT LOWER STILLWELL**

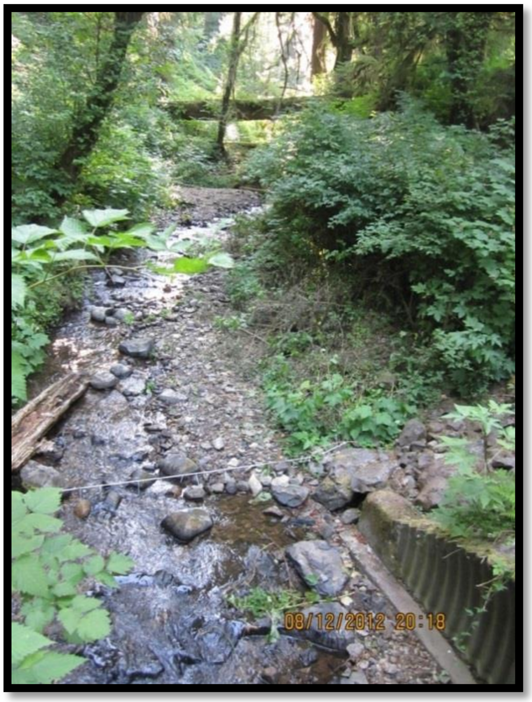


FIGURE 215: **LOOKING UPSTREAM AT THE INLET TRANSITION ZONE FROM THE TOP OF THE LOWER STILLWELL STRUCTURE**

FIGURE 216: LOOKING DOWNSTREAM AT THE LOWER STILLWELL INLET TRANSITION ZONE

FIGURE 217: LOOKING DOWNSTREAM AT THE LOWER STILLWELL OUTLET TRANSITION ZONE FROM THE TOP OF THE STRUCTURE

FIGURE 218: LOOKING UPSTREAM AT THE LOWER STILLWELL OUTLET

FIGURE 219: LOOKING UPSTREAM WITHIN THE LOWER STILLWELL STRUCTURE

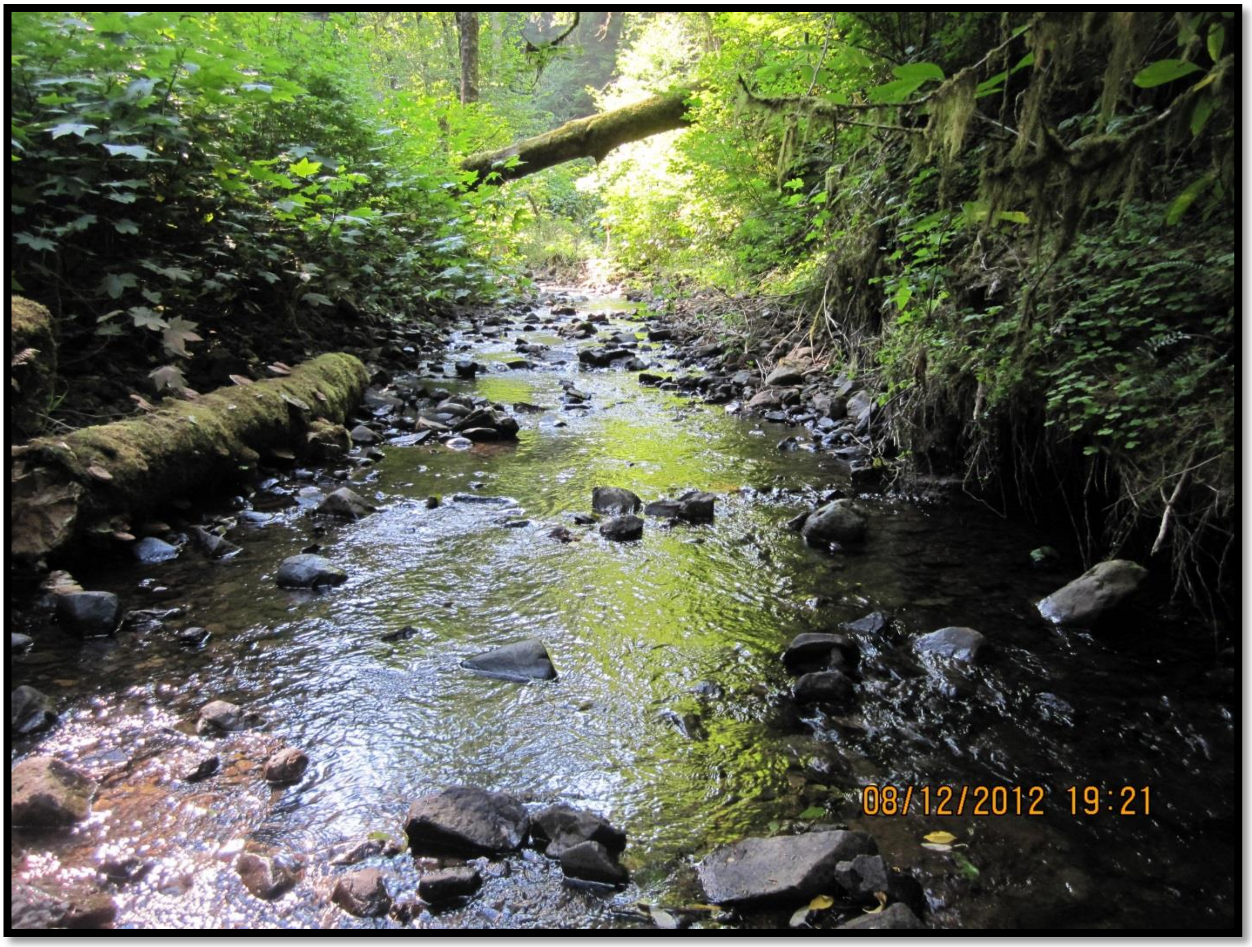


FIGURE 220: LOOKING UPSTREAM WITHIN THE LOWER STILLWELL REPRESENTATIVE REACH

A6.2 Lower Stillwell Representative Reach Analysis

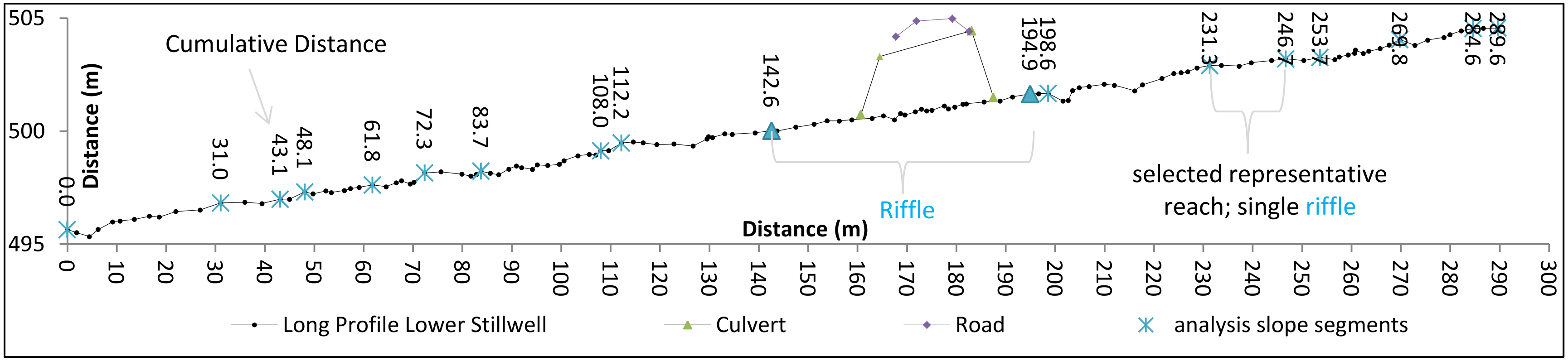


Figure 221: Lower Stillwell Longitudinal Profile

The Lower Stillwell design channel contains a single slope segment riffle in all design zones. The design channel gradient is 3%. The selected representative reach riffle has a 2% gradient. The structure is an open bottom pipe-arch with length 25.7 m, span 5.4 m and height 3.1 m. The blue triangles on the plot above mark the inlet and outlet transition zone boundaries. The Lower Stillwell longitudinal profile has a 5x vertical exaggeration.

Table 82: Lower Stillwell Design Channel Slope Segment Data

N (m)	E (m)	Cumu-lative Distance (m)	Elev (m)	Survey Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	Notes
497.89	494.60	142.57	500.03	gc15	50.71	1.62	52.35	0.03	this is the entire design reach (inlet tz, structure, and outlet trans zone)
484.16	445.79	194.93	501.65						
Culvert Length (m)		25.71		Slope segment Length (m)		52.3			

TABLE 83: LOWER STILLWELL REPRESENTATIVE REACH ANALYSIS

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	riffle crest (rc)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn successive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Notes
549.87	603.20	0.00	495.64		816.21	495.64	0.00	#DIV/0!		#DIV/0!	100.00	
530.15	584.39	31.05	496.83		27.25	1.18	31.05	0.04	#DIV/0!	-23.21	40.69	steep riffle, pool
530.98	572.53	43.12	496.99		11.89	0.17	12.07	0.01	-63.70	55.27	76.95	
527.34	569.20	48.10	497.31		4.94	0.32	4.98	0.06	361.96	-106.62	90.48	
515.71	562.34	61.81	497.62		13.49	0.31	13.71	0.02	-64.97	27.62	73.81	riffle, pool, riffle
510.92	554.44	72.34	498.15	gc6	9.24	0.53	10.53	0.05	125.74	-63.40	79.89	
508.15	543.98	83.73	498.23	gc8	10.82	0.08	11.40	0.01	-86.90	78.59	78.23	
503.05	527.14	108.05	499.13		17.59	0.90	24.31	0.04	461.52	-20.20	53.56	steep riffle, pool at bottom, pocket pools in riffle?
503.24	523.13	112.20	499.48		4.02	0.35	4.15	0.08	124.43	-169.76	92.07	

N (m)	E (m)	Cumu-lative Distance (m)	Elev (m)	riffle crest (rc)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Grad-ient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Notes
497.89	494.60	142.57	500.03	gc15	29.02	0.55	30.37	0.02	-78.34	41.56	41.99	moderate riffle, steep riffle, pool
484.16	445.79	194.93	501.65		50.71	1.62	52.35	0.03	71.12	0.00	0.00	design = long riffle with pocket pools, prominent ribs
484.72	442.15	198.60	501.67	gc22	3.67	0.02	3.67	0.01	-78.39	78.39	92.98	
489.87	413.52	231.32	502.90		29.09	1.23	32.72	0.04	462.99	-21.64	37.49	steep riffle, pool, steep riffle, step, pool
492.45	398.38	246.72	503.20		15.36	0.30	15.39	0.02	-48.45	37.29	70.60	Selected: long straight riffle with transverse ribs
493.84	391.63	253.66	503.26	gc27	6.90	0.06	6.95	0.01	-52.80	70.41	86.73	
494.93	377.18	269.81	504.06	gc30	14.49	0.80	16.15	0.05	438.34	-59.32	69.15	
499.79	363.70	284.65	504.54		14.33	0.48	14.83	0.03	-34.68	-4.06	71.67	steep riffle with pool at bottom
498.45	358.89	289.64	504.56		4.99	0.02	4.99	0.00	-84.99	84.38	90.47	

A6.3 LOWER STILLWELL DATA-BY-DISTANCE PLOTS

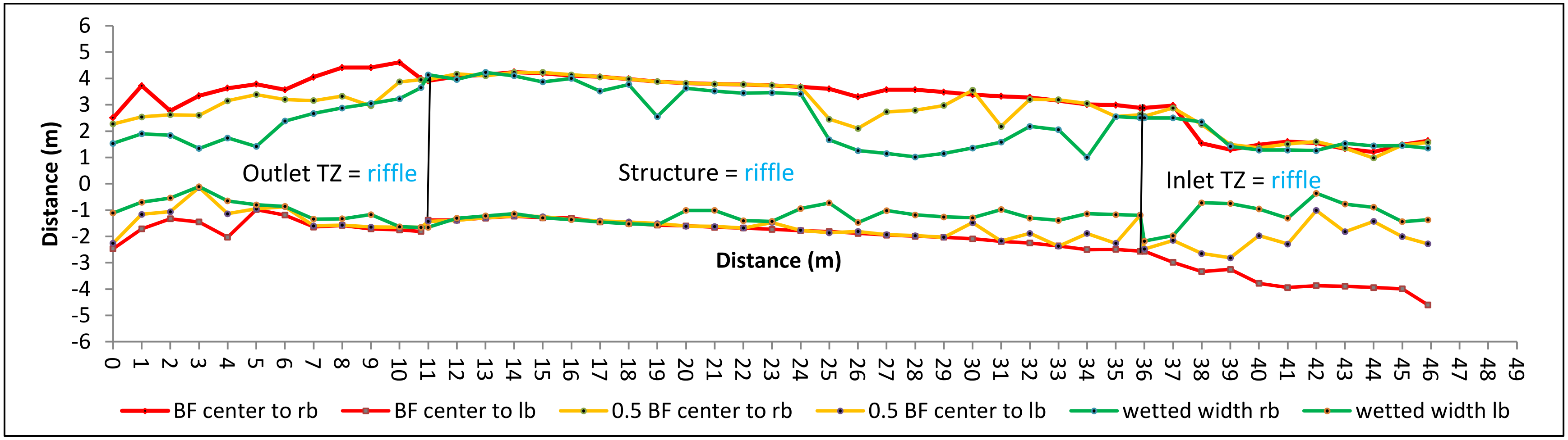


FIGURE 222: LOWER STILLWELL DESIGN CHANNEL WIDTHS

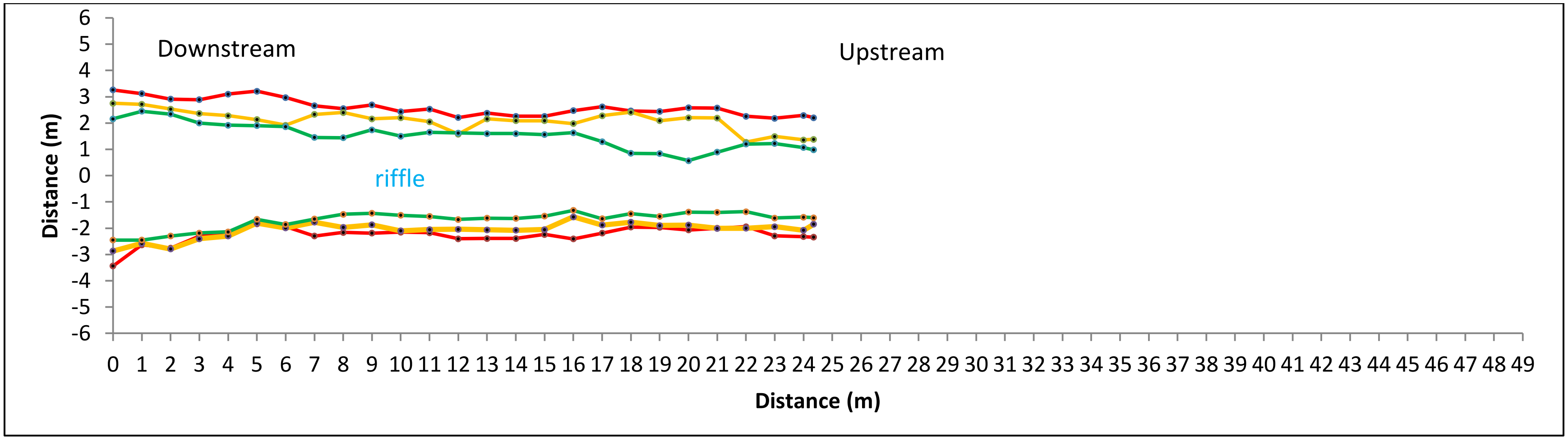


FIGURE 223: LOWER STILLWELL REPRESENTATIVE REACH WIDTHS

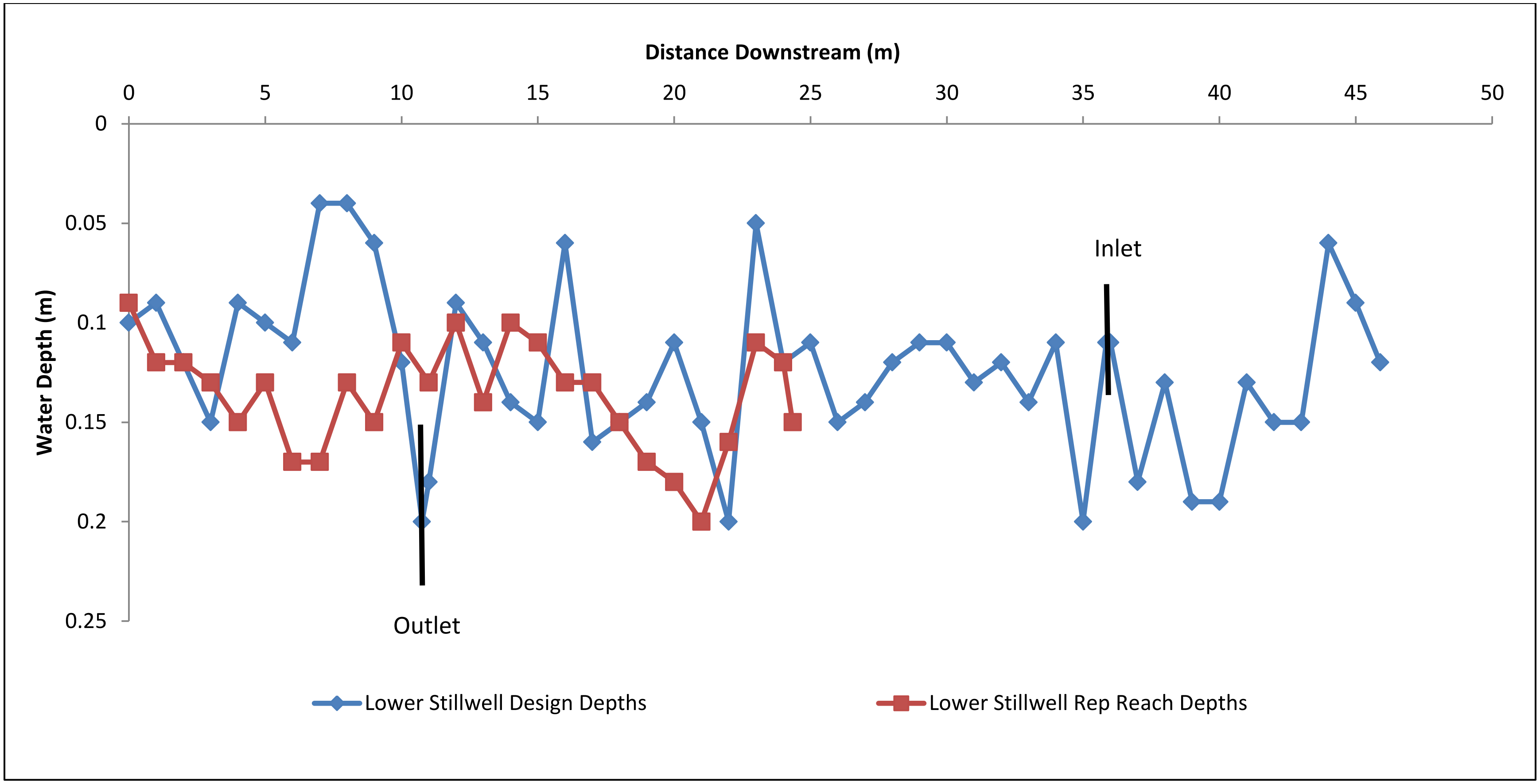


FIGURE 224: LOWER STILLWELL MAXIMUM DEPTHS

ALL ZONES ARE RIFFLES OF A SINGLE SLOPE SEGMENT.

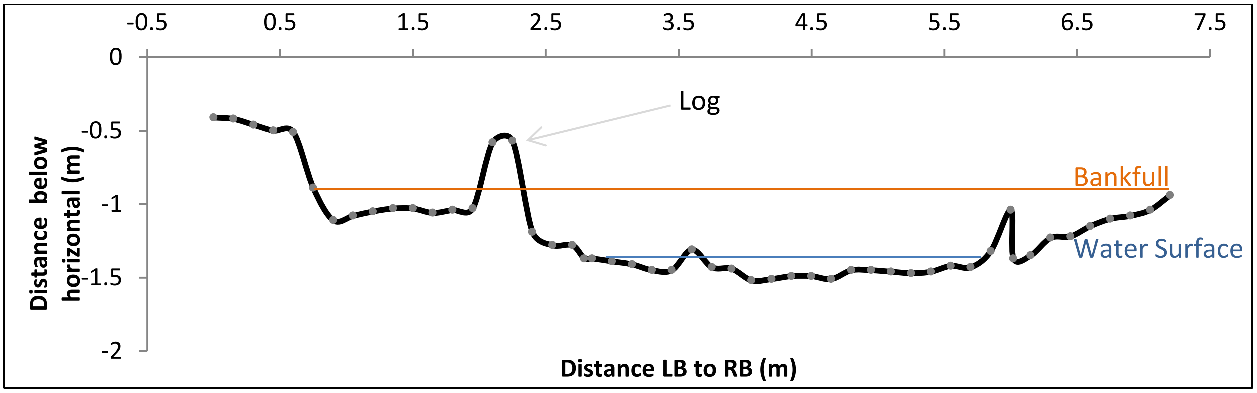


FIGURE 225: LOWER STILLWELL CROSS SECTION 1; OUTLET TRANSITION; RIFFLE

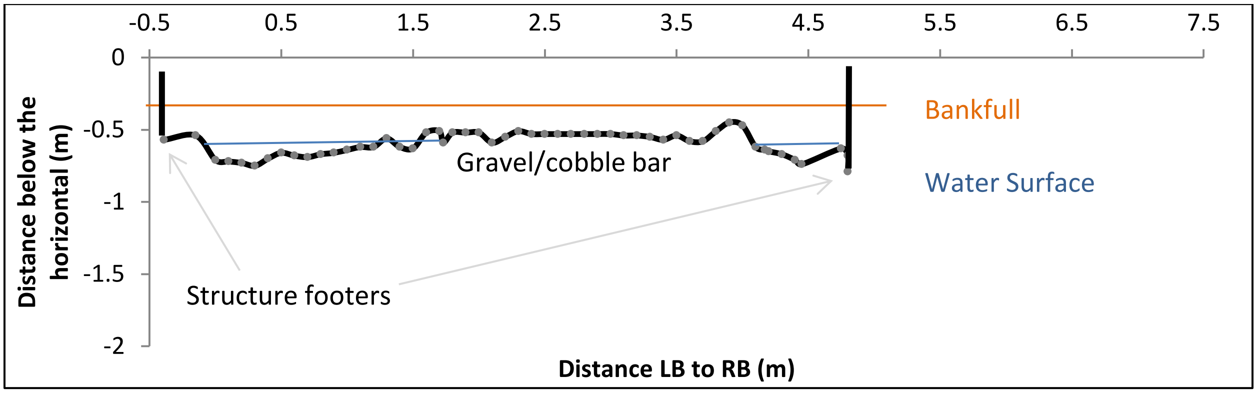


FIGURE 226: LOWER STILLWELL CROSS SECTION 2; LOWER CULVERT, ACROSS BAR

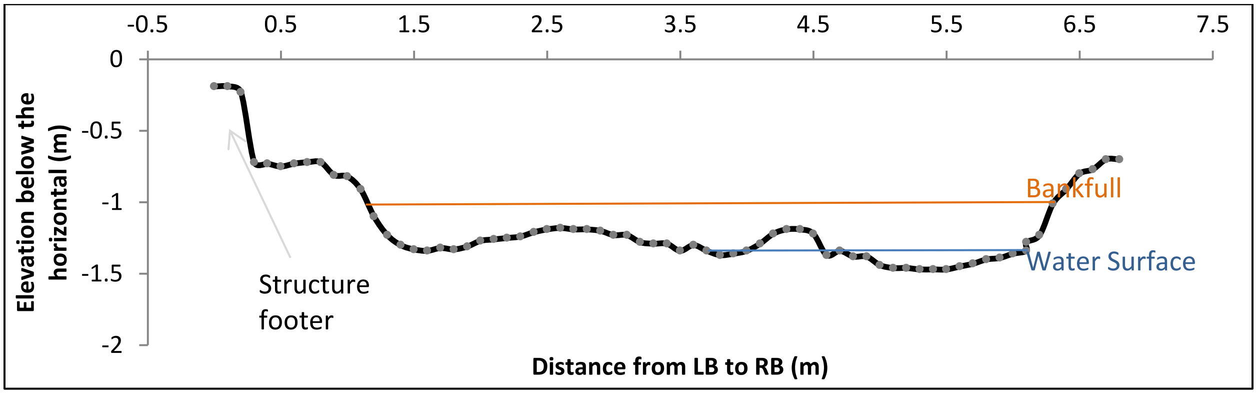


FIGURE 227: LOWER STILLWELL CROSS SECTION 3; RIFFLE IN CULVERT NEAR INLET

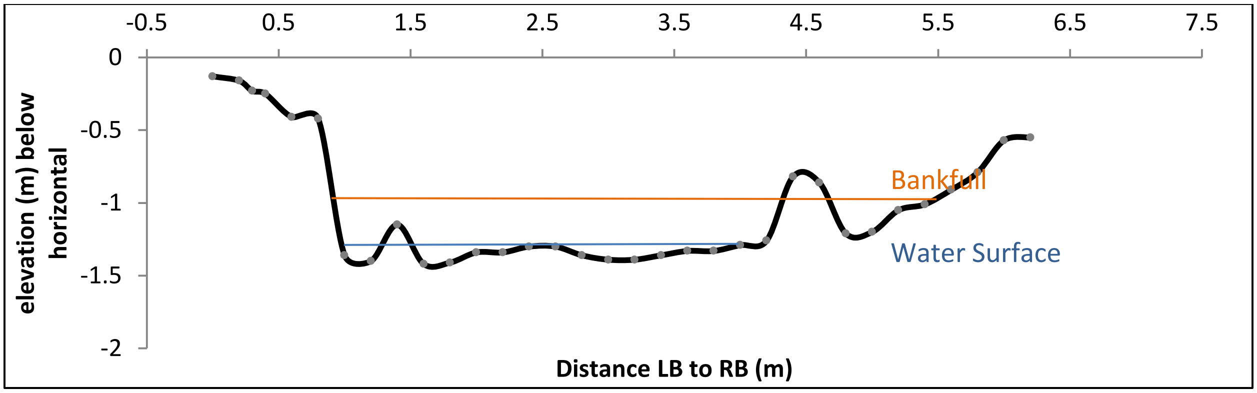


FIGURE 228: LOWER STILLWELL CROSS SECTION RR1; LOWER 1/2 RIFFLE

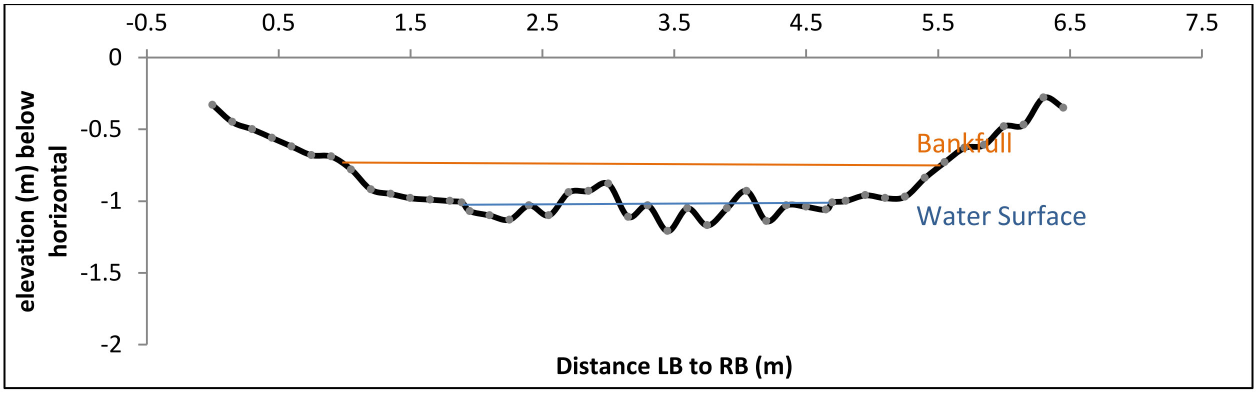


FIGURE 229: LOWER STILLWELL CROSS SECTION RR2; RIFFLE AND POCKET POOL

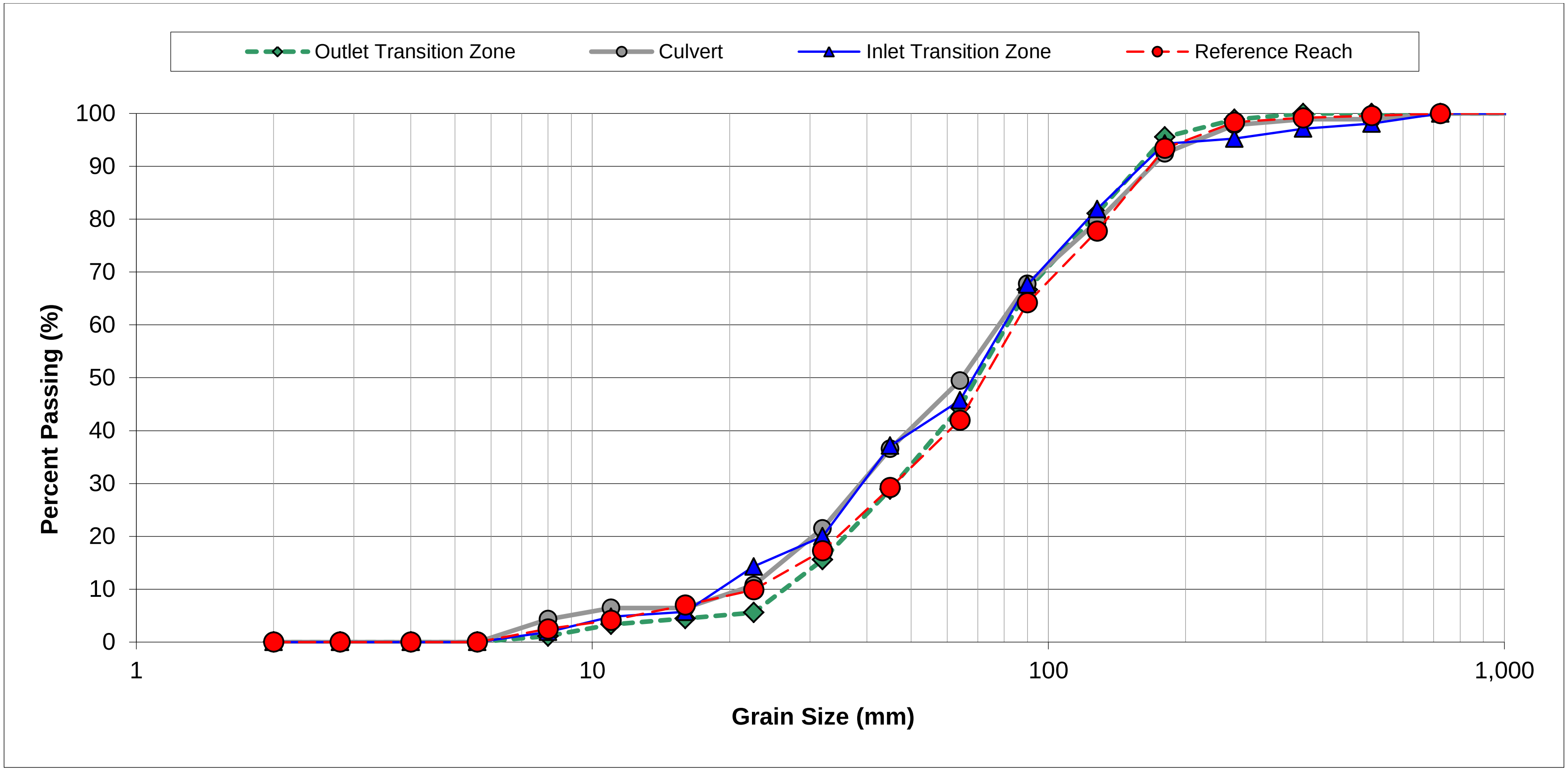


FIGURE 230: LOWER STILLWELL GRADATION

A6.4 LOWER STILLWELL BOXPLOTS AND HISTOGRAMS

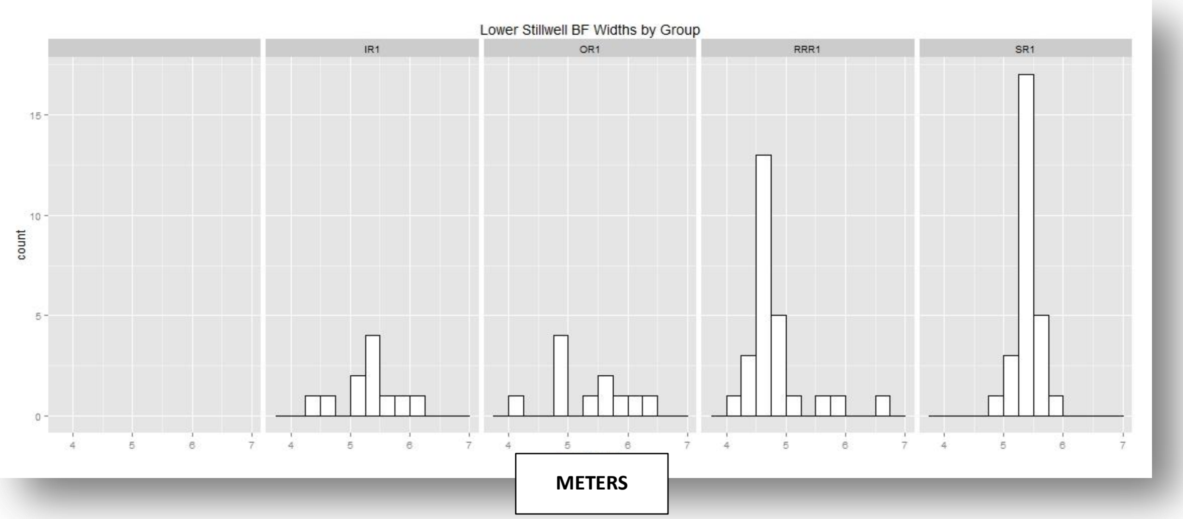


FIGURE 231: LOWER STILLWELL WIDTH AT BANKFULL STAGE; HISTOGRAM

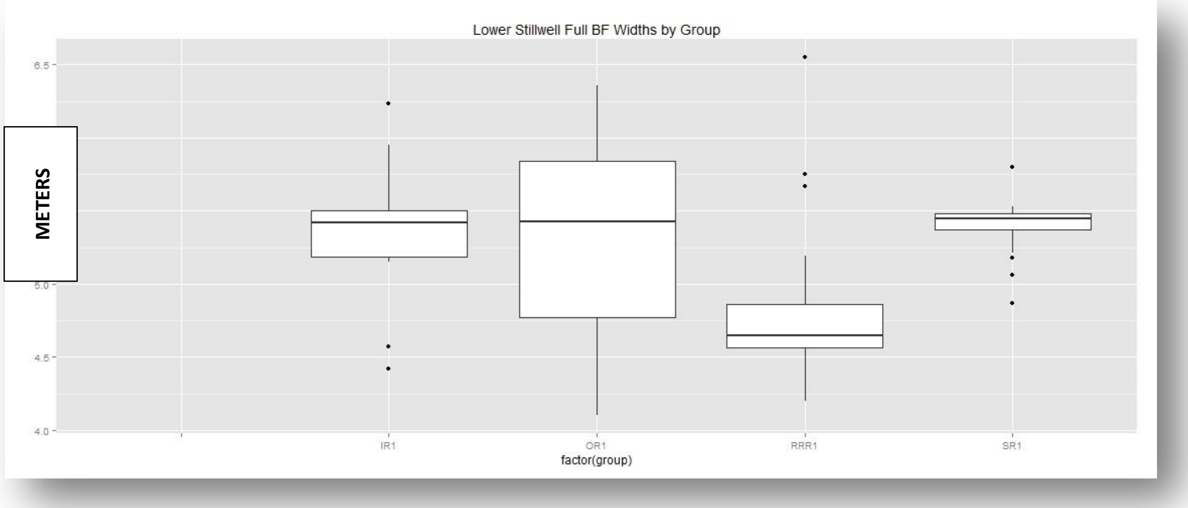


FIGURE 232: LOWER STILLWELL WIDTH AT BANKFULL STAGE; BOXPLOT

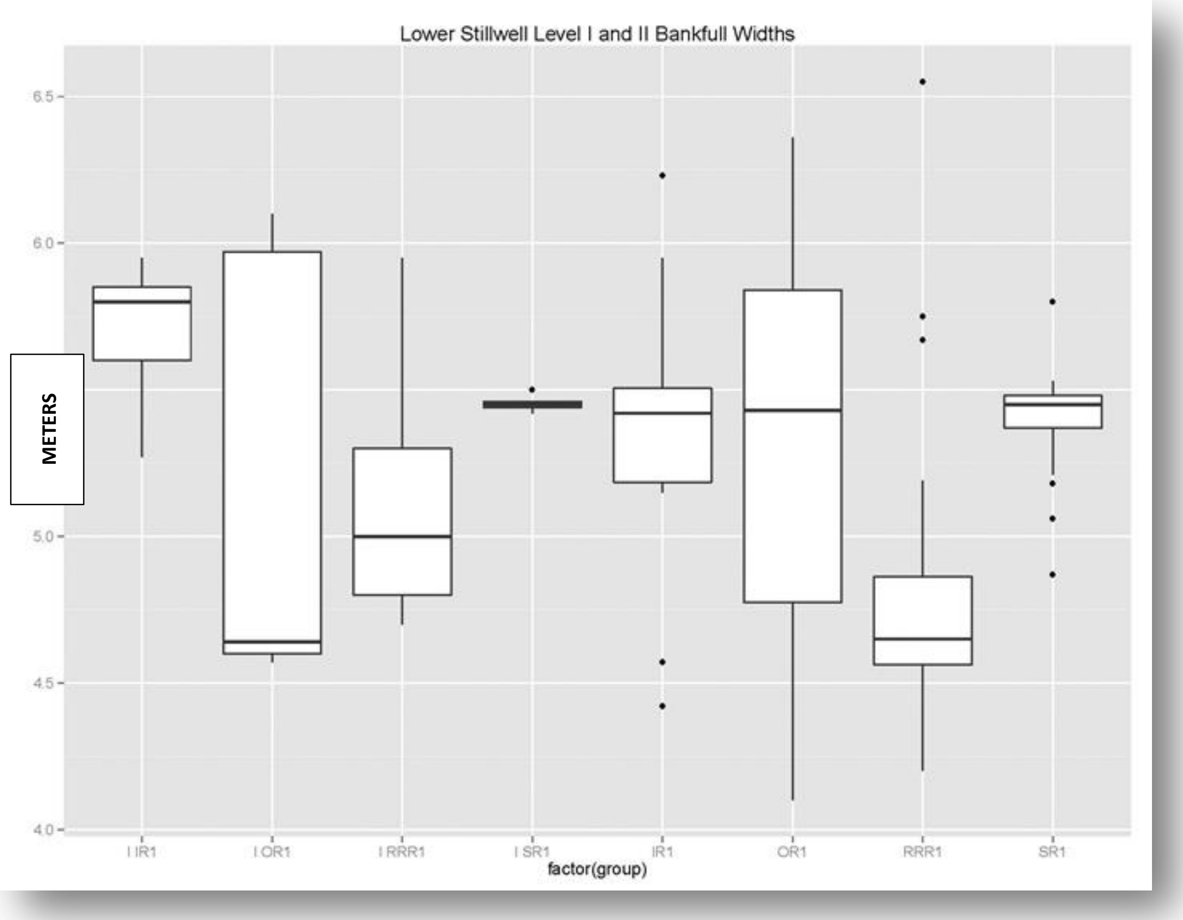


FIGURE 233: LOWER STILLWELL LEVELS I AND II BANKFULL WIDTHS

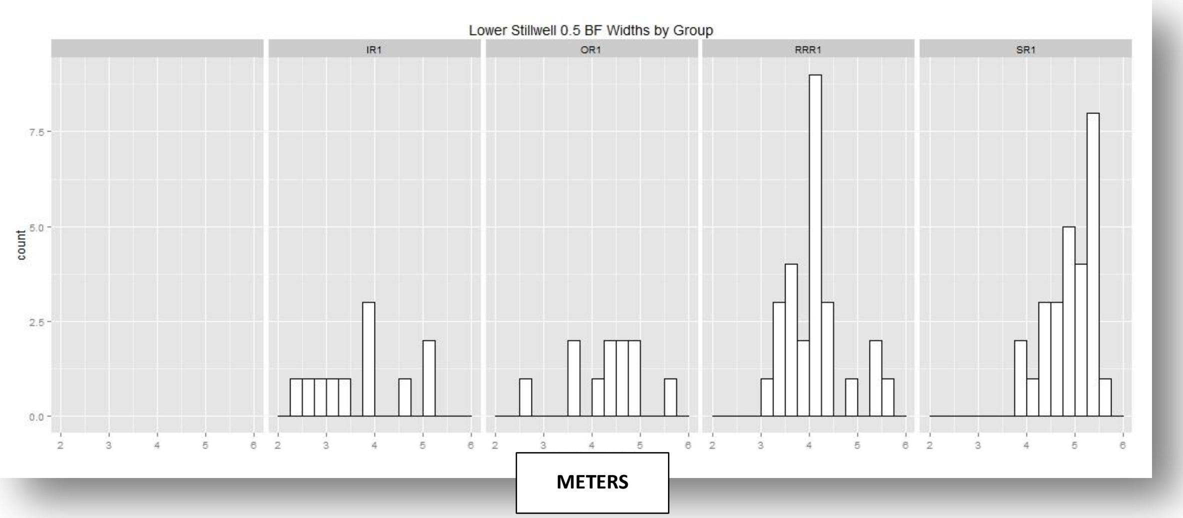


FIGURE 234: LOWER STILLWELL WIDTH AT HALF BANKFULL STAGE; HISTOGRAM

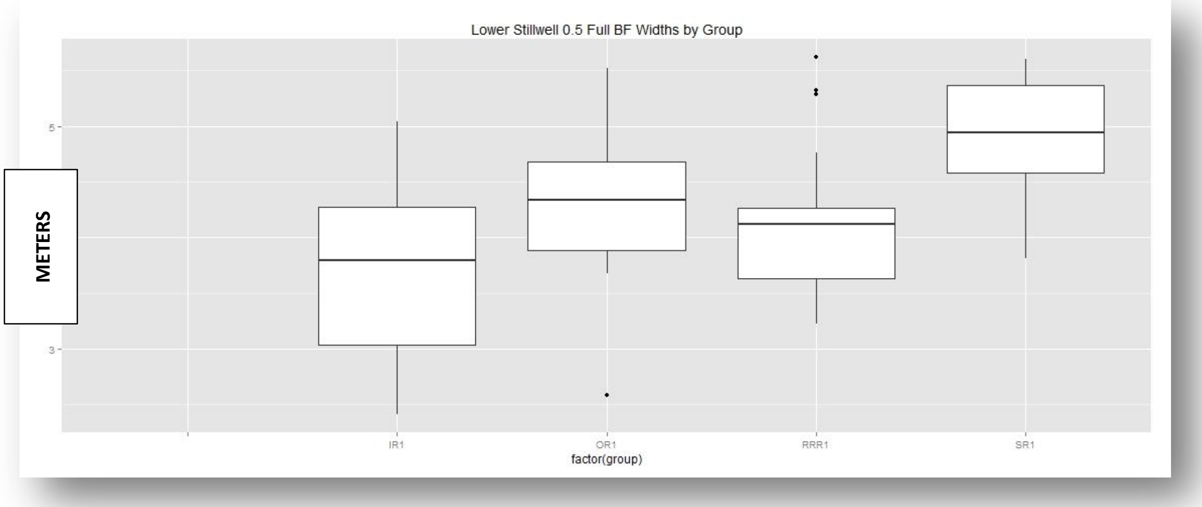


FIGURE 235: LOWER STILLWELL WIDTH AT HALF BANKFULL STAGE; BOXPLOT

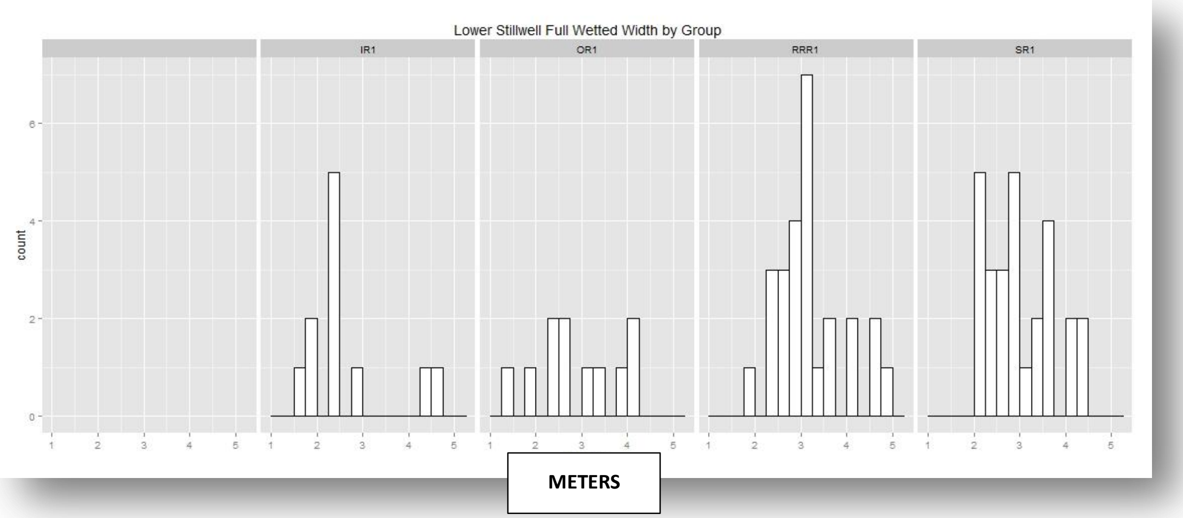


FIGURE 236: LOWER STILLWELL LOW FLOW (WETTED WIDTH); HISTOGRAM

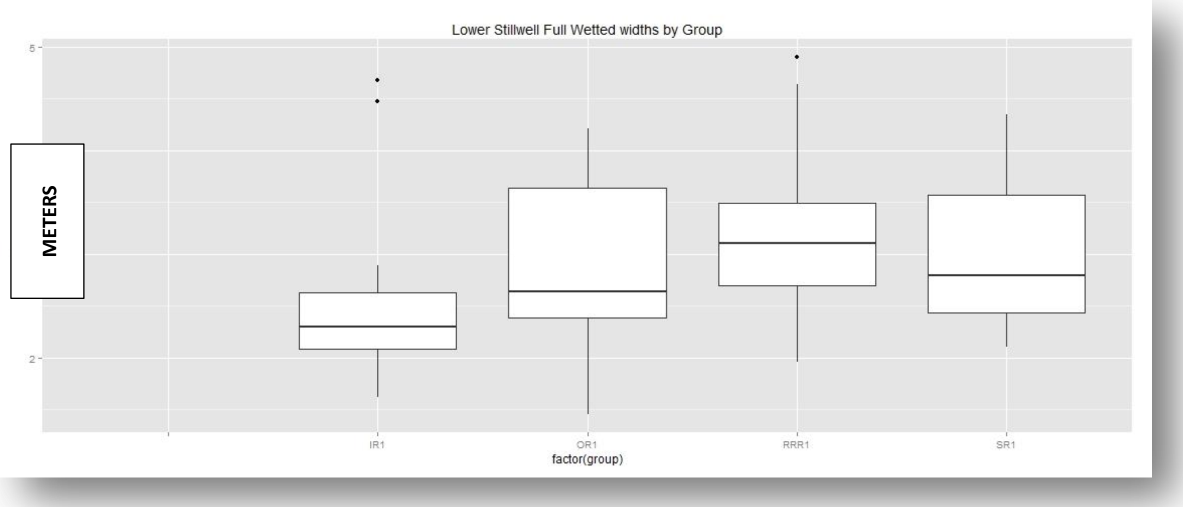


FIGURE 237: LOWER STILLWELL LOW FLOW (WETTED WIDTH); BOXPLOT

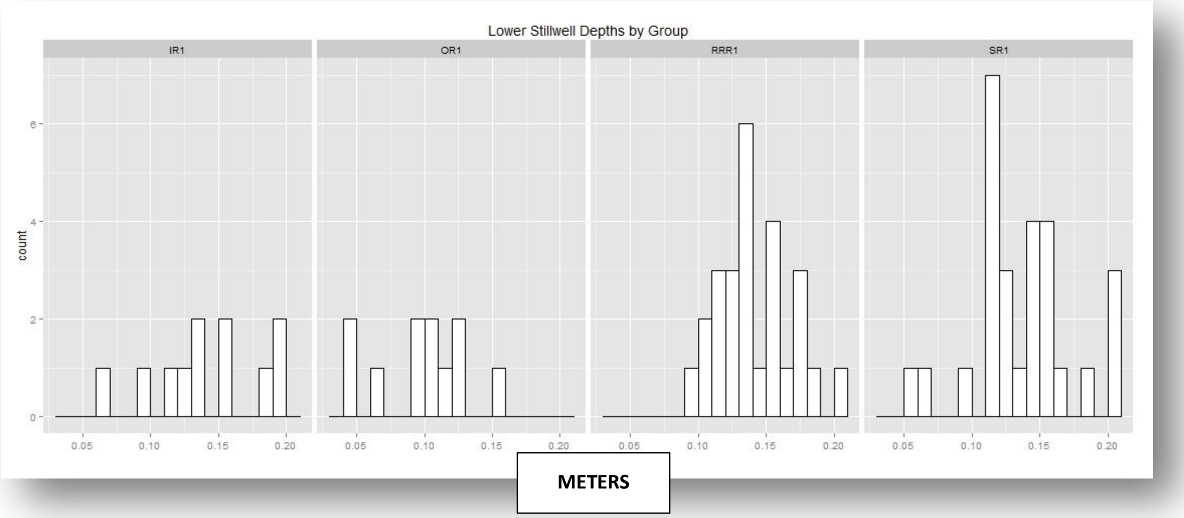


FIGURE 238: LOWER STILLWELL MAXIMUM DEPTH; HISTOGRAM

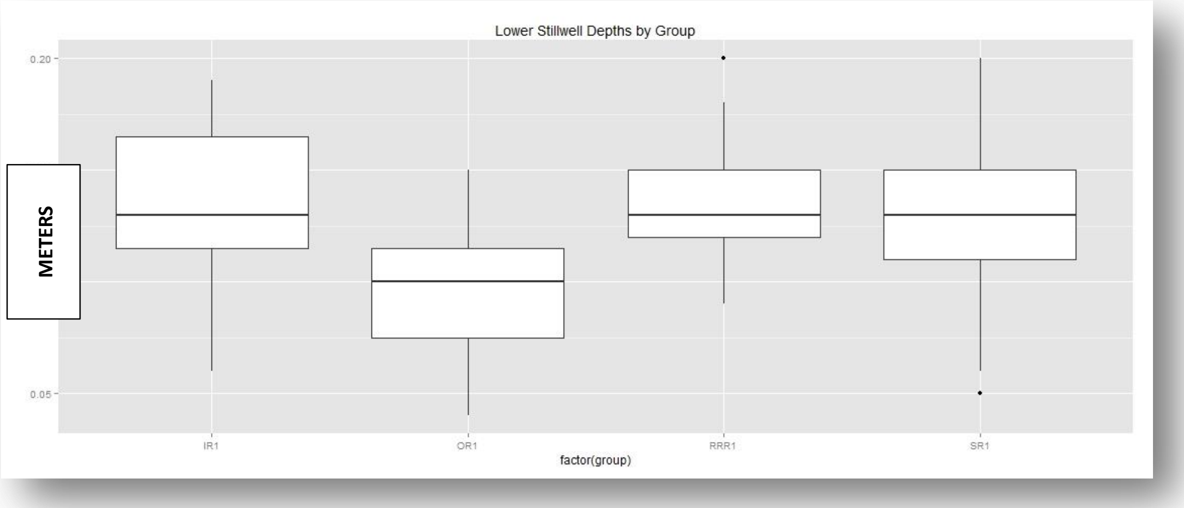


FIGURE 239: LOWER STILLWELL MAXIMUM DEPTH; BOXPLOT

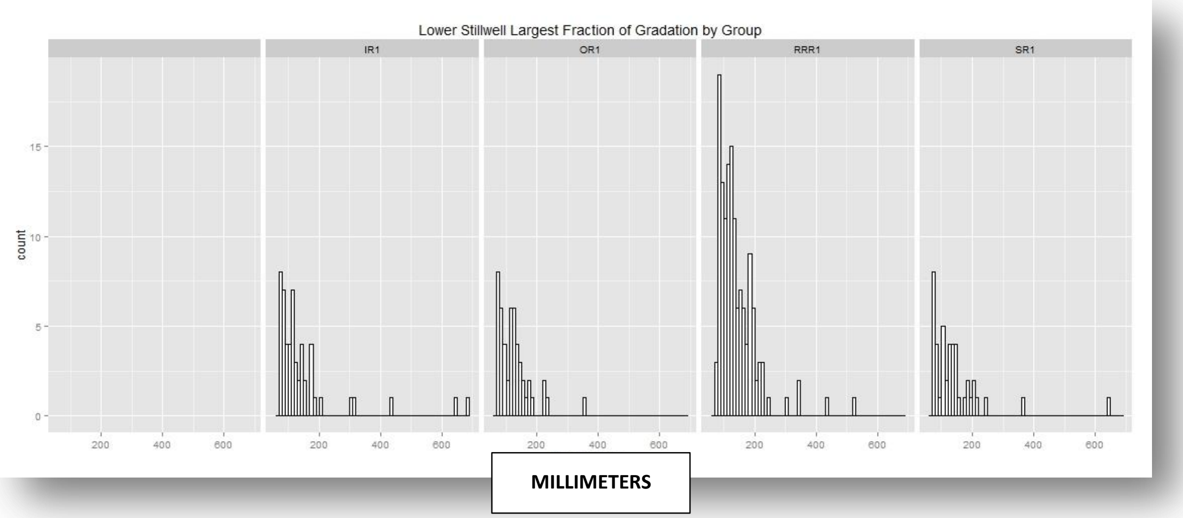


FIGURE 240: LOWER STILLWELL COARSE FRACTION OF THE GRADATION; HISTOGRAM

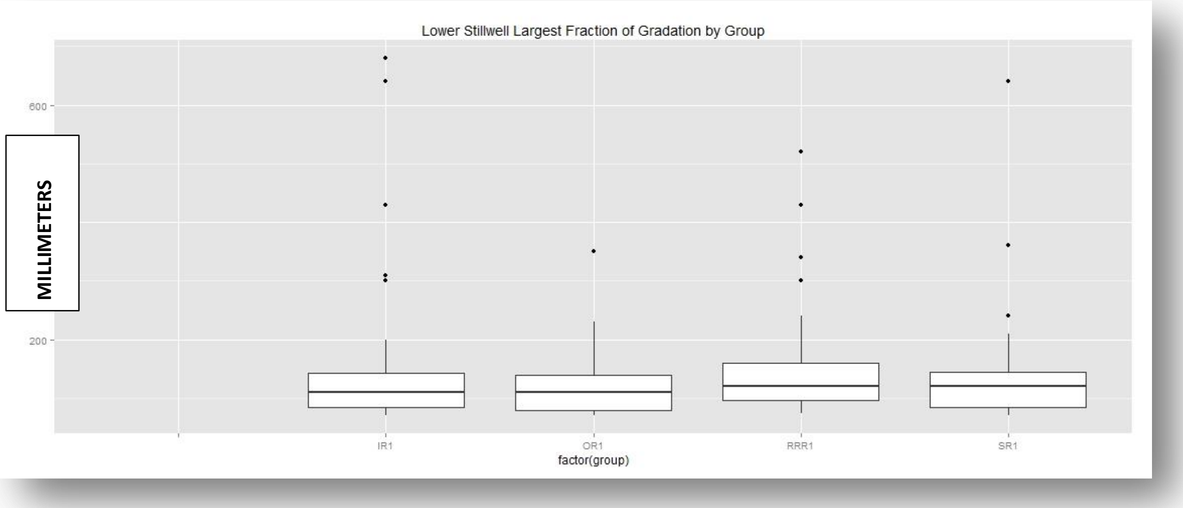


FIGURE 241: LOWER STILLWELL COARSE FRACTION OF THE GRADATION; BOXPLOT

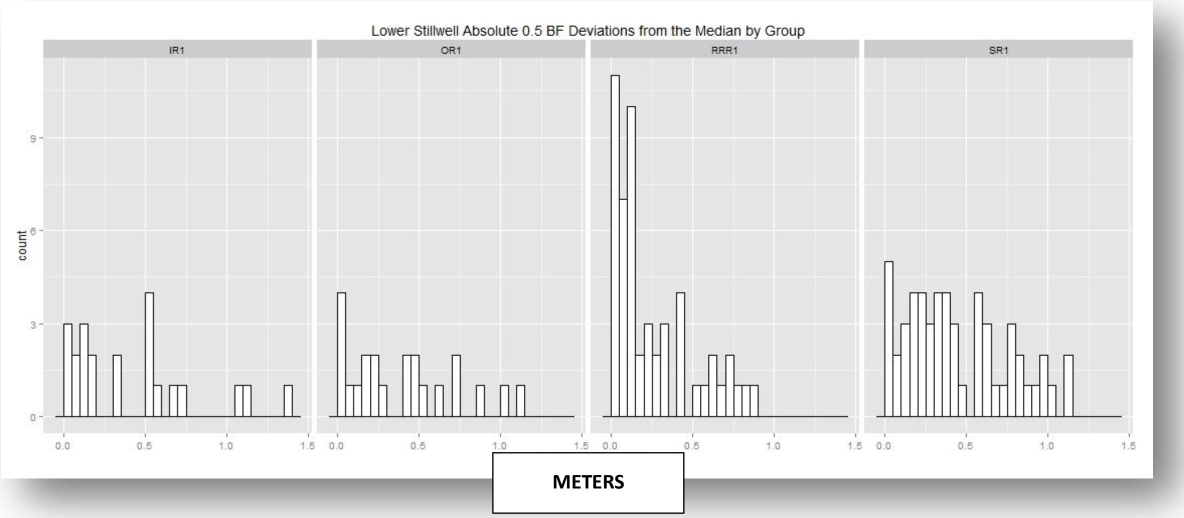


FIGURE 242: LOWER STILLWELL BANK IRREGULARITY HISTOGRAM

FIGURE 243: LOWER STILLWELL BANK IRREGULARITY; BOXPLOT

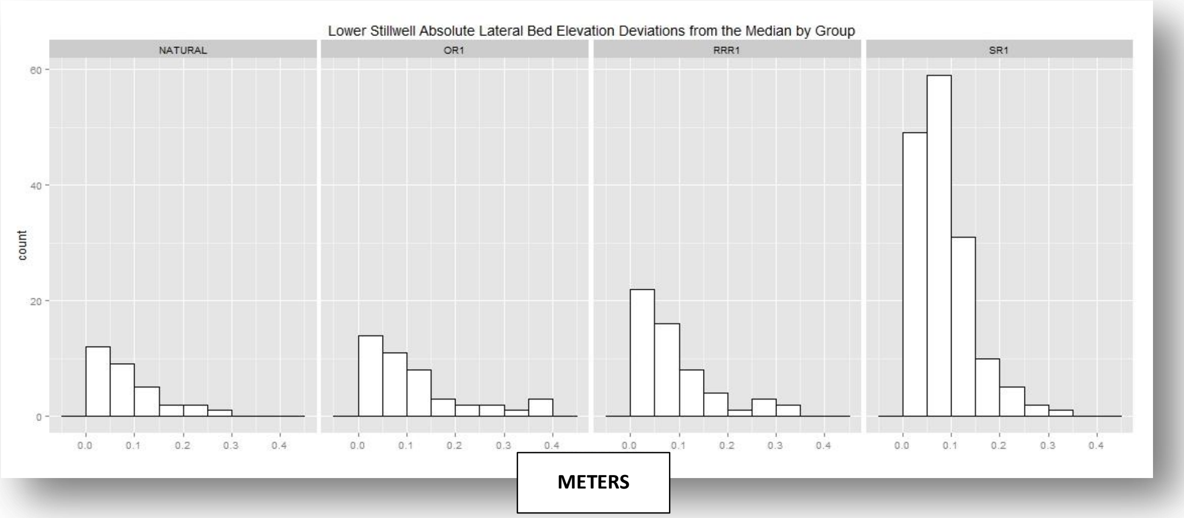


FIGURE 244: LOWER STILLWELL BED IRREGULARITY; HISTOGRAM

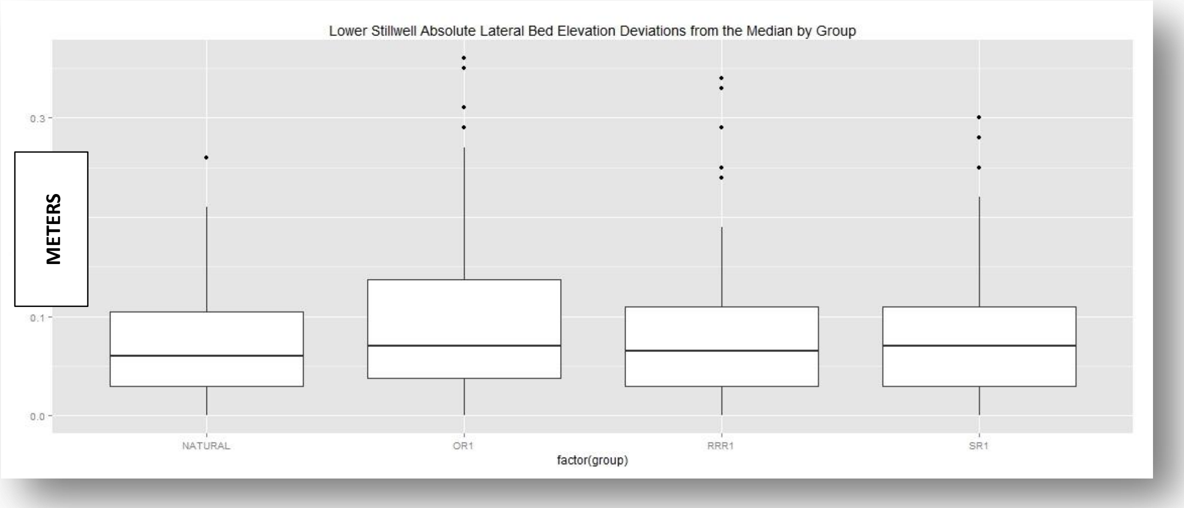


FIGURE 245: LOWER STILLWELL BED IRREGULARITY; BOXPLOT

A6.5 CONFIDENCE INTERVAL PLOTS

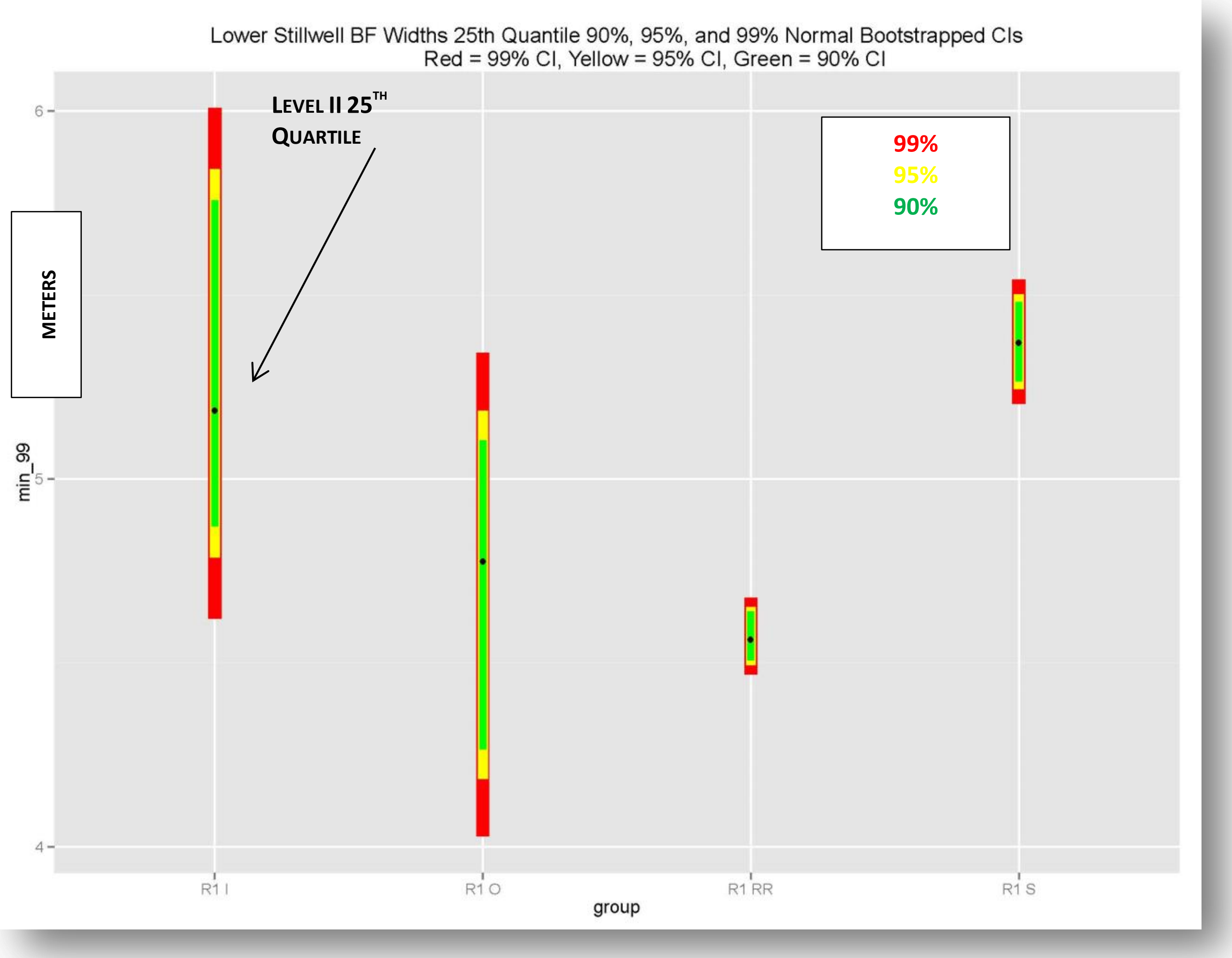


FIGURE 246: LOWER STILLWELL CONFIDENCE INTERVALS AROUND THE WIDTH AT BANKFULL STAGE 25TH QUARTILE

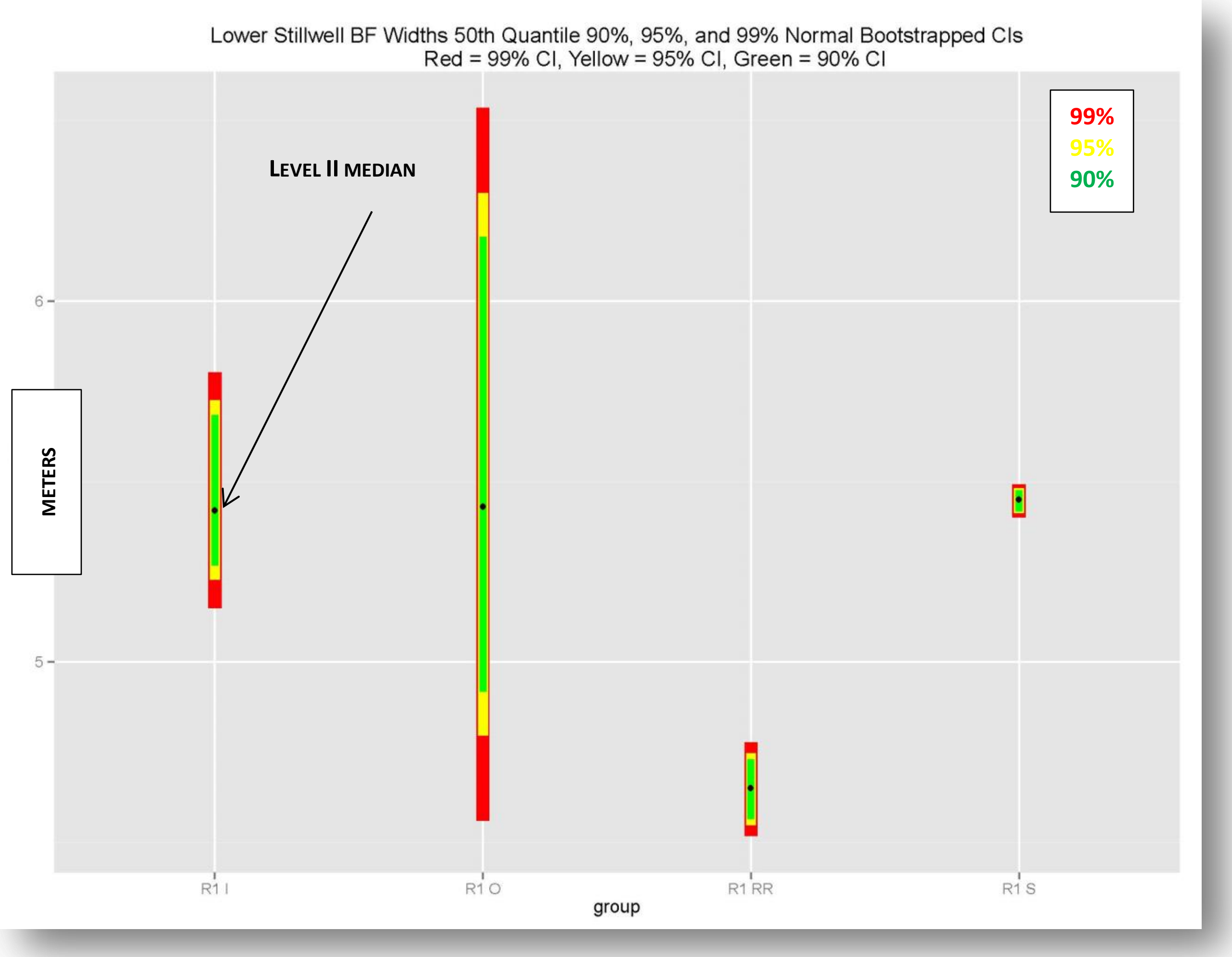


FIGURE 247: LOWER STILLWELL CONFIDENCE INTERVALS AROUND THE WIDTH AT BANKFULL STAGE 50TH QUARTILE

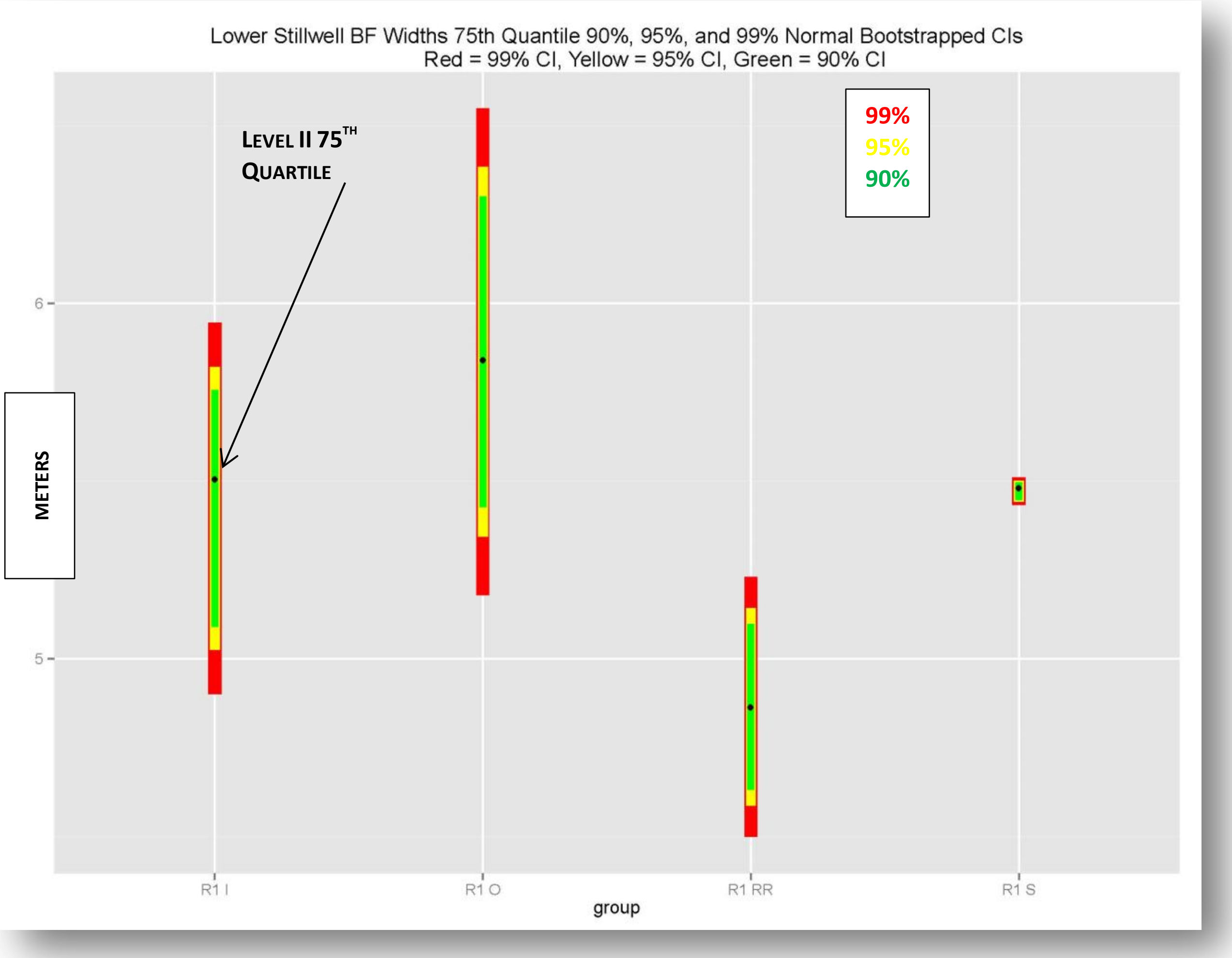


FIGURE 248: LOWER STILLWELL CONFIDENCE INTERVALS AROUND THE WIDTH AT BANKFULL STAGE 75TH QUARTILE

A6.6 LOWER STILLWELL SCORING SENSITIVITY ANALYSIS

TABLE 84: LOWER STILLWELL LEVEL II SCORING SENSITIVITY ANALYSIS

Channel Unit and Criteria for a Score of 3	Inlet Transition Zone			Structure Zone			Outlet Transition Zone		
	% Score	Evaluation	Over-ride	% Score	Evaluation	Over-ride	% Score	Evaluation	Override
Riffle 0.001 to 0.1	79	Similar		64	Questionable		69	Questionable	
Riffle 0.001 to 0.05	88	Similar		64	Questionable		69	Questionable	
Riffle 0.001 to 0.05 short	90	Similar		60	Questionable		65	Questionable	
Riffle 0.01 to 0.05	79	Similar		64	Questionable		69	Questionable	
Riffle 0.01 to 0.05 Short	80	Similar		60	Questionable		65	Questionable	
Riffle 0.01 to 0.1	69	Questionable		64	Questionable		69	Questionable	
Riffle 0.05 to 0.1	67	Questionable		64	Questionable		51	Questionable	

A7 NORTH FORK INDIAN SITE DATA

A7.1 NORTH FORK INDIAN PHOTOS

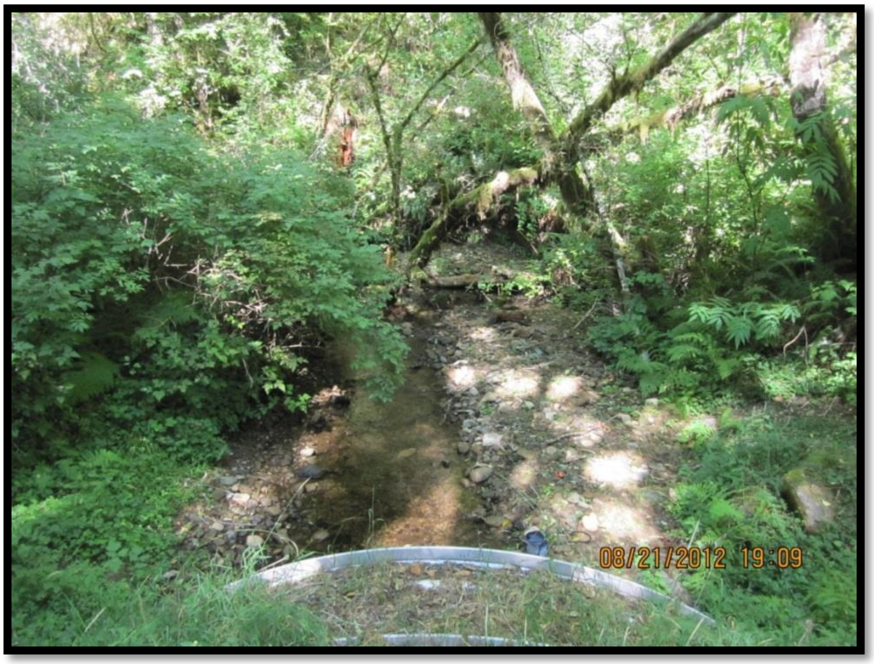


FIGURE 249: **LOOKING AT THE INLET TRANSITION ZONE FROM THE TOP OF THE STRUCTURE AT NORTH FORK INDIAN**

FIGURE 250: **LOOKING DOWNSTREAM AT THE INLET TRANSITION ZONE AND STRUCTURE INLET AT NORTH FORK INDIAN**

FIGURE 251: LOOKING AT THE OUTLET TRANSITION ZONE FROM THE TOP OF THE STRUCTURE AT NORTH FORK INDIAN

FIGURE 252: LOOKING UPSTREAM AT THE OUTLET TRANSITION ZONE FOR NORTH FORK INDIAN

Figure 253: Looking upstream within the North Fork Indian structure; SSR2 and SR1 channel units visible

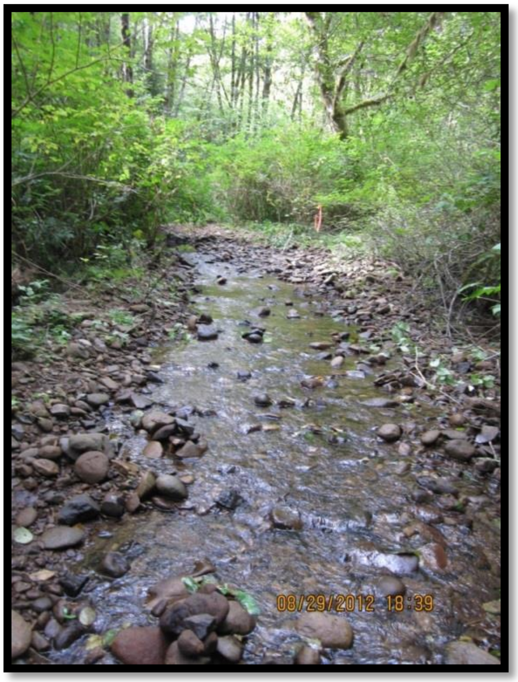
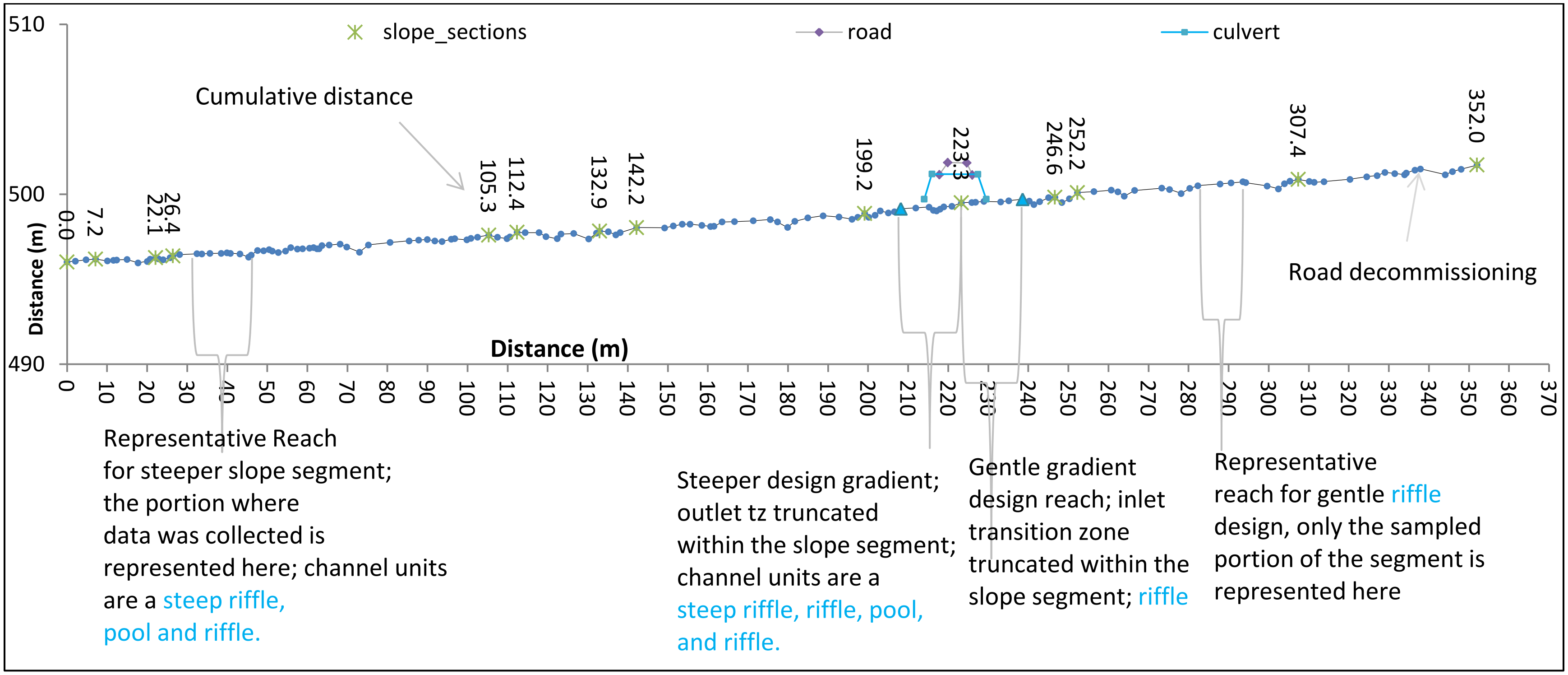


Figure 254: The North Fork Indian representative reach for the gentle design gradient slope section; RRR1 is visible

FIGURE 255: LOOKING AT THE NORTH FORK INDIAN REPRESENTATIVE REACH FOR THE STEEPER DESIGN SLOPE SECTION; RRSR2, RRP2, AND RRR2 UNITS ARE VISIBLE

A7.2 North Fork Indian Representative Reach Analysis



Representative Reach for steeper slope segment; the portion where data was collected is represented here; channel units are a steep riffle, pool and riffle.

Steeper design gradient; outlet tz truncated within the slope segment; channel units are a steep riffle, riffle, pool, and riffle.

Gentle gradient design reach; inlet transition zone truncated within the slope segment; riffle

Representative reach for gentle riffle design, only the sampled portion of the segment is represented here

Figure 256: North Fork Indian longitudinal profile Analysis

Two slope segments compose the design channel with gradients 1.4% and 2.6%. The selected representative reaches have gradients 1.4% and 1.6%. The channel unit within the upper, lower gradient slope segment is a riffle. The channel units within the lower slope segment are a steep riffle, riffle, pool and riffle. The structure is an open bottom pipe-arch with length 11.6 m, height 1.3 m, and span 3.9 m.

Although analysis by channel unit sequence was probably possible, the representative reaches were selected to match the design channel units. Additionally, data collected within the steep slope segment riffles should have been combined and analyzed together; instead riffles were analyzed separately according to their apparent slope (steep, gentle, etc.). The profile above has a 4x vertical exaggeration.

Table 85: North Fork Indian Design Channel Steep Slope Segment Data

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient
462.4	484.9	199.2	498.9				
481.8	487.5	223.3	499.5	19.6	0.6	24.1	0.0
steep slope segment length						24.1	
outlet trans is actually only						15.0	

Table 86: North Fork Indian Design Channel Gentle Slope Segment Data

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Notes
481.8	487.5	223.3	499.5								
501.8	495.8	246.6	499.8	21.6	0.3	23.3	0.0				
gentle slope segment length (m)						23.3	gentle riffle				
length of design portion of this slope segment						15					

TABLE 87: NORTH FORK INDIAN REPRESENTATIVE REACH ANALYSIS FOR THE STEEP DESIGN SLOPE SEGMENT

N (m)	E (m)	Distance (m)	Elev (m)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Notes
368.0	598.5	0.0	496.0								
366.3	591.7	7.2	496.2	7.1	0.2	7.2	0.0	#DIV/0!	6.2	52.3	units not good, need a pool and mod steep riffle. This is just a riffle.
369.0	579.5	22.1	496.3	12.5	0.1	15.0	0.0	-77.3	78.7	0.1	
372.9	580.0	26.4	496.4	3.9	0.1	4.3	0.0	333.5	7.8	71.5	steep riffle into pool; too short
415.8	539.8	105.3	497.6	58.8	1.2	78.8	0.0	-35.5	40.5	-425.7	long pool riffle sequence; selected because a pool and riffle of similar length within this reach exist for comparison. Will take measurements from distance 32 to 47 m from bottom of survey (length is approx twice that of pool riff sequence in design).
420.2	535.5	112.4	497.8	6.1	0.2	7.1	0.0	45.3	13.6	52.8	steep riffle into pool; too short; probably should have selected this channel unit *sequence*; channel units right, length about right for riffle (mod steep and steep combined) into pool.

N (m)	E (m)	Cumu-lative Dis-tance (m)	Elev (m)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Notes
434.2	535.4	132.9	497.8	13.9	0.1	20.6	0.0	-83.7	85.9	-37.3	
441.2	532.7	142.2	498.0	7.5	0.2	9.3	0.0	515.7	13.4	38.1	steep riffle into pool; distance short
462.4	484.9	199.2	498.9	52.3	0.8	56.9	0.0	-35.2	43.9	-279.6	
481.8	487.5	223.3	499.5	19.6	0.6	24.1	0.0	78.3	0.0	-60.8	
501.8	495.8	246.6	499.8	21.6	0.3	23.3	0.0	-46.8	46.8	-55.5	
504.3	494.2	252.2	500.1	3.0	0.3	5.6	0.0	243.8	-83.1	62.5	
524.1	445.2	307.4	500.9	52.8	0.8	55.1	0.0	-70.5	46.0	-267.5	
552.6	420.1	352.0	501.7	38.0	0.9	44.7	0.0	35.4	26.9	-197.7	reach is mostly pools; riffles too short

Table 88: North Fork Indian Representative Reach Analysis for the Gentle Design Slope Segment

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Notes
368.0	598.5	0.0	496.0								
366.3	591.7	7.2	496.2	7.1	0.2	7.2	0.0	#DIV/0!	-76.2	52.3	
369.0	579.5	22.1	496.3	12.5	0.1	15.0	0.0	-77.3	60.1	0.1	
372.9	580.0	26.4	496.4	3.9	0.1	4.3	0.0	333.5	-73.1	71.5	
415.8	539.8	105.3	497.6	58.8	1.2	78.8	0.0	-35.5	-11.7	-425.7	
420.2	535.5	112.4	497.8	6.1	0.2	7.1	0.0	45.3	-62.3	52.8	
434.2	535.4	132.9	497.8	13.9	0.1	20.6	0.0	-83.7	73.6	-37.3	
441.2	532.7	142.2	498.0	7.5	0.2	9.3	0.0	515.7	-62.6	38.1	
462.4	484.9	199.2	498.9	52.3	0.8	56.9	0.0	-35.2	-5.3	-279.6	
481.8	487.5	223.3	499.5	19.6	0.6	24.1	0.0	78.3	-87.8	-60.8	
501.8	495.8	246.6	499.8	21.6	0.3	23.3	0.0	-46.8	0.0	-55.5	
504.3	494.2	252.2	500.1	3.0	0.3	5.6	0.0	243.8	-243.8	62.5	
524.1	445.2	307.4	500.9	52.8	0.8	55.1	0.0	-70.5	-1.3	-267.5	selected; pool riffle sequence. Riffles will be sampled with similar gradients as those within the structure and inlet trans zone. Pools ignored.
552.6	420.1	352.0	501.7	38.0	0.9	44.7	0.0	35.4	-37.3	-197.7	352 is at the decom rd xing

A7.3 NORTH FORK INDIAN DATA-BY-DISTANCE PLOTS

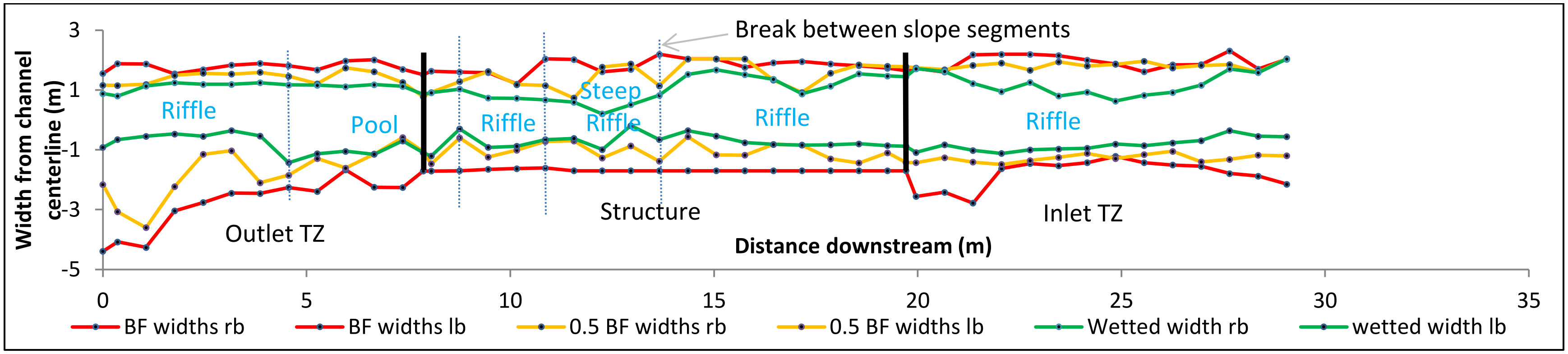


FIGURE 257: NORTH FORK INDIAN DESIGN WIDTHS

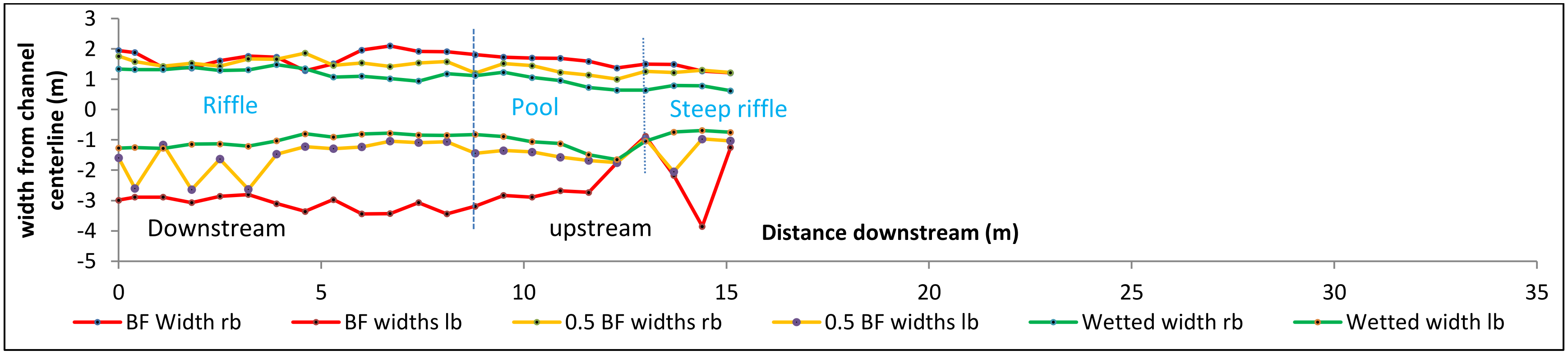


FIGURE 258: NORTH FORK INDIAN STEEP REPRESENTATIVE REACH WIDTHS

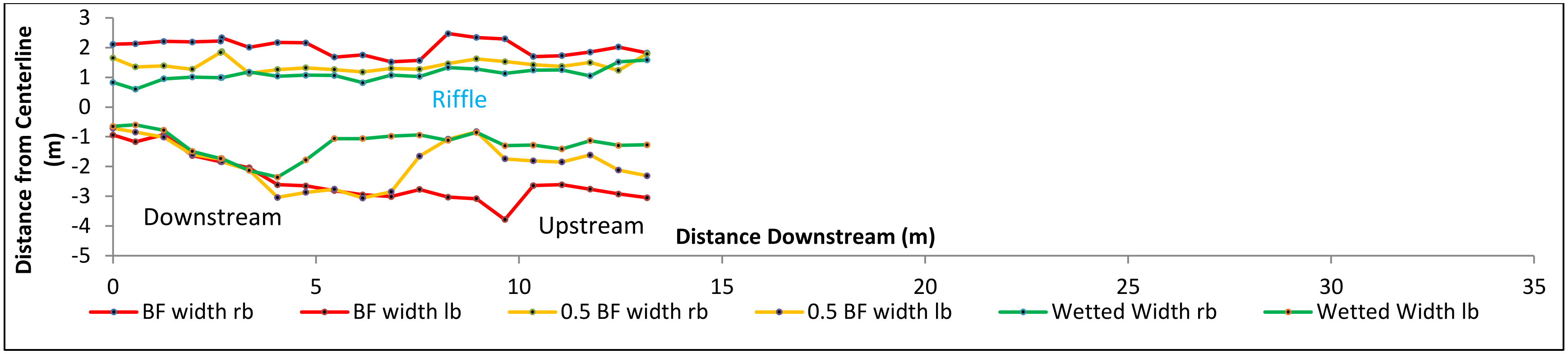


FIGURE 259: NORTH FORK INDIAN GENTLE REPRESENTATIVE REACH WIDTHS

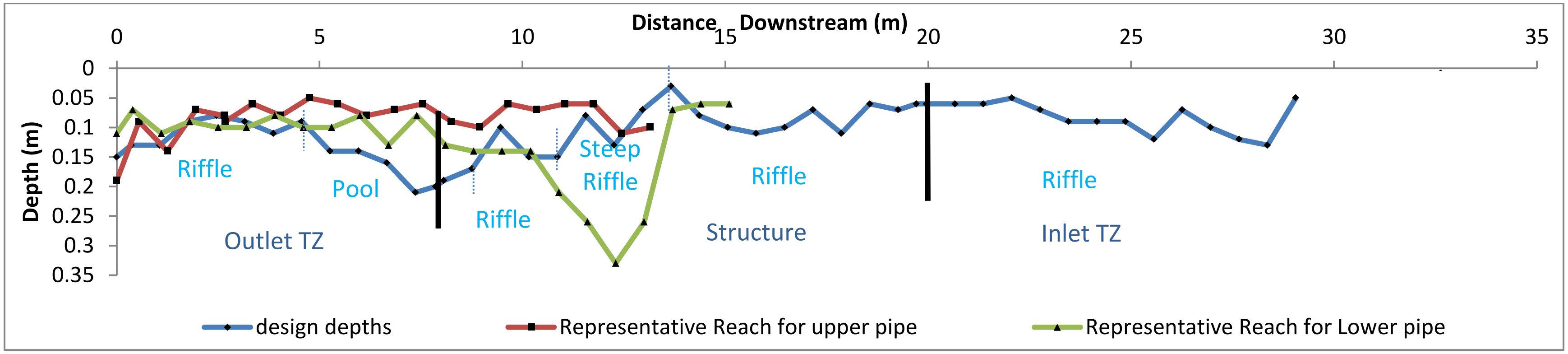


FIGURE 260: NORTH FORK INDIAN MAXIMUM DEPTHS

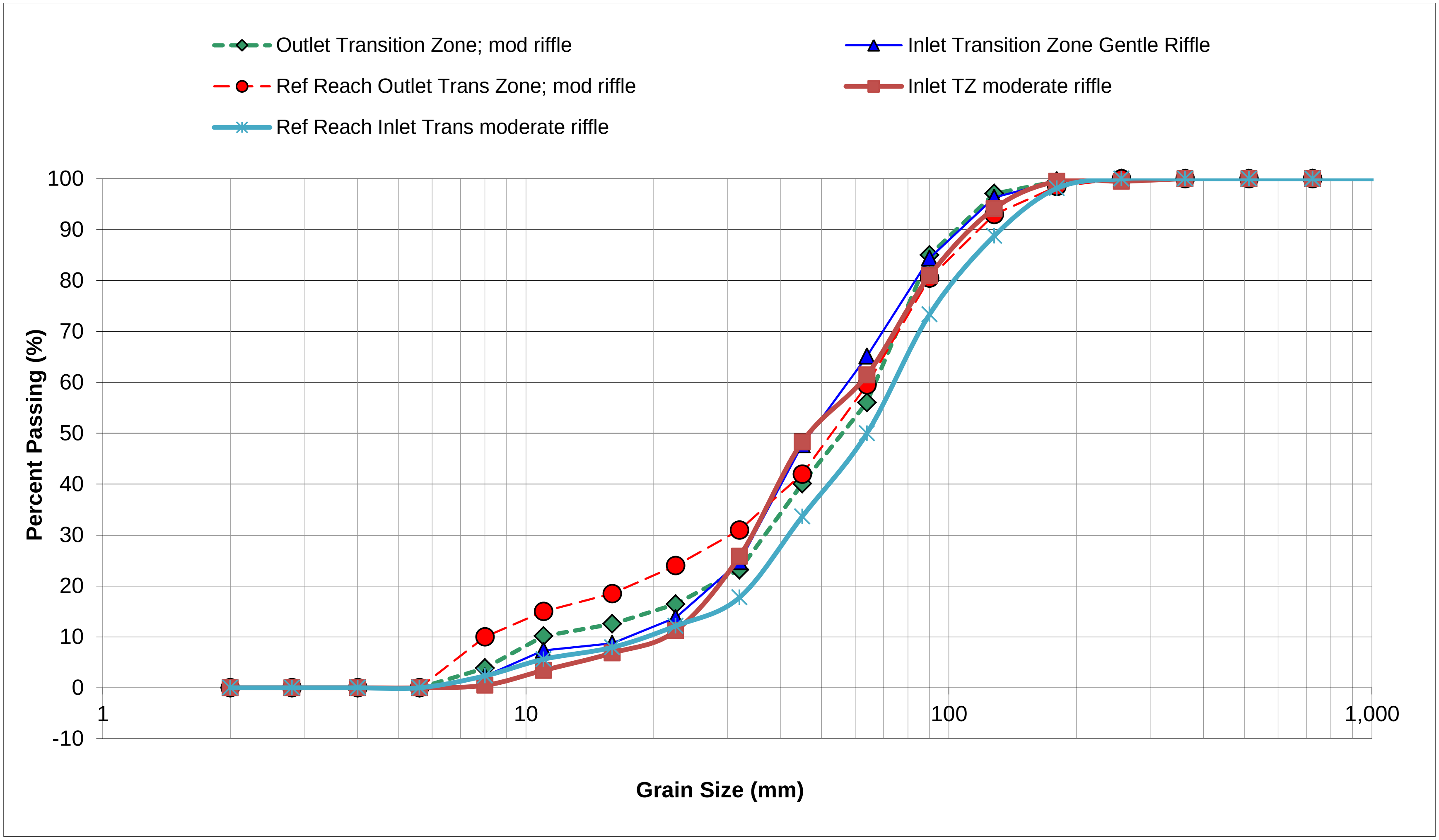


FIGURE 261: NORTH FORK INDIAN GRADATION

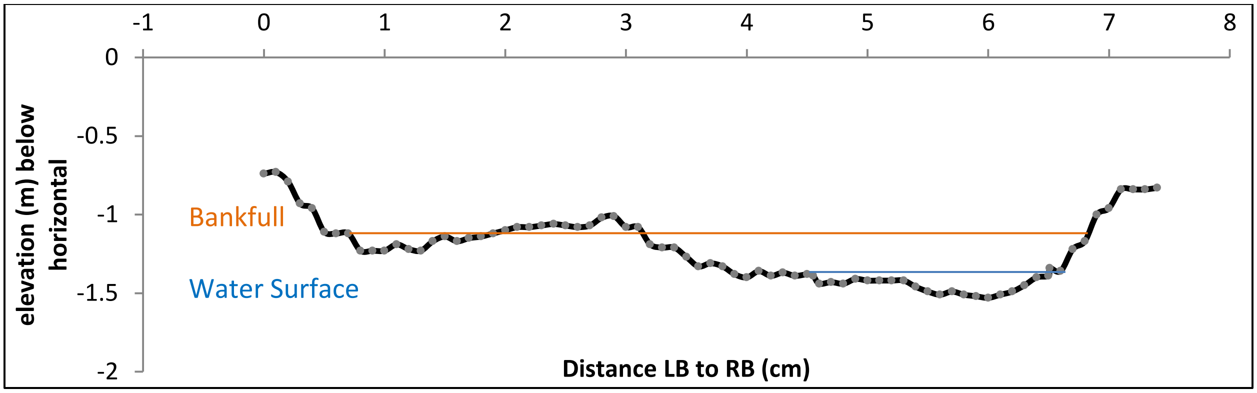


FIGURE 262: NORTH FORK INDIAN CROSS SECTION 1; INLET TRANSITION ZONE; RIFFLE

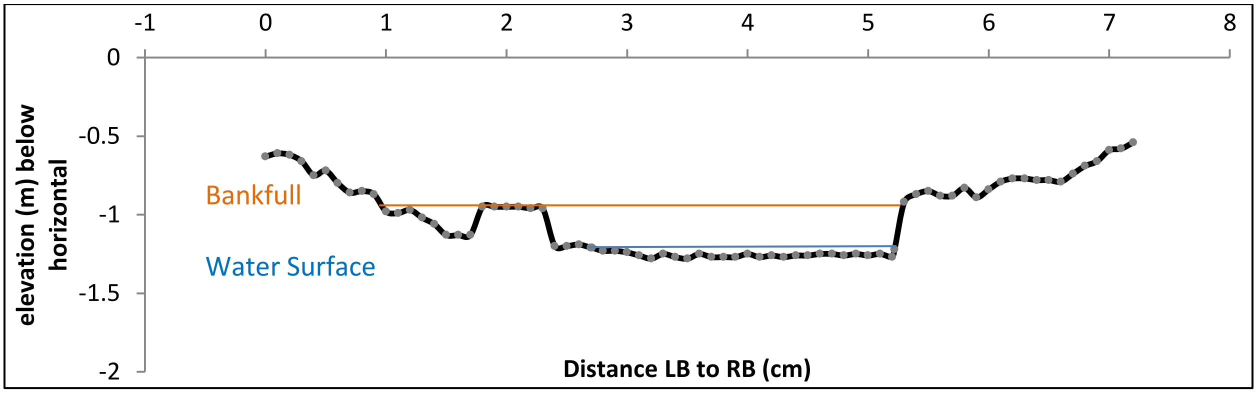


FIGURE 263: NORTH FORK INDIAN CROSS SECTION 2; INLET TRANSITION ZONE; RIFFLE

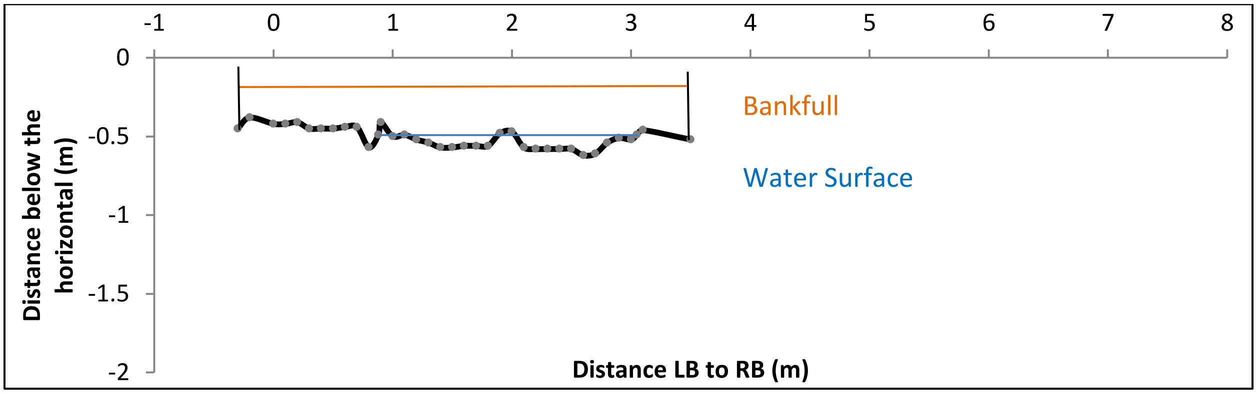


FIGURE 264: NORTH FORK INDIAN CROSS SECTION 3; UPPER HALF OF THE STRUCTURE; RIFFLE

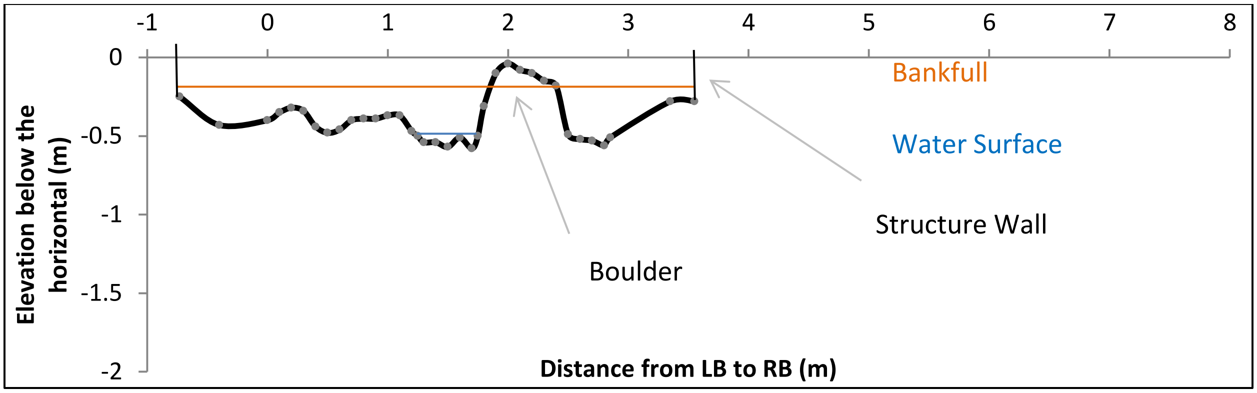


FIGURE 265: NORTH FORK INDIAN CROSS SECTION 4; WITHIN THE STRUCTURE; STEEP RIFFLE

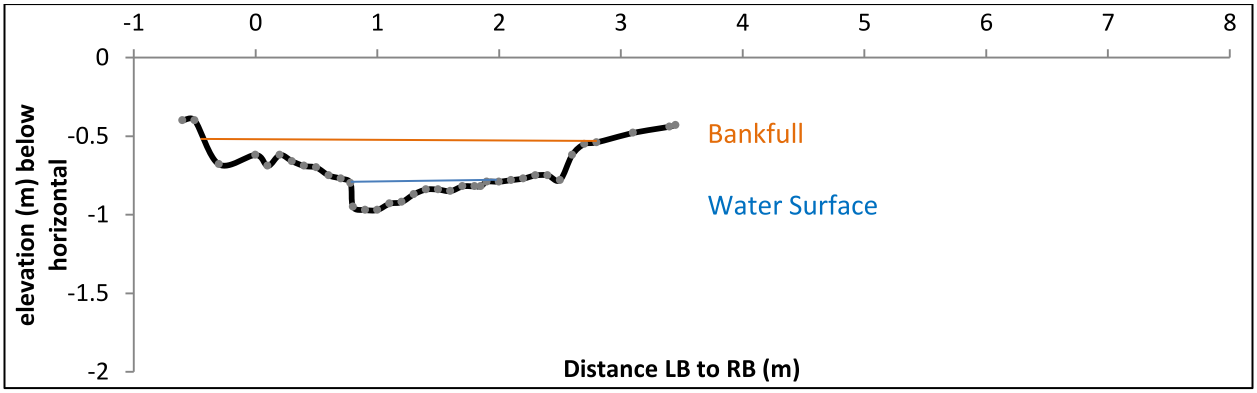


FIGURE 266: NORTH FORK INDIAN CROSS SECTION 5; WITHIN THE STRUCTURE; MODERATELY STEEP RIFFLE

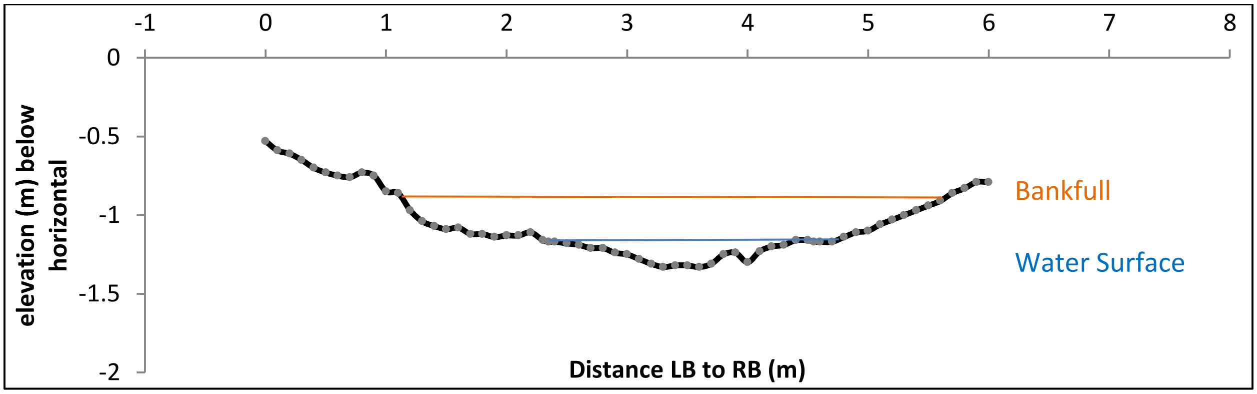


FIGURE 267: NORTH FORK INDIAN CROSS SECTION 6; OUTLET TRANSITION ZONE; POOL

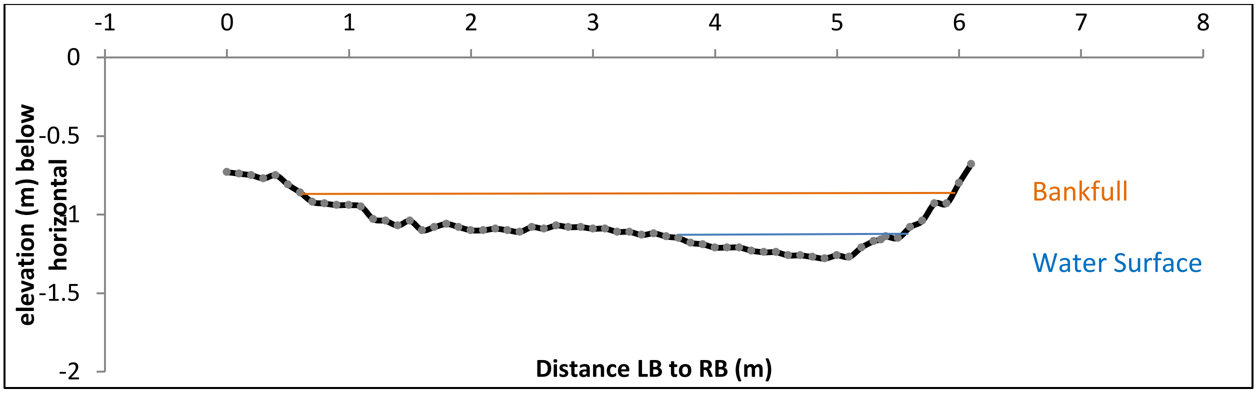


FIGURE 268: NORTH FORK INDIAN CROSS SECTION 7; REPRESENTATIVE REACH FOR STEEPER SLOPE SEGMENT; RIFFLE

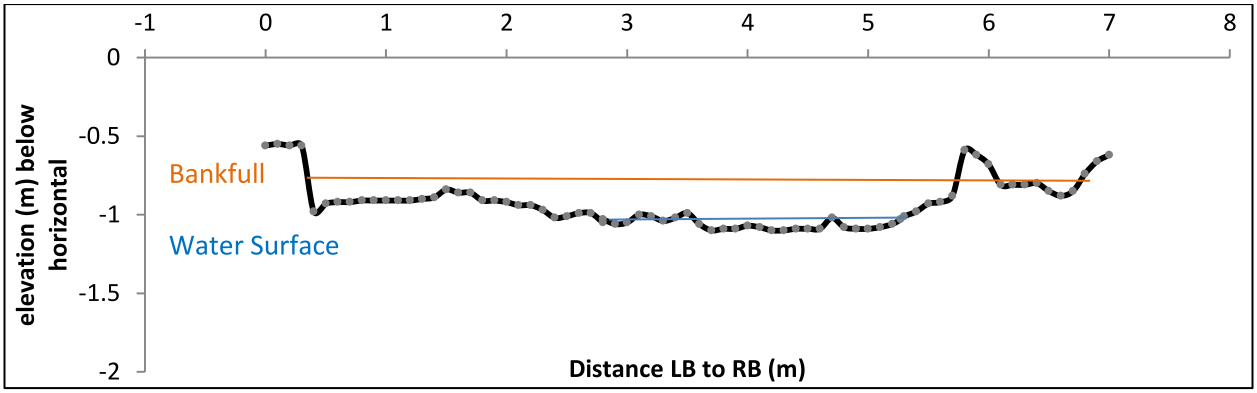


FIGURE 269: NORTH FORK INDIAN CROSS SECTION 8; REPRESENTATIVE REACH FOR GENTLE SLOPE SEGMENT; RIFFLE

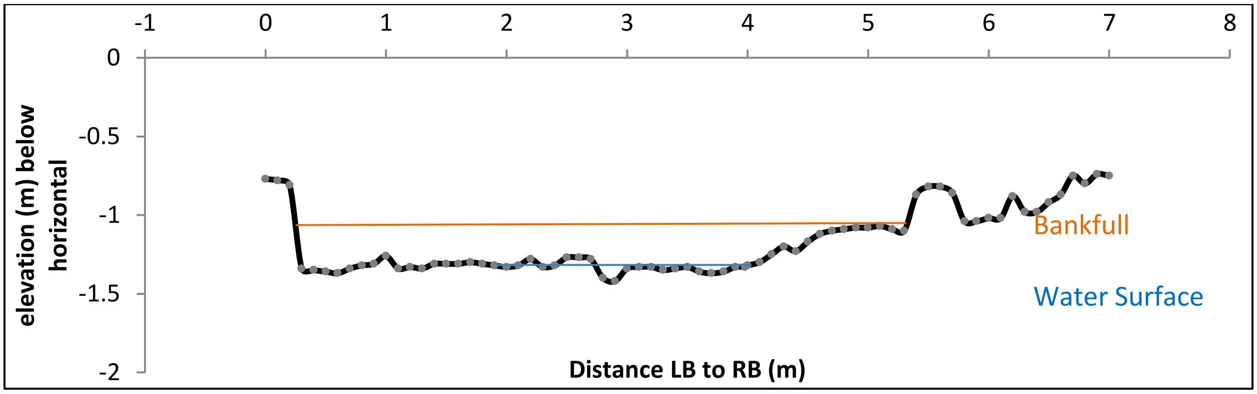


FIGURE 270: NORTH FORK INDIAN CROSS SECTION 9; REPRESENTATIVE REACH FOR GENTLE SLOPE SEGMENT; RIFFLE

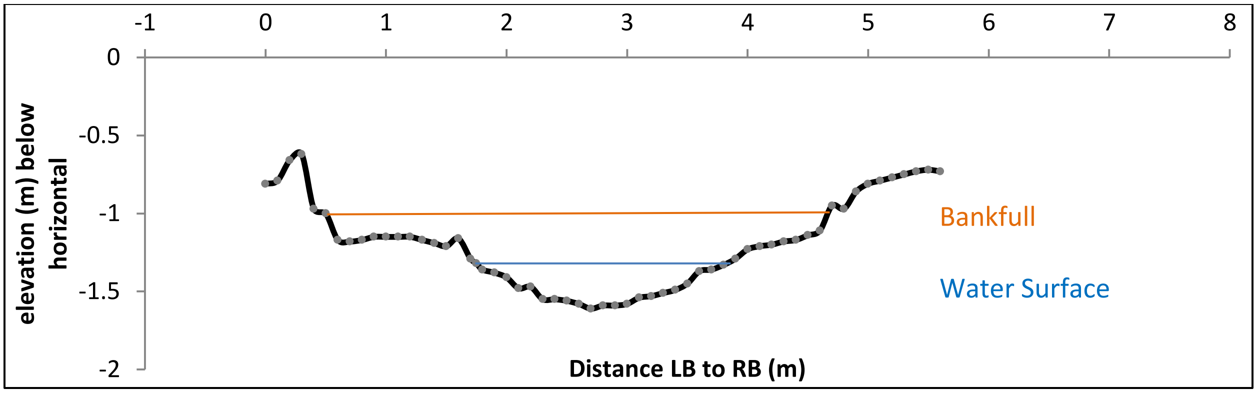


FIGURE 271: NORTH FORK INDIAN CROSS SECTION 10; REPRESENTATIVE REACH FOR STEEPER SLOPE SEGMENT; POOL

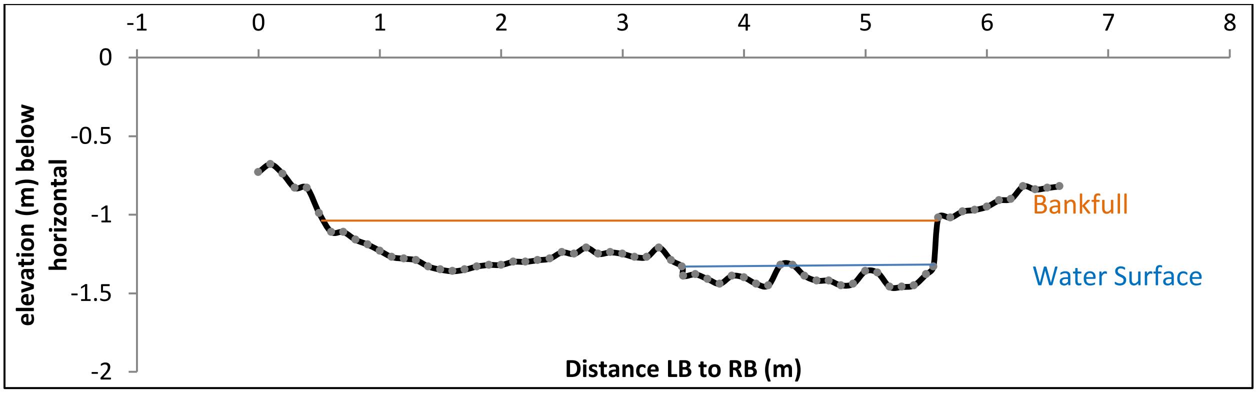


FIGURE 272: NORTH FORK INDIAN CROSS SECTION 11; REPRESENTATIVE REACH FOR STEEPER SLOPE SEGMENT; RIFFLE

A7.4 NORTH FORK INDIAN BOXPLOTS AND HISTOGRAMS

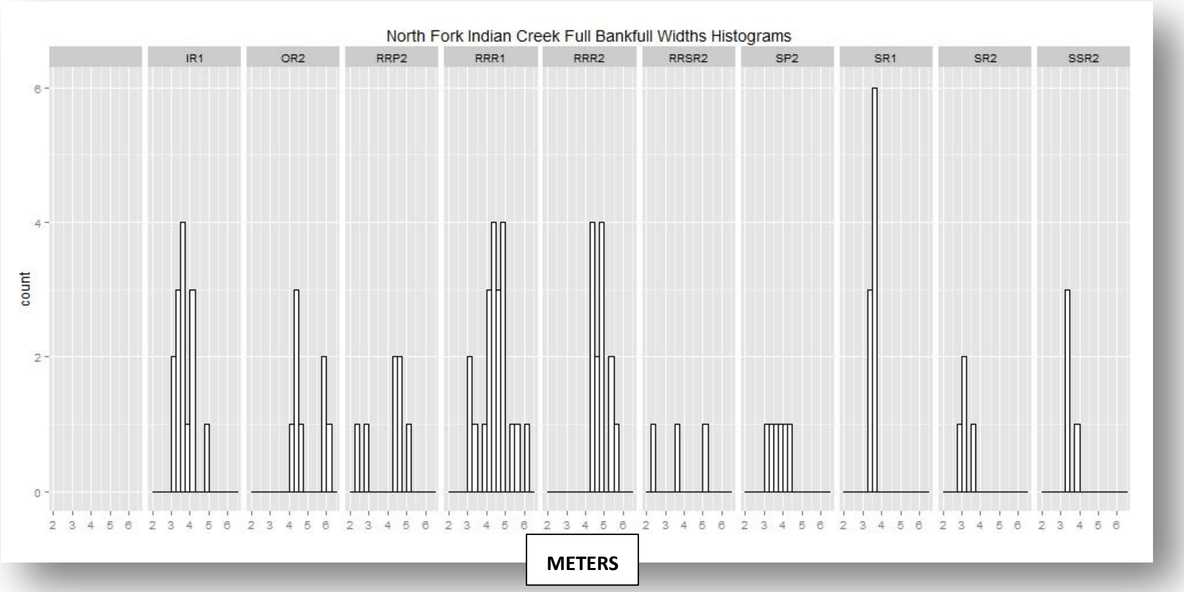


FIGURE 273: NORTH FORK INDIAN WIDTH AT BANKFULL STAGE; HISTOGRAM

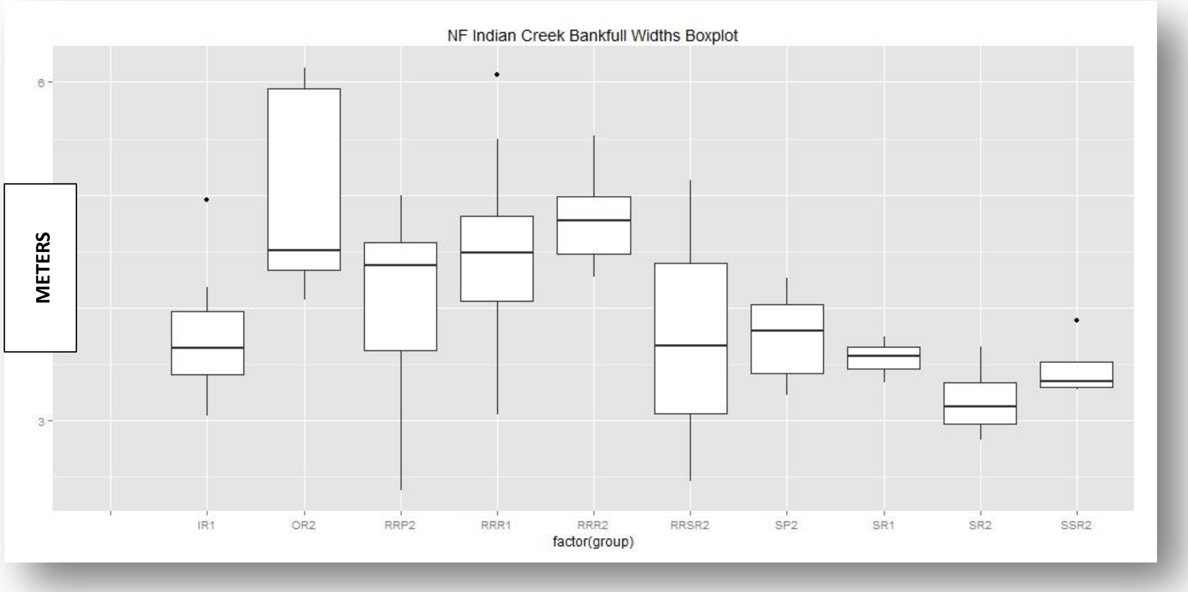


FIGURE 274: NORTH FORK INDIAN WIDTH AT BANKFULL STAGE; BOXPLOT

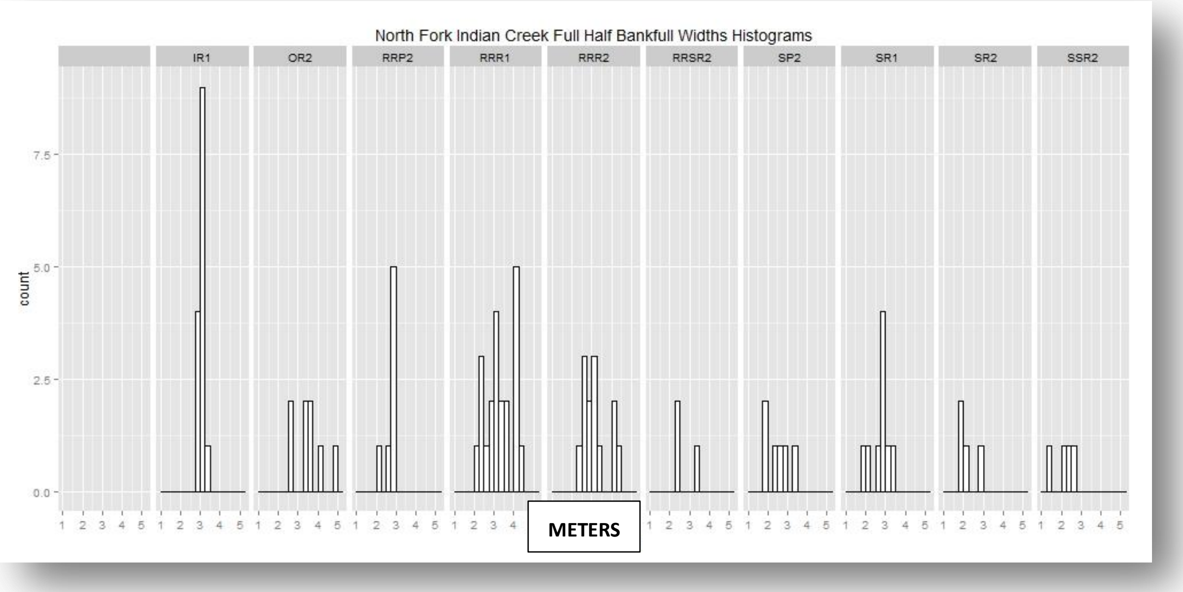


FIGURE 275: NORTH FORK INDIAN WIDTH AT HALF BANKFULL STAGE; HISTOGRAM

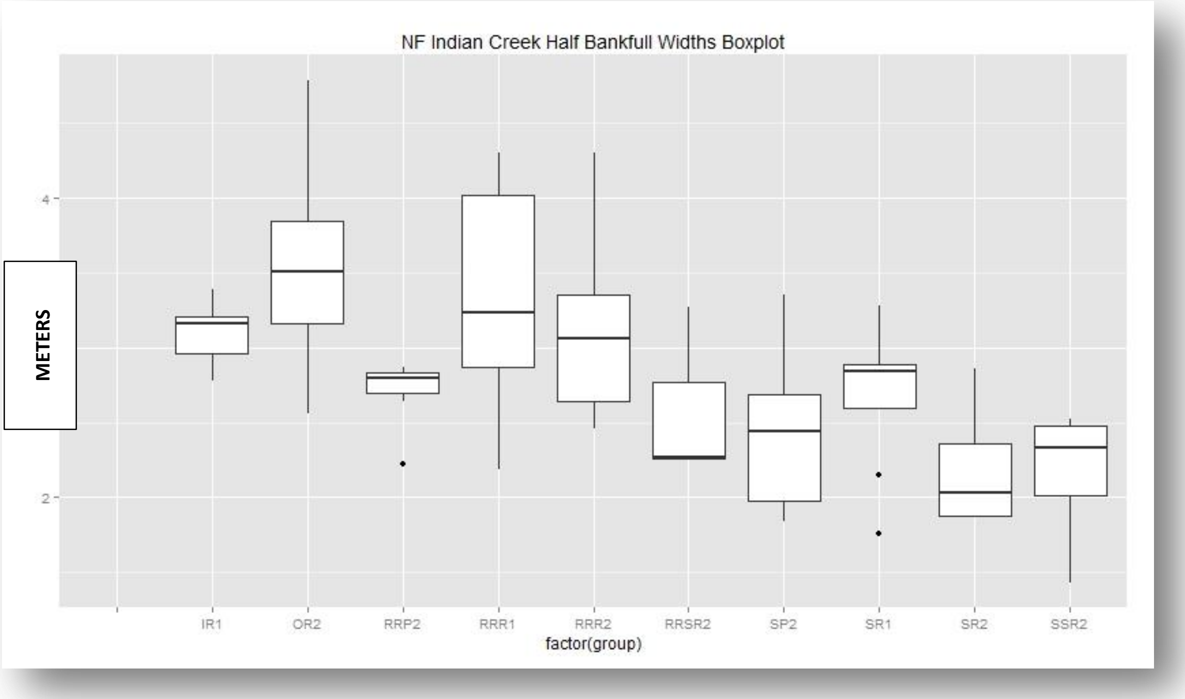


FIGURE 276: NORTH FORK INDIAN WIDTH AT HALF BANKFULL STAGE; BOXPLOT

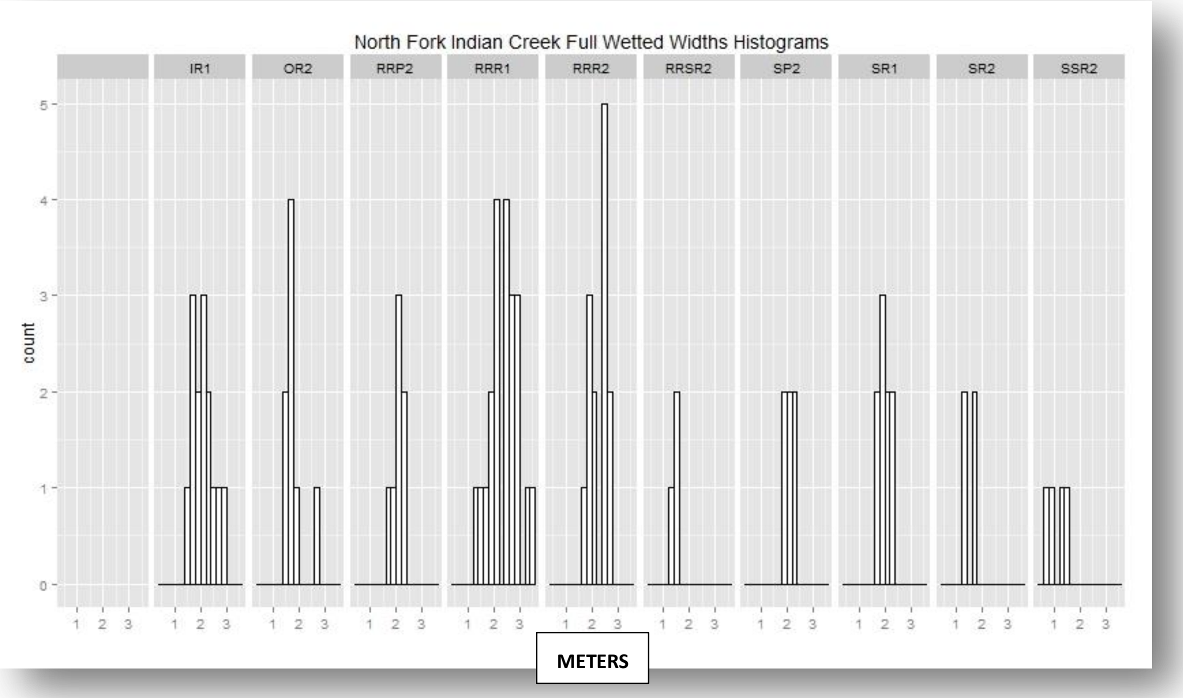


FIGURE 277: NORTH FORK INDIAN WIDTH AT LOW FLOW (WETTED); HISTOGRAM

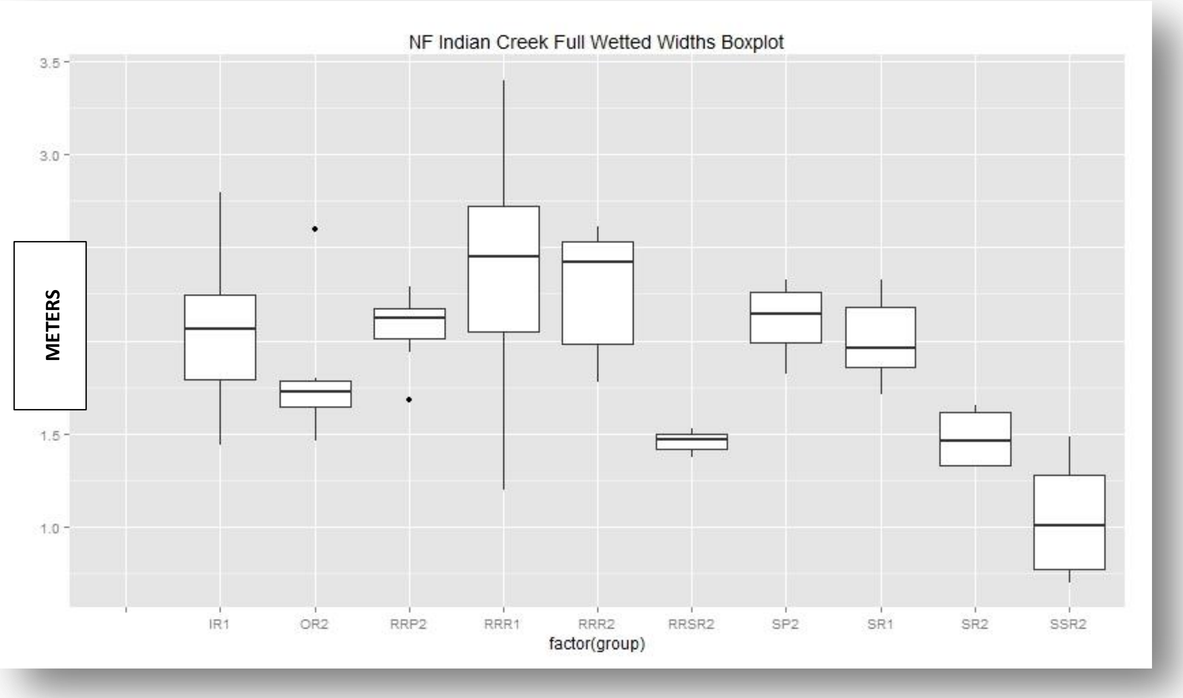


FIGURE 278: NORTH FORK INDIAN WIDTH AT LOW FLOW (WETTED); BOXPLOT

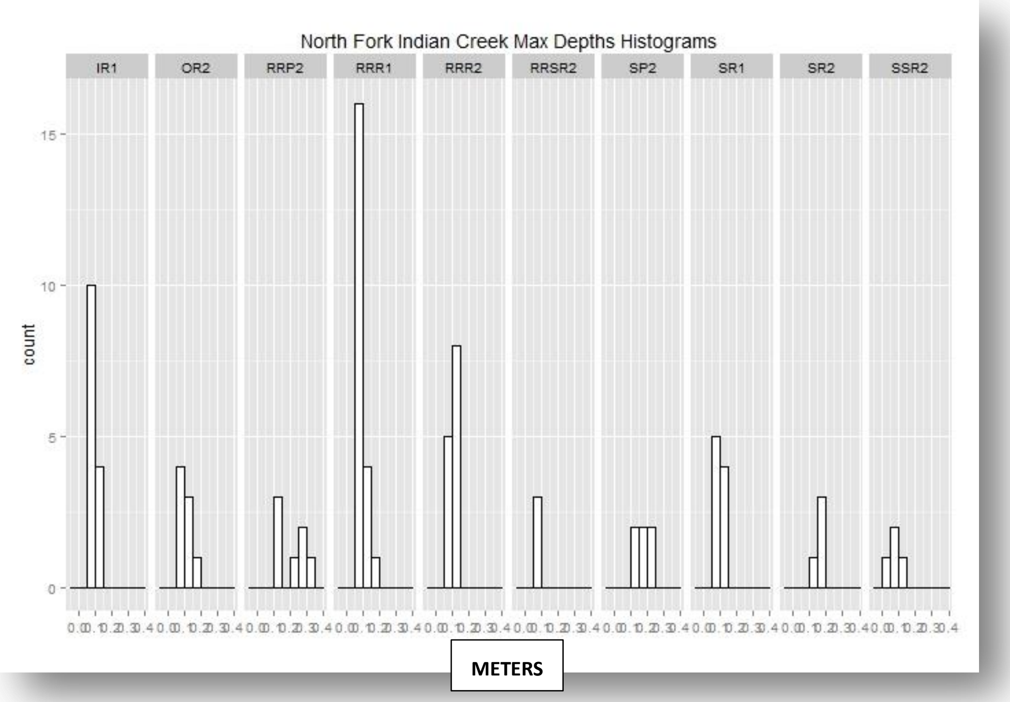


FIGURE 279: NORTH FORK INDIAN MAXIMUM DEPTH; HISTOGRAM

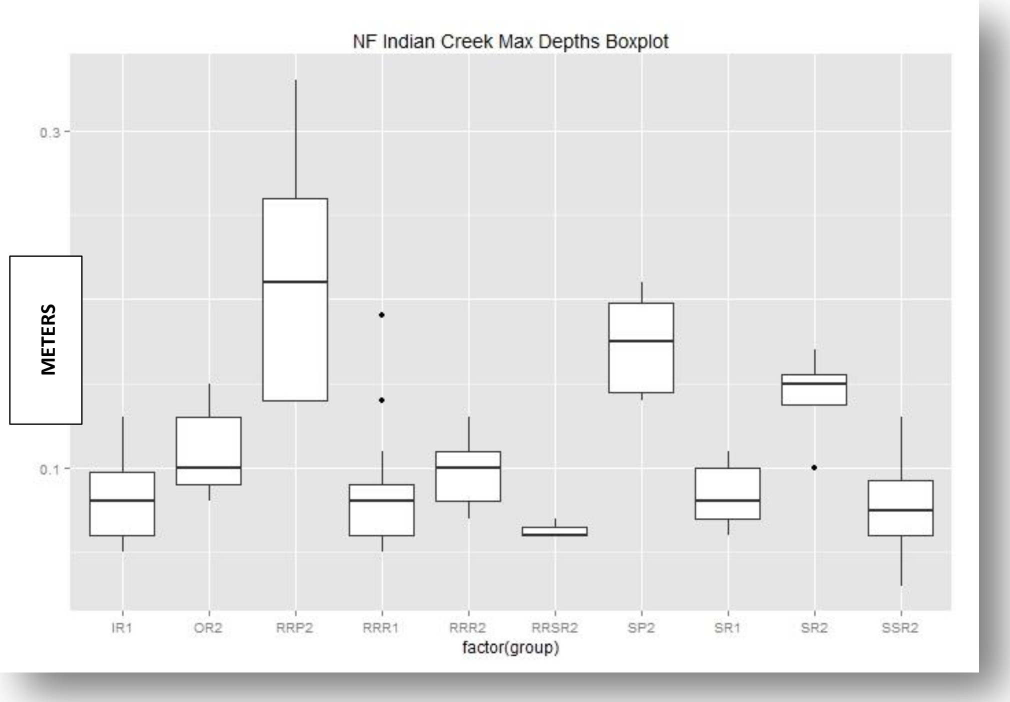


FIGURE 280: NORTH FORK INDIAN MAXIMUM DEPTH; BOXPLOT

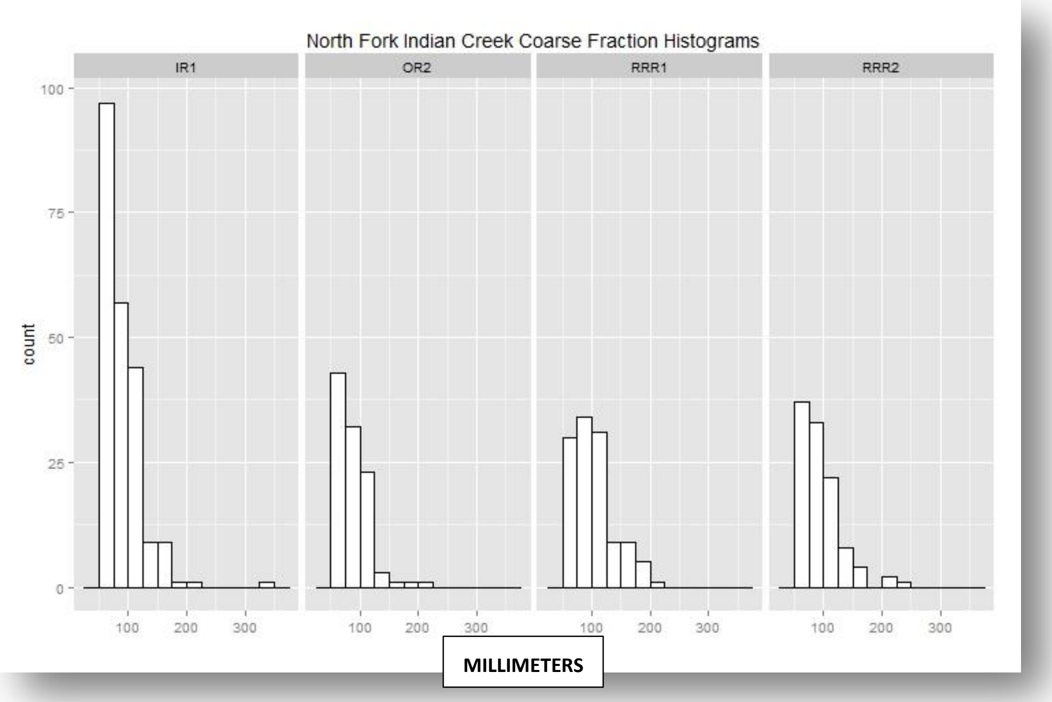


FIGURE 281: NORTH FORK INDIAN COARSE FRACTION; HISTOGRAM

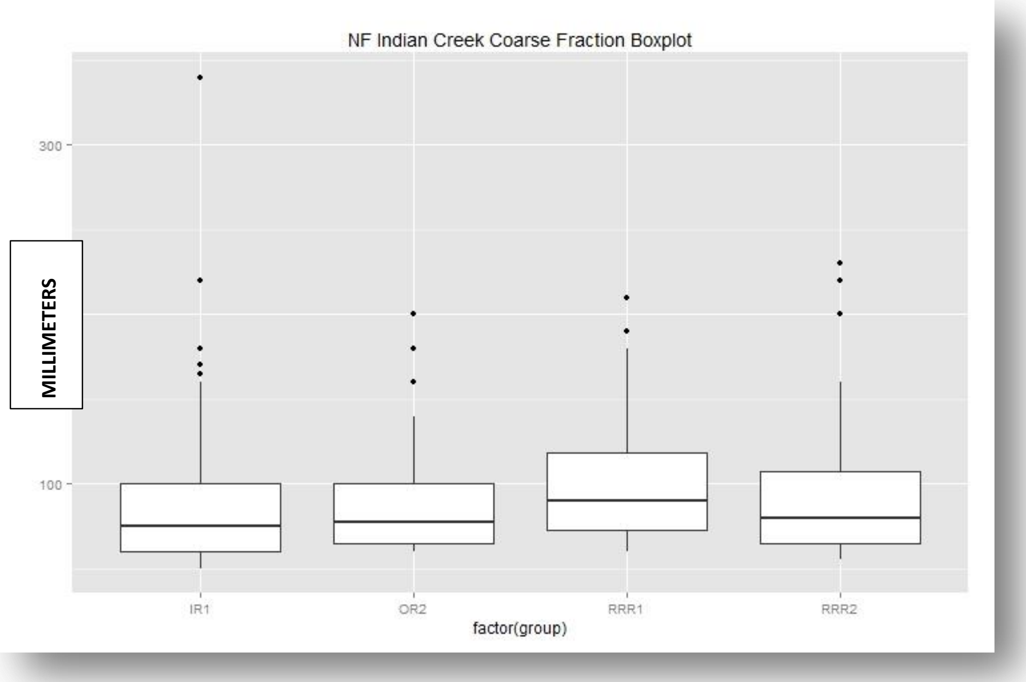


FIGURE 282: NORTH FORK INDIAN COARSE FRACTION; BOXPLOT

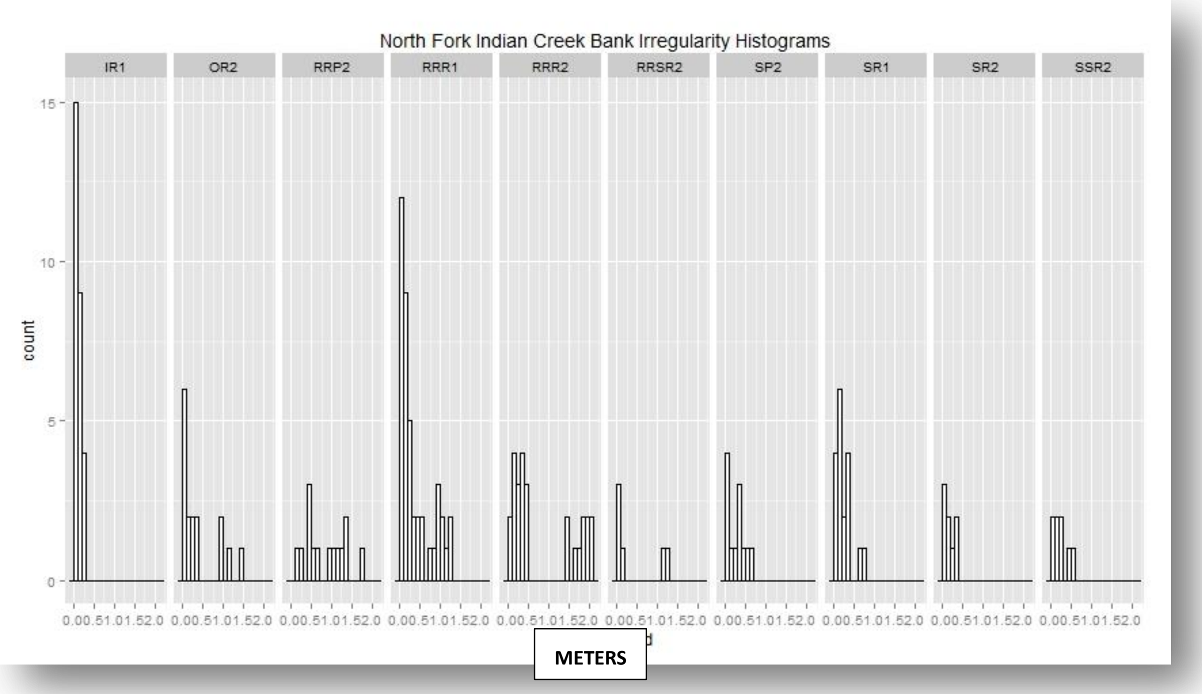


FIGURE 283: NORTH FORK INDIAN BANK IRREGULARITY; HISTOGRAM

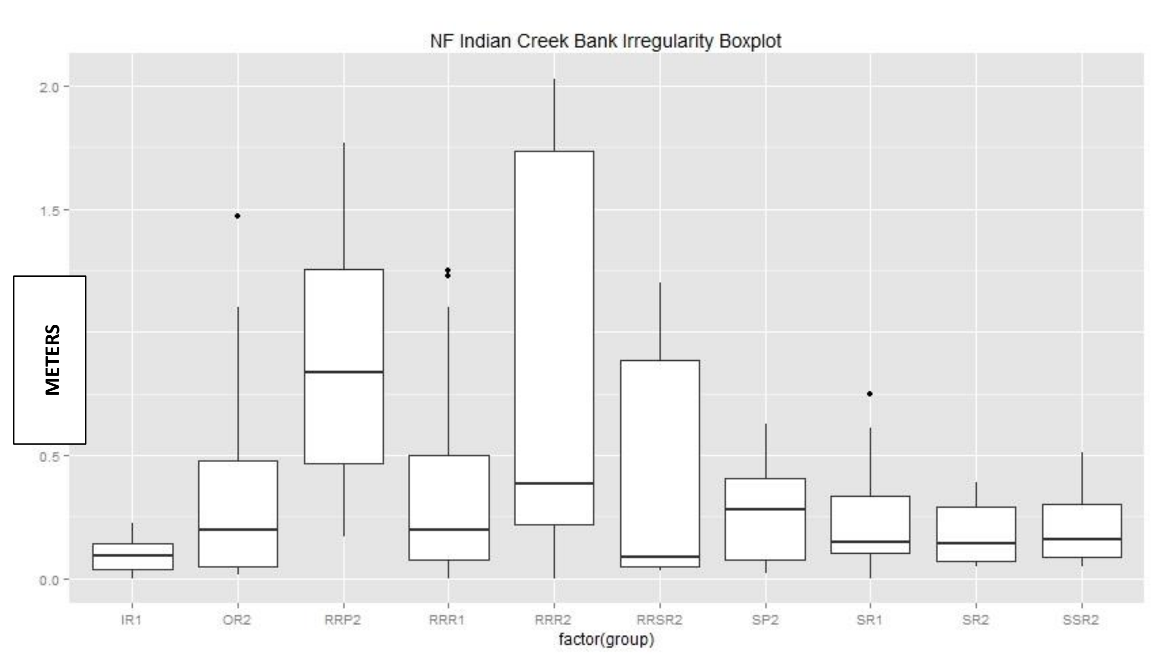


FIGURE 284: NORTH FORK INDIAN BANK IRREGULARITY; BOXPLOT

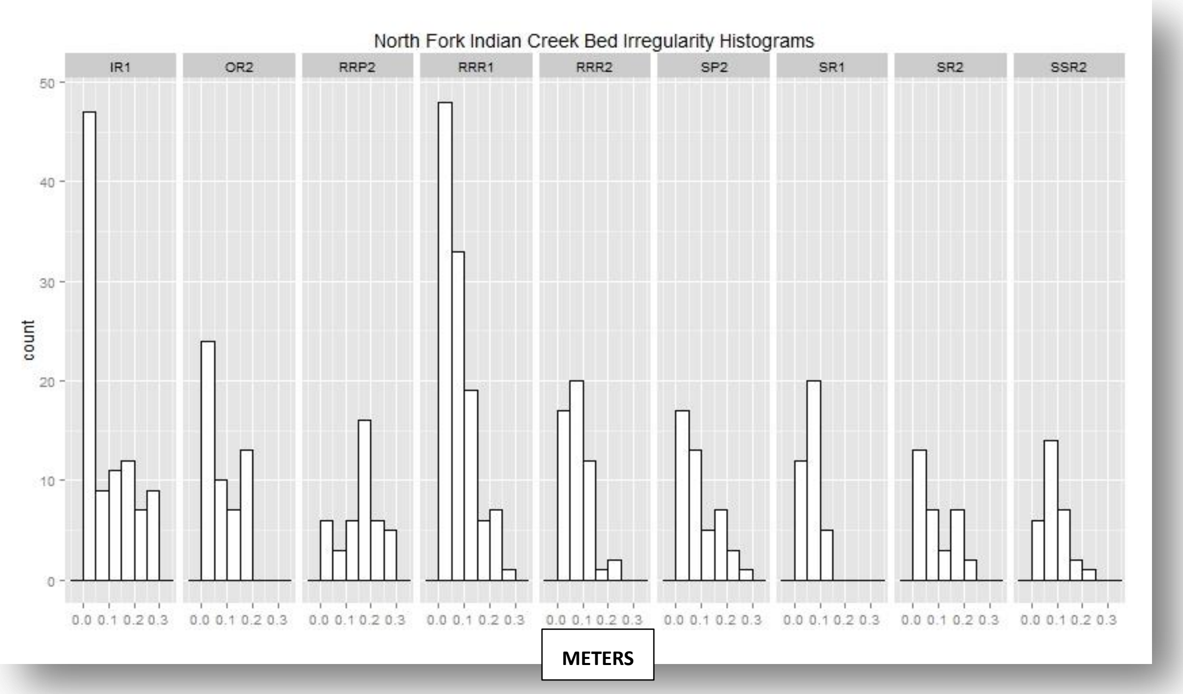


FIGURE 285: NORTH FORK INDIAN BED IRREGULARITY; HISTOGRAM

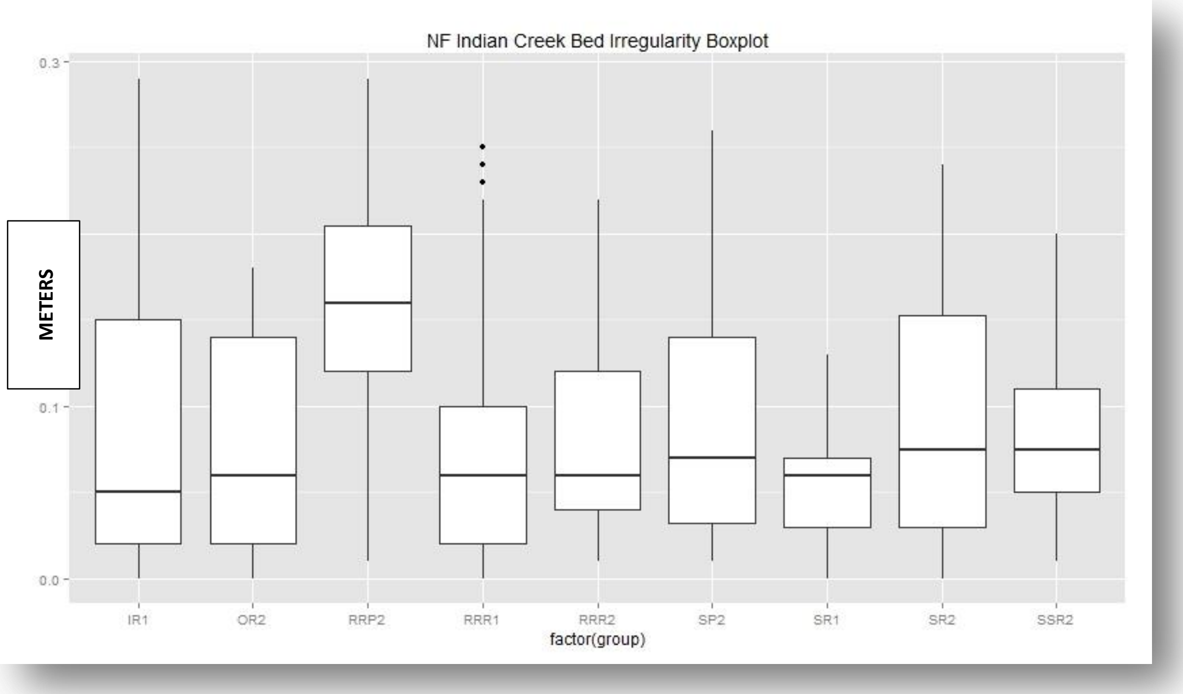


FIGURE 286: NORTH FORK INDIAN BED IRREGULARITY; BOXPLOT

A7.5 NORTH FORK INDIAN SCORING SENSITIVITY ANALYSIS

TABLE 89: NORTH FORK INDIAN LEVEL II SCORING SENSITIVITY ANALYSIS

Channel Unit And Criteria for a Score of 3	Inlet Transition Zone			Structure Zone			Outlet Transition Zone		
	% Score	Evaluation	Override	% Score	Evaluation	Override	% Score	Evaluation	Override
Riffle 1 0.01 to 0.05	56	Questionable		70	Questionable			Not Applicable	
Riffle 1 0.001 to 0.05	69	Questionable	→Similar	80	Similar	→Questionable		Not Applicable	
Riffle 2 0.01 to 0.05		Not Applicable		78	Similar		69	Questionable	
Riffle 2 0.001 to 0.05		Not Applicable		83	Similar	→ Questionable	76	Similar	
Steep riffle 2 0.01 to 0.05		Not Applicable		73	Questionable			Not Applicable	
Steep riffle 2 0.001 to 0.05		Not Applicable		73	Questionable	→Similar		Not Applicable	
Pool 2 0.01 to 0.05		Not Applicable		85	Similar			Not Applicable	
Pool 2 0.001 to 0.05		Not Applicable		85	Similar			Not Applicable	

A8 SITE 3 SITE DATA

A8.1 SITE 3 PHOTOS

FIGURE 287: LOOKING DOWNSTREAM AT THE SITE 3 INLET

FIGURE 288: LOOKING UPSTREAM AT THE SITE 3 OUTLET

Figure 289: Looking upstream at the Site 3 outlet transition zone boundary (major break in gradient)

Figure 290: Looking upstream within the Site 3 structure

FIGURE 291: LOOKING UPSTREAM AT THE SITE 3 REPRESENTATIVE REACH

A8.2 SITE 3 REPRESENTATIVE REACH ANALYSIS

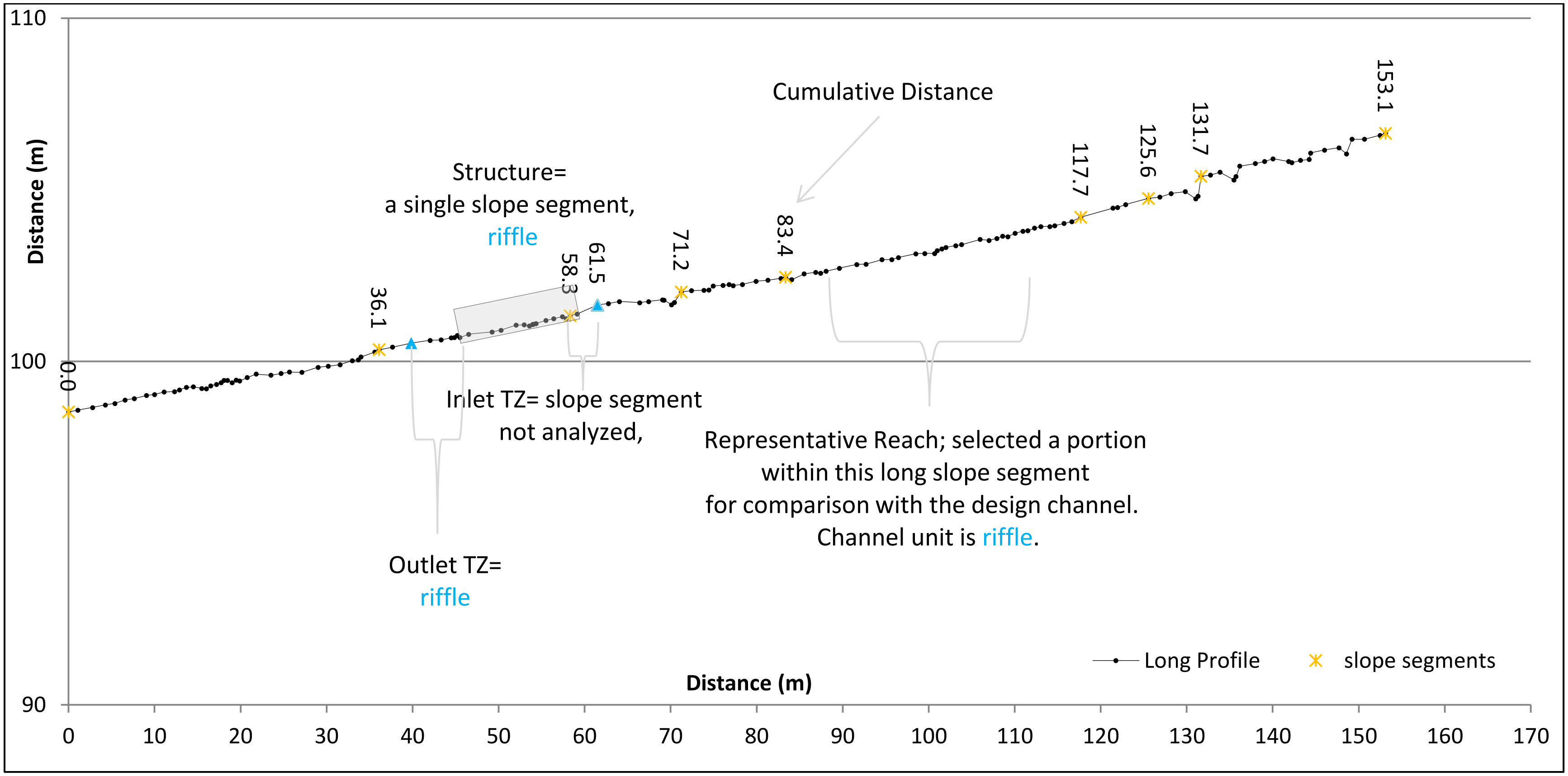


FIGURE 292: SITE 3 LONGITUDINAL PROFILE

THE SITE 3 LONGITUDINAL PROFILE ABOVE HAS A 4X VERTICAL EXAGGERATION. THE STRUCTURE (GREY RECTANGLE ABOVE) IS A CONCRETE CULVERT WITH LENGTH 13.3 M, HEIGHT 1.8 M AND WIDTH 1.8 M. TWO SLOPE SEGMENTS MAKE UP THE DESIGN CHANNEL. THE INLET TRANSITION ZONE IS A STEP AND RIFFLE WITH GRADIENT 10%; NO REPRESENTATIVE REACH WAS SELECTED FOR THE INLET TZ GRADIENT. THE STRUCTURE AND OUTLET TZ CHANNEL IS A SINGLE SLOPE SEGMENT RIFFLE WITH GRADIENT 4.5%. THE SELECTED REPRESENTATIVE REACH IS A RIFFLE WITH GRADIENT 5.1%. THE INLET AND OUTLET TZ BOUNDARIES ARE MARKED WITH BLUE TRIANGLES ON THE PLOT ABOVE.

TABLE 90: SITE 3 REPRESENTATIVE REACH SLOPE SEGMENT ANALYSIS

N (m)	E (m)	Elev (m)	Cumulative Distance (m)	riffle crest (rc)	Survey Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Comments
5002.5	4977.3	98.5	0.0	GC1 SS1	on step crest, made of sticks, not stable, in thalweg near LB								
5006.9	5006.4	100.3	36.1	GC 3.0 SS 3	in thalweg near LB, step crest, med cobbles, pebbles and fines. Sed deposit erodes, top of riffle section.	29.4	1.8	36.1	0.050				
5003.0	5027.0	101.3	58.3	in pipe	micro rib, gravels and small cobbles near right bank, thalweg.	20.9	1.0	22.2	0.045	-11.3	0.0	-62.9	
5001.2	5029.6	101.6	61.5	GC 5.5	at break in slope in sediment deposit	3.2	0.3	3.2	0.099	121.3	-121.3	76.7	

N (m)	E (m)	Elev (m)	Cumu-lative Distance (m)	riffle crest (rc)	Survey Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Comments
5002.8	5038.3	102.0	71.2	GC 7 SS 6	thalweg. Top of headcut on fines of pebbles.	8.8	0.4	9.8	0.039	-60.5	12.6	28.4	Not selected; too close to structure and has wrong units, is step pool riffle
5005.7	5048.4	102.5	83.4		pool tail crest, thalweg	10.5	0.4	12.1	0.035	-10.2	21.5	11.1	
4990.2	5073.3	104.2	117.7		step crest, channel centerline. Med and large cobbles, and fines, under big tree (suspended), channel centerline, thalweg?	29.3	1.8	34.3	0.051	45.8	-14.4	-151.9	Selected; Is much longer than structure, but only 110 to 88 m is compared. Is a riffle, riffle run, riffle.
4985.1	5076.2	104.8	125.6		top of steep riffle? Channel centerline. Break in slope on fines and med cobbles, no real defined rib.	5.8	0.5	7.9	0.070	36.9	-56.6	42.3	

N (m)	E (m)	Elev (m)	Cumu-lative Distance (m)	riffle crest (rc)	Survey Notes	Straight line seg-ment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Com-ments
4986.3	5081.6	105.4	131.7		crest of step. Step is large tree roots, growing across entire channel. Stable, live tree.	5.5	0.6	6.1	0.106	51.1	-136.7	55.3	
4979.5	5099.4	106.6	153.1		crest of micro rib. Medium cobbles, fines, not stable. Thalweg. Channel centerline.	19.0	1.2	21.5	0.058	-44.9	-30.3	-57.6	

TABLE 91: SITE 3 DESIGN SLOPE SEGMENT DATA (STRUCTURE AND OUTLET TZ ONLY)

N (m)	E (m)	Elev (m)	Cumulative Distance (m)	riffle crest (rc)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Grad-ient	Comments
5006.9	5006.4	100.3	36.1	GC 3.0 SS 3					is pool, riffle, pool, riffle, pool
5003.0	5027.0	101.3	58.3	in pipe	20.9	1.0	22.2	0.045	25% criteria
13.3 m is culvert length									

A8.3 Site 3 Data-by-Distance Plots

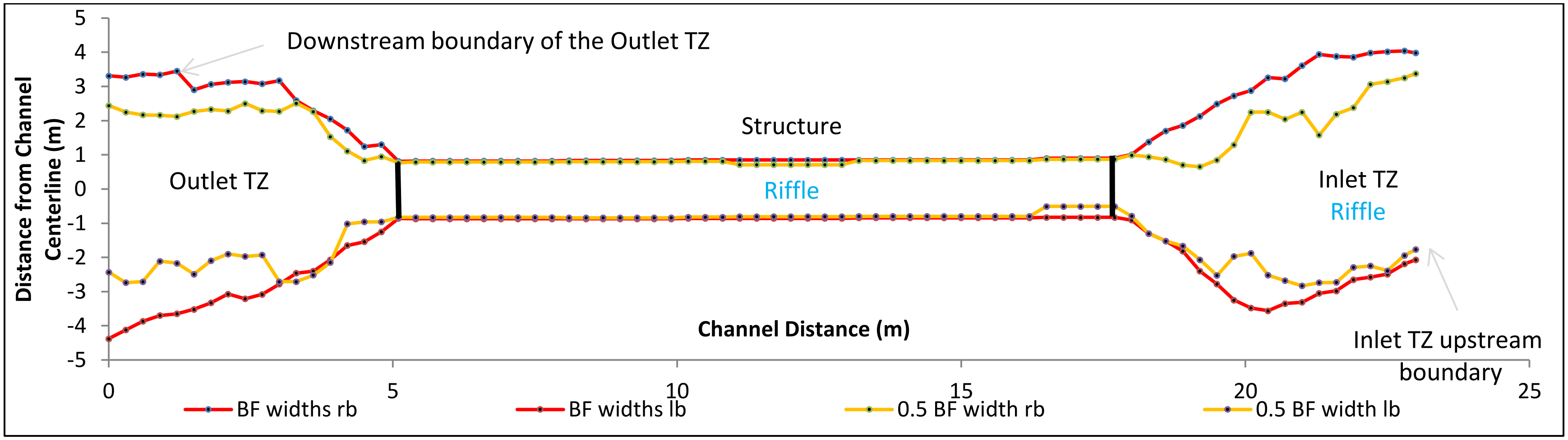


Figure 293: Site 3 Design Channel Widths

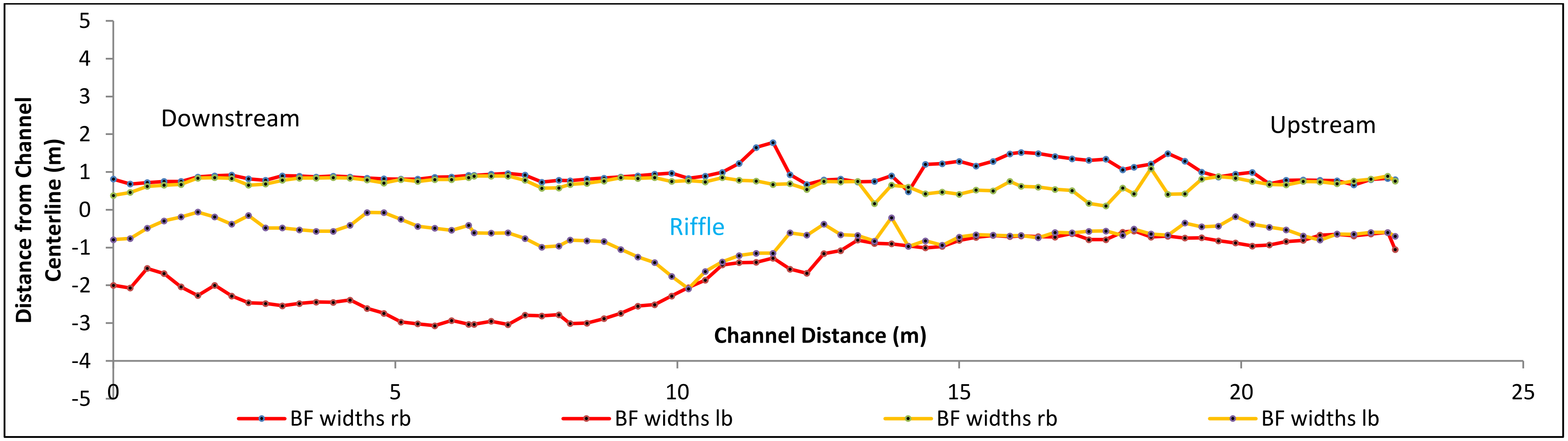


Figure 294: Site 3 Representative Reach Widths

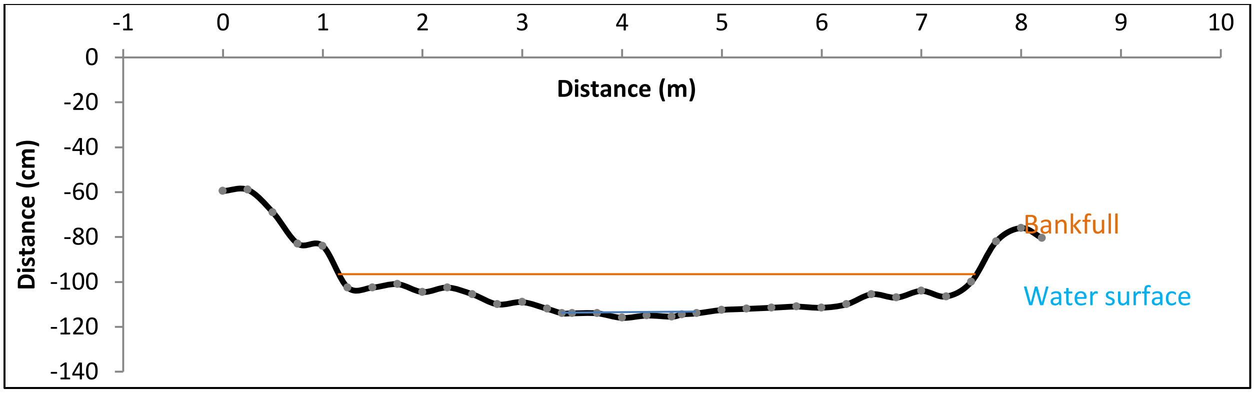


FIGURE 295: SITE 3 CROSS SECTION 1 OUTLET TRANSITION ZONE; RIFFLE

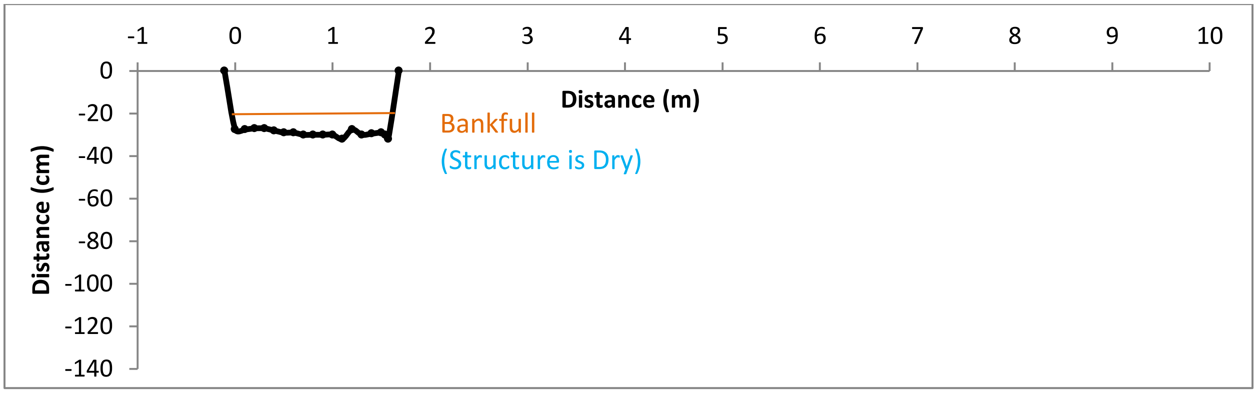


FIGURE 296: SITE 3 CROSS SECTION 2; WITHIN CULVERT AT MIDPOINT; RIFFLE

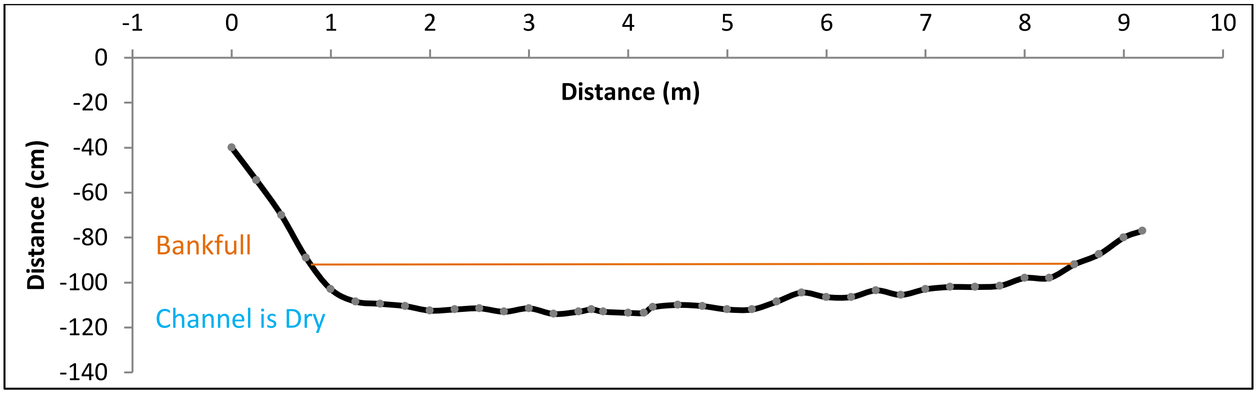


FIGURE 297: SITE 3 CROSS SECTION3 INLET TRANSITION ZONE; RIFFLE

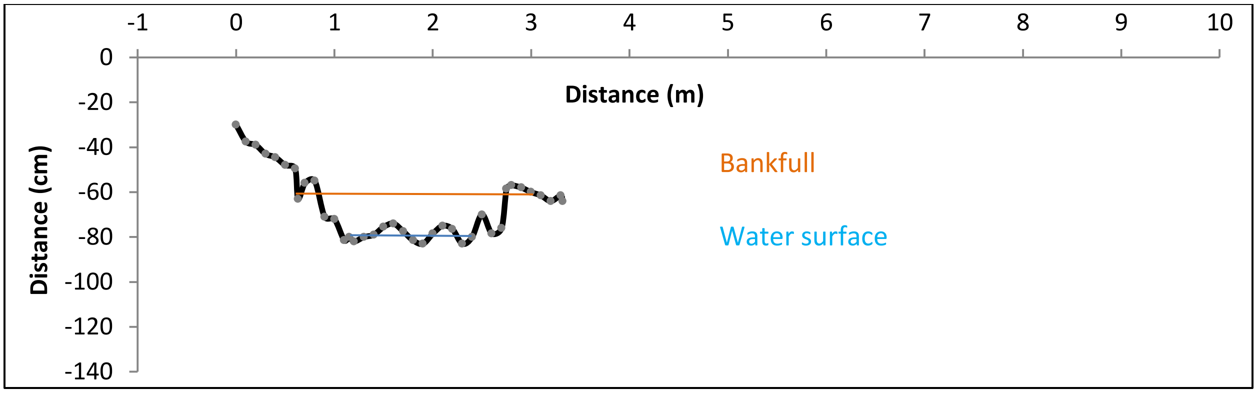


FIGURE 298: SITE 3 CROSS SECTION 4 REPRESENTATIVE REACH; RIFFLE

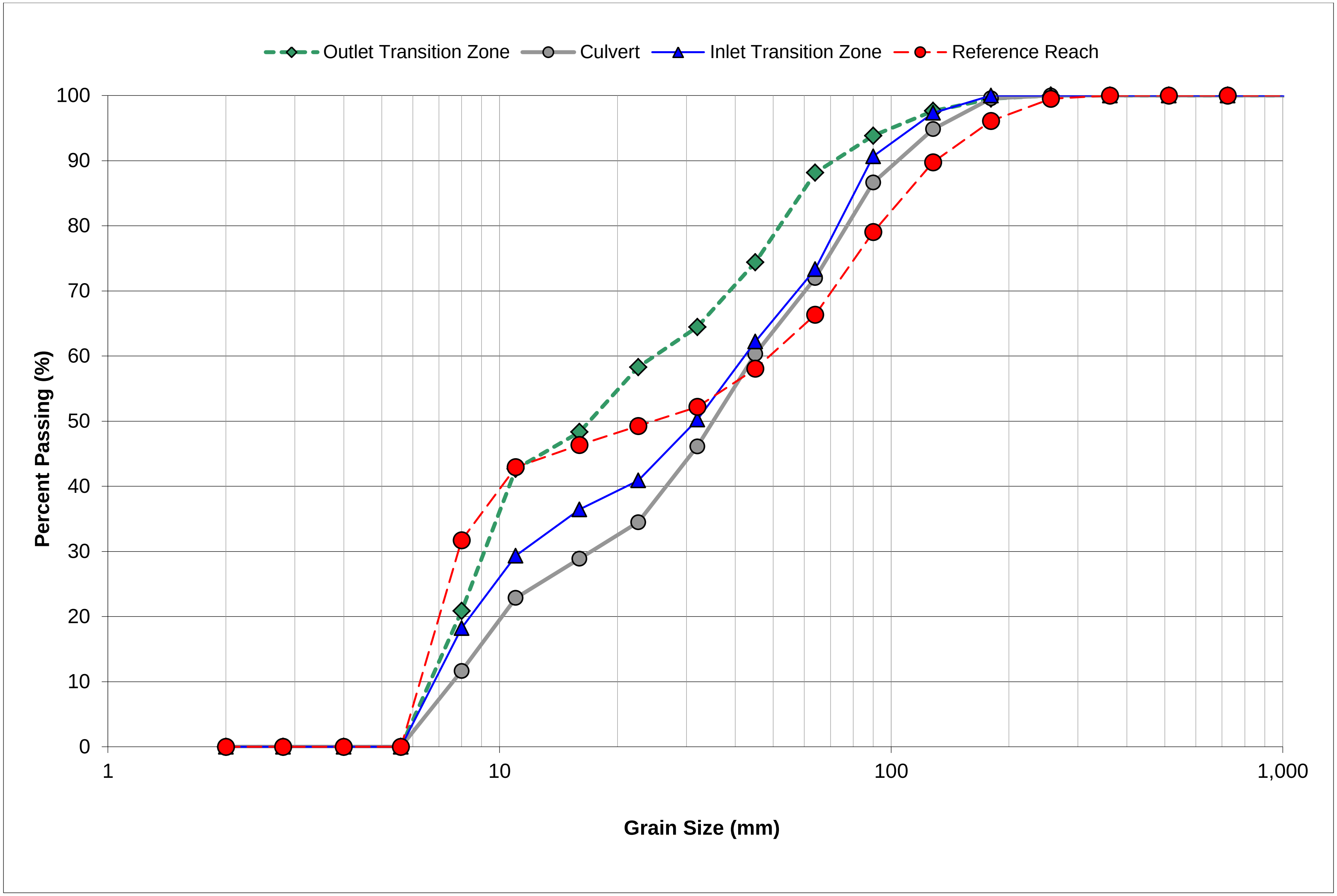


FIGURE 299: SITE 3 GRADATION

A8.4 SITE 3 BOXPLOTS AND HISTOGRAMS

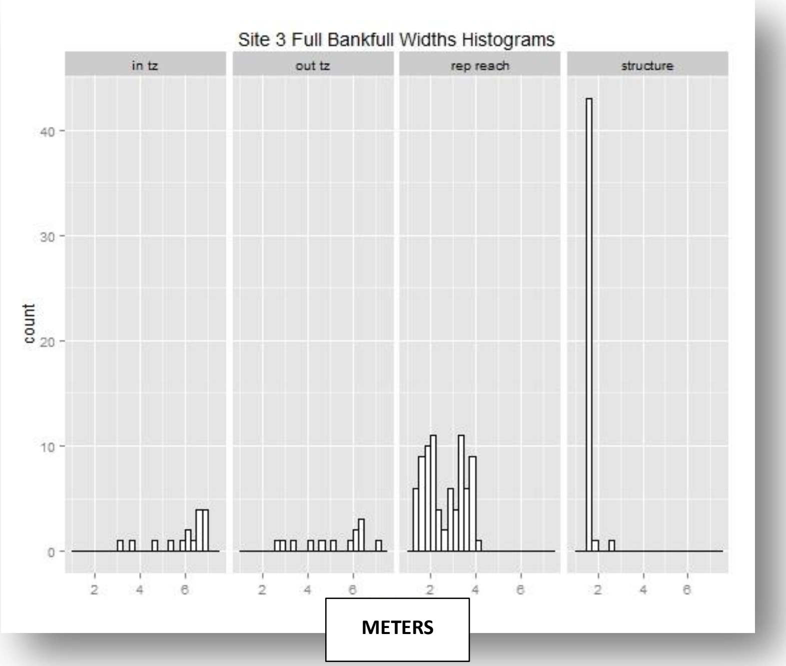


FIGURE 300: SITE 3 WIDTH AT BANKFULL STAGE; HISTOGRAM

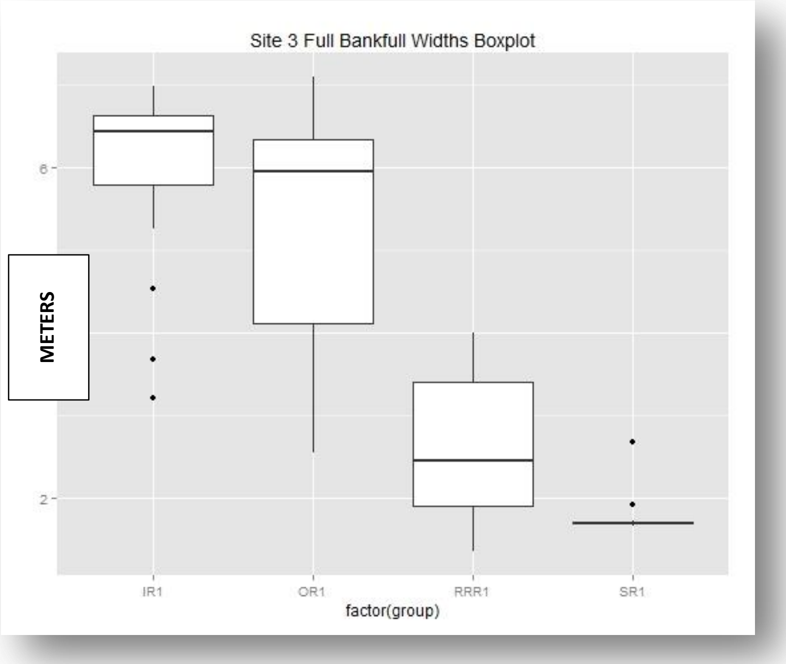


FIGURE 301: SITE 3 WIDTHS AT BANKFULL STAGE; BOXPLOT

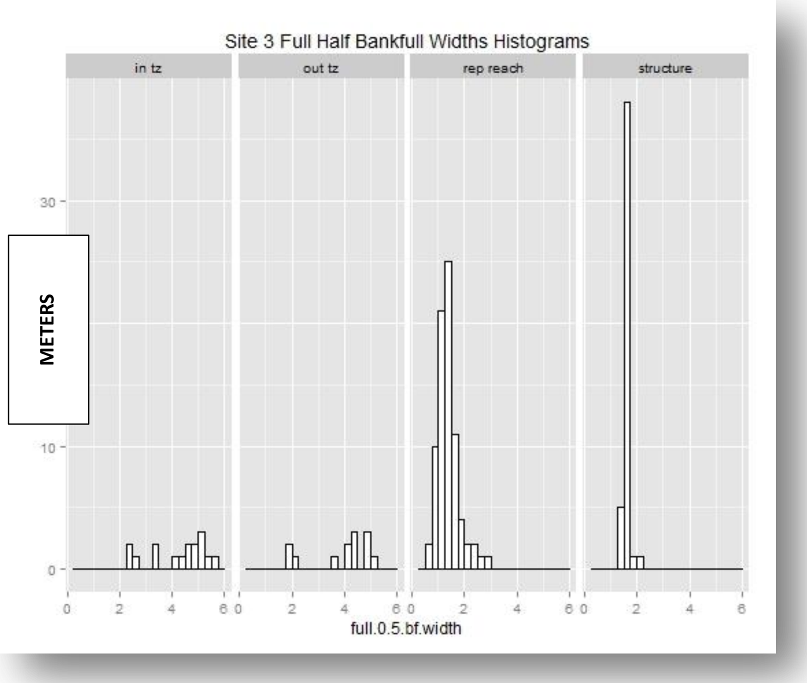


FIGURE 302: SITE 3 WIDTHS AT HALF BANKFULL STAGE; HISTOGRAM

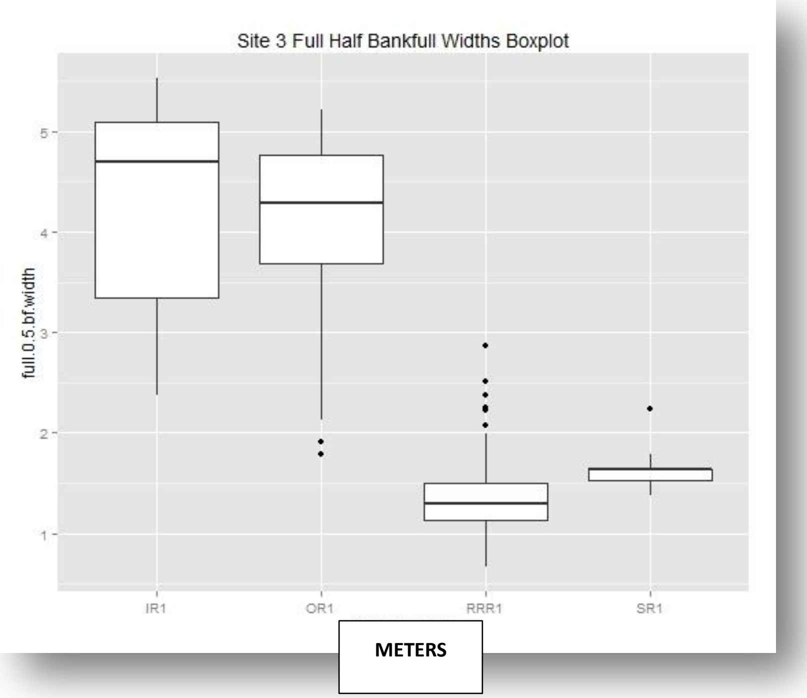


FIGURE 303: SITE 3 WIDTHS AT HALF BANKFULL STAGE; BOXPLOT

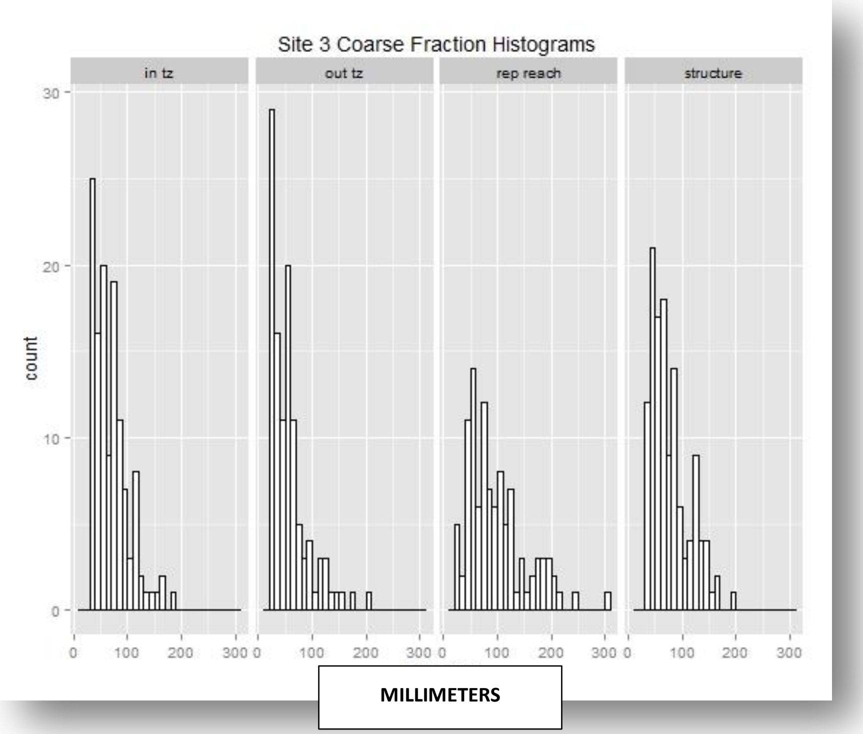


FIGURE 304: SITE 3 COARSE FRACTION OF THE GRADATION; HISTOGRAM

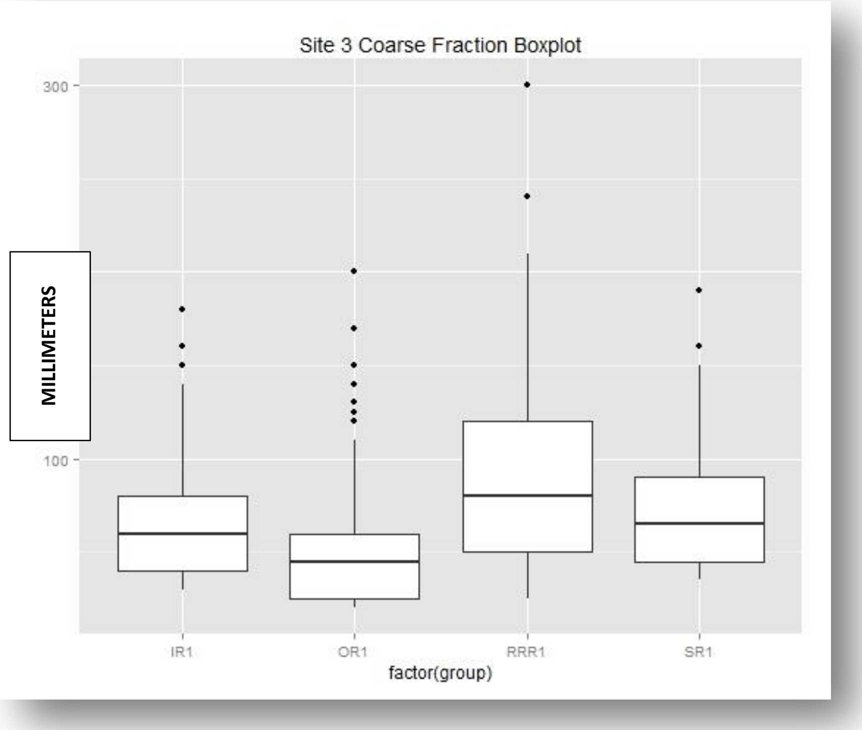


FIGURE 305: SITE 3 COARSE FRACTION OF THE GRADATION; BOXPLOT

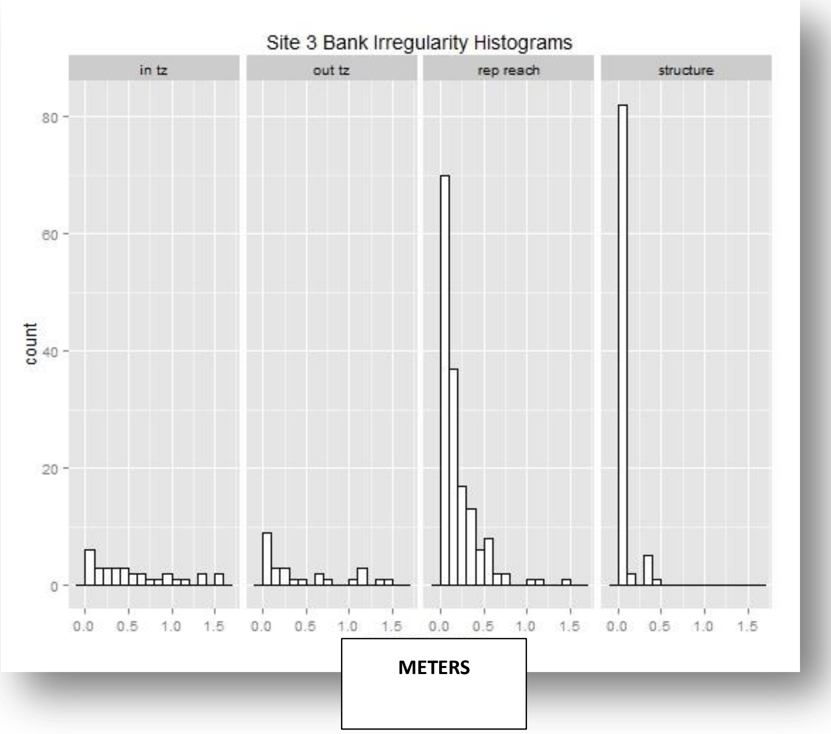


FIGURE 306: SITE 3 BANK IRREGULARITY; HISTOGRAM

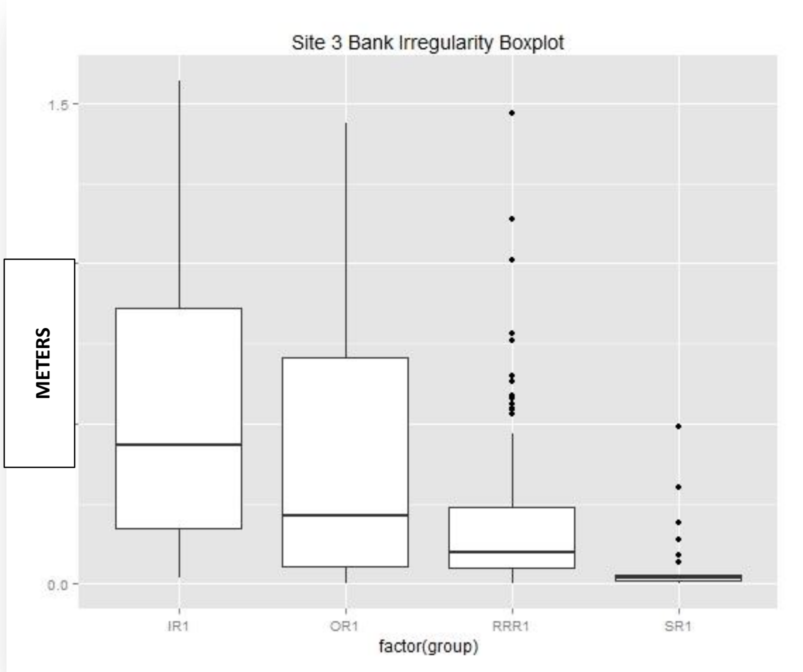


FIGURE 307: SITE 3 BANK IRREGULARITY; BOXPLOT

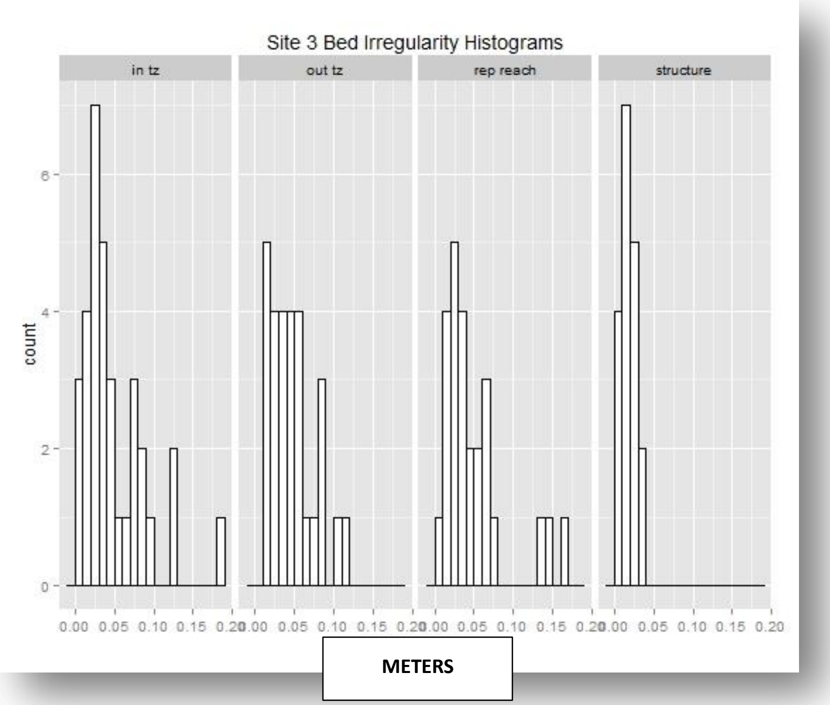


FIGURE 308: SITE 3 BED IRREGULARITY; HISTOGRAM

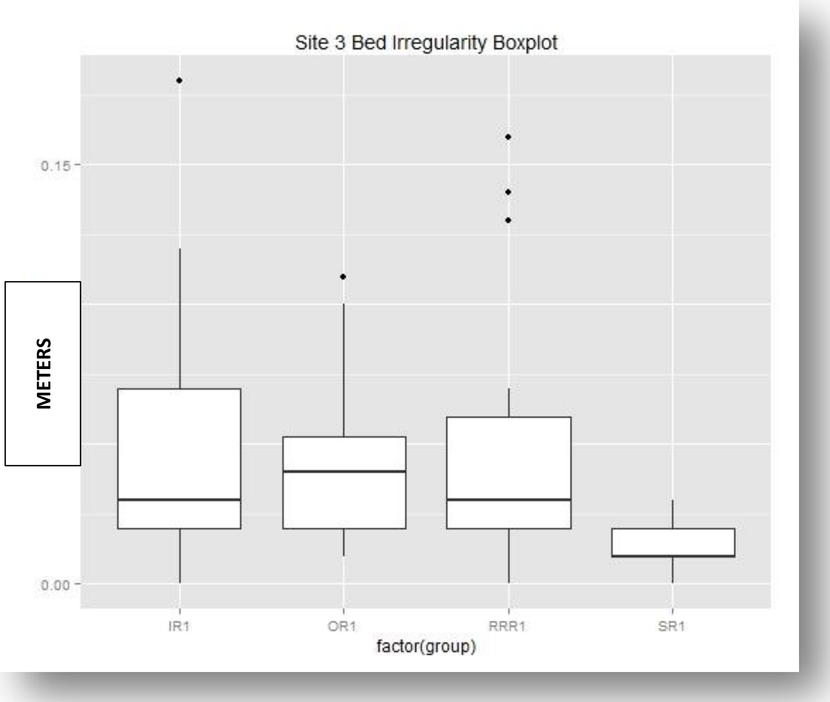


FIGURE 309: SITE 3 BED IRREGULARITY; BOXPLOT

A8.5 SITE 3 SCORING SENSITIVITY ANALYSIS

TABLE 92: SITE 3 LEVEL II SCORING SENSITIVITY ANALYSIS

Channel Unit and Criteria for a Score of 3	Inlet Transition Zone			Structure Zone			Outlet Transition Zone		
	% Score	Eval-uation	Over-ride	% Score	Evaluation	Over-ride	% Score	Evaluation	Over-ride
Riffle 0.01 to 0.05	na	na		20	Dissimilar		37	Dissimilar	
Riffle 0.001 to 0.05	na	na		30	Dissimilar		37	Dissimilar	
Riffle 0.001 to 0.05 short	na	na		31	Dissimilar		32	Dissimilar	
Riffle 0.01 to 0.1	na	na		20	Dissimilar		37	Dissimilar	
Riffle 0.001 to 0.1	na	na		30	Dissimilar		37	Dissimilar	

A9 SPARKS BROOK SITE DATA

A9.1 SPARKS BROOK PHOTOS

FIGURE 310: LOOKING UPSTREAM AT THE INLET TRANSITION ZONE FROM THE TOP OF THE SPARKS BROOK STRUCTURE

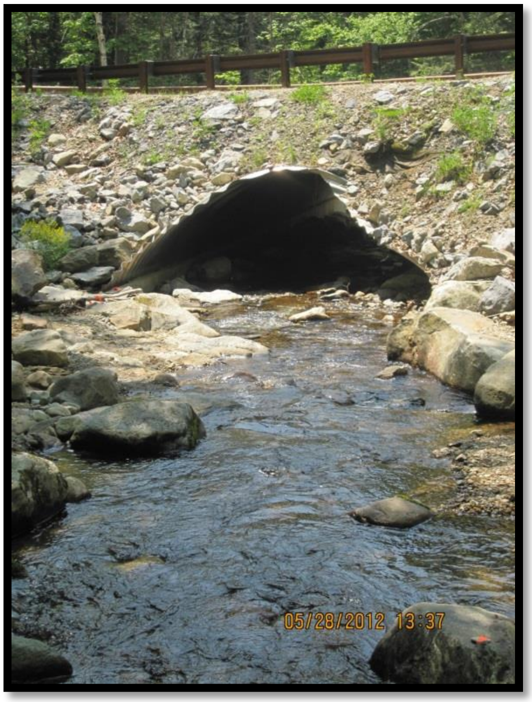


FIGURE 311: LOOKING DOWNSTREAM AT THE SPARKS BROOK STRUCTURE INLET

FIGURE 312: LOOKING UPSTREAM AT THE SPARKS BROOK INLET TRANSITION ZONE (FROM THE STRUCTURE INLET)

FIGURE 313: LOOKING UPSTREAM AT THE SPARKS BROOK INLET TRANSITION ZONE

Figure 314: Looking downstream at the Sparks Brook outlet transition zone (from the top of the structure)

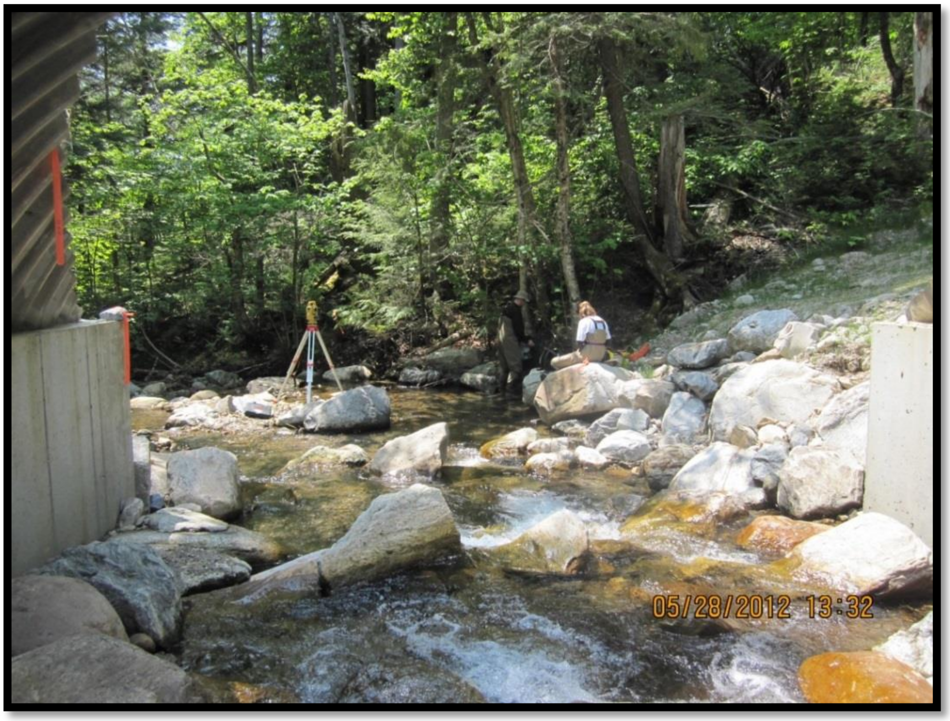


Figure 315: Looking downstream at the Sparks Brook outlet transition zone (from within the structure)

FIGURE 316: **LOOKING UPSTREAM AT THE SPARKS BROOK OUTLET TRANSITION ZONE AND STRUCTURE**

FIGURE 317: **LOOKING UPSTREAM FROM WITHIN THE SPARKS BROOK STRUCTURE**

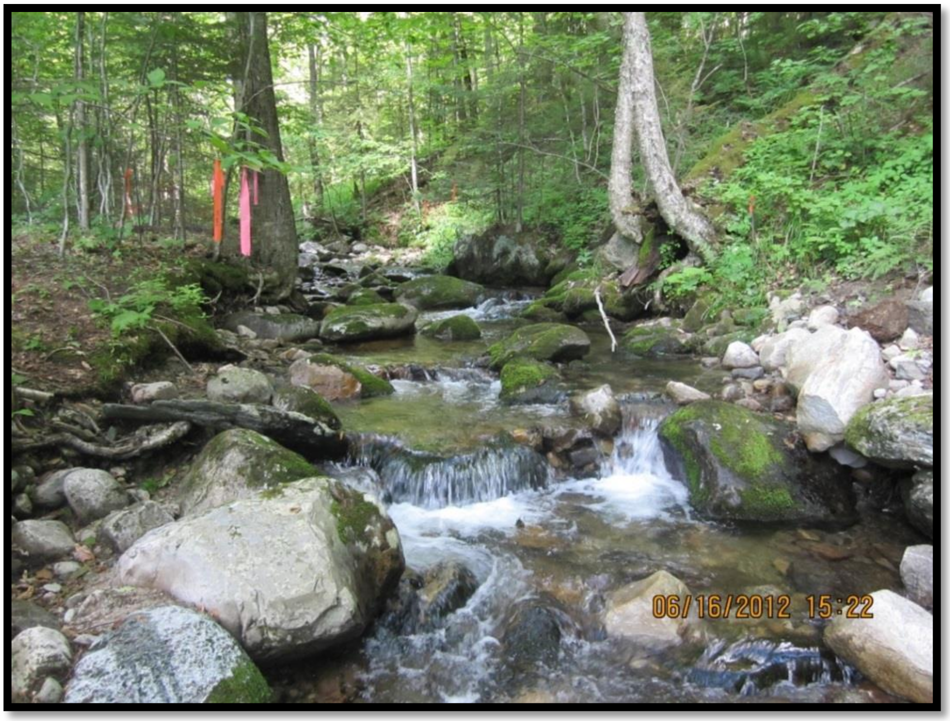


FIGURE 318: LOOKING UPSTREAM FROM THE DOWNSTREAM END OF THE STEEP SPARKS BROOK REPRESENTATIVE REACH

FIGURE 319: LOOKING DOWNSTREAM FROM THE TOP OF THE STEEP SPARKS BROOK REPRESENTATIVE REACH

FIGURE 320: LOOKING UPSTREAM FROM THE BOTTOM OF THE SPARKS BROOK GENTLE GRADIENT REPRESENTATIVE REACH

FIGURE 321: LOOKING DOWNSTREAM FROM THE TOP OF THE GENTLE GRADIENT SPARKS BROOK REPRESENTATIVE REACH

A9.2 SPARKS BROOK REPRESENTATIVE REACH ANALYSIS

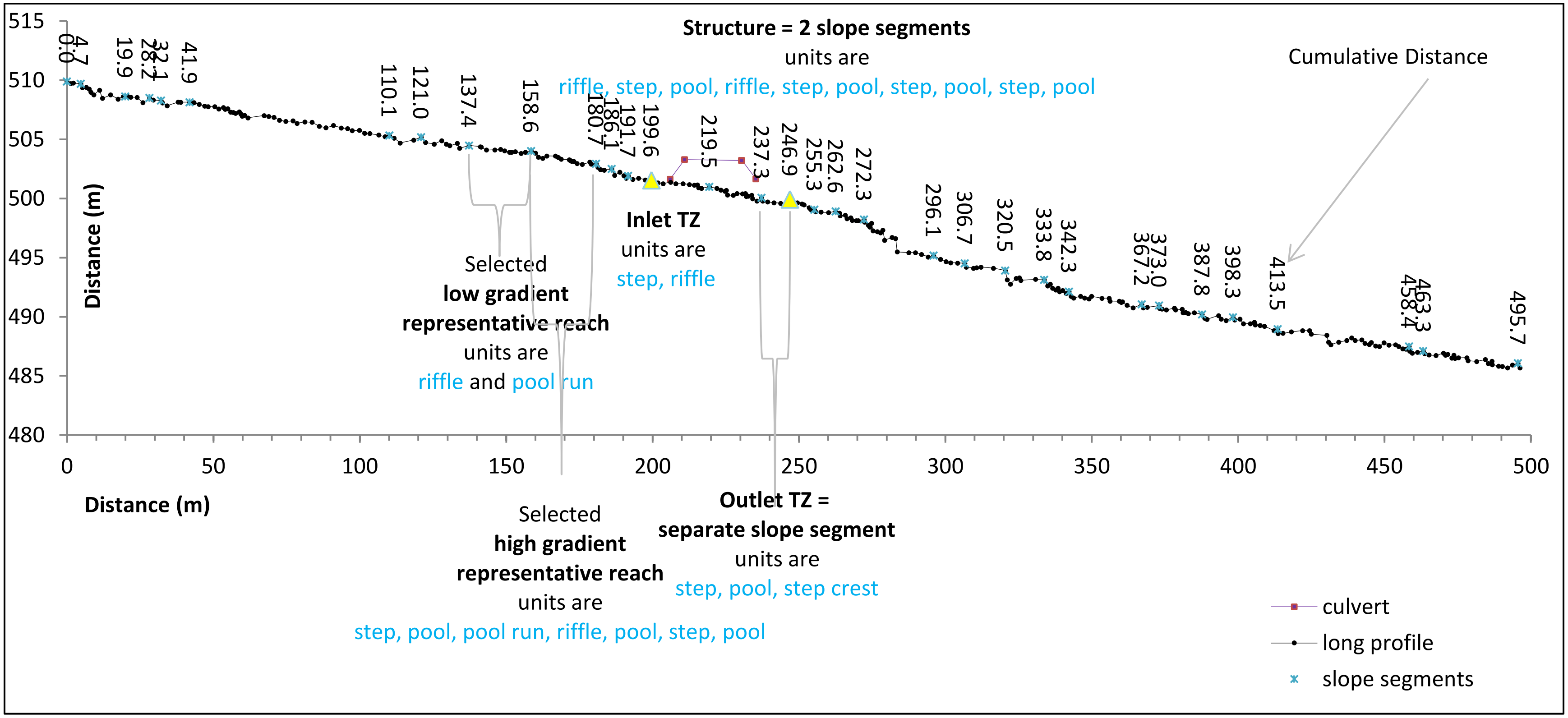


FIGURE 322: SPARKS BROOK LONGITUDINAL PROFILE

FIGURE 322 IS SHOWN WITH 4 X VERTICAL EXAGGERATION. THE STRUCTURE IS AN OPEN BOTTOM PIPE ARCH WITH LENGTH 28.3 M, HEIGHT 1.61 M AND SPAN 4.43 M. THREE SLOPE SEGMENTS MAKE UP THE DESIGN CHANNEL (INLET TRANSITION ZONE, STRUCTURE AND OUTLET TRANSITION ZONE) WITH GRADIENTS 3%, 5% AND 1.5%. NO REPRESENTATIVE REACH WAS SELECTED FOR THE OUTLET TRANSITION ZONE (ERRONEOUSLY). THE REPRESENTATIVE REACHES SELECTED FOR THE GRADIENTS WITHIN THE STRUCTURE AND INLET TRANSITION ZONE HAVE GRADIENTS 2.2% AND 4.9%.

TABLE 93: SPARKS BROOK GENTLE DESIGN CHANNEL SLOPE SEGMENT DATA

N (m)	E (m)	Elev (m)	straight line segment length (m)	Cumulative distance (m)	Distance between points	Field Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient
502.6	539.0	501.5	7.7	199.6	8.0	top of step, boulders highly stable				
501.4	520.4	501.0	18.6	219.5	19.8	riffle large boulder cobble, transverse rib; within structure	18.6	0.6	19.8	0.028
GENTLE DESIGN SLOPE SEGMENT length (m)							13.3		13.3	

TABLE 94: SPARKS BROOK STEEP DESIGN CHANNEL SLOPE SEGMENT DATA

N (m)	E (m)	Elev (m)	straight line segment length (m)	cumulative distance (m)	channel distance between successive points (m)	Field Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient
501.4	520.4	501.0	18.6	219.5	19.8	riffle large boulder cobble, transverse rib; within structure				
501.8	503.9	500.1	16.5	237.3	17.9	step, boulders/cobble high stability	16.5	0.9	17.9	0.051
steep slope segment length							15.8		15.8	

TABLE 95: SPARKS BROOK GENTLE GRADIENT REPRESENTATIVE REACH ANALYSIS

N (m)	E (m)	Elev (m)	straight line segment length (m)	Cumulative distance (m)	Distance between points	Field Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn successive slope segments	% diff. between S_{dc} and S_{nc} (upper segment)	% diff. between L_{dc} and L_{nc} (upper segment)	% diff. between culvert L_{dc} and L_{nc} (upper segment)	Selection Notes
624.9	666.5	509.9	0.0	0.0		crest of cascade									
622.4	662.5	509.7	4.7	4.7	4.7	crest of cascade	4.7	0.2	4.7	0.044		-58.0	76.1	64.4	
611.7	652.6	508.6	14.6	19.9	15.2	ptc	14.6	1.1	15.2	0.069	56.5	-147.2	23.3	-14.2	
607.2	646.8	508.5	7.3	28.2	8.3	crest of pool riffle ptc	7.3	0.1	8.3	0.017	-74.8	37.6	58.2	37.7	
604.9	643.9	508.3	3.7	32.1	3.9	crest of step	3.7	0.2	3.9	0.051	190.6	-81.2	80.2	70.5	
599.2	636.7	508.1	9.1	41.9	9.8	steep riffle with series of ribs	9.1	0.1	9.8	0.015	-70.3	46.1	50.6	26.4	
560.1	586.7	505.3	18.5	110.1	68.2	step crest	18.5	2.8	68.2	0.041	174.0	-47.7	-244.1	-412.9	
555.3	577.1	505.2	10.7	121.0	10.8	step/steep rapid	10.7	0.2	10.8	0.014	-66.0	49.8	45.3	18.5	
543.0	568.1	504.5	15.2	137.4	16.4	ptc, gravel small cobble	15.2	0.7	16.4	0.042	201.5	-51.5	17.3	-23.3	

N (m)	E (m)	Elev (m)	straight line segment length (m)	Cumulative distance (m)	Distance between points	Field Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn successive slope segments	% diff. between S_{dc} and S_{nc} (upper segment)	% diff. between L_{dc} and L_{nc} (upper segment)	% diff. between culvert L_{dc} and L_{nc} (upper segment)	Selection Notes
524.4	564.5	504.0	19.0	158.6	21.2	ptc associated with gc 44	19.0	0.5	21.2	0.022	-48.1	21.4	-6.8	-59.2	similar sequence to design channel; low gradient rep reach
508.9	554.8	502.9	18.2	180.7	22.2	step crest boulders/cobble highly stable	18.2	1.1	22.2	0.049	123.1	-75.3	-11.8	-66.7	
504.8	551.7	502.5	5.2	186.1	5.4	crest of step, large boulders, mossy	5.2	0.4	5.4	0.079	61.5	-183.2	72.7	59.3	
503.0	546.7	501.9	5.3	191.7	5.5	large boulder cobble mossy, incompletely developed pool; start inlet transition	5.3	0.6	5.5	0.106	33.6	-278.4	72.1	58.4	
502.6	539.0	501.5	7.7	199.6	8.0	top of step, boulders highly stable	7.7	0.4	8.0	0.046	-56.2	-65.9	59.8	40.1	

N (m)	E (m)	Elev (m)	straight line segment length (m)	Cumulative distance (m)	Distance between points	Field Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn successive slope segments	% diff. between S_{dc} and S_{nc} (upper segment)	% diff. between L_{dc} and L_{nc} (upper segment)	% diff. between culvert L_{dc} and L_{nc} (upper segment)	Selection Notes
501.4	520.4	501.0	18.6	219.5	19.8	riffle large boulder cobble, transverse rib; within structure	18.6	0.6	19.8	0.028	0.028	0.0	0.0	-49.0	
501.8	503.9	500.1	16.5	237.3	17.9	step, boulders/cobble high stability	16.5	0.9	17.9	0.051	0.051	-84.1	9.9	-34.2	
499.2	496.4	499.9	0.2	246.9	9.6	upper step boulders, high stability (end outlet transition)	0.2	0.1	9.6	0.015	0.015	45.5	51.5	27.6	
492.7	491.4	499.1	3.5	255.3	8.4	step crest within cascade/riffle	3.5	0.9	8.4	0.104	0.104	-271.0	57.7	36.9	
487.1	487.2	498.9	7.0	262.6	7.2	step boulder cobble highly stable	7.0	0.1	7.2	0.019	0.019	30.3	63.4	45.5	
485.2	479.3	498.2	8.1	272.3	9.7	crest of step in cascade	8.1	0.7	9.7	0.071	0.071	-153.2	51.1	27.1	
483.6	458.0	495.2	11.7	296.1	23.8	top of bedrock cascade	11.7	3.0	23.8	0.128	0.128	-358.0	-20.0	-78.9	
483.5	448.9	494.5	9.0	306.7	10.7	step crest boulder/bedrock high stability	9.0	0.6	10.7	0.061	0.061	-117.3	46.2	19.9	

N (m)	E (m)	Elev (m)	straight line segment length (m)	Cumulative distance (m)	Distance between points	Field Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn successive slope segments	% diff. between S_{dc} and S_{nc} (upper segment)	% diff. between L_{dc} and L_{nc} (upper segment)	% diff. between culvert L_{dc} and L_{nc} (upper segment)	Selection Notes
483.9	435.3	493.9	13.7	320.5	13.8	large woody debris step crest end riffle, rock, boulder, wood, moderate stability	13.7	0.6	13.8	0.045	-26.6	-59.6	30.5	-3.6	wood step, low stability Do not use
476.7	428.6	493.1	9.8	333.8	13.3	start of cascade, mossy boulders high stability	9.8	0.8	13.3	0.059	33.3	-112.7	32.9	0.0	
476.8	421.6	492.1	7.0	342.3	8.5	crest of step lower cascade	7.0	1.0	8.5	0.117	97.3	-319.8	57.4	36.5	
468.7	399.5	491.1	23.5	367.2	24.9	start of riffle rib, boulder, gravel cobble high stability	23.5	1.1	24.9	0.043	-63.4	-53.8	-25.8	-87.5	

N (m)	E (m)	Elev (m)	straight line segment length (m)	Cumulative distance (m)	Distance between points	Field Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn successive slope segments	% diff. between S_{dc} and S_{nc} (upper segment)	% diff. between L_{dc} and L_{nc} (upper segment)	% diff. between culvert L_{dc} and L_{nc} (upper segment)	Selection Notes
465.8	394.5	491.0	5.8	373.0	5.8	transverse rib in riffle	5.8	0.1	5.8	0.018	-57.5	34.7	70.5	56.1	
459.9	382.4	490.2	13.5	387.8	14.8	step crest at end of steep riffle, high stability, boulders cobble, moss	13.5	0.7	14.8	0.050	175.9	-80.2	25.6	-11.0	
455.1	374.7	490.0	9.0	398.3	10.5	gc12, rib at crest of riffle	9.0	0.3	10.5	0.024	-52.4	14.3	46.9	20.9	
450.0	361.6	489.0	14.0	413.5	15.2	rib crest of riffle tail	14.0	1.0	15.2	0.065	172.6	-133.6	23.1	-14.7	
453.3	321.7	487.5	40.0	458.4	44.9	step crest	40.0	1.5	44.9	0.033	-49.4	-18.1	-126.4	-237.4	
455.6	317.6	487.1	4.7	463.3	4.9	crest of rib, boulder, cobble, gravel, high stability	4.7	0.4	4.9	0.075	128.4	-169.7	75.3	63.1	
467.2	290.9	486.1	29.1	495.7	32.4	step crest, boulders, moss cobble high stability	29.1	1.0	32.4	0.032	-57.4	-14.9	-63.3	-143.4	

TABLE 96: SPARKS BROOK STEEP GRADIENT REPRESENTATIVE REACH ANALYSIS

N (m)	E (m)	Elev (m)	straight line segment length (m)	cumulative distance (m)	channel distance between successive points (m)	Field Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc} (lower segment)	% diff. between L_{dc} and L_{nc} (lower segment)	% diff. between culvert L_{dc} and L_{nc} (lower segment)	Selection Notes
624.9	666.5	509.9	0.0	0.0		crest of cascade									
622.4	662.5	509.7	4.7	4.7	4.7	crest of cascade	4.7	0.2	4.7	0.044		14.2	73.5	70.1	
611.7	652.6	508.6	14.6	19.9	15.2	ptc	14.6	1.1	15.2	0.069	56.5	-34.3	14.9	3.8	
607.2	646.8	508.5	7.3	28.2	8.3	crest of pool riffle ptc	7.3	0.1	8.3	0.017	-74.8	66.1	53.6	47.6	
604.9	643.9	508.3	3.7	32.1	3.9	crest of step	3.7	0.2	3.9	0.051	190.6	1.6	78.0	75.2	
599.2	636.7	508.1	9.1	41.9	9.8	steep riffle with series of ribs	9.1	0.1	9.8	0.015	-70.3	70.7	45.2	38.0	
560.1	586.7	505.3	18.5	110.1	68.2	step crest	18.5	2.8	68.2	0.041	174.0	19.8	-282.1	-331.8	
555.3	577.1	505.2	10.7	121.0	10.8	step/steep rapid	10.7	0.2	10.8	0.014	-66.0	72.7	39.3	31.4	
543.0	568.1	504.5	15.2	137.4	16.4	ptc, gravel small cobble	15.2	0.7	16.4	0.042	201.5	17.7	8.2	-3.7	
524.4	564.5	504.0	19.0	158.6	21.2	ptc associated with gc 44	19.0	0.5	21.2	0.022	-48.1	57.3	-18.6	-34.0	
508.9	554.8	502.9	18.2	180.7	22.2	step crest boulders/cobble highly stable	18.2	1.1	22.2	0.049	123.1	4.8	-24.1	-40.3	similar sequence to design channel; high gradient rep reach

N (m)	E (m)	Elev (m)	straight line segment length (m)	cumulative distance (m)	channel distance between successive points (m)	Field Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc} (lower segment)	% diff. between L_{dc} and L_{nc} (lower segment)	% diff. between culvert L_{dc} and L_{nc} (lower segment)	Selection Notes
504.8	551.7	502.5	5.2	186.1	5.4	crest of step, large boulders, mossy	5.2	0.4	5.4	0.079	61.5	-53.8	69.7	65.7	
503.0	546.7	501.9	5.3	191.7	5.5	large boulder cobble mossy, incompletely developed pool; start inlet transition	5.3	0.6	5.5	0.106	33.6	-105.5	69.0	64.9	
502.6	539.0	501.5	7.7	199.6	8.0	top of step, boulders highly stable	7.7	0.4	8.0	0.046	-56.2	9.9	55.4	49.6	
501.4	520.4	501.0	18.6	219.5	19.8	riffle large boulder cobble, transverse rib; within structure	18.6	0.6	19.8	0.028	-39.7	45.7	-11.0	-25.5	
501.8	503.9	500.1	16.5	237.3	17.9	step, boulders/cobble high stability	16.5	0.9	17.9	0.051	84.1	0.0	0.0	-13.0	
499.2	496.4	499.9	0.2	246.9	9.6	upper step boulders, high stability (end outlet transition)	0.2	0.1	9.6	0.015	-70.4	70.4	46.1	39.1	

N (m)	E (m)	Elev (m)	straight line segment length (m)	cumulative distance (m)	channel distance between successive points (m)	Field Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc} (lower segment)	% diff. between L_{dc} and L_{nc} (lower segment)	% diff. between culvert L_{dc} and L_{nc} (lower segment)	Selection Notes
492.7	491.4	499.1	3.5	255.3	8.4	step crest within cascade/riffle	3.5	0.9	8.4	0.104	581.3	-101.5	53.0	46.9	
487.1	487.2	498.9	7.0	262.6	7.2	step boulder cobble highly stable	7.0	0.1	7.2	0.019	-81.2	62.1	59.4	54.1	
485.2	479.3	498.2	8.1	272.3	9.7	crest of step in cascade	8.1	0.7	9.7	0.071	263.2	-37.5	45.7	38.6	
483.6	458.0	495.2	11.7	296.1	23.8	top of bedrock cascade	11.7	3.0	23.8	0.128	80.8	-148.7	-33.3	-50.6	
483.5	448.9	494.5	9.0	306.7	10.7	step crest boulder/bedrock high stability	9.0	0.6	10.7	0.061	-52.5	-18.0	40.3	32.6	
483.9	435.3	493.9	13.7	320.5	13.8	large woody debris step crest end riffle, rock, boulder, wood, moderate stability	13.7	0.6	13.8	0.045	-26.6	13.3	22.9	12.8	wood step, low stability Do not use
476.7	428.6	493.1	9.8	333.8	13.3	start of cascade, mossy boulders high stability	9.8	0.8	13.3	0.059	33.3	-15.5	25.5	15.8	

N (m)	E (m)	Elev (m)	straight line segment length (m)	cumulative distance (m)	channel distance between successive points (m)	Field Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc} (lower segment)	% diff. between L_{dc} and L_{nc} (lower segment)	% diff. between culvert L_{dc} and L_{nc} (lower segment)	Selection Notes
476.8	421.6	492.1	7.0	342.3	8.5	crest of step lower cascade	7.0	1.0	8.5	0.117	97.3	-128.0	52.7	46.5	
468.7	399.5	491.1	23.5	367.2	24.9	start of riffle rib, boulder, gravel cobble high stability	23.5	1.1	24.9	0.043	-63.4	16.5	-39.6	-57.8	
465.8	394.5	491.0	5.8	373.0	5.8	transverse rib in riffle	5.8	0.1	5.8	0.018	-57.5	64.5	67.3	63.0	
459.9	382.4	490.2	13.5	387.8	14.8	step crest at end of steep riffle, high stability, boulders cobble, moss	13.5	0.7	14.8	0.050	175.9	2.2	17.3	6.6	
455.1	374.7	490.0	9.0	398.3	10.5	gc12, rib at crest of riffle	9.0	0.3	10.5	0.024	-52.4	53.5	41.1	33.4	
450.0	361.6	489.0	14.0	413.5	15.2	rib crest of riffle tail	14.0	1.0	15.2	0.065	172.6	-26.9	14.6	3.5	
453.3	321.7	487.5	40.0	458.4	44.9	step crest	40.0	1.5	44.9	0.033	-49.4	35.9	-151.4	-184.0	
455.6	317.6	487.1	4.7	463.3	4.9	crest of rib, boulder, cobble, gravel, high stability	4.7	0.4	4.9	0.075	128.4	-46.5	72.5	69.0	
467.2	290.9	486.1	29.1	495.7	32.4	step crest, boulders, moss cobble high stability	29.1	1.0	32.4	0.032	-57.4	37.6	-81.3	-104.8	

A9.3 Sparks Brook Data-by-Distance Plots

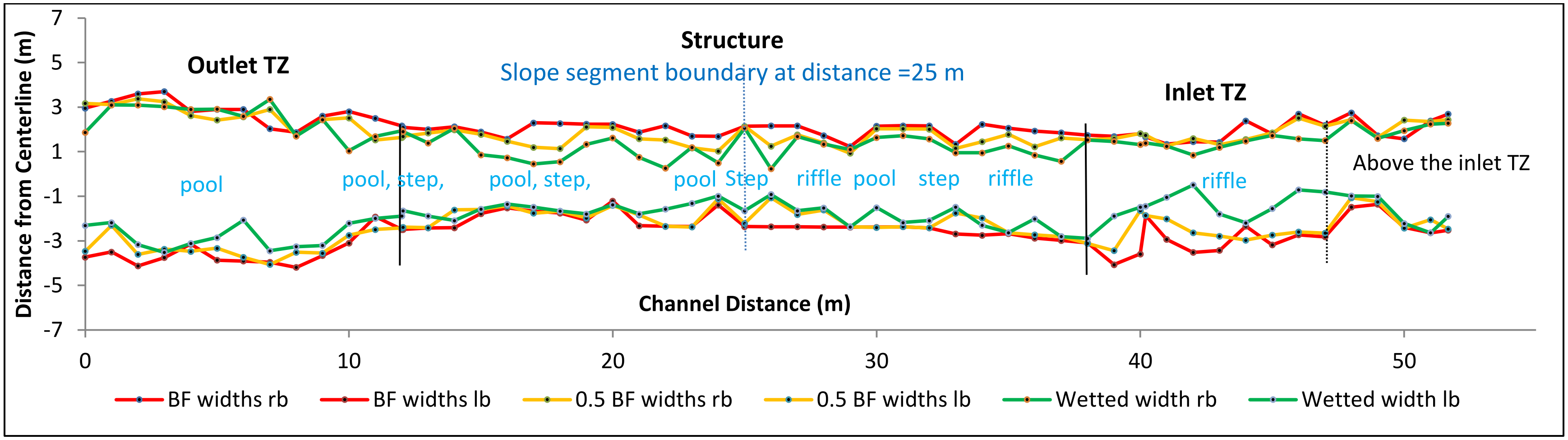


Figure 323: Sparks Brook Design Widths

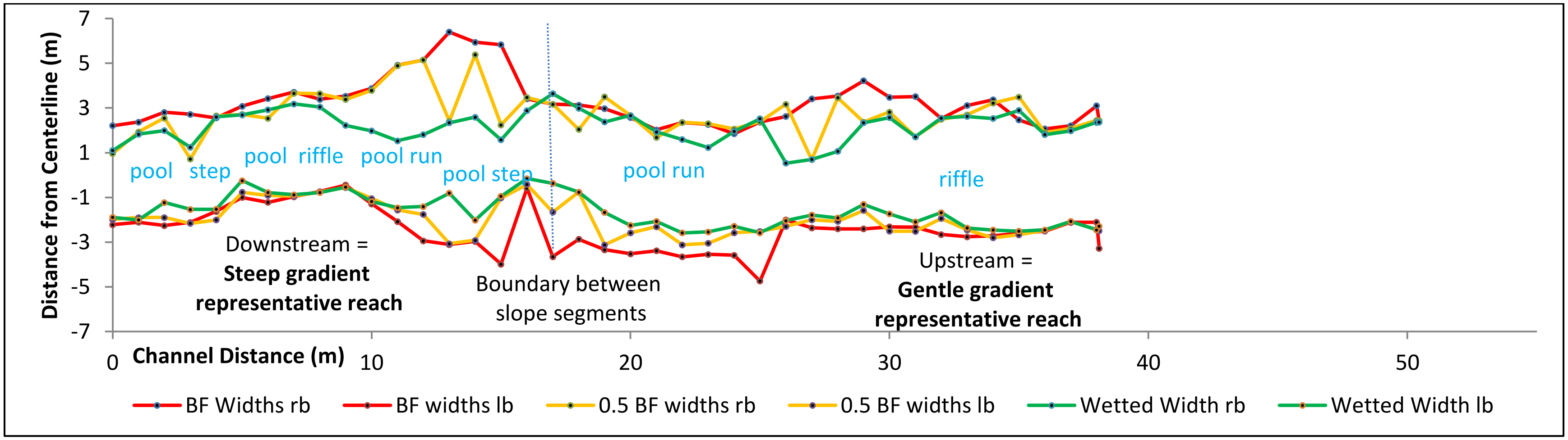


Figure 324: Sparks Brook Representative Reach Widths

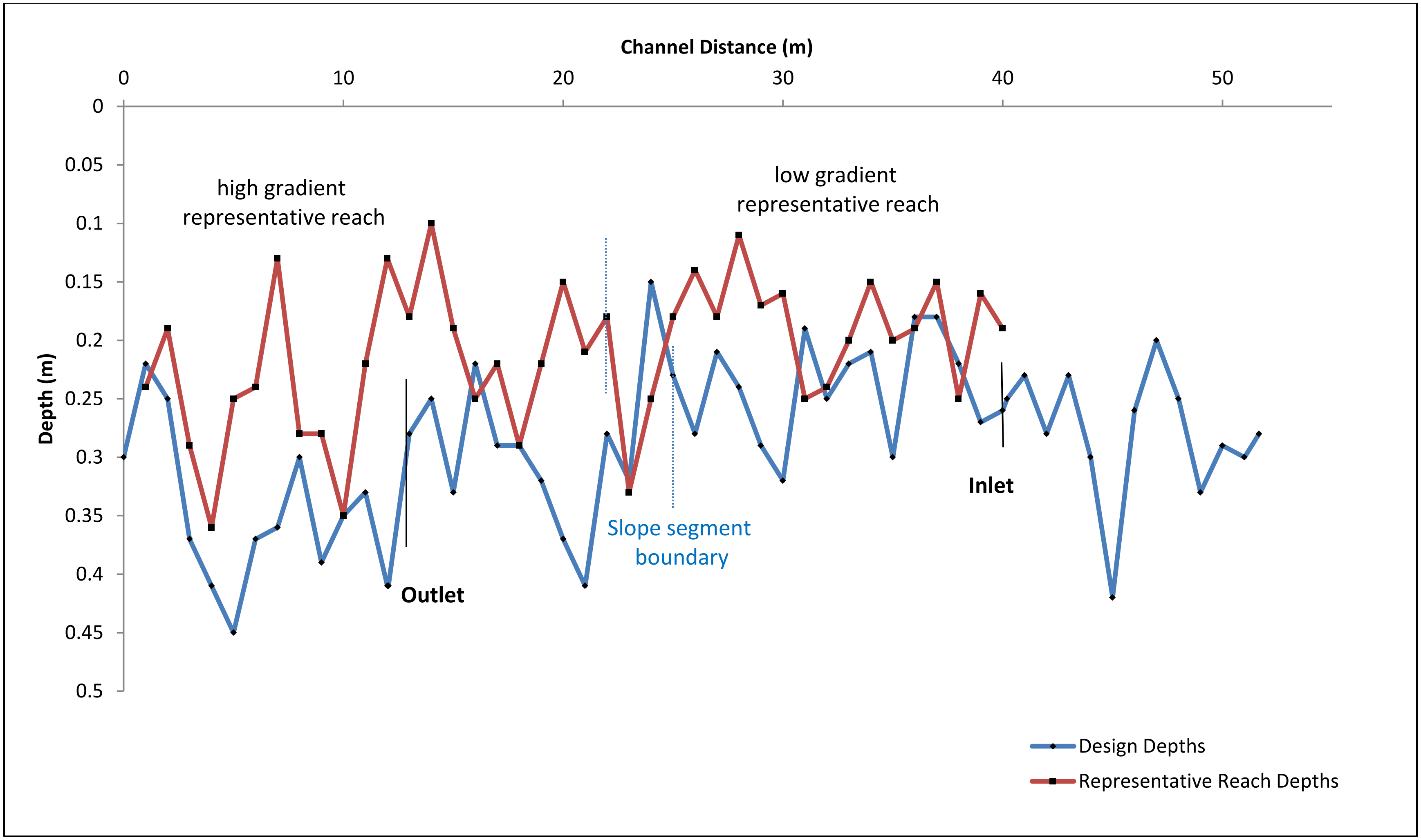


FIGURE 325: SPARKS BROOK MAXIMUM DEPTHS

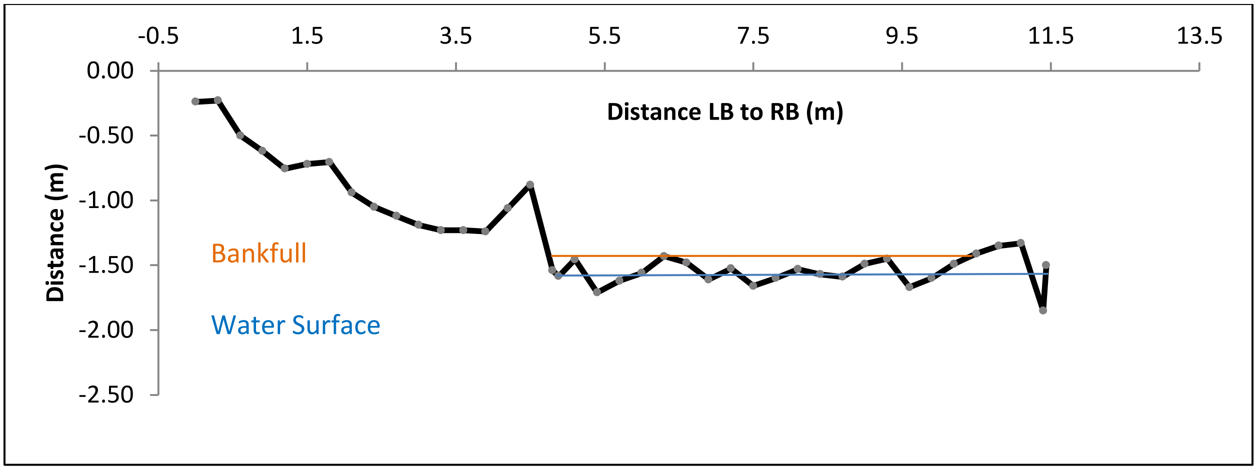


FIGURE 326: SPARKS BROOK CROSS SECTION 1; OUTLET TRANSITION ZONE, STEP CREST

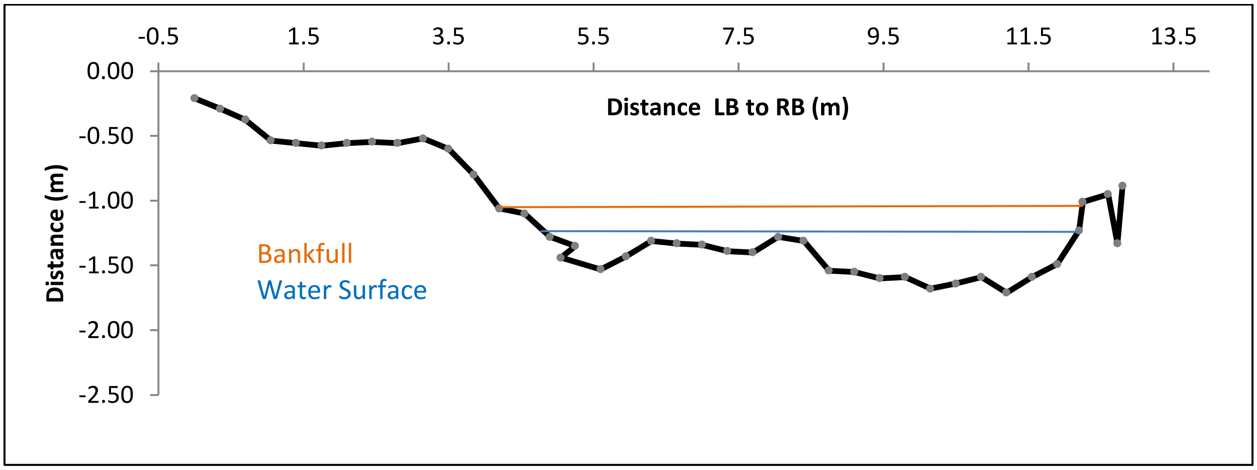


FIGURE 327: SPARKS BROOK CROSS SECTION 2; OUTLET TRANSITION ZONE; POOL

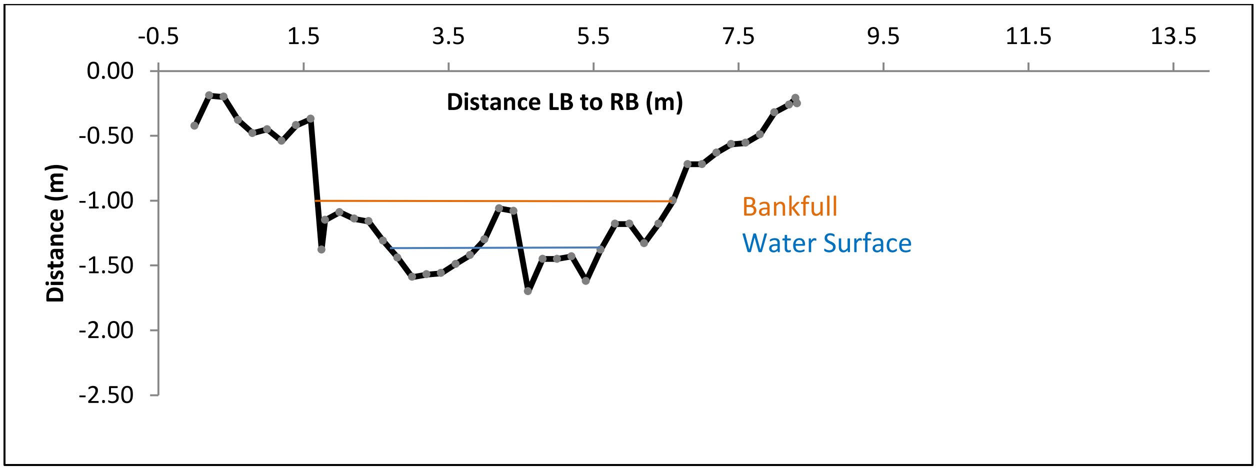


FIGURE 328: SPARKS BROOK CROSS SECTION 3; OUTLET TRANSITION ZONE; STEP

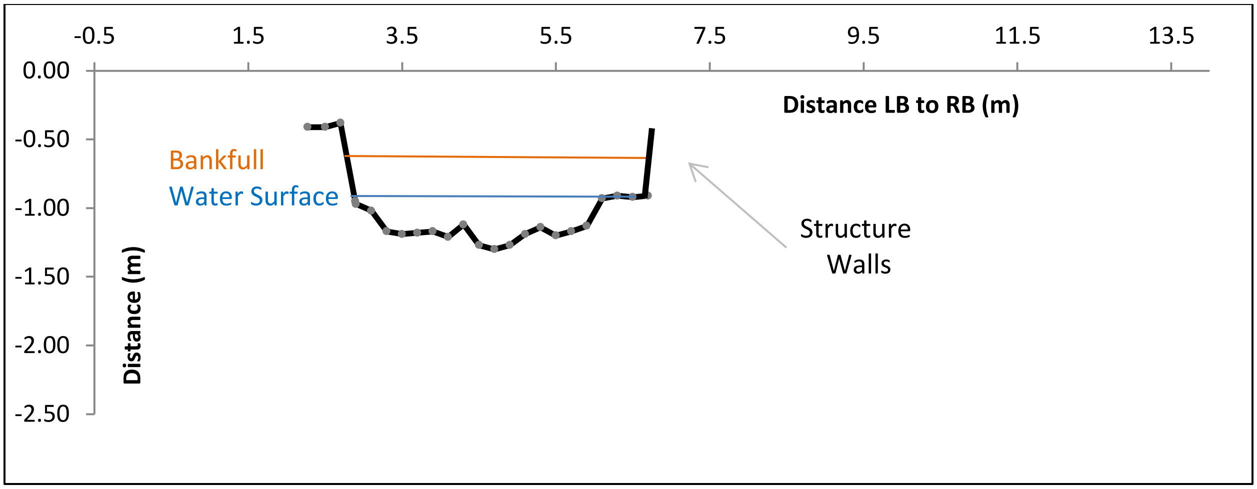


FIGURE 329: SPARKS BROOK CROSS SECTION 4; INSIDE CULVERT; STEP POOL

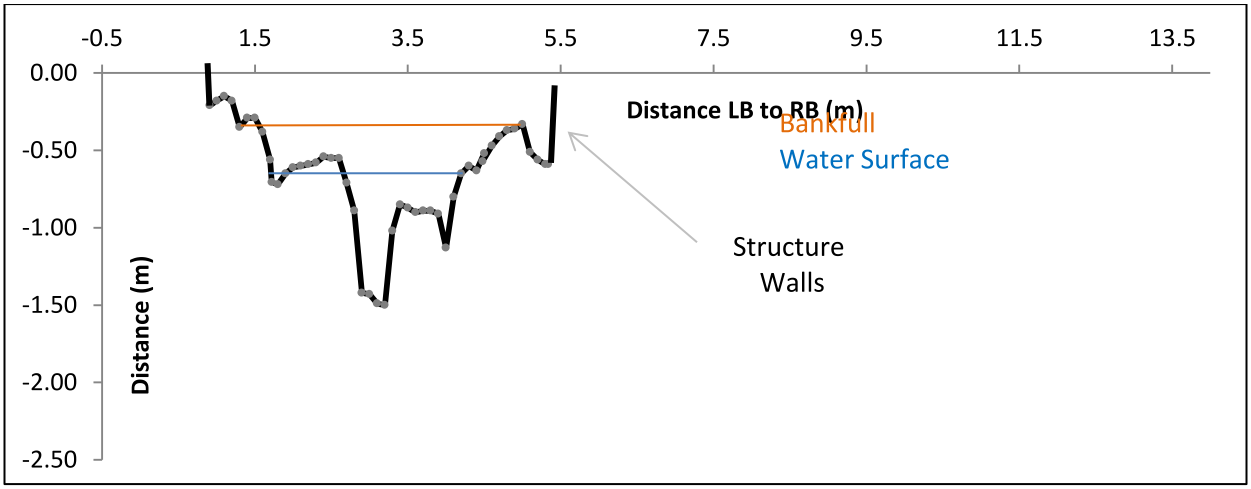


FIGURE 330: SPARKS BROOK CROSS SECTION 5; INSIDE CULVERT; STEP

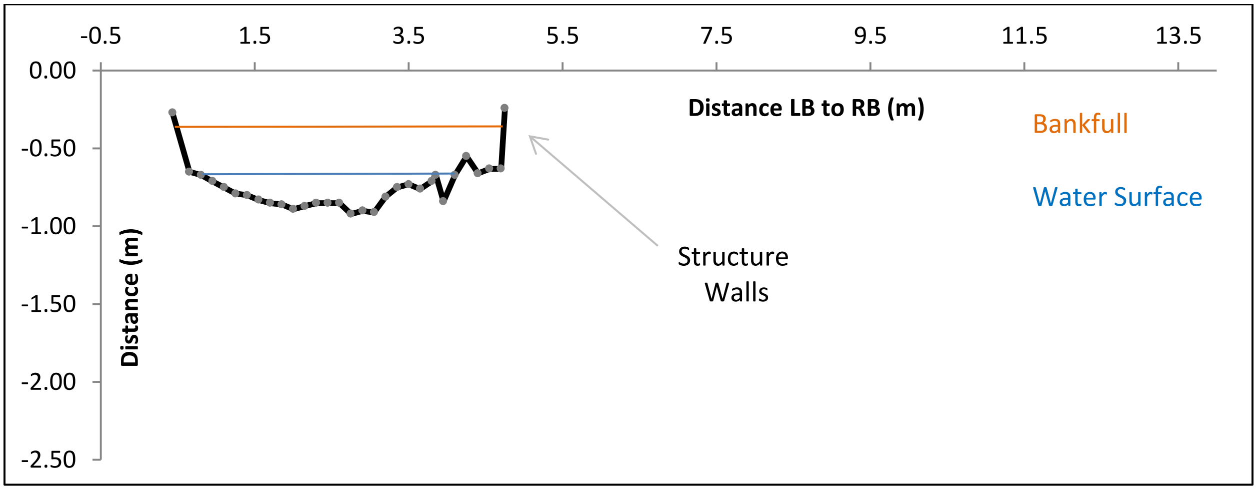


FIGURE 331: SPARKS BROOK CROSS SECTION 6; 1/2 WAY INSIDE CULVERT; SR1 = RIFFLE RUN

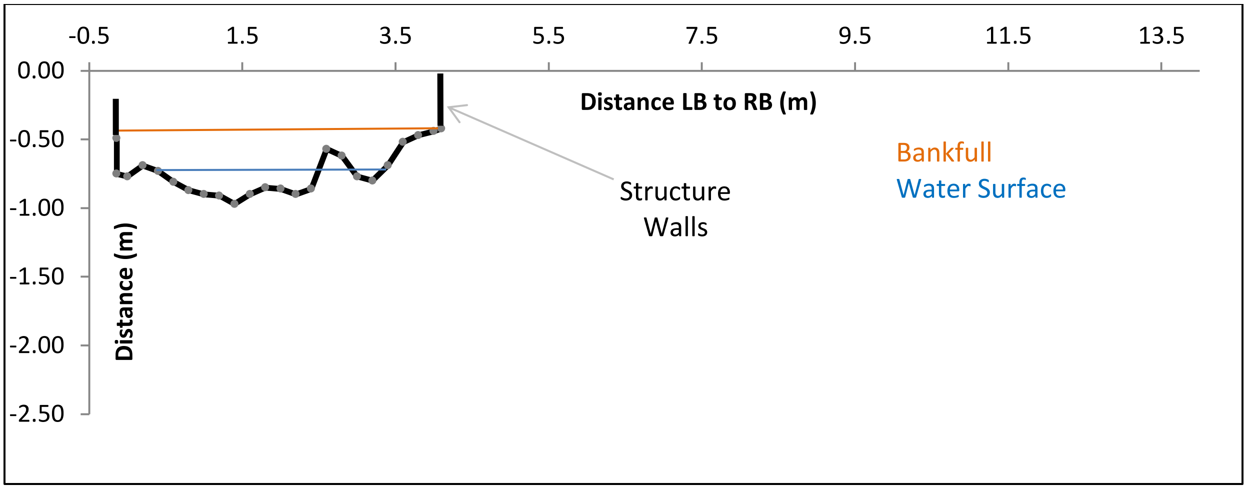


FIGURE 332: SPARKS BROOK CROSS SECTION 7; IN CULVERT NEAR INLET; SR1 = RIFFLE

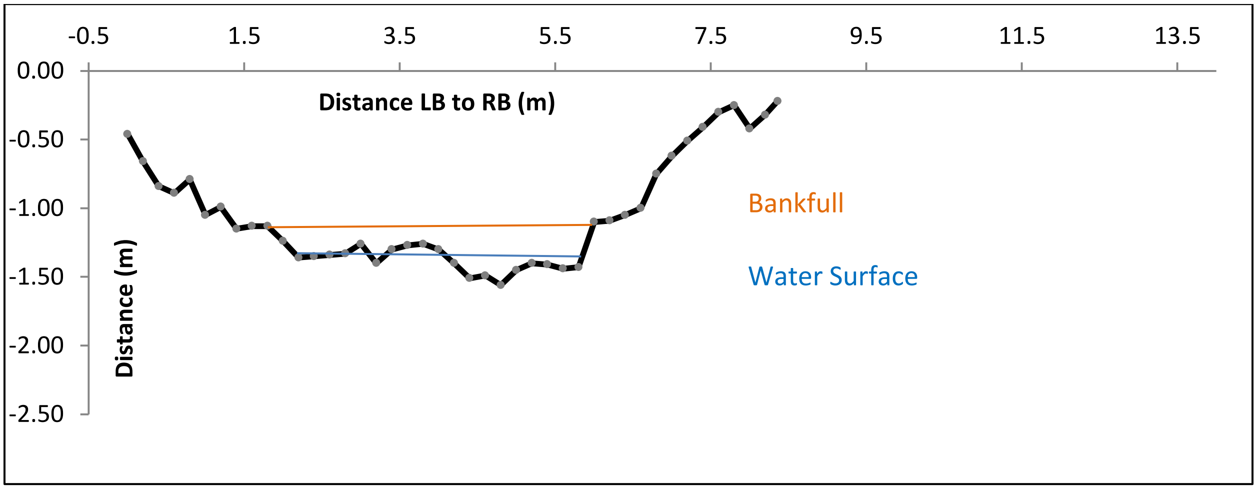


FIGURE 333: SPARKS BROOK CROSS SECTION 8; INLET TRANSITION ZONE; STEP

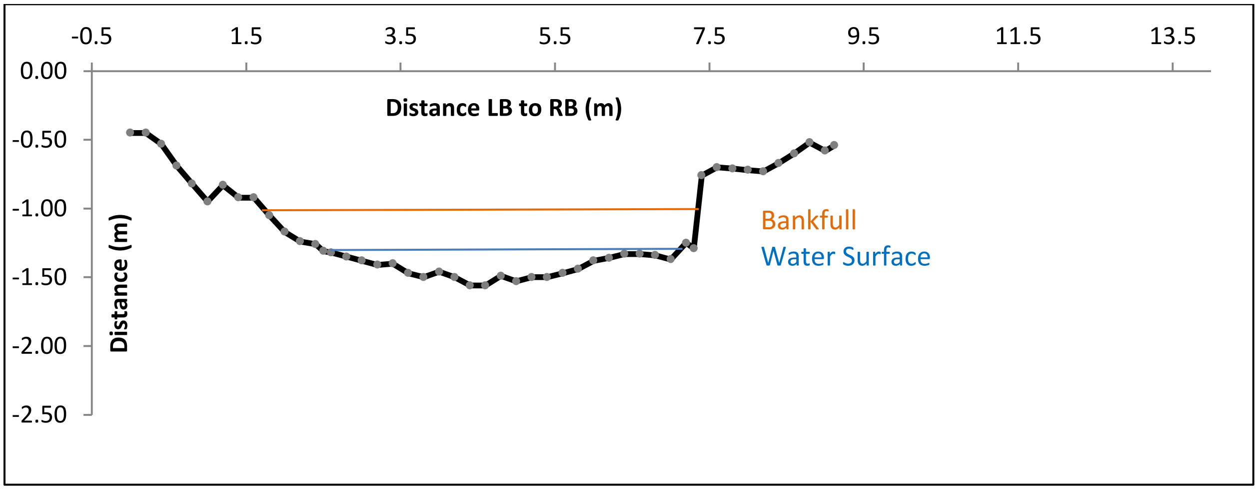


FIGURE 334: SPARKS BROOK CROSS SECTION 9; INLET TRANSITION ZONE; POOL-RUN

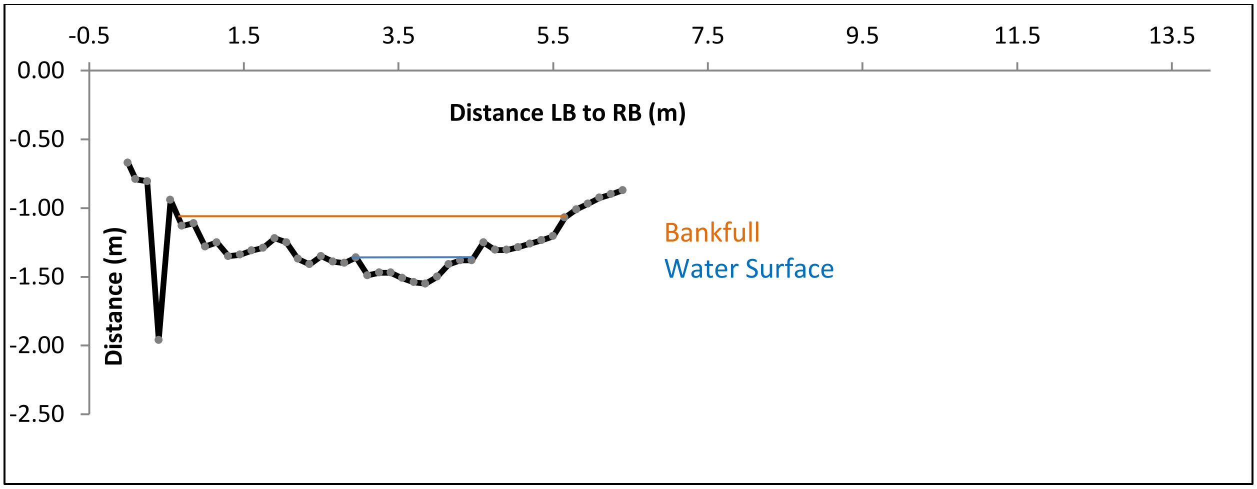


FIGURE 335: SPARKS BROOK CROSS SECTION 10; STEEP REPRESENTATIVE REACH; STEP CREST, GC 42

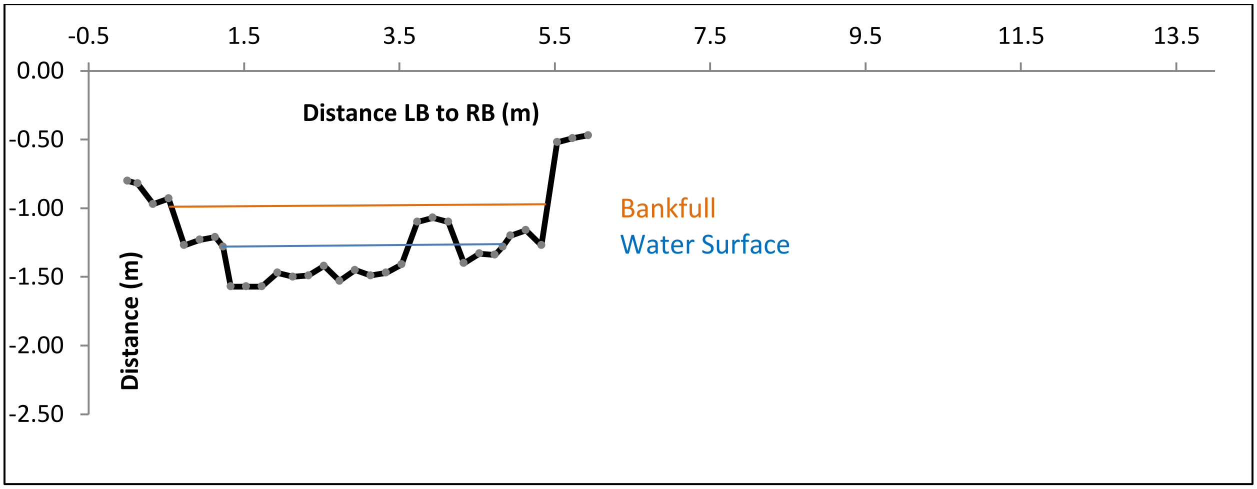


FIGURE 336: SPARKS BROOK CROSS SECTION 11; STEEP REPRESENTATIVE REACH; POOL-RUN

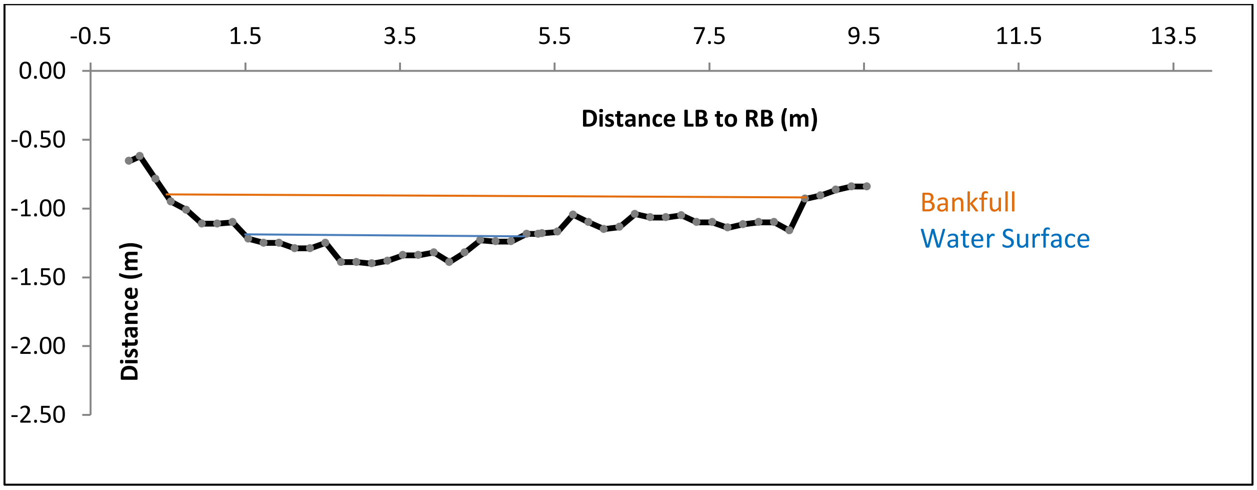


FIGURE 337: SPARKS BROOK CROSS SECTION 12; STEEP REPRESENTATIVE REACH; RIFFLE, ABOVE GC 43

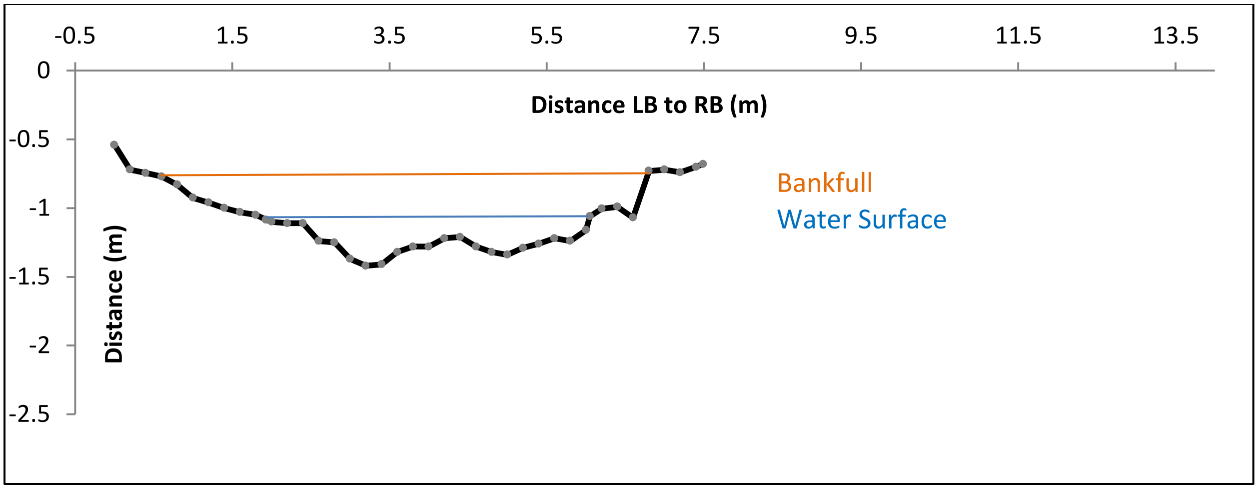


FIGURE 338: SPARKS BROOK CROSS SECTION 13; STEEP REPRESENTATIVE REACH; POOL-RUN, ABOVE GC 44

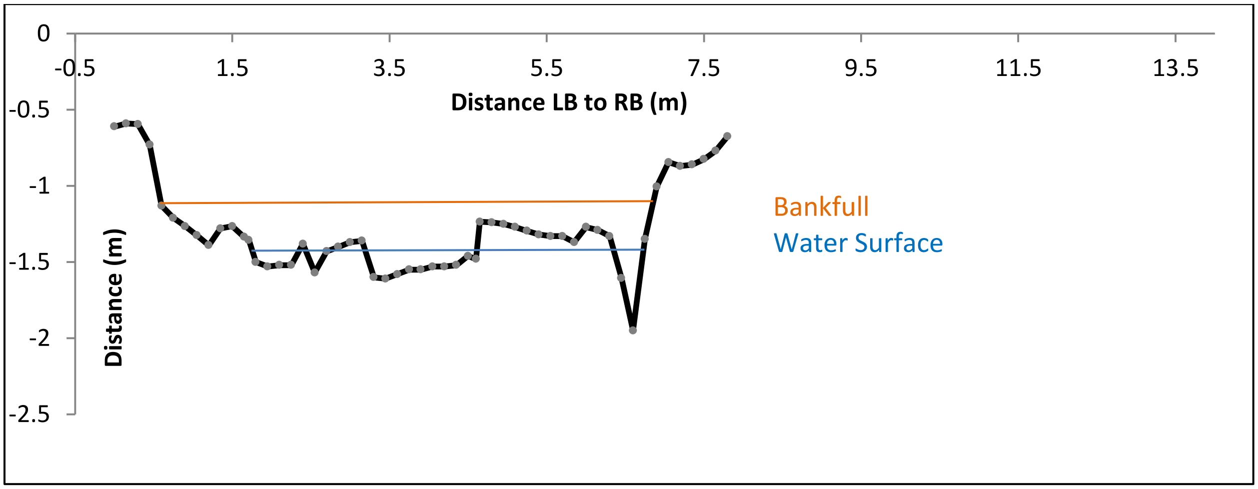


FIGURE 339: SPARKS BROOK CROSS SECTION 14; GENTLE REPRESENTATIVE REACH; ACROSS RIB, GC 42

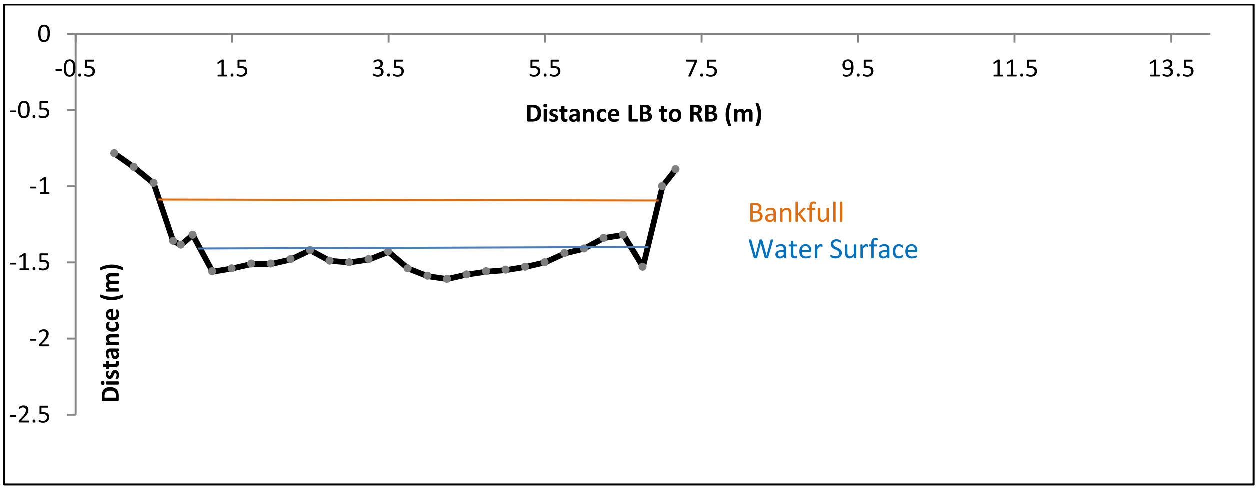


FIGURE 340: SPARKS BROOK CROSS SECTION 15; GENTLE REPRESENTATIVE REACH; POOL-RUN/RIFFLE

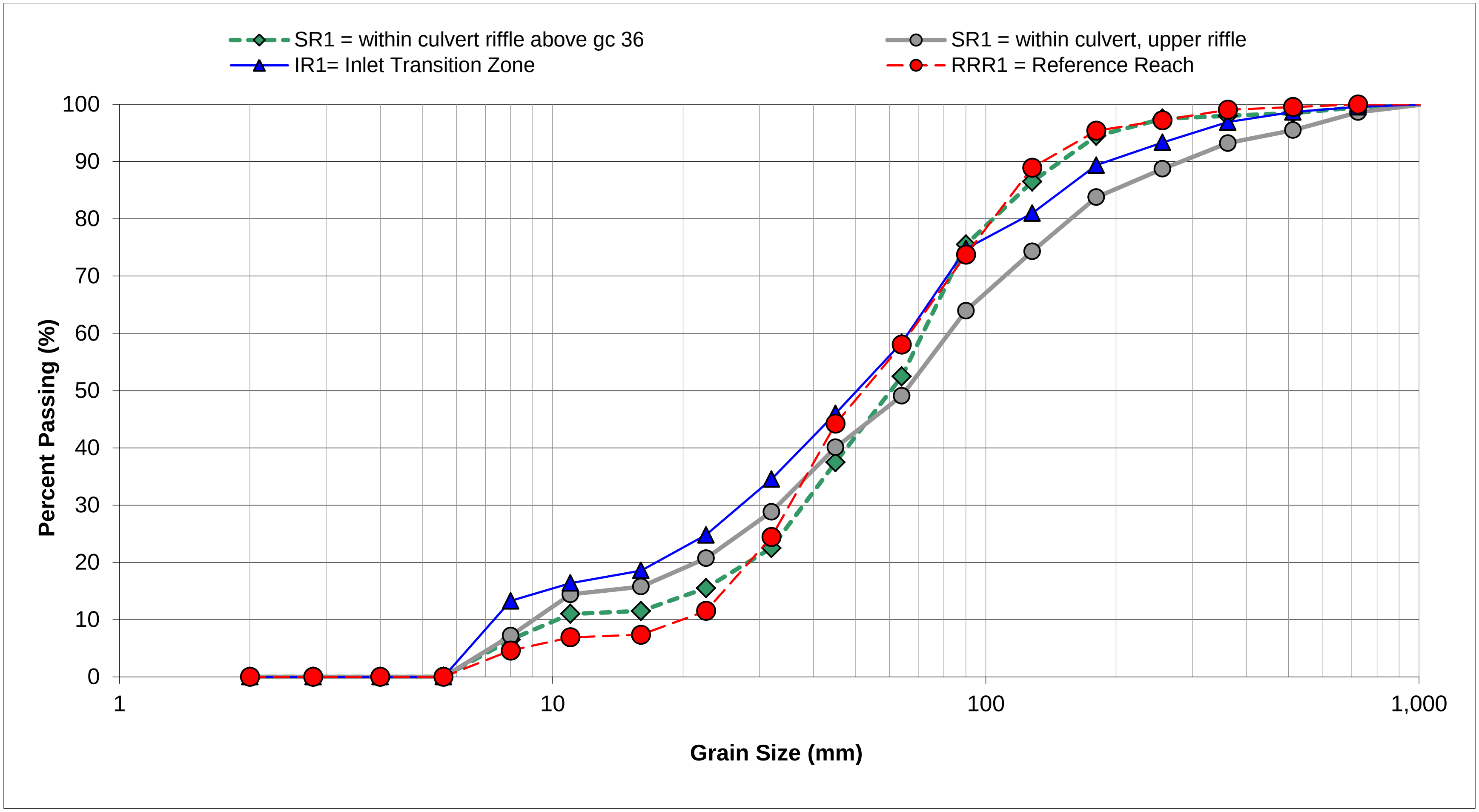


FIGURE 341: SPARKS BROOK GRADATION

A9.4 SPARKS BROOK BOXPLOTS AND HISTOGRAMS

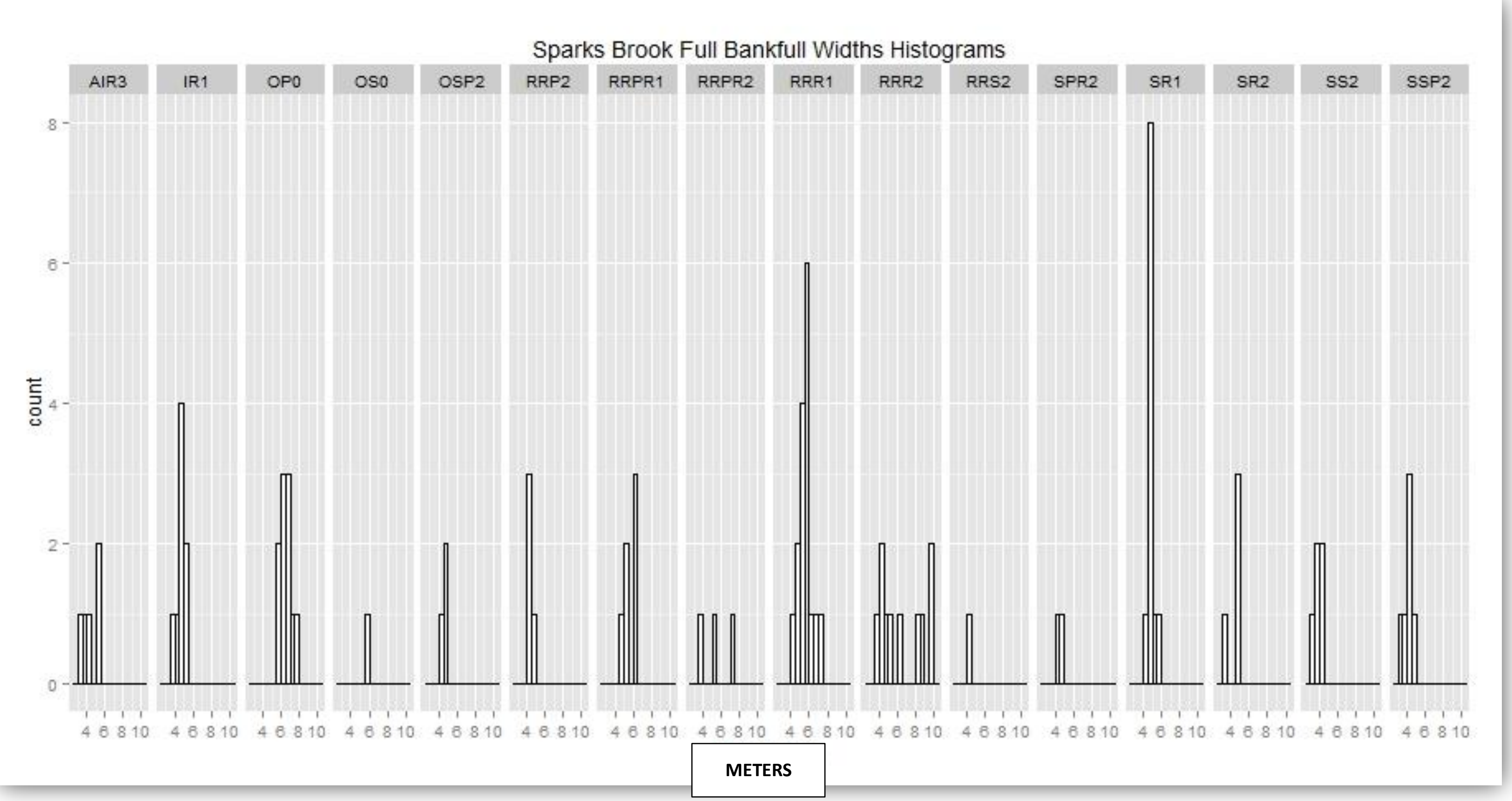


FIGURE 342: SPARKS BROOK WIDTH AT BANKFULL STAGE; HISTOGRAM

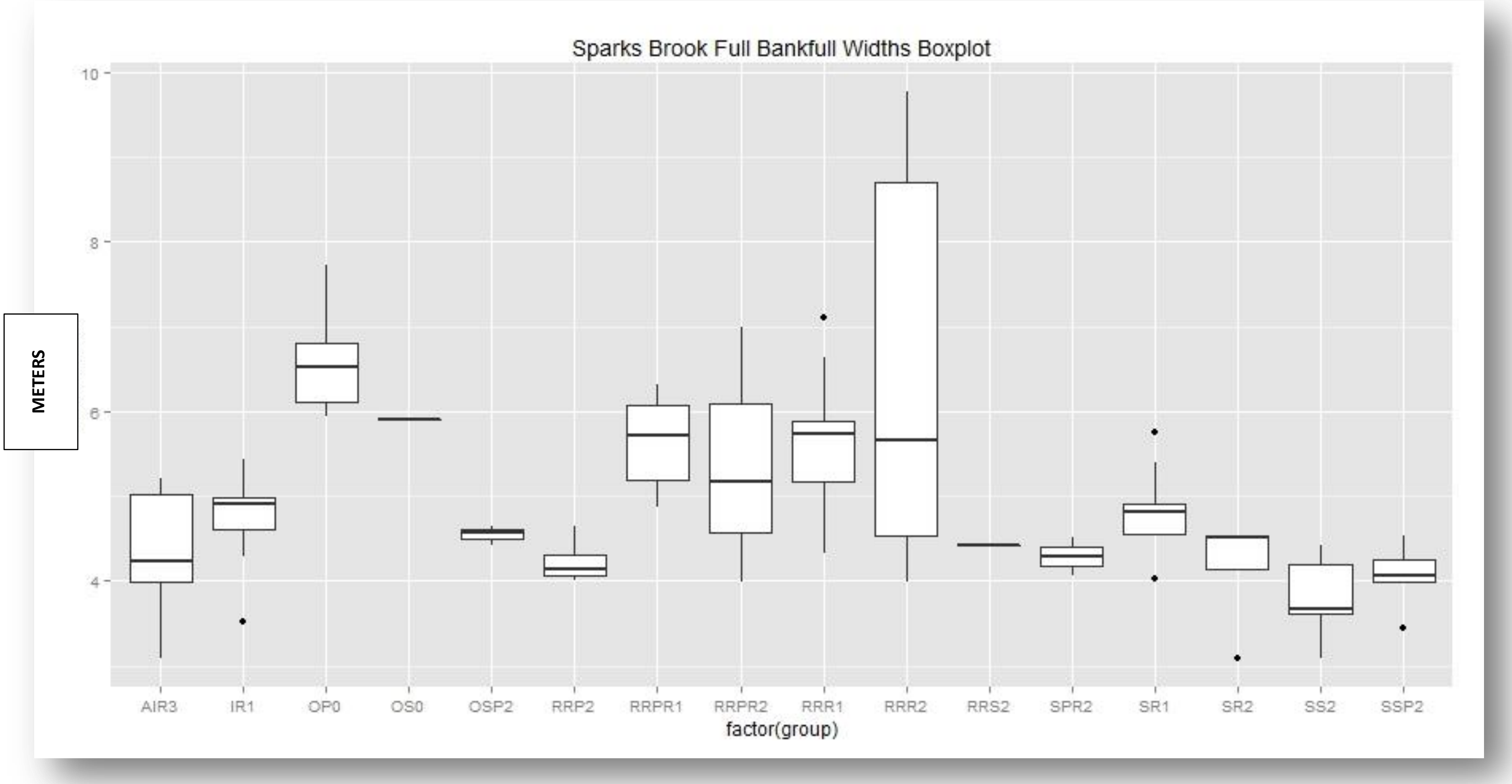


FIGURE 343: SPARKS BROOK WIDTHS AT BANKFULL STAGE; BOXPLOT

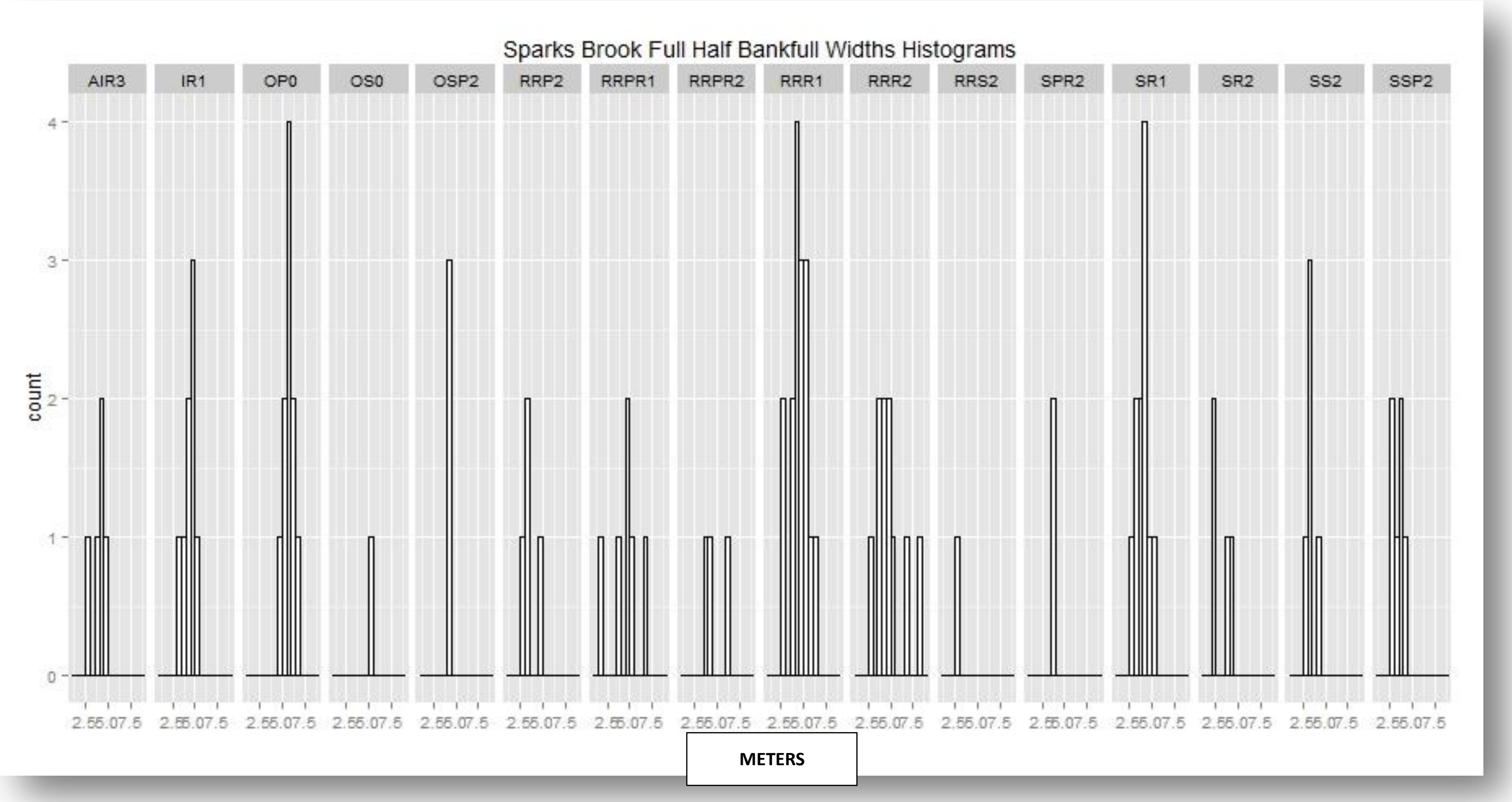


FIGURE 344: SPARKS BROOK WIDTH AT HALF BANKFULL STAGE; HISTOGRAM

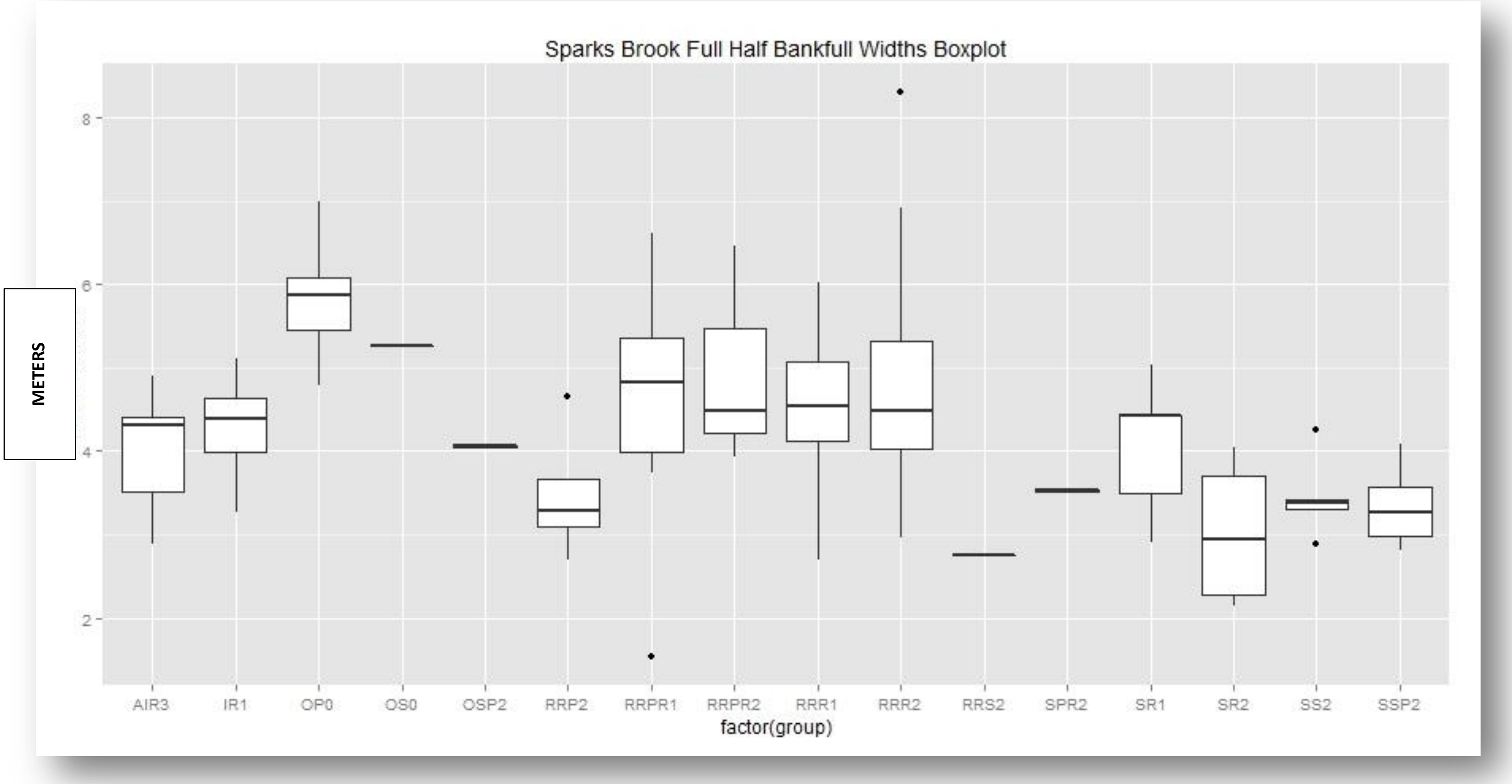


FIGURE 345: SPARKS BROOK WIDTH AT HALF BANKFULL STAGE; BOXPLOT

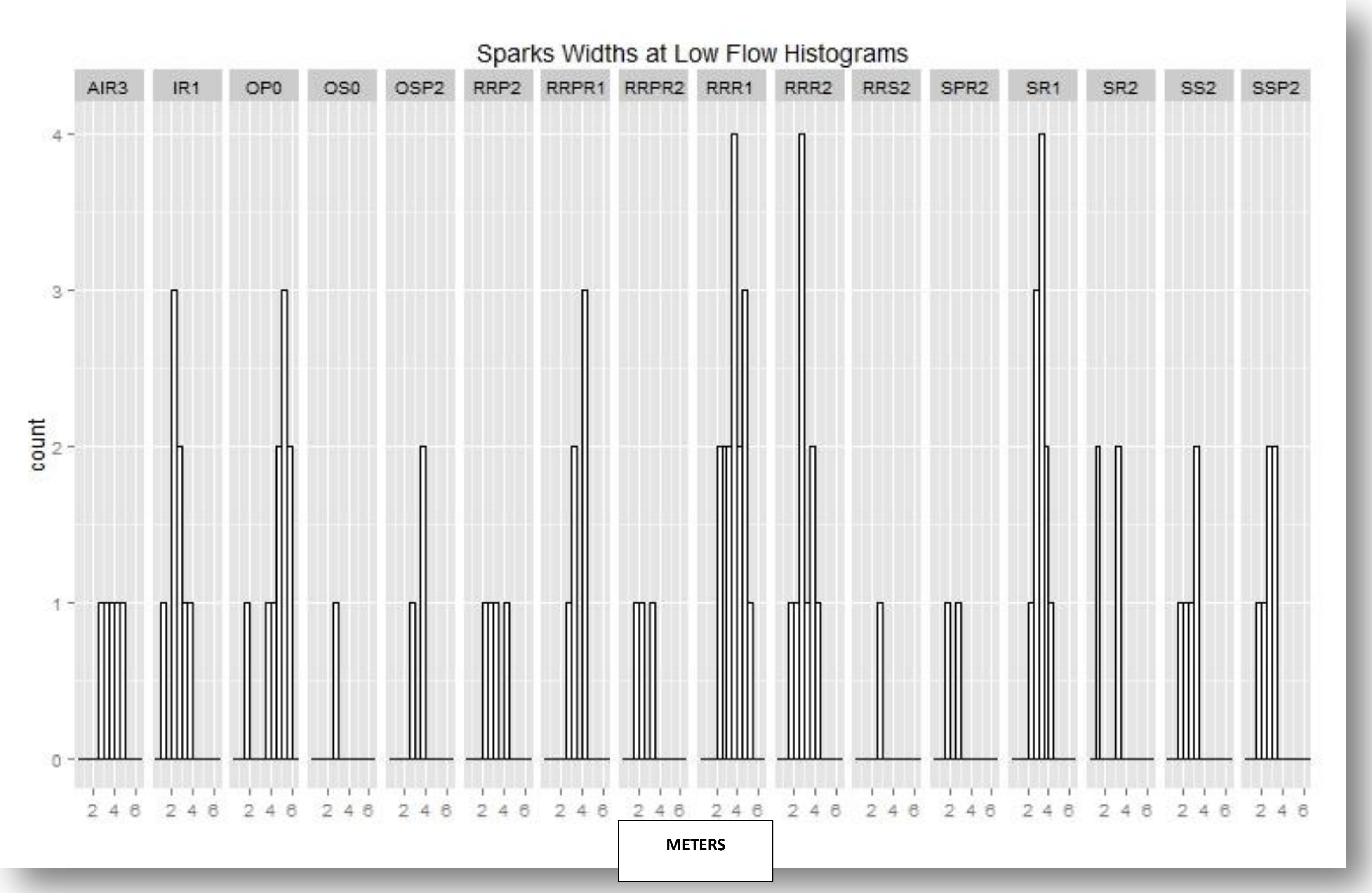


FIGURE 346: SPARKS BROOK LOW (WETTED) FLOW WIDTH; HISTOGRAM

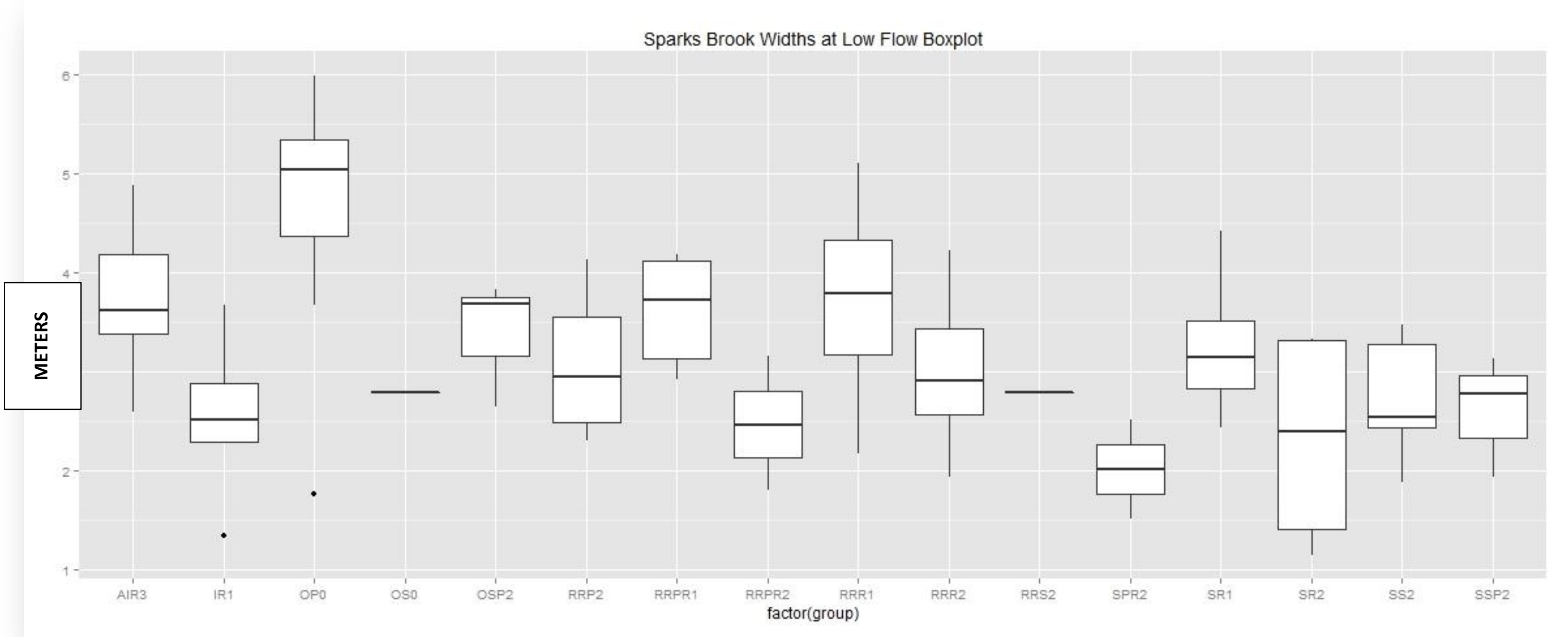


FIGURE 347: SPARKS BROOK LOW (WETTED) FLOW WIDTH; BOXPLOT

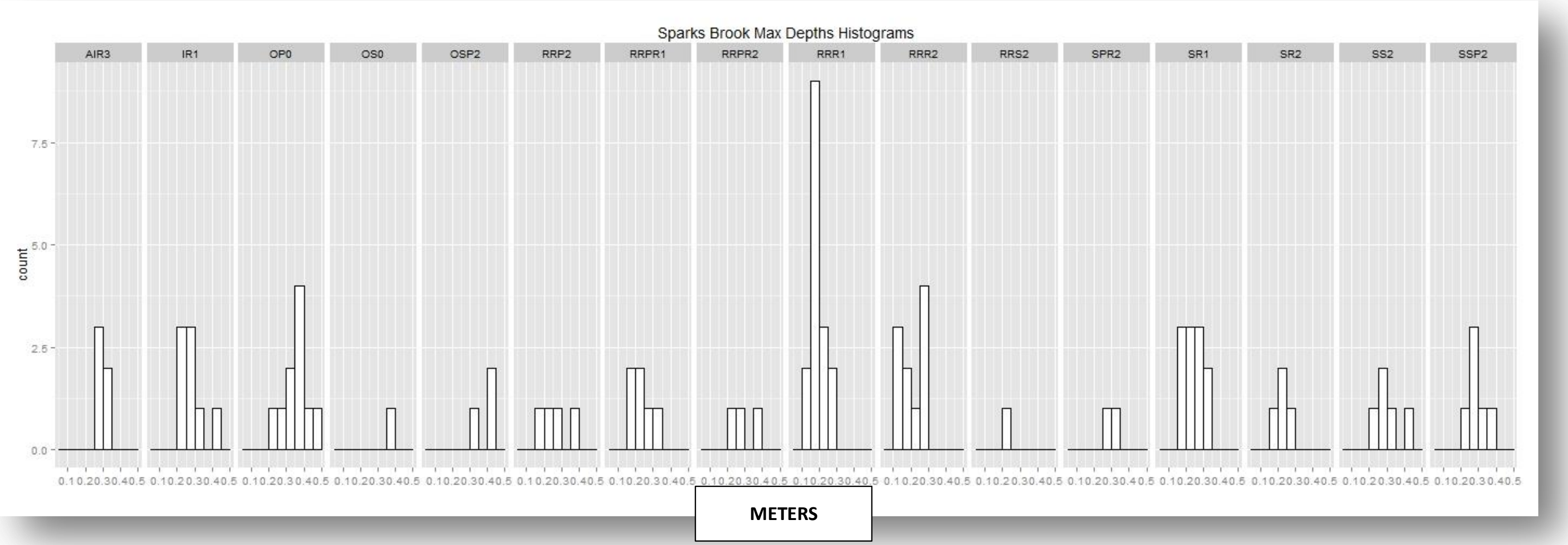


FIGURE 348: SPARKS BROOK MAXIMUM DEPTHS; HISTOGRAM

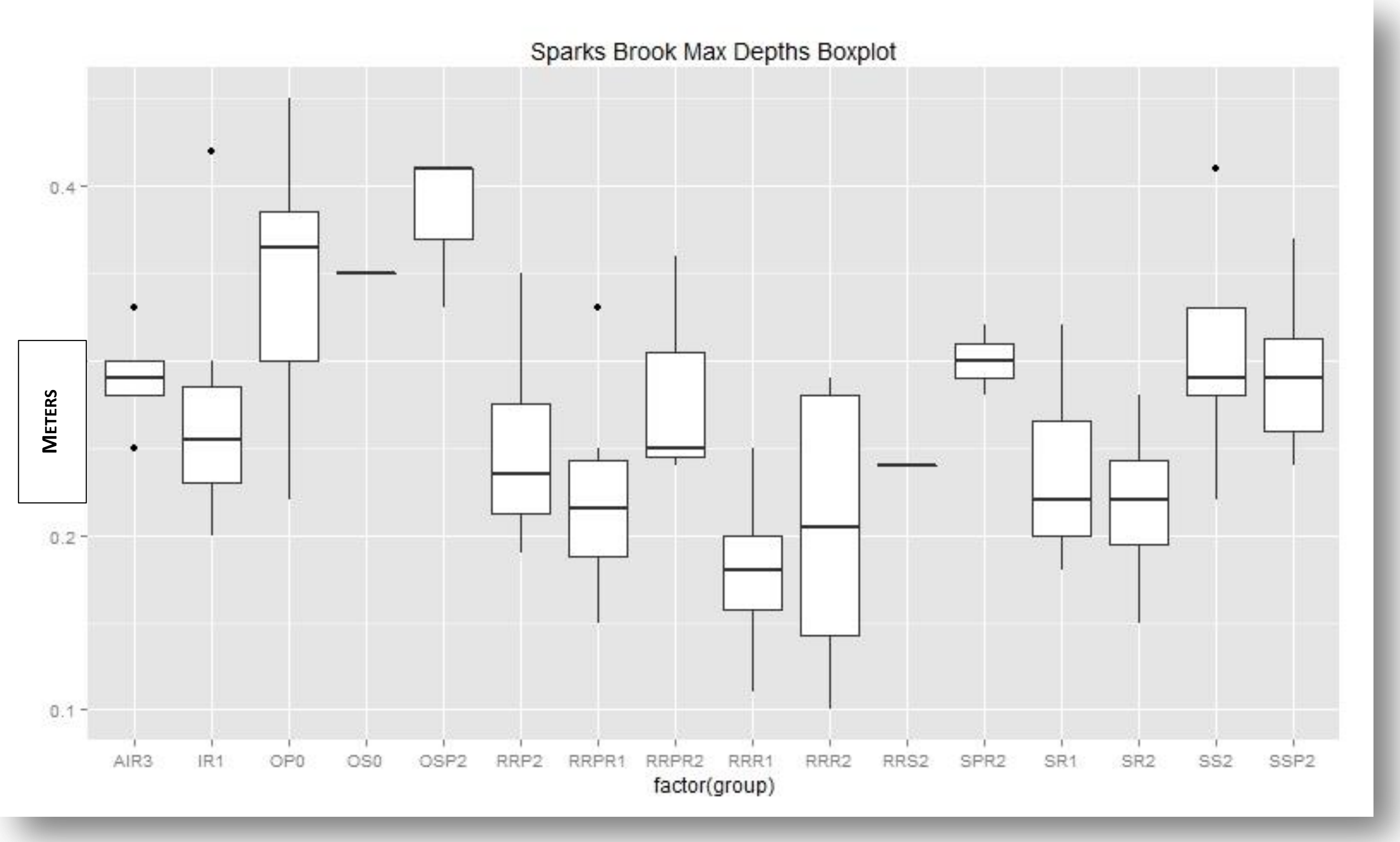


FIGURE 349: SPARKS BROOK MAXIMUM DEPTHS; BOXPLOT

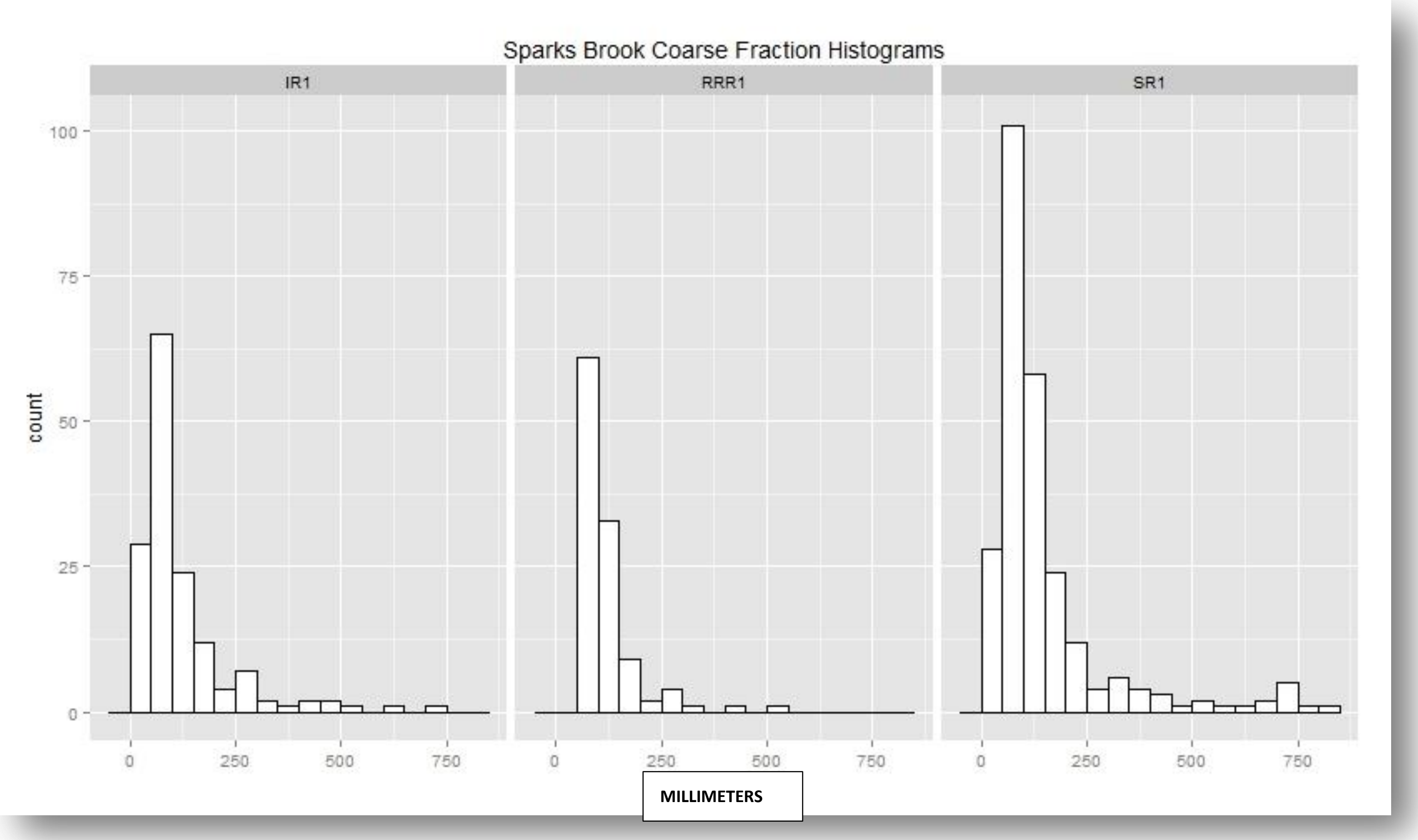


FIGURE 350: SPARKS BROOK COARSE FRACTION OF THE GRADATION; HISTOGRAM

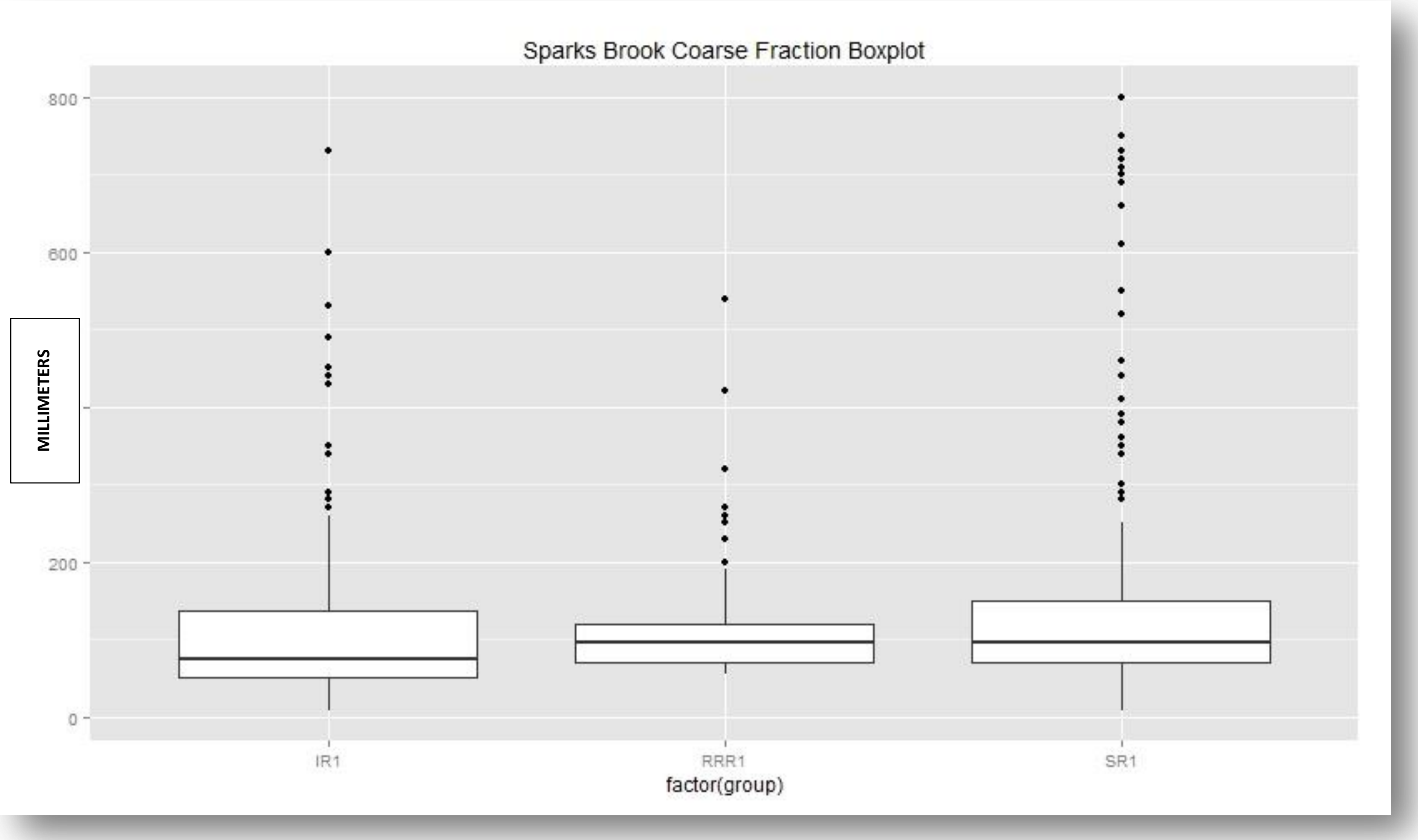


FIGURE 351: SPARKS BROOK COARSE FRACTION OF THE GRADATION; BOXPLOT

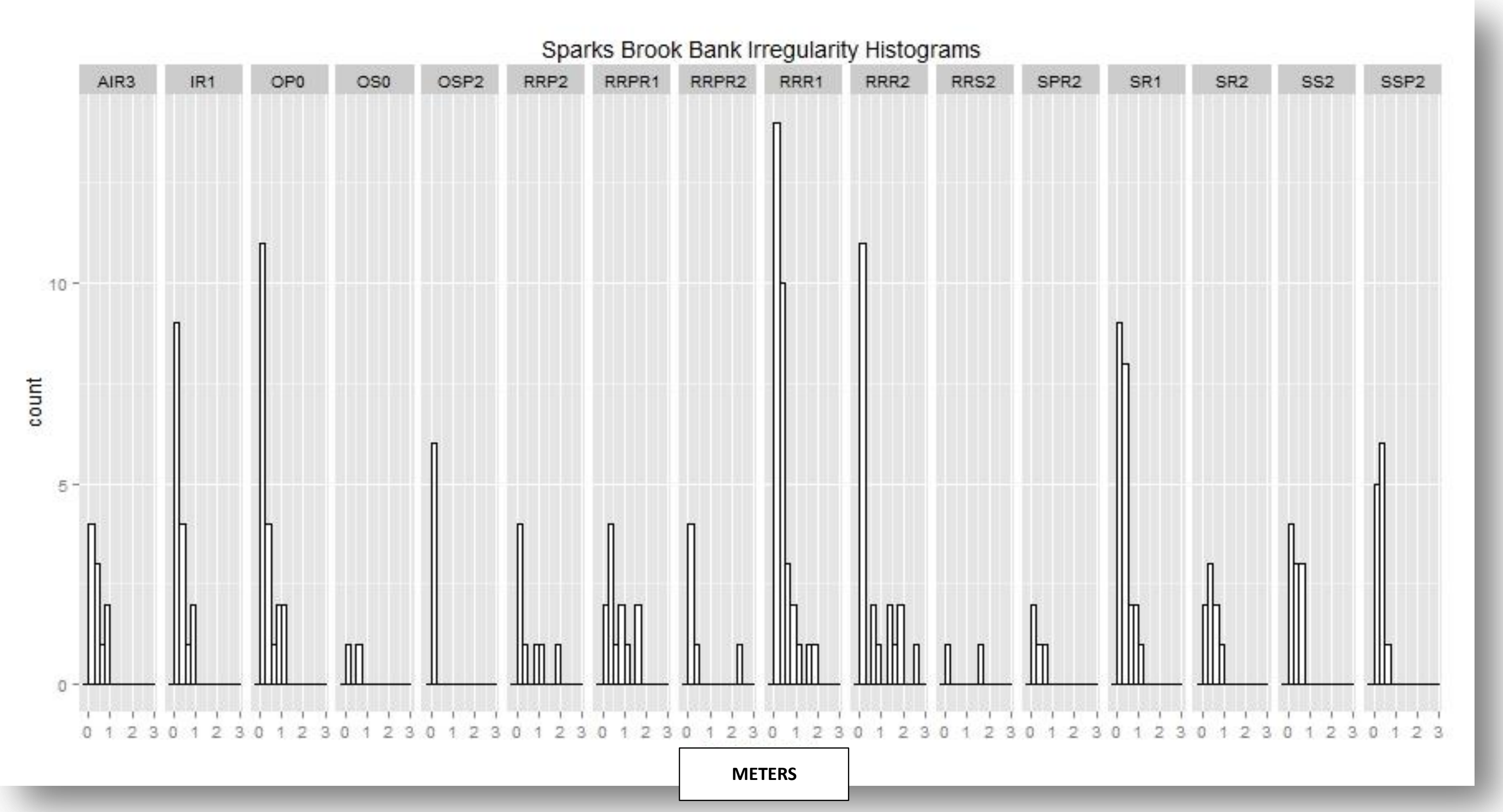


FIGURE 352: SPARKS BROOK BANK IRREGULARITY; HISTOGRAM

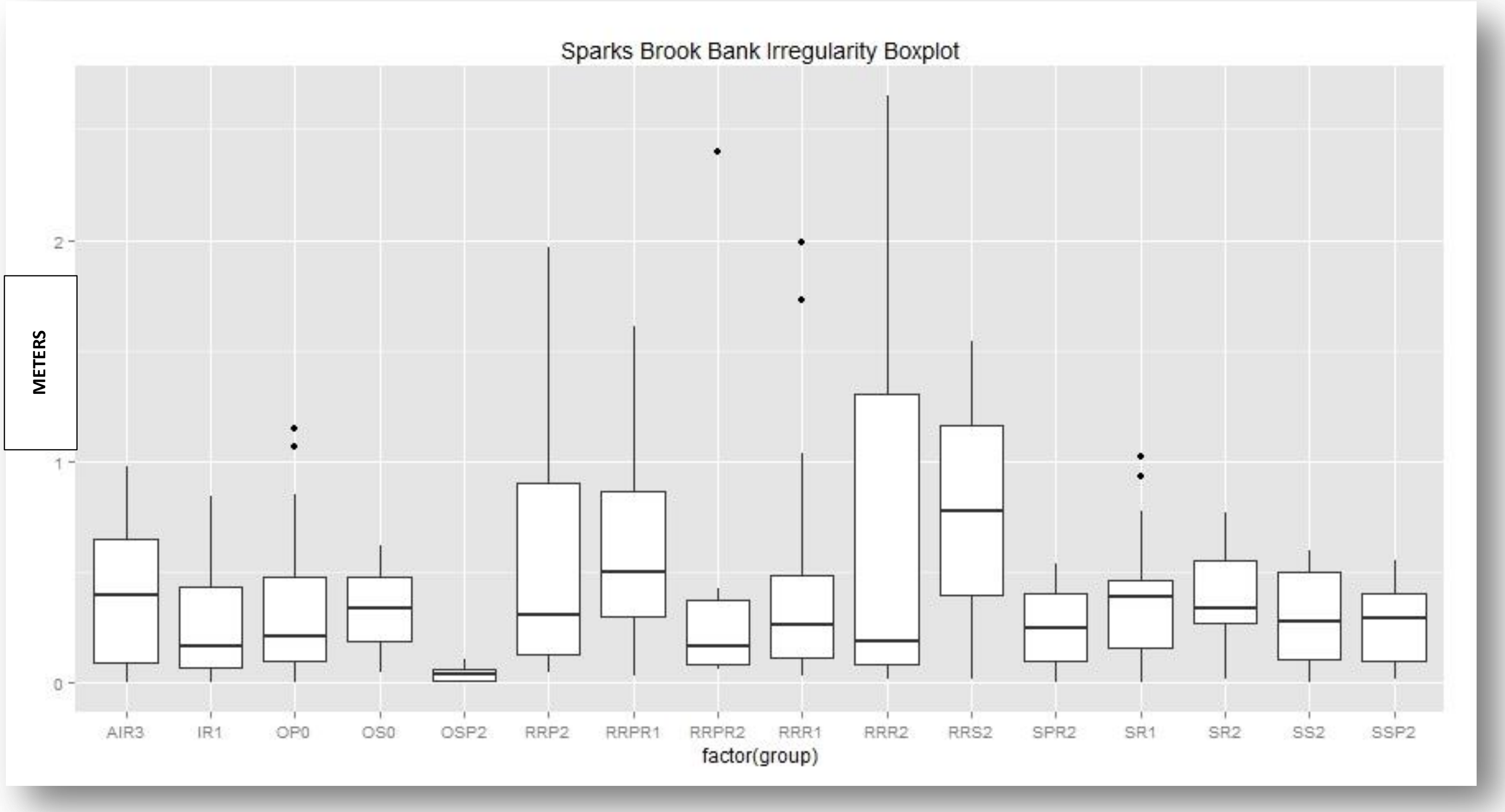


FIGURE 353: SPARKS BROOK BANK IRREGULARITY; BOXPLOT

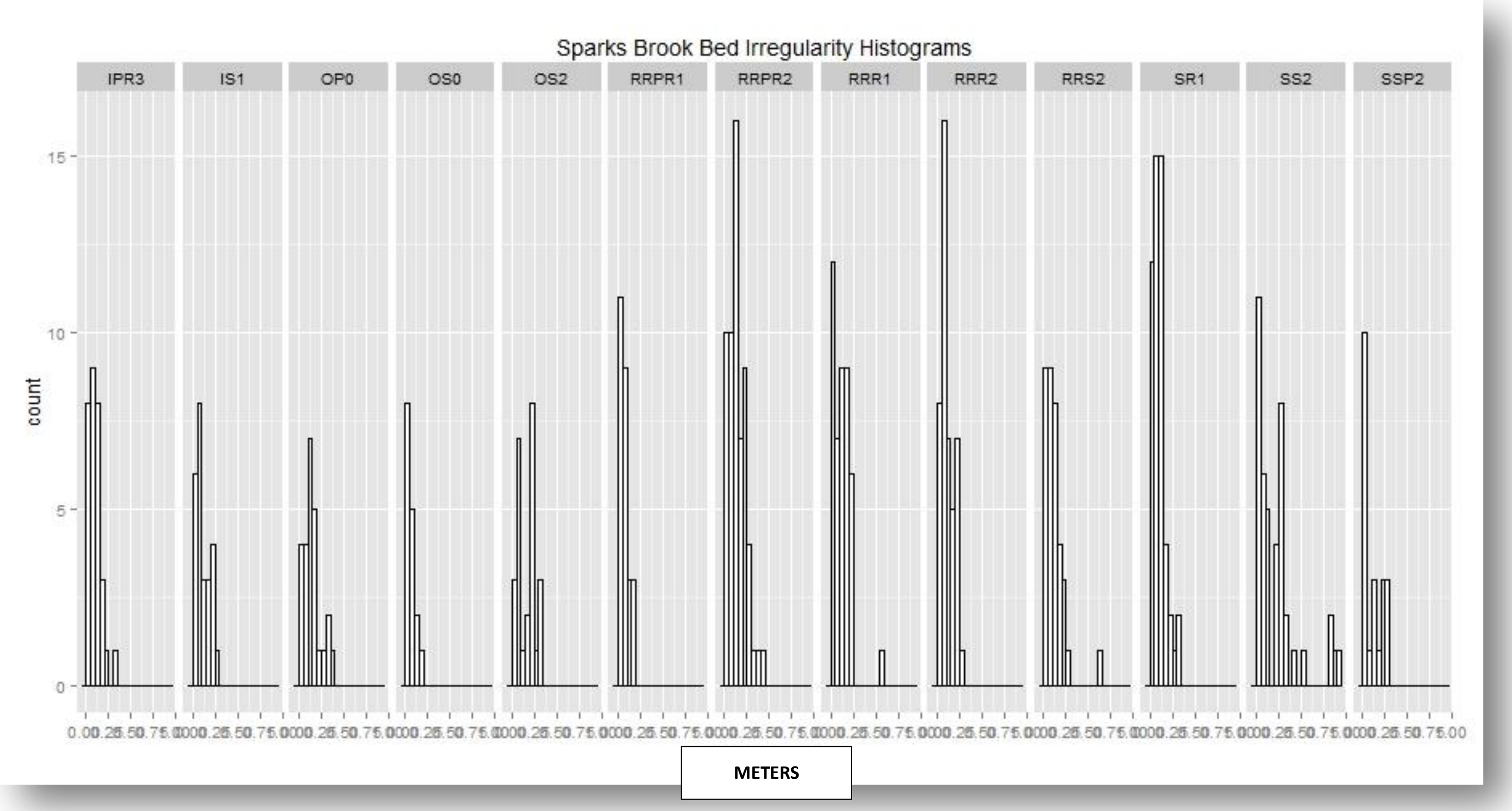


FIGURE 354: SPARKS BROOK BED IRREGULARITY; HISTOGRAM

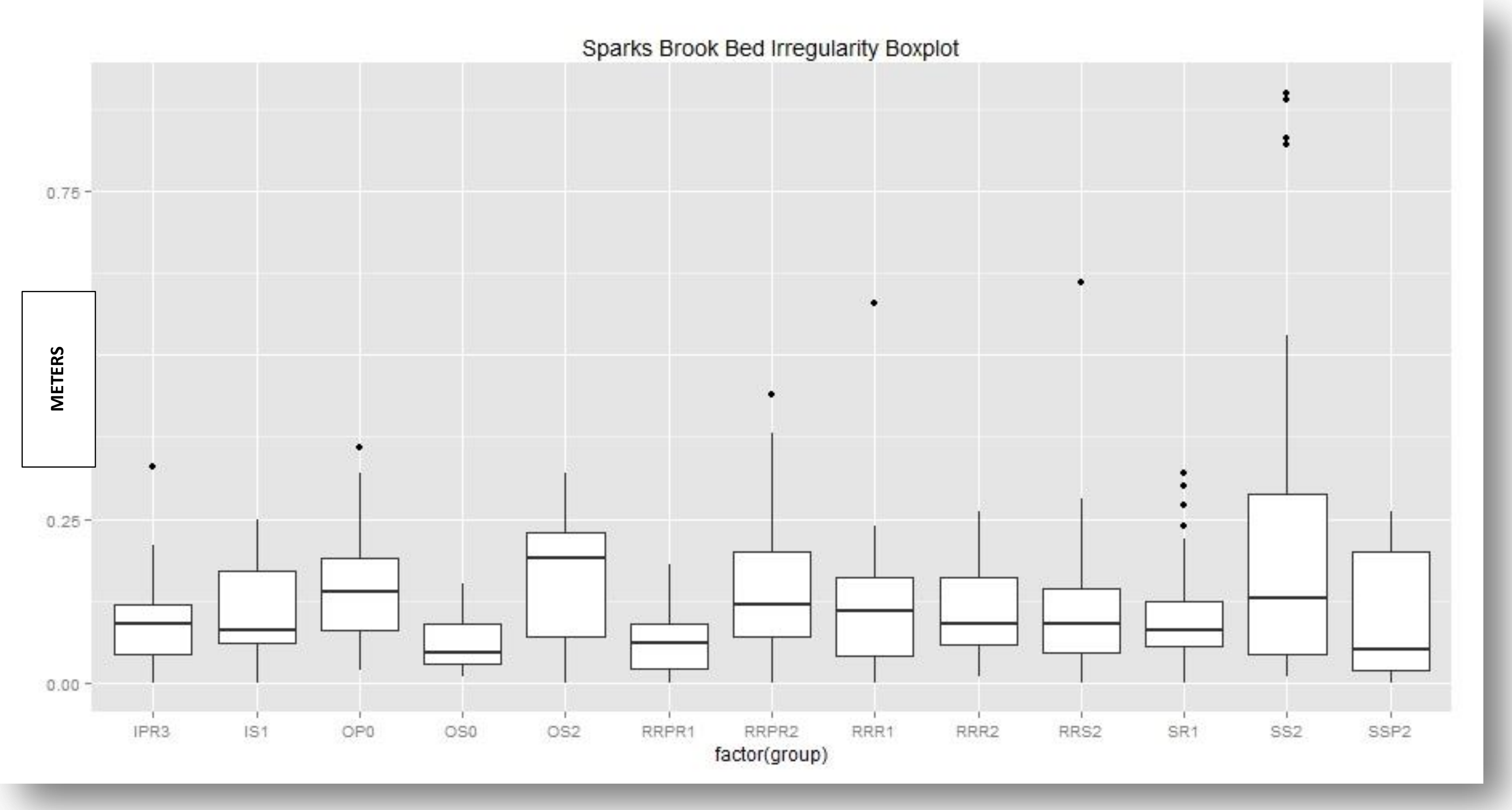


FIGURE 355: SPARKS BROOK BED IRREGULARITY; BOXPLOT

TABLE 97: SPARKS BROOK LEVEL II SCORING SENSITIVITY ANALYSIS

Channel Unit And Criteria for a Score of 3	Inlet Transition Zone			Structure Zone			Outlet Transition Zone		
	% Score	Evaluation	Over-ride	% Score	Evaluation	Over-ride	% Score	Evaluation	Over-ride
Riffle 1 0.01 to 0.05	67	Questionable		80	Similar			Not Applicable	
Riffle 1 0.001 to 0.05	79	Similar		88	Similar			Not Applicable	
Riffle 2 0.01 to 0.05		Not Applicable		87	Similar			Not Applicable	
Riffle 2 0.001 to 0.05		Not Applicable		87	Similar	Questionable		Not Applicable	
Steps				73	Questionable	Similar	35	Dissimilar	

A10 UTLEY BROOK SITE DATA

A10.1 UTLEY BROOK PHOTOS

FIGURE 356: LOOKING UPSTREAM AT THE INLET TRANSITION ZONE AND NATURAL CHANNEL FROM THE TOP OF THE UTLEY BROOK STRUCTURE

FIGURE 357: UTLEY BROOK STRUCTURE INLET WITH BOULDER RIP-RAP

FIGURE 358: VIEW OF THE OUTLET TRANSITION ZONE FROM THE TOP OF THE UTLEY BROOK STRUCTURE

FIGURE 359: LOOKING UPSTREAM AT THE UTLEY BROOK STRUCTURE OUTLET

FIGURE 360: LOOKING UPSTREAM AT THE STEEP RIFFLE/CASCADE WHICH BACKWATERS THE UTLEY BROOK DESIGN REACH; THE CREST IS THE DOWNSTREAM BOUNDARY OF THE OUTLET TRANSITION ZONE

FIGURE 361: A TYPICAL POOL-RIFFLE REACH WITHIN THE UTLEY BROOK NATURAL CHANNEL

FIGURE 362: THE LARGEST POOL FOUND WITHIN THE UTLEY BROOK NATURAL CHANNEL

A11 WF01 SITE DATA

A11.1 WF01 SITE PHOTOS

FIGURE 363: LOOKING AT THE INLET TRANSITION ZONE FROM THE TOP OF THE WF01 STRUCTURE

FIGURE 364: LOOKING UPSTREAM AT THE WF01 INLET TRANSITION ZONE

Figure 365: Looking downstream at the WF01 inlet transition zone and structure inlet

Figure 366: Looking at the WF01 outlet transition zone from the top of the structure

FIGURE 367: LOOKING UPSTREAM AT THE WF01 OUTLET TRANSITION ZONE AND STRUCTURE

FIGURE 368: LOOKING UPSTREAM WITHIN THE WF01 STRUCTURE

FIGURE 369: LOOKING UPSTREAM AT THE POSSIBLE HEADCUT BETWEEN WF01 AND WF02

FIGURE 370: LOOKING UPSTREAM AT THE POSSIBLE HEADCUT BETWEEN WF01 AND WF02

FIGURE 371: LOOKING UPSTREAM AT THE WF01 AND WF02 RIFFLE REPRESENTATIVE REACH

A11.2 WF01 and WF02 Representative Reach Analysis

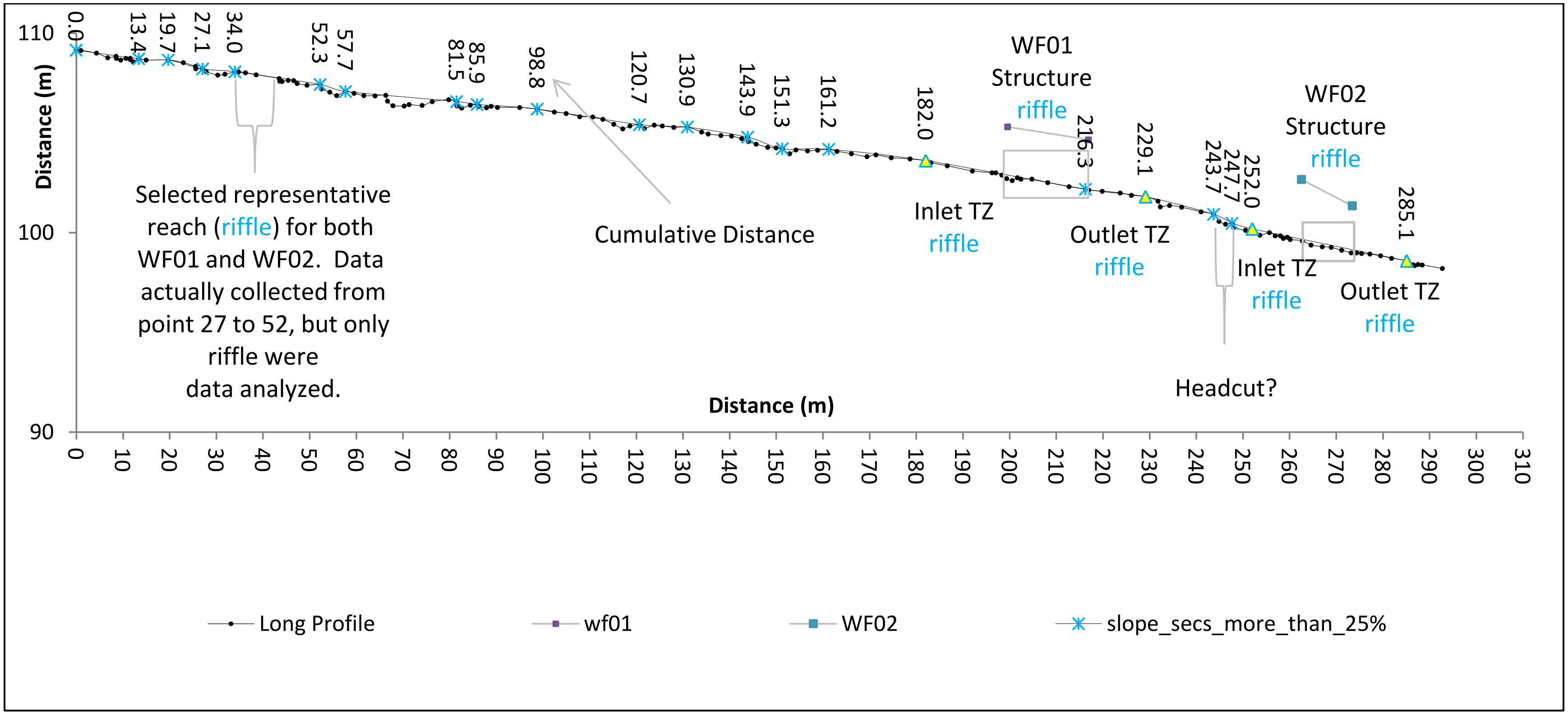


Figure 372: WF01 and WF02 Longitudinal Profile

Figure 372 is shown with 4.5 x vertical exaggeration. Channel units for all design zones (WF01 and WF02) are riffles. The selected representative reach is also a riffle. The slope segments within the WF01 design channel have gradients 4.17% and 2.94%. The WF02 design channel slope segment has gradient 4.84%. The representative reach selected for all design zone slope segments (WF01 and WF02) has gradient 3.51%. The WF01 structure is a pre-fabricated concrete box culvert. It is 17.3 m long, 2.45 m high and has a 3.65 m span. The WF02 structure is a pre-fabricated concrete box culvert. WF02 is 11 m long, 2.5 m high and has a 3.7 m span.

TABLE 98: WF01 STEEP SLOPE SEGMENT DATA

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	Survey Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn successive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Selection Notes
5024.4	5060.1	182.0	103.6	GC8, slope break (U/S inlet transition)								
5027.6	5029.3	216.3	102.2	GC6, slope break, steeper U/S in structure	31.0	1.4	34.3	0.042		25% criteria		outlet trans grade not analyzed?

TABLE 99: WF01 OUTLET TRANSITION ZONE SLOPE SEGMENT DATA

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	Survey Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn successive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Selection Notes
5027.6	5029.3	216.3	102.2	GC6, slope break, steeper U/S in structure								
5020.2	5019.2	229.1	101.8	GC5 (SS4), step crest, DS outlet transition	12.5	0.4	12.8	0.029		25% criteria		outlet trans slope segment analyzed here; same chosen segment works for out tz also.

Table 100: WF01 Steep Slope Segment Analysis

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	Survey Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn successive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Selection Notes
5024.3	5206.0	0.0	109.2	GC28(SS15 start), ptc								
5034.8	5198.1	13.4	108.7	GC25 (SS15), ptc	13.1	0.4	13.4	0.032		22.2	23.8	
5039.0	5193.7	19.7	108.7	GC? Break in riffle grade	6.1	0.1	6.3	0.009	-71.7	78.0	64.3	
5040.6	5186.5	27.1	108.2	GC23, rib crest	7.4	0.5	7.4	0.061	564.2	-46.1	57.7	
5039.7	5180.1	34.0	108.1	GC22 (SS13), ptc	6.4	0.1	6.9	0.020	-67.5	52.5	60.6	pool, riffle, step pool selected in original analysis, though I don't agree with original slope segment delineation
5033.4	5164.6	52.3	107.4	GC20 (SS12), top of cascade, step	16.8	0.6	18.2	0.035	77.2	15.9	-3.9	pool; riffle; step pool, riffle. selected in original analysis, though I don't agree with original slope segment delineation

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	Survey Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn successive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Selection Notes
5030.8	5160.0	57.7	107.1	GC19.5, ptc (old road crossing)	5.3	0.3	5.5	0.064	82.2	-53.2	69.0	
5026.1	5138.2	81.5	106.6	GC18 (SS10), step crest	22.3	0.5	23.8	0.021	-66.9	49.3	-35.4	
5026.7	5133.9	85.9	106.4	GC17, step crest	4.4	0.1	4.4	0.034	58.5	19.7	74.9	not selected; units are wrong; step pool, short seg
5027.6	5121.6	98.8	106.2		12.3	0.2	12.8	0.018	-45.3	56.1	26.9	
5017.3	5103.9	120.7	105.4	GC14, step crest	20.5	0.8	21.9	0.035	92.8	15.3	-24.6	long riffle, into pool
5009.8	5098.8	130.9	105.3	GC13 (SS7), riffle crossover	9.1	0.1	10.3	0.012	-64.7	70.1	41.6	
5004.9	5089.2	143.9	104.8	GC12, step crest, top of cascade	10.8	0.5	12.9	0.039	214.1	6.1	26.4	not selected; in field is cross over riffle section, bend, split flow, bar deposit on inner bend; poor match
5009.3	5084.9	151.3	104.2	GC11.5, D/S cascade section	6.1	0.6	7.4	0.078	98.3	-86.2	57.9	
5017.2	5079.4	161.2	104.2	GC10 (SS6), ptc	9.7	0.0	10.0	0.003	-96.3	93.1	43.3	

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	riffle crest (rc)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn successive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Selection Notes
5024.4	5060.1	182.0	103.6	GC8, slope break (U/S inlet transition)	20.5	0.6	20.8	0.027	846.6	34.5	-18.2	
5027.6	5029.3	216.3	102.2	GC6, slope break, steeper U/S in structure	31.0	1.4	34.3	0.042	52.6	0.0	-95.0	long rifle, bend scour pool, riffle
5020.2	5019.2	229.1	101.8	GC5 (SS4), step crest, DS outlet transition	12.5	0.4	12.8	0.029	-29.6	29.6	27.0	
5010.8	5008.3	243.7	100.9	GC4 (SS3), step crest	14.3	0.9	14.6	0.060	105.3	-44.6	16.7	
5008.1	5005.6	247.7	100.5	GC3.5, step crest, bldr-cobble	3.9	0.4	4.0	0.113	87.6	-171.3	77.4	
5004.9	5002.7	252.0	100.2	gc 3	4.3	0.3	4.3	0.066	-41.8	-57.8	75.6	forced gc, is top of inlet trans
4999.1	4973.5	285.1	98.6	GC1 (SS1), crest of deposit into Greenbrier R (D/S outlet transition)	29.7	1.6	33.1	0.048	-26.5	-15.9	-88.4	is outlet trans of wf02; not natural channel

TABLE 101: WF01 OUTLET TRANSITION ZONE SLOPE SEGMENT ANALYSIS

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	Survey Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn successive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Selection Notes
5024.3	5206.0	0.0	109.2	GC28(SS15 start), ptc								
5034.8	5198.1	13.4	108.7	GC25 (SS15), ptc	13.1	0.4	13.4	0.032		-10.4	23.8	
5039.0	5193.7	19.7	108.7	GC? Break in riffle grade	6.1	0.1	6.3	0.009	-71.7	68.8	64.3	
5040.6	5186.5	27.1	108.2	GC23, rib crest	7.4	0.5	7.4	0.061	564.2	-107.4	57.7	
5039.7	5180.1	34.0	108.1	GC22 (SS13), ptc	6.4	0.1	6.9	0.020	-67.5	32.6	60.6	pool, riffle, step pool; selected in original analysis, though I don't agree with original slope segment delineation
5033.4	5164.6	52.3	107.4	GC20 (SS12), top of cascade, step	16.8	0.6	18.2	0.035	77.2	-19.4	-3.9	pool; riffle; step pool, riffle; selected in original analysis, though I don't agree with original slope segment delineation
5030.8	5160.0	57.7	107.1	GC19.5, ptc (old road crossing)	5.3	0.3	5.5	0.064	82.2	-117.5	69.0	
5026.1	5138.2	81.5	106.6	GC18 (SS10), step crest	22.3	0.5	23.8	0.021	-66.9	28.1	-35.4	
5026.7	5133.9	85.9	106.4	GC17, step crest	4.4	0.1	4.4	0.034	58.5	-14.0	74.9	not selected; units are wrong; step pool, short seg

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	Survey Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn successive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Selection Notes
5027.6	5121.6	98.8	106.2		12.3	0.2	12.8	0.018	-45.3	37.7	26.9	
5017.3	5103.9	120.7	105.4	GC14, step crest	20.5	0.8	21.9	0.035	92.8	-20.2	-24.6	long riffle, into pool
5009.8	5098.8	130.9	105.3	GC13 (SS7), riffle crossover	9.1	0.1	10.3	0.012	-64.7	57.6	41.6	
5004.9	5089.2	143.9	104.8	GC12, step crest, top of cascade	10.8	0.5	12.9	0.039	214.1	-33.3	26.4	not selected; in field is cross over riffle section, bend, split flow, bar deposit on inner bend; poor match
5009.3	5084.9	151.3	104.2	GC11.5, D/S cascade section	6.1	0.6	7.4	0.078	98.3	-164.3	57.9	
5017.2	5079.4	161.2	104.2	GC10 (SS6), ptc	9.7	0.0	10.0	0.003	-96.3	90.2	43.3	
5024.4	5060.1	182.0	103.6	GC8, slope break (U/S inlet transition)	20.5	0.6	20.8	0.027	846.6	7.0	-18.2	
5027.6	5029.3	216.3	102.2	GC6, slope break, steeper U/S in structure	31.0	1.4	34.3	0.042	52.6	-42.0	-95.0	long rifle, bend scour pool, riffle
5020.2	5019.2	229.1	101.8	GC5 (SS4), step crest, DS outlet transition	12.5	0.4	12.8	0.029	-29.6	0.0	27.0	
5010.8	5008.3	243.7	100.9	GC4 (SS3), step crest	14.3	0.9	14.6	0.060	105.3	-105.3	16.7	
5008.1	5005.6	247.7	100.5	GC3.5, step crest, bldr-cobble	3.9	0.4	4.0	0.113	87.6	-285.2	77.4	

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	Survey Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn successive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Selection Notes
5004.9	5002.7	252.0	100.2	gc 3	4.3	0.3	4.3	0.066	-41.8	-124.0	75.6	forced gc, is top of inlet trans
4999.1	4973.5	285.1	98.6	GC1 (SS1), crest of deposit into Greenbrier R (D/S outlet transition)	29.7	1.6	33.1	0.048	-26.5	-64.6	-88.4	is outlet trans of wf02; not natural channel

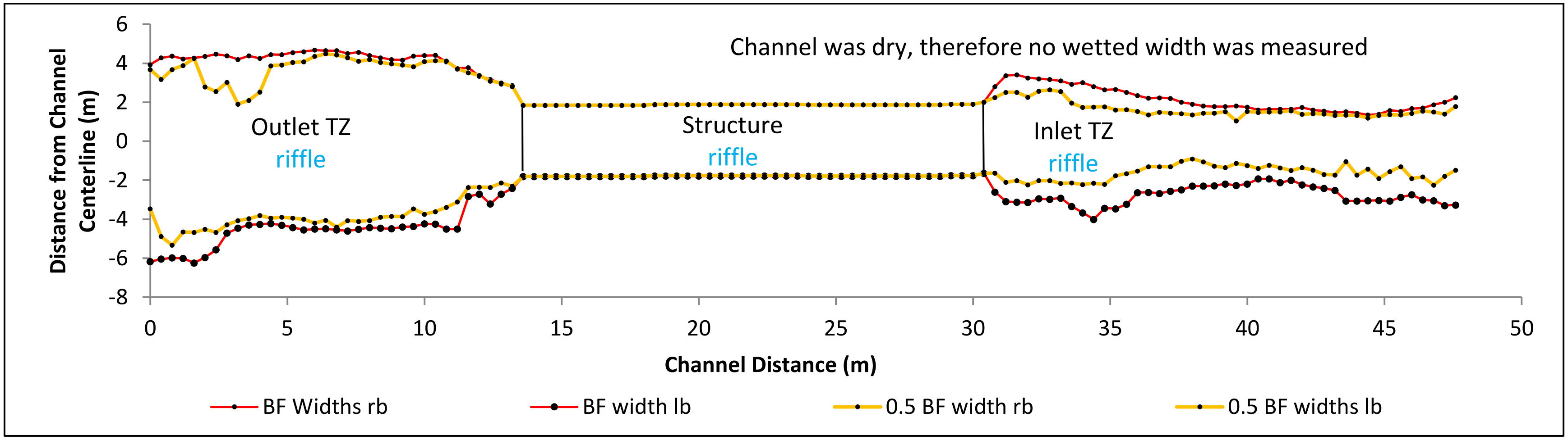


FIGURE 373: WF01 DESIGN CHANNEL WIDTHS

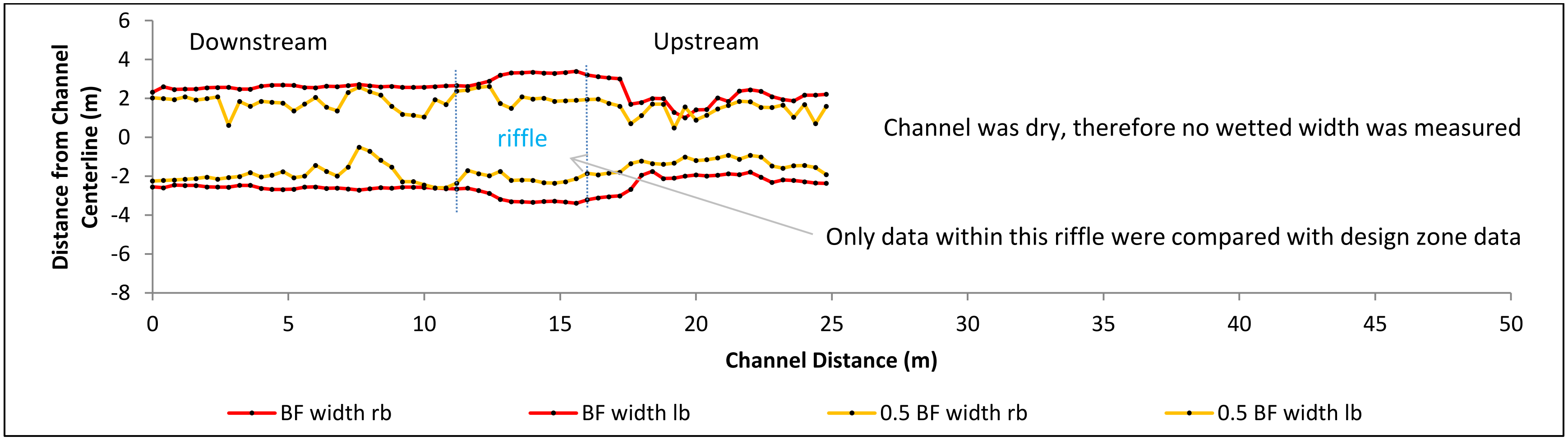


FIGURE 374: WF01 AND WF02 REPRESENTATIVE REACH WIDTHS

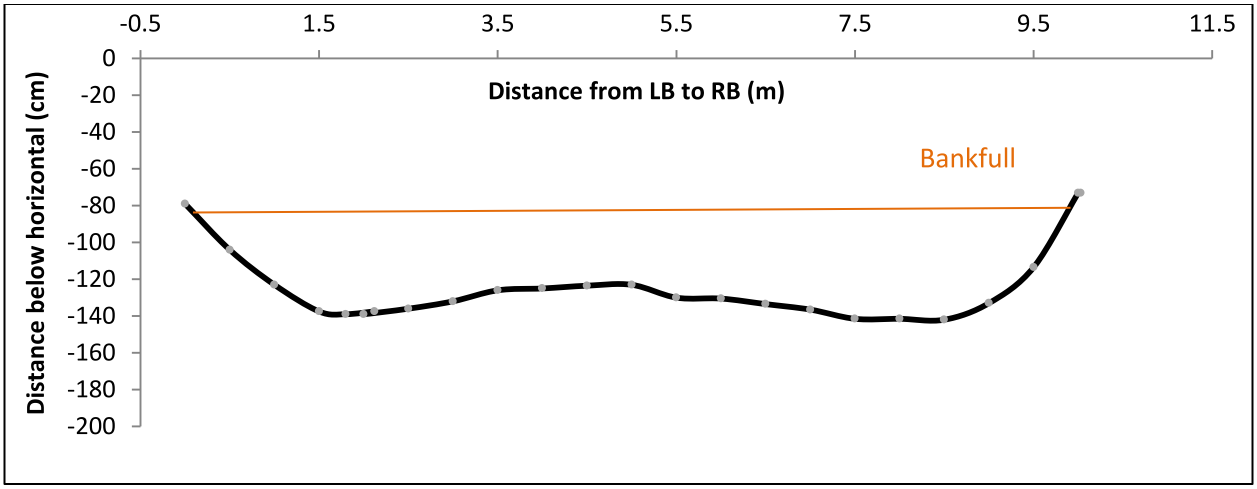


FIGURE 375: WF01 CROSS SECTION 4; OUTLET TRANSITION ZONE; RIFFLE

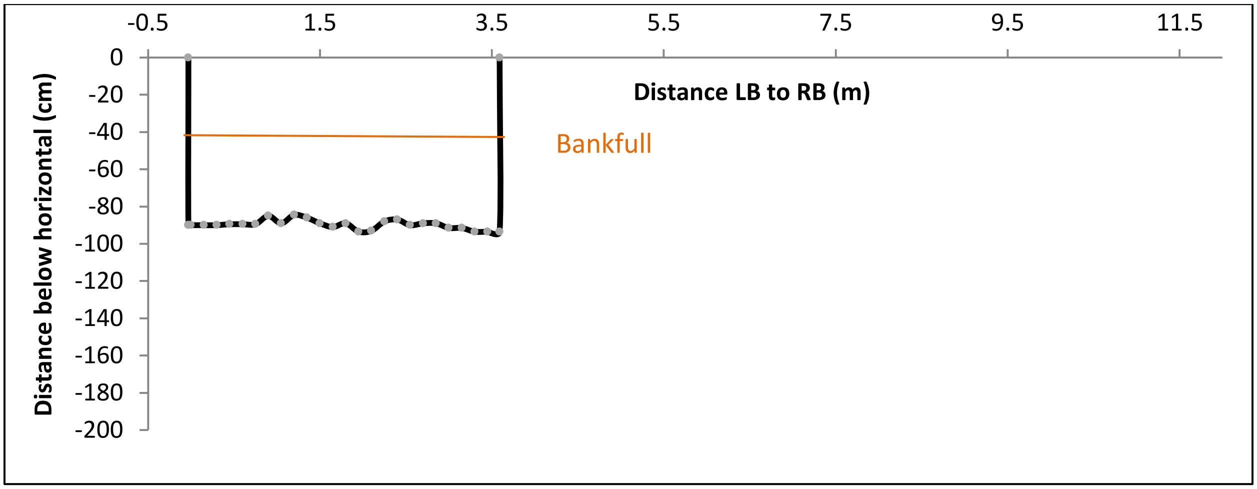


FIGURE 376: WF01 CROSS SECTION 5; WITHIN STRUCTURE; RIFFLE

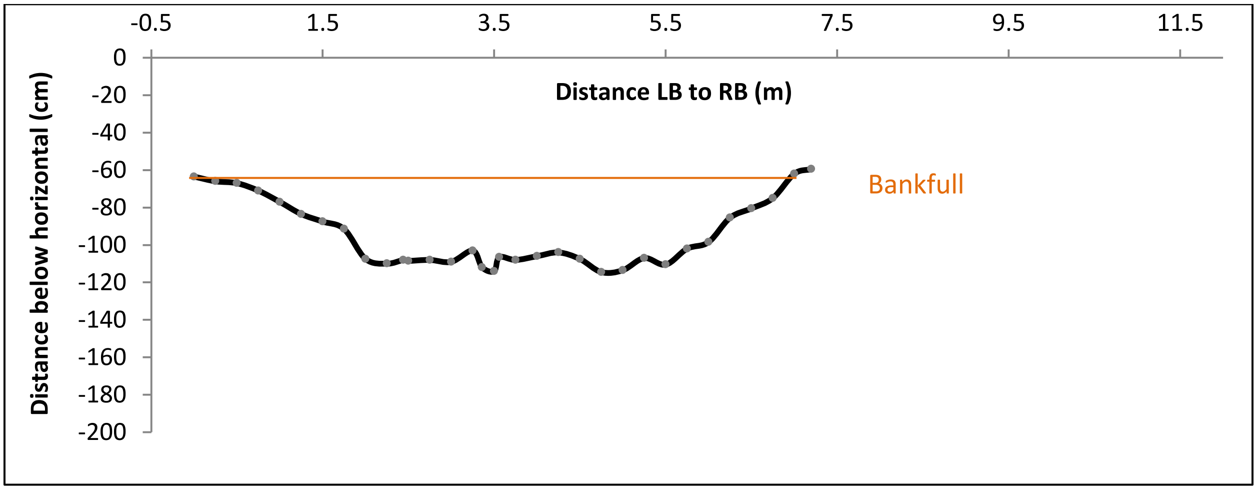


FIGURE 377: WF01 CROSS SECTION 6; INLET TRANSITION ZONE; RIFFLE

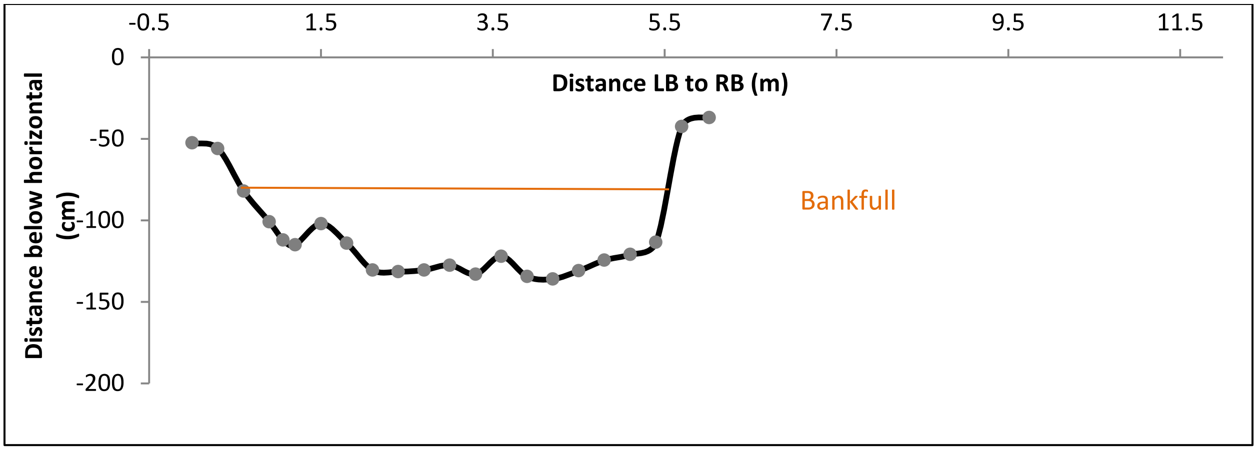


FIGURE 378: WF01 X SEC 7; REPRESENTATIVE REACH; DATA NOT USED (NOT WITHIN RIFFLE)

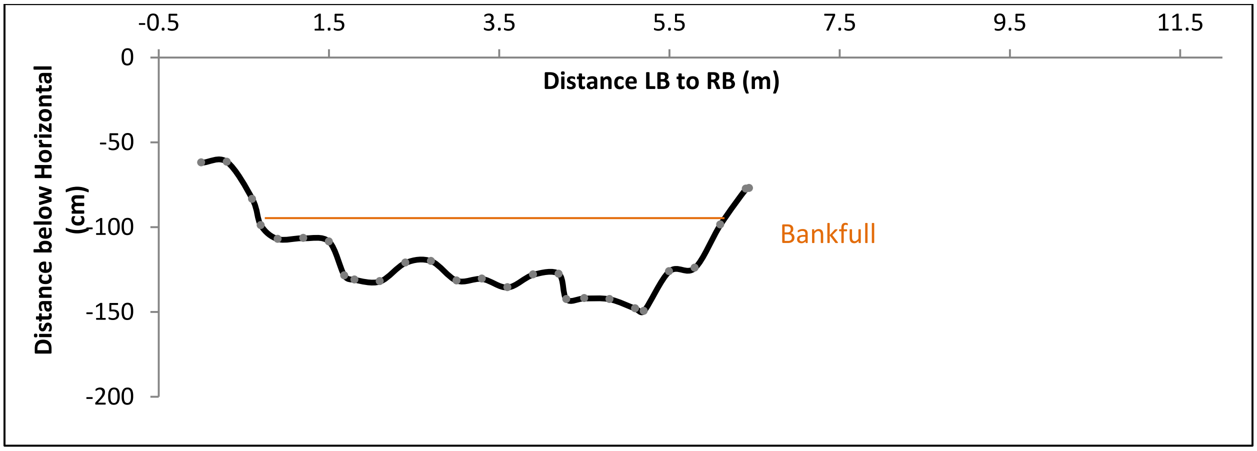


FIGURE 379: WF01 CROSS SECTION 8; REPRESENTATIVE REACH; RIFFLE

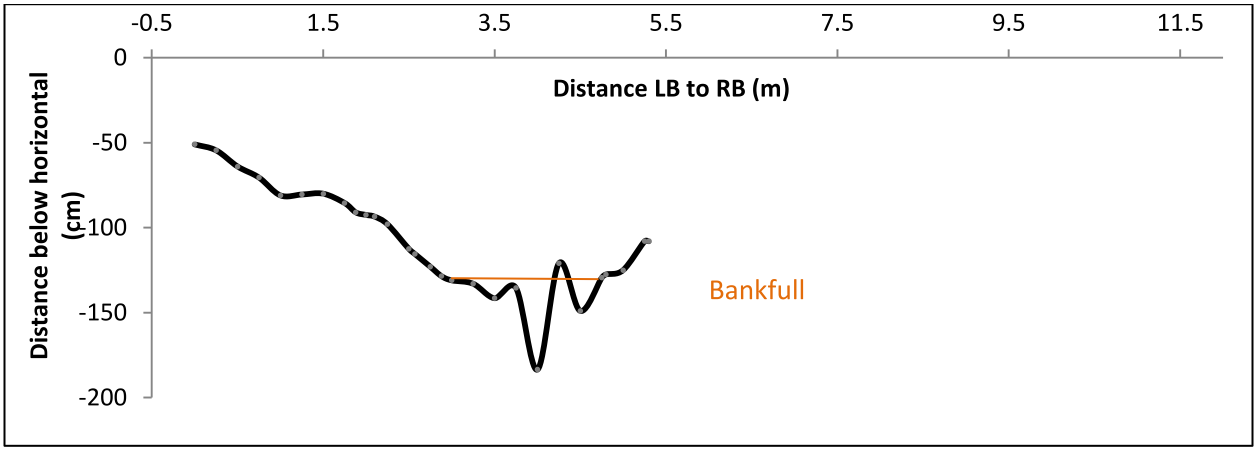


FIGURE 380: WF01 CROSS SECTION 9; REPRESENTATIVE REACH; POOL (DATA NOT USED)

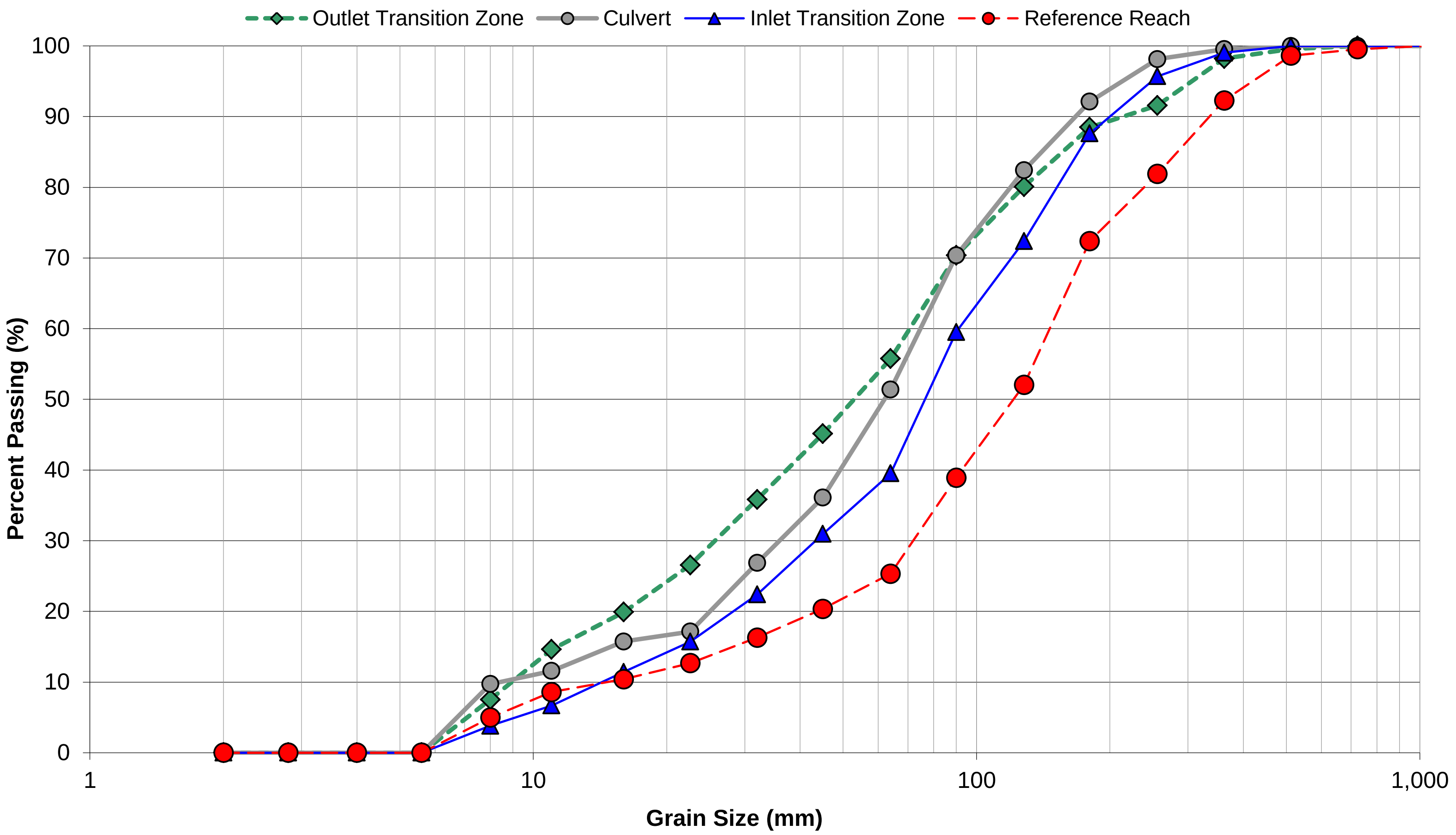


FIGURE 381: WF01 GRADATION

A11.4 WF01 BOXPLOTS AND HISTOGRAMS

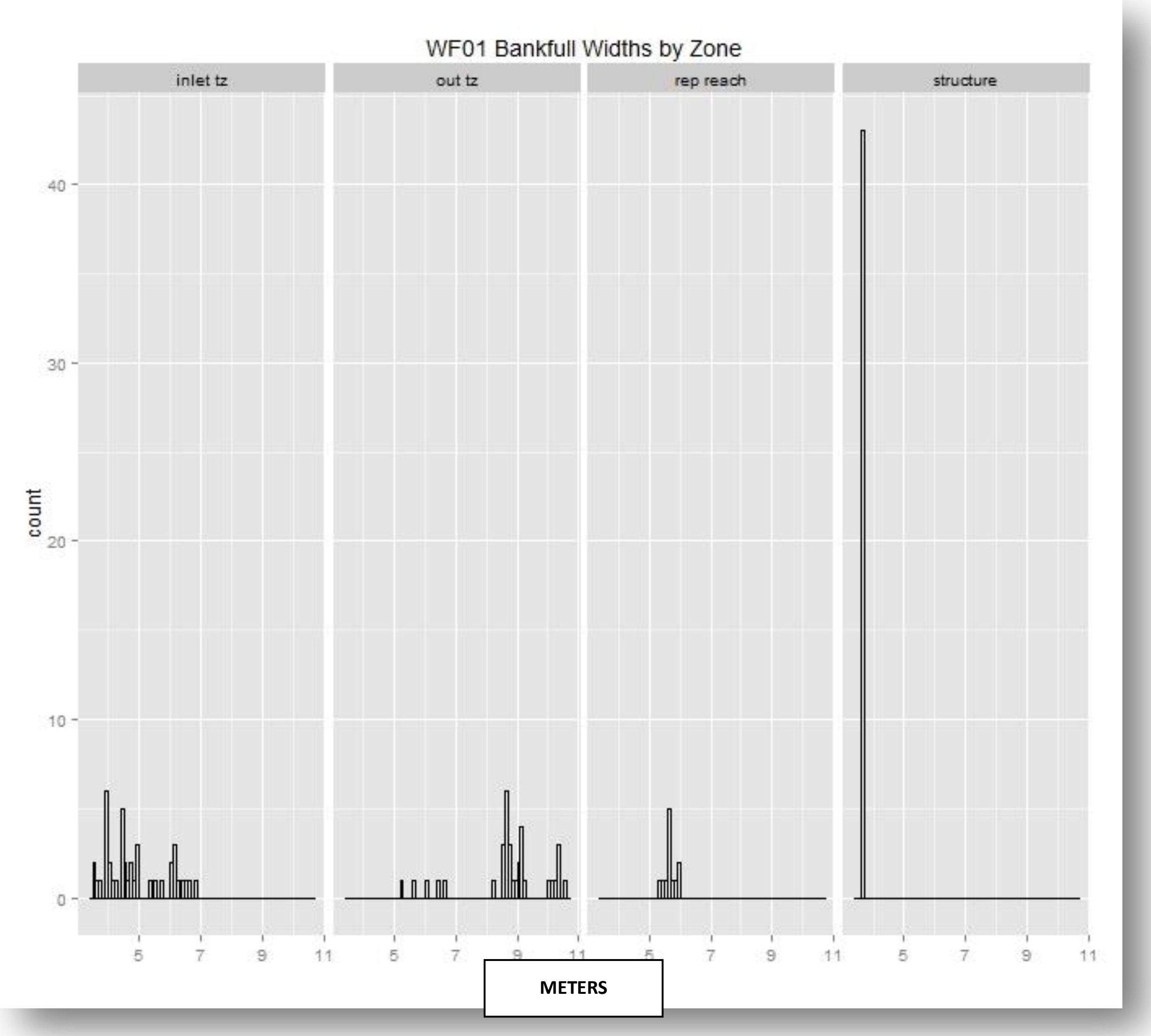


FIGURE 382: WF01 WIDTH AT BANKFULL STAGE; HISTOGRAM

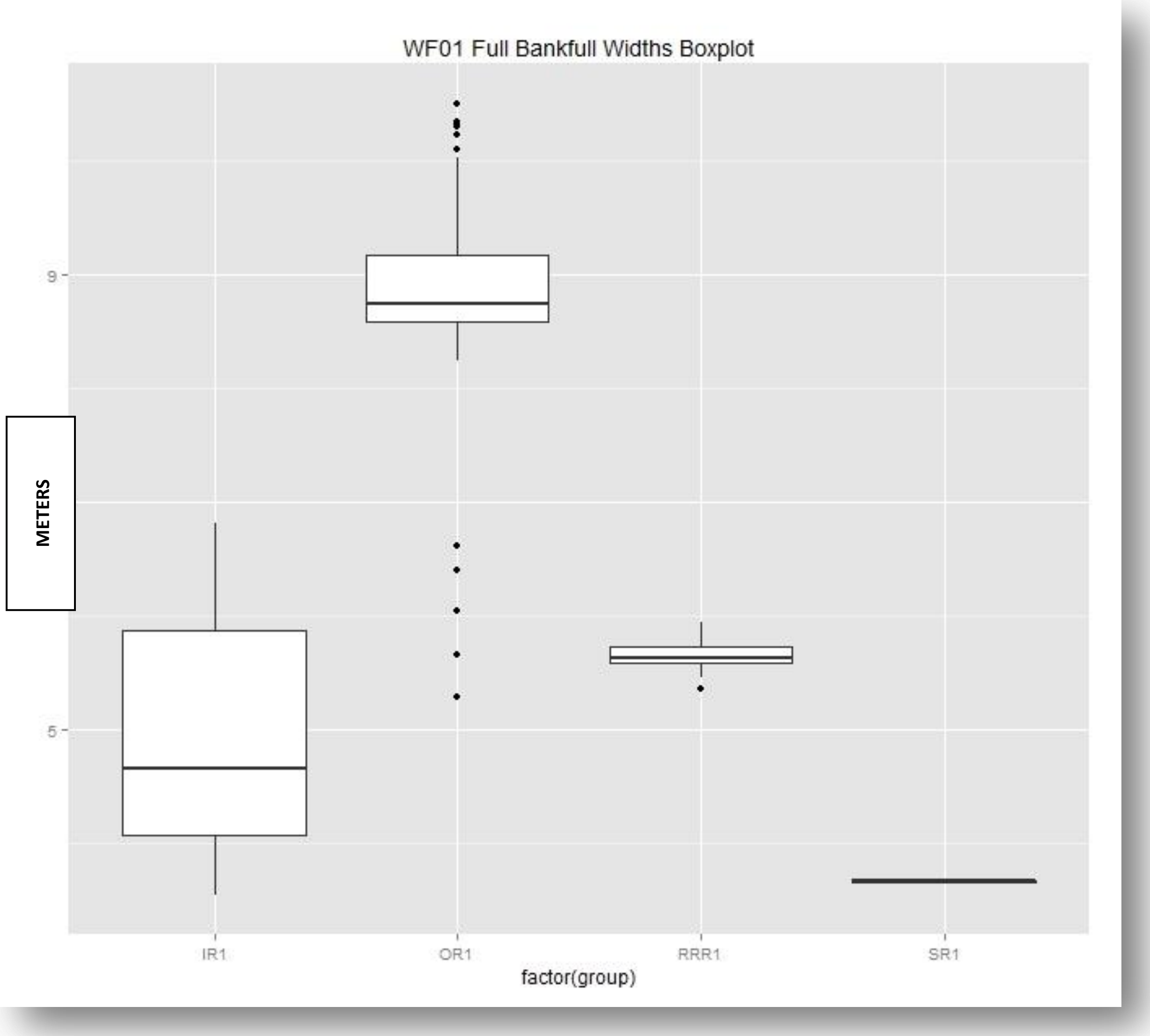


FIGURE 383: WF01 WIDTH AT BANKFULL STAGE; BOXPLOT

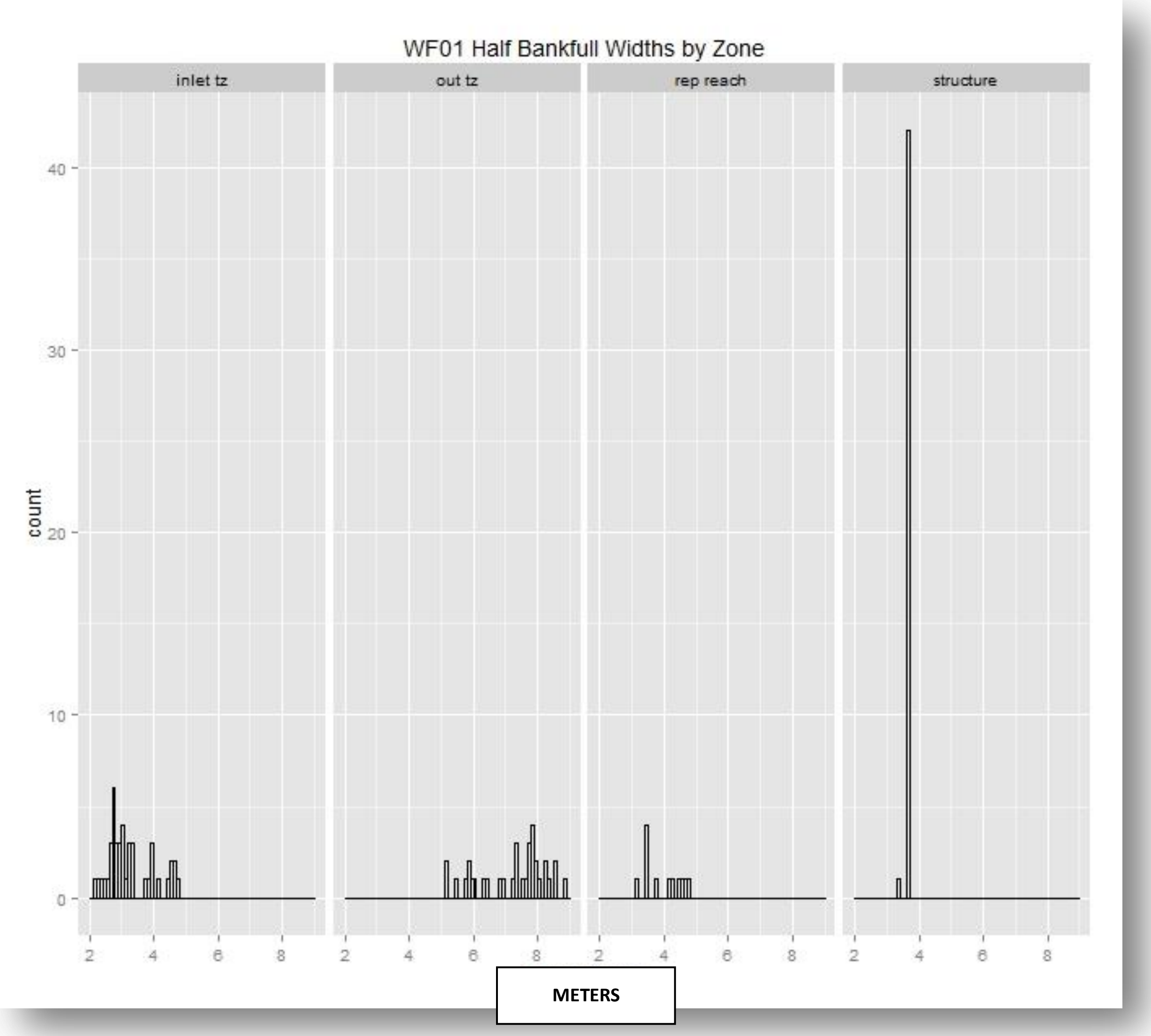


FIGURE 384: WF01WIDTH AT HALF BANKFULL STAGE; HISTOGRAM

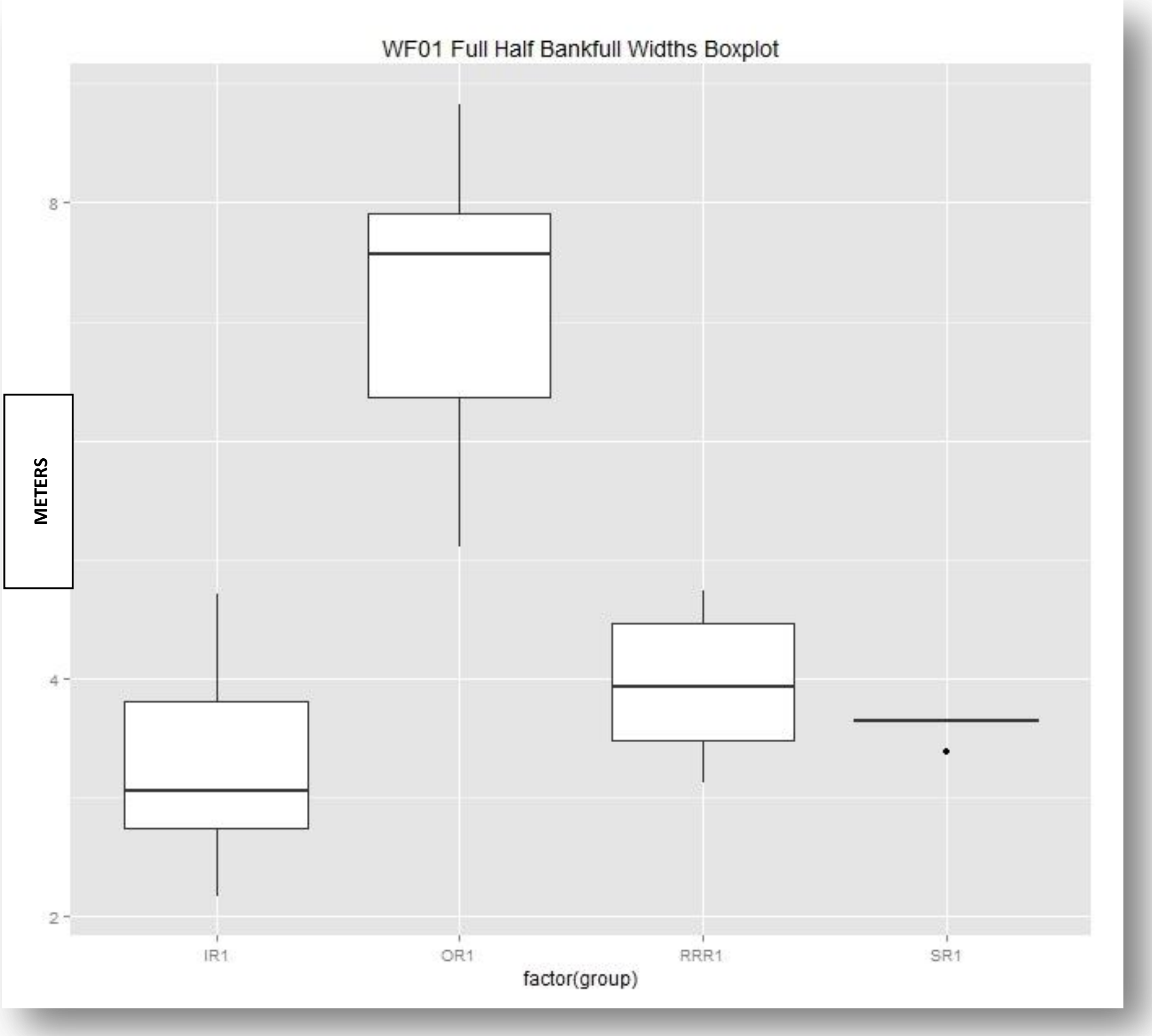


FIGURE 385: WF01 WIDTH AT HALF BANKFULL STAGE; BOXPLOT

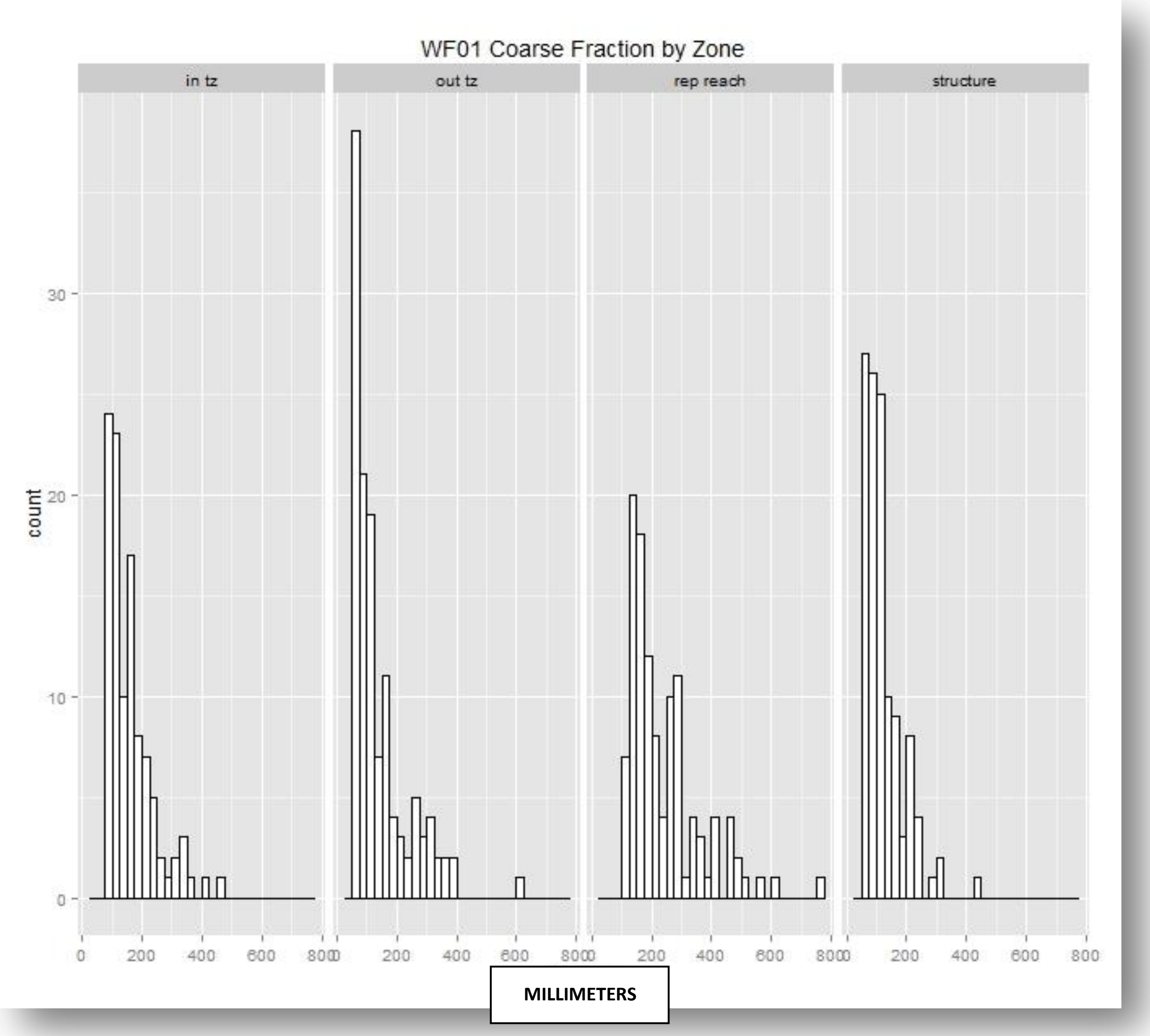


FIGURE 386: WF01 COARSE FRACTION OF THE GRADATION; HISTOGRAM

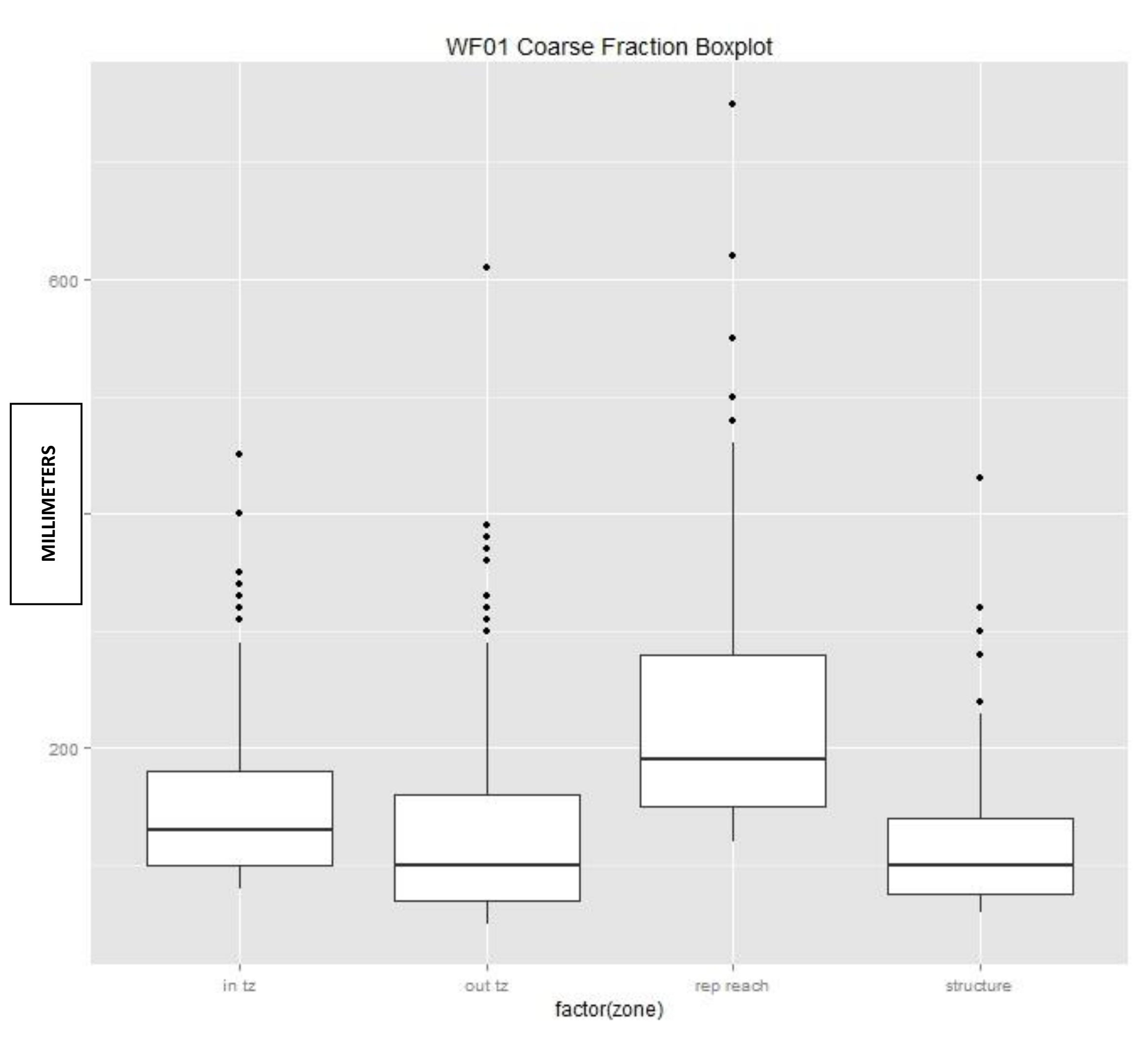


FIGURE 387: WF01 COARSE FRACTION OF THE GRADATION; BOXPLOT

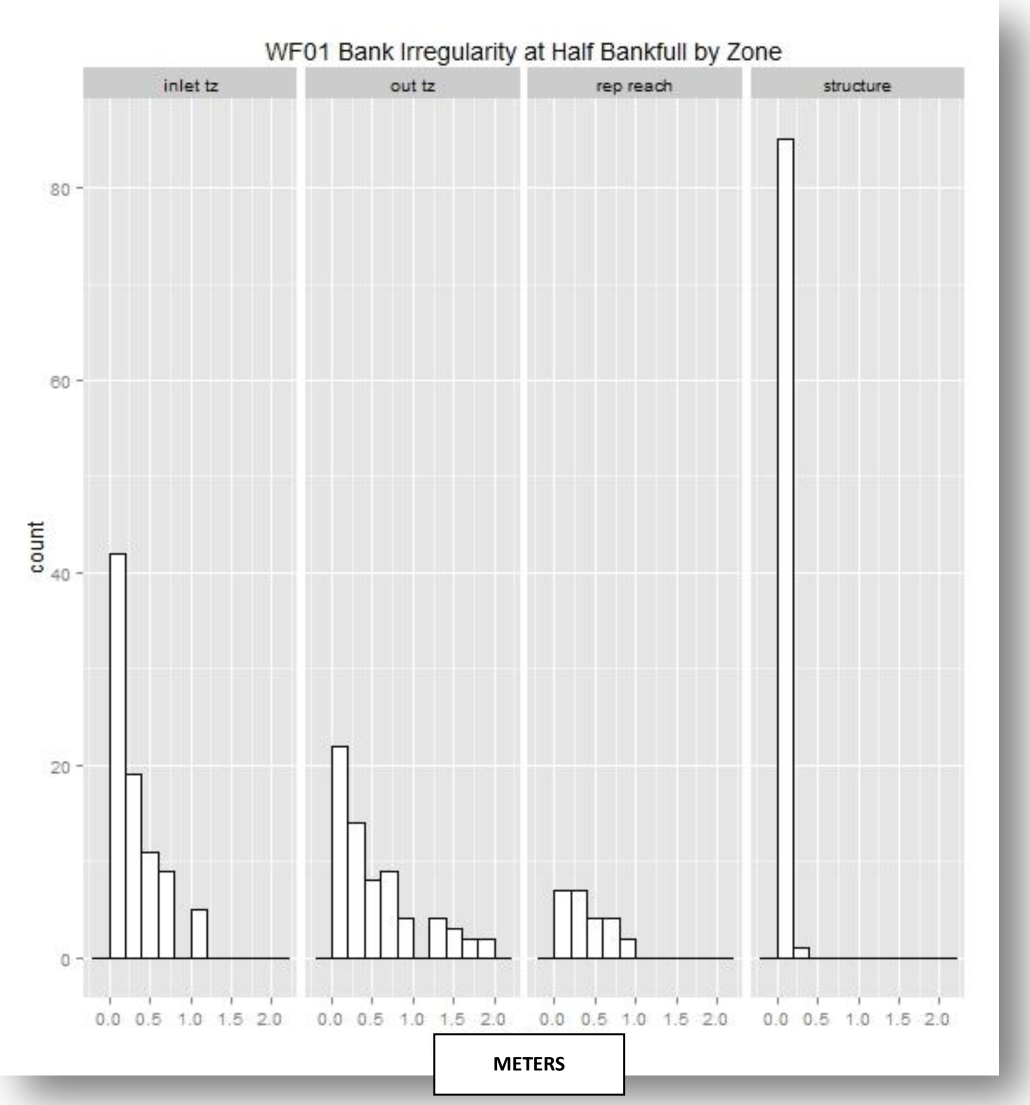


FIGURE 388: WF01 BANK IRREGULARITY; HISTOGRAM

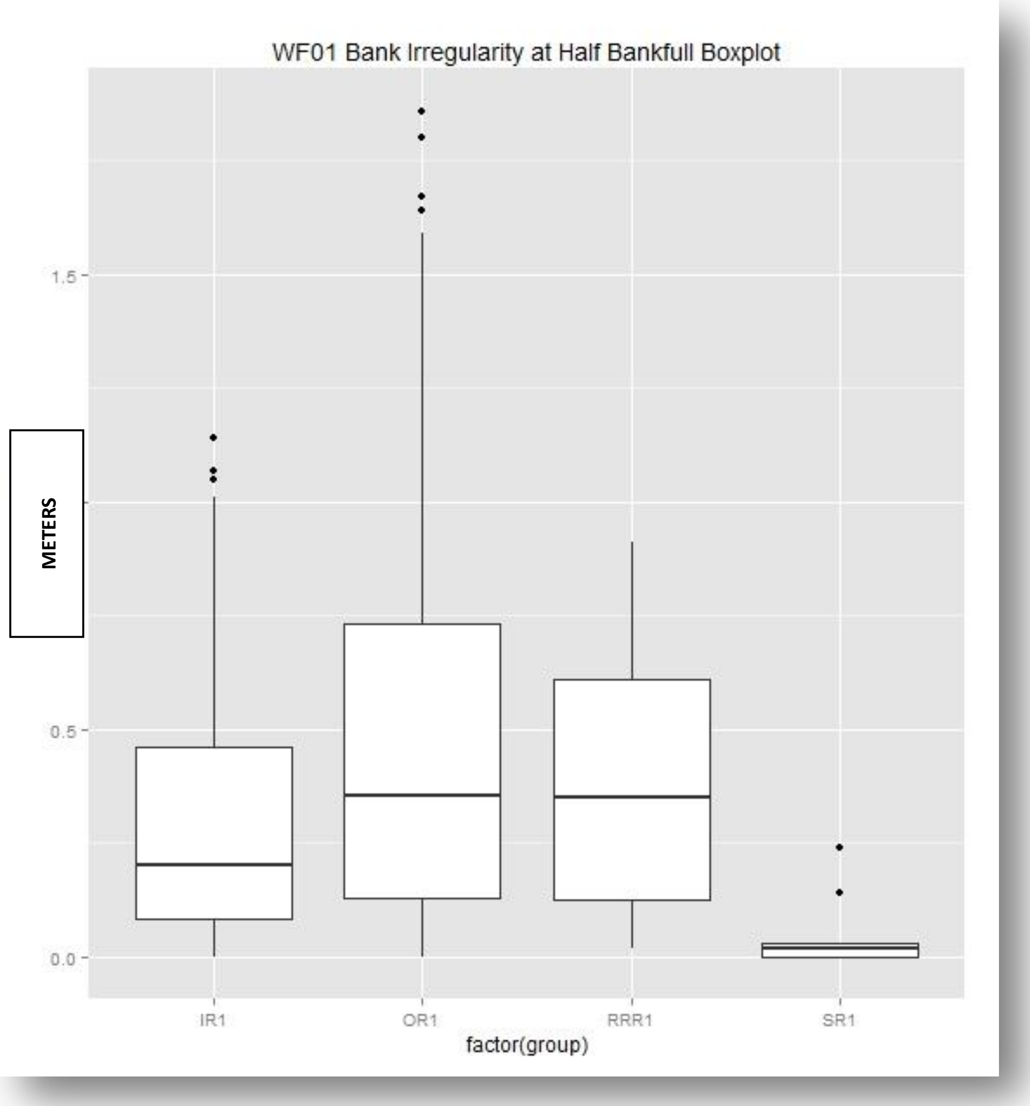


FIGURE 389: WF01 BANK IRREGULARITY; BOXPLOT

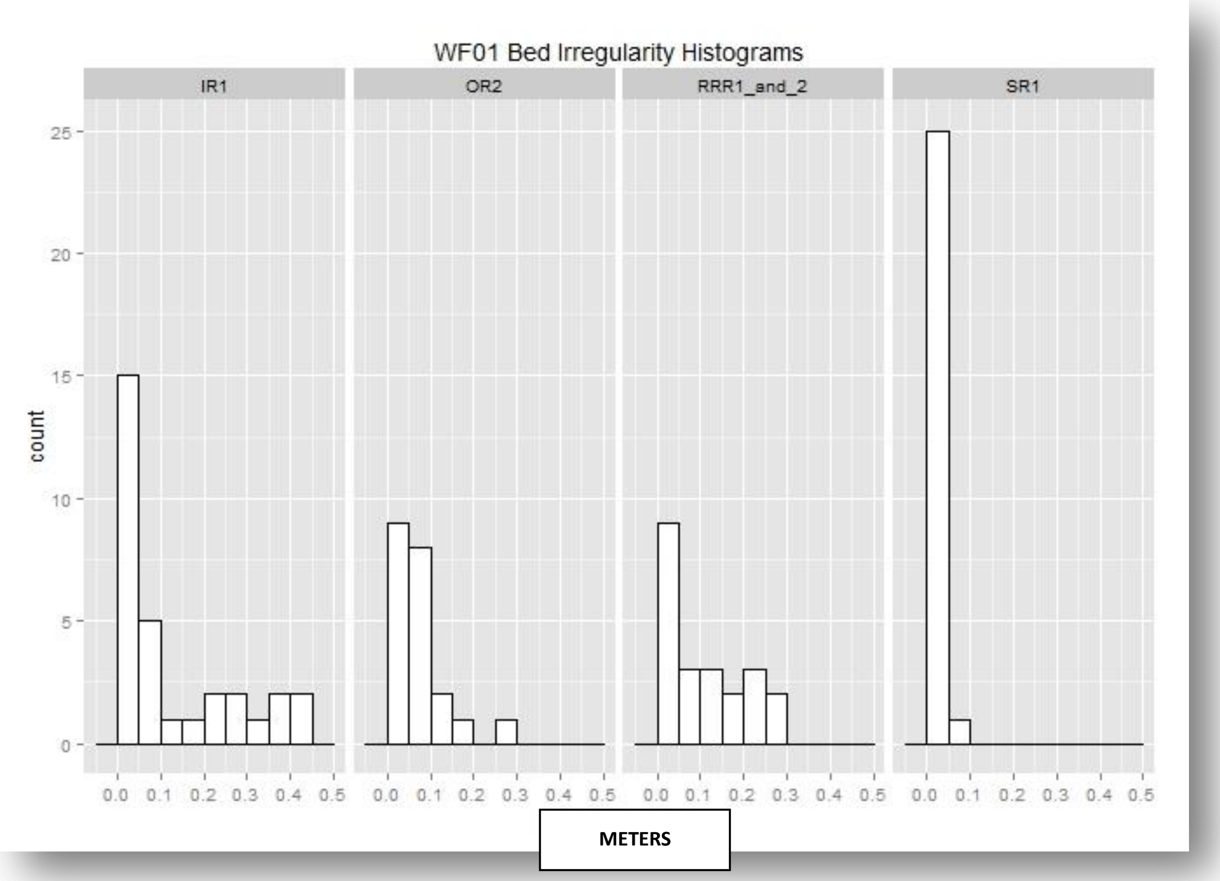


FIGURE 390: WF01 BED IRREGULARITY; HISTOGRAM

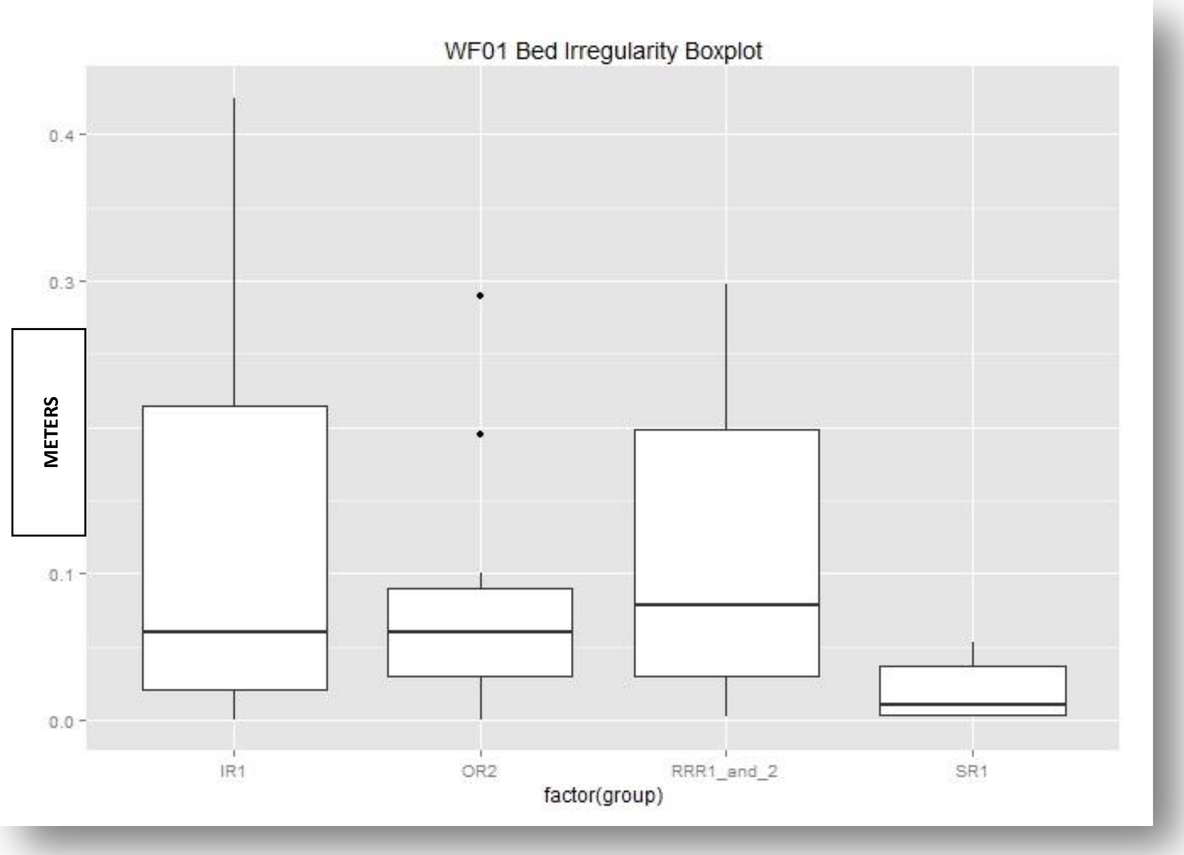


Figure 391: Bed Irregularity; Boxplot

TABLE 102: WF01 LEVEL II SCORING SENSITIVITY ANALYSIS

Channel Unit and Criteria for a Score of 3	Inlet Transition Zone			Structure Zone			Outlet Transition Zone		
	% Score	Evaluation	Override	% Score	Evaluation	Override	% Score	Evaluation	Override
Riffle 1 = 0.01 To 0.05	49	Dissimilar		35	Dissimilar		NA	NA	
Riffle Short 1 = 0.01 To 0.05	52	Questionable		37	Dissimilar		NA	NA	
Riffle 1 = 0.001 To 0.05	57	Questionable		35	Dissimilar		37	Dissimilar	
Riffle 1 = 0.001 To 0.1	69	Questionable		35	Dissimilar		NA	NA	
Riffle 1 = 0.01 To 0.1	43	Dissimilar		35	Dissimilar		NA	NA	
Rifle 2 = 0.001 To 0.05	NA	NA		NA	NA		37	Dissimilar	

A12 WF02 SITE DATA

A12.1 WF02 PHOTOS

FIGURE 392: LOOKING AT THE INLET TRANSITION ZONE FROM THE TOP OF THE WF02 STRUCTURE

FIGURE 393: LOOKING AT THE OUTLET TRANSITION ZONE AND THE COVE RUN/GREENBRIER CONFLUENCE FROM THE TOP OF THE WF02 STRUCTURE

FIGURE 394: LOOKING UPSTREAM AT THE WF02 OUTLET AND THE CONFLUENCE OF COVE RUN AND THE GREENBRIER RIVER

FIGURE 395: LOOKING UPSTREAM WITHIN THE WF02 STRUCTURE

FIGURE 396: LOOKING UPSTREAM AT THE REPRESENTATIVE REACH FOR THE WF01 AND WF02 RIFFLE DESIGNS

A12.2 WF01 and WF02 Representative Reach Analysis

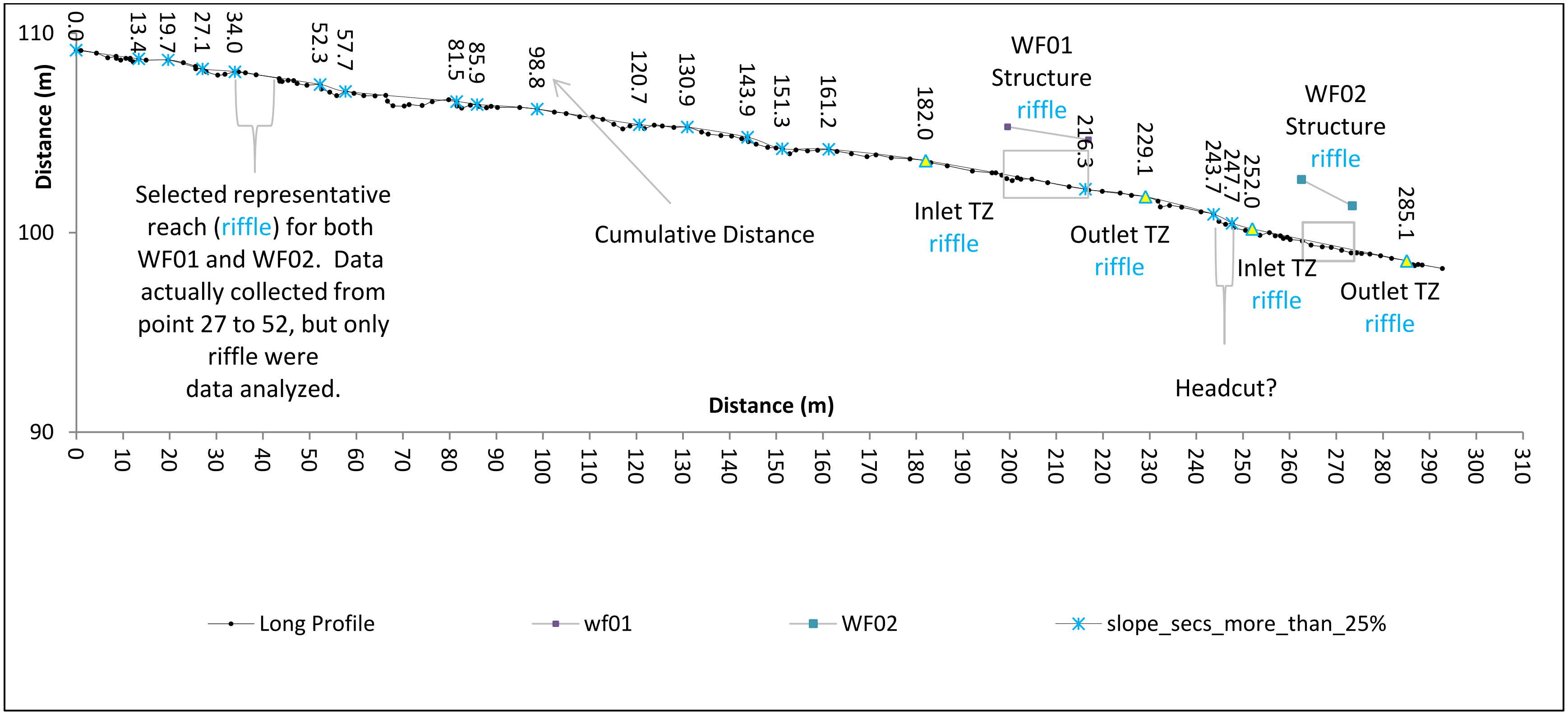


Figure 397: WF01 and WF02 Longitudinal Profile

Figure 397 is shown with 4.5 x vertical exaggeration. Channel units for all design zones (WF01 and WF02) are riffles. The selected representative reach is also a riffle. The slope segments within the WF01 design channel have gradients 4.17% and 2.94%. The WF02 design channel slope segment has gradient 4.84%. The representative reach selected for all design zone slope segments (WF01 and WF02) has gradient 3.51%. The WF01 structure is a pre-fabricated concrete box culvert. It is 17.3 m long, 2.45 m high and has a 3.65 m span. The WF02 structure is a pre-fabricated concrete box culvert. WF02 is 11 m long, 2.5 m high and has a 3.7 m span.

TABLE 103: WF02 DESIGN CHANNEL SLOPE SEGMENT DATA

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	Survey Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Selection Notes
5004.9	5002.7	252.0	100.2	gc 3								
4999.1	4973.5	285.1	98.6	GC1 (SS1), crest of deposit into Greenbrier R (D/S outlet transition)	29.7	1.6	33.1	0.048		50% criteria		

Table 104: WF02 Representative Reach Slope Segment Analysis

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	Survey Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Selection Notes
5024.3	5206.0	0.0	109.2	GC28(SS15 start), ptc								
5034.8	5198.1	13.4	108.7	GC25 (SS15), ptc	13.1	0.4	13.4	0.032		32.9	-15.2	step pool
5039.0	5193.7	19.7	108.7	GC? Break in riffle grade	6.1	0.1	6.3	0.009	-71.7	81.0	46.0	
5040.6	5186.5	27.1	108.2	GC23, rib crest	7.4	0.5	7.4	0.061	564.2	-26.0	36.1	steep riffle
5039.7	5180.1	34.0	108.1	GC22 (SS13), ptc	6.4	0.1	6.9	0.020	-67.5	59.1	40.4	pool; selected in original analysis, though I don't agree with slope segment delineation.

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	Survey Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Selection Notes
5033.4	5164.6	52.3	107.4	GC20 (SS12), top of cascade, step	16.8	0.6	18.2	0.035	77.2	27.5	-57.0	riffle; step pool, riffle; selected in original analysis, though I don't agree with slope segment delineation.
5030.8	5160.0	57.7	107.1	GC19.5, ptc (old road crossing)	5.3	0.3	5.5	0.064	82.2	-32.1	53.1	units are not good; cascade into pool
5026.1	5138.2	81.5	106.6	GC18 (SS10), step crest	22.3	0.5	23.8	0.021	-66.9	56.3	-104.7	riffle, to step pool
5026.7	5133.9	85.9	106.4	GC17, step crest	4.4	0.1	4.4	0.034	58.5	30.7	62.0	step pool, short seg
5027.6	5121.6	98.8	106.2		12.3	0.2	12.8	0.018	-45.3	62.1	-10.5	riffle
5017.3	5103.9	120.7	105.4	GC14, step crest	20.5	0.8	21.9	0.035	92.8	27.0	-88.4	long riffle, into pool
5009.8	5098.8	130.9	105.3	GC13 (SS7), riffle crossover	9.1	0.1	10.3	0.012	-64.7	74.2	11.7	

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	Survey Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Selection Notes
5004.9	5089.2	143.9	104.8	GC12, step crest, top of cascade	10.8	0.5	12.9	0.039	214.1	19.0	-11.3	in field is cross over riffle section, bend, split flow, bar deposit on inner bend; poor match
5009.3	5084.9	151.3	104.2	GC11.5, D/S cascade section	6.1	0.6	7.4	0.078	98.3	-60.6	36.3	
5017.2	5079.4	161.2	104.2	GC10 (SS6), ptc	9.7	0.0	10.0	0.003	-96.3	94.0	14.3	
5024.4	5060.1	182.0	103.6	GC8, slope break (U/S inlet transition)	20.5	0.6	20.8	0.027	846.6	43.5	-78.7	riffle, pool riffle
5027.6	5029.3	216.3	102.2	GC6, slope break, steeper U/S in structure	31.0	1.4	34.3	0.042	52.6	13.7	-194.8	is reach within WF01 structure; long rifle, bend scour pool, riffle

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	Survey Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn success-ive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Selection Notes
5020.2	5019.2	229.1	101.8	GC5 (SS4), step crest, DS outlet transition	12.5	0.4	12.8	0.029	-29.6	39.2	-10.3	is outlet trans of wf01
5010.8	5008.3	243.7	100.9	GC4 (SS3), step crest	14.3	0.9	14.6	0.060	105.3	-24.7	-25.8	is between structures; step pool riffle
5008.1	5005.6	247.7	100.5	GC3.5, step crest, bldr-cobble	3.9	0.4	4.0	0.113	87.6	-134.0	65.9	
5004.9	5002.7	252.0	100.2	gc 3	4.3	0.3	4.3	0.066	-41.8	-36.1	63.1	forced gc, is top of inlet trans
4999.1	4973.5	285.1	98.6	GC1 (SS1), crest of deposit into Greenbrier R (D/S outlet transition)	29.7	1.6	33.1	0.048	-26.5	0.0	-184.7	is outlet trans of wf02; riffle

A12.3 WF02 Data-by-Distance Plots

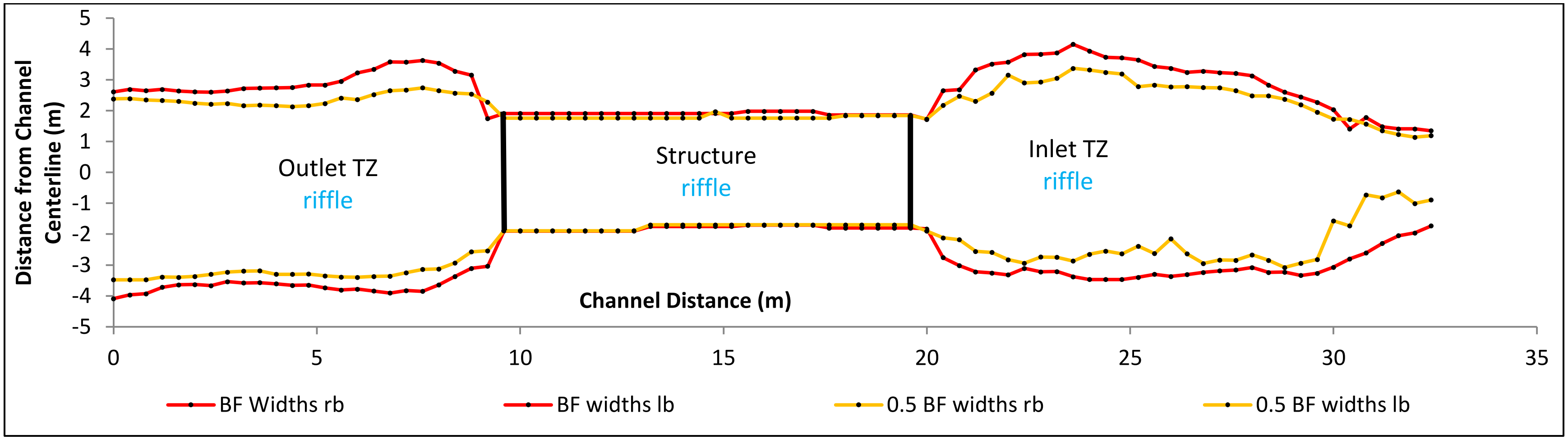


Figure 398: WF02 Design Widths

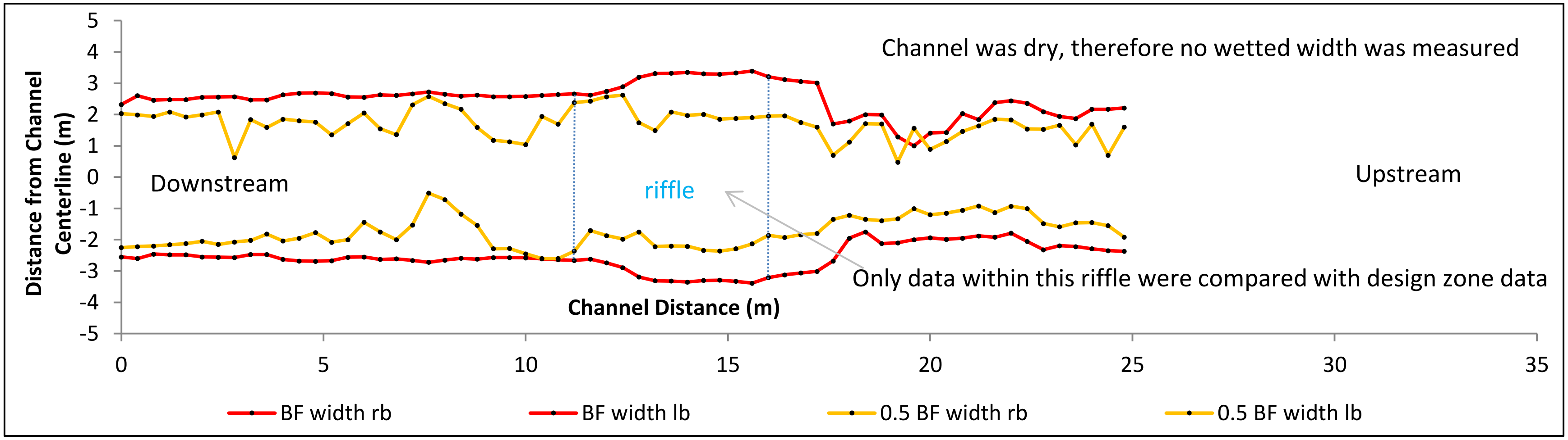


Figure 399: WF01 and WF02 Representative Reach Widths

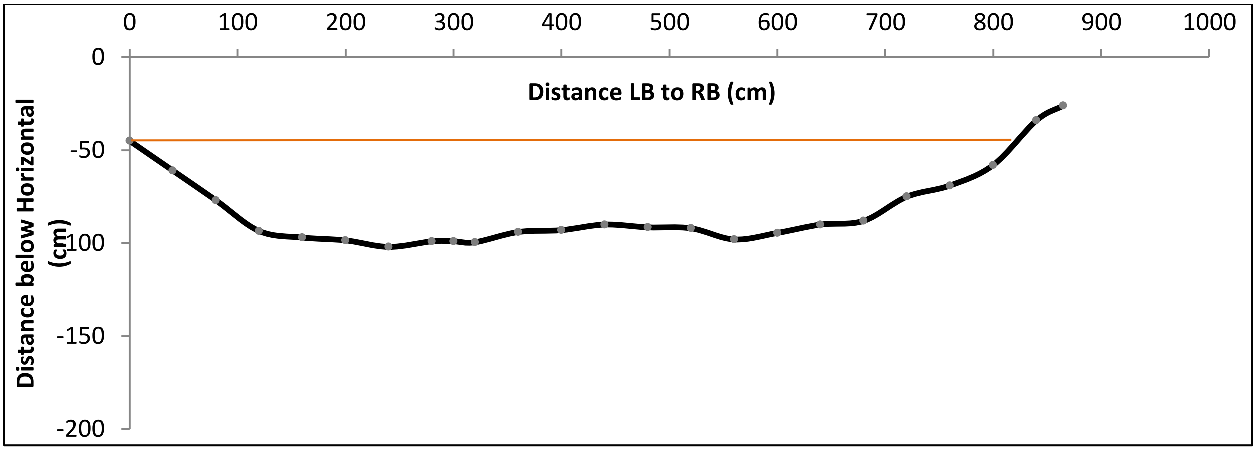


FIGURE 400: **WF02 CROSS SECTION 1; OUTLET TRANSITION ZONE; RIFFLE**

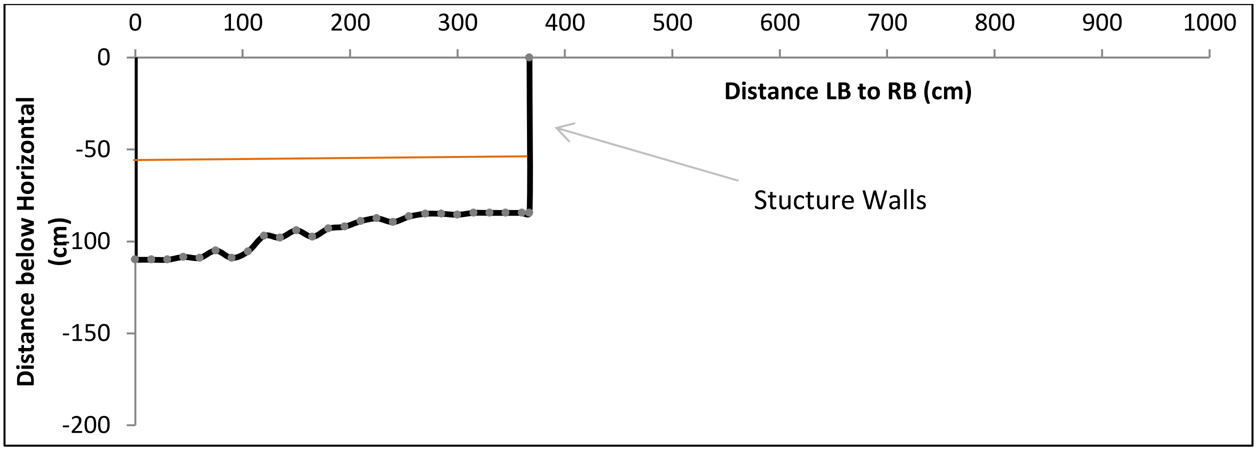


FIGURE 401: **WF02 CROSS SECTION 2; WITHIN THE STRUCTURE; RIFFLE**

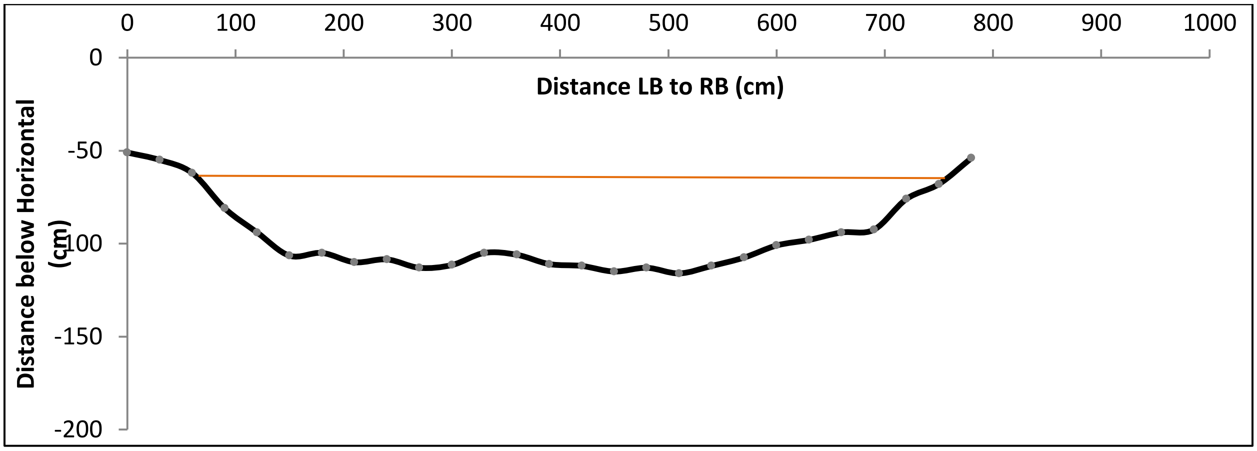


FIGURE 402: **WF02 CROSS SECTION 3A; INLET TRANSITION ZONE; RIFFLE**

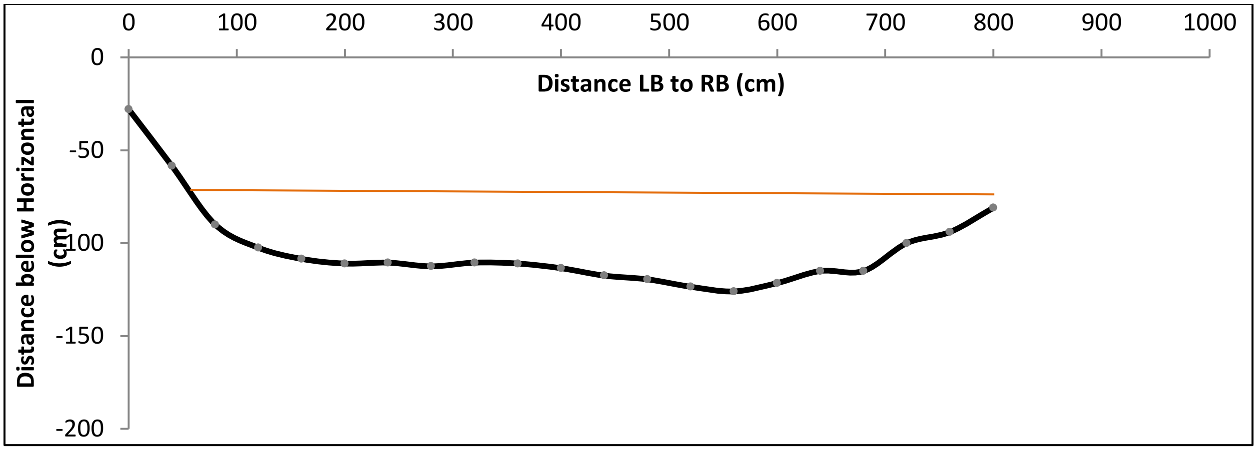


Figure 403: WF02 Cross Section 3b: Inlet Transition Zone; Riffle

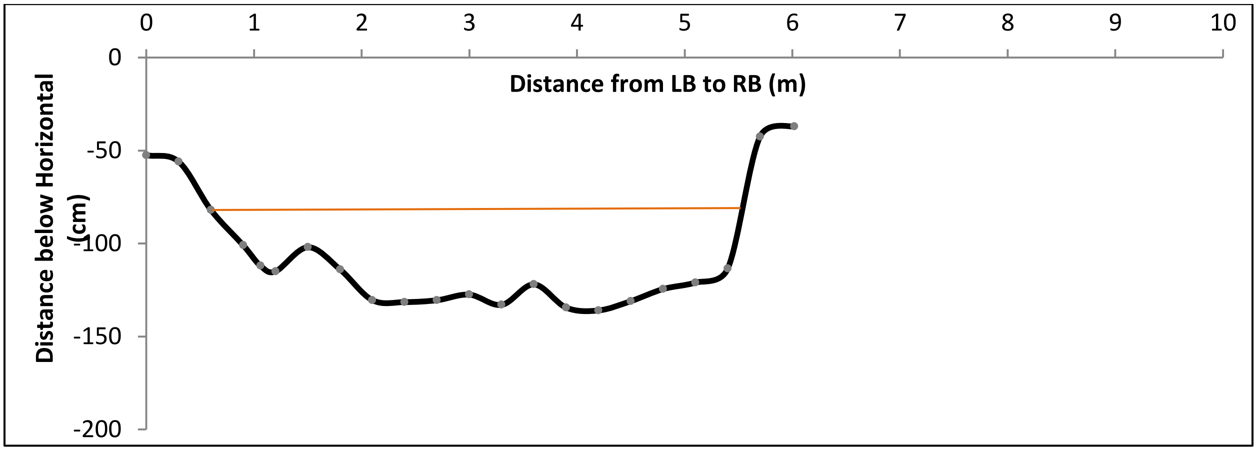


Figure 404: WF02 Cross Section 7; Representative Reach; Data not Used (not within riffle)

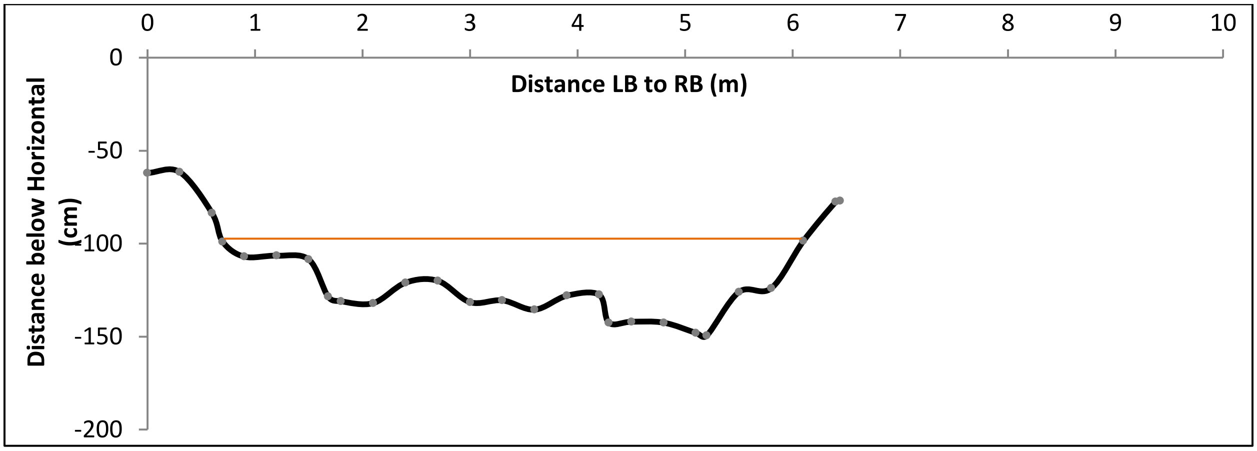


Figure 405: WF02 Cross Section 8; Representative Reach; Riffle

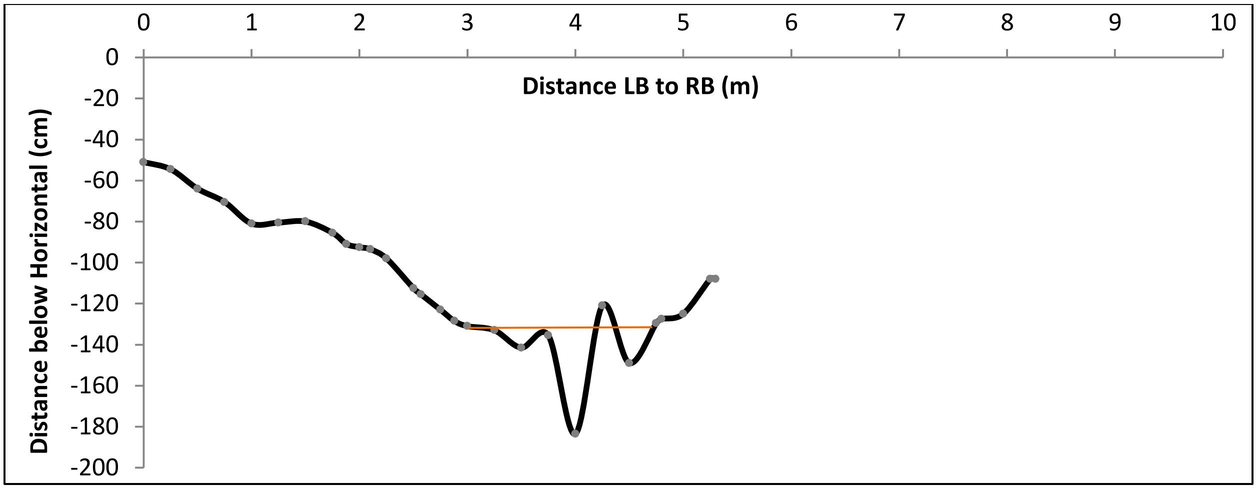


FIGURE 406: WF02 CROSS SECTION 9; REPRESENTATIVE REACH; POOL (DATA NOT USED)

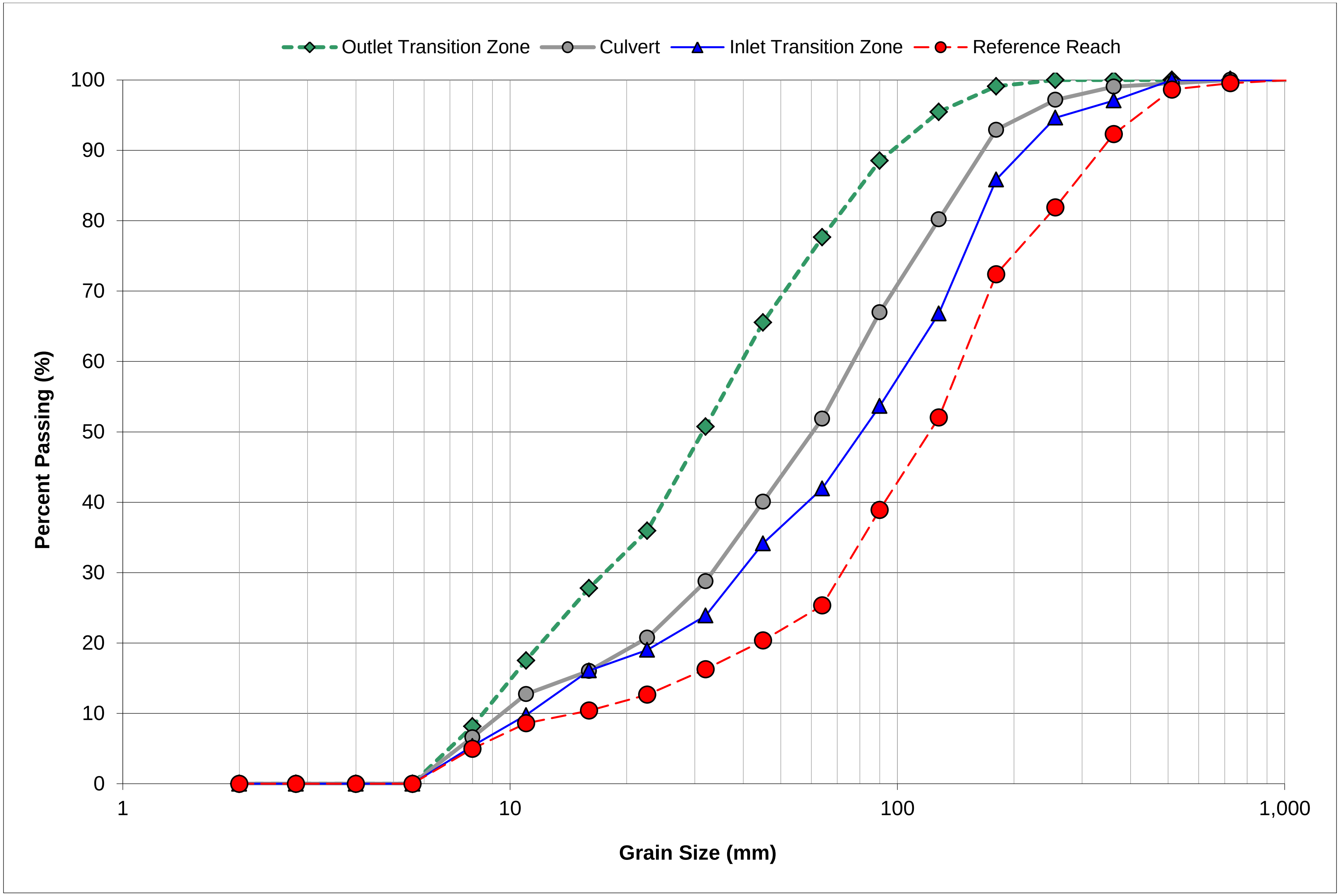


FIGURE 407: WF02 GRADATION

A12.4 WF02 BOXPLOTS AND HISTOGRAMS

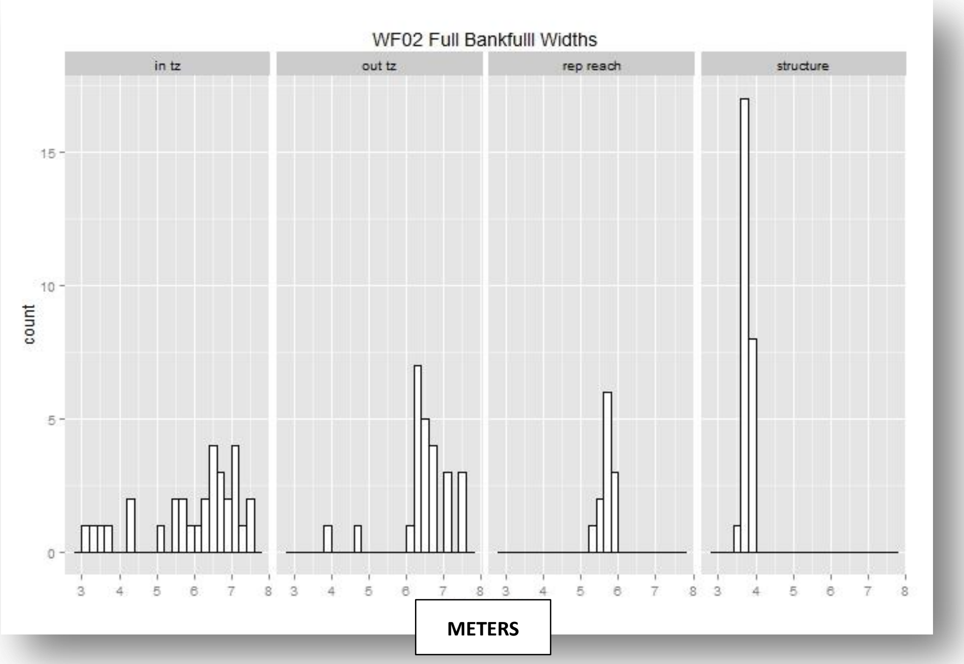


FIGURE 408: WF02 WIDTH AT BANKFULL STAGE; HISTOGRAM

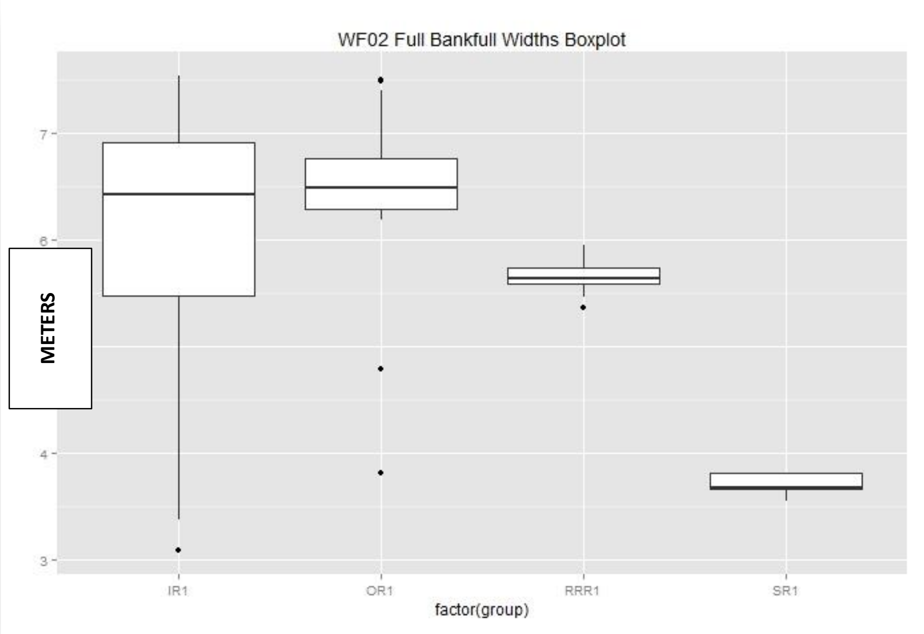


FIGURE 409: WF02 WIDTH AT BANKFULL STAGE; BOXPLOT

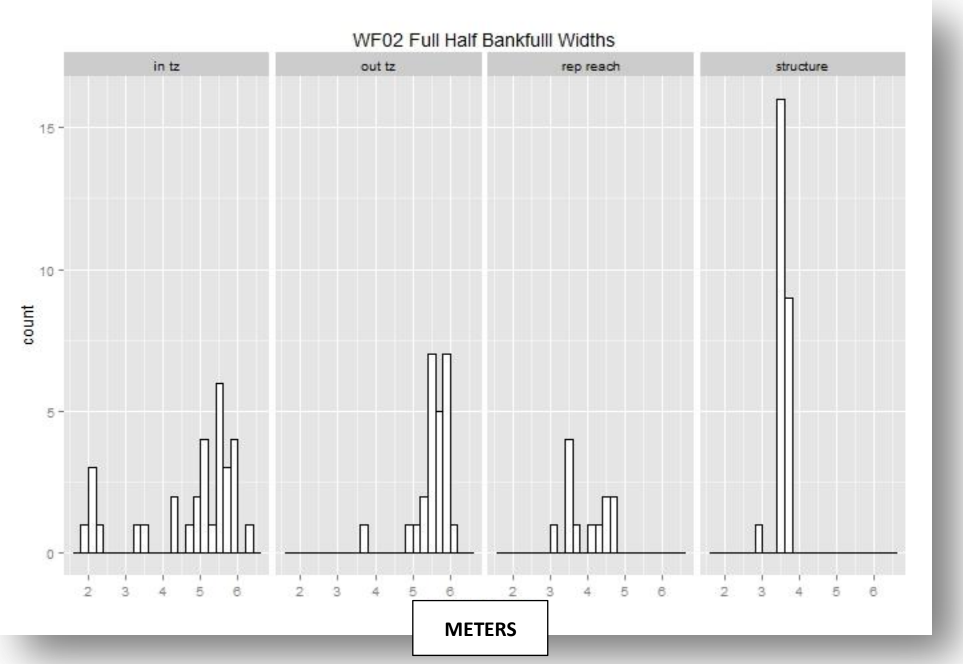


FIGURE 410: WF02 WIDTH AT HALF BANKFULL STAGE; HISTOGRAM

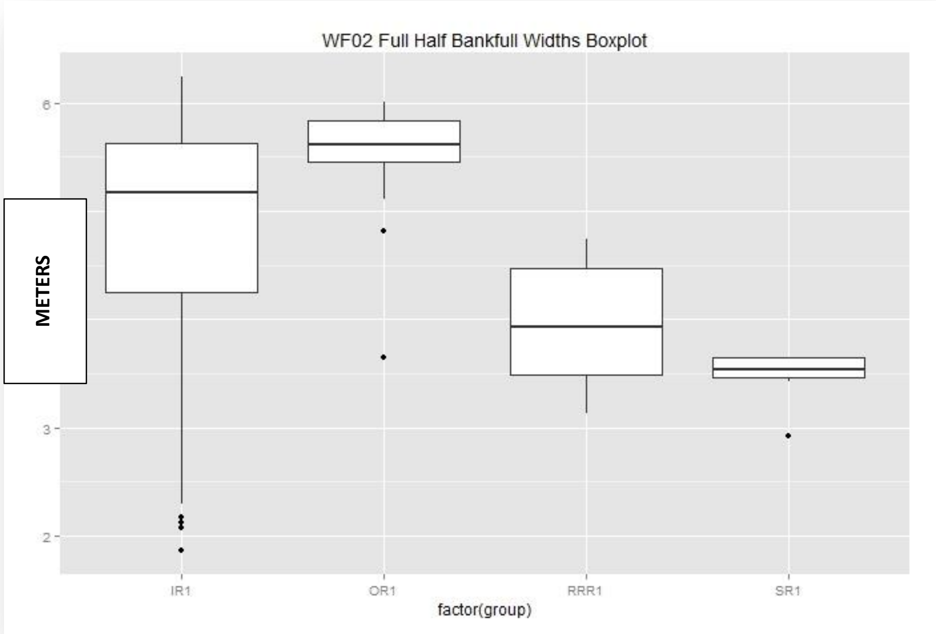


FIGURE 411: WF02 WIDTH AT HALF BANKFULL STAGE; BOXPLOT

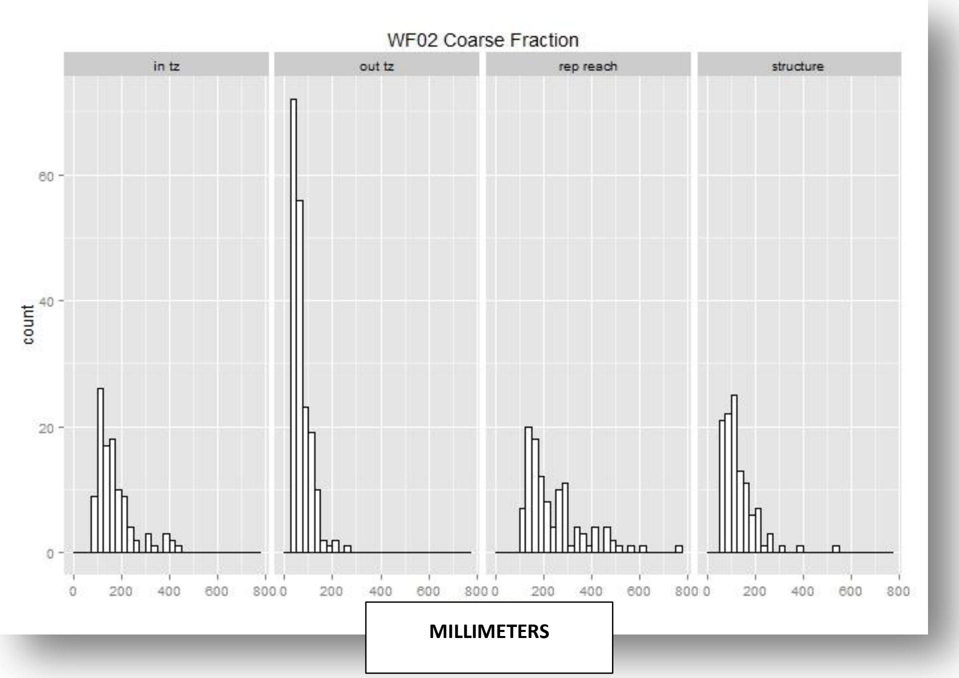


FIGURE 412: WF02 COARSE FRACTION; HISTOGRAM

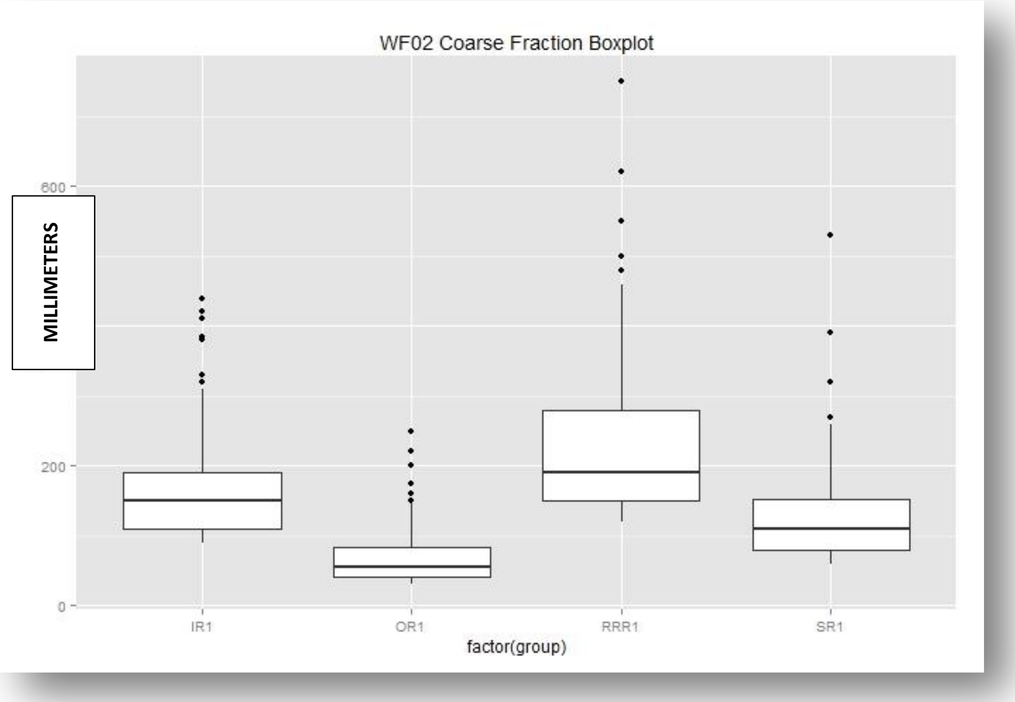


FIGURE 413: WF02 COARSE FRACTION; BOXPLOT

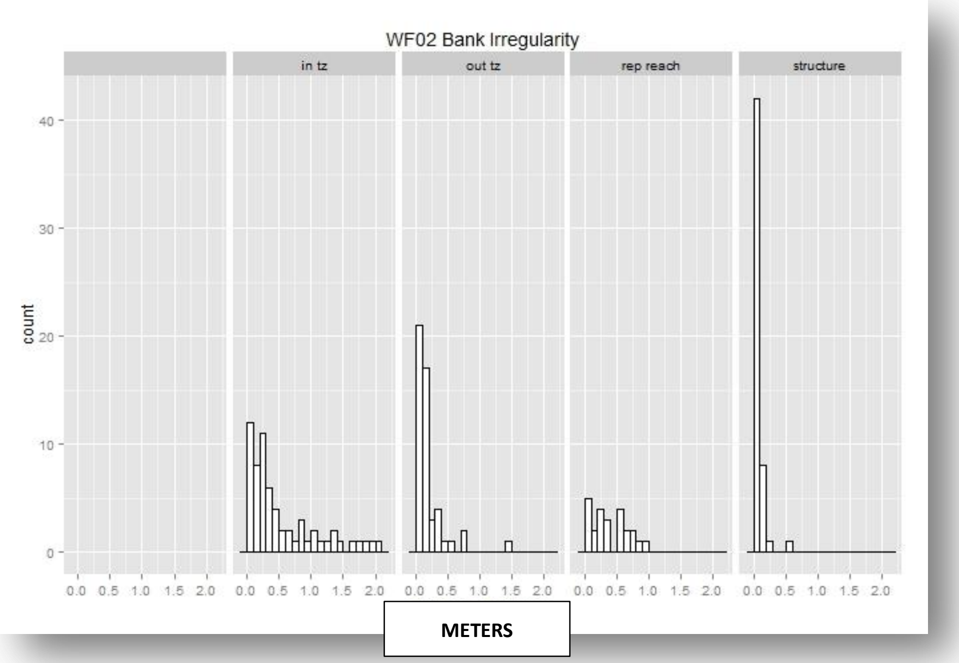


FIGURE 414: WF02 BANK IRREGULARITY; HISTOGRAM

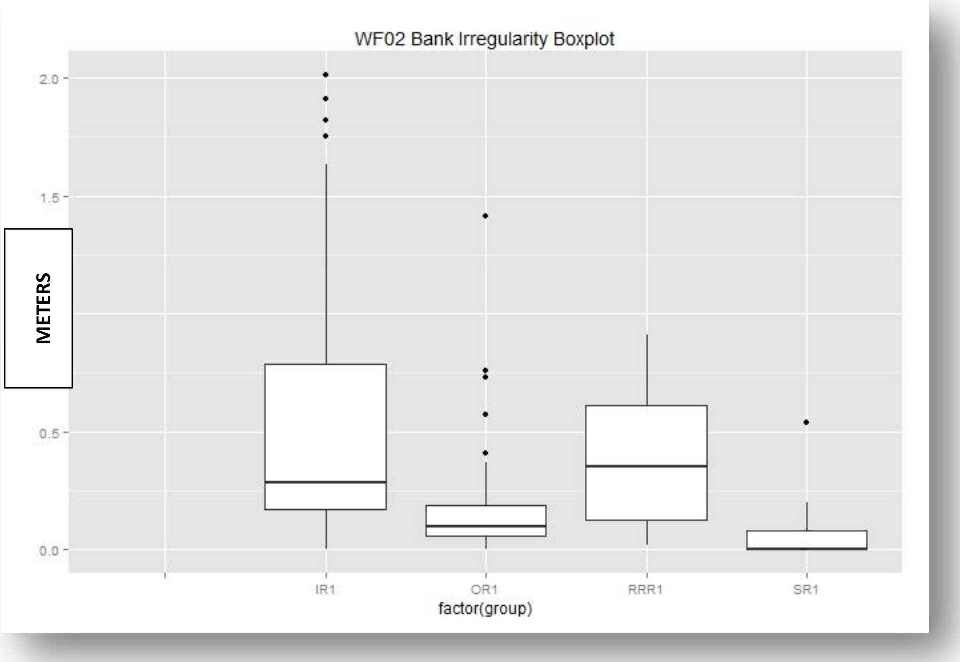


FIGURE 415: WF02 BANK IRREGULARITY; BOXPLOT

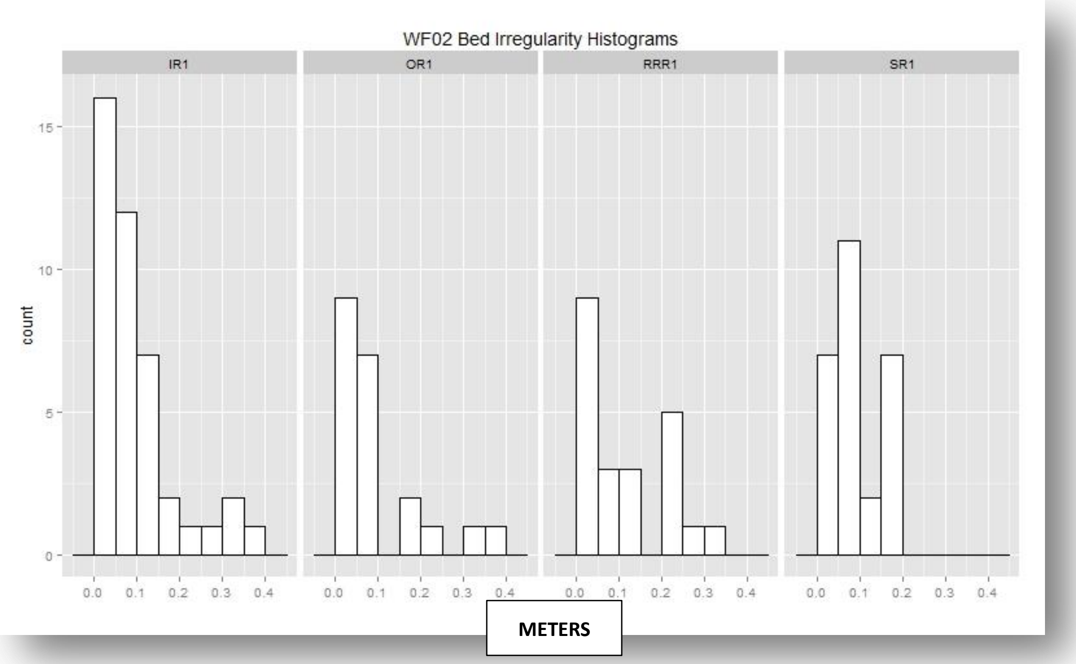


FIGURE 416: WF02 BED IRREGULARITY; HISTOGRAM

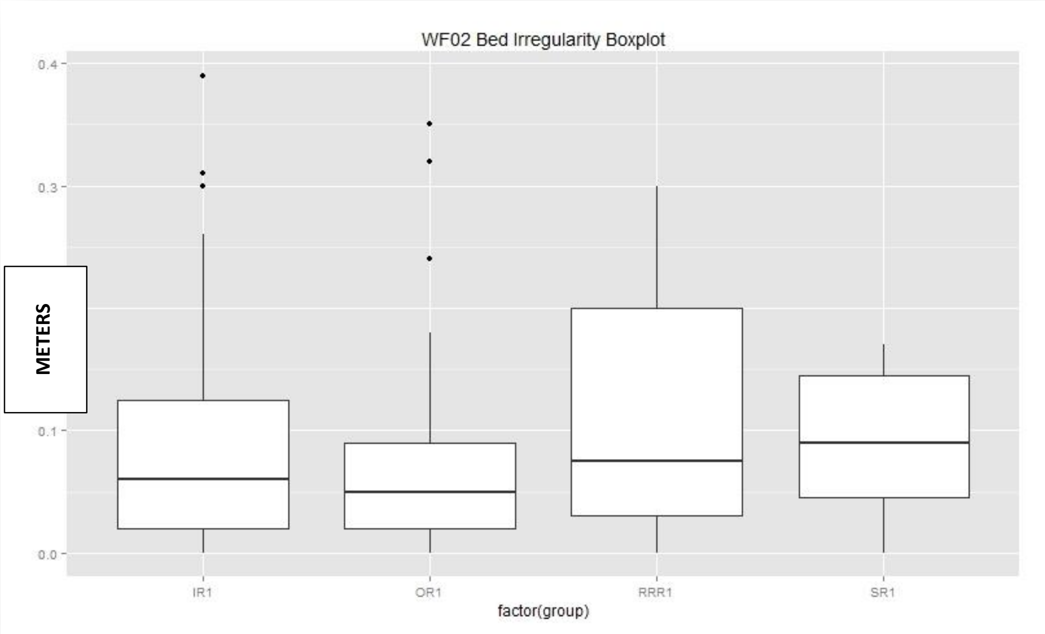


FIGURE 417: WF02 BED IRREGULARITY; BOXPLOT

A12.5 WF02 SCORING SENSITIVITY ANALYSIS

TABLE 105: WF02 LEVEL II SCORING SENSITIVITY ANALYSIS

Channel Unit and Criteria for a Score of 3	Inlet Transition Zone			Structure Zone			Outlet Transition Zone		
	% Score	Evaluation	Over-ride	% Score	Evaluation	Over-ride	% Score	Evaluation	Override
Riffles 0.01 to 0.05	49	Dissimilar		33	Dissimilar		26	Dissimilar	
Riffles 0.01 to 0.05 short	45	Dissimilar		28	Dissimilar		20	Dissimilar	
Riffles 0.01 to 0.1	49	Dissimilar		33	Dissimilar		26	Dissimilar	
Riffles 0.001 to 0.05	57	Questionable		33	Dissimilar		31	Dissimilar	
Riffles 0.001 to 0.1	57	Questionable		33	Dissimilar		31	Dissimilar	

B LEVEL II 2013 FIELD PROTOCOL

The level II physical effectiveness monitoring protocol compares physical channel dimensions between the design channel and the natural channel. Specifically, three zones compose the design channel: the inlet transition zone, the structure, and the outlet transition zone. The channel characteristics of each design zone are compared with the channel characteristics of a representative reach (also a zone) within the natural channel. Data are always compared between a design zone and a representative reach. Design zones are never compared with one another.

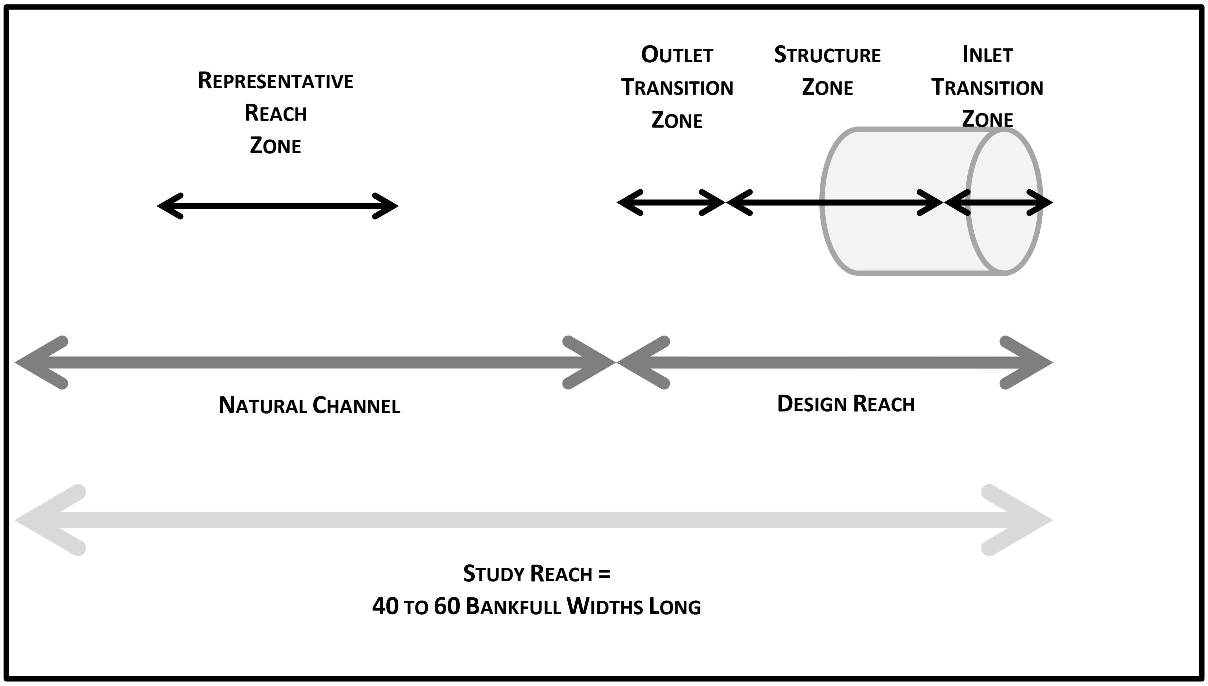


FIGURE 418: SITE ANATOMY

Field Protocol

1. The **site name and location are documented**. Sites are typically named for a combination of descriptive factors: National Forest, water body, road, and mile post number. Where possible, use names consistent with other records.

2. The **type of structure and its dimensions** (length, span, and height) are recorded. Height can be either measured from the streambed to the top of the structure, or the top of the support footers to the top of the structure, depending on the structure type. Note which height measurements are taken. **Observations** about the condition of the structure (e.g., rusting) are also described.

3. The level II monitoring protocol is determined **applicable** when a **decision tree** is successfully navigated (i.e., all answers are "Yes"):

   - Is there substrate within the structure?
   - Is the structure at least as wide as ¾ the bankfull width?
   - Is there reason to believe the site has experienced sufficiently high flows for adjustment?
   - Are the channel units in the design channel present and similar in dimensions to those in the adjacent natural channel?

       ◊ When any of the answers to the above questions are "No," the level II monitoring protocol is terminated. Either qualitatively monitoring the site, or returning to the site after sufficiently high flows have occurred will be more appropriate.

4. **Bankfull channel width** is determined within the natural channel using geomorphic and biologic indicators. Bankfull stage indicators can be: the edge of the active floodplain, highest active depositional feature, breaks in slope on the banks, changes in particle size (finer), changes in vegetation type (moss to lichen, etc.), and stain lines (see Harrelson et al., 1994 and http://www.stream.fs.fed.us/publications/videos.html).

   - Within the natural channel, bankfull width should be measured at locations where discharge and sediment supply are the same as those which pass through the structure (i.e., measurements are taken downstream of tributary confluences and large sediment sources).
   - The distance between the two banks at the bankfull stage is most easily measured with a stadia rod fit with a bubble level. The stadia rod is placed horizontally with one end level with the bankfull indicator, the other end is held level by reading the bubble taped to the rod. Bankfull should be measured within several different channel unit types; the median value will be used.

5. The water surface serves as a reference point from which the bankfull elevation can be identified within the design channel (where indicators are usually absent). The **distance from the water surface to bankfull stage** is measured within the natural channel, generally at the same locations where bankfull widths are measured. Several measurements should be collected within different channel units and the median value calculated.
   - This measurement is most easily taken with a stadia rod fit with a bubble level and a pocket rod or measuring tape. The stadia rod is placed horizontally with one end at the bankfull indicator; the other end is held level by reading the bubble taped to the rod. While level, the distance between the rod and the water surface is measured with the plumb pocket rod or measuring tape.

6. The **study reach is then measured and marked**. In general, it should extend 20-30 bankfull channel widths upstream and 20-30 bankfull channel widths downstream from the structure's inlet and outlet. By starting at the structure inlet, 20 m segments are measured with a cloth tape and marked with flagging until the 20-30 bankfull channel widths limit is reached in the upstream direction. Place the upstream study reach boundary at a *grade control* (see below). The same technique and terminus are repeated in the downstream direction.
   - The study reach is truncated at tributary confluences and large sediment sources. If truncated very close to the structure, it may need to be extended in the opposite direction beyond the 20 to 30 bankfull channel widths so as to maintain a total length of 40 to 60

bankfull channel widths. Doing so offers more natural channel (with consistent discharge and sediment supply) from which to select a representative reach.

7. Within the study reach **grade controls and slope segments are delineated** with consecutively numbered flags. It is easiest to see grade controls and slope segments when walking the study reach from downstream to upstream.

    - Grade controls are key structural features which control the channel gradient. They may be step crests, pool-tail crests/riffle crests, transverse ribs within riffles, bedrock outcrops, embedded large woody debris, and beaver dams. Grade controls are identified in the channel with consecutively numbered flags hung on vegetation.

    - A slope segment is a section of channel with a fairly uniform gradient. Slope segments are typically identified at the channel unit sequence scale (i.e., a slope segment may be a pool and riffle, or pool, riffle, pool, and riffle). Slope segments may however be composed of a single channel unit (e.g., riffle). Slope segment boundaries are marked with flags, hung on vegetation at grade controls.

    - The slope segment(s) within the *design channel* are particularly important. They may extend beyond the structure, inlet and outlet transition zone boundaries. Where possible, the inlet and outlet transition zone boundaries are placed coincident with slope segment boundaries (see below). The structure boundaries may not be coincident with slope segment boundaries.

    - When analyzing the surveyed longitudinal profile (see Appendix B3) slope segments are quantitatively assessed (boundaries may be adjusted) to ensure that adjacent slope segments are at least 25% different in gradient. It is helpful to keep this in mind when delineating the slope segments in the field.

8. The design channel is bounded by the outlet transition zone and inlet transition zone boundaries. These limits should be placed within three bankfull channel widths upstream of the inlet and downstream of the outlet, but the actual position will vary depending on site conditions. The minimum length is one bankfull width from the structure. **Place the transition zone boundaries** by evaluating the greatest of the following criteria:

    - The maximum extent of disturbance from the previously replaced culvert,
    - The maximum extent of the existing structure's hydraulic influence during flood conditions (backwater at the inlet or scour at the outlet), or
    - The maximum extent of construction disturbance.

        ◊ If a slope segment (grade control) boundary exists within one bankfull width from the maximum criterion, place the transition zone boundary at that grade control. If no grade control is present, place the boundary at the limit of disturbance/influence.

9. For each *zone* (inlet transition, structure, and outlet transition) and each *slope segment* within the design channel **determine the unique channel units/sequences to be analyzed.** Here, "unique" means each channel unit/sequence belongs to a single zone and slope segment combination. **Measure the length of each channel unit and channel unit sequence to be analyzed.**

- It is important to remember that comparisons are made between design and natural channel units (or sequences) of similar type and gradient, *per zone*. Therefore, design zone boundaries can affect how channel units are analyzed:
    - ◊ Where riffles extend beyond structure boundaries, any portion (inside or outside the structure) of the riffle less than one bankfull channel width in length is not analyzed.
    - ◊ Where pools extend beyond structure boundaries, they may not be analyzed. If less than half the length of the pool extends beyond a design zone boundary, the pool may be analyzed as if it were entirely within a single zone.
- Channel units (riffle, pool, and step) are defined according to the following rules:
    - ◊ Riffles and pools less than one bankfull channel width in length are not considered independent units.
    - ◊ Where: the length of a pool is not greater than its width, its length is less than bankfull channel width, and/or its maximum depth does not exceed 1.5 times the depth at the pool tail crest; the pool is not considered an independent unit. It is then analyzed as part of the surrounding riffle unit.
    - ◊ Steps not followed by a scour pool are not considered steps, but instead are prominent ribs within a steep riffle (cascade).
- Where possible, data at pool and riffle channel units are collected and analyzed by channel unit sequence (e.g., pool, riffle). Analyzed sequences must be composed of valid channel units located entirely within a single slope segment and zone.
    - ◊ Where multiples of the same channel unit/sequence exist within a single slope segment and zone (e.g., riffle, pool, riffle, pool), data are collected per the minimum repeating sequence (e.g., riffle, pool). Data from each repeating sequence (per slope segment and zone) are then combined to be analyzed together (sample size becomes beneficially larger).
    - ◊ Data at step-pool sequences are collected by step-pool pairs. Only the tallest step, per zone and slope segment is measured.

10. A **longitudinal profile for the entire study reach is surveyed** with a Total Station, data logger, prism and survey rod. See the longitudinal profile survey and analysis (Appendix B3). The purpose of the longitudinal profile is to identify a slope segment or several slope segments within the natural channel (**representative reach**) to which the design channel slope segments may be compared.

11. At each unique channel unit or sequence, **channel metrics** (measurements) are collected according to channel unit type. For each metric the zone, channel unit/sequence type and slope segment are noted.

    - Detailed **channel width measurements are recorded at three elevations**: bankfull stage, half bankfull stage, and wetted width (low flow). Measurements are taken from the channel center line to the right and left banks at each elevation. The width measurements (as described here) are collected only within riffle and pool channel units.

        - ◊ For every elevation, where large boulders or wood interrupt the measurement, the obstruction width is also tracked separately. For example, a measurement from the centerline to the right bank might read: centerline to rock = 1.2, rock to rock = 0.75, rock to bank = 1.7. In other words, a fish swimming past this channel location would have 2.9 m of swimmable channel, but must avoid the 0.75 meter rock.

- ◊ The longitudinal interval between measurements must provide a minimum of 20 measurement stations in the shortest of either the structure or representative reach, with a minimum 30 cm between measurements. The maximum longitudinal interval distance should be limited to 20% of the bankfull width. This same interval is then used for width measurements in all zones.

- ◊ Measurements are collected by stretching measuring tapes between rebar stakes inserted along the channel centerline for the entirety of each zone. A tape is pinned (using an alligator clip) to each rebar at bankfull and half bankfull stages, so that it approximately parallels the water surface (see Figure 420). To do this, it is important to place stakes at major breaks in slope, such as riffle rib crests.

- ◊ A width measurement is taken at a station by leveling the survey rod, or pocket rod, at the elevation of the bankfull or half bankfull tape. The rod is extended until it touches the bank and the measurement is recorded (see Figure 421). Alternatively, a laser level can be positioned at the centerline tape. After ensuring the instrument is level, a laser is reflected off the channel bank, indicating the distance (see Figure 422 and Figure 428). The laser distance meter is likely much faster and less cumbersome than the leveled rod technique, but probably less accurate when bank vegetation is thick. The wetted width is most easily measured with a plastic rolled measuring tape held across the channel, parallel to the water surface.

- **Maximum depth** measurements are recorded for every station at which width measurements were collected (make sure the rebar and tapes are left in place until the depth measurements are complete). Depth is measured with a plumb stadia rod. Maximum depth measurements are collected only within pools and riffles; the metric is not applicable to step channel units.

- **Bed material gradation** is measured within each riffle using a variable grid sampling frame (see equipment photo, Figure 427 and Figure 419). The intermediate diameter (b-axis) of each particle located beneath a frame vertex is recorded. Vertices are adjusted to a width so that only the very largest particles will intersect multiple vertices. Measurements are taken with a pocket tape (mm). A minimum of 200 particles per channel unit are measured. Transects are laid out so as to evenly cover the entire channel region. The grid vertices should be spaced so as to avoid counting particles more than once, but narrow enough to ensure 200 particles can be measured within the unit. If particles are too large to pick up, their size is estimated. Particles less than 8 mm are recorded as <8.

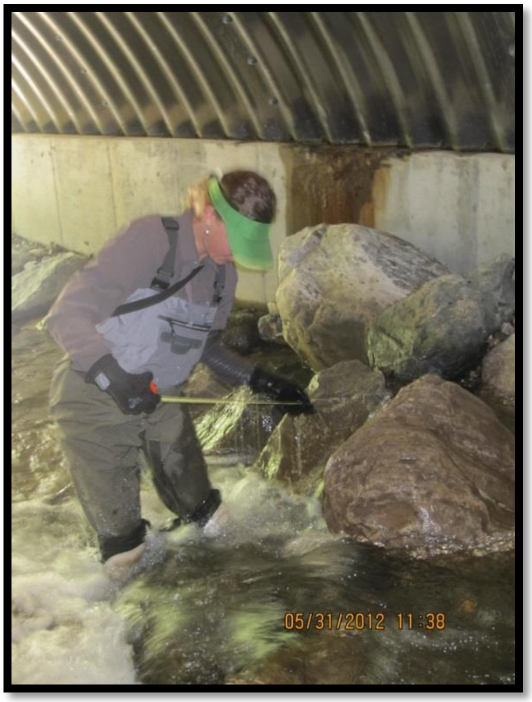
- **Cross sections** are taken in each unique riffle and pool channel unit. Additionally, cross sections should be measured at the maximum width within the inlet and outlet transition zones.

  - ◊ Cross sections should extend beyond bankfull width and capture twice the bankfull depth.
  - ◊ A minimum of 20 measurements within the wetted width should be captured.
  - ◊ It is faster to measure down from a level elevation to the ground than to set up the Total Station. To do this, pound rebar pins (above bankfull stage) at both banks, stretch a taught string and measuring tape between the rebar. Level the string by attaching a bubble level.
  - ◊ Measure down to the stream bed from the string at measurement intervals. The distance from the horizontal string to the channel bed is recorded along the interval as well as at the left edge of water, right edge of water and thalweg (Figure 423).

- **Particle size is measured at each analyzed step**. The intermediate diameter (b-axis) of the 9-11 largest particles which compose a step are measured in place with a rigid ruler or tape.

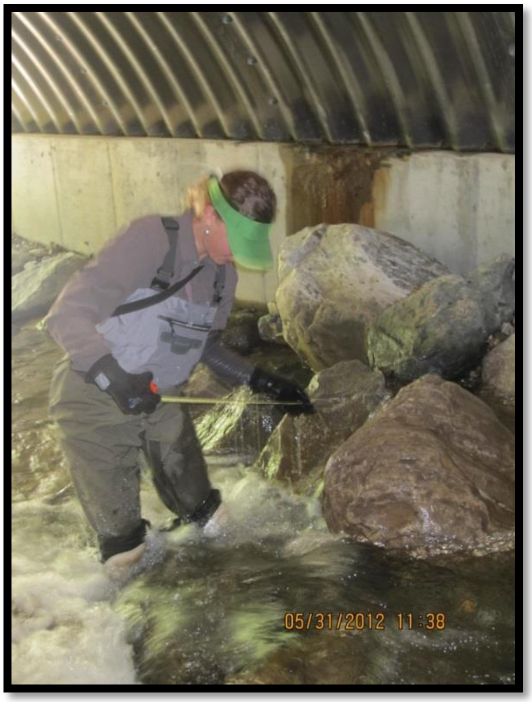
- **Residual pool depth** is measured at each pool associated with steps. The residual pool depth is the distance between the maximum depth of the pool and the downstream pool tail crest (Figure 425).

- **Step height** is measured at each analyzed step. The step height is the distance from the water surface at the base of the step to the flat water surface at the step crest. 3-5 measurements per step are taken. A tape measure is held level at the elevation of the flat water surface above the step crest. Another tape measure is held perpendicular so as to capture the vertical distance between the water surface at the base of the step and the flat water at the crest of the step (
-
-



- Figure 424).

- **Step length** is measured at each analyzed step. The step length is the longitudinal distance from its maximum extent upstream to its maximum extent downstream (
-
-



- Figure 424). Three to five step length measurements are taken (per step) at 0%, 25%, 50%, 75%, and 100% the step width.

- **Bankfull width** at steps is measured across the step crest. Within the design zones where indicators are likely absent, one may determine bankfull stage by measuring up from the water surface to the previously measured height within the natural channel.

12. The **study reach is sketched**. Sketches should capture the channel planform, bank heights, flood plains, terraces, large wood, bars, thalweg, grade controls, unit types, structure orientation, road, landslides, inlet and outlet transition zone boundaries, grade controls (numbered), the locations of cross sections, representative reach boundaries, and tributary confluences. The sketch is extremely helpful for tracking the spatial relationship of channel features and the locations where data are collected.

13. **Photos** are taken looking upstream and downstream *from* each point of interest. Points of interest are as follows: the top of the inlet transition zone, the structure inlet, halfway through the structure, the structure outlet, bottom of the outlet transition zone, top of the representative reach, halfway point within the representative reach, and bottom of the representative reach. In addition, photos looking upstream from the edge of the road/top of the structure, looking downstream from the edge of the road/top of the structure, looking up the road, looking down the road, and of any additional channel features of interest.

14. **General notes** regarding the site are recorded in a field notebook.

15. Finally, all **flagging is collected** and disposed of.

B1 PHOTOS OF SELECTED DATA COLLECTION METHODS

FIGURE 419: PEBBLE COUNT WITH THE ADJUSTABLE VERTICES SAMPLING FRAME

FIGURE 420: TAPES SET UP AT BANKFULL AND HALF BANKFULL ELEVATIONS FOR STATIONING WIDTH AND DEPTH MEASUREMENTS

PHOTO CREDIT: D. CENDERELLI

FIGURE 421: MEASURING WIDTHS WITH A LEVELED STADIA ROD AT THE HALF BANKFULL STAGE

PHOTO CREDIT: D. CENDERELLI

FIGURE 422: MEASURING WIDTHS WITH A LASER DISTANCE METER

FIGURE 423: MEASURING CROSS-SECTIONS FROM A LEVEL STRING

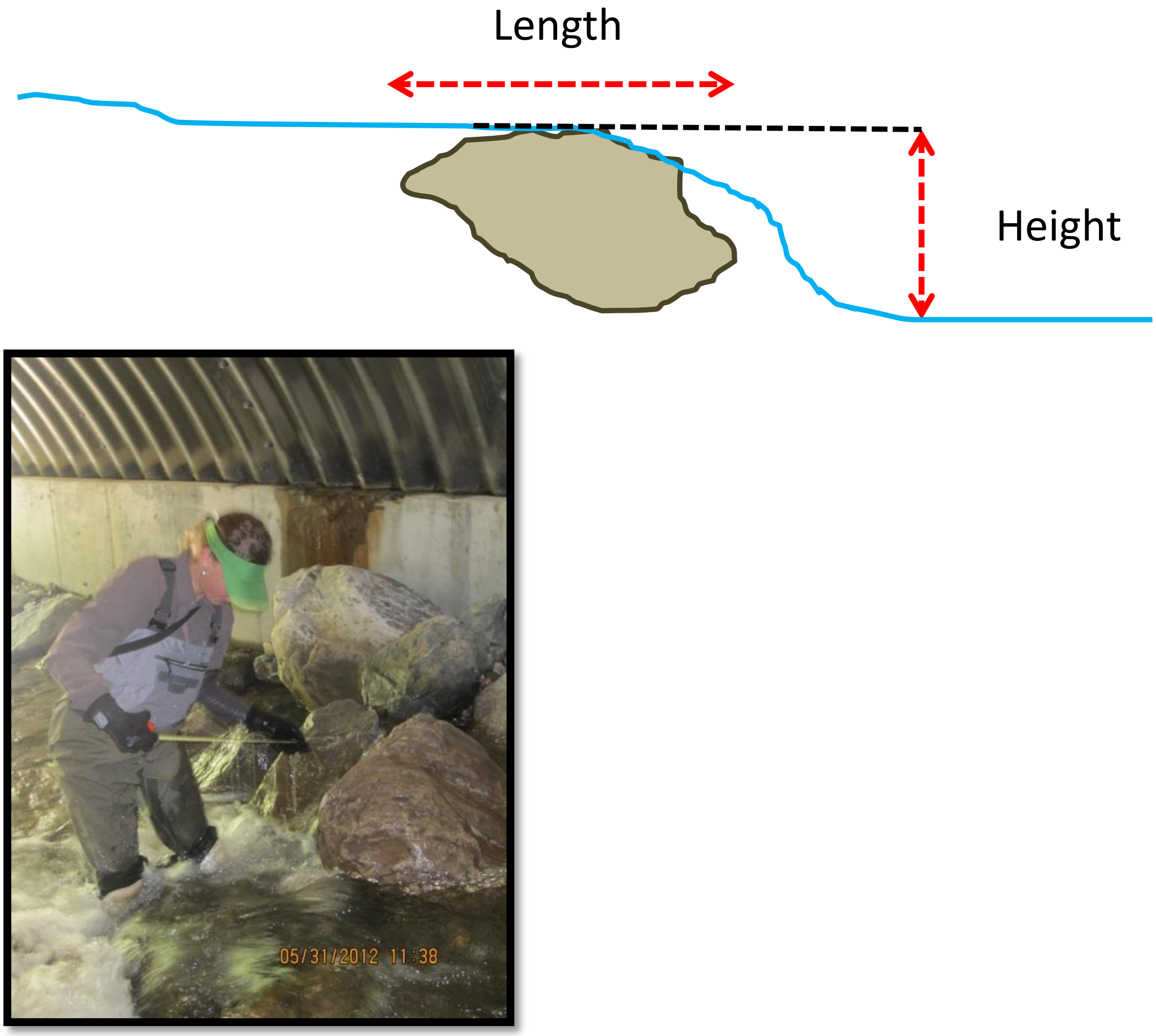


FIGURE 424: STEP LENGTH AND HEIGHT

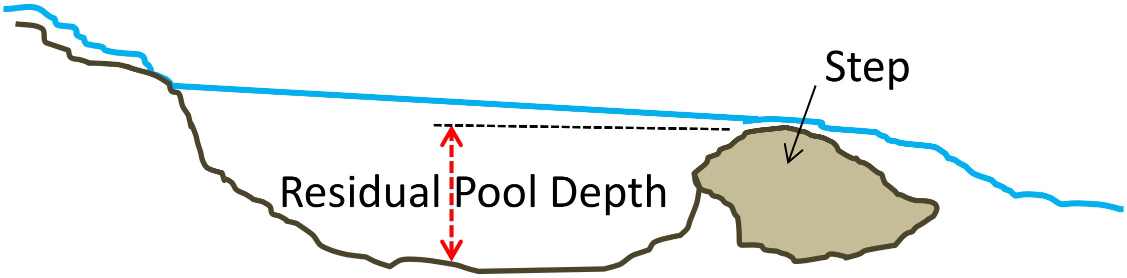


FIGURE 425: RESIDUAL POOL DEPTH AT STEPS

B2 LEVEL II DATA SHEETS

WIDTH MEASUREMENTS

project:	date:	project:	date:
site location:	weather:	site location:	weather:
personnel:	bankfull height above water surface (m):	personnel:	bankfull height above water surface (m):
comments:		comments:	

station number (m)	bankfull width, center-line to right bank (m)	bankfull width, center-line to left bank (m)	0.5 bankfull width, center-line to right bank (m)	0.5 bankfull width, center-line to left bank (m)	water surface width, center-line to right bank (m)	water surface width, center-line to left bank (m)	Maximum depth (m)	comments (channel unit, grade control, channel features, etc.)

CROSS-SECTIONS

project:	date:	Cross Section location:
site location:	weather:	Channel Unit:
personnel:	equipment:	
comments:		

station number	**distance below horizontal**	**comments**	**station number**	**distance below horizontal**	**comments**

PEBBLE COUNTS

project:	sample date:
sampler name:	sample ID:
pebble count method:	sample interval (cm):
sample location:	length of transects (m):
channel unit sampled:	number of transects:
orientation of transects:	distance between transects (m):

general description of sediment sampled (embeddedness, imbrication, particle shape, particle roundness, etc.):

No.	particle size (mm)	comments	No.	particle size (mm)	comments	No.	particle size (mm)	comments
1			43			85		
2			44			86		
3			45			87		
4			46			88		
5			47			89		
6			48			90		
7			49			91		
8			50			92		
9			51			93		
10			52			94		
11			53			95		
12			54			96		
13			55			97		
14			56			98		
15			57			99		
16			58			100		
17			59			101		
18			60			102		
19			61			103		
20			62			104		
22			64			106		

B3 LONGITUDINAL PROFILE SURVEY

The purpose of this task is to select the representative reach(es) for level II physical effectiveness monitoring.

1. **When**- The longitudinal profile is surveyed during one of the initial steps of the level II field protocol. Immediately after the survey is complete, data are imported into an Excel workbook for analysis.
2. **Length**- The survey extends 20-30 bankfull channel widths upstream and downstream of the structure inlet and outlet. However, if the culvert is ten times longer than the bankfull channel width, the survey should extend at least five times the length of the culvert. They survey may be truncated at a distance less than 20-30 bankfull widths where a tributary confluence joins the study channel or major sediment source is located. Where this occurs, it may be necessary to extend the survey in the upstream or downstream direction in order to analyze enough of the channel for representative reach selection.
3. **What**- The survey should capture each geomorphic channel unit (e.g., pools, riffles, steps, and cascades) along the stream bed. Enough points should be measured so as to clearly delineate these features from one another. Grade controls are key structural features which control the channel gradient. They may be step crests, pool-tail crests/riffle crests, transverse ribs within riffles, bedrock outcrops, embedded large woody debris, and beaver dams.
    - In addition to capturing all grade controls, apex channel bends, tributary confluences, large sediment sources, maximum pool depths, pool entrance and exit slopes, and the base of steps should also be surveyed. Where the bed topography is fairly uniform, survey points should be no more than one half bankfull width apart from one another. Aside from capturing the maximum pool depth, points should be located as close as possible to the channel centerline.

- The constructed dimensions at the channel crossing are also important features to survey. Key points on the structure are the base of the left and right bank support footers (at the inlet and outlet), the top of the left and right-bank footers)at the inlet and outlet), the base of the left and right bank wing-walls or miters (at the inlet and outlet), the top of the left and right-bank miters (at the inlet and outlet), the top of the structure (at the inlet and outlet), the base of the fill (at the inlet and outlet), the edge of the road (at the inlet and outlet), and the road centerline. In general, it is convenient, as well as improves survey accuracy, when these points are established as turning points with which to connect the upstream and downstream surveys.
- When surveying the channel bed through the design channel, the inlet and outlet transition zone boundaries, the structure inlet, and the structure outlet are captured and noted.

4. **Defining Channel Units**- Channel units less than one bankfull width in length are not considered independent units. Where the length of a “pool” is not greater than its width, the length is less than the bankfull channel width, or the maximum depth does not exceed 1.5 times the depth at the pool-tail-crest, it is not considered a pool. “Steps” which are not followed by a scour pool are not considered steps, but instead are prominent ribs within a steep riffle (cascade).
5. **Flags and Notes**- Numbered flags are hung along the channel to mark key grade controls and/or slope segments. When surveying, notes are recorded for each survey point which indicate the type of feature and the flag number (if the point coincides with a flag). The flags help to relate the survey profile to the stream channel as well as the locations where data are collected.
6. **Plotting the Survey Data**- The longitudinal profile and planform of the channel are then plotted. It is critical that data are displayed with a vertical exaggeration less than 5 x the horizontal; for steeper channels (>3%), a vertical exaggeration less than 2 x the horizontal should be used. Excess exaggeration will identify too many small scale slope segments.

B4 LONGITUDINAL PROFILE ANALYSIS

1. Line segment "shapes" are used to identify preliminary slope segments on the longitudinal profile. A slope segment is delineated where a line segment connects successive grade controls; grade controls should not sit higher, nor lower than a line segment. Where grade control points don't fall on the line, the slope segment is divided so as to best represent the bed topography.

2. Elevation/location data relevant to the grade controls which represent the boundaries between successive slope segments are copied into their own analysis spreadsheet. They are symbolized and plotted separately on the longitudinal profile.

3. Mathematically, delineated successive slope segments are then compared with one another. Gradient differences less than 25% between successive segments indicate the segments should be combined. Slope segments should be bound by stable grade controls.

4. Once the slope segments have been finalized, they are each compared with the slope segment(s) present in the 3 design zones (inlet transition zone, structure, and outlet transition). If there is only 1 slope segment within the design channel, 1 representative reach will be selected. If there is more than 1 slope segment within the design channel, a representative reach is selected for each design slope segment. The representative reach is selected based on how similar the design and natural channel slope segment gradients are, as well as similarity of channel units and slope segment lengths. Gradients are determined "similar" by the following criteria:

- Where design channels are greater than 3% in slope, the design and representative slope segments will differ in gradient by less than or equal to 25%

- Where design channels are less than 3%, but greater than or equal to 0.5% in slope, the design and representative slope segments will differ in gradient by less than or equal to 50%

- Where design channels are less than 0.5% in slope, the design and representative slope segments will differ in gradient by less than or equal to 100%

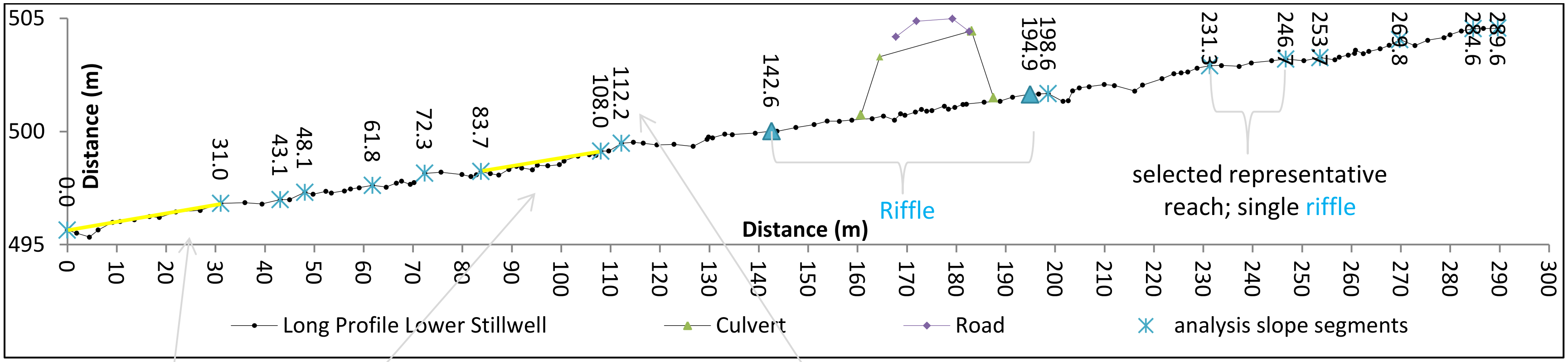
5. Representative reach channel units should be in the same sequence and with the same lengths as those within the design slope segment. At sites where the sequence of channel units present within the design channel cannot be found in the natural channel, individual channel units with gradients similar to the design slope segment(s) are selected.

6. The selected representative reach(es) are then field verified.

7. If no representative reach or representative channel units can be identified, the protocol is terminated and the design is evaluated qualitatively or with limited measurements. Design flaws are likely obvious.

B4.1 Example Longitudinal Profile

Lower Stillwell Site



The Lower Stillwell design channel contains a single slope segment riffle in all design zones. The design channel gradient is 3%. The selected representative reach riffle has a 2% gradient. The structure is an open bottom pipe-arch with length 25.7 m, span 5.4 m and height 3.1 m. The blue triangles on the plot above mark the inlet and outlet transition zone boundaries. The Lower Stillwell longitudinal profile has a 5x vertical exaggeration.

Line "shapes" help to see and define slope segments

Cumulative Distance, as shown in analysis spreadsheets

DESIGN CHANNEL SLOPE SEGMENT DATA

Design Channel Data (Single slope segment riffle)									
N (m)	E (m)	Cumulative Distance (m)	Elev (m)	Survey Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	Selection Notes
497.89	494.60	142.57	500.03	gc15	50.71	1.62	52.35	0.03	this is the entire design reach (inlet tz, structure, and outlet trans zone) channel unit is a single riffle
484.16	445.79	194.93	501.65						
Culvert Length (m)	25.71	Design Slope Segment Length (m)	52.35						

The design slope segment length is compared with the length of each natural channel slope segment

The design gradient is compared with the gradient of each natural channel slope segment. "Similar" gradient is determined by the following criteria:

- Where design channels are greater than 3% in slope, the design and representative slope segments will differ in gradient by less than or equal to 25%
- Where design channels are less than 3%, but greater than or equal to 0.5% in slope, the design and representative slope segments will differ in gradient by less than or equal to 50%
- Where design channels are less than 0.5% in slope, the design and representative slope segments will differ in gradient by less than or equal to 100%

REPRESENTATIVE REACH ANALYSIS (LOWER STILLWELL EXAMPLE)

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	Survey Notes	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn successive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Notes
549.87	603.20	0.00	495.64		816.21	495.64	0.00	#DIV/0!		#DIV/0!	100.00	
530.15	584.39	31.05	496.83		27.25	1.18	31.05	0.04	#DIV/0!	-23.21	40.69	steep riffle, pool
530.98	572.53	43.12	496.99		11.89	0.17	12.07	0.01	-63.70	55.27	76.95	
527.34	569.20	48.10	497.31		4.94	0.32	4.98	0.06	361.96	-106.62	90.48	
515.71	562.34	61.81	497.62		13.49	0.31	[illegible]	[illegible]	-54.97	27.62	[illegible]	
510.92	554.44	72.34	498.15	gc6	9.24	0.[illegible]	[illegible]	[illegible]	125.74	-63.40	[illegible]	
508.15	543.98	83.73	498.23	gc8	10.82	0.[illegible]	[illegible]	[illegible]	-86.90	78.59	[illegible]	
503.05	527.14	108.05	499.13		17.59	0.90	24.31	0.04	461.52	-20.20	[illegible]	[illegible]t bottom, pocket pools in riffle?
503.24	523.13	112.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	124.[illegible]	[illegible]	[illegible]	

SHOULD BE GREATER THAN 25%, OTHERWISE COMBINE SLOPE SEGMENTS

CHANNEL UNITS SHOULD BE SIMILAR BETWEEN THE REP REACH AND DESIGN CHANNEL

THESE DATA ARE PLOTTED TOGETHER TO PRODUCE THE LONGITUDINAL PROFILE (DISTANCE = X AXIS, ELEVATION = Y AXIS)

NEEDS TO MEET GRADIENT CRITERIA TO BE CONSIDERED SIMILAR TO THE DESIGN GRADIENT

THE SELECTED REPRESENTATIVE REACH SHOULD MINIMIZE THE DIFFERENCE IN LENGTH BETWEEN THE DESIGN SLOPE SEGMENT AND THE REP. REACH SLOPE SEGMENT

THESE ARE THE SLOPE SEGMENT BOUNDARIES

THESE DATA ARE PLOTTED TOGETHER TO PRODUCE THE PLANVIEW (E = X AXIS, N = Y AXIS)

N (m)	E (m)	Cumulative Distance (m)	Elev (m)	riffle crest (rc)	Straight line segment length (m)	El. Diff. (m)	Channel Length (m)	Gradient	% diff. btwn successive slope segments	% diff. between S_{dc} and S_{nc}	% diff. between L_{dc} and L_{nc}	Notes
497.89	494.60	142.57	500.03	gc15	29.02	0.55	30.37	0.02	-78.34	41.56	100.00	moderate riffle, steep riffle, pool
484.16	445.79	194.93	501.65		50.71	1.62	52.35				40.69	design = long riffle with pocket pools, prominent ribs
484.72	442.15	198.60	501.67	gc22	3.67	0.02	3.67				76.95	
489.87	413.52	231.32	502.90		29.09	1.23	32.72	0.04	462.99	-21.64	90.48	steep riffle, pool, steep riffle, step, pool
492.45	398.38	246.72	503.20		15.36	0.30	15.39	0.02	-48.45	37.29	73.81	Selected: long straight riffle with transverse ribs
493.84	391.63	253.66	503.26	gc27	6.90	0.06	6.95	0.01	-52.80	70.41	79.89	
494.93	377.18	269.81	504.06	gc30	14.49	0.80	16.15	0.05	438.34	-59.32	78.23	
499.79	363.70	284.65	504.54		14.33	0.48	14.83	0.03	-34.68	-4.06	53.56	steep riffle with pool at bottom
498.45	358.89	289.64	504.56		4.99	0.02	4.99	0.00	-84.99	84.38	92.07	

MEETS THE 50% GRADIENT DIFFERENCE CRITERIA

The level I physical effectiveness monitoring protocol compares physical channel dimensions between the design channel and the natural channel. Specifically, three zones compose the design channel: the inlet transition zone, the structure, and the outlet transition zone. The channel characteristics of each design zone are compared with the channel characteristics of a representative reach (also a zone) within the natural channel. Data are always compared between a design zone and a representative reach. Design zones are never compared with one another.

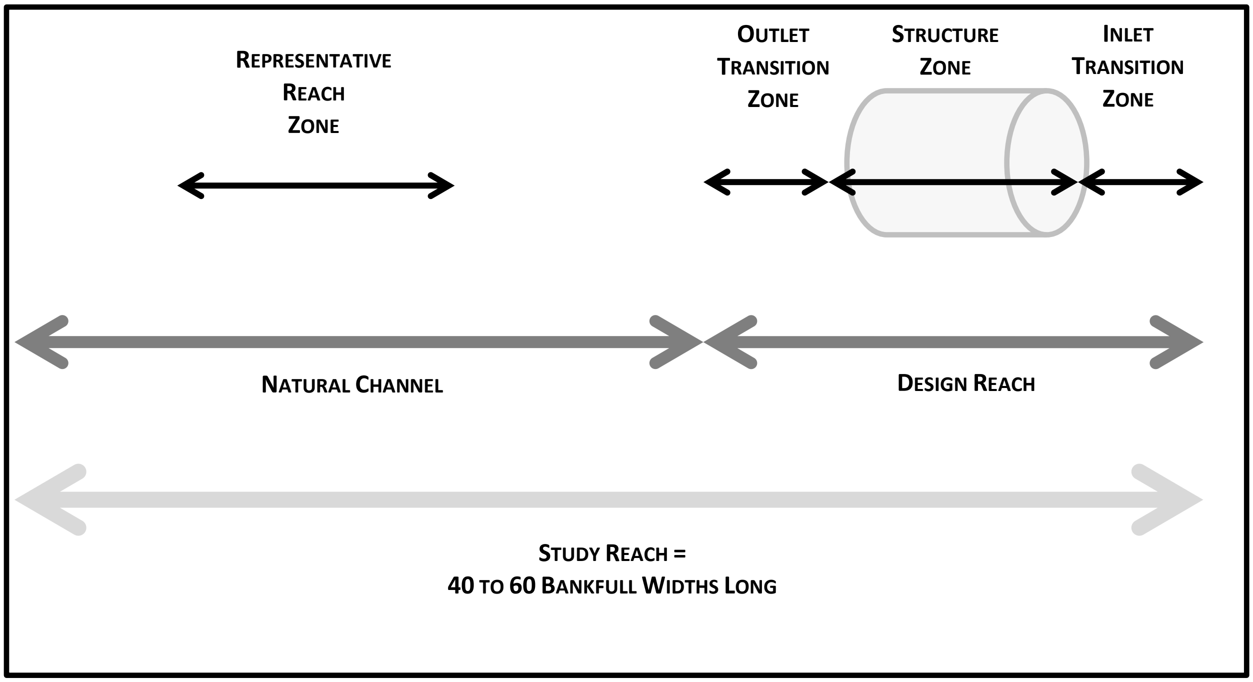


FIGURE 426: SITE ANATOMY

Field Protocol

1. The **site name** is documented. **Structure type and dimensions** are measured: length, span, and height. Height can be measured either from the streambed to the top of the structure, or from the top of the footers to the top of the structure, depending on the structure type. **Observations** of structure condition such as rusting or collapse are also described.

2. The natural channel near the structure (beyond its influence) is walked. **Bankfull channel width** is determined within the natural channel using geomorphic and biologic indicators within the natural channel. Bankfull stage indicators can be: the edge of the active floodplain, highest active depositional feature, breaks in slope on the banks, changes in particle size (finer), changes in vegetation type (moss to lichen, etc.), and stain lines (see http://www.stream.fs.fed.us/publications/videos.html).
    - The distance between the two banks at the bankfull stage is most easily measured with a stadia rod fit with a bubble level. The stadia rod is placed horizontally with one end level with the bankfull indicator, the other end is held level by reading the bubble taped to the rod. Bankfull should be measured within several different channel unit types; the median value will be used.

3. The **distance between the current water surface to the bankfull stage** is also measured within the natural channel. The water surface serves as a reference point from which the bankfull elevation can later be identified within the design channel (indicators are usually absent). This measurement is most easily taken with a stadia rod fit with a bubble level and a pocket rod or measuring tape. The stadia rod is placed horizontally with one end level with the bankfull indicator, the other end is held level by reading the bubble taped to the rod. While level, the distance between the rod and the water surface is measured with the pocket rod or measuring tape. Several measurements should be taken within different channel units; the median value will be used.

4. The **boundaries of the study reach** are then determined and marked; 20-30 bankfull channel widths are measured upstream from the structure inlet and downstream from the structure outlet. Boundaries should be truncated at significant tributary confluences and sediment sources. Where this occurs, it may be necessary to extend the study reach in the opposite direction so as to reach 40 to 60 bankfull channel widths (total).

5. **Slope segment boundaries within the study reach are delineated** with consecutively numbered flags. It is easiest to see slope segments when walking the study reach from downstream to upstream.

    - A slope segment is a section of channel with a fairly uniform gradient. Slope segments are typically identified at the channel unit sequence scale (i.e., a slope segment may be a pool and riffle, or pool, riffle, pool, and riffle). Slope segments may however be composed of a single channel unit (e.g., riffle).

- Adjacent slope segments should be at least 25% different in (estimated) gradient, otherwise segments should be combined.

- Slope segment boundary flags are hung at grade controls. Grade controls are key structural features which control the channel gradient. They may be step crests, pool-tail crests/riffle crests, transverse ribs within riffles, bedrock outcrops, embedded large woody debris, and beaver dams.

- The slope segment(s) within the *design channel* are particularly important. They may extend beyond the structure, inlet and outlet transition zone boundaries. Where possible, the inlet and outlet transition zone boundaries are placed coincident with slope segment boundaries (see below). The structure boundaries may not be coincident with slope segment boundaries.

6. **The upstream boundary for the inlet transition zone and the downstream boundary for the outlet transition zone are identified and marked.** They should be within 3 bankfull channel widths upstream of the inlet and downstream of the outlet, but the actual length will vary depending on site conditions. The minimum length is 1 bankfull width. Place the transition zone boundaries by evaluating the greatest of the following criteria:
   - The maximum extent of disturbance from the previously replaced culvert,
   - The maximum extent of the existing structure's hydraulic influence during flood conditions (backwater at the inlet or scour at the outlet), or
   - The maximum extent of construction disturbance.
   - If a slope segment (grade control) boundary exists within one bankfull width from the maximum criterion, place the transition zone boundary at that grade control. If no grade control is present, place the boundary at the limit of disturbance/influence.

7. For each *zone* (inlet transition, structure, and outlet transition) and each slope segment within the design channel **determine the unique channel units/sequences to be analyzed.** Here, "unique" means each channel unit/sequence belongs to a single zone and slope segment combination. **Measure the length of each channel unit and sequence to be analyzed. Estimate (ocularly) the gradients of each slope segment within the design channel.**
   - Channel units (riffle, pool, and step) are defined according to the following rules:
     - ◊ Riffles and pools less than one bankfull channel width in length are not considered independent units.
     - ◊ Where: the length of a pool is not greater than its width, its length is less than bankfull channel width, and/or its maximum depth does not exceed 1.5 times the depth at the pool tail crest; the pool is not considered an independent unit. It is then analyzed as part of the surrounding riffle unit.
     - ◊ Steps not followed by a scour pool are not considered steps, but instead are prominent ribs within a steep riffle (cascade).
   - Where possible, data at pool and riffle channel units are collected and analyzed by channel unit sequence (e.g., pool, riffle). Identified sequences must be composed of valid channel units located entirely within a single slope segment and zone.
     - ◊ Where multiples of the same channel unit/sequence exist within a single slope segment and zone (e.g., riffle, pool, riffle, pool), data are collected per the minimum

    repeating sequence (e.g., riffle, pool). Data from each repeating sequence (per slope segment and zone) are then combined to be analyzed together.
    - ◊ Data at step-pool sequences are collected by step-pool pairs. Only the tallest step, per zone and slope segment is measured.
- It is important to remember that comparisons are made between design and natural channel units (or sequences) of similar type and gradient, *per zone*. Therefore, design zone boundaries can affect how channel units are analyzed:
    - ◊ Where riffles extend beyond structure boundaries, any portion (inside or outside the structure) of the riffle less than one bankfull channel width in length is not analyzed.
    - ◊ Where pools extend beyond structure boundaries, they may not be analyzed. If less than half the length of the pool extends beyond a design zone boundary, the pool may be analyzed as if it were entirely within a single zone.
    - ◊ Where steps are separated from their pools by a design zone (or slope segment) boundary, the step and pool are analyzed together as if they were both located within the same zone (or segment).

8. **A representative reach (or reaches) within the natural channel is then identified.** The representative reach is a slope segment which has approximately the same gradient (estimated ocularly), the same channel unit types and/or sequences with the same lengths as those in the design slope segment(s). Ideally, each unique design channel unit/sequence (per slope segment and zone) will have a comparable channel unit/sequence within the selected representative reach(es). If entire slope segments are not comparable, separate channel units or sequences within the natural channel can be selected.

9. At each unique channel unit or sequence, **channel metrics (measurements) are collected according to channel unit type**. For each metric the zone, channel unit/sequence type and slope segment are noted.
    - Nine measurement stations are marked within each design or representative reach pool and riffle sequence or channel unit. Measurements are taken at equally spaced intervals along the length of the channel unit or sequence. Rocks tied with flagging can serve as helpful markers for measurement location.
        - ◊ At the marked stations, nine **width** measurements are collected at two elevations (**bankfull stage** and **wetted (low flow)** width). Where natural indicators are absent, one may need to measure up from the water surface to the known bankfull height, and then measure across the channel with a level rod or tape.
        - ◊ At the nine marked stations, the maximum depth for each channel cross section is also measured. A rigid rod is the most useful tool for taking this measurement.
    - Nine to eleven of the **largest bed particles** are measured (b-axis only) within each riffle (per slope segment and zone). The largest particles are chosen by ocular estimate.
    - The tallest step within each unique design zone and slope segment combination is measured and compared with the tallest step within the corresponding representative reach slope segment.
        - ◊ The **largest particles which compose each step** are measured in place (b-axis only).
        - ◊ **Width at bankfull stage** is measured across the step crest. Within the design zones, one may determine bankfull stage by measuring up from the water surface to the previously measured height within the natural channel.

  - ◊ **Step height** is measured. The step height is the vertical distance from the water surface at the base of the step to the flat water surface at the step crest. Three to five step height measurements are taken (per step) at 0%, 25%, 50%, 75%, and 100% the step width.
  - ◊ **Step length** is measured. The step length is the longitudinal distance from its maximum extent upstream to its maximum extent downstream. Three to five step length measurements are taken (per step) at 0%, 25%, 50%, 75%, and 100% the step width.
  - ◊ **Residual pool depth** is measured for each pool associated with a step. The residual pool depth is the distance between the maximum depth of the pool and the downstream pool tail crest.
- **Bank irregularity** is assessed by ocular estimate for each unique channel unit/sequence. "Irregular" means bank undulations or protrusions (which extend into the channel 0.3 to 0.6 m) are located less than 2 bankfull channel widths apart. "Varied" banks have bank undulations exactly 2 bankfull channel widths apart when averaged along the reach. "Regular" banks have bank undulations greater than 2 bankfull channel widths apart. Both banks are assessed together as if they were continuous.
- **Bank continuity within the structure is assessed.** Banks are "continuous" if ≥75% of banks at half bankfull elevation are present through the structure. Structures with less than 50% bank continuity are considered "discontinuous". Banks within the natural channel, inlet and outlet transition zones are always considered continuous.
- **Sketches of the design and representative reaches are made**. They should be simple and clear in order to convey the following information: units measured, unit lengths, unit locations, floodplains, key pieces/large boulders, large instream wood, and planform layout.
- **Photos** are taken looking upstream and downstream *from* each point of interest. Points of interest are as follows: top of the inlet transition zone, structure inlet, half way through the structure, structure outlet, bottom of the outlet transition zone, top of the representative reach, halfway within the representative reach, and bottom of the representative reach. In addition, photos are taken looking upstream from the edge of the road/top of the structure, looking downstream from the edge of the road/top of the structure, looking up the road, looking down the road.

C1 Level I Data Sheets

Site Location:					Structure Span (m):			
Sampling Date:					Structure Height (m):			
Observer:					Structure Length (m):			
	Channel Unit Length (m)							
Zone	Channel Unit	Length (m)	Channel Unit	Length (m)	Channel Unit	Length (m)	Channel Unit	Length (m)
Representative Channel								
Inlet Transition Zone								
Structure								
Outlet Transition Zone								
	Estimated Reach Gradients							
Zone	Channel Unit	Gradient	Channel Unit	Gradient	Channel Unit	Gradient	Channel Unit	Gradient
Representative Channel								
Inlet Transition Zone								
Structure								
Outlet Transition Zone								
Zone	Channel Unit		Bankfull Height Above Water Surface (m)					Median (m)
Natural Channel								

Zone	Channel Unit	Bankfull Width (m): 9 measurements					Median (m)
Representative Channel							
Inlet Transition							
Structure							
Outlet Transition							

Zone	Channel Unit	**Wetted Width (m): 9 measurements**					Median (m)
Representative Channel							
Inlet Transition							
Structure							
Outlet Transition							

Zone	Channel Unit	**Maximum Depth (m): 9 measurements**					Median (m)
Representative Channel							
Inlet Transition							
Structure							
Outlet Transition							

Zone	Channel Unit	**Maximum Particle Size (mm): 9 to 11 particles**					Median (mm)
Representative Channel							
Inlet Transition							
Structure							
Outlet Transition							

Zone	Step Number	**Step Height (m): 3 to 5 measurements**					Median (m)
Representative Channel							
Representative Channel							
Inlet Transition							
Inlet Transition							
Structure							
Structure							
Outlet Transition							
Outlet Transition							

Zone	Step Number	**Step Length (m): 3 to 5 measurements**					Median (m)
Representative Channel							
Representative Channel							
Inlet Transition							
Inlet Transition							
Structure							
Structure							
Outlet Transition							
Outlet Transition							

Zone	Step Number	**Residual Pool Depth (m): 1 measurement**	Measurement (m)
Representative Channel			
Representative Channel			
Inlet Transition			
Inlet Transition			
Structure			
Structure			
Outlet Transition			
Outlet Transition			

Zone	Step Number	**Bankfull Width at Steps (m): 1 measurement**	Measurement (m)
Representative Channel			
Representative Channel			
Inlet Transition			
Inlet Transition			
Structure			
Structure			
Outlet Transition			
Outlet Transition			

Bank Irregularity				
Zone	Channel Unit	Over the reach, bank undulations or protrusions (0.3-0.6 m) are *less than* 2 BF channel widths apart (irregular) score = 5	Over the reach, bank undulations or protrusions (0.3-0.6 m) *are* 2 BF channel widths apart (varied) score = 3	Over the reach, bank undulations or protrusions (0.3-0.6 m) are *greater than* 2 BF channel widths apart (regular) score = 1
Representative Channel				
Representative Channel				
Inlet Transition				
Inlet Transition				
Structure				
Structure				
Outlet Transition				
Outlet Transition				

Bank Continuity				
Zone	Channel Unit	More than 75% of banks (heights greater than 0.5 bankfull) are continuous Score = 5	50-75% of banks (heights greater than 0.5 bankfull) are continuous Score = 3	Less than 50% of banks (heights greater than 0.5 bankfull) are continuous Score = 1
Structure				
Structure				
Structure				
Structure				
Structure				

D EQUIPMENT USED

D1 EQUIPMENT LIST

Clockwise, from top left, spiraling towards the center of the photo:

- Carlson data logger
- Total station
- 409 disinfectant for waders and boots
- Stadia rod
- Pocket rod
- Prism
- Prism pole
- Tripod
- Knee pads
- Neoprene gloves
- Adjustable vertices sampling frame
- Write- in-the-rain notebook
- Write-in-the-rain data sheets and clip-board
- 20 rebar stakes (4’ long x ¼’’ diameter)
- 40 alligator clips
- Flagging
- 2-way radios
- Sledge hammer
- Bubble levels
- String on stick
- Compass
- Laser distance meter

- Whistle
- 3 100 m long cloth tapes
- Machete

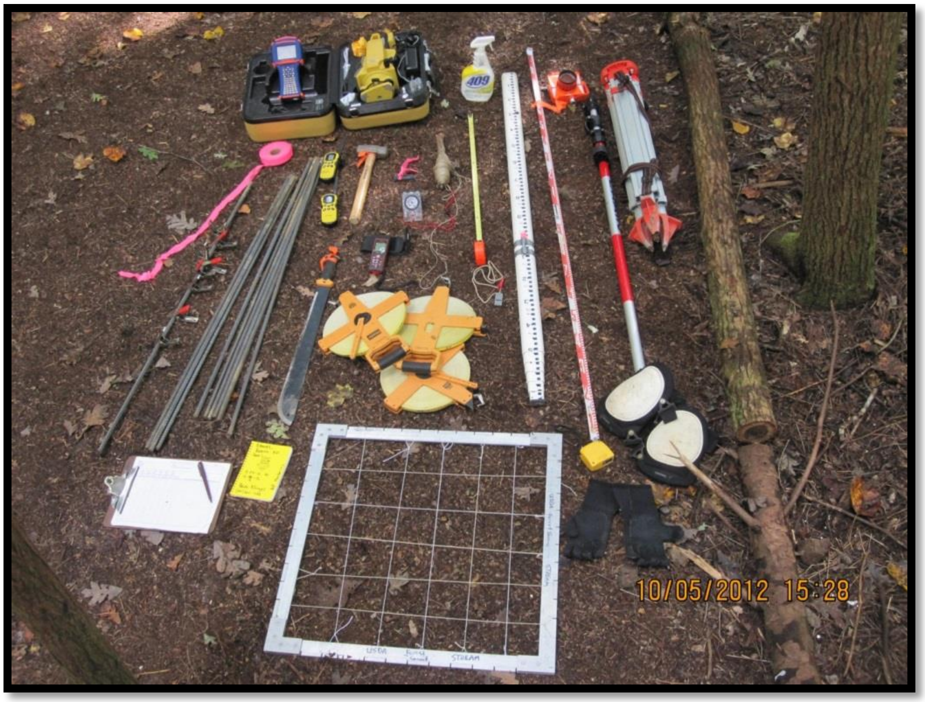


FIGURE 427: ALL LEVEL II EQUIPMENT USED (LEVEL I IS A SUBSET)

FIGURE 428: LASER DISTANCE METER USED FOR LEVEL II WIDTH MEASUREMENTS

E SUMMARY RUBRICS

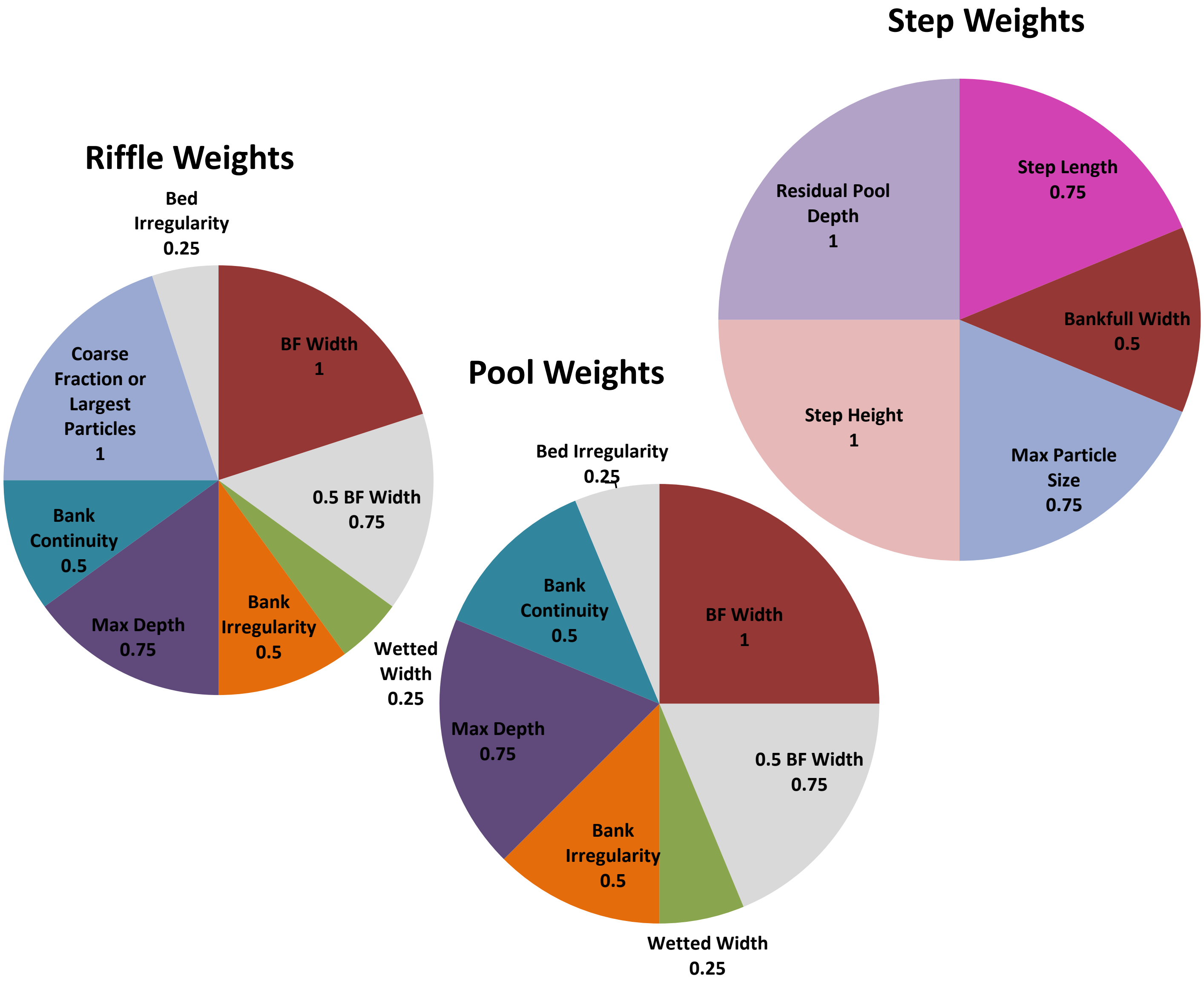


FIGURE 429: METRIC WEIGHTS FOR EACH CHANNEL UNIT

E2 LEVEL II SUMMARY RUBRIC

Below is a print-out of the level II summary rubric. It is a Microsoft® Excel® workbook. Each group, by channel unit type (riffle, pool, and step), is analyzed on a separate worksheet. The user is required to fill in information for every white cell. Grey cells contain code which calculates scores. The calculations performed by each worksheet in the tool can be described mathematically as follows:

(score = 5, 3, or 1)(metric weight) = metric score
∑ metric scores = group score
∑ (score = 5) (metric weight) = total possible points
group score/total possible points = group evaluation score (similar, questionable, dissimilar)

Quartile data for each metric are filled in by the user at the right side of the worksheet. They are used to help check the validity of the p-value and score for each metric. The scoring scheme is explicitly stated at the top of each worksheet.

The Lower Stillwell site is used as an example for the riffles worksheet. Pools and step worksheets are included but are not populated with data (the design channel at Lower Stillwell is a single riffle within all zones).

E2.1 LEVEL II LOWER STILLWELL EXAMPLE: RIFFLES

Site Location:	Lower Stillwell Creek (Siuslaw NF)	**Structure Span (m):**	5.4
Date:	August 2012	**Structure Height (m):**	3.1
Observer:	Heidi Klingel, CMH	**Structure Length (m):**	25.2

Wilcox Rank Sum Test of Medians (Exact p-values)	**2 sided tests: H0=Medians are equal; Ha=Medians are not equal; 1 sided tests: H0= Rep Reach Median <= Design Median; Ha= Rep Reach Median > Design Median**	**p<alpha: H0 is rejected and Ha is true**
criteria	score	interpretation
$p < 0.001$	1	H0 is rejected at significance level 0.01. P value is very small.
$0.001 \leq p < 0.05$	3	H0 is rejected at the significance level of alpha = 0.05
$p \geq 0.05$	5	H0 is not rejected. P value is large.

Zone	Channel Unit	Gradient	Length (m)
Representative	riffle 1	0.019	23.4
Inlet Transition	riffle 1	0.03	10
Structure	riffle 1	0.03	25.2
Outlet Transition	riffle 1	0.03	11.3

Width at Bankfull Stage										25th quartile	Median	75th quar-tile
Zone	Channel Unit	p value	Good Rating (5)	Fair Rating (3)	Poor Rating (1)	Metric Rating	Weight	Total Score		4.56	4.65	4.86
Inlet Transition	riffle 1	0.009	The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.001, but less than the alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is less than the alpha value of 0.001 (H0: Medians are equal)	3	1.00	3.00		5.19	5.42	5.51
Structure	riffle 1	0.000				1	1.00	1.00		5.37	5.45	5.48
Outlet Transition	riffle 1	0.011				3	1.00	3.00		4.78	5.43	5.84

Width at 1/2 Bankfull Stage										25th quartile	Median	75th quartile
Zone	**Channel Unit**	**p value**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weight**	**Total Score**		3.64	4.12	4.27
Inlet Transition	riffle 1	0.143	The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.001, but less than the alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is less than the alpha value of 0.001 (H0: Medians are equal)	5	0.75	3.75		3.04	3.80	4.28
Structure	riffle 1	0.000				1	0.75	0.75		4.59	4.94	5.37
Outlet Transition	riffle 1	0.201				5	0.75	3.75		3.89	4.34	4.68

Wetted Width									**25th quartile**	**Median**	**75th quartile**
Zone	**Channel Unit**	**p value**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weight**	**Total Score**	2.70	3.10	3.49
Inlet Transition	riffle 1	0.01	The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.001, but less than the alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is less than the alpha value of 0.001 (H0: Medians are equal)	3	0.25	0.75	2.09	2.30	2.63
Structure	riffle 1	0.26				5	0.25	1.25	2.43	2.79	3.57
Outlet Transition	riffle 1	0.47				5	0.25	1.25	2.39	2.64	3.64

Maximum Depth at Low Flow (one sided p value, design deeper ok)									25th quartile	Median	75th quartile
Zone	**Channel Unit**	**p value**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weight**	**Total Score**	0.12	0.13	0.15
Inlet Transition	riffle 1	0.56	The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.001, but less than the alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is less than the alpha value of 0.001 (H0: Medians are equal)	5	0.75	3.75	0.12	0.13	0.17
Structure	riffle 1	0.30				5	0.75	3.75	0.11	0.13	0.15
Outlet Transition	riffle 1	0.0002				1	0.75	0.75	0.08	0.10	0.12

Coarse Fraction (>d50) Gradation

Zone	Channel Unit	p value	Good Rating (5)	Fair Rating (3)	Poor Rating (1)	Metric Rating	Weight	Total Score
Inlet Transition	riffle 1	0.10	The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.001, but less than the alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is less than the alpha value of 0.001 (H0: Medians are equal)	5	1.00	5.00
Structure	riffle 1	0.76				5	1.00	5.00
Outlet Transition	riffle 1	0.0499				3	1.00	3.00

25th quartile	Median	75th quartile
120.00	160.00	150.00
110.00	142.50	140.00
120.00	145.00	140.00
110.00	140.00	130.00

Bank Irregularity (One Sided p-value, design more irregular is OK)										**25th quartile**	**Median**	**75th quartile**
Zone	**Channel Unit**	**p value**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weight**	**Total Score**		0.06	0.13	0.40
Inlet Transition	riffle 1	0.96	The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.001, but less than the alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is less than the alpha value of 0.001 (H0: Medians are equal)	5	0.50	2.50		0.13	0.33	0.57
Structure	riffle 1	1.00				5	0.50	2.50		0.20	0.38	0.66
Outlet Transition	riffle 1	0.94				5	0.50	2.50		0.12	0.35	0.59

Bed Irregularity

Zone	Channel Unit	p value	Good Rating (5)	Fair Rating (3)	Poor Rating (1)	Metric Rating	Weight	Total Score
Inlet Transition	riffle 1	na	The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.001, but less than the alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is less than the alpha value of 0.001 (H0: Medians are equal)	na	0.25	#VALUE!
Structure	riffle 1	0.97				5	0.25	1.25
Outlet Transition	riffle 1	0.42				5	0.25	1.25

25th quartile	Median	75th quartile
0.03	0.07	0.11
na	na	na
0.03	0.07	0.11
0.04	0.07	0.14

Bank Continuity								
Zone	**Channel Unit**	**% OF STRUCTURE WITH BANKS AT 0.5 BF ELEVATION**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weight**	**Total Score**
Inlet Transition	riffle 1	NA	More than or equal to 75% of the data points within the structure have banks at half bankfull elevation	Between 50% and 75% of the data points within the structure have banks at half bankfull elevation	Less than <50% of the data points within the structure have banks at half bankfull elevation			
Structure	riffle 1	0.35				1	0.50	0.50
Outlet Transition	riffle 1	NA						

Summary Scores for Riffles (Riffle 1)

Zone	Maximum Total Score Possible	Total Score	Percent Total Score	Evaluation	Comments
Inlet Transition	21.25	18.75	88	Similar	Similar Attributes/Good Rating: Score between 75 and 100 percent. Questionable Attributes/At Risk Rating: Score between 50 and 75 percent. Dissimilar Attributes/Poor Rating: Score less than 50 percent.
Structure	25.00	16.00	64	Questionable	
Outlet Transition	22.50	15.50	69	Questionable	

E2.2 POOLS

Site Location:		**Structure Span (m):**	
Date:		**Structure Height (m):**	
Observer:		**Structure Length (m):**	

Zone	**Channel Unit**	**Gradient**	**Length (m)**
Representative	Pool		
Inlet Transition	Pool		
Structure	Pool		
Outlet Transition	Pool		

Wilcox Rank Sum Test of Medians (Exact)	**2 sided tests: H0=Medians are equal; Ha=Medians are not equal; 1 sided tests: H0= Rep Reach Median <= Design Median; Ha= Rep Reach Median > Design Median**	**p<alpha: H0 is rejected and Ha is true**
criteria	**score**	**interpretation**
$p < 0.001$	1	H0 is rejected at significance level 0.01. P value is very small.
$0.001 \le p < 0.05$	3	H0 is rejected at the significance level of alpha = 0.05
$p \ge 0.05$	5	H0 is not rejected. P value is large.

Width at Bankfull Stage								
Zone	**Channel Unit**	**p value**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weight**	**Total Score**
Inlet Transition	Pool 1		The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.001, but less than the alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is less than the alpha value of 0.001 (H0: Medians are equal)		1.00	
Structure	Pool 1						1.00	
Outlet Transition	Pool 1						1.00	

25th quartile	Median	75th quartile

Width at 1/2 Bankfull Stage								
Zone	**Channel Unit**	**p value**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weight**	**Total Score**
Inlet Transition	Pool 1		The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.001, but less than the alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is less than the alpha value of 0.001 (H0: Medians are equal)		0.75	
Structure	Pool 1						0.75	
Outlet Transition	Pool 1						0.75	

25th quartile	Median	75th quartile

Low Flow (Wetted) Width										25th quartile	Median	75th quar-tile
Zone	**Channel Unit**	**p value**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weight**	**Total Score**				
Inlet Transition	Pool 1		The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.001, but less than the alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is less than the alpha value of 0.001 (H0: Medians are equal)		0.25					
Structure	Pool 1						0.25					
Outlet Transition	Pool 1						0.25					

Maximum Depth (2-sided test)										25th quartile	Median	75th quar-tile
Zone	**Channel Unit**	**p value**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weight**	**Total Score**				
Inlet Transition	Pool 1		The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.001, but less than the alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is less than the alpha value of 0.001 (H0: Medians are equal)		0.75					
Structure	Pool 1						0.75					
Outlet Transition	Pool 1						0.75					

Bank Irregularity (1 sided test; design more irregular is OK)											25th quartile	Median	75th quartile
Zone	**Channel Unit**	**p value**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weight**	**Total Score**					
Inlet Transition	Pool 1		The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.001, but less than the alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is less than the alpha value of 0.001 (H0: Medians are equal)		0.50						
Structure	Pool 1						0.50						
Outlet Transition	Pool 1						0.50						

Bed Irregularity											25th quartile	Median	75th quartile
Zone	**Channel Unit**	**p value**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weight**	**Total Score**					
Inlet Transition	Pool 1		The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is greater than or equal to the significance alpha value of 0.001, but less than the alpha value of 0.05 (H0: Medians are equal)	The p-value of the Wilcoxon Rank Sum test is less than the alpha value of 0.001 (H0: Medians are equal)		0.25						
Structure	Pool 1						0.25						
Outlet Transition	Pool 1						0.25						

Bank Continuity								
Zone	**Channel Unit**	**% OF STRUCTURE WITH BANKS AT 0.5 BF ELEVATION**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weight**	**Total Score**
Inlet Transition	Pool 1	NA	More than or equal to 75% of the data points within the structure have banks at half bankfull elevation	Between 50% and 75% of the data points within the structure have banks at half bankfull elevation	Less than <50% of the data points within the structure have banks at half bankfull elevation			
Structure	Pool 1						0.50	#VALUE!
Outlet Transition	Pool 1	NA						

Summary Score for Pools					
Zone	**Maximum Total Score Possible**	**Total Score**	**Percent Total Score**	**Evaluation**	**Comments**
Inlet Transition				Not Applicable	Similar Attributes/Good Rating: Score between 75 and 100 percent. Questionable Attributes/At Risk Rating: Score between 50 and 75 percent. Dissimilar Attributes/Poor Rating: Score less than 50 percent.
Structure				Not Applicable	
Outlet Transition				Not Applicable	

E2.3 Steps

Site Location:		**Structure Span (m):**	
Date:		**Structure Height (m):**	
Observer:		**Structure Length (m):**	

Channel Unit Length

Zone	Channel Unit	Gradient	Length (m)	Percent Difference	Good Rating (5)	Fair Rating (3)	Poor Rating (1)	Metric Rating	Weight
Representative	step			na	Channel unit length is within 25% of representative channel	Channel unit length is within 25 - 50% of representative channel	Channel unit length is more than 50% different than representative channel	na	na
Inlet Transition	step								0.75
Structure	step								0.75
Outlet Transition	step								0.75

Bankfull Width

Zone	Channel Unit	Median Width (m)	Percent Difference	Good Rating (5)	Fair Rating (3)	Poor Rating (1)	Metric Rating	Weight	Total Score
Representative	step		na	Median bankfull width is within 10% of representative channel	Median bankfull width is within 10 - 30% of representative channel	Median bankfull width is more than 30% different from representative channel	na	na	na
Inlet Transition	step							0.50	
Structure	step							0.50	
Outlet Transition	step							0.50	

Maximum Particle Size												
Zone	**Channel Unit**	**Min (m)**	**25th Perc. (m)**	**Median (m)**	**75th Perc. (m)**	**Max (m)**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weigh**	**Total Score**
Representative	step						Median particle size falls within the 25th and 75th percentile data of representative channel	Median particle size falls within the range of data from representative channel	Median particle size falls outside the range of data from representative channel	na	na	na
Inlet Transition	step										0.75	
Structure	step										0.75	
Outlet Transition	step										0.75	

Step Height												
Zone	**Channel Unit**	**Min (m)**	**25th Perc. (m)**	**Median (m)**	**75th Perc. (m)**	**Max (m)**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weigh**	**Total Score**
Representative	step						Median step height falls within the 25th and 75th percentile data of representative channel	Median step height falls within the range of data from representative channel	Median step height falls outside the range of data from representative channel	na	na	na
Inlet Transition	step										1.00	
Structure	step										1.00	
Outlet Transition	step										1.00	

Residual Pool Depth									
Zone	**Channel Unit**	**Depth (m)**	**Percent Difference**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weight**	**Total Score**
Representative	step		na	Residual pool depth is within 25% of representative channel	Residual pool depth is within 25 - 50% of representative channel	Residual pool depth is more than 50% different than representative channel	na	na	na
Inlet Transition	step							1.00	
Structure	step							1.00	
Outlet Transition	step							1.00	

Step Length												
Zone	**Channel Unit**	**Min (m)**	**25th Perc. (m)**	**Median (m)**	**75th Perc. (m)**	**Max (m)**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weigh**	**Total Score**
Representative	step						Median step length falls within the 25th and 75th percentile data of representative channel	Median step length falls within the range of data from representative channel	Median step length falls outside the range of data from representative channel	na	na	na
Inlet Transition	step										1.00	
Structure	step										1.00	
Outlet Transition	step										1.00	

Summary Score for Steps

Zone	Maximum Total Score Possible	Total Score	Percent Total Score	Evaluation	Comments
Inlet Transition					Similar Attributes/Good Rating: Score between 75 and 100 percent. Questionable Attributes/At Risk Rating: Score between 50 and 75 percent. Dissimilar Attributes/Poor Rating: Score less than 50 percent.
Structure					
Outlet Transition					

E3 LEVEL I SUMMARY RUBRIC

Within this section, the 2013 level I summary rubric is presented. It is a Microsoft® Excel® workbook.

Each design slope segment is analyzed separately by channel unit type (riffle, pool, step) on a separate worksheet. The user is required to fill in information for every white cell. Grey cells contain code which calculate scores. The calculations performed by each evaluation worksheet in the tool can be described mathematically as follows:

(score = 5, 3, or 1)(metric weight) = metric score
∑ metric scores = group score
∑ (score = 5) (metric weight) = total possible points
group score/total possible points = group evaluation score (similar, questionable, dissimilar)

The level I data entry sheet is included; it is used to calculate the percentile values. The riffles worksheet is populated with Lower Stillwell data. Pool and step worksheets are included, but are not populated with data (the design channel at Lower Stillwell is a single riffle within all zones).

DATA ENTRY SHEET FOR LEVEL I

Zone	Channel Unit	BF Width Measurements (m)									Minimum	25th perc.	50th perc.	75th perc.	Maximum
Representative Channel															
Inlet Transition															
Structure															
Outlet Transition															

Zone	Channel Unit	Wetted Width Measurements (m)									Minimum	25th perc.	50th perc.	75th perc.	Maximum
Representative Channel															
Inlet Transition															
Structure															
Outlet Transition															

Zone	Channel Unit	Maximum Particle Size Measurements (mm)					minimum	25th perc.	50th perc.	75th perc.	maximum
Representative Channel											
Inlet Transition											
Structure											
Outlet Transition											

Zone	Channel Unit	**Maximum Depth Measurements (m)**									Minimum	25th perc.	50th perc.	75th perc.	Maximum
Representative Channel															
Inlet Transition															
Structure															
Outlet Transition															

Zone	Step Number	**Step Height Measurements (m)**					minimum	25th perc.	median	75th perc.	maximum
Representative Channel											
Representative Channel											
Inlet Transition											
Inlet Transition											
Structure											
Structure											
Outlet Transition											
Outlet Transition											

Zone	Step Number	**Step Length Measurements (m)**					minimum	25th perc.	median	75th perc.	maximum
Representative Channel											
Representative Channel											
Inlet Transition											
Inlet Transition											
Structure											
Structure											
Outlet Transition											
Outlet Transition											

E3.1 LEVEL I LOWER STILLWELL EXAMPLE: RIFFLES

Site Location:	Lower Stillwell	**Structure Span (m):**	5.4
Date:	8/2/2012	**Structure Height (m):**	25.2
Observer:	hk and cmh	**Structure Length (m):**	3.1

Bankfull Width												
Zone	**Channel Unit**	**Min. (m)**	**25th perc. (m)**	**50th perc. (m)**	**75th perc. (m)**	**Max. (m)**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weight**	**Total Score**
Representative	riffle	4.70	4.80	5.00	5.30	5.95	Median bankfull width falls within the 25th and 75th percentile data of representative channel	Median bankfull width falls within the range of data from representative channel	Median bankfull width falls outside the range of data from representative channel	na	na	na
Inlet Transition	riffle	5.27	5.60	5.80	5.85	5.95				3	1.00	3.00
Structure	riffle	5.42	5.44	5.45	5.46	5.50				3	1.00	3.00
Outlet Transition	riffle	4.57	4.60	4.64	5.97	6.10				1	1.00	1.00

Low Flow Width

Zone	Channel Unit	Min. (m)	25th perc. (m)	50th perc. (m)	75th perc. (m)	Max. (m)	Good Rating (5)	Fair Rating (3)	Poor Rating (1)	Metric Rating	Weight	Total Score
Rep-resentative	riffle	2.80	3.00	3.40	3.90	4.80	Median wetted width falls within the 25th and 75th percentile data of representative channel	Median wetted width falls within the range of data from representative channel	Median wetted width falls outside the range of data from representative channel	na	na	na
Inlet Transition	riffle	2.35	2.50	2.61	4.05	4.90				1	0.25	0.25
Structure	riffle	2.50	2.80	3.35	3.83	4.90				5	0.25	1.25
Outlet Transition	riffle	2.42	3.31	3.32	3.90	4.15				5	0.25	1.25

Maximum Depth (one sided, Riffles can be deeper than the representative reach)

Zone	Channel Unit	Min. (m)	25th perc. (m)	50th perc. (m)	75th perc. (m)	Max. (m)	Good Rating (5)	Fair Rating (3)	Poor Rating (1)	Metric Rating	Weight	Total Score
Rep-resentative	riffle	0.10	0.11	0.13	0.14	0.15	Median max depth falls within the 25th and 50th percentile data of representative channel	Median max depth falls within the minimum and 50th percentile data of representative channel	Median max depth is less than the 25th percentile data of the representative channel	na	na	na
Inlet Transition	riffle	0.10	0.12	0.14	0.15	0.16				5	0.75	3.75
Structure	riffle	0.06	0.10	0.12	0.16	0.17				5	0.75	3.75
Outlet Transition	riffle	0.06	0.06	0.11	0.13	0.15				5	0.75	3.75

Maximum Particle Size

Zone	Channel Unit	Min. (m)	25th perc. (m)	50^{th} perc. (m)	75th perc. (m)	Max. (m)	Good Rating (5)	Fair Rating (3)	Poor Rating (1)	Metric Rating	Weight	Total Score
Representative	riffle	280	300	330	380	480	Median particle size falls within the 25th and 75th percentile data of representative channel	Median particle size falls within the range of data from representative channel	Median particle size falls outside the range of data from representative channel	na	na	na
Inlet Transition	riffle	380	405	430	498	710				3	1.00	3.00
Structure	riffle	290	348	395	400	440				3	1.00	3.00
Outlet Transition	riffle	290	320	345	418	490				5	1.00	5.00

Bank Irregularity
(one sided assessment, design can be more irregular than representative reach)

Zone	Channel Unit	Rating Index	Rating Index Difference	Good Rating (5)	Fair Rating (3)	Poor Rating (1)	Metric Rating	Weight	Total Score
Representative	riffle	3	na	Bank protrusions (1-2 ft.) have the same, or greater, index rating (rep reach – design = 0 or -#)	Bank protrusions (1-2 ft.) have an index rating difference of +1 (rep. reach - design channel)	Bank protrusions (1-2 ft.) have an index rating difference of +2 (rep. reach - design channel)	na	na	na
Inlet Transition	riffle	3	0				5	0.50	2.50
Structure	riffle	5	-2				5	0.50	2.50
Outlet Transition	riffle	3	0				5	0.50	2.50

Bank Continuity								
Zone	**Channel Unit**	**Rating Index**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weight**	**Total Score**
Representative	riffle	5	More than 75% of banks (heights greater than 0.5 bankfull) are continuous through structure	50-75% of banks (heights greater than 0.5 bankfull) are continuous through structure	Less than 50% of banks (heights greater than 0.5 bankfull) are continuous through structure	na	na	na
Inlet Transition	riffle	5				5	0.50	2.50
Structure	riffle	1				1	0.50	0.50
Outlet Transition	riffle	5				5	0.50	2.50

Summary Score for Riffles					
Zone	**Maximum Total Score Possible**	**Total Score**	**Percent Total Score**	**Evaluation**	**Comments**
Inlet Transition	18	13	71	Questionable	Similar Attributes/Good Rating: Score between 75 and 100 percent. Questionable Attributes/At Risk Rating: Score between 50 and 75 percent. Dissimilar Attributes/Poor Rating: Score less than 50 percent.
Structure	20	14	70	Questionable	
Outlet Transition	18	14	77	Similar	

E3.2 POOLS

Site Location:		**Structure Span (m):**	
Date:		**Structure Height (m):**	
Observer:		**Structure Length (m):**	

Bankfull Width												
Zone	**Channel Unit**	**Min. (m)**	**25th perc. (m)**	**50th perc. (m)**	**75th perc. (m)**	**Max. (m)**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weight**	**Total Score**
Representative	pool						Median bankfull width falls within the 25th and 75th percentile data of representative channel	Median bankfull width falls within the range of data from representative channel	Median bankfull width falls outside the range of data from representative channel	na	na	na
Inlet Transition	pool										1.00	
Structure	pool										1.00	
Outlet Transition	pool										1.00	

Low Flow Width

Zone	Channel Unit	Min. (m)	25th perc. (m)	50th perc. (m)	75th perc. (m)	Max. (m)	Good Rating (5)	Fair Rating (3)	Poor Rating (1)	Metric Rating	Weight	Total Score
Representative	pool						Median wetted width falls within the 25th and 75th percentile data of representative channel	Median wetted width falls within the range of data from representative channel	Median wetted width falls outside the range of data from representative channel	na	na	na
Inlet Transition	pool										0.25	
Structure	pool										0.25	
Outlet Transition	pool										0.25	

Maximum Depth
(2-sided, design must be similar to rep. reach)

Zone	Channel Unit	Min. (m)	25th perc. (m)	50th perc. (m)	75th perc. (m)	Max. (m)	Good Rating (5)	Fair Rating (3)	Poor Rating (1)	Metric Rating	Weight	Total Score
Representative	pool						Median depth falls within the 25th and 75th percentile data of representative channel	Median depth falls within the range of data from representative channel	Median depth falls outside the range of data from representative channel	na	na	na
Inlet Transition	pool										0.75	
Structure	pool										0.75	
Outlet Transition	pool										0.75	

Bank Irregularity (1-sided, design may have greater irregularity than rep. reach)

Zone	Channel Unit	Rating Index	Rating Index Difference	Good Rating (5)	Fair Rating (3)	Poor Rating (1)	Metric Rating	Weight	Total Score
Representative	pool		na	Bank protrusions (1-2 ft.) have the same, or greater, index rating (rep reach – design = 0 or -#)	Bank protrusions (1-2 ft.) have an index rating difference of +1 (rep. reach -design channel)	Bank protrusions (1-2 ft.) have an index rating difference of +2 (rep. reach -design channel)	na	na	na
Inlet Transition	pool							0.50	
Structure	pool							0.50	
Outlet Transition	pool							0.50	

Bank Continuity								
Zone	**Channel Unit**	**Rating Index**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weight**	**Total Score**
Representative	pool	5	More than 75% of banks (heights greater than 0.5 bankfull) are continuous through structure	50-75% of banks (heights greater than 0.5 bankfull) are continuous through structure	Less than 50% of banks (heights greater than 0.5 bankfull) are continuous through structure	na	na	na
Inlet Transition	pool					na	na	na
Structure	pool						0.50	
Outlet Transition	pool	5				na	na	na

Summary Score for Pools					
Zone	**Maximum Total Score Possible**	**Total Score**	**Percent Total Score**	**Evaluation**	**Comments**
Inlet Transition				Not Applicable	Similar Attributes/Good Rating: Score between 75 and 100 percent. Questionable Attributes/At Risk Rating: Score between 50 and 75 percent. Dissimilar Attributes/Poor Rating: Score less than 50 percent.
Structure				Not Applicable	
Outlet Transition				Not Applicable	

E3.3 STEPS

Site Location:		**Structure Span (m):**	
Date:		**Structure Height (m):**	
Observer:		**Structure Length (m):**	

Bankfull Width at Steps									
Zone	**Channel Unit**	**Width (m)**	**Percent Difference**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weight**	**Total Score**
Representative	step		na	Bankfull width is within 10% of representative channel	Bankfull width is within 10 - 30% of representative channel	Bankfull width is more than 30% different from representative channel	na	na	na
Inlet Transition	step							0.50	
Structure	step							0.50	
Outlet Transition	step							0.50	

Maximum Particle Size												
Zone	**Channel Unit**	**Min. (m)**	**25th perc. (m)**	**50th perc. (m)**	**75th perc. (m)**	**Max. (m)**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weight**	**Total Score**
Representative	step						Median particle size falls within the 25th and 75th percentile of representative channel data	Median particle size falls within the range of representative channel data	Median particle size falls outside the range of representative channel data	na	na	na
Inlet Transition	step										0.75	
Structure	step										0.75	
Outlet Transition	step										0.75	

Step Height												
Zone	**Channel Unit**	**Min. (m)**	**25th perc. (m)**	**50th perc. (m)**	**75th perc. (m)**	**Max. (m)**	**Good Rating (5)**	**Fair Rating (3)**	**Poor Rating (1)**	**Metric Rating**	**Weight**	**Total Score**
Representative	step						Median step height falls within the 25th and 75th percentile of representative channel data	Median step height falls within the range of representative channel data	Median step height falls outside the range of representative channel data	na	na	na
Inlet Transition	step										1.00	
Structure	step										1.00	
Outlet Transition	step										1.00	

Step Length

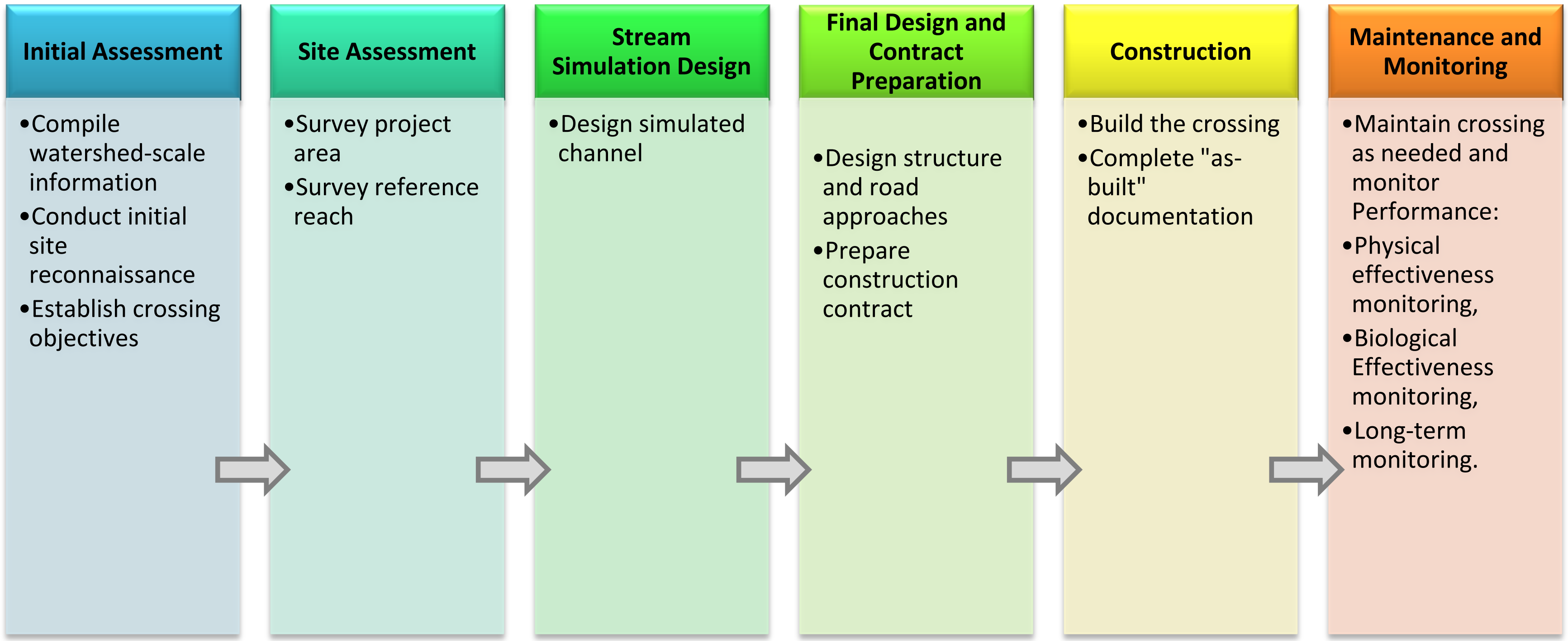
Zone	Channel Unit	Min. (m)	25th perc. (m)	50th perc. (m)	75th perc. (m)	Max. (m)	Good Rating (5)	Fair Rating (3)	Poor Rating (1)	Metric Rating	Weight	Total Score
Representative	step						Median step length falls within the 25th and 75th percentile of representative channel data	Median step length falls within the range of representative channel data	Median step length falls outside the range of representative channel data	na	na	na
Inlet Transition	step										1.00	
Structure	step										1.00	
Outlet Transition	step										1.00	

Residual Pool Depth

Zone	Channel Unit	Depth (m)	Percent Difference	Good Rating (5)	Fair Rating (3)	Poor Rating (1)	Metric Rating	Weight-	Total Score
Representative	step		na	Residual pool depth is within 25% of representative channel	Residual pool depth is within 25 - 50% of representative channel	Residual pool depth is more than 50% different than representative channel	na	na	na
Inlet Transition	step							1.00	
Structure	step							1.00	
Outlet Transition	step							1.00	

Summary Score for Steps					
Zone	**Maximum Total Score Possible**	**Total Score**	**Percent Total Score**	**Evaluation**	**Comments**
Inlet Transition				Not Applicable	Similar Attributes/Good Rating: Score between 75 and 100 percent. Questionable Attributes/At Risk Rating: Score between 50 and 75 percent. Dissimilar Attributes/Poor Rating: Score less than 50 percent.
Structure				Not Applicable	
Outlet Transition				Not Applicable	

F1 STREAM SIMULATION FLOW CHART



Initial Assessment

- Compile watershed-scale information
- Conduct initial site reconnaissance
- Establish crossing objectives

Site Assessment

- Survey project area
- Survey reference reach

Stream Simulation Design

- Design simulated channel

Final Design and Contract Preparation

- Design structure and road approaches
- Prepare construction contract

Construction

- Build the crossing
- Complete "as-built" documentation

Maintenance and Monitoring

- Maintain crossing as needed and monitor Performance:
- Physical effectiveness monitoring,
- Biological Effectiveness monitoring,
- Long-term monitoring.

FIGURE 430: STREAM SIMULATION DESIGN METHOD FLOW CHART

ADAPTED FROM FIGURE 3.4 IN THE STREAM SIMULATION MANUAL (STREAM SIMULATION DESIGN WORKING GROUP, 2008).

F2 STREAM SIMULATION HIGHLIGHTED STEPS

This section is meant to help the reader better understand physical effectiveness monitoring, as many of the channel metrics assessed are closely related to the stream simulation design procedure. Although the levels I and II physical effectiveness monitoring protocols are not limited to assessing stream simulation designs, stream simulation is a common method currently taught by the Forest Service and widely utilized across the US.

The information within this section has been paraphrased from the "Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings" design guide, written by the Stream Simulation Working Group and published in 2008 (currently available at http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsm91_054564.pdf). It is neither intended to be exhaustive nor complete, but simply an overview.

Initial Assessment

After determining a crossing is interrupting geomorphic and/or ecological continuity , the next step is gathering information at the watershed scale (initial assessment). Big picture information provides context for the conditions at the road-stream crossing and calls attention to potential risks and opportunities. During this phase, specialists should ask themselves: Is this road necessary? Where in the watershed is this road located and what are the implications? Would it be possible to better locate this road (i.e. on the ridge-top?). Is there evidence of instability within the stream network which might affect the site in the future (i.e. recent wildfires, headcuts)? Are large sediment or wood inputs likely to complicate the design? Is the elevation difference between the inlet and outlet especially large? What adjustments are likely to occur at the site over the lifetime of the structure? Answering these questions may indicate stream simulation is not an appropriate action and will generate critical information to be considered while drafting a design.

Site Assessment

The goals of this phase include understanding the geomorphic context at the site, generating an engineering site plan map for the design, better understanding the risks and long-term changes at the site, identifying detailed project objectives, and selecting a reference reach (stream bed design template).

Site Sketch

A detailed planview sketch of the natural channel, road, and existing structure is drawn. Features such as the floodplain, bankfull elevations, terraces, side channels, abandoned channels, channel bed units, large boulders, instream wood, eroding banks, bedrock, bank irregularities, gravel bars, direction of flow, thalweg, and valley features should be captured. It is also important to document where subsequent measurements are taken such as cross sections and pebble counts.

Site Survey

A three dimensional perspective of the road-stream crossing, valley and channel geometry is created by conducting a detailed survey. Three products are generated from the survey data: a topographic map of the road-stream crossing, floodplain, and valley walls, a longitudinal profile of the channel bed including the “bed” through the existing crossing, and cross-sections of the stream channel near the crossing as well as within the natural channel. The topographic map should be detailed enough to use for design purposes. The longitudinal profile should extend 20-30 bankfull widths upstream and downstream of the structure so as to capture repeating sequences of bedforms within the natural channel. Cross sections are collected immediately upstream and downstream of the existing crossing structure, and within the natural channel. The number of cross sections collected varies with the complexity of the natural channel and the crossing site. Cross sections may highlight risk factors such as channel incision and headcutting downstream of the crossing.

Bed Material

The size and arrangement of bed and bank materials is documented. Characterizing the substrate of the channel helps predict how it might respond to future disturbances, provides a template from which bed materials in the simulated reach are specified, and ensures that the reaches upstream of the design reach will resupply eroded bed material. Specifically, pebble counts and/or bulk samples are collected. Bed mobility, armoring, structure and stability observations are documented. Bed mobility determines a transport versus response type channel (Montgomery and Buffington, 1997) and therefore its susceptibility to adjustment. Bed mobility varies with bed unit type; therefore, sampling techniques also vary with unit type. Key features, those pieces of rock and wood which are largely immobile and affect channel slope, channel dimensions, water velocity, flow direction and sediment deposition are separately characterized. Because they are largely immobile, they are not likely to form within the design reach on their own and must be built. Even small sized pieces of wood can affect the bed stability; therefore, all wood should be noted. Although wood can’t be used in simulation designs, it is mimicked with rock.

Stream Banks

In addition to forming the stream channel boundary, the stream banks define the edge habitat used by many species. They can be described by their irregularity, stability, and vegetation. Specifically, the dimensions of bank protrusions and materials are recorded. Stability should be assessed at the existing structure to predict how banks will react should the channel bed adjust by downcutting after the stream simulation design has been implemented.

Floodplains

Special care should be taken to capture observations and data on the floodplain so as to ensure the resulting design has the least possible impact on floodplain processes. Floodplain conveyance, entrenchment ratio, and roughness are important data. High floodplain conveyance and frequent floods make it necessary to incorporate floodplain drainage structures in order to avoid funneling floodplain flows through the main structure.

Geotechnical/Subsurface Assessment

Information about bedrock, soil, susceptibility to mass-wasting, and groundwater at the site will inform design plans. In particular, the extent of the design channel should be investigated.

Logistical Constraints

Logistical constrains such as time, road closure, site access, material availability, utilities, rights of way, property boundaries, visibility, radius of road curvature, and road grade, among others, may affect the site design.

Site Risks and Complications

Key steps during the site assessment phase involve identifying potential risks and complications. Risks don’t necessarily preclude implementing a stream simulation design, but will affect the design details. Some of the situations to be considered are stream profile shape, regional channel incision, road-impounded wetlands, vertical adjustment potential, high floodplain conveyance, laterally migrating channels, headcutting after culvert replacement, debris (i.e., large wood) conveyance through the new structure, mass wasting, and the passage of terrestrial organisms through the structure (requires dry banks within a larger structure).

Representative Reach Selection

A representative (also referred to as the “reference”) reach serves as the template for the segment of stream channel built within the replaced crossing structure. Data from several potential representative reaches should be collected during the initial site assessment phase. The perfect representative reach represents the physical, hydrologic and hydraulic characteristics of the natural stream channel that would exist in the channel if a stream-crossing was not there. In reality, this perfect reach does not often exist. “Representative” must be allowed to include characteristics within the natural range of variability.

The representative reach slope must be similar to the design reach slope through the crossing. This is the primary criteria upon which a representative reach is selected, although the reach cross section and entrenchment ratio should not be anomalous relative to the reaches directly adjacent to the crossing. The chosen reach must be stable, as well as have the same water and sediment discharge as the crossing site; tributaries, sediment sources and sinks between the chosen reach and the crossing site need to be avoided. The representative reach should be located outside of the influence of the crossing site, ideally upstream of the crossing to avoid choosing a reach which has been impacted by the crossing itself. If the chosen reach is located downstream of the crossing site, the bed material within the representative reach should be of similar size and mobility as that within the reach that will supply sediment to the simulated stream bed within the crossing. The length of the representative reach should be at least as long as the stream crossing structure. Highly sinuous reaches should be avoided because building curves within a straight structure is difficult if not impossible. When selecting the reach, consider the distribution and pattern of channel units immediately upstream and downstream of the structure. To ensure continuity, the spacing and sequence of channel units may dictate which representative reach is chosen. At complicated sites, representative reaches from similar, nearby watersheds may be chosen, although extreme caution is advised when using this technique.

Data required to select the reference reach are largely collected within the site assessment phase of the project including: the long profile, cross sections, bed and bank material data. Additional data collected are residual pool depths, the size, spacing, height, and mobility of grade controls and key features.

Designing the Crossing

The goal of stream simulation is to create a self-sustaining crossing which is free to adjust. This is only accomplished when the channel changes freely with incoming flows and sediment loads. Critical to this requirement is a sufficiently large structure where both vertical and lateral degradation and aggradation are accommodated. When a crossing is self-sustaining in this way, it should present no more of an obstacle to aquatic organisms than the natural channel. Stream simulation works best for new road crossings where open-bottom structures can be placed around the in-tact, natural streambed.

Alignment

The first step in designing the simulated stream bed involves inspecting the longitudinal profile and planview survey plots. When a road crosses a channel at an angle other than 90 degrees (skewed), the risk of lateral migration, excessive bed scour, reduced structure capacity and sedimentation are elevated. Designing an appropriate crossing at a skewed structure requires making site-specific decisions to minimize these risks. These choices essentially result in design trade-offs between structure width, length, project cost, road safety, road location, channel re-alignment, and energy dissipation. The options available are: match the culvert alignment to the stream alignment, realign the stream to minimize the culvert length, widen and/or shorten the culvert, move the road to better cross the stream at a normal angle, build a curved structure, or build a bridge with a wider span. Risks are associated with each option, although re-aligning the stream to cross the road at a better angle is the greatest risk.

Transitions

Once the alignment has been decided, the transitions into and out of the structure are designed. Smooth transitions are important because they avoid exacerbating the risks mentioned in the previous paragraph. Poor transitions may cause unwanted scour, which can threaten structure foundations and banks. Poor transitions are also prone to accumulations of sediment and woody debris, which can plug structure inlets. Surveyed cross sections upstream and downstream of the design channel are compared with the designed channel immediately upstream and downstream of the structure to ensure smooth transitions.

Design Gradient

Next, the design channel bed slope through the structure is determined. Using the surveyed longitudinal profile, stable grade controls upstream and downstream of the design reach are selected and a gradient line is drawn between them. The design profile will be longer if channel incision or other instability extends far beyond the design channel. Stable grade controls might be bedrock outcrops, riffle crests, well embedded logs, etc. The ideal profile has only one gradient, although concave or convex stream profiles may necessitate several design gradients. In that case, it is best to locate the break in slope outside of the structure.

Representative Reach Identification

Possible representative reaches are verified by comparing their bed slopes with the design gradient. The slope of the representative reach should be within 25% of the design gradient. The representative reach is ideally straight, as long as the necessary crossing structure and as long as the project profile. If no appropriate representative reach within the natural channel can be found, several options exist: 1) completely reconstruct (restore) the channel up or downstream from the structure, so that the slope through the design will match a slope within the natural channel; 2) steepen the stream simulation channel through the structure (up to 25% of the natural channel gradient); or 3) steepen the reaches upstream or downstream of the culvert, so that the gradient within the structure will match a representative reach. If the channel is steepened, grade controls are placed to stabilize the bed. They should be similar in dimension and spacing to those within the natural channel.

Design Bed Material

The simulated channel bed material and features are based on the bed within the representative reach; it is as exact a replicate as possible. Bed material within the simulated reach is chosen based on the particle size distribution and the size and spacing of key pieces within the representative reach. It is important to size the bed material within the structure correctly so that it is mobilized at the same discharge as the representative reach. This will maintain sediment continuity through the structure. Rock used for the simulated bed should be durable and have equal angularity to the natural bed. The bed and key pieces act as roughness elements which dissipate energy, influence the channel gradient, bed stability, and the physical and hydraulic diversity within the design reach. The bed is designed to be as mobile as the natural channel streambed, while the key pieces are designed to be immobile. Wooden key pieces within the natural channel are approximated with angular rock in the design channel.

The design bed mixture should also be poorly sorted. An adequate portion of fines (less than 2 mm in diameter) should be incorporated so as to seal the voids in the bed, thereby reducing permeability and maintaining surface flow. Larger particles (D_{95}, D_{84}, and D_{50}) provide bed structure; they should be accurately sized based on similar particles within the natural channel. Within the design channel, these larger rocks are used to mimic the wood in the natural channel.

For unarmored beds, the particle size distribution measured by surface pebble count within the representative reach can be used to size the design reach bed material. For armored beds, a surface pebble count will underestimate the finer portion of the bed; instead, the Fuller Thompson (1907) equation is used to calculate the proper design bed gradation:

$$\frac{\boldsymbol{P}}{\mathbf{100}} = [\boldsymbol{d} * \boldsymbol{D}_{\boldsymbol{max}}]\boldsymbol{n}$$

where *d* is any particle size of interest, *P* is the percentage of the mixture smaller than *d*, D_{max} is the largest size material in the mix, and *n* is a parameter that determines how fine or coarse the resulting mix will be. An *n* value of 0.5 produces a maximum density mix when particles are round.

The subsurface design bed specified by the Fuller Thompson equation will result in a bed coarser than the subsurface natural gradation. This is a safety precaution; should the bed scour, coarser material below the surface will remain.

Design Bed Cross Section

The simulated channel should be at least as wide as the representative reach channel width at bankfull stage, plus extra width for channel banks constructed within the structure. Although over time, channels with mobile beds will shape themselves, problems are avoided if the bed cross section is initially constructed. A low flow v-shaped channel will keep the thalweg from initially hugging the structure walls. It also ensures adequate depth for organisms during low flow periods. Over time, a natural thalweg will develop. In channel types with less mobile beds, features such as steps and pools should be constructed to mimic those within the representative reach. Channel margins (banks) should be constructed with enough protrusions to mimic the irregularity of the natural channel. Within the structure, immobile rock is used in place of large wood, roots and vegetation. Bank margin diversity is critical to the upstream movement of some weaker swimming species. Features such as steps and banks should be designed to be immobile during high flows. As an initial estimate, particles twice the size of the D_{95} within the natural channel should be adequate for constructing stable steps and banks.

Designing Channel Bed Types

The bed forms present in the representative reach will be replicated within the design channel. Sand bed dune-ripple channels have an extremely mobile bed. One can choose to import bed material, or let the structure fill naturally. Constructing bedforms is unnecessary, although placing small pieces of wood may be helpful for maintaining a gradient. Adding roughness to the stream margins will help avoid scour along the culvert walls.

Pool-riffle channels with intermediate bed mobility will need constructed riffle crests. Spacing should be equal to the average spacing within the representative reach. Riffle crests will need to replicate the particle packing (such as imbrication) found within the representative reach. Plane bed channels are relatively featureless cobble beds, although rocks should be placed along the channel margins to add hydraulic diversity.

Step pool channels require immobile steps to be constructed. Step particles should be large enough to remain immobile during the largest floods. Step stability can be aided by vertical steel sill plates around which step particles are placed. Pools are expected to form themselves, although constructing them with the expectation they will adjust is also valid. Steps are spaced to mimic the representative reach, usually one to four bankfull channel widths apart.

Cascade channels are very steep (>8%) and should be immobile in very high flows. Special care should be taken to ensure that the cascade forming particles are large enough to remain immobile for the life-span of the project. Sills can be used to aid their stability.

Bedrock channel beds require only a few key pieces along the margins of the structure and within the channel to provide hydraulic diversity.

It should be noted that stream simulation design techniques have not been well tested on low gradient streams with fine sediments, cohesive soils, or densely vegetated streambeds.

Designing the Structure

Now that the bed and banks within the project channel have been designed, a crossing structure is fit around them. Bridges are also applicable structures, although not discussed here; similar width and height considerations will apply.

Culvert elevation and dimensions will affect bed mobility. Therefore, considering the structure and available bed material together is important. A culvert is sized based on the bankfull width of the channel, the width of the bank-lines and overbank surfaces, the range of possible vertical adjustments, the maximum sizes of bed and key particles, skew towards road alignment, bed stability and flow capacity analysis. Specific project objectives such as risk of blockage by heavy wood or sediment loads will further advise culvert size. The elevation of the structure invert should ensure it is deep enough to avoid exposing the footings or culvert wall at maximum scour. The height of the structure must also maintain adequate flood and debris capacity. Key particle stability analysis results will not be accurate if the culvert is submerged and flows become pressurized. Culvert shape and material decisions are advised by availability, structure longevity, road elevation and depth of fill, constructability, construction logistics, soil-bearing capacity, site access and flood capacity.

As mentioned above, a bed mobility analysis is performed to ensure that bed particles of similar size will become mobile within the simulated streambed and representative bed during a particular flow. Results of the bed mobility analysis will indicate whether adjustments to the bed-material size, channel width, or flood-plain capacity in the design reach need to be made. Flood-plain relief culverts can also help equalize bed mobility. The D_{84} grain size is analyzed because when D_{84} is mobile, smaller bed sediments are also mobile. A mobility analysis identifies the flows which mobilize the D_{84} or D_{95} sized particles within the representative reach (critical unit discharge equation (Bathurst, 1987) or a modified critical shear stress equation). The same calculation is done for D_{84} or D_{95} within the design reach. When the mobilizing discharges are equal between the design and representative reaches, equal mobility has been achieved. The recurrence interval of the mobilizing discharge is calculated and compared with the recurrence interval of the design discharge.

The stability of key features (designed to be immobile at the high bed-design flow) is verified by calculating the critical shear stress and the discharge at which this shear stress would occur. If the calculated flow is less than the high bed-design flow, the key pieces are too small. Perhaps more appropriate equations for individual large rocks would be Fischenich and Seal (2000), which calculate the stress necessary to mobilize boulders by sliding or rolling. The U.S. Army Corps of Engineers has also created several models used for sizing stable riprap.

G WILCOXON RANK-SUM R CODE USED

G1 R STATISTICAL PACKAGE SOURCE CODE FOR THE WILCOXON RANK SUM TEST WITH EXACT P-VALUES

Used the “Exact Rank Tests” Package

```
UseMethod("wilcox.exact")
<environment: namespace:exactRankTests>
[1] wilcox.exact.default wilcox.exact.formula
A single object matching ‘wilcox.exact.default’ was found
It was found in the following places
  package:exactRankTests
  registered S3 method for wilcox.exact from namespace exactRankTests
  namespace:exactRankTests
with value

function (x, y = NULL, alternative = c("two.sided", "less", "greater"),
    mu = 0, paired = FALSE, exact = NULL, conf.int = FALSE, conf.level = 0.95,
    ...)
{
    alternative <- match.arg(alternative)
    if (!missing(mu) && ((length(mu) > 1) || !is.finite(mu)))
        stop("mu must be a single number")
    if (conf.int) {
        if (!((length(conf.level) == 1) && is.finite(conf.level) &&
            (conf.level > 0) && (conf.level < 1)))
            stop("conf.level must be a single number between 0 and 1")
    }
    MIDP <- NULL
    if (!is.numeric(x))
        stop("`x' must be numeric")
    if (!is.null(y)) {
        if (!is.numeric(y))
            stop("`y' must be numeric")
        DNAME <- paste(deparse(substitute(x)), "and", deparse(substitute(y)))
        if (paired) {
            if (length(x) != length(y))
                stop("x and y must have the same length")
            OK <- complete.cases(x, y)
            x <- x[OK] - y[OK]
            y <- NULL
        }
        else {
            x <- x[is.finite(x)]
            y <- y[is.finite(y)]
        }
    }
    else {
        DNAME <- deparse(substitute(x))
        if (paired)
```

```
    stop("y missing for paired test")
  x <- x[is.finite(x)]
}
if (length(x) < 1)
  stop("not enough (finite) x observations")
CORRECTION <- 0
if (is.null(y)) {
  METHOD <- "Exact Wilcoxon signed rank test"
  x <- x - mu
  ZEROES <- any(x == 0)
  if (ZEROES)
    x <- x[x != 0]
  n <- length(x)
  if (is.null(exact))
    exact <- (n < 50)
  r <- rank(abs(x))
  STATISTIC <- sum(r[x > 0])
  names(STATISTIC) <- "V"
  TIES <- (length(r) != length(unique(r)))
  if (exact) {
    PVAL <- switch(alternative, two.sided = pperm(STATISTIC,
      r, n, alternative = "two.sided", pprob = TRUE),
      greater = pperm(STATISTIC, r, n, alternative = "greater",
       pprob = TRUE), less = pperm(STATISTIC, r, n,
       alternative = "less", pprob = TRUE))
    MIDP <- PVAL$PPROB
    PVAL <- PVAL$PVALUE
    if (conf.int && !is.na(x)) {
      x <- x + mu
      alpha <- 1 - conf.level
      diffs <- outer(x, x, "+")
      diffs <- sort(diffs[!lower.tri(diffs)])/2
      if (TIES) {
       fs <- function(d) {
        xx <- x - d
        sum(rank(abs(xx))[xx > 0])
       }
       w <- sapply(diffs, fs)
      }
      else {
       w <- sum(rank(abs(x))):1
      }
      cint <- switch(alternative, two.sided = {
       qu <- qperm(alpha/2, r, n)
       ql <- qperm(1 - alpha/2, r, n)
       if (qu <= min(w)) lci <- max(diffs) else lci <- min(diffs[w <=
        qu])
       if (ql >= max(w)) uci <- min(diffs) else uci <- max(diffs[w >
```

```
                ql])
              c(uci, lci)
            }, greater = {
              ql <- qperm(1 - alpha, r, n)
              if (ql >= max(w)) uci <- min(diffs) else uci <- max(diffs[w >
                ql])
              c(uci, Inf)
            }, less = {
              qu <- qperm(alpha, r, n)
              if (qu <= min(w)) lci <- max(diffs) else lci <- min(diffs[w <=
                qu])
              c(-Inf, lci)
            })
            attr(cint, "conf.level") <- conf.level
            wmean <- sum(r)/2
            ESTIMATE <- mean(c(min(diffs[w <= ceiling(wmean)]),
              max(diffs[w > wmean])))
            names(ESTIMATE) <- "(pseudo)median"
        }
    }
    else {
        METHOD <- "Asymptotic Wilcoxon signed rank test"
        wmean <- sum(r)/2
        wvar <- sum(r^2)/4
        PVAL <- pnorm((STATISTIC - wmean)/sqrt(wvar))
        if (alternative == "greater")
            PVAL <- 1 - PVAL
        if (alternative == "two.sided")
            PVAL <- 2 * min(PVAL, 1 - PVAL)
        if (conf.int && !is.na(x)) {
            x <- x + mu
            alpha <- 1 - conf.level
            mumin <- min(x)
            mumax <- max(x)
            CORRECTION.CI <- 0
            wdiff <- function(d, zq) {
              xd <- x - d
              xd <- xd[xd != 0]
              nx <- length(xd)
              dr <- rank(abs(xd))
              zd <- sum(dr[xd > 0])
              zd <- (zd - wmean)/sqrt(wvar)
              zd - zq
            }
            cint <- switch(alternative, two.sided = {
              l <- uniroot(wdiff, c(mumin, mumax), tol = 1e-04,
                zq = qnorm(alpha/2, lower.tail = FALSE))$root
              u <- uniroot(wdiff, c(mumin, mumax), tol = 1e-04,
```

```
              zq = qnorm(alpha/2))$root
            c(l, u)
          }, greater = {
            l <- uniroot(wdiff, c(mumin, mumax), tol = 1e-04,
              zq = qnorm(alpha, lower.tail = FALSE))$root
            c(l, +Inf)
          }, less = {
            u <- uniroot(wdiff, c(mumin, mumax), tol = 1e-04,
              zq = qnorm(alpha))$root
            c(-Inf, u)
          })
          attr(cint, "conf.level") <- conf.level
          ESTIMATE <- uniroot(wdiff, c(mumin, mumax), tol = 1e-04,
            zq = 0)$root
          names(ESTIMATE) <- "(pseudo)median"
        }
      }
    }
    else {
      if (length(y) < 1)
        stop("not enough y observations")
      METHOD <- "Exact Wilcoxon rank sum test"
      r <- rank(c(x - mu, y))
      n.x <- length(x)
      n.y <- length(y)
      if (is.null(exact))
        exact <- (n.x < 50) && (n.y < 50)
      STATISTIC <- sum(r[seq(along = x)]) - n.x * (n.x + 1)/2
      names(STATISTIC) <- "W"
      TIES <- (length(r) != length(unique(r)))
      if (exact) {
        PVAL <- switch(alternative, two.sided = pperm(STATISTIC +
          n.x * (n.x + 1)/2, r, n.x, alternative = "two.sided",
          pprob = TRUE), greater = pperm(STATISTIC + n.x *
          (n.x + 1)/2, r, n.x, alternative = "greater",
          pprob = TRUE), less = pperm(STATISTIC + n.x *
          (n.x + 1)/2, r, n.x, alternative = "less", pprob = TRUE))
        MIDP <- PVAL$PPROB
        PVAL <- PVAL$PVALUE
        if (conf.int) {
          if (mu != 0)
            r <- rank(c(x, y))
          alpha <- 1 - conf.level
          diffs <- sort(outer(x, y, "-"))
          if (TIES) {
            fs <- function(d) sum(rank(c(x - d, y))[seq(along = x)]) -
              n.x * (n.x + 1)/2
            w <- sapply(diffs, fs)
```

```
        }
        else {
          w <- (n.x * n.y):1
        }
        cint <- switch(alternative, two.sided = {
          qu <- qperm(alpha/2, r, n.x) - n.x * (n.x +
            1)/2
          ql <- qperm(1 - alpha/2, r, n.x) - n.x * (n.x +
            1)/2
          if (qu <= min(w)) lci <- max(diffs) else lci <- min(diffs[w <=
            qu])
          if (ql >= max(w)) uci <- min(diffs) else uci <- max(diffs[w >
            ql])
          c(uci, lci)
        }, greater = {
          ql <- qperm(1 - alpha, r, n.x) - n.x * (n.x +
            1)/2
          if (ql >= max(w)) uci <- min(diffs) else uci <- max(diffs[w >
            ql])
          c(uci, +Inf)
        }, less = {
          qu <- qperm(alpha, r, n.x) - n.x * (n.x + 1)/2
          if (qu <= min(w)) lci <- max(diffs) else lci <- min(diffs[w <=
            qu])
          c(-Inf, lci)
        })
        attr(cint, "conf.level") <- conf.level
        wmean <- n.x/(n.x + n.y) * sum(r) - n.x * (n.x +
          1)/2
        ESTIMATE <- mean(c(min(diffs[w <= ceiling(wmean)]),
          max(diffs[w > wmean])))
        names(ESTIMATE) <- "difference in location"
    }
}
else {
    METHOD <- "Asymptotic Wilcoxon rank sum test"
    N <- n.x + n.y
    wmean <- n.x/N * sum(r)
    wvar <- n.x * n.y/(N * (N - 1)) * sum((r - wmean/n.x)^2)
    PVAL <- pnorm((STATISTIC + n.x * (n.x + 1)/2 - wmean)/sqrt(wvar))
    if (alternative == "greater")
        PVAL <- 1 - PVAL
    if (alternative == "two.sided")
        PVAL <- 2 * min(PVAL, 1 - PVAL)
    if (conf.int) {
        alpha <- 1 - conf.level
        mumin <- min(x) - max(y)
        mumax <- max(x) - min(y)
```

```
            CORRECTION.CI <- 0
            wdiff <- function(d, zq) {
              dr <- rank(c(x - d, y))
              dz <- sum(dr[seq(along = x)])
              dz <- (dz - wmean)/sqrt(wvar)
              dz - zq
            }
            cint <- switch(alternative, two.sided = {
              l <- uniroot(wdiff, c(mumin, mumax), tol = 1e-04,
                zq = qnorm(alpha/2, lower.tail = FALSE))$root
              u <- uniroot(wdiff, c(mumin, mumax), tol = 1e-04,
                zq = qnorm(alpha/2))$root
              c(l, u)
            }, greater = {
              l <- uniroot(wdiff, c(mumin, mumax), tol = 1e-04,
                zq = qnorm(alpha, lower.tail = FALSE))$root
              c(l, +Inf)
            }, less = {
              u <- uniroot(wdiff, c(mumin, mumax), tol = 1e-04,
                zq = qnorm(alpha))$root
              c(-Inf, u)
            })
            attr(cint, "conf.level") <- conf.level
            ESTIMATE <- uniroot(wdiff, c(mumin, mumax), tol = 1e-04,
              zq = 0)$root
            names(ESTIMATE) <- "difference in location"
        }
    }
}
if (!is.null(MIDP)) {
    names(MIDP) <- "point prob"
    RVAL <- list(statistic = STATISTIC, pointprob = MIDP,
        p.value = PVAL, null.value = c(mu = mu), alternative = alternative,
        method = METHOD, data.name = DNAME)
}
else {
    RVAL <- list(statistic = STATISTIC, p.value = PVAL, null.value = c(mu = mu),
        alternative = alternative, method = METHOD, data.name = DNAME)
}
if (conf.int) {
    RVAL$conf.int <- cint
    RVAL$estimate <- ESTIMATE
}
```

G2 R COMMAND LINE CODE FOR THE WILCOXON RANK-SUM TEST USING THE "EXACT RANK TEST "PACKAGE

G2.1 ONE SIDED TEST

```
#wilcox exact test (one sided for depths and irregularity metrics):  we are saying it is ok if the rep
#reach is more shallow or less irregular than the design
#Ho is that the rep reach (x) <= design group (y); Ha is that the rep reach (x) > design group (y),
#and therefore x-y is positive, and mu is greater than zero
#small p means that the design is more shallow than the rep reach,
#failure to reject means rep reach = design median, or design median is deeper

wilcox.exact(x, y, alternative = "greater", mu = 0,
        paired = FALSE, exact = TRUE,
        conf.int = TRUE, conf.level = 0.95)
```

G2.2 TWO SIDED TEST

```
wilcox.exact(x, y, alternative = "two.sided",
        mu = 0, paired = FALSE, exact = TRUE,
        conf.int = TRUE, conf.level = 0.95s
```