Winter 2012

Analysis of the geomorphic characteristics of streams with large wood hydraulic controls in coastal New Hampshire

Matthew A. Hergott
University of New Hampshire, Durham

Recommended Citation

Hergott, Matthew A., "Analysis of the geomorphic characteristics of streams with large wood hydraulic controls in coastal New Hampshire" (2012). *Master's Theses and Capstones.* 754.
https://scholars.unh.edu/thesis/754

ANALYSIS OF THE GEOMORPHIC CHARACTERISTICS OF STREAMS WITH LARGE WOOD HYDRAULIC CONTROLS IN COASTAL NEW HAMPSHIRE

BY

MATTHEW A. HERGOTT

B.S. Civil Engineering, College of Engineering and Physical Sciences, 2010

THESIS

Submitted to the University of New Hampshire
in Partial Fulfillment of
the Requirements for the Degree of

Master of Science
In
Civil Engineering

December, 2012

ProQuest LLC
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106-1346

This thesis has been examined and approved.

Thesis Director, Dr. Thomas Ballestero, Associate Professor of Civil Engineering

Dr. Jennifer Jacobs, Professor of Civil Engineering

Dr. Anne Lightbody, Assistant Professor of Hydrology

14 Dec 2012

Date

ACKNOWLEDGMENTS

I wish to thank first and foremost, my advisor Dr. Tom Ballestero whose interest in stream restoration lead me into this field. His knowledge of this subject was instrumental in moving this thesis forward.

My utmost gratitude goes to my committee members Dr. Jennifer Jacobs and Dr. Anne Lightbody whose constructive advice helped shape this thesis into what it is today. I would like to thank the New Hampshire Department of Environmental Services whose study helped jumpstart this thesis. I am also indebted to my fellow classmates who helped in data collection and support during research and analysis.

I would finally like to thank my friends and family for their ongoing support and motivation throughout the process of writing this thesis. Without them, I would not be where I am today.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

ANALYSIS OF THE GEOMORPHIC CHARACTERISTICS OF STREAMS WITH LARGE WOOD HYDRAULIC CONTROLS IN COASTAL NEW HAMPSHIRE

by

Matthew A. Hergott

University of New Hampshire, December, 2012

Wood is an integral part of stream health. Large woody debris (LWD) creates habitat and refuge for both fish and invertebrates. Knowing the effects of LWD on stream geomorphology is helpful for stream restoration projects so that the placement of wood mimics the natural condition. This study compares conventional-sediment riffles to wood-dominated riffles in southeastern, coastal New Hampshire. Wood riffles are fast-moving sections of the stream where the presence of LWD creates a local change in stream slope. Past studies have found that log steps are wider, shallower, steeper, more closely spaced, have finer bed sediments than conventional riffles on the same system.

Field surveys were conducted on wood-riffle and conventional sediment riffle sections of several streams in the seacoast region of New Hampshire. Geomorphic data were collected as well as regional geomorphic data from a Rapid Geomorphic Assessment from 2011. Properties of the wood riffles were compared to the representative reference riffle sections and to the regional data. Analysis shows that wood riffles are wider, have larger area, are finer upstream, and coarser downstream than conventional riffles. They also have more variation in slope and spacing than the reference sections.

CHAPTER 1

INTRODUCTION

1.1 Importance of Large Woody Debris

Wood is an integral part of stream health. It is naturally present in streams throughout the world. There has been extensive research on the ecological benefits of wood. It retains organic matter for the consumption of small organisms (Bilby & Likens 1980). This in turn provides food for fish as well. Wood creates protective habitat for fish and an available food source for invertebrates (Angermeier & Karr 1984). It can also support large populations of different species by creating varied habitats up and down a stream profile (Gurnell et al. 2002). The damming effect of woody debris can speed recovery of unstable channels (Wallerstein & Thorne 2004) and further connect a channel with its adjacent floodplain (Gippel et al. 1996). Wood also has an important function on stream geomorphology. Its presence in streams has been tied to wider channels, bed erosion, bed deposition, and channel migration (Keller & Swanson 1979).

Most research in this area has focused on relatively steep headwater streams in the northwestern U.S. and Europe with only one study within New England (Magilligan et al. 2008). Specific geomorphic, hydraulic, and ecological effects of wood can vary from system to system due to differences in sediment transport regimes and wood recruitment processes (Gurnell et al. 2002). Unlike previously researched systems, streams in coastal New England are low-gradient and predominantly convey and deposit sediment. Thus, it is important to look at the effects of large woody debris on stream geomorphology in New Hampshire. In this way, regional restoration efforts can use wood to provide a more natural condition. The White Paper, which presently guides stream restoration in New Hampshire, is largely silent on the subject of large woody debris and how to include it in restoration projects (Schiff, MacBroom & Bonin 2006).

Large woody debris (LWD) can be defined as dead wood that is within the floodplain and is greater than 0.1 m in diameter and longer than 1 m (Keller & Swanson 1979; Gippel 1995). LWD can enter a stream through various input processes. Bank failure is the predominant mechanism for low gradient streams as well as wind or ice damage to a lesser degree (Keller & Swanson 1979; Wallerstein & Thorne 2004). Wood that enters the stream through bank failure and blow downs is generally immobile because of the dense root wad (Wallerstein & Thorne 2004). Bank failure causes LWD to topple across the channel, more or less perpendicular to the banks (Wallerstein & Thorne 2004). In cases where debris is mobile, LWD may be carried downstream when the stream overflows its banks during floods. Since debris is more mobile in wider and deeper streams with larger flows, smaller headwater streams tend to contain more LWD (Keller & Swanson 1979)

Riffles refer to the shallow, higher velocity portions of a stream made up of coarser sediments. These sections are important in sediment transport and where energy is dissipated over a steeper length. Wood riffles are not made of sediment but instead consist of wood. A log step more specifically refers to the instance where LWD crosses the entire channel section perpendicular to flow and causes a change in water elevation (Marston 1982; Montgomery et al. 2003). An idealized profile for such a system is shown in Figure 1. This study focuses on log steps specifically, but it should be noted there are many ways that wood can act as a riffle. It has been found that most log steps or wood riffles occur in medium-sized third order streams as opposed to larger or smaller channels. This is possibly because the topography of smaller streams limits the ability for a log to block the channel or cause breakage (Marston 1982; Nakamura & Swanson 1993). In small, headwater streams, the larger debris generally remains where it fell and can dominate channel morphology for decades (Keller & Swanson 1979; Montgomery & Buffington 1998; Piégay & Gurnell 1997). The stability of LWD is generally a function of its size in relation to the channel size (Gurnell et al. 2002). Logs shorter than the average bankfull width are less stable than those that are larger (Hilderbrand et al. 1998; Wallerstein & Thorne 2004). Wood often occurs in groups even when these pieces are not trapped by other pieces. This arrangement can be attributed to grouped pieces being more hydraulically efficient or creating less backwater (Gippel et al. 1996).

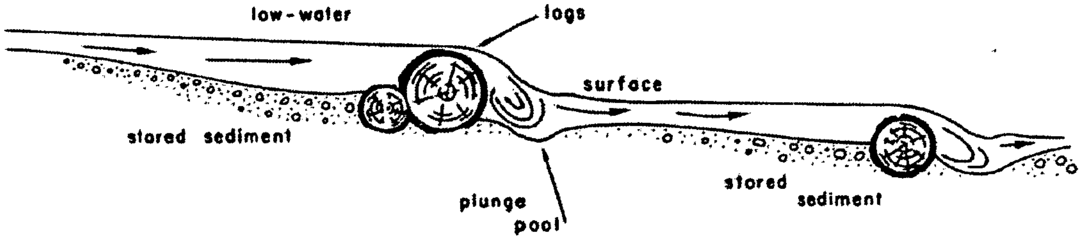


Figure 1: Typical log step sequence from Keller & Swanson 1979.

LWD can effect flooding in different ways. Wood, as any blockage to flow, increases water level behind it and can lead to increased bank overflow or flooding of the banks (Gippel et al. 1996). However, log steps are essentially run-of-river dams and can dissipate flood waves through flow routing (Gippel et al. 1996). The resistance effect of a log step can be described by drag. Blockage ratio and the angle of the log influence drag the most (Gippel et al. 1996):

$$B = {}^{Ld}/_{A} \tag{1}$$

where blockage ratio, B, is unit-less, L is the length of wood in flow, d is the diameter of wood in flow, and A is the cross-sectional area of flow.

1.2 LWD and Geomorphology

Geomorphology is the study of the development of landforms based upon the effects of erosion and weathering (Leopold, Wolman & Miller 1964). More specifically, fluvial geomorphology looks at how rivers and streams change in form over time. Form is often quantified by variables categorized as dimension, pattern, and profile. LWD can have significant effects on these channel properties through erosion and deposition. Channel widening, bed scour, bar development, and channel movement can all be facilitated by wood deposition (Keller & Swanson 1979).

The majority of studies on LWD have focused on sediment transport, energy dissipation, and hydraulic function (Marston 1982; Gippel et al. 1996; Gippel et al. 1996; Wilcox & Wohl 2006). Several studies specifically address geomorphological effects of LWD on dimension, pattern, and profile (Keller & Swanson 1979; Montgomery et al. 1995; Beebe 2000; Kail 2003; Faustini & Jones 2003; Nakamura & Swanson 1993; Wallerstein & Thorne 2004).

Keller and Swanson (1976) studied the effects of woody debris in low and high gradient streams. They found that the influence of LWD on stream morphology is a function of the source of wood, the stream size, and the valley morphology. It was seen that wood can widen the banks, scour the bed, create mid-channel bars, and create meander cut-offs. Step spacing was small, only 1-2 channel widths, in the streams studied. The effects of wood after it was removed by natural processes seemed to remain. They also found that the effect of LWD on sediment storage and energy was more significant in steeper streams.

Nakamura and Swanson (1993) studied the effects of coarse woody debris, another name for LWD, on geomorphology in the Oregon Cascades. It was found that wood was associated with wider and slightly steeper channels. When adjusted for watershed area, streams with wood were 1.5 times wider than streams without it. The result was a stream profile that had a shallow slope before the wood jam then became much steeper after the jam. The spacing of this sharp gradient change and pools were around 3-4 channel widths as compared to the common 5-7 channel widths for conventional sediment streams (Leopold, Wolman & Miller 1964). Channel migration or pattern changes occurred only in streams present in less confined valleys.

Montgomery and Buffington (1995) studied the relationship between LWD loading and pool spacing in forested streams of southeastern Alaska and Washington. It was found that pool spacing in forested mountain streams was a function of LWD loading, channel type, slope, and width. Riffle-pool and forced riffle-pool streams with wood had smaller pool spacings (2-4 and 2-3 channel widths, respectively) than streams without wood. The majority of pools surveyed were not free-formed but were created by scour due to the presence of wood.

Beebe (2000) conducted flume experiments to investigate downstream flow disturbance due to the presence of logs. Obstructions were placed perpendicular to flow and three trials were conducted with differing obstruction percentages. Obstruction percentage was defined as the ratio of the diameter of the log to the depth of flow. This represents a similar concept to blockage ratio (Gippel et al. 1996). It was found that all three cylindrical obstructions created similarly shaped scour pools. Additionally, these seemed to occur in the most stable part of the log.

Kail (2003) conducted field investigations of single fallen trees in six European stream sections and compared them to sections free of debris. This was accomplished using terrain models and cross-sections. The study found pool volume had a strong correlation to blockage ratio, a parameter that measures the cross sectional area blocked by LWD. Some LWD sections were linked to total pool volumes 7 to 11 times greater than those without. In general, LWD influenced sections were wider than conventional sections. The largest differences between free and woody sections occurred in low gradient sand bed streams.

Faustini and Jones (2003) analyzed the geomorphic effects of wood removal on third-order, high-gradient stream channel morphology. Removal caused coarsening and bed degradation whereas an untouched segment actually accumulated sediment. They found that LWD creates more variability in slope and bed particle size and increased channel stability. Wallerstein and Thorne (2004) connected LWD loading with the channel evolution model for low-gradient, sand-bed, incising streams. They discovered that over two thirds of the debris jams investigated were due to bank failure and half of those were on the outside of a meander bend. Debris loading was highest during widening and incising immediately after equilibrium is compromised. It was found that debris jams tend to retain more sediment than lose through scour. In this way channel evolution can be accelerated toward equilibrium.

A large component of the overall view of stream morphology must include sediment transport. In many systems, wood can be the dominant sediment storage control often containing more than twice the mean annual sediment discharge (Nakamura & Swanson 1993; Marston 1982). LWD traps sediment and reduces the total energy in a stream (Marston 1982; Montgomery et al. 2003). Additional downstream sediment deposition can also be associated with the scour pool created by LWD (Montgomery et al. 2003). Wood creates roughness within the stream which reduces overall energy and shear stress on the bed and sediment transport leading to smaller bed grain sizes (Montgomery et al. 2003; Faustini & Jones 2003; Wilcox & Wohl 2006).

The effect of wood on various channel processes is a function of its horizontal and vertical orientation (Gippel et al. 1996; Montgomery et al. 2003; Hilderbrand et al. 1998). Horizontally, logs may be perpendicular, parallel, or oblique to flow. Possible vertical orientations include dam, pitched/ramped into or out of flow, or vertically sticking out of the water (Hilderbrand et al. 1998). Orientation effectively concentrates and controls flow to focus scour and deposition on different areas of the stream (Beebe 2000). Because of the multitude of combinations, this thesis focuses on log steps or log dams that are perpendicular to flow. Cases such as this lead to significant geomorphological effects such as bed scour, deposition, and channel widening. These are some of the most stable forms of wood riffles and have more predictable effects. The effects of log steps still can vary due to slight differences in horizontal and vertical orientation; this is the result of the natural placement of wood along the channel. In general, streams with LWD have a more variable and wider cross-section than unforested streams (Montgomery et al. 2003; Nakamura & Swanson 1993; Montgomery et al. 1995). This is due to flow redirection by logs. LWD also influences pool spacing. Higher wood loading is correlated with smaller pool to pool spacing (Montgomery et al. 1995).

1.3 LWD in Coastal New England

Past research has primarily focused on steep-sloped streams of the U.S. Northwest and Alaska (Nakamura & Swanson 1993; Montgomery et al. 1995; Faustini & Jones 2003). These cases are not typical for coastal New England where streams tend to be low to moderate gradient. Wood loading in streams in the northwest tends to be heavily influenced by the logging industry and thus changes in wood loading, such as removal, is more predominant. A recent study conducted in Maine found that LWD loading was smaller than anywhere else in the country and mostly occurred parallel to flow (Magilligan et al. 2008). Wood was not a driving force in pool formation. They concluded that the lack of LWD was likely due to the active logging industry as most wood present was small and from young growth.

Coastal New Hampshire does not have an active logging industry like much of Maine. Although much of the land was not forested throughout most of the 1800's, by the turn of the twentieth century, farm abandonment had resulted in significant reforestation (Foster 1992). Today most of these forests are mature and present throughout much of the region. They are dense enough and contain enough large enough trees to contribute to significant wood loading.

1.4 Objective of Research

The purpose of this research is to compare the metrics of wood-dominated riffle systems to those metrics for conventional-sediment riffles of low gradient streams in coastal New Hampshire. It is hypothesized that when compared to conventional riffles,

- Wood-dominated riffles will be wider
- Wood-dominated riffles will be shallower
- Wood-dominated riffles will have a lower gradient upstream followed by a steep gradient downstream
- Wood-dominated riffles will have a smaller spacing from riffle head to riffle head
- Wood-dominated riffles will have smaller bed sediment diameters upstream of the riffle and larger diameters downstream

Through these findings, a better understanding of the function of wood in lowland New England streams will be obtained. The effects of wood steps on geomorphology will give ecological restoration efforts more insight as to the placement of wood to more accurately mimic the natural presence of wood in reference streams. This would be practical for areas where historic or current tree removals in the immediate vicinity of the stream have altered natural wood deposition schemes.

CHAPTER 2

METHODS AND SITE DESCRIPTIONS

2.1 Seacoast New Hampshire Regional Data

Cross-sections, pebble counts, and spacing data were gathered over the summer of 2011 as part of a Rapid Geomorphic Assessment (RGA) of the Cochecho and Lamprey River watersheds. The complete dataset can be found in the Appendix. Data were gathered from the North, Little, North Branch, Piscassic, Lamprey, and Cochecho Rivers. Only sections from third and fourth order reaches are included in the regional dataset.

The North River is a tributary of the Lamprey River and flows from its headwaters in Northwood, NH through Nottingham and Lee, NH. It has a watershed area of 93.47 square km and is a 5th order stream when it reaches the Lamprey. North River Pond dam is the only known flow regulation along the river. A total length of 25.12 km of reaches was assessed, and 21 sections were evaluated between June 30 and July 28, 2011. Eight sections from this river are included in the regional dataset.

The Little River is a tributary of the Lamprey River with headwaters in Mendum's Pond, Barrington, NH. It flows through Barrington, Nottingham, and Lee, NH and covers a total watershed area of 52.06 square km. It is a 3rd order stream when it reaches the Lamprey. There are two known flow regulation structures upstream of the assessed reaches: Mendum's Pond dam and Nottingham Lake dam. A total length of 13.31 km of reaches was assessed along the Little River with 13 sections evaluated between June 7 and June 27, 2011. Twenty-two sections from this river are included in the regional dataset.

The North Branch River is a 13.1 km long tributary of the Lamprey River with headwaters in Beaver Pond in Deerfield, NH. It flows through Deerfield, Candia, and Raymond, NH and covers a total watershed area of 44.7 square km. It is a 3rd order stream when it reaches the Lamprey River. Three sections from this river are included in the regional dataset.

The Piscassic River is a 25.1 km long tributary of the Lamprey River with headwaters in Fremont, NH. It flows through Epping, Newfields, and Newmarket, NH and covers a total watershed area of 59.4 square km. Six sections from this river are included in the regional dataset.

The Lamprey River is a 76.1 km long river with headwaters in Northwood, NH. It flows through Deerfield, Candia, Raymond, Epping, Lee, Durham, and Newmarket NH and covers a total watershed area of 554 square km. It empties into the Great Bay in Newmarket. Fifteen sections from this river are included in the regional dataset.

The Cochecho River flows from its headwaters in Alton, NH through New Durham, Farmington, Rochester, and Dover, NH. It has a watershed area of 478.55 square km and is a 5th order stream when it reaches the Piscatiqua River. There are many flow regulations along the river but none occur upstream of the reaches assessed. A total of 8.96 km of reaches was assessed with six sections evaluated in August 2011. Twelve sections from this river are included in the regional dataset

2.2 Log Step Survey Locations

Several river systems in seacoast New Hampshire were investigated for suitable log steps survey locations. Geomorphic surveys were conducted at eight sites. Figure 2 shows the locations of the reaches surveyed in relation to the rest of the seacoast. A summary of the sites is presented in Table 2. Each section is also assigned a Rosgen Classification which groups streams by geomorphologic type (A, B, C, D, E, F, and G) based on braiding, width/depth, entrenchment ratio, slope, sinuosity, and bed material (Rosgen 1994). This is provided so that the context of each river is known.

All sections are labeled by the river name and reach number followed by a dash and the section number. Table 1 shows the river labeling scheme. For example NR04-1 corresponds to North River, Reach 4, Section 1. For specific wood and conventional reference section surveys, a 'C' or 'W' is used to distinguish conventional or wood dominated section. For example LiRW-03 refers to Little River, Wood Section 3.

Table 1 River Labeling Scheme

Prefix	River
LiR	Little River
NR	North River
CR	Cochecho River
MB	Mallego Brook
OR	Oyster River
BR	Bellamy River
PR	Piscassic River
LR	Lamprey River
NBR	North Branch River

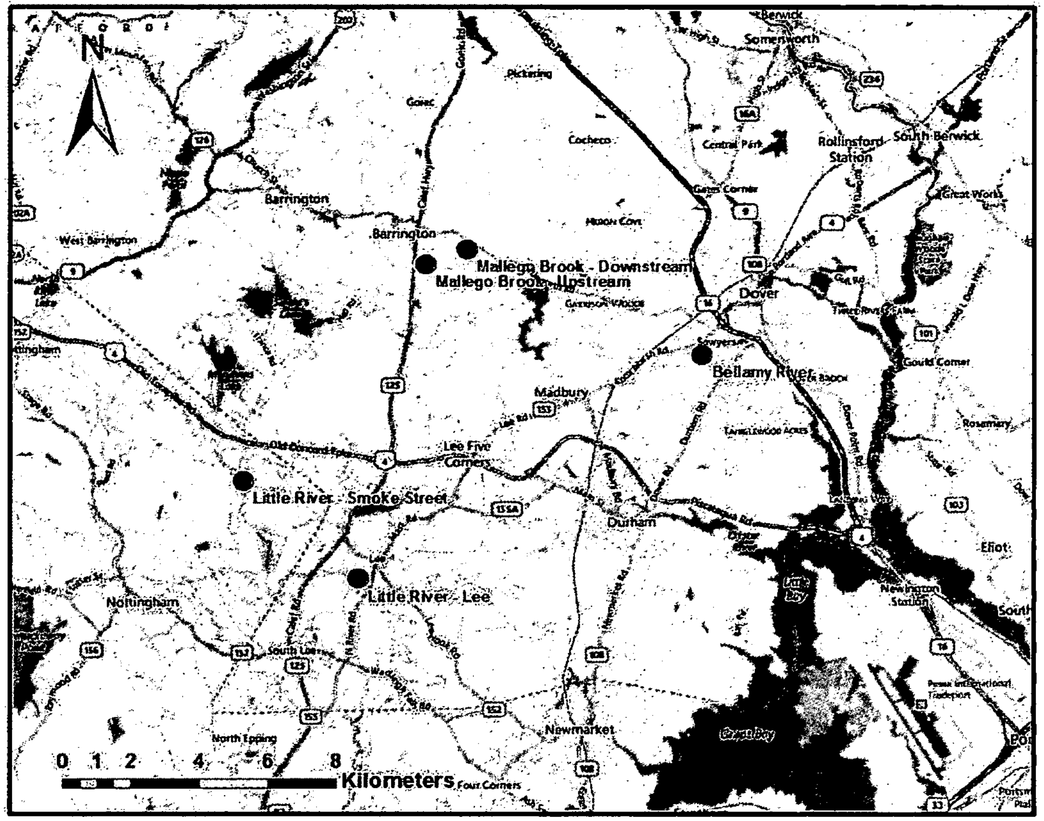


Figure 2: Locations of wood-controlled and conventional reference riffle surveys

Table 2 Summary of Surveyed Reaches. Stream order refers to the Strahler Stream order of the reach. WA is the total watershed area upstream of section.

Section	Date surveyed	Type of riffle	Stream Order	WA (sq. km)	Description	Rosgen Classification
LiRW-03	10/25/2011	Wood	3	31.88	Partial log step, partial underflow	C4
LiRW-04	11/8/2011	Wood	3	31.93	Partial log step, partial underflow	E4*
LiRC-01	11/8/2011	Conventional	3	31.91	Reference section	C4
MBW-01	3/20/2012	Wood	3	13.93	Underflow jam, partial debris dam	C4b
MBW-02	3/20/2012	Wood	3	13.99	Complete log step	C4
MBC-03	3/20/2012	Conventional	3	14.01	Reference section	C4
MBW-04	3/27/2012	Wood	3	15.85	Complete log step, mostly embedded	C5
MBW-05	3/27/2012	Wood	3	15.85	Debris dam with large key piece	C5b
MBC-06	3/27/2012	Conventional	3	15.93	Reference section	C3
BRW-01	4/1/2012	Wood	4	67.55	Complete log step, bedrock confined	F1
BRC-02	4/1/2012	Conventional	4	67.57	Reference section, bedrock confined	F1
LiRW-05	6/7/2012	Wood	3	51.33	Complete log step	C4b*
LiRC-06	6/7/2012	Conventional	3	51.39	Reference section	C4*

*bed composition estimated based on observations

2.2.1 Little River: Smoke Street

This site is located about 150 meters downstream of the Smoke Street culvert in Nottingham, NH. Two wood-controlled riffles and one conventional riffle were evaluated at this location. The first section (LiRW-03) is the farthest upstream and can be described as a 19.5 cm diameter blow-down impeding flow, shown in Figure 4. The obstruction forces most water toward the left bank, or the left side when looking downstream. A significant portion of flow occurs over the log step however. The second section (LiRC-01) downstream is a conventional riffle, shown in Figure 5. The final section (LiRW-04) is a wood hydraulic control composed of two parallel logs of 28 and 18 cm, shown in Figure 6. Water flows over and under in a narrow, deep section of the stream. The floodplain for both sections is mostly wetlands and located on the left bank. Field measurements were conducted in October 2011 and March 2012.

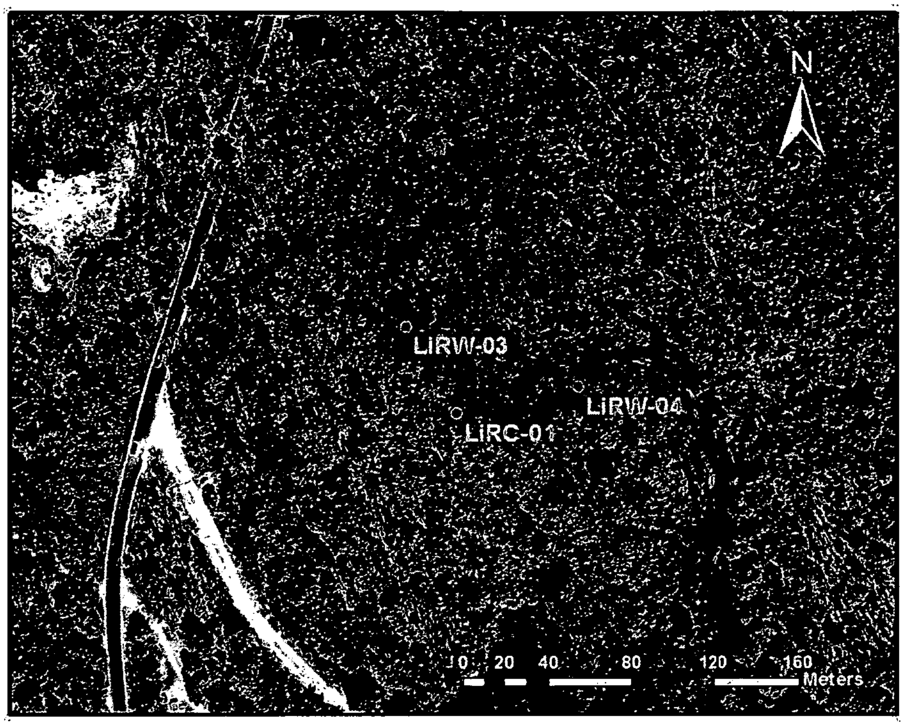


Figure 3: Little River-Smoke Street survey locations

Figure 4: Wood riffle LiRW-03 looking north, upstream

Figure 5: Reference section LiRC-01 looking south, downstream

Figure 6: Wood-riffle LiRW04 looking west, upstream

2.2.2 Little River: Lee

This site is located about midway between NH-155 and Lee Hill Road in Lee, NH. The first section (LiRW-05) is upstream and is located on a bend in the river shown in Figure 8. This is a 20 cm blow-down located between four similar wood-controls in a row. This classic log step is located on a meander bend with large gravel sediment buildup upstream and a plunge pool directly below. The sediment is primarily located on the left bank or the inside of the meander bend and is probably a point bar. The second section (LiRC-06) is a conventional sediment riffle located around 300 feet downstream shown in Figure 9. The floodplain is located on the left bank for both sections and ends at a terrace. Field measurements were conducted in June 2012.

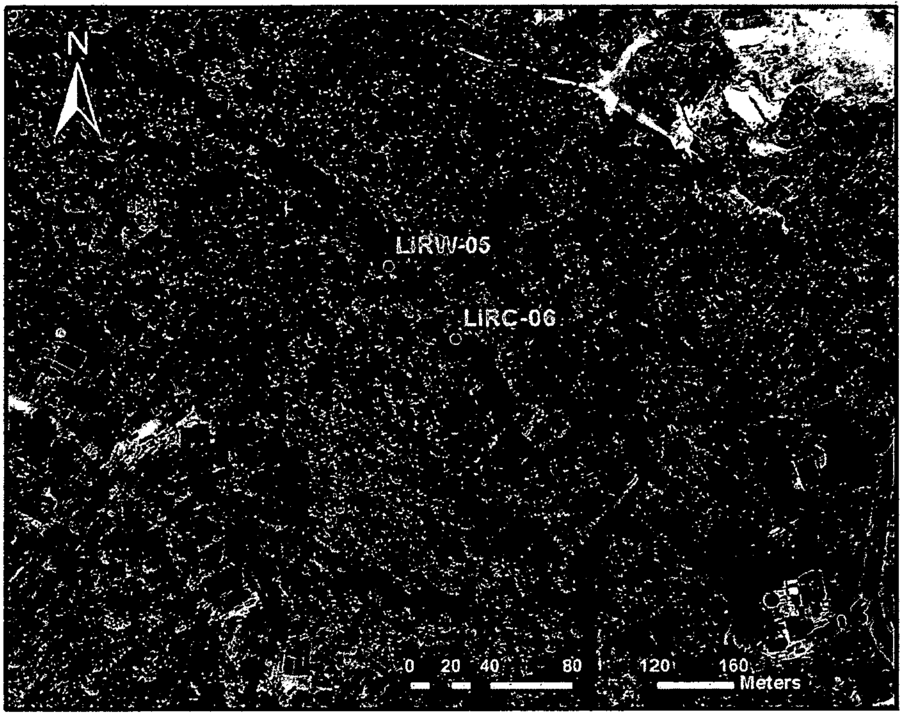


Figure 7: Little River-Lee survey Locations

Figure 8: Wood riffle LiRW-05 looking south, downstream

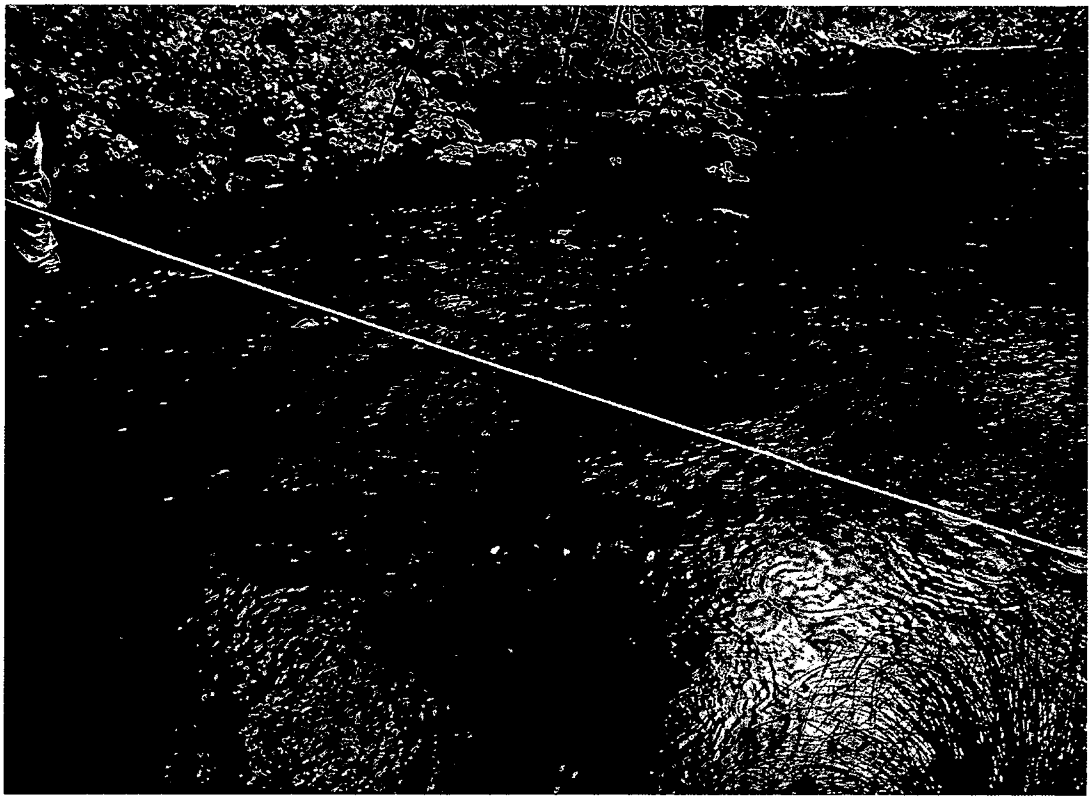


Figure 9: Reference section LiRC-06 looking east, downstream

2.2.3 Bellamy River

This site is located upstream of Bellamy Road in Dover, NH. One wood-controlled riffle and one conventional sediment riffle were evaluated at this location. BRW-01 is the most upstream and consists of 15.5 cm and 21 cm logs crossing the entire section, shown in Figure 11. The two logs fell from opposite sides and create a low, angled point in the middle where the step occurs at most flows. There is some flow underneath and through debris that is caught on the logs. BRC-02 is located around 100 feet downstream and is shown in Figure 12. The channel has a bedrock bed of jagged shale and is heavily entrenched in the banks. There is little access to the floodplain.

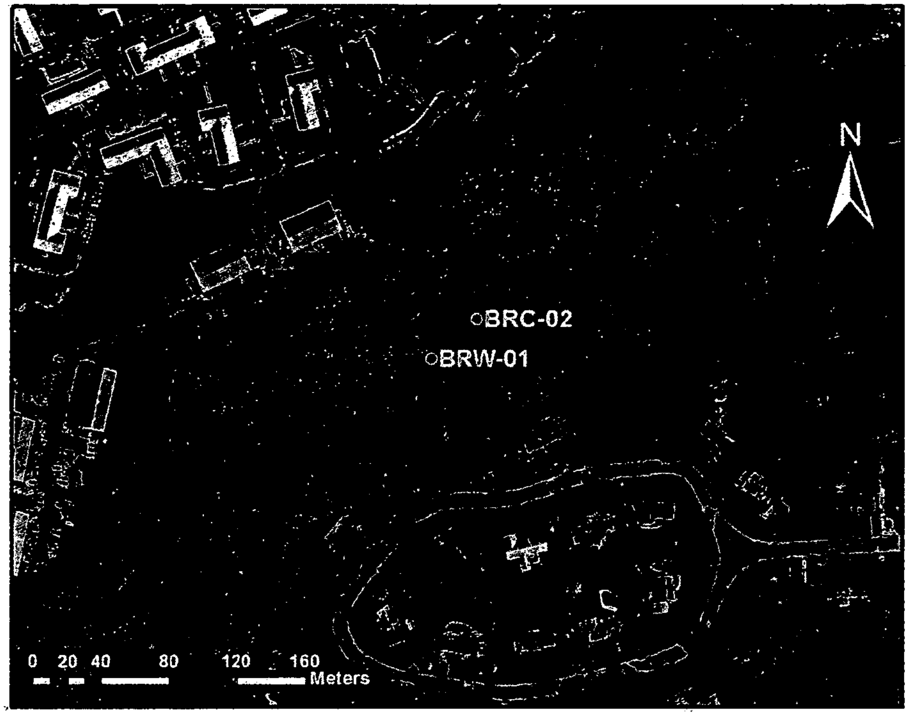


Figure 10: Bellamy River survey locations

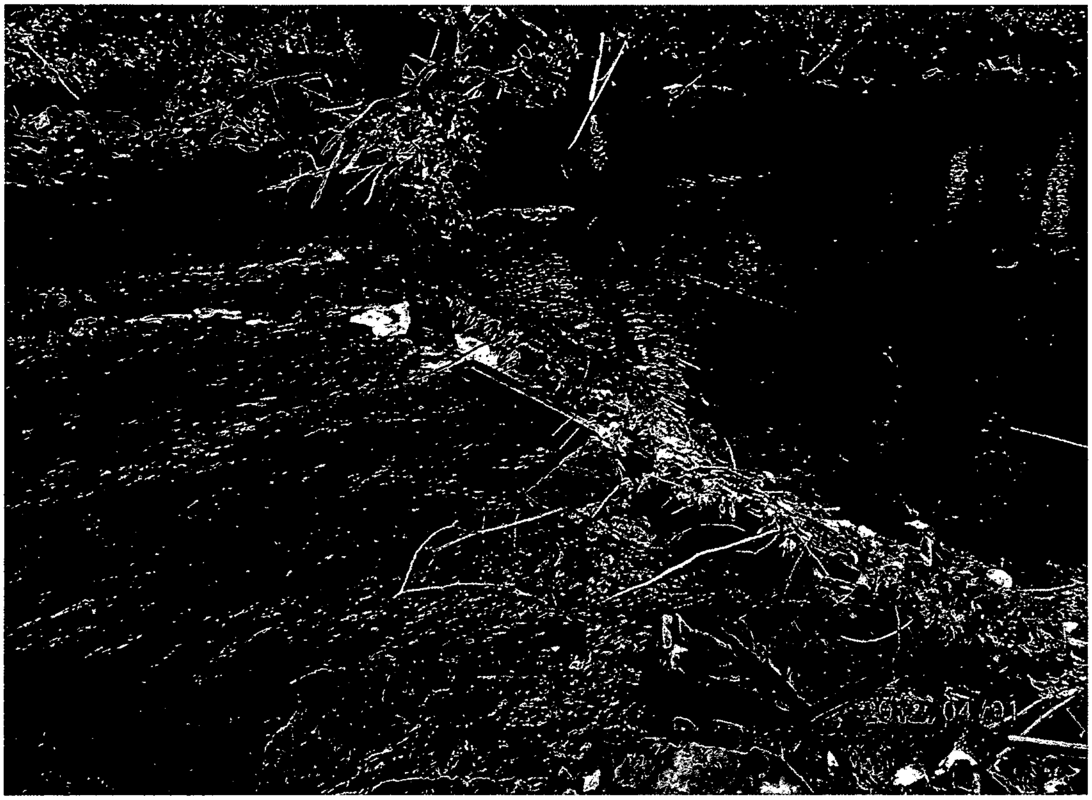


Figure 11: Wood riffle BRW-01 looking south, upstream

Figure 12: Reference section BRC-02 looking east, downstream

2.2.4 Mallego Brook

This site is located between NH-9 and NH-125 behind the Barrington Middle School in Barrington, NH. Four wood-controlled riffles and two conventional riffles were evaluated at this location: a set of three close to NH-125 and a set of three close to NH-9. The most upstream section (MBW-01) can be described as a 29 cm diameter blowdown with all flow going under the log except at bankfull and higher events, shown in Figure 14. The next section downstream (MBW-02) consists of a 19 cm true log step with sediment build up behind it, shown in Figure 15. A portion of flow occurs under an overhang on the left bank. The conventional section (MBC-03) is located just downstream of this, shown in Figure 16. There is a low area off the left bank that may become flooded during bankfull but is not part of the channel. Floodplains are located on either side of the stream and there is evidence of recent flooding. Field measurements were conducted in March 2012.

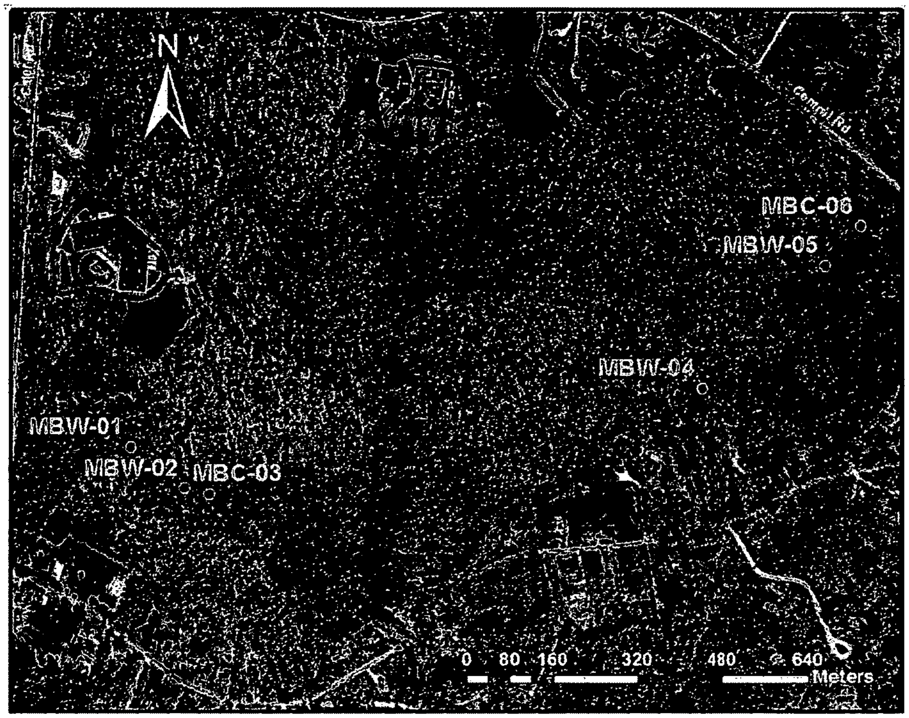


Figure 13: Mallego Brook survey locations

Figure 14: Wood riffle MBW-01 looking north, at left bank

Figure 15: Wood riffle MBW-02 looking east, downstream

Figure 16: Reference section MBC-03 looking west, upstream

The second cluster of sections begins with MBW-04 which is an old 17 cm diameter log step buried in sediment that impacts low flows, shown in Figure 17. Upon later visits, a beaver dam downstream backed up flow to the point where there is no longer an impact. The next section downstream (MBW-05) is a debris jam created by logs around 10 cm buried in other coarse woody debris, shown in Figure 18. There was no evidence that this was created by beaver activity. The cause of this jam is from the confinement of the banks and stonewall. There is a considerable step down to a pool; the bed consists of cobbles downstream. Flow occurs over and through the obstruction. The conventional riffle (MBC-06) is the farthest downstream and is in a slow moving section upstream of a snowmobile bridge, shown in Figure 19. Floodplain access is near the same on both banks for all three sections. Field measurements were taken in March 2012.

Figure 17: Wood riffle MBW-04 looking south, at right bank

Figure 18: Wood riffle MBW-05 looking west, at left bank

Figure 19: Reference section MBC-06 looking north, downsream

2.3 Metrics

2.3.1 Dimension Properties

Dimension characteristics are found by surveying each location and are cross-sectional metrics; bankfull width (W_{bkf}), bankfull depth (d_{bkf}), mean bankfull depth ($\overline{d_{bkf}}$), bankfull area (A_{bkf}), and width of flood-prone area (W_{fpa}). Sections for the Cochecho and Lamprey conventional riffle dataset were found using a 91.5 meter bank tape and Crain surveying rod. The tape was stretched perpendicularly across characteristic riffles and secured with long screwdrivers used as stakes. Heights were read for each station from the river bed or bank to the bank tape elevation. Stations were determined based on significant changes in slope. Left and Right bankfull elevations were noted. Elevations were calculated using MS Excel based off the bankfull elevation. Floodprone width was found using a rangefinder on either bank, held at approximately twice bankfull depth from the thalweg, or the deepest part of the stream.

Detailed LWD and conventional sediment sections were measured with an optical level, 300 foot bank tape, and surveying rod using a similar procedure as the previous dataset. The optical level added more accuracy to readings. Floodprone width was found using the bank tape and twice bankfull depth. Sections were created and relevant metrics were extracted using AutoCAD.

Measurements were examined in context to ensure accuracy. Two changes were made. On MBW-02 there was an overhang of 0.6 m on the left bank. This could not be measured and was not part of the section but is still an area that sees flow. It was added into the section post-survey. Another case occurred on MBC-03. When re-examined, a low area adjacent to the left bank created an inaccurate measure of width. This area is below bankfull and thus was incorporated into both width and area. It was effectively a hole on the floodplain. This depression would not see flow in a bankfull event as it is blocked off from the main channel by a significant lip, and therefore should not be included as a part of the active channel.

2.3.2 Pattern Properties

Pattern characteristics are plan-view metrics; radius of curvature, amplitude, and sinuosity are measures of the relative sinuosity of the stream. Since pattern metrics are more of a reach characteristic, they were evaluated qualitatively in the field.

2.3.3 Profile Properties

Pool to pool characteristics are longitudinal section metrics: riffle-pool spacing (Sp), bed slope (S_{bed}), and bed slope across the riffle (S_{rp}). Longitudinal profiles were surveyed using an optical level, surveying rod, and 300 foot bank tape. The bank tape was strung through the channel centerline to approximate the thalweg, or deepest point along the channel. Differential elevations and water levels were recorded for riffle heads and the deepest part of the pools along the approximate thalweg. For each section, profile data were collected to the nearest riffle upstream and downstream. Bed slope was measured from the top of the riffle to the top of the subsequent riffle. Another type of bed slope, slope across the riffle, was calculated from the top of the riffle or log step of interest to the point of maximum depth in the subsequent pool. This was useful in looking at scour.

Similarly, spacing is reported as the distance from the riffle or log step of interest to the nearest upstream and downstream riffle. Average spacing is the average of the individual upstream and downstream spacing measurements. Spacing is normalized by bankfull width. This allows for cross-comparison between stream systems. Spacing values for the summer 2011 dataset were found using a rangefinder throughout the reach and averaged.

Riffle – pool elevation differences were calculated for each wood riffle, from the top of the log to the deepest point of the subsequent pool. For conventional sediment riffles, these differences were averaged from one riffle upstream and one riffle downstream.

2.3.4 Bed Sediment Characteristics

Bed material was evaluated by conducting pebble counts at the date when surveys were performed. The method described in Harrelson et al. (1994) was used. A metric ruler was used and measured in centimeters. For reference reaches conducted during summer 2011, pebble counts were conducted within riffle sections. This was slightly altered in the case of log steps; 50 measurements were taken immediately upstream of the LWD and 50 were taken in the subsequent downstream pool. This gives a representative 100 samples for the wood riffle-pool sequence. Data were plotted as millimeters in a particle size distribution (PSD) which allowed for comparison of reaches.

2.3.5 Statistical Methods

Statistical hypothesis tests are used to compare data using a set method. This is useful as conclusions can be drawn in a consistent and reproducible manner, and it allows for a numeric value or p-value, to represent the confidence of the conclusion (Helsel & Hirsch n.d.). The basic procedure is to choose the test, determine a null and alternate hypothesis, determine a suitable error level (alpha), calculate the test statistic, calculate the matching p-value, and compare this with the alpha value. When the numeric value or "p-value" is less than a predetermined confidence level "alpha", the null hypothesis is rejected. There are parametric and nonparametric tests. Parametric tests are used when the data are normally distributed. The probability plot correlation test (PPCC) is used to test for normality. Nonparametric tests were used in all tests in this report as data were not normally distributed.

The goal of this analysis is to provide a statistical basis for the observed results. Two different tests are used; one for comparing all eight wood riffles to the regional riffle characteristics and one for comparing each wood riffle with its corresponding reference section.

The first test used is the rank-sum test. This is a hypothesis test that compares two independent groups. The regional dataset is comprised of measurements from various streams in the area. When this is compared to the eight sections wood riffle sections, there is no inherent pairing and therefore is comparison between two independent groups. The rank-sum test statistically determines whether one dataset tends to contain larger values than another dataset. This is accomplished by ranking the dataset assigning a score (W_{rs}). This can be used to find a Z value from a normal distribution as well as a p value. There is an exact and approximate form of this test. The exact test is used with sample sizes smaller than 10. Although the smaller dataset was only 8, the approximate test had to be used as the regional dataset was so large.

The second test used is the sign test. This is a hypothesis test that compares paired data groups. This test is appropriate as the eight wood hydraulic control sections are inherently paired with a reference section on the same reach. The sign test statistically determines whether a dataset is larger or smaller than another. This is based on differences between the medians of the two data groups. A test statistic, S+, or number positive differences between the pairs, is calculated. An associated p value is found using Appendix B5 of Helsel and Hirsch, found in the Appendix. The exact form of the sign test was used as the sample size was smaller than ten.

CHAPTER 3

RESULTS

3.1 Dimension

Stream dimension properties are summarized in Table 3. Area, width, and depth are normalized based on drainage area so that different stream systems can be compared. Five of the eight wood-riffles evaluated have larger bankfull widths than their conventional counterparts (LiRW-03, MBW-04, MBW-05, BRW-01, and LiRW-05). Conversely, four or half of the sections were shallower than their conventional reference sections. Only two log-step sections had bankfull areas that were smaller than the conventional riffles, LiRW-03 and LiRW-04. Four of the eight wood-riffle sections have larger wetted perimeters.

One way to investigate correlations between log steps and conventional riffles is by plotting dimensional properties. Points that fall above a 1:1 line indicate a trend towards wood having the larger characteristic. Data were normalized by watershed area for comparison purposes.

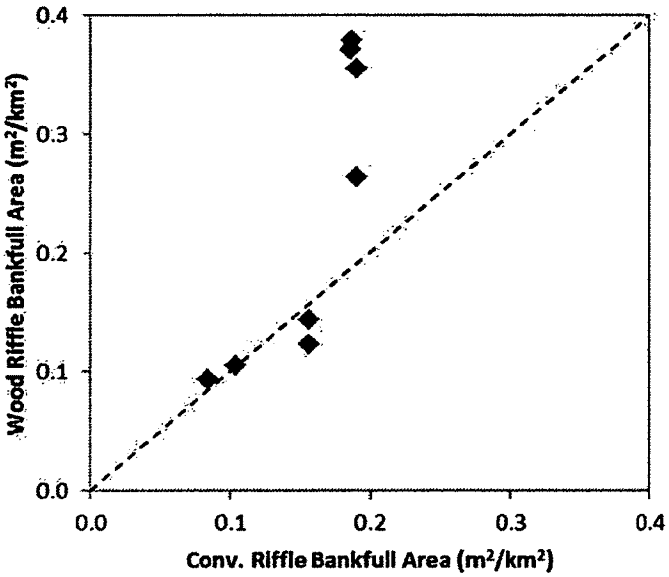


Figure 20 shows that the wood riffles have larger areas when compared to the conventional riffles. This was expected because logs effectively act as flow impoundments and back up water. It was assumed that each wood riffle and corresponding conventional sediment riffle were similar due to their proximity to each other.

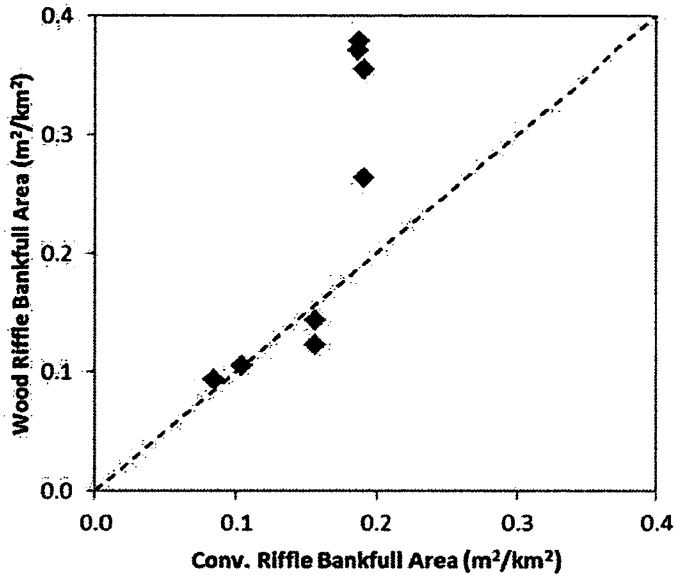


Figure 20: Bankfull area for conventional and wood-dominated riffles, normalized by drainage area

Figure 21 shows that wood-controlled riffles tend to be wider than conventional sediment riffles. Seven of the points plot higher than the 1:1 line. This was expected as log dams tend to spread flow out horizontally.

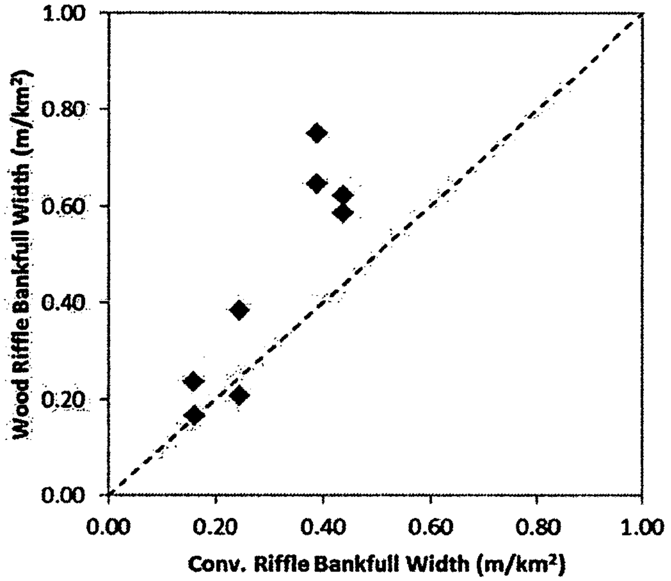


Figure 21: Normalized bankfull width for conventional and wood-dominated riffles

Figure 22 shows that conventional riffles and wood riffles tend to have similar depths. This was not expected. Since wood-controlled riffles tend to have larger areas, width seems to be a more defining aspect than does depth.

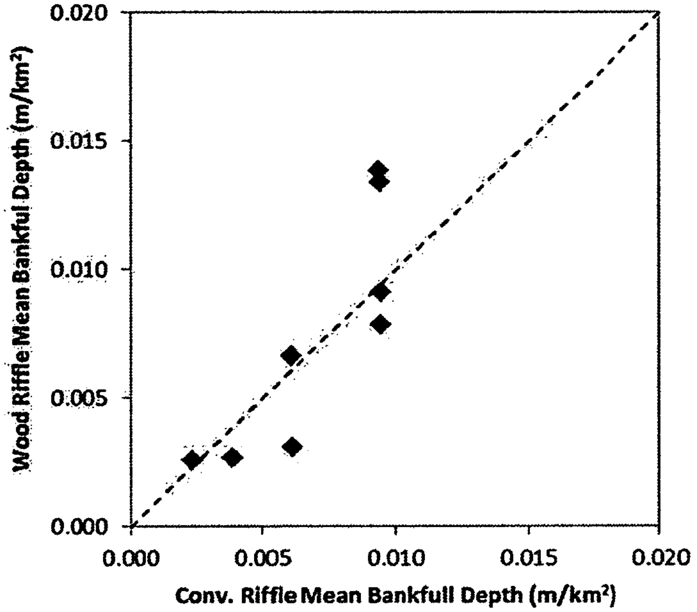


Figure 22: Mean bankfull depth for conventional and wood-dominated riffles, normalized by drainage area

The regional data are used to compare the eight wood-dominated riffles to regional conventional riffles. Dimensional regional data are presented in Table 11 in the appendix. The boxplot in Figure 23 shows that wood riffles are significantly wider. There is very little overlap in the 25-75 percentiles; most conventional riffles are 0 to 2 ft/mi^2 while the wood riffles had a wider range from 2 to 6 ft/mi^2. Figure 24 shows the conventional riffles cover a small range in bankfull depth as well. All of the regional depths are below 0.05 m/km^2. Conversely, the wood-dominated riffles cover a much wider range that is larger. Wood riffle bankfull areas are also larger and more varied, as shown in Figure 25 as one would expect. Kail (2003) observed similar variability and increased width, depth, and area in low-gradient European streams. These results match the observed trends of the surveyed sections discussed previously.

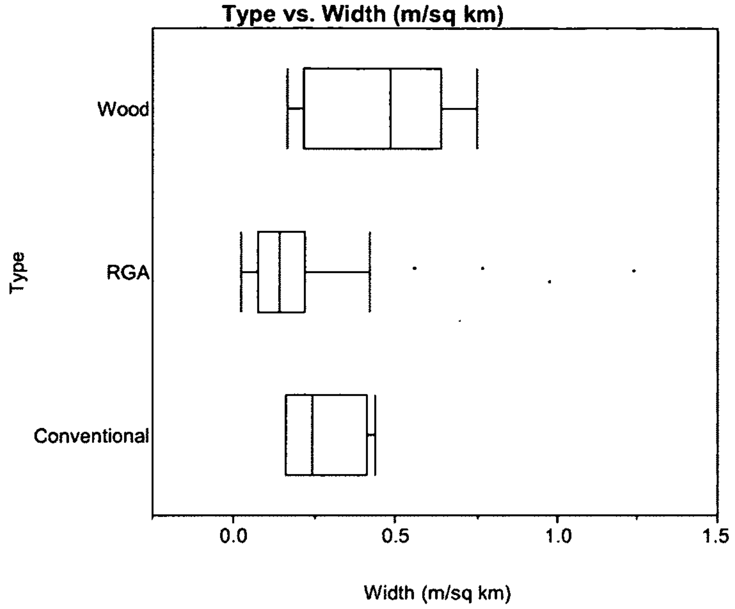


Figure 23: Boxplot of bankfull width of wood riffles, regional conventional data (RGA), and conventional riffles normalized by drainage area

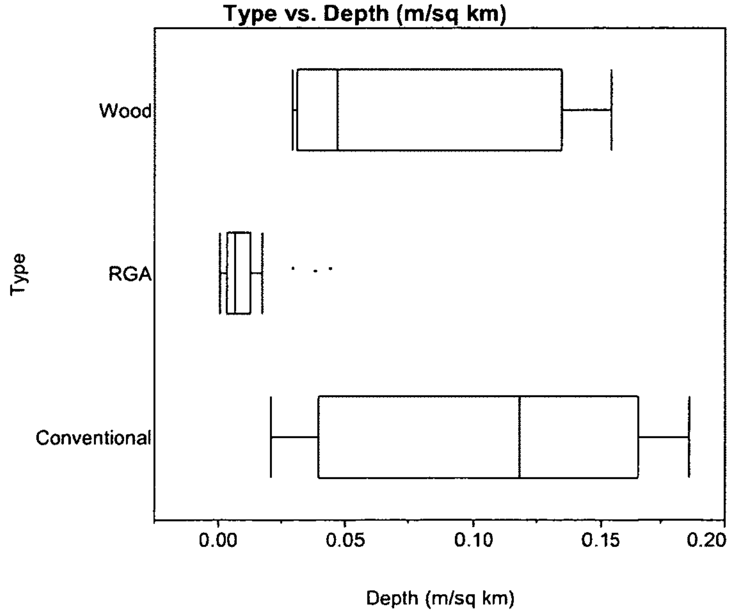


Figure 24: Boxplot of mean bankfull depth of wood riffles, regional conventional data (RGA), and conventional riffles normalized by drainage area

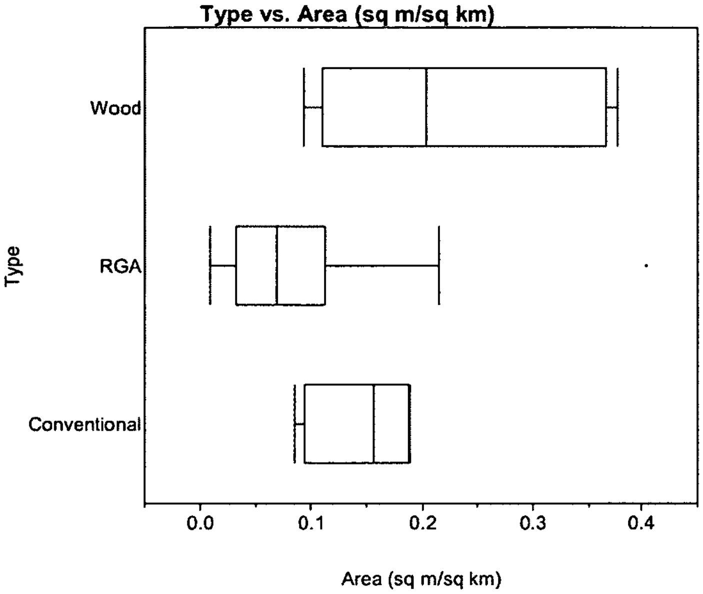


Figure 25: Boxplot of bankfull area of wood riffles, regional conventional data (RGA), and conventional riffles normalized by drainage area

Table 3 Dimension Characteristics. A_{bkf} refers to bankfull area; WA refers to watershed area; W_{bkf} refers to bankfull width; d_{bkf} refers to bankfull depth; P_w refers to wetted perimeter; and w/d Ratio refers to width to depth ratio

Section	Type	A_{bkf} (m^2)	A_{bkf}/WA (m^2/km^2)	W_{bkf} (m)	W_{bkf}/WA (m/km^2)	Mean d_{bkf} (m)	d_{bkf}/WA (m/km^2)	Max d_{bkf} (m)	P_w (m)	w/d Ratio
LiRW-03	Wood	3.91	0.123	12.24	0.384	0.32	0.010	0.67	8.39	38.28
LiRW-04	Wood	4.58	0.143	6.64	0.208	0.69	0.022	1.16	8.39	9.62
LiRC-01	Conv.	4.99	0.156	7.81	0.245	0.64	0.020	0.72	8.55	12.22
MBW-01	Wood	5.28	0.379	8.65	0.621	0.61	0.044	0.96	8.98	14.17
MBW-02	Wood	5.19	0.371	8.18	0.585	0.63	0.045	0.71	8.84	12.90
MBC-03	Conv.	2.61	0.187	6.10	0.435	0.43	0.031	0.58	6.67	14.22
MBW-04	Wood	4.17	0.263	10.23	0.645	0.41	0.026	0.73	10.66	25.05
MBW-05	Wood	5.62	0.355	11.87	0.749	0.47	0.030	0.99	12.62	25.05
MBC-06	Conv.	3.02	0.190	6.17	0.387	0.49	0.031	0.71	6.44	12.59
BRW-01	Wood	6.29	0.093	11.19	0.166	0.56	0.008	0.75	12.00	19.92
BRC-02	Conv.	5.73	0.085	10.97	0.162	0.52	0.008	0.93	11.90	20.98
LiRW-05	Wood	5.38	0.105	12.08	0.235	0.45	0.009	0.74	12.40	27.13
LiRC-06	Conv.	5.35	0.104	8.19	0.159	0.65	0.013	0.83	8.82	12.55

3.2 Pattern

Pattern metrics are also known as plan-view characteristics. Based on field observations, sinuosity was not significantly impacted by single pieces of large wood that was investigated in this study. LWD may have a reach-wide impact on pattern characteristics, but that was out of the scope of this research. However, this study looked at single riffle sections. Half of the wood riffles observed occurred on meander bends (LiRW-04, LiRW-05, MBW-01, and MBW-04). This does not necessarily mean that wood causes meandering or vice versa but does point toward a linkage. Conventionally, riffles occur between bends and pools normally occur on the bends. Based on the few log-steps encountered, half of them occurring on bends points toward a connection. Six out of the eight wood riffles were the result of bank failure (LiRW-03, LiRW-04, LiRW-05, BRW-01, MBW-01, and MBW-02). The recruitment mechanism for MBW-04 was unclear as the log was deeply embedded. Erosion naturally occurs on the outer bank of the bends. The bank may fail gradually or suddenly; just as a tree may gradually angle across the channel as in LiRW-03, or snap or slide in due to wind on an already weakened bank as in BRW-01.

Large debris jams are far more likely to cause more permanent changes in planform as the entire channel cross-section is sometimes blocked. This was seen in various reaches evaluated during the RGA in 2011.

3.3 Profile

Profile data are presented as slope and spacing characteristics in the appendix on Table 9 and Table 10 respectively.

Six of the eight wood riffle cross sections (LiRW-04, LiRW-05, MBW-01, MBW-02, MBW-04, and MBW-05) had shorter average riffle-pool spacing than the conventional reference sections. Only half of the wood riffle sections had a larger average riffle pool bed slope: (MBW-01, MBW-02, MBW-03, and LiRW-05). Spacing in the Bellamy River is unique as the channel bed is composed of bedrock. This acts as a grade control limiting both spacing and slope. The log step backed up water at least 300 meters upstream. This is different than sand and gravel beds where sediment can easily be mobilized upstream and downstream of a blockage.

Several processes could control spacing in reaches with wood riffles. Spacing in wood riffles could be determined by the recruitment of immobile wood or the placement of the mobile wood could be dictated by spacing. Wood recruitment either causes changes in riffle spacing or wood simply becomes “stuck” on riffles and inherits the underlying reach spacing. A combination of both scenarios can also occur when mobile wood become lodged but affects upstream and downstream spacing. None of these scenarios could be supported based on observations.

Riffle- pool spacing data are plotted in Figure 26. Wood-dominated riffles had a greater variability than the reference riffles. Wood riffle spacing was observed both smaller and larger than conventional sediment riffle spacing. Greater variability and smaller spacing was observed by Montgomery & Buffington (1995) and Keller & Swanson (1976) in forested mountain channels. The conventional riffles all fell between 1 and 3 bankfull widths. This differs slightly from the generally accepted 2 to 5 bankfull widths for riffle-pool or Rosgen type C reaches (Leopold, Wolman & Miller 1964;

Montgomery et al. 1995; Rosgen 1994). This range was observed in the regional dataset (median 2.09 bankfull widths) shown in Figure 27.

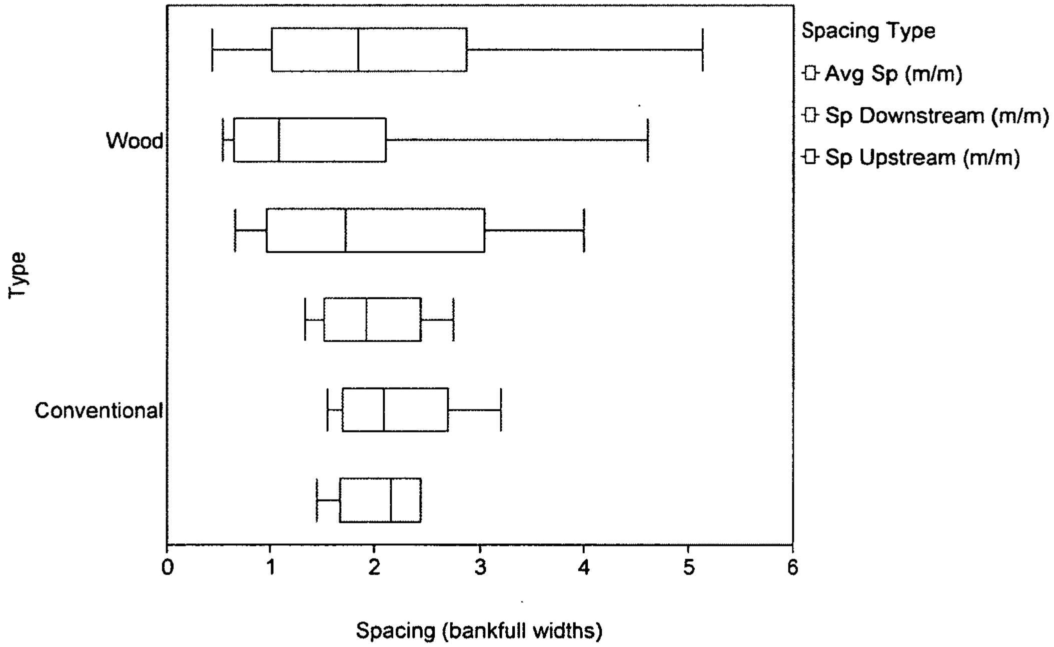


Figure 26: Box plot of average, upstream, and downstream riffle pool spacing for conventional and wood riffles; normalized by bankfull width.

There is a median riffle to pool spacing value of 2.09 bankfull widths for the regional data. This falls within the accepted range of 2 to 5 for C type channels (Leopold, Wolman & Miller 1964; Rosgen 1994). Wood riffle spacing was similar to the regional data. It does not appear to be lower or even as varied as the RGA spacing data.

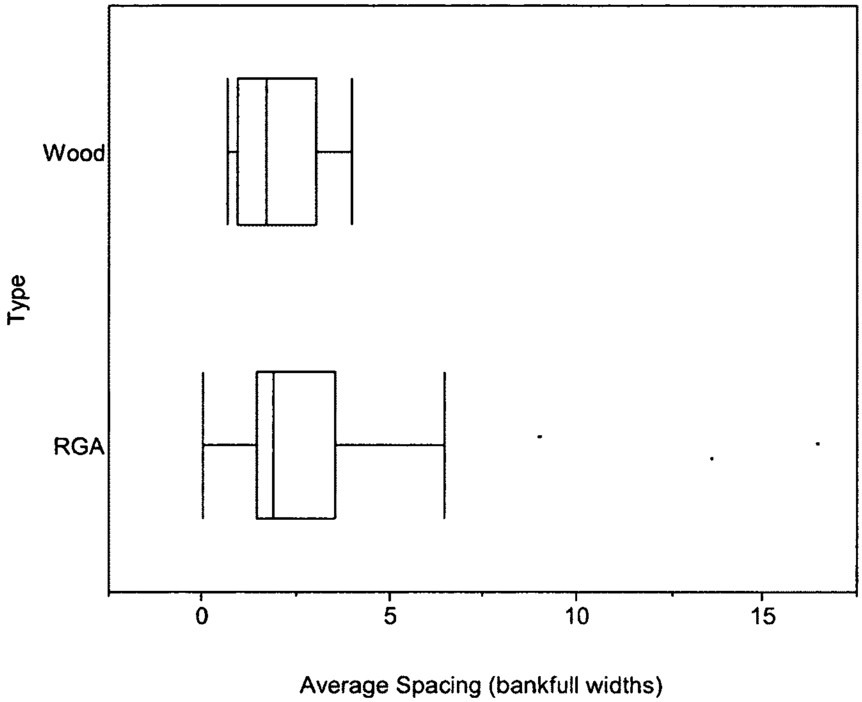


Figure 27: Boxplot of wood riffle average spacing values compared to regional RGA average spacing values normalized by bankfull widths

Slope was calculated from the riffle head to the max downstream pool depth. The hope was this would give an indication as to the effect of scour from log steps. It was expected that wood-controlled steps would create a closer deeper pool and thus yield a much larger slope. Figure 28 shows that although the wood-dominated riffles did have a larger slope, it was not the large difference expected.

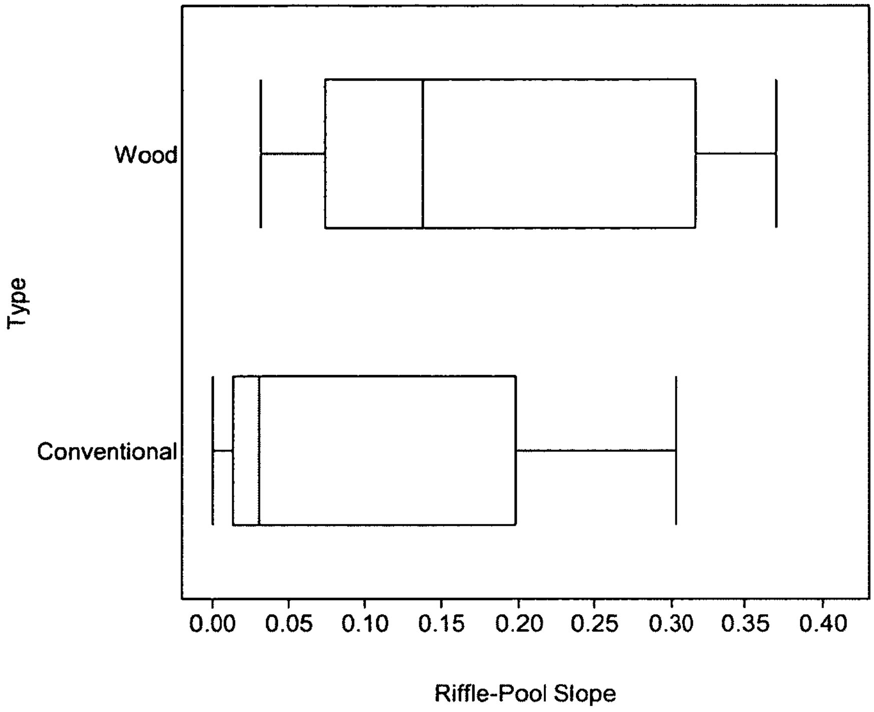


Figure 28: Boxplot of slope from riffle head to max depth of subsequent pool for conventional and wood-dominated riffles

Scour data are presented in Table 4. It was expected that log steps would create greater scour and thus larger differences. This was seen in all but three sections: LiRW-03, MBW-02, and MBW-04. LiRW-03 had a larger difference than the next upstream riffle-pool sequence of 0.62 ft. This points to local spatial variation in the stream profile. MBW-04 is a highly embedded log therefore its effects are probably reduced. The largest difference between conventional sediment and wood riffles were in the Bellamy and Little River-Lee sections. The Bellamy is bedrock controlled so the amount of scour caused by wood is limited. The Little River-Lee sequence is part of a series of three consecutive log steps which may contribute to a larger drop. Scour was definitely present in most conventional and wood riffle sites based on field observations.

Scour is expected to be lower in low-gradient systems. Lower systems tend to move or deposit sediment. While scour was observed, it was not as significant as previous studies in high-gradient systems (Keller & Swanson 1979; Montgomery et al. 2003; Beebe 2000). No relationship was found between the bed slope and the scour caused by the riffle. The function of wood in the observed stream systems may tend more toward the storage of sediments.

Table 4 Pool and Wood Characteristics

Section	Type	Average Pool Elev. Diff. (m)
LiRW-03	Wood	0.26
LiRW-04	Wood	0.45
LiRC-01	Conventional	0.31
MBW-01	Wood	0.34
MBW-02	Wood	0.30
MBC-03	Conventional	0.32
MBW-04	Wood	0.49
MBW-05	Wood	0.63
MBC-06	Conventional	0.59
BRW-01	Wood	0.72
BRC-02	Conventional	0.38
LiRW-05	Wood	0.62
LiRC-06	Conventional	0.051

3.4 Bed Sediment

A summary of pebble counts conducted at each location are presented in the appendix. D16, D50, and D84 specifically for the riffle and the pool are presented in Table 5. Pool depth at LiRW-04 and MBW-01 was too deep to conduct pebble counts thus the adjacent counts are regarded as representative of the reach. The lower sections of the Mallego River were predominantly sand, making pebble counting difficult. The water depth had also increased at MBW-04 making sampling impossible. No data were collected from the Bellamy since it has a bedrock bed.

Table 5 Representative sediment sizes for pebble count locations

Section	**Type**	**Date**	**Riffle D16 (mm)**	**Riffle D50 (mm)**	**Riffle D84 (mm)**	**Pool D16 (mm)**	**Pool D50 (mm)**	**Pool D84 (mm)**
LiRW-03	Wood	10/25/2011	1.0	5.0	15.0	8.0	15.0	28.0
LiRC-01	Conv.	11/8/2011	5.0	13.0	25.0	1.0	3.0	10.0
MBW-02	Wood	3/20/2012	1.0	7.0	17.0	1.0	7.0	13.0
MBC-03	Conv.	3/20/2012	2.0	10.0	25.0	3.8	12.0	22.0
LiRW-05	Wood	6/7/2012	21.0	34.0	56.0	5.0	28.0	70.0
LiRC-06	Conv.	6/7/2012	11.0	61.0	100.0	5.0	21.0	59.0

Figures 29 through 37 show particle size distribution plots (PSD) for each location for both the entire section and just the riffle and pool segments. The entire section plots are representative of a riffle-pool sequence. All three sections were different in terms of this holistic view: Little River-Smoke Street has a coarser wood riffle section with a more uniform conventional riffle section; Little River-Lee has a finer conventional riffle section with a more uniformly gravel wood riffle; and Mallego Brook-Upstream has a finer wood riffle although no sands were present.

These are divided into riffle and pool only PSDs for comparison. Wood riffles are expected to be finer as a log step effectively dams a stream and slows velocity. This is observed in Little River-Smoke Street and Mallego Brook PSDs. The wood riffle sections are finer than the conventional reference sections. Little River-Lee has a more uniform PSD for wood riffles. This is possibly due to the selected log step being in the middle of a tight series of log steps. The scour from the upstream step may be sweeping the fines downstream.

Pool PSDs are expected to be coarser for wood riffles due to scour as water flows over the logs. This is observed in all three PSDs. The Little River-Lee PSD has very similar plots for the wood and reference sections. This could be due the tight series of log steps present, similar to the riffle for this section. The next step downstream may create a slight backwater condition that allows for finer sediments to settle out.

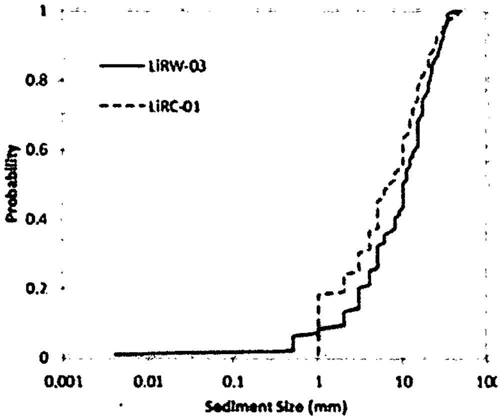


Figure 29: Section PSD for Little River – Smoke Street

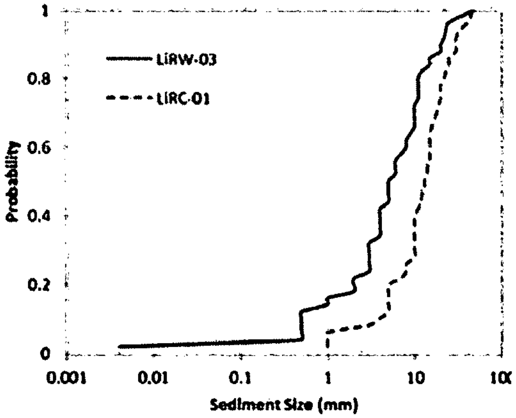


Figure 30: Riffle PSD for Little River – Smoke Street

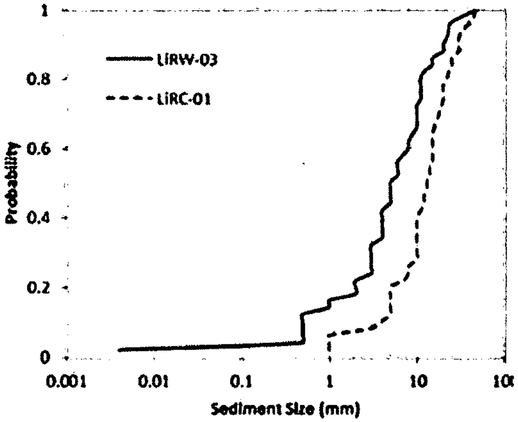


Figure 31: Pool PSD for Little River – Smoke Street

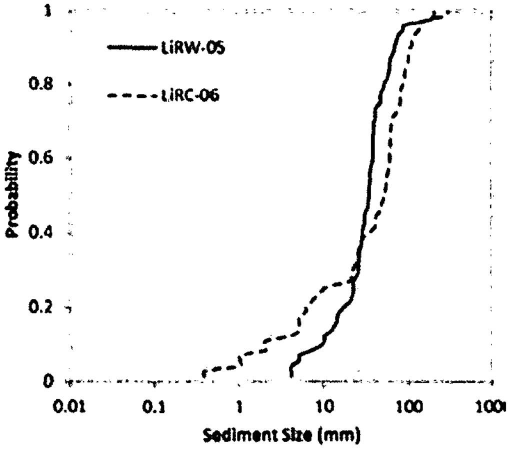


Figure 32: Section PSD for Little River - Lee

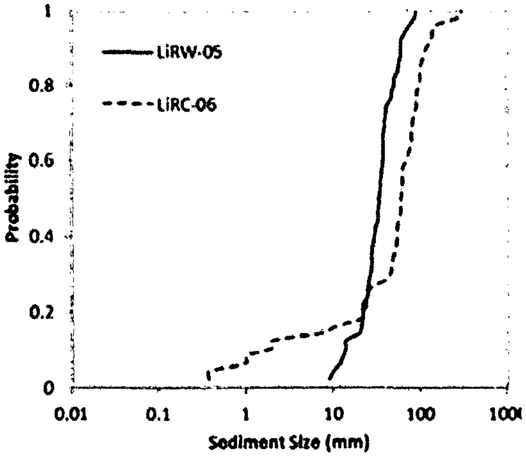


Figure 33: Riffle PSD for Little River - Lee

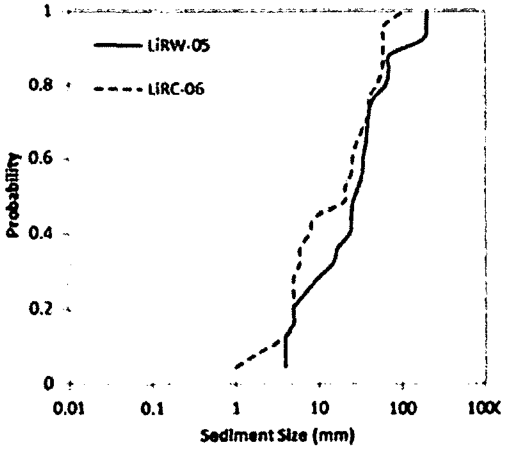


Figure 34: Pool PSD for Little River - Lee

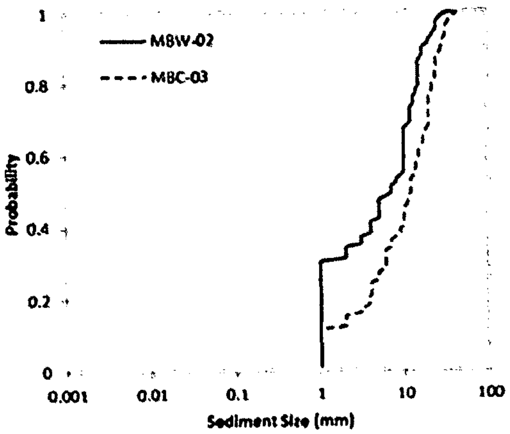


Figure 35: Section PSD for Mallego Brook - Upstream

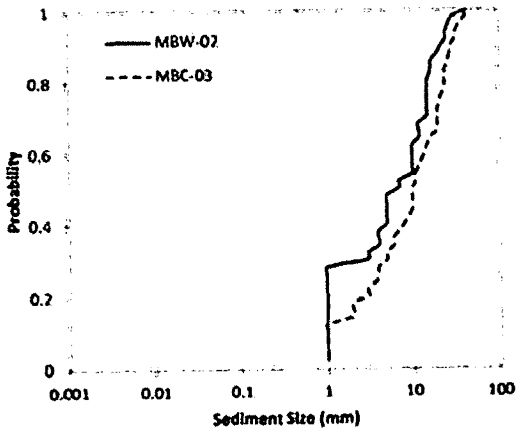


Figure 36: Riffle PSD for Mallego Brook - Upstream

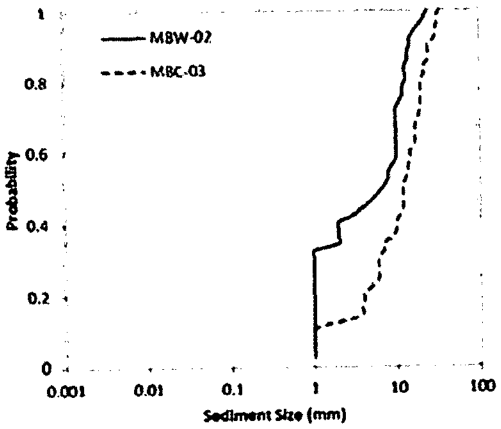


Figure 37: Pool PSD for Mallego Brook - Upstream

3.5 Statistical Analysis

In the first test, normalized bankfull width, bankfull depth, and bankfull area are compared between the wood-riffle and regional datasets using the one-sided rank sum test. The null hypotheses in all cases are that wood riffles and conventional riffles are similar, and the hypotheses from Chapter I are used as alternate hypotheses (H_a) for each geomorphic characteristic. An alpha value of 0.05 was used in all cases.

The hypothesis test results are shown in Table 6. Wood-controlled riffles have statistically larger bankfull widths and areas than the regional dataset. Wood riffles do not have statistically smaller bankfull depths since the null hypothesis could not be rejected. These findings are similar to the graphical analysis of dimensional properties in section 3.1. This is expected as plotting this data is essentially creating a visualization of the statistical tests.

Table 6: Statistical hypothesis tests with regional data

Test	H_0	H_a	α	Test Statistic	Z	p-value	Conclusion
Rank Sum Test	Wood riffles and regional conventional riffles have similar bankfull widths	Wood riffles tend to have larger widths	0.05	$W_{rs}=483$	-3.17692	0.000744	$p < \alpha$; Reject null hypothesis
Rank Sum Test	Wood riffles and regional conventional riffles have similar bankfull depths	Wood riffles tend to have smaller depths	0.05	$W_{rs}=556.5$	4.45685	0.999996	$p > \alpha$; Cannot reject null hypothesis
Rank Sum Test	Wood riffles and regional conventional riffles have similar bankfull areas	Wood riffles tend to have larger area	0.05	$W_{rs}=496$	-3.40324	0.00333	$p < \alpha$; Reject null hypothesis

In the second test, three normalized dimensional properties, bankfull width, bankfull depth, and bankfull area; and one profile property, bed slope across the riffle, are compared. This statistical comparison is made between the wood-riffle and the corresponding reference riffle using the one-sided sign test. The null hypotheses in all cases are that wood riffles and conventional riffles are similar, and the hypotheses from Chapter I are used as alternate hypotheses (H_a) for each geomorphic characteristic. An alpha value of 0.05 was used in all cases.

The hypothesis test results are shown in Table 7. Wood-controlled riffles have statistically larger bankfull widths than their corresponding reference riffle sections. Wood riffles do not have statistically larger bankfull areas or smaller bankfull depths since the null hypothesis could not be rejected. Dimensional results from section 3.1 point towards wood riffles having larger areas, but this cannot be shown statistically. A possible reason for this discrepancy could be the small sample size or the fact that there is not a large enough difference between the areas.

Wood riffles have a statically larger bed slope across the riffle to the subsequent pool. This was also seen in the previous graphical profile results from section 3.3. Because slope is defined as the change in elevation over change in distance, the log steps either have a greater drop in elevation or a closer spacing. Both these scenarios are hypothesized for wood riffles. Previous results from section 3.3 show that spacing observed in this study is more varied, and thus elevation change may be the controlling factor. Further research is needed to confirm that this is the result of larger elevation changes and not a result of closer spacing.

Table 7: Statistical hypothesis tests with field data

Test	H_0	H_a	α	Test Statistic	p-value	Conclusion
Sign Test	Wood riffles and conventional riffles have similar bankfull widths	Wood riffles tend to have larger widths	0.05	S+=7	0.03516	$p<\alpha$; Reject null hypothesis
Sign Test	Wood riffles and conventional riffles have similar bankfull depths	Wood riffles tend to have smaller depths	0.05	S+=4	0.6367	$p<\alpha$; Cannot reject null hypothesis
Sign Test	Wood riffles and conventional riffles have similar bankfull areas	Wood riffles tend to have larger areas	0.05	S+=6	0.6367	$p<\alpha$; Cannot reject null hypothesis
Sign Test	Wood riffles and conventional riffles have similar slopes from riffle head to subsequent pool	Wood riffles tend to have larger slopes	0.05	S+=7	0.03516	$p>\alpha$; Reject null hypothesis

CHAPTER 4

DISCUSSION

The results from this current study can be put in context of data from previous studies. The New Hampshire Stream Team developed regional hydraulic reference curves to aid in stream restoration projects in the state of New Hampshire. These are regression curves that plot bankfull flow, width, depth, and area based on watershed area. This aids in stream restoration design where geomorphic properties are needed, but there no suitable reference sections available to use as a comparison.

Dimensional characteristics from the eight LWD sections from the current study are plotted on the NH regression curves in Figure 38. The LWD characteristics plot below the curves in all three cases. This means that wood riffles are have smaller bankfull areas, widths, and depths than the regional trends predict. This runs counter to the findings from the current study. One possible explanation is that the regression curves were created using data that may include sections influenced by wood. Sections used in the regression curves were chosen based on ideal conditions, or in this case, lack of wood influence. Regression curves have a broad error range as they seek to base geomorphic characteristics to one metric, in this case drainage area.

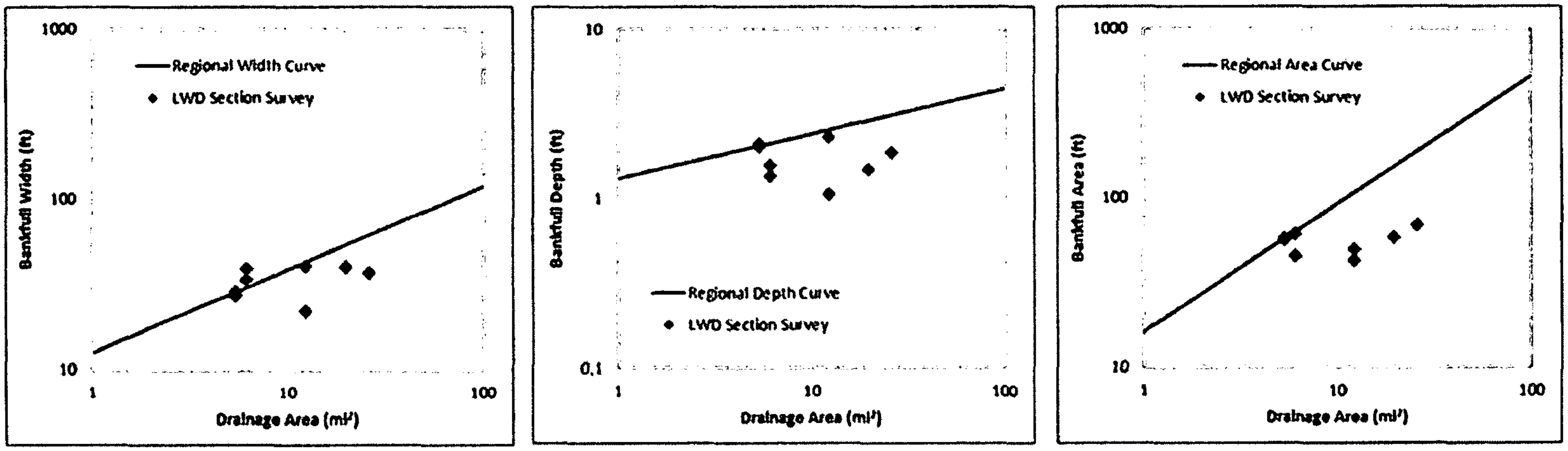


Figure 39: LWD sections plotted on NH regional regression curves for bankfull width, bankfull depth, and bankfull area (from left to right) (NHST 2005)

A common metric across several studies is bankfull width. The findings from Kail (2003), Keller and Swanson (1979), Nakumura and Swanson (1993), and the NH regression curves are compared to this current study (identified by "NH Wood Sections") in Figure 39. This puts results from the current study in context with others. All four studies plot closely with the NH regression curve and each other. This is expected as width generally has an exponential relationship with watershed area.

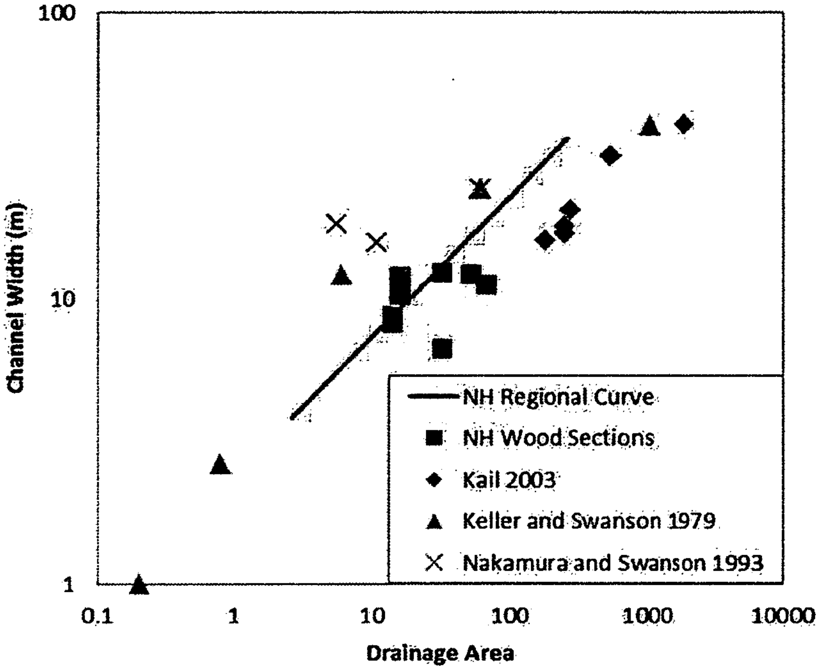


Figure 39: Bankfull width data from past studies compared to findings in this study (NH) and the NH regional regression curve

Another way to compare this study to others is by wood loading. Large woody debris was tallied as part of the Rapid Geomorphic Assessment and represents a regional view of the amount of wood in streams. These tallies were tabulated as LWD pieces per km of the reach. The average frequency of the regional reaches was 19 pieces/km. This falls within the frequency range of 14-55 pieces/km observed by Magilligan et al (2008) in Maine. Other comparable studies report LWD loading as either mass per volume of stream or pieces per square meter of stream, which was not measured as part of this study.

A final way to compare studies is to look at wood diameter. Wood diameter for each wood riffle section is shown in Table 8. Wood diameter was also comparable to Magilligan et al (2008) as six pieces were smaller than 20 cm.

Table 8: Wood Diameter

Section	LWD Diameter (cm)
LiRW-03	19.5
LiRW-04	28
MBW-01	29
MBW-02	19
MBW-04	17
MBW-05	10
BRW-01	15.5
LiRW-05	20

CHAPTER 5

CONCLUSIONS

Wood riffles are geomorphically different from conventional sediment riffles in low-gradient coastal New Hampshire. Log steps impact flow and thus impact geomorphology within a stream reach. They are significantly wider and cover a larger area. Wood riffles also tend to be deeper. It is hypothesized that this is due to preferential flow that scours around logs. Wood should replace riffles in deeper sections just prior to a pool. The varied nature of characteristics for log steps needs to be recognized as channel processes may change the intended design more rapidly than conventional riffles.

It was observed that meander bends were more likely to recruit LWD rather than be formed by the presence of wood. This could mean that during restoration projects, wood may be added at any point along the profile without concern of changes in the meanders. Log steps tend to be spaced closer than conventional sediment riffles. Wood added to restoration projects should be placed closer together and sloped steeper than would be designed for conventional riffles.

Scour was not as evident as previously thought. Some coarsening of the bed and small differences in pool depth between conventional and wood riffles was observed but not significantly. Wood riffles investigated were not true "log steps" as observed in the high-gradient systems of the northwest. Elevation differences caused by the logs were not significant enough to cause such stepping. Velocity was relatively slow as these systems are more coastal and low gradient. The primary function of the streams observed was either the transport or slight aggrading of sediment. The function of wood in seacoast New Hampshire stream systems is the storage of sediment rather than the scour of it.

Bank failure was observed to be the major recruitment process for the log steps surveyed. This can be indicative of a widening channel but most were probably due to normal channel processes. Wallerstein and Thorne (2004) concluded that LWD in unstable reaches, or those that are widening, retain sediment and thus accelerates recovery.

5.1 Future Work

It is recommended that a larger survey be conducted to determine a correlative relationship between wood and conventional riffles in coastal New England. A larger sample size should be used from the region or an entire stream system. Dimension, pattern, and profile data should be collected similar to this study but on a larger scale. This would include cross sections at each debris jam encountered. This would result in more powerful statistics. This study should explore correlations between geomorphic metrics and other characteristics such as the diameter of the wood or bed particle size. If a relationship is found, it can be used to define a range of spacing, slope, width, depth, or other geomorphic properties. This defines a range to be used regionally in design projects. Correlations can be applied to another, separate reference system to see if the naturally occurring wood riffles fall within the expected range. Restoration goals can be achieved using wood in a manner that encourages habitat and stream stability.

List of References

Angermeier, PL & Karr, JR 1984, 'Relationships between woody debris and fish habitat in aa small warmwater stream', *Transactions of the American Fisheries Society*, vol 113, pp. 716-726.

Beebe, JT 2000, 'Flume studies on the effect of perpendicular log obstructions on flow patterns and bed topagraphy', *The Great Lakes Geographer*, vol 7, no. 1, pp. 9-25.

Bilby, RE & Likens, GE 1980, 'Importance of organic debris dams in the structure and function of stream ecosystems', *Ecology*, vol 61, no. 5, pp. 1107-113-13.

Faustini, JM & Jones, JA 2003, 'Influence of large woody debris on channel morphology and dynamics in steep, boulder-rich mountain streams, western Cascades, Oregon', *Geomorphology*, vol 51, pp. 187-205.

Foster, DR 1992, 'Land-use history (1730-1990) and vegetation dynamics in central New England, USA', *British Ecological Society*, vol 80, no. 4, pp. 753-771.

Gippel, CJ 1995, 'Environmental hydraulics of large woody debris in streams and rivers', *Journal of Environmental Engineering*, pp. 388-395.

Gippel, CJ, O'Niell, IC, Finlayson, BL & Schnatz, I 1996, 'Hydraulic guidelines for the re-introduction and management of large woody debris in lowland rivers', *Regulated Rivers: Research & Management*, vol 12, pp. 223-236.

Gurnell, AM, Piégay, H, Swanson, FJ & Gregory, SV 2002, 'Large wood and fluvial processes', *Freshwater Biology*, vol 47, pp. 601-619.

Harrelson, CC, Rawlins, CL & Potyondy, JP 1994, 'Stream Channel Reference Sites: An Illustrated Guide to Field Technicque', U.S. Deptartment of Agriculture, Forest Service, Fort Collins, CO.

Helsel, DR & Hirsch, RM, 'Statistical Methods in Water Resources', in *Techniques of Water-Resources Investigations of the United States Geological Survey*, USGS.

Hilderbrand, RH, Lemly, AD, Dolloff, CA & Harpster, KL 1998, 'Design considerations for large woody debris placement in stream enhancement projects', *North American Journal of Fisheries Management*, vol 18, pp. 161-167.

Kail, J 2003, 'Influence of large woody debris on the morphology of six central European streams', *Geomorphology*, vol 51, pp. 207-223.

Keller, EA & Swanson, FJ 1979, 'Effects of large organic material on channel form and fluvial processes', *Earth Surface Processes*, vol 4, pp. 361-380.

Leopold, LB, Wolman, MG & Miller, JP 1964, *Fluvial Processes in Geomorphology*, 1st edn, W. H. Freeman and Company, San Francisco.

Magilligan, FJ, Nislow, KH, Fisher, GB, Wright, J, Mackey, G & Laser, M 2008, 'The geomorphic function and characteristics of large woody debris in low gradient rivers, coastal Maine, USA', *Geomorphology*, vol 97, pp. 467-482.

Marston, RA 1982, 'The geomorphic significance of log steps in forest streams', *Annals of the Association of American Geographers*, vol 72, no. 1, pp. 99-108.

Montgomery, DR & Buffington, JM 1998, 'Channel Processes, Classification, and Response', in *River Ecology and Management: Lessons from the Pacific Coastal Ecoregion*, Springer-Verlag, New York.

Montgomery, DR, Buffington, JM, Smith, RD, Schmidt, KM & Pess, G 1995, 'Pool spacing in forest channels', *Water Resources Research*, vol 31, pp. 1097-1105.

Montgomery, DR, Collins, BD, Buffington, JM & Abbe, TB 2003, 'Geormorphic Effects of Wood in Rivers', American Fisheries Society, Corvallis, OR.

Nakamura, F & Swanson, FJ 1993, 'Effects of coarse woody debris on morphology and sediment storage of a mountain stream in western Oregon', *Earth Surface Processes and Landforms*, vol 18, pp. 43-61.

NHST 2005, 'New Hampshire 2005 Regional Hydraulic Geometry Curves (Provisional)', The New Hampshire Stream Team, Concord, NH.

Piégay, H & Gurnell, AM 1997, 'Large woody debris and river geomorphological pattern', *Geomorphology*, vol 19, pp. 99-116.

Rosgen, DL 1994, 'A classification of natural rivers', *Catena*, vol 22, pp. 169-199.

Schiff, R, MacBroom, JG & Bonin, JA 2006, 'White Paper: River Restoration and Fluvial Geomorphology', NHDES and NHDOT, Concord, NH.

Wallerstein, NP & Thorne, CR 2004, 'Influence of large woody debris on morphological evolution of incesed, sand-bed channels', *Geomorphology*, vol 57, pp. 53-73.

Warren, DR & Kraft, CE 2008, 'Dynamics of large wood in an eastern U.S. mountain stream', *Forest Ecology and Management*, vol 256, pp. 808-814.

Wilcox, AC & Wohl, EE 2006, 'Flow resistance dynamics in step-pool stream channels: 1. Large woody debris and controls on total resistance', *Water Resources Research*, vol 42.

APPENDIX

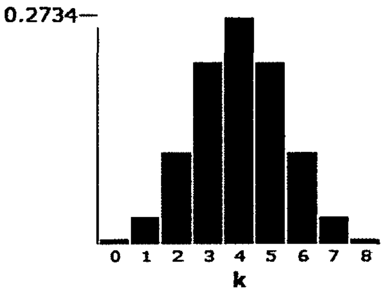
Table 9 Spacing Characteristics. Sp_{avg} refers to average riffle-pool spacing; Sp_{up} refers to upstream riffle-pool spacing; Sp_{dn} refers to downstream riffle-pool spacing; and W_{bkf} refers to bankfull width (used to normalize spacing data)

Section	Type	Sp_{avg} (m)	Sp_{avg}/W_{bkf} (m)	Sp_{up} (m)	Sp_{up}/W_{bkf} (m/m)	Sp_{dn} (m)	Sp_{dn}/W_{bkf} (m/m)
LiRW-03	Wood	11.2	0.92	14.6	1.20	7.8	0.64
LiRW-04	Wood	16.4	2.47	21.0	3.17	11.7	1.77
LiRC-01	Conv.	19.0	2.44	13.1	1.68	25.0	3.20
MBW-01	Wood	9.6	1.11	8.2	0.95	11.0	1.27
MBW-02	Wood	11.0	1.34	14.6	1.79	7.3	0.89
MBC-03	Conv.	13.9	2.29	12.9	1.33	14.9	1.54
MBW-04	Wood	21.5	2.10	20.4	2.00	22.6	2.21
MBW-05	Wood	7.8	0.65	61.0	5.14	7.8	0.65
MBC-06	Conv.	14.9	2.42	16.9	2.75	12.9	2.09
BRW-01	Wood	36.2	3.23	20.9	1.87	51.4	4.60
BRC-02	Conv.	20.6	1.88	21.0	1.91	20.2	1.84
LiRW-05	Wood	5.7	0.47	5.0	0.42	6.4	0.53
LiRC-06	Conv.	17.7	2.16	17.4	2.12	18.0	2.19

Table 10 Slope Characteristics. S_{bed} refers to bed slope; S_{up} refers to bed slope upstream of the section; S_{dn} refers to bed slope downstream of the section; S_{rp} refers to slope across the riffle to max pool depth

Section	Type	S_{bed}	S_{up}	S_{dn}	S_{rp}
LiRW-03	Wood	0.0063	0.0008	0.0118	0.0933
LiRW-04	Wood	0.0021	0.0025	0.0018	0.0710
LiRC-01	Conventional	0.0098	0.0126	0.0071	0.0308
MBW-01	Wood	0.0225	0.0444	0.0006	0.3700
MBW-02	Wood	0.0124	0.0123	0.0125	0.3267
MBC-03	Conventional	0.0074	0.0071	0.0078	0.3036
MBW-04	Wood	0.0055	0.0045	0.0065	0.0831
MBW-05	Wood	0.0557	N/A	0.0557	0.1809
MBC-06	Conventional	0.0095	0.0009	0.0182	0.0935
BRW-01	Wood	0.0078	0.0061	0.0095	0.0323
BRC-02	Conventional	0.0155	0.0164	0.0145	0.0278
LiRW-05	Wood	0.0205	0.0158	0.0252	0.2900
LiRC-06	Conventional	0.0074	0.0089	0.0058	0.0000

From Appendix B5 of (Helsel & Hirsch n.d.)



Cumulative Probability			
k	Exact Probability	From Left to Right Sum of Exact Probabilities for 0 through k, inclusive	From Right to Left Sum of Exact Probabilities for k through 8, inclusive
0	0.00390625	0.00390625	1.0
1	0.03125	0.03515625	0.99609375
2	0.109375	0.14453125	0.96484375
3	0.21875	0.36328125	0.85546875
4	0.2734375	0.63671875	0.63671875
5	0.21875	0.85546875	0.36328125
6	0.109375	0.96484375	0.14453125
7	0.03125	0.99609375	0.03515625
8	0.00390625	1.0	0.00390625

Table 11: Regional dimensional data from the Rapid Geomorphic Assessment conducted in the summer of 2011

Section	River	Stream Order	Watershed Area (mi^2)	Area/W.A . (ft^2/mi^2)	Width/W.A . (ft/mi^2)	depth/W.A . (ft/mi^2)
LiR01-1	Little River	3	20.19	1.883	1.178	0.079
LiR01-2	Little River	3	20.19	2.886	1.380	0.104
LiR02-1	Little River	3	19.96	3.665	2.033	0.090
LiR04-1	Little River	3	19.85	2.509	1.713	0.074
LiR04-2	Little River	3	19.85	1.626	1.530	0.054
LiR04-3	Little River	3	19.85	1.496	1.455	0.052
LiR06A-1	Little River	3	18.51	3.193	1.499	0.115
LiR06A-2	Little River	3	18.51	1.749	1.311	0.072
LiR06B-1	Little River	3	18.51	2.666	1.850	0.078
LiR06B-2	Little River	3	18.51	4.582	1.829	0.135
LiR07-1	Little River	3	14.39	2.445	1.697	0.100
LiR07-2	Little River	3	14.39	2.707	1.851	0.102
LiR07-3	Little River	3	14.39	3.790	2.122	0.124
LiR09-1	Little River	3	13.67	2.850	3.555	0.059
LiR09-2	Little River	3	13.67	2.747	2.738	0.073
LiR09-3	Little River	3	13.67	1.604	1.699	0.069
LiR10-1	Little River	3	12.00	2.625	2.264	0.097
LiR10-2	Little River	3	12.00	5.465	3.389	0.134
LiR10-3	Little River	3	12.00	2.693	1.963	0.114
LiR11A-1	Little River	3	11.78	2.453	1.745	0.119
LiR11A-2	Little River	3	11.78	2.212	1.591	0.118
LiR11B-1	Little River	3	11.78	2.537	1.978	0.109
LR36-1	Lamprey River	3	31.41	1.120	1.003	0.036
LR36-2	Lamprey River	3	31.41	1.345	1.103	0.039
LR39-1	Lamprey River	3	19.19	1.379	1.552	0.046
NBR02A-1	North Branch River	3	55.83	1.392	0.740	0.034
NBR02B-1	North Branch River	3	55.83	0.434	0.394	0.020

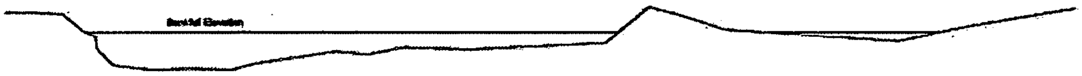
NBR12-1	North Branch River	3	39.65	0.851	0.719	0.030
NR18-1	North River	3	2.87	11.272	10.551	0.372
NR18-2	North River	3	2.87	6.003	6.498	0.322
NR18-3	North River	3	2.87	5.822	8.258	0.246
CR12-1	Cochecho River	4	59.19	5.989	1.601	0.063
CR12-2	Cochecho River	4	59.19	5.155	1.221	0.071
CR14-1	Cochecho River	4	58.50	2.038	0.980	0.036
CR14-2	Cochecho River	4	58.50	2.109	0.904	0.040
CR16A-1	Cochecho River	4	51.40	3.117	1.104	0.055
CR16B-1	Cochecho River	4	51.40	2.202	1.137	0.038
CR16B-2	Cochecho River	4	51.40	0.890	0.777	0.022
CR17-1	Cochecho River	4	44.41	1.950	0.986	0.045
CR17-2	Cochecho River	4	44.41	0.707	1.008	0.016
CR17-3	Cochecho River	4	44.41	1.314	1.177	0.025
CR19-1	Cochecho River	4	24.70	1.299	0.948	0.055
CR19-2	Cochecho River	4	24.70	1.721	1.290	0.054
LR16-1	Lamprey River	4	246.86	1.442	0.386	0.015
LR16-2	Lamprey River	4	246.86	0.729	0.306	0.010
LR17A-1	Lamprey River	4	244.94	0.256	0.313	0.003
LR17A-2	Lamprey River	4	244.94	0.270	0.237	0.005
LR19A-1	Lamprey River	4	232.76	0.370	0.192	0.008
LR19C-1	Lamprey River	4	232.76	0.375	0.263	0.006
LR22-1	Lamprey River	4	183.27	0.368	0.385	0.005
LR23B-1	Lamprey	4	172.37	0.701	0.410	0.010

	River					
LR28-1	Lamprey River	4	105.66	0.592	0.443	0.013
LR28-2	Lamprey River	4	105.66	0.576	0.409	0.013
LR31-1	Lamprey River	4	53.12	0.866	0.779	0.021
LR31-2	Lamprey River	4	53.12	1.315	0.788	0.031
NR10-1	North River	4	13.99	4.958	3.158	0.112
NR10-2	North River	4	13.99	3.182	2.170	0.105
NR15A-1	North River	4	8.36	3.465	3.317	0.125
NR15B-1	North River	4	8.36	4.061	3.234	0.150
NR15C-1	North River	4	8.36	4.903	4.721	0.124
PR01-1	Piscassic River	4	72.15	3.389	0.709	0.066
PR02-1	Piscassic River	4	66.01	1.311	0.514	0.039
PR04A-1	Piscassic River	4	63.12	0.671	0.462	0.023
PR04B-1	Piscassic River	4	63.12	1.721	0.432	0.063
PR06A-1	Piscassic River	4	55.04	0.765	0.331	0.042
PR06B-1	Piscassic River	4	55.04	0.801	0.369	0.039

Characteristics of the wood hydraulic controls were recorded such as orientation, appearance, type of wood (when known), and general appearance of obstruction. Diameter and length were measured with measuring tape to within 1 cm.

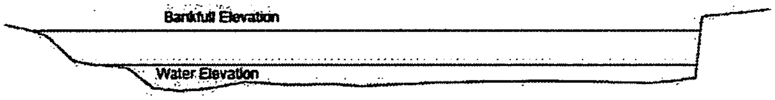
Cross Sections

LiRW-03

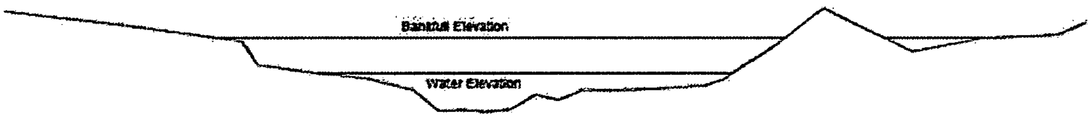


LiRW-04

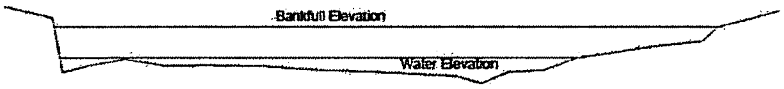
LiRC-01



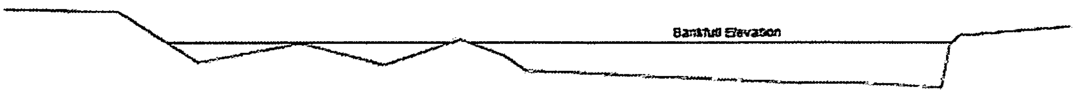
MBW-01



MBW-02

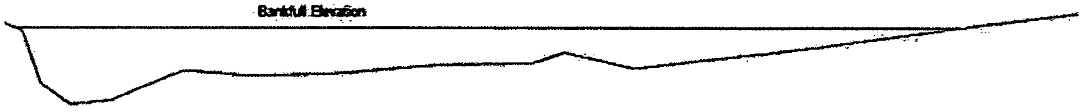


MBC-03

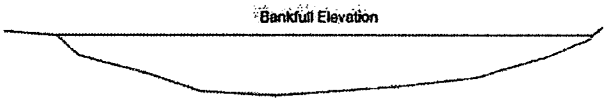


MBW-04

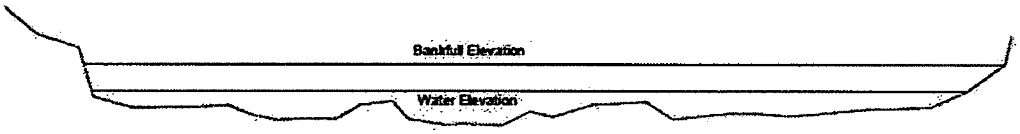
MBW-05



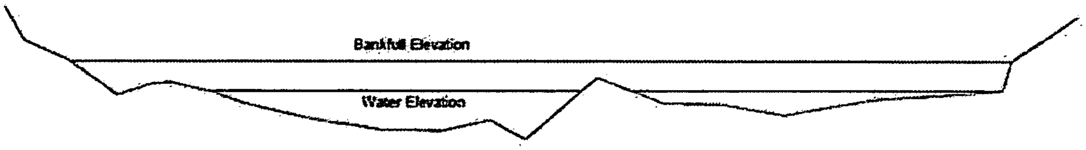
MBC-06



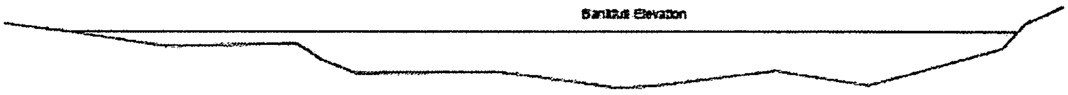
BRW-01



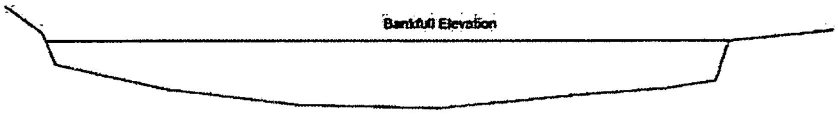
BRC-02



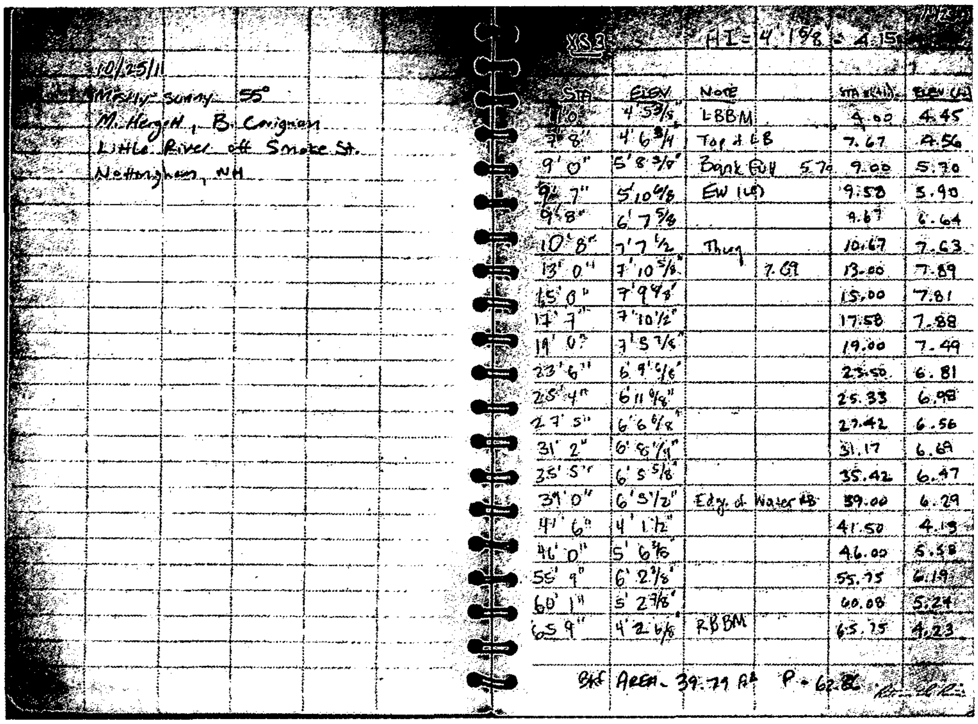
LiRW-05



LiRC-06



Field Notes

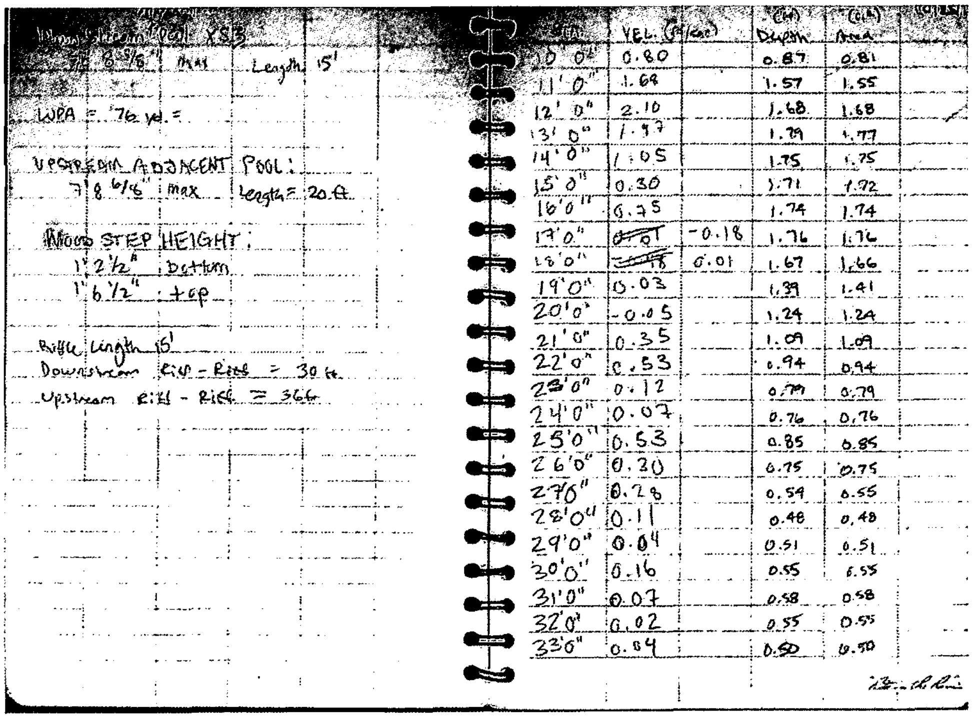


10/25/11
Mostly sunny 55°
M. Hegitt, B. Carignan
Little River off Smoke St.
Nottingham, NH

XS3   HI = 4' 1 5/8 = 4.15

STA	ELEV	NOTE		STA (ft)	ELEV (ft)
4'0"	4'5 3/8"	LBBM		4.00	4.45
7'8"	4'6 3/4	Top of LB		7.67	4.56
9'0"	5'8 3/8"	Bank Full	5.70	9.00	5.70
9'7"	5'10 6/8	EW (LB)		9.58	5.90
9'8"	6'7 5/8			9.67	6.64
10'8"	7'7 1/2	Thwg		10.67	7.63
13'0"	7'10 5/8"		7.69	13.00	7.89
15'0"	7'9 6/8'			15.00	7.81
17'7"	7'10 1/2"			17.58	7.88
19'0"	7'5 7/8"			19.00	7.49
23'6"	6'9 5/8"			23.50	6.81
25'4"	6'11 6/8"			25.33	6.98
27'5"	6'6 6/8"			27.42	6.56
31'2"	6'8 1/4"			31.17	6.69
35'5"	6'5 5/8"			35.42	6.47
39'0"	6'3 1/2"	Edge of Water RB		39.00	6.29
41'6"	4'1 1/2"			41.50	4.13
46'0"	5'6 7/8			46.00	5.58
55'9"	6'2 3/8"			55.75	6.19
60'1"	5'2 7/8"			60.08	5.24
65'9"	4'2 6/8	RBBM		65.75	4.23

Bkf AREA - 39.79 ft² P = 62.82



Upstream Pool XS3
7' 8 5/8" max   Length 15'

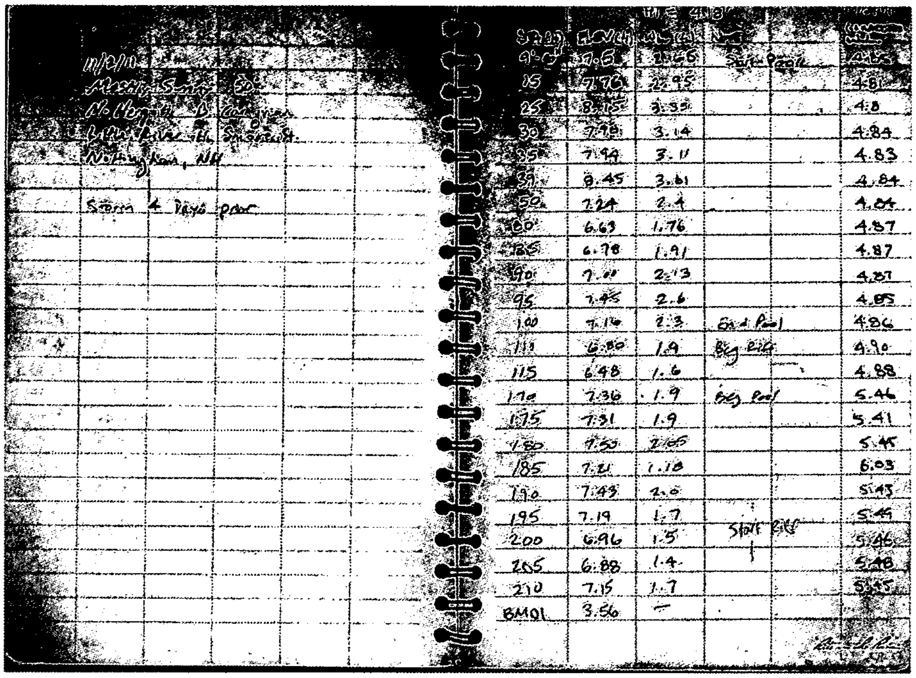
WPA = 76 yd. =

UPSTREAM ADJACENT POOL:
7' 8 6/8" max   Length = 20 ft.

WOOD STEP HEIGHT:
1' 2 1/2" bottom
1' 6 1/2" top

Riffle Length 15'
Downstream Riff - Riff = 30 ft.
Upstream Riff - Riff = 36 ft

STA	VEL. (ft/sec)		(ft) Depth	(ft²) Area
10'0"	0.80		0.87	0.81
11'0"	1.64		1.57	1.55
12'0"	2.10		1.68	1.68
13'0"	1.97		1.79	1.77
14'0"	1.05		1.75	1.75
15'0"	0.30		1.71	1.72
16'0"	0.75		1.74	1.74
17'0"	~~0.07~~	-0.18	1.76	1.76
18'0"	~~18~~	0.01	1.67	1.66
19'0"	0.03		1.39	1.41
20'0"	-0.05		1.24	1.24
21'0"	0.35		1.09	1.09
22'0"	0.53		0.94	0.94
23'0"	0.12		0.79	0.79
24'0"	0.07		0.76	0.76
25'0"	0.53		0.85	0.85
26'0"	0.30		0.75	0.75
27'0"	0.28		0.54	0.55
28'0"	0.11		0.48	0.48
29'0"	0.04		0.51	0.51
30'0"	0.16		0.55	0.55
31'0"	0.07		0.58	0.58
32'0"	0.02		0.55	0.55
33'0"	0.04		0.50	0.50

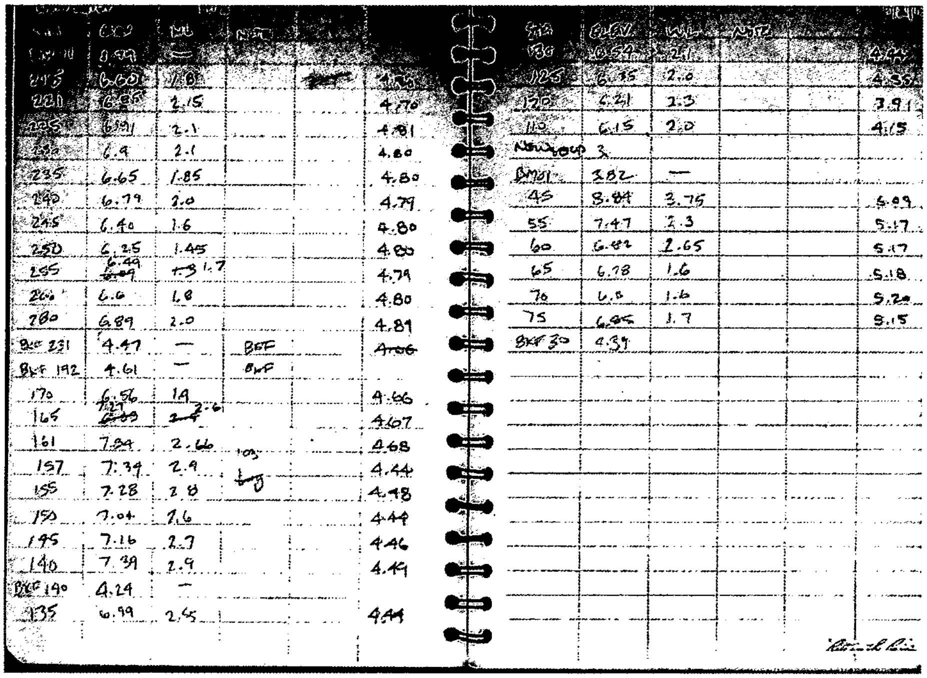


11/2/11
[illegible] Swamp [illegible]
[illegible]
Little River [illegible]
N. Hampton, NH

Storm 4 Days prior

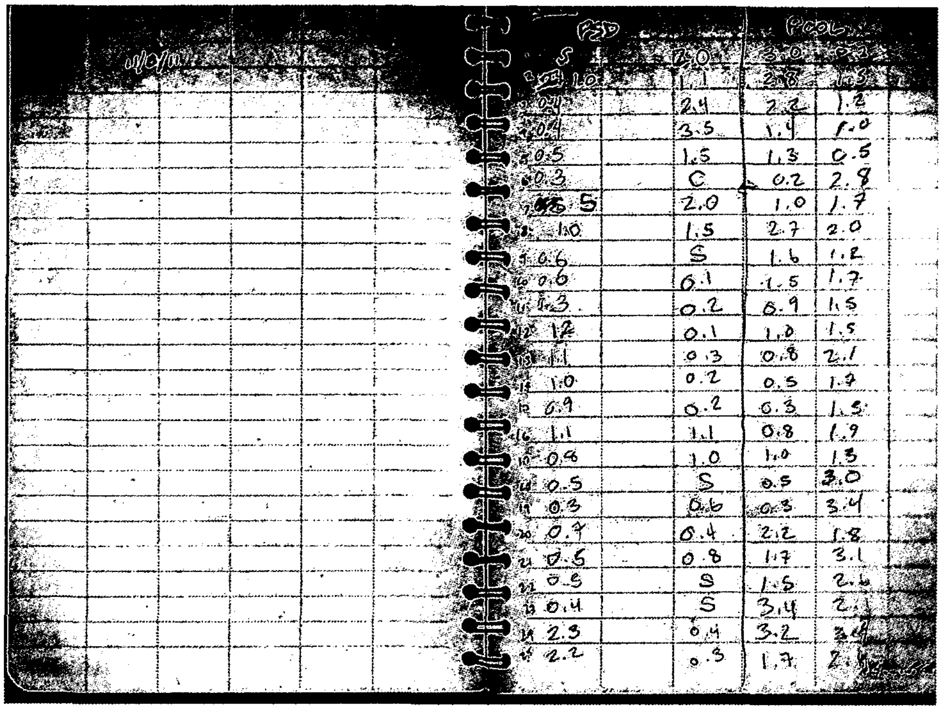
HI = 4.18'

STA (ft)	ELEV (ft)	WL (ft)	Notes		[illegible]
9.5	7.61	2.66	Start Pool		4.65
15	7.76	2.95			4.81
25	8.15	3.35			4.8
30	7.98	3.14			4.84
35	7.94	3.11			4.83
39	8.45	3.61			4.84
50	7.24	2.4			4.84
80	6.63	1.76			4.87
85	6.78	1.91			4.87
90	7.00	2.13			4.87
95	7.45	2.6			4.85
100	7.16	2.3	End Pool		4.86
110	6.80	1.9	Beg Riff		4.90
115	6.48	1.6			4.88
170	7.36	1.9	Beg Pool		5.46
175	7.31	1.9			5.41
180	7.50	2.05			5.45
185	7.21	1.18			6.03
190	7.43	2.0			5.43
195	7.19	1.7			5.49
200	6.96	1.5	Start Riff		5.46
205	6.88	1.4			5.48
210	7.15	1.7			5.45
BM01	3.56	—			

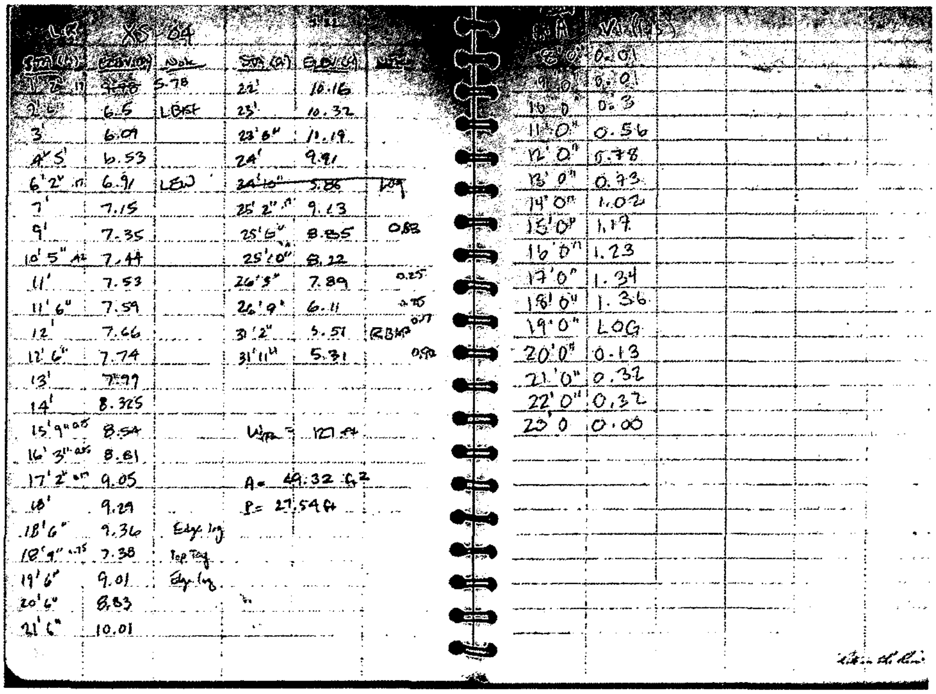


STA	ELEV	WL	NOTES		
BM01	8.99	—			
215	6.60	1.8		~~[illegible]~~	[illegible]
220	6.85	2.15			4.70
225	6.91	2.1			4.81
230	6.9	2.1			4.80
235	6.65	1.85			4.80
240	6.79	2.0			4.79
245	6.40	1.6			4.80
250	6.25	1.45			4.80
255	~~6.09~~ 6.49	~~1.3~~ 1.7			4.79
260	6.6	1.8			4.80
280	6.89	2.0			4.89
BKF 231	4.47	—	BKF		~~4.06~~
BKF 192	4.61	—	BKF		
170	6.56	1.9			4.66
165	~~6.89~~ 7.27	~~2.4~~ 2.6			4.67
161	7.34	2.66			4.68
157	7.34	2.9	log		4.44
155	7.28	2.8			4.48
150	7.04	2.6			4.44
145	7.16	2.7			4.46
140	7.39	2.9			4.49
BKF 140	4.24	—			
135	6.99	2.45			4.44

STA	ELEV	WL	NOTE		
130	6.54	2.1			4.44
125	6.35	2.0			4.55
120	6.21	2.3			3.91
110	6.15	2.0			4.15
New group 3					
BM01	3.82	—			
45	8.84	3.75			5.09
55	7.47	2.3			5.17
60	6.82	1.65			5.17
65	6.78	1.6			5.18
70	6.8	1.6			5.20
75	6.85	1.7			5.15
BKF 30	4.39				

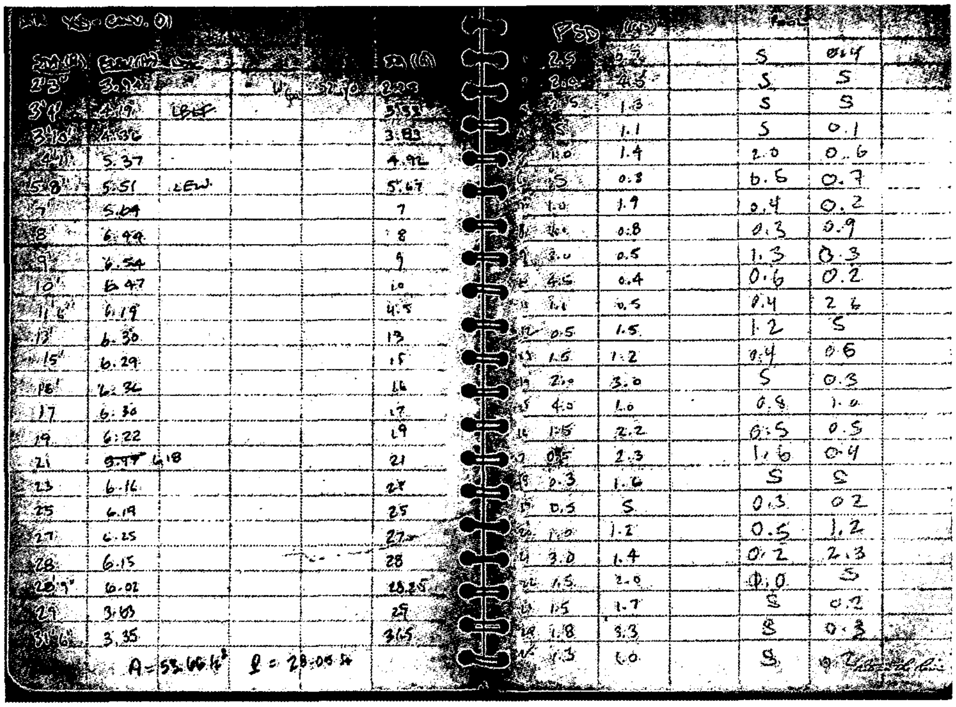

4/9/11

	FSD		POOL	
S	2.0		3.0	[illegible]
1 1.0	1.1		2.8	1.3
2 0.4	2.4		2.2	1.2
0.4	3.5		1.4	1.0
5 0.5	1.5		1.3	0.5
6 0.3	C		0.2	2.8
7 5	2.0		1.0	1.7
8 1.0	1.5		2.7	2.0
9 0.6	S		1.6	1.2
10 0.6	0.1		1.5	1.7
11 1.3	0.2		0.9	1.5
12 1.2	0.1		1.0	1.5
13 1.1	0.3		0.8	2.1
14 1.0	0.2		0.5	1.7
15 0.9	0.2		0.3	1.5
16 1.1	1.1		0.8	1.9
17 0.8	1.0		1.0	1.3
18 0.5	S		0.5	3.0
19 0.3	0.6		0.3	3.4
20 0.7	0.4		2.2	1.8
21 0.5	0.8		1.7	3.1
22 0.5	S		1.5	2.6
23 0.4	S		3.4	2.1
24 2.3	0.4		3.2	3.4
25 2.2	0.3		1.7	2.[illegible]


LR XS-04

STA (ft)	ELEV (ft)	Note	STA (ft)	ELEV (ft)	Note
1' 2"	~~9.78~~ 5.78		22'	10.16	
2' 6"	6.5	LBKF	23'	10.32	
3'	6.09		23' 6"	11.19	
4' 5'	6.53		24'	9.91	
6' 2"	6.91	LEW	~~24' 10"~~	~~5.86~~	~~Log~~
7'	7.15		25' 2"	9.13	
9'	7.35		25' 6"	8.85	0.83
10' 5"	7.44		25' 10"	8.22	
11'	7.53		26' 3"	7.89	0.25
11' 6"	7.59		26' 9"	6.11	0.75
12'	7.66		31' 2"	5.51	RBKF 0.77
12' 6"	7.74		31' 11"	5.31	0.92
13'	7.99				
14'	8.325				
15' 9" 0.05	8.54		Wbf = 12.54		
16' 3" 0.45	8.81				
17' 2" 0.7	9.05		A = 49.32 ft²		
18'	9.29		P = 27.54 ft		
18' 6"	9.36	Edge log			
18' 9" 0.75	7.38	Top log			
19' 6"	9.01	Edge log			
20' 6"	8.83				
21' 6"	10.01				

STA (ft)	Vel (ft/s)
8' 0"	0.01
9' 0"	0.01
10' 0"	0.3
11' 0"	0.56
12' 0"	0.78
13' 0"	0.73
14' 0"	1.02
15' 0"	1.17
16' 0"	1.23
17' 0"	1.34
18' 0"	1.36
19' 0"	LOG
20' 0"	0.13
21' 0"	0.32
22' 0"	0.32
23' 0	0.00

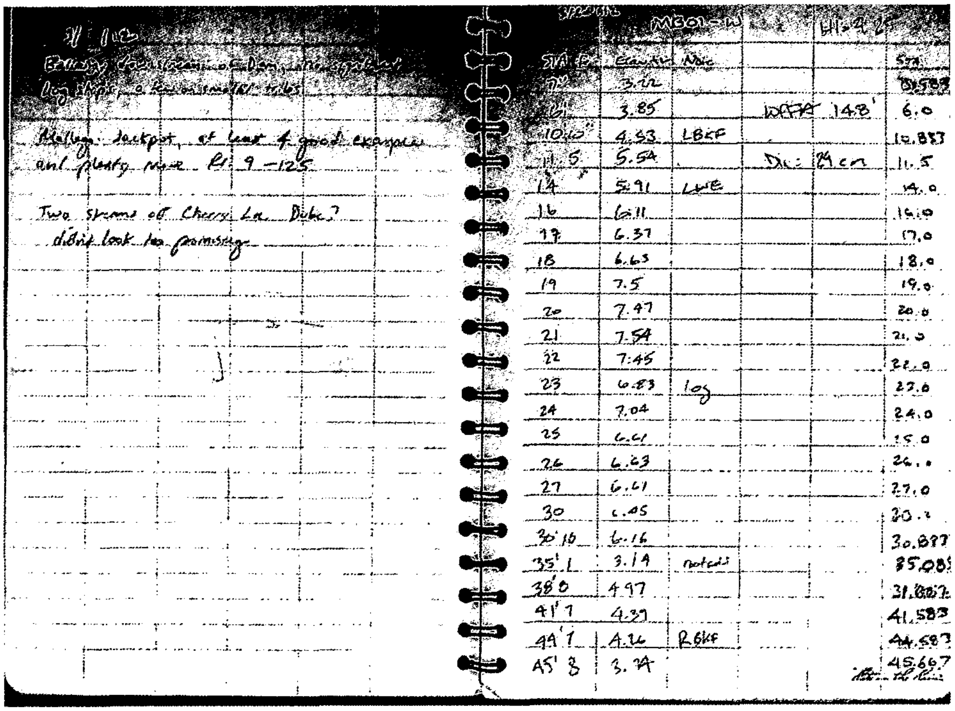


[illegible] XS-Conv. 01

STA (ft)	Elev (ft)				STA (ft)
2'3"	3.94			[illegible] 52.0	[illegible]
3'4"	4.19	LBKF			3.33
3'10"	4.36				3.83
4'11"	5.37				4.92
5'8"	5.51	LEW			5.67
7'	5.69				7
8'	6.49				8
9'	6.54				9
10'	6.47				10
11'6"	6.19				11.5
13'	6.30				13
15'	6.29				15
16'	6.36				16
17	6.30				17
19	6:22				19
21	~~5.97~~ 6.18				21
23	6.16				23
25	6.19				25
27	6.25				27
28	6.15				28
28'9"	6.02				28.75
29	3.63				29
31'6"	3.35				31.5

A = 53.66 ft² ℓ = 28.05 ft

PSD	(in)		Pool	
2.5	0.2		S	0.4
2.0	4.5		S	S
2.5	1.3		S	S
S	1.1		S	0.1
1.0	1.4		2.0	0.6
1.5	0.8		0.5	0.7
1.0	1.9		0.4	0.2
2.0	0.8		0.3	0.9
3.0	0.5		1.3	0.3
4.5	0.4		0.6	0.2
1.1	0.5		0.4	2.6
0.5	1.5		1.2	S
1.5	1.2		0.4	0.6
2.0	3.0		S	0.3
4.0	1.0		0.8	1.0
1.5	2.2		0.5	0.5
0.5	2.3		1.6	0.4
0.3	1.6		S	S
0.5	S		0.3	0.2
1.0	1.2		0.5	1.2
3.0	1.4		0.2	2.3
1.5	2.0		0.0	S
1.5	1.7		S	0.2
1.8	3.3		S	0.3
1.3	6.0		S	0.2



3/ 1 [illegible]

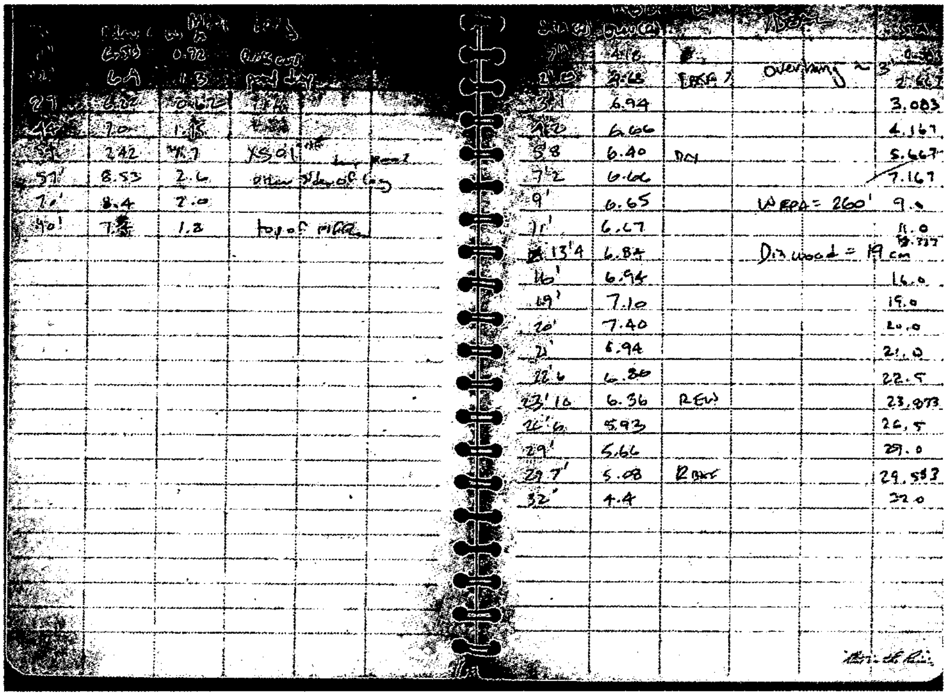
Bailey [illegible] of Dam, no significant log steps, a few on smaller tribs

Alley: Jackpot, at least 4 good examples and plenty more Rt 9 - 125

Two streams off Cherry Ln Dike?
didn't look too promising

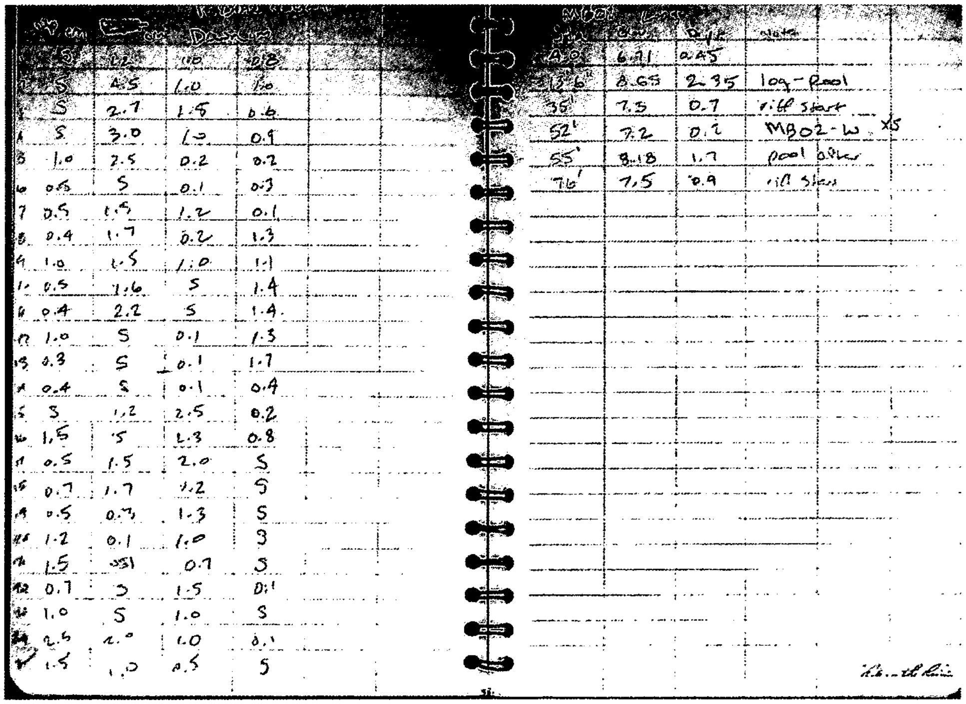
[illegible] MB01-W H1-9 25

STA ft	Elev ft	Note			Sta
7"	3.22				0.583
6'	3.85		~~WDFA~~ 148'		6.0
10'10"	4.53	LBKF			10.833
11'5	5.54		Dx:	24 cm	11.5
14	5.91	LWE			14.0
16	6.11				16.0
17	6.37				17.0
18	6.63				18.0
19	7.5				19.0
20	7.47				20.0
21	7.54				21.0
22	7:45				22.0
23	6.83	log			23.0
24	7.04				24.0
25	6.61				25.0
26	6.63				26.0
27	6.61				27.0
30	6.45				30.0
30'10	6.16				30.833
35'1	3.14	notch			35.083
38'0	4.97				[illegible]
41'7	4.29				41.583
44'7	4.26	RBKF			44.583
45'8	3.74				45.667



[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	6.58	0.92	[illegible]
[illegible]	6.A	1.3	pool [illegible]
27	6.22	0.62	[illegible]
49	7.0	1.15	[illegible]
51	2.42	[illegible].7	XS01 [illegible] log Pool
57'	8.53	2.6	other side of log
70'	8.4	2.0	
90'	7.[illegible]	1.2	top of riffle

[illegible]	[illegible]		[illegible]	[illegible]
7"	4.16	[illegible]		0.583
2'8	[illegible]	[illegible]	overhang ~ 3'	2.667
3'1	6.94			3.083
4'2	6.66			4.167
5'8	6.40	DM		5.667
7'2	6.66			7.167
9'	6.65		WEPA = 260'	9.0
11'	6.67			11.0
13'4	6.84		Dia wood = 19 cm	13.333
16'	6.94			16.0
19'	7.10			19.0
20'	7.40			20.0
21'	6.94			21.0
22'6	6.80			22.5
23'10	6.36	REW		23.833
26'6	5.93			26.5
29'	5.66			29.0
29'7'	5.08	Rbkf		29.583
32'	4.4			32.0

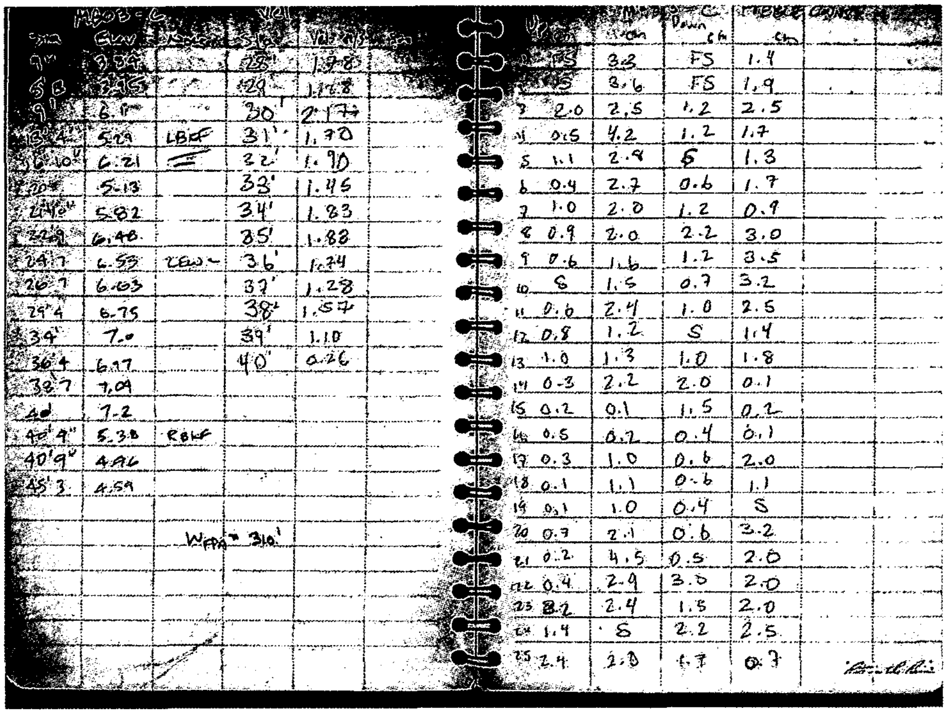


[illegible] cm [illegible] cm Datum

	S	1.2	1.0	0.8
	S	4.5	1.0	1.0
	S	2.7	1.5	0.6
4	S	3.0	1.0	0.9
5	1.0	2.5	0.2	0.2
6	0.5	S	0.1	0.3
7	0.5	1.5	1.2	0.1
8	0.4	1.7	0.2	1.3
9	1.0	1.5	1.0	1.1
10	0.5	1.6	S	1.4
11	0.4	2.2	S	1.4
12	1.0	S	0.1	1.3
13	0.3	S	0.1	1.7
14	0.4	S	0.1	0.4
15	S	1.2	2.5	0.2
16	1.5	S	1.3	0.8
17	0.5	1.5	2.0	S
18	0.7	1.7	1.2	S
19	0.5	0.7	1.3	S
20	1.2	0.1	1.0	S
21	1.5	.051	0.7	S
22	0.7	S	1.5	0.1
23	1.0	S	1.0	S
24	2.5	2.0	1.0	0.1
25	1.5	1.0	0.5	S

MB02 Long[illegible]

Sta	Elev	Depth	Note
4.0	6.71	0.45	
13'6"	8.65	2.35	log-Pool
35'	7.5	0.7	riff start
52'	7.2	0.2	MB02-W X5
55'	8.18	1.7	pool after
76'	7.5	0.9	riff start



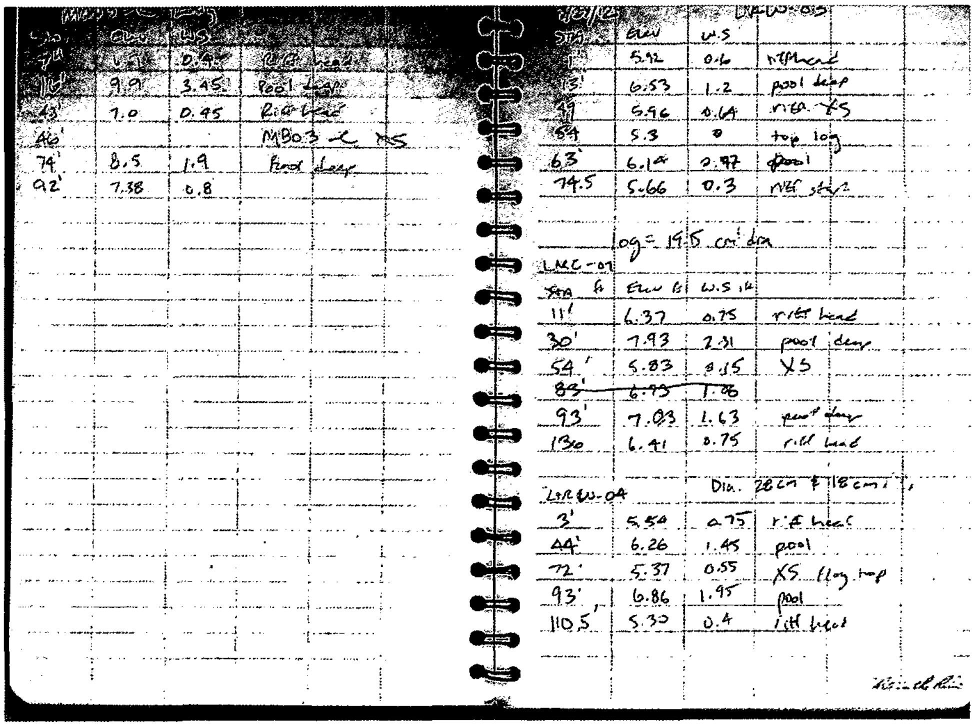
MB03-C Vel

Sta	Elev	[illegible]	Sta	Vel [illegible]
9"	3.84		28'	1.78
5'8	3.15		29'	[illegible]
9'	6.1		30'	2.17
13'4"	5.29	LBKF	31'	1.70
16'10"	6.21	=	32'	1.90
20'	5.13		33'	1.45
21'10"	5.82		34'	1.83
22'9	6.48		35'	1.88
24'7	6.53	REW~	36'	1.74
26'7	6.03		37'	1.28
29'4	6.75		38'	1.57
34'	7.0		39'	1.10
36'4	6.97		40'	0.26
38'7	7.09			
40	7.2			
40'4"	5.30	RBKF		
40'9"	4.96			
45'3	4.59			

W_FPA = 310'

MB03-C Pebble Counts

	Up ch	ch	Down ch	ch
1	FS	3.3	FS	1.4
2	FS	3.6	FS	1.9
3	2.0	2.5	1.2	2.5
4	0.5	4.2	1.2	1.7
5	1.1	2.9	S	1.3
6	0.4	2.7	0.6	1.7
7	1.0	2.0	1.2	0.9
8	0.9	2.0	2.2	3.0
9	0.6	1.6	1.2	3.5
10	S	1.5	0.7	3.2
11	0.6	2.4	1.0	2.5
12	0.8	1.2	S	1.4
13	1.0	1.3	1.0	1.8
14	0.3	2.2	2.0	0.1
15	0.2	0.1	1.5	0.2
16	0.5	0.2	0.4	0.1
17	0.3	1.0	0.6	2.0
18	0.1	1.1	0.6	1.1
19	0.1	1.0	0.4	S
20	0.7	2.1	0.6	3.2
21	0.2	4.5	0.5	2.0
22	0.4	2.9	3.0	2.0
23	8.2	2.4	1.5	2.0
24	1.4	S	2.2	2.5
25	2.4	2.0	1.7	0.7



MB03-C [illegible]

Sta	Elev	WS	
7'	[illegible]	0.4	Rif head
16'	9.9	3.45	Pool deep
43'	7.0	0.45	Rif head
46'			MB03 ℄ XS
74'	8.5	1.9	Pool deep
92'	7.38	0.8	

[illegible]/12 LRW-05

Sta	Elev	W.S	
1'	5.92	0.6	riffhead
13'	6.53	1.2	pool deep
49	5.96	0.64	riff. XS
54	5.3	0	top log
63'	6.1	0.97	pool
74.5	5.66	0.3	riff start

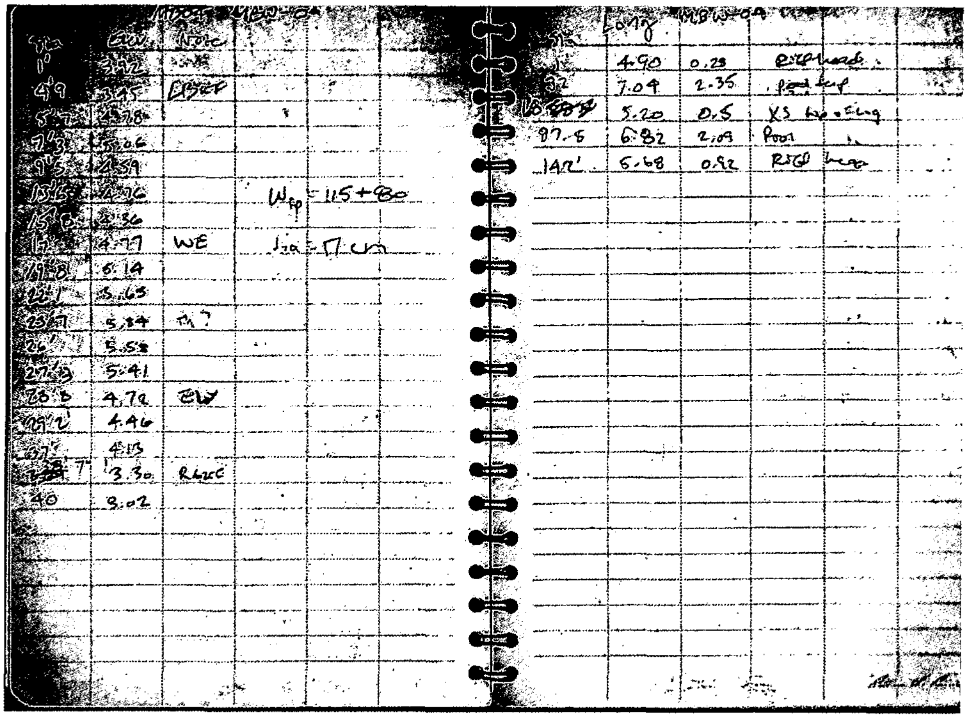
log = 19.5 cm dia

LMC-07

Sta ft	Elev ft	W.S ft	
11'	6.37	0.75	riff head
30'	7.93	2.31	pool deep
54'	5.83	0.15	XS
~~83'~~	~~6.93~~	~~1.06~~	
93'	7.03	1.63	pool deep
130	6.41	0.75	riff head

LRW-04 Dia. 28cm & 18cm

3'	5.54	0.75	riff head
44'	6.26	1.45	pool
72'	5.37	0.55	XS (log top
93'	6.86	1.95	pool
110.5'	5.30	0.4	riff head



[illegible] MBW-0[illegible]

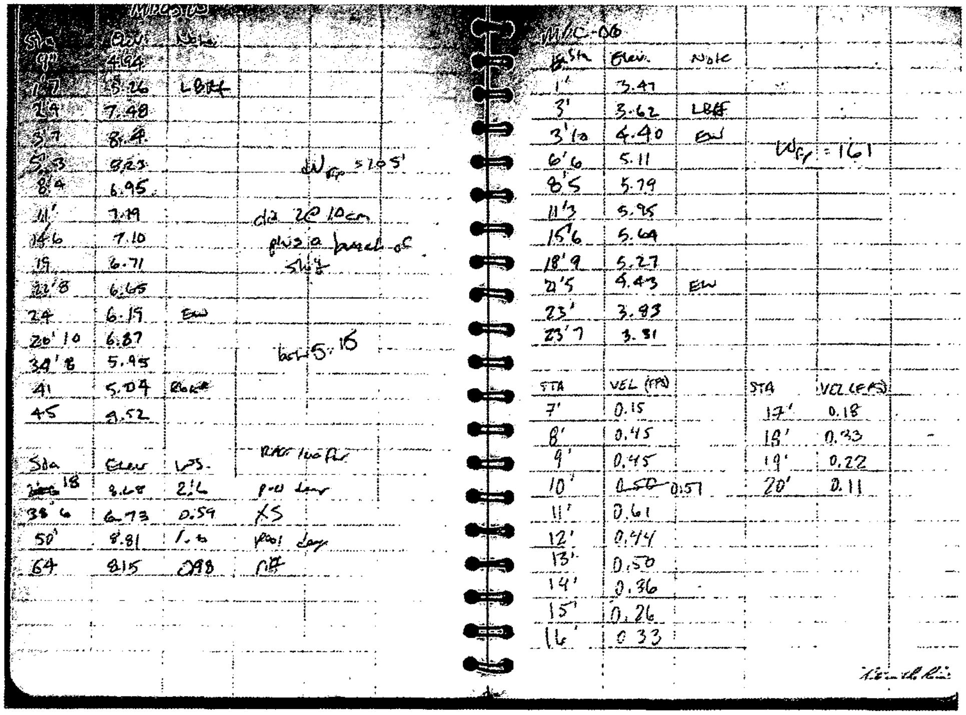
Sta	Elev	Note
1'	3.92	
4'9	3.95	LBBF
5'7	4.78	
7'3	5.06	
9'5	4.59	
13'6	4.76	
15'8	4.36	
17'	4.77	WE
19'8	6.14	
22'1	5.65	
23'7	5.84	TA ?
26'	5.58	
27'3	5.41	
28'5	4.72	EW
29'2	4.46	
37'	4.13	
~~38~~ 7'	3.30	RBBF
40	3.02	

W_{fp} = 115+80

d_{50} = 17 cm

Long MBW-04

Sta			
1'	4.90	0.23	Riffle head
32	7.04	2.35	pool tail
18 ~~[illegible]~~	5.20	0.5	XS beginning
87.5	6.82	2.09	Pool
142'	5.68	0.92	[illegible]



[illegible]

Sta	Elev	Note
9"	4.94	
1'7	5.26	LBBF
2'9	7.48	
3'7	8.4	
5'3	8.23	
8'4	6.95	
11'	7.19	
14'6	7.10	
19	6.71	
22'8	6.65	
24	6.19	EW
20'10	6.87	
34'8	5.95	
41	5.04	RBBF
45	9.52	

W_{fp} = 105'

d_{50} 2@10cm plus a bunch of silt

[illegible] 5.16

[illegible] 100 ft

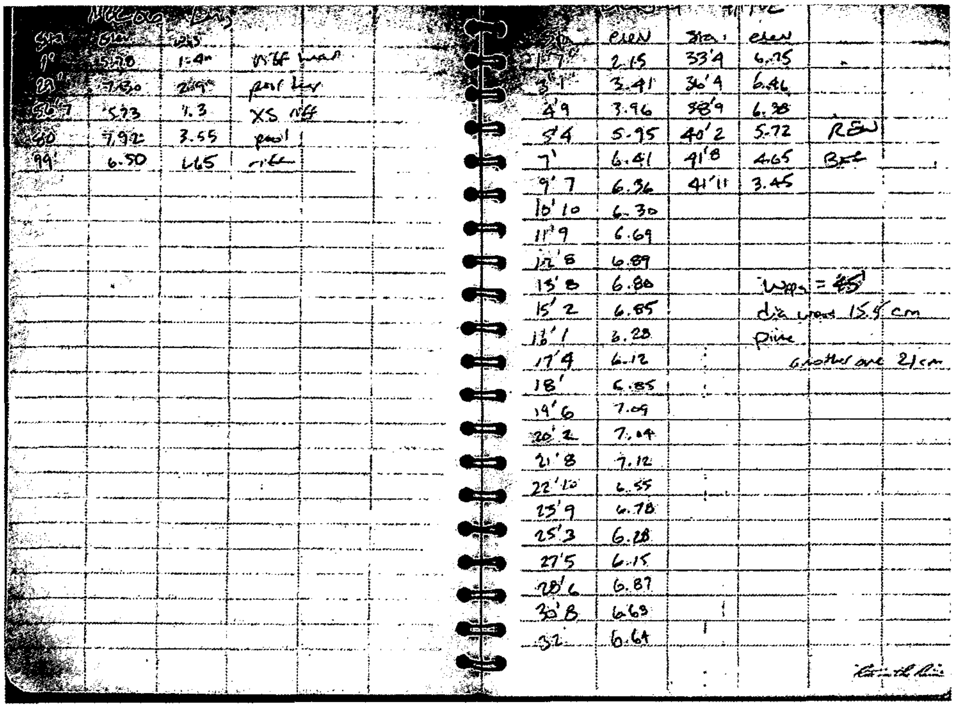
Sta	Elev	WS.	
~~[illegible]~~ 18	8.68	2.16	[illegible]
38'6	6.73	0.59	XS
50'	8.81	1.6	Pool [illegible]
64	8.15	0.98	[illegible]

M/C-06

Sta	Elev.	Note
1'	3.41	
3'	3.62	LBBF
3'10	4.40	EW
6'6	5.11	
8'5	5.79	
11'3	5.95	
15'6	5.69	
18'9	5.27	
21'5	4.43	EW
23'	3.93	
23'7	3.31	

W_{fp} = 161

STA	VEL (FPS)	STA	VEL (FPS)
7'	0.15	17'	0.18
8'	0.45	18'	0.33
9'	0.45	19'	0.22
10'	~~0.50~~ 0.57	20'	0.11
11'	0.61		
12'	0.44		
13'	0.50		
14'	0.36		
15'	0.26		
16'	0.33		

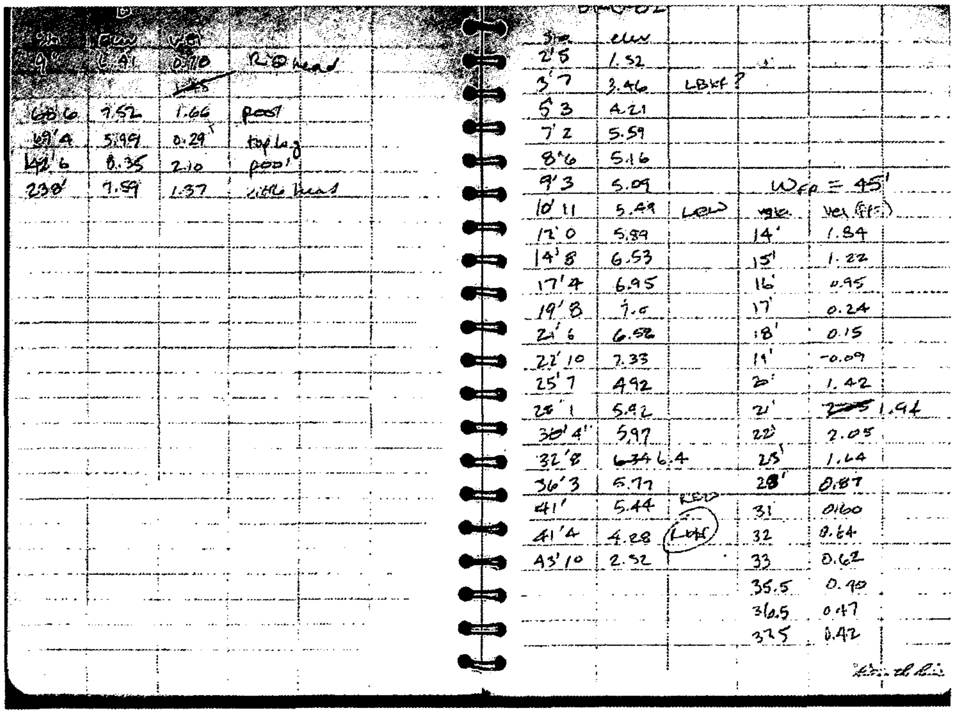


[illegible]

Sta	elev	d	
9'	5.70	1.4"	riff head
29'	7.30	2.9"	pool tail
56'7	5.73	1.3	XS riff
80'	7.92	3.55	pool
99'	6.50	1.65	riffle

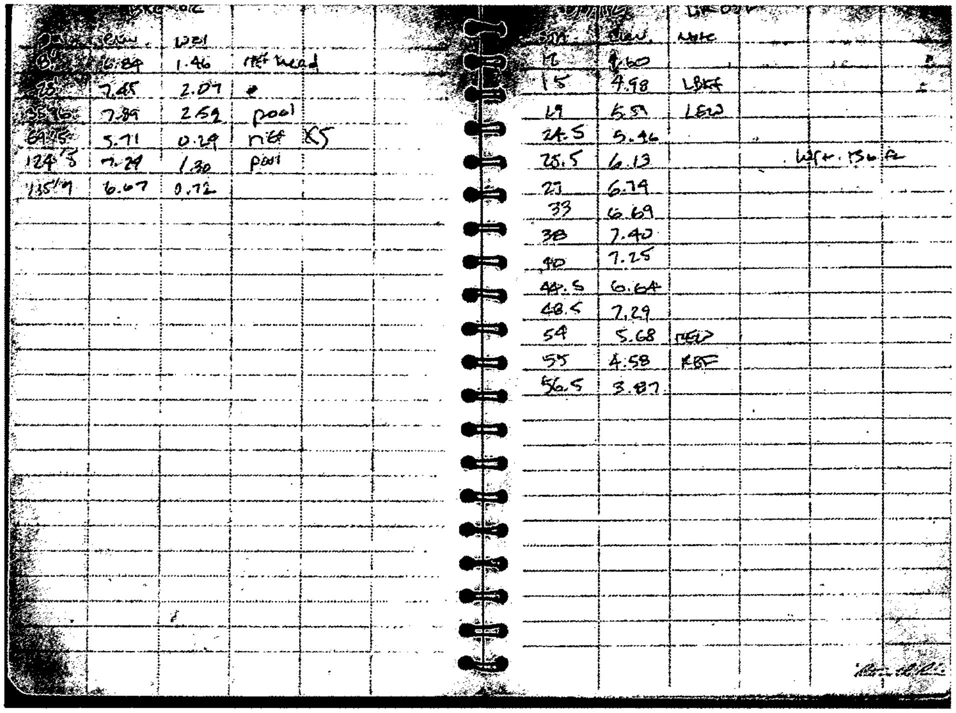
Sta	elev	Sta	elev	
1'7	2.15	33'4	6.75	
3'1	3.41	36'4	6.46	
4'9	3.96	38'9	6.38	
5'4	5.95	40'2	5.72	REW
7'	6.41	41'8	4.65	BF
9'7	6.36	41'11	3.45	
10'10	6.30			
11'9	6.69			
12'8	6.89			
13'8	6.80			
15'2	6.85			
16'1	6.28			
17'4	6.12			
18'	6.85			
19'6	7.09			
20'2	7.04			
21'8	7.12			
22'10	6.55			
23'9	6.78			
25'3	6.28			
27'5	6.15			
28'6	6.87			
30'8	6.63			
32'	6.64			

Wfps = 45'
dia wood 15.9 cm
pine
another one 21cm



Sta	elev	vel	
9'	6.41	0.70 ~~1.45~~	R@ head
68'6	7.52	1.66	pool
69'4	5.99	0.29	top log
142'6	8.35	2.10	pool
238'	7.59	1.37	riffle head

Sta	elev		Wfp = 45'	
2'5	1.52			
3'7	3.46	LBKF?		
5'3	4.21			
7'2	5.59			
8'6	5.16			
9'3	5.09			
10'11	5.49	LEW	sta	vel (ft/s)
12'0	5.89		14'	1.84
14'8	6.53		15'	1.22
17'4	6.95		16'	0.95
19'8	7.0		17'	0.24
21'6	6.58		18'	0.15
22'10	7.33		19'	-0.09
25'7	4.92		20'	1.42
28'1	5.42		21'	~~2.25~~ 1.94
30'4"	5.97		22'	2.05
32'8	~~6.34~~ 6.4		23'	1.64
36'3	5.77		28'	0.87
41'	5.44	REW	31	0.60
41'4	4.28	LBF	32	0.64
43'10	2.32		33	0.62
			35.5	0.40
			36.5	0.47
			37.5	0.42

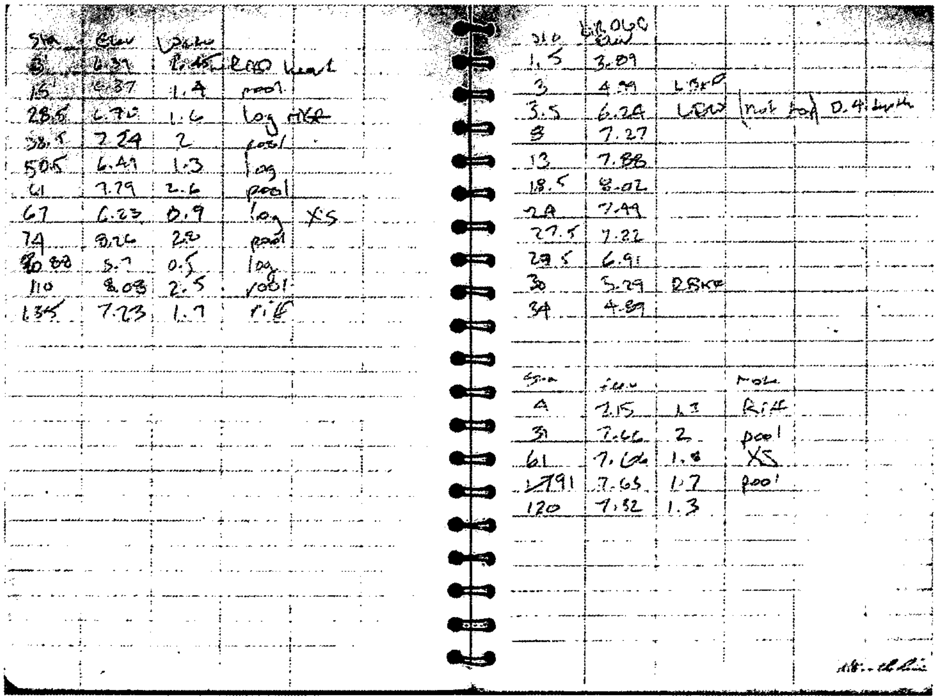


[illegible]

Sta	Elev	WD	
8	6.89	1.46	riff head
25	7.45	2.07	
35.96	7.89	2.59	pool
69.45	5.71	0.29	riff XS
124.5	7.29	1.30	pool
135.9	6.67	0.72	

[illegible]

Sta	Elev	Note	
12	4.60		
15	4.98	LBKF	
19	5.59	LEW	
24.5	5.46		
25.5	6.13		[illegible] 15.6 ft
27	6.79		
33	6.69		
38	7.40		
40	7.25		
44.5	6.64		
48.5	7.29		
54	5.68	REW	
55	4.58	RBF	
56.5	3.87		

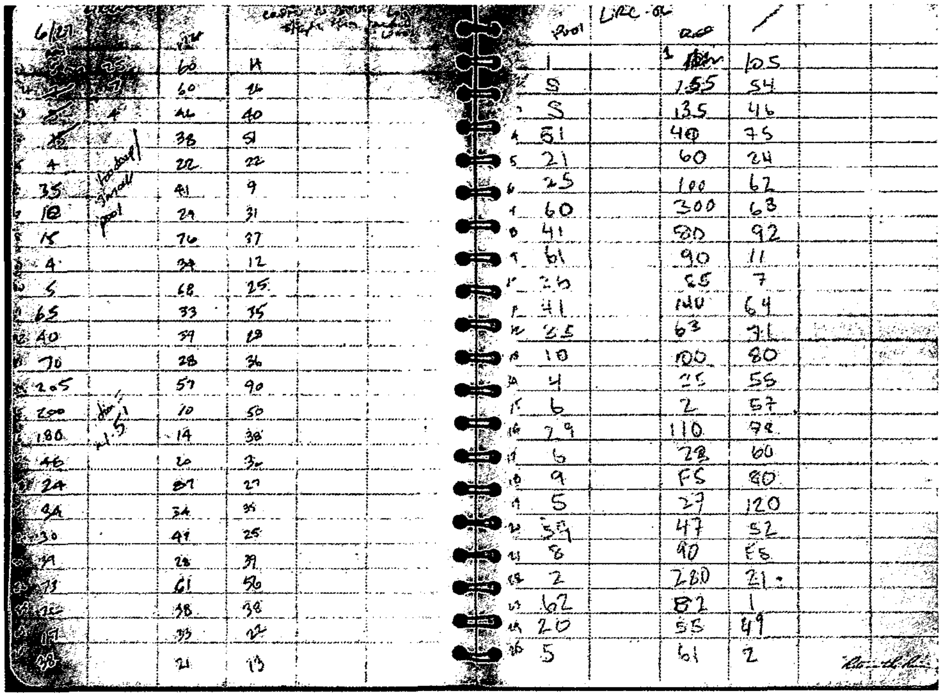


Sta	Elev	Water	
8	6.39	2.45	Riff head
15	6.37	1.4	pool
28.5	6.70	1.6	log riff
38.5	7.24	2	pool
50.5	6.49	1.3	log
61	7.79	2.6	pool
67	6.23	0.9	log XS
74	8.26	2.8	pool
80.88	5.7	0.5	log
110	8.03	2.5	pool
135	7.23	1.7	riff

[illegible]

Sta	Elev		
1.5	3.09		
3	4.99	LBKF	
3.5	6.29	LEW	not [illegible] 0.4 depth
8	7.27		
13	7.88		
18.5	8.02		
24	7.49		
27.5	7.22		
29.5	6.91		
30	5.29	RBKF	
34	4.89		

Sta	Elev		Note
4	7.15	1.3	Riff
31	7.66	2	pool
61	7.66	1.8	XS
1791	7.65	1.7	pool
120	7.32	1.3	



6/21	[illegible]		
[illegible]	25	60	14
[illegible]	7	60	26
~~2~~	4	46	40
~~15~~		38	51
4	[illegible] small pool	22	22
35		41	9
10		29	31
15		76	37
4		39	12
5		68	25
65		33	35
40		39	19
70		28	36
205		57	90
200	[illegible] 1	10	50
180	[illegible] 5	14	38
46		20	32
24		87	27
34		34	35
30		49	25
39		28	39
73		61	56
72		38	38
17		33	22
38		21	13

	Pool	LRC-06	[illegible]	/
[illegible]	1		1 [illegible]	105
[illegible]	5		155	54
3	5		135	46
4	51		40	75
5	21		60	24
6	25		100	62
7	60		300	63
8	41		80	92
9	61		90	11
10	26		85	7
11	41		140	64
12	35		63	71
13	10		100	80
14	4		25	55
15	6		2	57
16	79		110	78
17	6		28	60
18	9		85	80
19	5		27	120
20	59		47	52
21	8		90	58
22	2		280	21
23	62		82	1
24	20		55	49
25	5		61	2