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Spatial Variation in Characterized Buried Soils and Legacy Sediments of the Northeast USA

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SPATIAL VARIATION IN CHARACTERIZED BURIED SOILS AND LEGACY SEDIMENTS OF THE NORTHEAST USA

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An Honors Thesis submitted in partial fulfillment

of the requirements for the degree of Bachelor of Arts

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ABSTRACT

The role of historical mill dams in transforming river systems, especially throughout New England and the mid-Atlantic Piedmont regions of the United States has recently emerged as a topic of debate amongst the scientific community. In both physiographic provinces, large post-settlement alluvium "legacy" deposits originating from colonial-era deforestation, agriculture, and ongoing hillslope land-use disturbances characterize the floodplains. Furthering land-use impacts, water-powered milling from the late 17^{th} to early 20^{th} century was historically intensive throughout Southeastern New England and Pennsylvania, aiding in the floodplain storage of legacy deposits behind mill dams. These geologically recent legacy sediments overlay comparatively organic-rich, pre-colonial buried floodplain soils. Along mid-Atlantic Piedmont streams, debate has emerged regarding the ubiquity of both the interpreted pre-disturbance land surface, and the thickness of the legacy sediment layers in modern floodplains. When coupled with management concerns regarding the potential for legacy sediment to serve as a source for nutrient-rich sediment pollution and the rise of a billion dollar stream restoration industry, it is imperative that our understanding of the nature and extent of these floodplain deposits is pushed further. In this study, field sampling of exposed riverbanks was carried out along two major tributaries to the Christina and Brandywine Rivers in Pennsylvania and along two tributaries to the Connecticut River in order to characterize the nature and spatial variation of legacy sediment and buried soil thicknesses along the floodplain continuum. Floodplain deposits were analyzed for thickness, organic material, grain size, and color. A longitudinal survey accompanied the deposit measurements relative to the stream gradient and bank elevation. Deposit thicknesses were mapped using GIS and investigated for correlations with known historical mills and dams. Sites were cross-compared to explore the role of glacial history in legacy sediment deposition and variability of the pre-disturbance floodplain surface. Results indicated that floodplain deposits vary greatly within and between watersheds as well as within different glacial settings. Buried soils were consistently richer in organic content than post-settlement alluvium, but both layers had similar characteristic grain-size distributions. Post-settlement alluvium deposits varied widely in thickness within and between watersheds (20-160 cm in PA, 51-143 cm in CT), as did buried organic soils (0-80cm in PA, 20-48cm in CT). Mill dams served as a source of legacy sediment preservation, but were not collectively coupled with sediment deposits. Differences in regional and glacial histories influenced the magnitude to which sediments were stored in the floodplains, but it was slope, sinuosity, and depositional environment that appeared to most significantly impact the preservation of sediments in the landscape. The overall trends in the results suggest patchy distributions of pre-colonial floodplain conditions (e.g. grass dominated wetland, bottomland forest) as well as a patchy post-settlement depositional environment.

ACKNOWLEDGEMENTS

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1.0 Introduction

Rivers and streams have been the bloodlines of civilization since the earliest recorded human history. The importance of rivers for fresh water, food, recreation, navigation, and economic purposes is well known, yet there is increasing evidence that the once free-flowing natural rivers of the U.S have been in rapid decline for the last few centuries (Turner and Rabalais, 1991; Gergel et al., 2002; Walling, 2006). Early agricultural activity and deforestation throughout the Northeast from the 17^{th} to 19^{th} century rapidly eroded the upland landscape; just as the rise of dam construction trapped the downstream sediment influx coming off the land. In particular, these land-use impacts have created a tremendous amount of deposited anthropogenic sediment along rivers. Often referred to as legacy deposits, anthropogenic sediments exposed to land-use impacts are seen throughout the floodplain landscape. Management concerns regarding the contemporary impact legacy sediments have on rivers and streams create a need for understanding how waterways have been altered in order to adequately restore them.

Increasing scientific interest in the implications of human alteration to river systems has been spurred by a need to restore rivers. In the past few decades, river restoration has grown to over a billion dollar a year industry (Bernhardt et al., 2005). Restoration relies heavily on the interpreted understanding of natural streams and utilizes pre-disturbed river systems as a baseline. A 2008 study by Walter and Merritts described the pre-colonial floodplain landscape across the mid-Atlantic Piedmont region as a grass-dominated wetland. However, debate has emerged regarding the ubiquity of their interpreted landscape across locations, especially as a template for restoration (Bain et al., 2008; Wilcock, 2008; Montgomery, 2008). This study, in the broadest sense, questions the extent to which human activities created a pulse of sediment in the landscape and whether the layer found below the human disturbance legacy deposit shows the pre-colonial surface. Specifically, it aims to add understanding to both the contemporary influence of legacy deposits in historically altered river environments and the interpretation of the pre-disturbance floodplain landscape in glaciated versus unglaciated settings. Study sites in southeastern Pennsylvania and central Connecticut were used to test the ideas in question. The study locations all experienced historically heavy levels of land use across the landscape associated with deforestation, agriculture, and mill dams.

Human land-use activities have fundamentally changed the geomorphology of rivers. Land-use describes the various ways in which human beings use and manage the land and its resources. Today, nearly one-half of land surfaces have been transformed by human alteration, and an estimated two-thirds of the fresh water flowing in rivers obstructed by dams (Vitousek et al., 1997; Nilsson and Berggren, 2000). Human modification of land cover over the past few centuries in the United States has resulted in large volumes of sediment eroded from hillsides and deposited in valleys along rivers and streams (Walter and Merritts, 2008).

The influence of landscape changes on rivers has long been studied (Hynes, 1975; Vannote et al., 1980; Allan, 2004). However, the level of change from a river's "natural" state is difficult to both quantify and qualify. Assessing the impact of land-use change and related human activity on the geomorphology of rivers, in particular, is challenged by the general lack of long-term records of sediment transport (Walling, 1999). Human activities impact how both the channels and floodplains of a river evolve. When a river overtops its banks and floods, it leaves behind layers of sediment on either side of the channel referred to as the floodplain. Floodplain formation can be shaped by braided channels, which are multiple channels separated by small and often-temporary sediment bars, or a single, meandering channel. Alterations in flow regimes, sediment regimes, and vegetation cause rivers to switch between multi-thread and single-thread channels (Tal, 2003; Wohl, 2004). The variety and influence of land-use histories necessitates a need to address site-specific and regional land-use histories, which might have influenced the geomorphology of rivers and streams observed today.

Human impacts to aquatic ecosystems often involve changes in hydrologic connectivity and flow (Kondolf et al., 2006). Hydrologic connectivity refers to the fluxes of material, energy, and organisms moved by water within the channel, floodplain, and all other components of the ecosystem (Pringle, 2001). Connectivity is important for adequately characterizing fluxes within the landscape, and for understanding how humans alter those fluxes (Kondolf et al., 2006). In-stream structures, such as dams, alter hydrologic connectivity and may effectively interrupt or eliminate connectivity of sediment (Wohl, 2014). Sediment connectivity can refer to the movement, or storage, of sediment down hillslopes, into channels, or along channel networks (Harvey, 1997; Fryirs et al., 2007; Brierley and Fryirs, 2013). Activities that reduce geomorphic complexity and storage of fine sediment and nutrients typically increase longitudinal connectivity of rivers (Wohl, 2014). Historically, prolific damming of streams along the eastern seaboard from the 17th to 20th century for water-powered milling compromised longitudinal connectivity and left a long-term legacy on the region. Dams trapped large volumes of sediment originating from colonial-era deforestation and ongoing hillslope land disturbance in the river valleys and streams of the East. By limiting overbank flows, however, these alterations reduced lateral connectivity between the channel and floodplain (Wohl, 2014). Rivers and streams disconnected from the natural system by human modifications explain much of the ecological degradation seen in waterways across the nation (Wohl, 2004).

While prior studies suggested the role that land-use and damming have on sediment deposits along rivers (Milliman et al., 1983; Walling, 1999; James and Lecce, 2013), few studies have taken into account the influence of geologic setting and glacial history between study localities. At the time of the last ice age, Connecticut and most of the Southern New England region remained under glaciation. However, the ice in Southern New England was thinner and retreated at a faster rate than its Northern New England counterparts (Soto and Huoppi, 2002). Soil that once covered New England was scraped away by glacial advancement and retreat, leaving a rocky landscape and limited loose sediment available to enter rivers and streams and be stored in the adjacent floodplains. In the mid-Atlantic Piedmont region, glaciation did not extend beyond the northernmost corners of Pennsylvania. The use of stream sites between two different geographic regions with unique glacial histories in this study provides a broader scope of understanding how geologic history influences stream formation and anthropogenic sediment accumulation.

The large extent of suspected legacy sediments deposited along floodplains in preliminary field reconnaissance constitutes a reexamination of natural channel formation. Legacy sediments were identified based on soil color and composition. The issues of most interest involve understanding the similarities and differences in characterized legacy deposits and buried organic soil layers along riverbanks between and within Connecticut and Pennsylvania sites. This study, in the broadest sense, aims to 1) characterize the spatial variation of legacy sediment deposits across floodplain landscapes in two different geographical settings, with particular interest in the spatial relations between colonial mill dams and legacy deposits as well as the relationship between legacy deposit patterns and glacial history and 2) determine the variability and nature of the buried pre-settlement A horizon layers. It is hypothesized that 1) the presence of legacy sediment deposits vary depending on proximity to historic mill dam locations and glacial history, and that 2) buried organic soil layers vary in composition, reflecting a heterogeneous pre-settlement floodplain landscape. Hypotheses were tested through extensive fieldwork collecting samples along exposed banks in Connecticut and Pennsylvania and through detailed sediment analysis of the samples collected. The observations made are critical to a broader and more thorough understanding of legacy sediments and the pre-disturbance floodplain surface. Little evidence has been given for the uniformity of historic valley-bottom surfaces, which often serve as a restoration template. Understanding of the pre-disturbance landscape is necessary for advancing river-restoration efforts. Knowledge of how human activities have contributed to landscape change also serves as a prerequisite for informed land-management and restoration decisions (Walter and Merritts, 2008).

2.0 Background

To identify patterns of sediment deposition along rivers and streams, it is necessary to understand how sediment arrives into the system. Sediment dynamics are difficult to measure but often change substantially over time in response to variations in the landscape (i.e glacial activity, dam sedimentation, land use) (James et al., 2009). It is therefore important to look at the known individual impacts to fluvial sediments and how they affect river landscapes. Understanding the history of sediment change aids in anticipating responses to current river and stream management.

2.1 Historic Land-use Impacts on Rivers

Land-use activities, whether converting natural landscapes for human use or changing management practices on human-dominated lands, have transformed a large proportion of the earth's terrestrial surface (Foley et al., 2005). The history of settlement patterns and socioeconomic conditions has produced various types of human land-use impacts on the rivers of the United States (Wohl, 2004). Graf (2001) calculated that humans have affected 79% of American rivers. In many cases, land-use activities have unintended consequences, creating a lasting legacy on the processes and form of a river (Wohl, 2014).

2.1.1 Degradation of the American forest

With the retreat of the last glaciation, the spread of forests over what had previously been a subartic plain introduced a whole new way of life upon the early human race (Wood, 1971). Forests had flourished unassisted for nearly 50 million years, remaining largely unmanaged (Williams, 1992). Evidence of land use from prehistoric and Native American maize-based agriculture prior to the Little Ice Age suggests an increased sedimentation in valley bottoms around 1100–1600 A.D (Denevan, 1992; Stinchcomb et al., 2011). This anthropogenic sedimentation and land use change began roughly 500 years prior to major European settlement (Denevan, 1992; Stinchcomb et al., 2011). The arrival of early European colonists to New England, however, added more small forest clearings used for planting crops. Overall the lack of a market for excess production caused forest clearing to remain quite slow through the 17th century. As the emerging seaboard nation expanded westward, however, the supply of wood had to keep up with the demand of houses and ships being built (Wood, 1971).

In direct response to the need for more wood, forest clearings increased in size and abundance (Wood, 1971). The invention of the circular saw in the early 1800s further increased the scale of deforestation (McGregor, 1988). Stonewalls soon replaced fences in New England, as wood became a dwindling commodity. The wood-pulp process for making paper pushed loggers even deeper into the forest (Wood, 1971). Overnight, the new folk hero Paul Bunyan emerged, and the purchase of cheap land soared (Stewart et al., 1916). Deforestation, which had begun in New England and swept across New York and Pennsylvania, soon became a nation-wide trend. By the mid-1800s land clearing and agriculture had come to a stop in New England as people moved west to more-arable soils. By the time westward forest clearing gained ground, ninety-six percent of the original forests of the northeastern and central states were already gone due largely to their settled populations and better agricultural soils and climate (Wohl, 2004).

In clearing vast tracts of land, loggers of the 18th and 19th-century caused colossal amounts of erosion along hill slopes (Figure 2.1, 2.2). Forest removal increased water yield, especially within the first year after cutting (Lee, 1980). Tree roots and plant cover that had previously stabilized soil and hillslopes no longer aided in water absorption (Wohl, 2004). By exposing the soil to water, deforestation increased hillslopes' vulnerability to mass movements (Harr, 1976). Geologically rapid erosion followed the removal of forest cover, transporting high volumes of water, sediment, and nutrients down into river channels (Wohl, 2004; Montgomery, 2012). Sedimentation from poor logging practices choked streambeds many miles downstream causing a loss of natural stream vegetation and destruction of fish habitat (Meade, 1996) (Figure 2.2). The widespread soil erosion and stream siltation, caused by deforestation, left New England streams that once swarmed with seasonal migrations of herring, thick with mud and empty of fish (Wohl, 2004). As deforestation persisted and expanded across the country, the downstream effects were felt on a greater scale (Figure 2.2). A 1970s testimony by the director of the Pacific Northwest Division of the Environmental Protection Agency, further showed that streams in logged areas contained up to 7,000 times more sediment than they contained before they were logged (Wood, 1971).

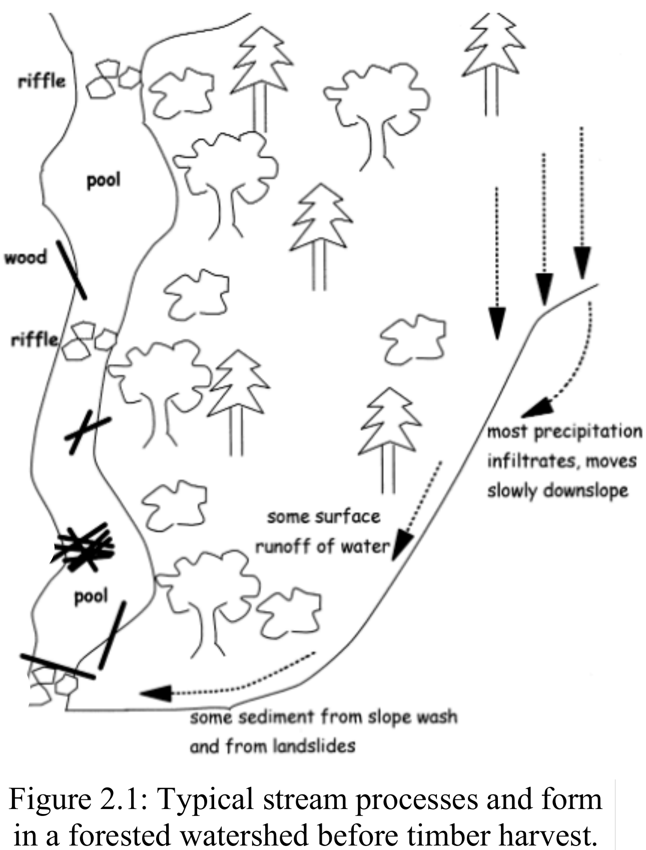

Figure 2.1: Typical stream processes and form in a forested watershed before timber harvest. Source: Wohl, 2004.

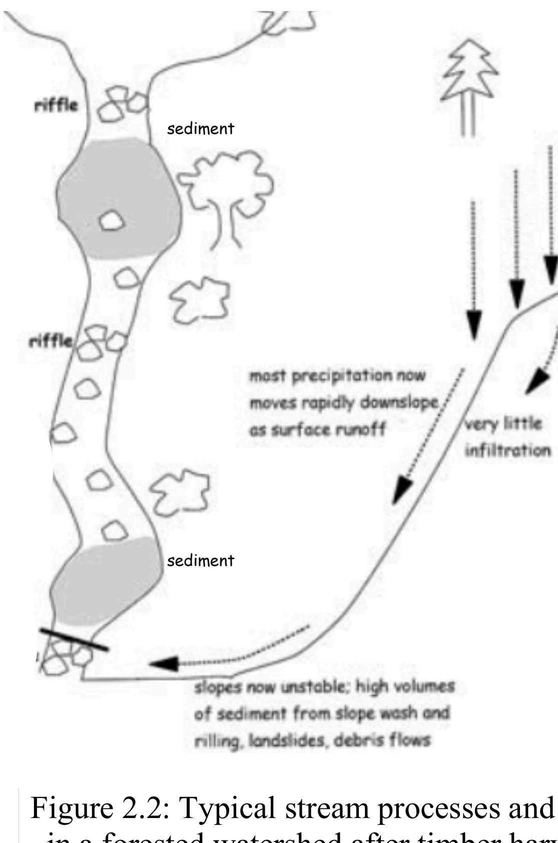

Figure 2.2: Typical stream processes and form in a forested watershed after timber harvest. Source: Wohl, 2004.

2.1.2 Agricultural Land-use Impacts

With an abundance of newly cleared and arable land throughout the Northeast, the impact of agricultural land-use followed suit in its erosive potential and sediment load. Early farming prioritized the floodplains for agricultural development (Bogucki, 1988). However, few places produce soil fast enough to sustain industrial agriculture over human time scales, let alone over geologic time (Montgomery, 2012). Agriculture in fertile valley bottoms of the eastern U.S. allowed populations to grow to the point where they had to farm on sloping land (Montgomery, 2012). The agricultural economy of the northeast transformed with the urban, industrial economy of the late 18th to the middle of the 19th century (Bidwell, 1921). Intensive agricultural practices by the second half of the 19th century along the eastern seaboard increased erosion, nutrient pollution, and sediment load to streams and rivers.

Several of the first studies documenting the effects of forest clearing and agricultural land-use focused on the Piedmont valley of Maryland (Wolman, 1967; Costa, 1975). A 1967 study by Wolman indicated that sediment yields from forested areas pre-farming were less than 35,000 kg per km^2 yearly. Yields from the same region increased to between 105,000 and 280,000 kg per km^2 yearly with the advent of extensive agriculture (Wolman, 1967; Wohl, 2004). A subsequent study of Piedmont streams in Maryland observed that agricultural sediment that was not eroded or transported downstream remained in the watershed as alluvium in the upper one meter of the floodplains (Costa, 1975). A number of more recent studies showed that rates of soil erosion from traditional agriculture practices are much greater than production of new soil by geologic processes (Langland and Cronin, 2003; Keller, 2010).

Growing concern toward the concentration of nutrients stored in sediment deposits has caused for further examination of the role agricultural erosion and land-use runoff play in fluvial systems. The influence of sediment in water pollution is tied both to the particle size of sediment and the amount of particulate organic carbon associated with sediment (Edwin, 1996). The chemically active fraction of sediment is usually cited as that portion which is smaller than 63 μm and is typically classified as silt and clay (Wentworth, 1922; Edwin, 1996). A large number of contaminants are associated with agriculture and insoluble in water or hydrophobic, causing them to associate with particulates or adsorb to sediments after being released (Malmon et al., 2002).

Results from a study by Malmon et al. (2002) advanced knowledge of a floodplain's ability to strongly influence the redistribution of anthropogenic pollutants in fluvial environments (2002). A study by Niemitz et al. (2013) of streams in Cumberland County, Pennsylvania further showed that agriculturally affected watersheds had increasing concentrations of nutrient elements and trace metals in post-disturbance floodplain deposits. Niemitz et al. (2013) attributed the source of the excess nutrients such as phosphorus, copper, and lead to fertilizers, pesticides, and other historic soil amendments. Historically polluted sediments pose greater concern to aquatic systems as they are eroded from banks and transported downstream to additional bodies of water.

2.2 Dam Impacts on Rivers

The increased sediment flux from land-use was met with further complication downstream as humans began to structurally modify rivers and streams. At the same time that timber harvest and agriculture were rising to prominence throughout the eastern United States, small dams began to segment the flow of rivers to meet the demands of industrialization. A dam, in its most simplistic definition, is constructed to store water or raise the water level upstream to divert water into a canal or to increase the 'hydraulic head'. The hydraulic head is the difference in height between the surface of a reservoir and the river downstream. A comparison model by Syvitski et al. (2005) estimated that humans increased the global river sediment transport through soil erosion and intensive land use by over two billion metric tons per year, yet simultaneously reduced the flux of sediment reaching the world's coasts by over one billion metric tons per year due mainly to retention behind dams. By nature of design, dams since their early implementation, have been considered a factor of sediment storage along rivers and streams.

While scientific attention is almost exclusively given to large dams, the use of dams in the United States long predates the era of monumental structures seen across the landscape today (Goldsmith et al., 1986; McCully, 1996; Graf, 1999; Graf, 2006; Macy, 2010). The first dams constructed in the United States corresponded with the first areas of European settlement (Schnitter, 1994). Early dams built through the 17th and 18th centuries were smaller and simpler in design, utilizing readily available materials. Prior to 1850, many small American dams were built using wood or stone stacked across stream channels (Jansen, 1980). Such methods made effective use of local materials at a time when transportation was limited. These early designs led to the use of timber crib dams filled with rock and covered with wood planking (Jansen, 1980). Regardless of building design or material, pre-industrial dams were low, crude, structures designed solely to increase water fall by raising the stream level for milling activities such as timber and grain (Billington et al., 2005).

2.2.1 The Rise of Milling

The need for dams rose with the need for timber along the Eastern Seaboard. As the timber industry assumed its place in the American marketplace, sawmills began to pop up throughout the Northeast, with streams and rivers serving as the necessary energy source to their success (Wood, 1971). The adoption by states of mill acts as early as the 1700s encouraged the construction of mills and dams (Hunter, 1979; Walter and Merritts, 2008). Preferential treatment toward mill development included financial assistance, free local labor for construction, and the granting of water rights on local streams to power waterwheels (Cech, 2010). At the turn of the 18th century, for example, the Maryland General Assembly passed the Maryland Mill Act to encourage continued construction of water mills in the state. The act entitled developers to an 80-year lease on ten acres of private, riparian property on both sides of the stream (Hart, 1995). The Massachusetts Legislature passed a mill act shortly after which awarded mill owners the right to construct milldams with little regard to the effects of flooding on upstream landowners (Steinberg, 2003; Cech, 2010).

The mid-to-late 1700s ushered in a period of unprecedented economic growth for the United States (Melosi, 1984). Sawmills, gristmills, paper mills, and cotton mills, among others, dotted the sides of streams (Figure 2.3a, Figure 2.4). Milling intensified with economic growth in colonial America, peaking along the eastern seaboard in the 1800s. Mill sites were selected by the ease with which the necessary head and fall of water could be obtained. Aside from the waterwheel, the dam was the most essential element of a mill (Billington et al., 2005). Small dams became critical to control the flow of water fueling the mills (Figure 2.3b).

Figure 2.3a and 2.3b: An abandoned mill located on White Clay Creek in Avondale, PA and a rock dam located on Doe Run in Coatesville, PA.

Figure 2.4: Historic mill and dam in Sudbury Massachusetts. Photo source: Douglas Thompson

2.2.2 Mill Dam Technology

The technology of water mills in colonial America was wholly European in origin and character (Hunter, 1979). Dam design along rivers and streams in the Northeast wavered little from its pre-industrial construction through the early stages of the industrial revolution (Figure 2.5). Mill owners of the 17th to 19th century were completely dependent on the hydrologic cycle for their supply of water power. The right amount of water was crucial. Too little water did not provide enough force to turn the wheel, while too much water kept the wheel from turning. Thus, the introduction of mill races or sluiceways became critical to the success of mill operations (Macy, 2010). In some locations, dams directed water into a mill race or sluiceway located upstream from the mill. The mill race diverted water from the stream to feed the water wheel. Mill races ranged in length depending on the need to build head. The better the site, the shorter the mill race. At the end of the mill race, a waterwheel turned and powered the mill, and the tailrace carried the water back into the stream or river (Reynolds, 2002). The dam was anchored into the riverbank with abutments designed to allow excess water to spill over (Cech, 2010).

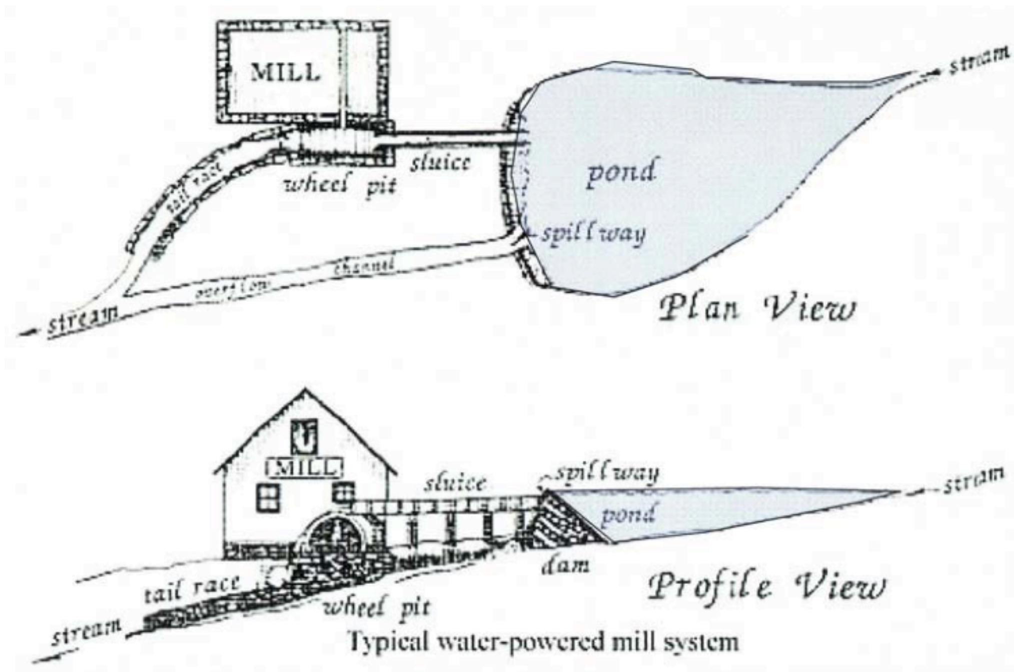

Figure 2.5: Mills on the Tsatsawassa: Techniques for Documenting Early 19th Century Water-Power Industry in Rural New York, by Philip L. Lord

2.2.3 Mill Dam Locations

Water-powered milling was especially intensive in the mid-Atlantic Piedmont region, west of the Atlantic Seaboard Fall Line (Figure 2.6). Stream gradients in the mid-Atlantic Piedmont region were conducive to milldam construction and the close proximity of shipping ports along the Coastal Plain was an added incentive (Walter and Merritts, 2008). New England had the highest regional density of dams, with 0.015 dams per km^2 (Graf, 1999). The density of dams in New England, much akin to the mid-Atlantic, can be attributed to its regional history of milling along rivers and streams (Figure 2.6). Areas of historically intensive milling saw a decline in water quality as more dams utilized the natural supply of streams and rivers. Throughout New England, New Jersey, New York, and Pennsylvania, sawmill waste polluted streams. Local sawmills extensively dumped sawdust into the water to the point that fish populations rapidly declined (Wohl, 2004).

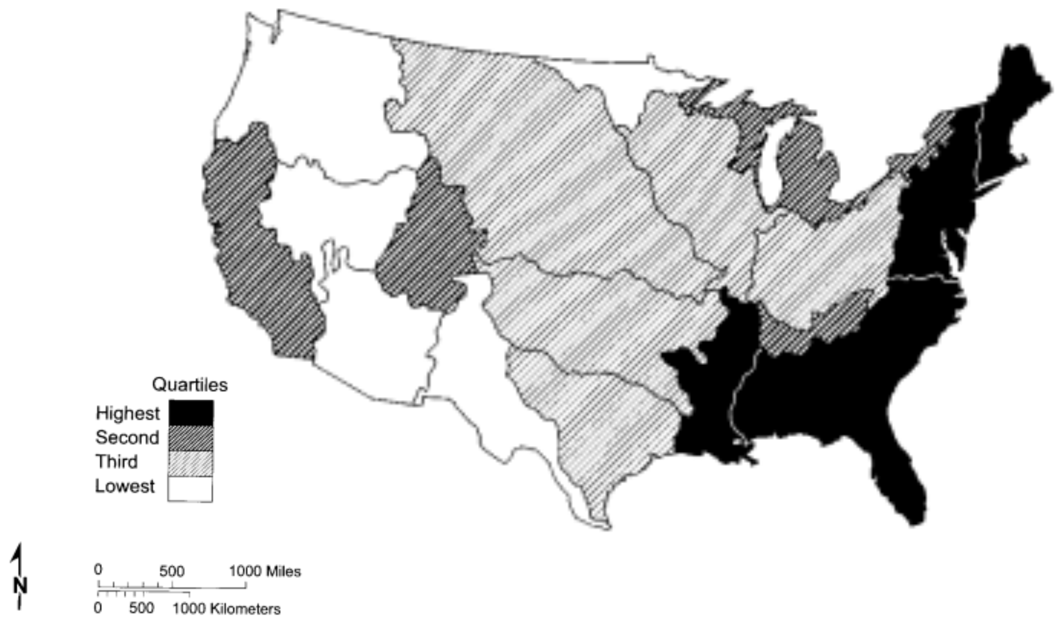

Figure 2.6: A map of dam density per area in the United States. Source: Graf, 1999

2.2.4 The Modern Day Legacy of Dams

Although structures were generally small for most of the history of dam building, new technologies in the 19th and 20th centuries allowed the construction of much larger and more complicated structures to generate hydroelectricity, control floods, support large-scale irrigation, and improve navigation (Smith, 1971; Schnitter, 1994). By current statistics, the United States has, on average, constructed the equivalent of one dam every day since Thomas Jefferson was president (DamNation, 2014). The Army Corps of Engineers maintains a National Inventory of Dams, which includes more than 76,500 "large" structures over ten meters (Graf, 1993). Yet, there are over 2.5 million dams in the United States, most of which are small (generally <2 m), privately owned structures that are not taken into statistical account on a national level (National Research Council et al., 1992) (Figure 2.7). In addition, these older, small dams are frequently failing and causing damage, injury, and property loss. The discrepancy in criteria used by governmental agencies and organizations to classify dam size is not reflected in statistics nor is dam size used in a consistent manner (Poff et al., 2002).

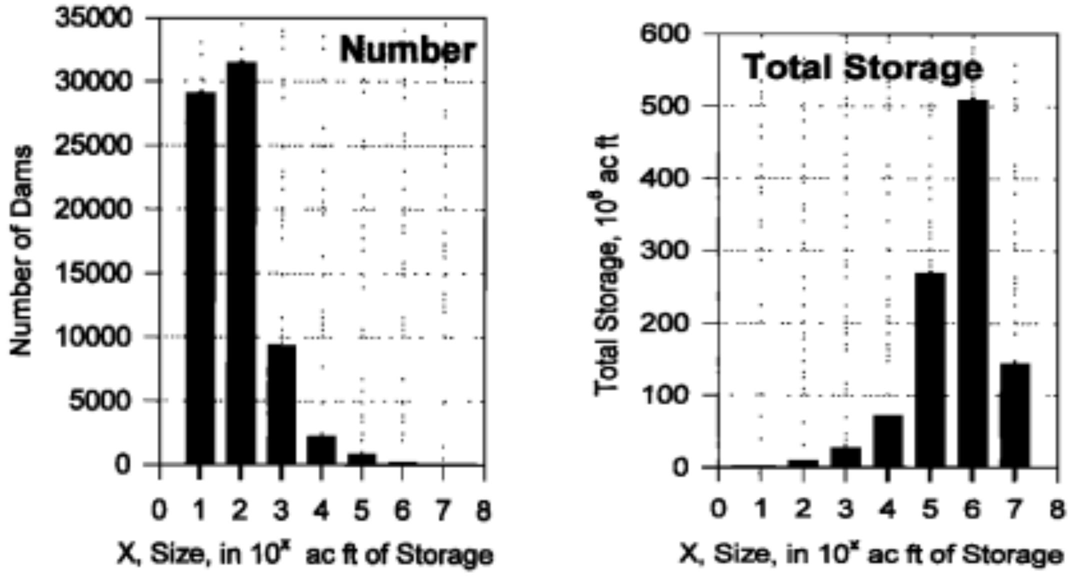

Figure 2.7: Number and storage capacity of dams and reservoirs in the continental United States. Data from U.S. Army Corps of Engineers, 1996. Source of figure: Graf, 1999.

As the burgeoning scientific study of dam removal has grown, there has been significant attention to large dams in the United States and on a global scale, while the impact of small dams has gone largely unrecognized (Schnitter, 1994; Graf, 2006). In part, the lack of information on small dams can be directly attributed to the lack of any scientific studies of dams predating the 1900s. Consequently, the dams being constructed post-1900 were larger and more industrial in style and function than their earlier mill dam precursors. Long-term scientific evaluation has been instated on multiple large-dam removal sites. However, it is important to note that most of the dams in the U.S. are relatively small structures, and dam removal thus far has been dominated by the removal of small, often decrepit structures. While it is tempting to use size as a primary descriptor of a dam’s potential ecological impact (Poff et al., 2002), an evaluation of the environmental impact of small dams is also critical to the issue of dam removal. In areas where dams were historically heavily concentrated, the high density of structures is likely to provide a greater localized aggregate effect than what is anticipated for a single small dam (Figure 2.6). Niemitz et al. (2013) argued that the remobilization of anthropogenic sediments from thousands of mill ponds in the eastern United States may add significant degradation of downstream ecosystems. The storage of water and capture of sediment by dams of any size causes profound downstream changes in the natural patterns of hydrologic variation and sediment transport (Poff et al., 2002).

2.3 River and Stream Channels

2.3.1 Channel Formation

As geology, climate, and anthropogenic factors change with time, river channels adjust in response. The type of river response depends on the magnitude and persistence of changes in water and sediment entering the river (Wohl, 2004). Channels originate in a variety of ways, related in part to the history of the land surface on which they develop. Water can flow down slope at the surface as overland flow, which is used to describe surface flow outside the confines of a channel (Wohl, 2014). The first formal theory of channel-formation mechanics was proposed by Horton (1945) and revolutionized geomorphological analysis (Dunne et al., 1995). Horton overland flow described the tendency of water to flow horizontally across land surfaces when rainfall exceeded infiltration capacity. Horton overland flow is most common where vegetation is sparse, slope gradients are steep, soil is thin or of low permeability, and precipitation intensities are high. A second type of overland flow, referred to as saturation overland flow, occurs when the soil becomes saturated, and any additional water input causes runoff (Dunne and Leopold, 1978; Montgomery and Dietrich, 2002). It is expected that saturation overland flow occurs more frequently than Horton overland flow with large land-use changes.

Sediment, much like water, also moves downslope through overland flow as well as through mass movements such as slides and flows. Slides typically result from a decrease in the shear strength of the soil as a result of weathering, freezing and thawing, or human alterations such as deforestation (Wohl, 2014). A flow occurs when debris is sufficiently liquefied or vibrated and experiences substantial internal deformation. Both slides and flows may be primarily erosional at high gradients and depositional at low gradients (Wohl, 2000). At some point downslope, surface irregularities concentrate overland flow into slight depressions that then enlarge as the rising water depth increases the shear stress acting on the substrate at the base of the flow (Wohl, 2014). This can give rise to rills and gullies, typically described as parallel channels with few or no tributaries (Wohl, 2014). Rills and gullies can form effective outlets for sediment erosion down slopes and into river networks (Sutherland, 1991). Rills can develop nearly simultaneously across a terrain and then integrate into a network (Dunne, 1980), forming definable banks, which separate the unchanneled areas from channel networks (Dietrich and Dunne, 1993). Channel formation further occurs where the sediment transport rate, defined as a function of stream power, increases rapidly (Knighton, 1976). As discharge increases during a flood, for example, flow velocity increases, and the greater force of flow exerted against the streambed and banks brings sediment into transport (Wohl, 2004). Channel morphology thus results from and responds to variation in the size of material eroded and deposited in various areas of the channel (Clifford, 1993).

2.3.2 Channel Adjustments

River-corridor geometry depends upon fluxes of water, sediment, and organic matter from headwaters to the river mouth, and between river channels and floodplains. Leopold and Wolman (1957) classified the change in shape or pattern of a river from headwater to deposition zone as planform characteristics (Leopold and Wolman, 1957). One characteristic of the classification includes whether the river has one, single-thread, or several, multithread, channels. As the supply of water and/or sediment increases, alluvial channels change from single-thread, meandering channels to braided, multithread channels (Knighton, 1976). The dynamic channel structure of rivers and streams is highly dependent on the flow of water, sediment supply, and vegetation. Channel classification based on planform characteristics has long been of interest to fluvial research (Schoor et al., 1999). Leopold and Wolman (1957) used an analysis of channel forming discharge (Q) and slope (S) to identify the threshold condition that separated single-thread and braided channels (Leopold et al., 1957). Schumm (1977;1985) followed with a study relating channel planform to sediment transport, channel stability, and measured channel dimensions. Rosgen's classification (1994) several years later described channel types that differed in entrenchment, gradient, width-depth ration, and sinuosity. Van den Berg (1995) further used stream power and bed-material size to predict channel planform. More recently, scientists have recognized the limitations of classifying channels solely on braided, straight, or meandering characteristics and have additionally stressed the relative response of a river to sediment inputs (Montgomery and Buffington, 1997).

Along today's river systems, braided channels are much less commonly observed than meandering channels. Braided streams typically have wide and shallow channels separated by sediment bars and tend to occur on steeper gradients where there is a large supply of sediment for braided bar formation (Wohl, 2000). Braiding at the reach scale is commonly associated with a large source of sediment from a hillslope mass movement or glacial activity (Knighton, 1976). Braided channels tend to store sediment for shorter periods of time and have rapid turnover times for floodplains compared to meandering or straight channel segments in the same region (Wohl, 2000; Beechie et al., 2006). Moreover, braided rivers are characterized by changes in width, where relatively small increases of water depth are associated with a large increase in surface area (Van der Nat et al., 2002; Ashmore and Sauks, 2006; Welber et al., 2013). Numerous field observations from studies conducted on large rivers show a strong relationship between braided channels and wood accumulation (Piégay et al., 1999; Gurnell et al., 2001; Bertoldi et al., 2013; Welber et al., 2013). The occurrence of sediment bars provides both a source for vegetative growth and wood retention sites. Braided channels are often distinguished from similar anabranching channels by the rate of bar formation in relation to established vegetation. The tendency toward braiding versus anabranching may be influenced by a river's ability to turn over its bed within the characteristic time for riparian vegetation to establish and grow to a mature state (Gran and Paola, 2001). Anabranching channels include multiple flow paths, but unlike a braided channel, individual subchannels are seperated by semi-perminant islands (Wohl, 2000)

Single-thread channels, on the other hand, are typically differentiated on the basis of sinuosity, the ratio defined by actual flow path downstream to straight-line distance between two points (Wohl, 2014). Straight channels have a single channel with sinuosity less than 1.5. River reaches with a low sinuosity are often confined by steep valley walls or occur in erodible, alluvial boundaries (Wohl, 2014). In return, water moves faster through low sinuosity reaches of rivers, limiting the ability of sediment deposition and retention. Rivers flowing over gently sloping ground begin to curve back and forth across the landscape. These are called meandering rivers. A single-channel river with a sinuosity greater than 1.5 is classified as meandering and is the most widespread and common type of channel planform (Leopold, 1994; Wohl, 2014).
A meander forms when moving water in a stream flows faster along the outer banks, eroding the bank and widening its valley, while the inner part of the river has less energy and deposits silt

along the inside of the meander bend. Leopold and Langbein (1966) determined that meanders appear to be the form in which a river does the least work in turning; hence they are the most probable form a river can take (Leopold et al., 1966). The slower water cannot carry as much sediment and deposits its load on a series of point bars.

Widespread, intense human impacts on river systems, particularly over recent centuries, have caused major changes in channel characterization. Intensive erosion from deforestation and a lack of wood in streams has the potential to result in erosion down to bedrock, a more uniform longitudinal profile, and less channel form diversity (Frear, 1982). Human activities impact all three major controls on channel pattern: flow regime, sediment regime, and vegetation, causing a switch between multi-thread and single-thread channels (Figure 2.8).

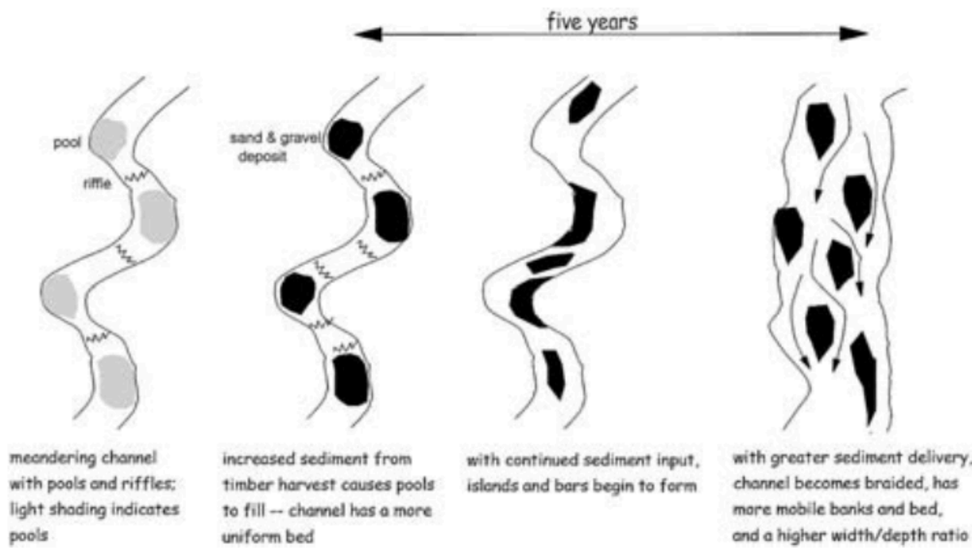

Figure 2.8: An example of river adjustment from single-thread meandering to multi-thread braided. Source: Wohl, 2014

2.3.3 Role of Vegetation

Numerous studies have documented the influence of riparian vegetation on channel morphology and flow dynamics (Graf, 1978; Johnson, 1994; Micheli and Kirchner, 2002; Simon and Collison, 2002, Tal et al., 2007). The riparian zone is the interface between terrestrial and aquatic ecosystems, and includes sharp gradients of environmental factors, ecological processes, and biotic communities (Gregory et al., 1991). The presence of a riparian zone can strongly influence the characteristics of water, sediment, and solutes entering a river. Thus, removal of streamside vegetation from the riparian zone, whether by natural means or human activity, can have a tremendous impact on the hydraulics and morphology of stream channels. Tal and Paola (2007) conducted a series of flume experimentations to show that vegetation used to stabilize banks can shape the path of water and convert the planform morphology from braided to single-thread.

2.4 River and Stream Deposition

When the balance of sediment load and/or channel geometry and slope is changed there is often a response, or adjustment of the fluvial system as it attempts to re-establish the equilibrium condition. River systems, or reaches, are considered in equilibrium when there is a balance between the amount of sediment load being supplied to the system and the capacity of the system to carry that sediment load out (Field, 2002) (Figure 2.9). Dynamic equilibrium assumes that changes may be made to the movement of sediment within the fluvial system, but those changes have a net effect of zero and allow for the continued downstream motion of sediment. Dynamic equilibrium is achieved through sediment continuity. Hard engineering features (i.e dams) disrupt continuity. Sediment downstream is eroded more but the sediment upstream is not able to replace the downstream sediment due to a lack of connectivity, therefore preventing the system from remaining in equilibrium.

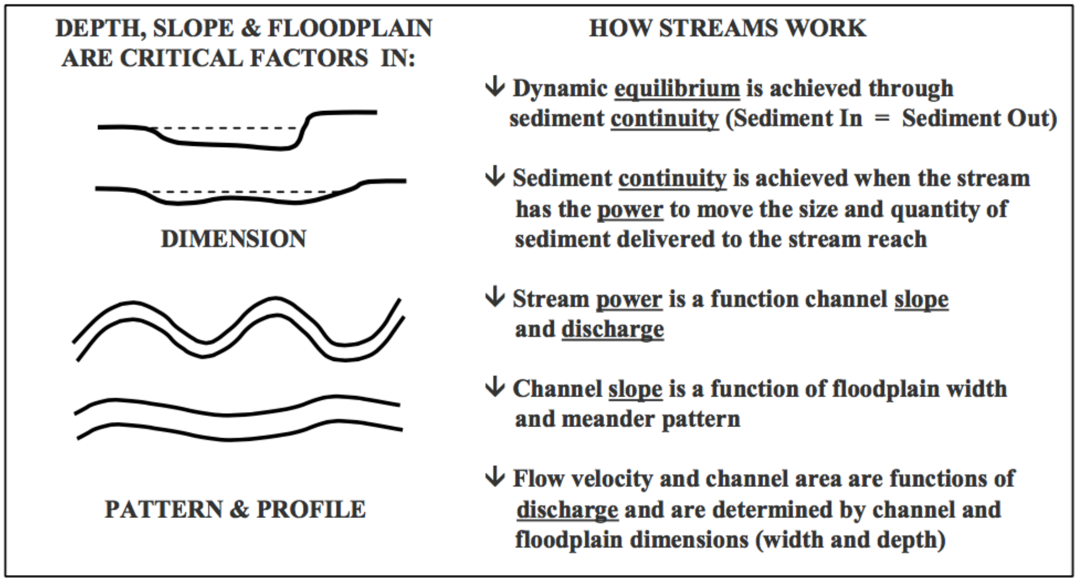

Figure 2.9: Fluvial processes necessary to achieve sediment continuity and dynamic equilibrium. Source: Vermont Agency of Natural Resources

2.4.1 Sediment transport

Sediments that are deposited by flowing water in river valleys and deltas are commonly referred to as alluvium. Alluvial sediment originates from the weathering of parent material on land. Alluvium is then transported downslope by erosion, overland water flow, and river flow, and deposited in areas of the river valley where the water flow velocity is lower (Goudie, 2004). The particulate sediment transported by rivers and streams is often distinguished by suspended load, dissolved load, and bed load. Suspended load is the finest size fraction of the total sediment load and typically consists of grains with an intermediate diameter ≤ 0.062 mm. Suspended load consists of particles not found in large quantities on the bed surface. The settling velocities of the suspended particles are so small that they move at approximately the same velocity as the flow and only settle from suspension when velocity declines substantially (Wohl, 2014). Much of the suspended load in a river comes from bank erosion and surface erosion across the drainage basin. Globally, suspended sediment accounts for about 70% of total fluvial sediment transport to the oceans (Wohl, 2014). In reservoirs or mill pond locations, where water is pooled, an accumulation of suspended sediments is often found (Merritts et al., 2010).

Bed-material load includes grains typically coarser than 0.062 mm. These grains move either in contact with the bed by rolling, sliding, saltating, or suspended just above the bed (Wohl, 2014). In most river systems, the bed load is what influences the channel morphology and stability (Kondolf et al., 2002). The dissolved load is material carried in solution downstream. The introduction of metallic pollutants into a river, whether it is natural (erosion) or artificial (anthropogenic), can occur in dissolved form (Jain et al., 2004). Trace metals, in particular, receive significant attention as contaminants occurring in concentrations and carried downstream in the dissolved load. Because many trace metals are adsorbed to fine sediment, the mobility and storage of fine sediments along banks and floodplains can strongly influence the spread of trace metals through a river network (Wohl, 2014).

2.4.2 Floodplains

The area of sediment deposition adjacent to the channel is referred to as the floodplain. The floodplain is generally considered to be the relatively flat area of land that stretches from the banks of the parent stream to the base of the valley walls and over which water from the parent stream flows at times of high discharge (Goudie, 2004). Whereas a wide variety of present-day floodplain types can be defined, their formation can be regarded, in most cases, as the product of the interaction of two processes, vertical and lateral accretion (Nanson, 1986; Wright et al., 1993). Wolman and Leopold (1957) concluded that lateral accretion and within-channel deposition are the dominant processes of floodplain formation, accounting for up to 90 percent of the deposits (Knighton, 1976). Lateral accretion develops point bars, a depositional feature made of alluvium that accumulates on the inside bend of streams and rivers. Vertical accretion on the other hand is most often attributed to overbank deposition. Most of the vertical floodplain deposition occurs during floods when flow velocity and sediment transport rates are large with the most fine-grained alluvium deposited furthest from the channel. When a succession of floods causes overbank deposition, each flood elevates the surface higher above the channel (Wright et al., 1993). Land-use changes including agriculture and forest clearing have the potential to exacerbate naturally occurring floods and therefore overbank deposition. When the increased sediment supply produced by land-use accumulates in rivers, channel capacity is reduced, and floods are more likely to spill beyond the channel and across the valley bottom (Wohl, 2004).

2.4.3 Terraces

Geologically ancient floodplains are often represented in the landscape by fluvial terraces. Terraces form when streams carve downward into the floodplain, leaving discontinuous remnants of older floodplain surfaces as step-like features along the sides of the valley (USGS, 2004). Terraces serve as an excellent indicator of change in a rivers' longitudinal profile through time because they represent channel and floodplain surfaces no longer subject to active fluvial modification (Wohl, 2000). Many factors influence why streams and river episodically carve into their floodplains, forming terraces. Because stream terraces are typically widely distributed along steams throughout a region, changing climatic conditions are likely an important factor in their formation (Bull, 1991). Streams broaden their floodplains when sediment supplies are high and down cutting by stream erosion is abated (USGS, 2004). The elevation of a terrace indicates the recurrence interval in which it is flooded. Data on the age, spatial extent, and stratigraphy of the terraces as well as independent information on the timing and nature of base-level change, glaciations, and historical land use are necessary to explain terrace formation (Wohl, 2014).

Numerous classifications are used in conjunction with terraces. Terraces are often categorized into two types based on their composition, and distinguished as strath or depositional terraces. Strath terraces have low-relief terrace treads formed in bedrock or other cohesive materials such as glacial till, and are overlain by a thin veneer of alluvium (Wohl, 2014). Existence of a strath terrace implies a period of vertical stability during which a river forms a relatively planar bedrock valley bottom by lateral erosion, followed by a period of vertical incision as transport capacity increases beyond sediment supply (Wohl, 2014). Strath terraces are less likely to form as rates of incision increase, because the river is cutting downward too fast to form a strath tread (Merritts et al., 1994). Strath terraces tend to be more extensive where rivers flow over bedrock less resistant to weathering and erosion (Montgomery, 2004; Wohl, 2008, Wohl, 2014).

Depositional terraces form from alluvium. Depositional terraces are alluvial sequences too thick to be mobilized throughout their depth by the river (Wohl, 2014). Because depositional terraces can form more rapidly than strath terraces, they do not necessarily imply a period of vertical stability. They do, however, imply a period of deposition, followed by incision. Alluvium in depositional terraces is commonly topped by a tenth of a meter to one meter of fine overbank sediments (Pazzaglia, 2013). Depositional terraces have been attributed to a range of activities including fluctuating water and sediment discharge during glacial cycles and sediment moving downstream over periods of tens to hundreds of years in response to hillslope mass movements (Pazzaglia, 2013). More recently, the direct modification of rivers and watersheds by human land-use has resulted in the development of depositional terraces along many rivers and streams (Blum et al., 2000).

Another categorical descriptor of terraces is paired and unpaired. Paired terraces have equivalent surface heights on both sides of a river valley. Unpaired terraces do not match across the valley and might occur in situations of continued incision as a river migrates laterally across the valley (Wohl, 2014).

2.4.4 Legacy Sediments

Human-accelerated hillslope erosion and deposition of sediments has caused the alluvium layers found in floodplains and terraces to be thicker than typically expected in a natural stream system (Walter and Merritts, 2008). Legacy sediments are alluvium deposits left as a result of past human activities such as changes in land cover or construction of mill dams. Legacy sediments persist and continue to heavily influence river process and form. The potential for legacy sediments to remobilize suggests that they might add significant degradation to downstream ecosystems (Niemitz et al., 2013).

2.5 Soil Development

The soils that compose floodplains and terraces can be used to distinguish between the two geomorphic features. Given enough time, distinctive soils develop, the character of which depends upon climate, vegetation, topography, and source material (Bridge, 2009). Soil can be used to give a sense of the age of geomorphic surfaces. The nature and degree of soil development varies in time and space as a function of floodplain-deposition rate, parent materials, climate, topography, and vegetation (Goudie, 2004). For soil to initially develop, weathering, or the physical and chemical breakdown of rocks, has to occur.

Vertical and horizontal movements of the materials in a soil system create a distinct layering, parallel to the surface called a soil profile (Keller, 2010). Each layer is referred to as a soil horizon (Figure 2.10). The O horizon and A horizon contain highly concentrated organic material. The difference between these two layers reflects the lack of mineral sediments present in the O horizon. Generally, the O horizon consists entirely of plant litter and other organic material, while the underlying A horizon contains both organic and mineral material (Birkeland, 1999). The pure organic of the uppermost O horizon tends to go away quickly. The A horizon tends to be dark in color because of the abundant organic material (Figure 2.10). Below the A horizon, some soils have an E horizon, or zone of leaching; a light-colored layer that is leached of iron-bearing components (Figure 2.10). The B horizon, or zone of accumulation, underlies the O, A, or E horizons and consists of a variety of materials and minerals translocated downward from overlying horizons (Jenny, 1994). The C horizon is composed of weathered parent material that can be alluvial in nature (Figure 2.10). The bottommost R horizon is unweathered parent material (Keller, 2010).

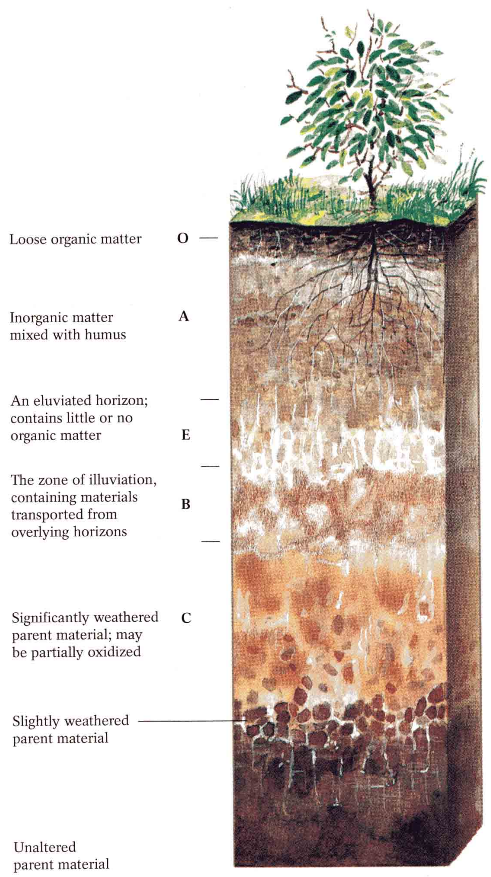

Figure 2.10: Soil horizons from loose organic surface matter to parent material. Source: http://spot.pcc.edu/~kleonard/G202/Lecture4.html

The age of a soil can be estimated by the amount of weathering that has occurred and extent to which the parent material has been converted to distinct horizons. Soil age is based on three general criteria: 1) the more horizons that are present, the older the soil; 2) the thicker the horizons, the older the soil; and 3) the greater difference there is between adjacent horizons, the older the soil (University of Nebraska Cooperative Extension, 1999). The color of soils can also serve as an indicator of age. Soil chronosequences have been increasingly used to link color and age (Jenny, 1994). Chronosequences are related soils that evolved under similar conditions of parent material, vegetation, topography, and climate, but at different times (Harden, 1982). Chronosequences translate spatial differences between soils into temporal differences (Huggett, 1998).

Color can also indicate the physical and chemical composition of a soil. The B horizon shows the most dramatic differences in color, varying from yellow-brown to light red-brown to dark red, depending upon the presence of clay minerals and iron oxides (Keller, 2010). Dark colors are usually due to the presence of organic matter. Therefore, the darker the surface horizon, the more organic matter content assumed. Since the A horizon is typically the most organic rich of mineral horizons, coloring tends to be a dark brown to black with often visible organic material. Distinguishable A horizon layers that are visible along stream and river banks are an accumulation of buried A horizon soils over time.

2.6 Floodplain Interpretation Debate

A study by Walter and Merritts (2008) changed the way of thinking about floodplain deposits in relation to human land-use and river system alterations. Walter and Merritts (2008) characterized pre-disturbance Eastern stream systems as small multithread channels situated within widespread vegetated wetlands. Water and Merritts (2008) observed dark, organic-rich A horizons with abundant seeds and woody debris, interpreted to be pre-settlement alder shrub-scrub and grass-dominated meadows. They inferred that Holocene wetland sediments persisted until European settlement, and were often preserved beneath historic sediment deposits stored along valley bottoms (Walter and Merritts, 2008). These geologically recent, light-colored deposits were suspected to be a result of upland soil erosion, mill damming, and road building that began circa late 17th to 18th century (Snyder, 2015).

Walter and Merritts (2008) argued the damming that accompanied colonial settlement and industrialization disturbed the channel-floodplain connectivity, causing a build-up of sediment behind dams. Slackwater sedimentation buried the pre-disturbance floodplain and left large legacy deposits along streams where milling was particularly intensive (Walter and Merritts, 2008). Walter and Merritts (2008) attributed the legacy deposits to historic dam impoundments. Their results show that a single mill dam is capable of enhancing sedimentation over several hectares (Walter and Merritts, 2008). When coupled with an increase in erosion as a response to deforestation and agricultural practices, mill-dam construction converted river valleys into a series of linked sediment-filled ponds (Walter and Merritts, 2008). As many crudely constructed mill dams breached, channels incised to create the single-thread, meandering channels widely observed across the landscape today (Walter and Merritts, 2008). Walter and Merritts (2008) point to legacy-sediment deposits as a reason why so many eastern streams exhibit much lower bankfull heights than actual heights of banks. Walter and Merritts (2008) further call for a reevaluation of current restoration attempts that rely on the meandering eroding channel bank as the natural reference condition.

Debate has emerged regarding the ubiquity of both the interpreted pre-disturbance grass-dominated wetlands, and the thickness of the legacy sediment mantle in modern floodplains.

Walter and Merritts (2008) give one interpretation of how and why certain floodplain depositional characteristics are seen today, but their interpretation begs for further analysis of what the channel looked like before disturbance across landscapes, and the possibility to return to that state.

Bain et al. (2008) questioned Walter and Merritts (2008) hypothesis that milldams were primary factors in historic sedimentation along mid-Atlantic valleys. In response to Walter and Merritts (2008), Bain et al. (2008) suggests that local observations can not necessarily be generalized to wider settings, as pre-colonial forms were inconsistently documented. Bain et al. (2008) argued that post-settlement land clearing and farming also added to immense volumes of fine-grained sediment along valley bottoms. Bain et al. (2008) interpreted the conclusions made by Walter and Merritts (2008) to suggest that pre-Colonial river valley forms represent an updated ideal condition for restoration. While enhanced understanding of historic valley conditions can offer useful guidance for stream rehabilitation design (i.e. observations of organic-rich, hydric soils by Walter and Merritts), Bain et al. (2008) argued that watershed managers need to consider both historic and contemporary causes of sediment supplies before deciding how to respond in restoration efforts.

Wilcock (2008) took the restoration fragment a bit further, questioning what should be done in terms of improving streams. He raised issue with Walter and Merritts (2008) advocacy for remediation methods, which he interpreted to be large-scale. Wilcock (2008) referred to “hot spots” of erosion found along stream banks that might lead to local reductions of sediment loading, but have not been addressed by current science. Wilcock (2008) agreed with the statement made by Walter and Merritts (2008) that today’s streams differ from their pre-colonial condition, emphasizing that a pristine stream is an unlikely template for restoration because the drivers of stream dynamics (i.e. water and sediment) have changed (Wilcock, 2008).

Several components of the arguments made by Walter and Merritts (2008) as well as the critique by their colleagues require further examination. Walter and Merritts (2008) argue a pre-disturbance wetland landscape characterized the mid-Atlantic Piedmont region. Little evidence has been provided, however, to generalize the full extent of pre-contact, historic landcover for the mid-Atlantic Piedmont region beyond localized observations, a point made in Bain et al.'s (2008) critique. Evidence is thus needed to justify broad application of these findings elsewhere or to examine whether other possible pre-disturbance landscapes might have characterized parts of the region. The regional scale of Walter and Merritts' (2008) observations of legacy sediment thicknesses in relation to mill dam locations also requires further investigation. Lancaster County, Pennsylvania experienced more industrialization than other areas of mill operation in the mid-Atlantic Piedmont region, begging the question of how deposits may vary with damming frequency.

On a level of restoration, the pre-disturbance characterizations made by Walter and Merritts (2008) may be beneficial on a local level, but can be detrimental to restoration efforts if applied regionally. Restoration ecology is a relatively young interdisciplinary field (Hanson et al., 2008). When applied to rivers, restoration is strictly defined as a return to a close approximation of the river condition before human disturbance (Wohl, 2004). It is by definition necessary to fully understand the pre-disturbance surface at each restoration site. In a response article to Walter and Merritts (2008) *Science* publication, geomorphologist David Montgomery necessitated the importance of understanding how natural streams work for river restoration (Montgomery, 2008). The sinuous form of meandering channels, which evolved out of the studies of Luna Leopold and M. Gordon Wolman in the 1950s, still constitutes the natural ideal of a stream in channel restoration design across the United States. Walter and Merritts (2008) showed that the clearing of large wood and damming of streams altered the morphology of many rivers, which were previously thought to be natural. Thus a reconstitution of what represents a natural channel requires reexamination (Montgomery, 2008).

While Bain et al. (2008) and Wilcock (2008) are skeptical in their adoption of Walter and Merritts (2008) claims, they're critiques provide little in the way of progressing current standards of river restoration and rehabilitation. The continual debate over natural stream conditions shows there has been no conclusion as a science, causing restoration to remain largely unchecked. River and stream restoration projects are increasingly numerous and economically driven, but rarely subjected to systematic post-project evaluation (Kondolf et al., 1995). The few evaluations that have been conducted indicated a high percentage of failures (Kondolf et al., 1995), and few reliable data sets on which to base an estimate or true value exist.

The numerous gaps remaining in the data leave many unanswered questions as a science. Walter and Merritts (2008), among a growing number of studies, indicate that dam-related sedimentation is common in the mid-Atlantic Piedmont (Walter and Merritts, 2008; Pizzuto and O'Neal, 2009). Far fewer studies have addresses the pervasiveness of historic mill dam sedimentation in the New England region. Both regions have a similar history, timing and intensity of European settlement. Both New England and the mid-Atlantic relied on intensive agriculture, with Pennsylvania continuing to rely on industrial farming beyond the timescale of New England. However, glaciation occupied New England's Pleistocene landscape, while the mid-Atlantic region remained ice-barren. It is critical to comparatively study the role of geography and glacial history in floodplain deposition along streams to gain insight into the ubiquity of both the impact legacy sediments have on modern streams, as well as the pre-disturbance surface that once covered the valley-bottom.

Previous research related to river and stream sedimentation patterns shows how changes to the landscape influences the way sediment is deposited in the floodplains and the long-term influences human activity has on morphology (James and Lecce, 2013). Glacial activity, land-use, and dam sedimentation all influence the way channels form as well as how sediment enters the river valley and deposits out in the landscape. However, many questions remain unanswered in connecting regional landscape histories with observed modern-day floodplain deposits. This study aims to look at how changes in the landscape in two states might affect patterns of sedimentation and whether patterns are localized or occur on a regional scale. Data were collected at two sites in both Connecticut and Pennsylvania that had known historic human-alterations, but varying glacial histories.

3.0 Study Area

Select streams in the New England and mid-Atlantic Piedmont physiographic provinces were studied to look at where and why legacy sediment deposits occurred along river valleys as well as to assess the continuity of a buried pre-disturbance floodplain landscape below the anthropogenic deposits. Two study areas in Pennsylvania and Connecticut with known colonial mill-dam activity were chosen to examine the influence of dams on legacy-sediment deposition. Connecticut and Pennsylvania were further selected as study locations to examine the role that differing geography and post-glacial activity play in floodplain-sediment storage. Before the selection of the study basin, a number of prospective sites were visited. The four streams selected were chosen on the basis of their ease of access, multiple exposed banks, and known human impacts.

3.1 Christina River Basin Study Sites

3.1.1 Basin Characteristics

The sixth order Christina River Basin is 1440 km^2 and consists of four sub-watersheds: White Clay Creek (277 km^2), Red Clay Creek (140 km^2), Brandywine Creek (842 km^2), and the tidal Christina River (202 km^2). Streams within the Christina River Basin range in Strahler's stream order from first order at the headwaters of White Clay Creek to seventh order at the mouth of the Delaware River. Strahler's stream order is a classification used to define stream size based on a hierarchy of tributaries (Strahler, 1957). When two first order streams come together, they form a second order stream. It is not until two second order streams combines that a third order stream is designated. Streams ranking sixth or higher are generally major, navigable rivers. For comparison, the Mississippi River is a tenth order stream and the Amazon River is a twelfth order stream.

The Christina River Basin straddles southeastern Pennsylvania and northern Delaware (Figure 3.1). All four sub-watersheds flow into the Delaware River Estuary. The Christina River Basin transitions through the two most populated physiographic provinces in the U.S. In 2010, the National Science Foundation designated the Christina River Basin as one of ten integrative Critical Zone Observatory sites across the United States. Specifically, the basin hosts a continual study of vertical and lateral carbon, mineral, and water fluxes over a range of modern and historical land-use areas. Both sampled stream reaches were within the municipal boundaries of Chester County, Pennsylvania, an area with an average annual precipitation of 1,145 mm. Geologically, a diverse lithology, ranging from micaceous schist and gneiss to quartzite and marble (Figure 3.2) spans across Chester County and is overlaid by deep, unglaciated soils (Soto, 1994).

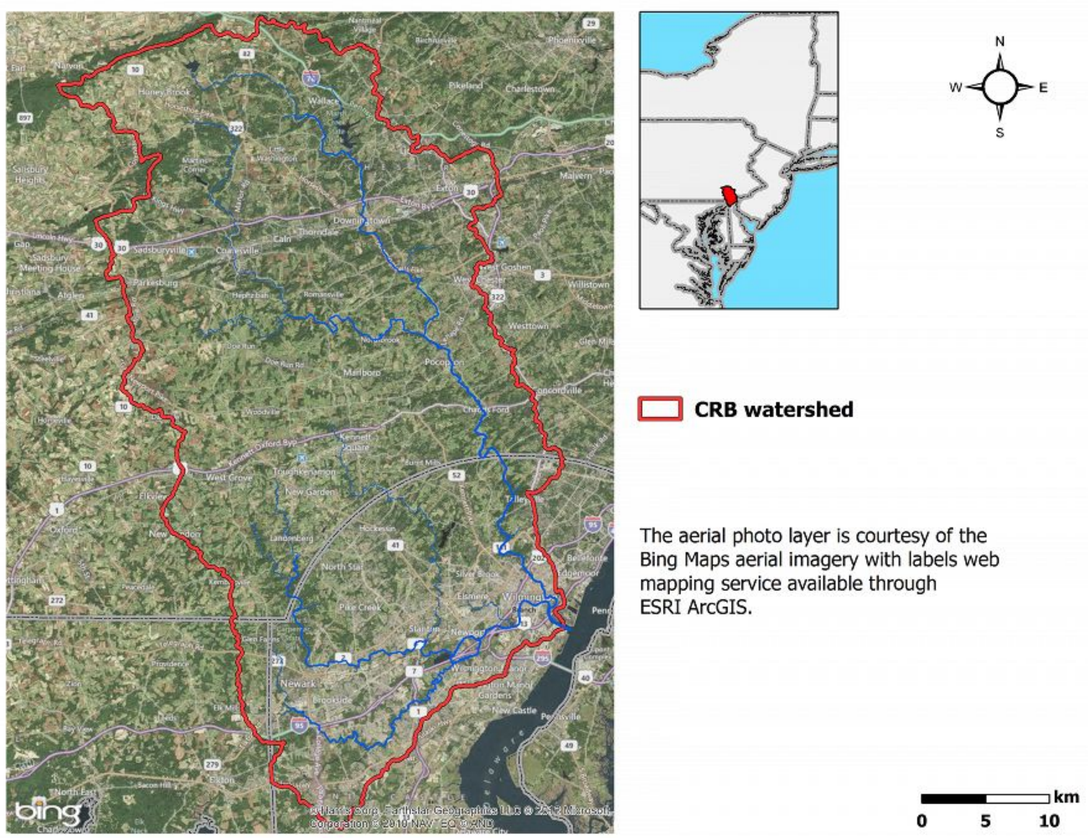

Figure 3.1: Aerial map of the Christina River Basin watershed. Source: SWRC.

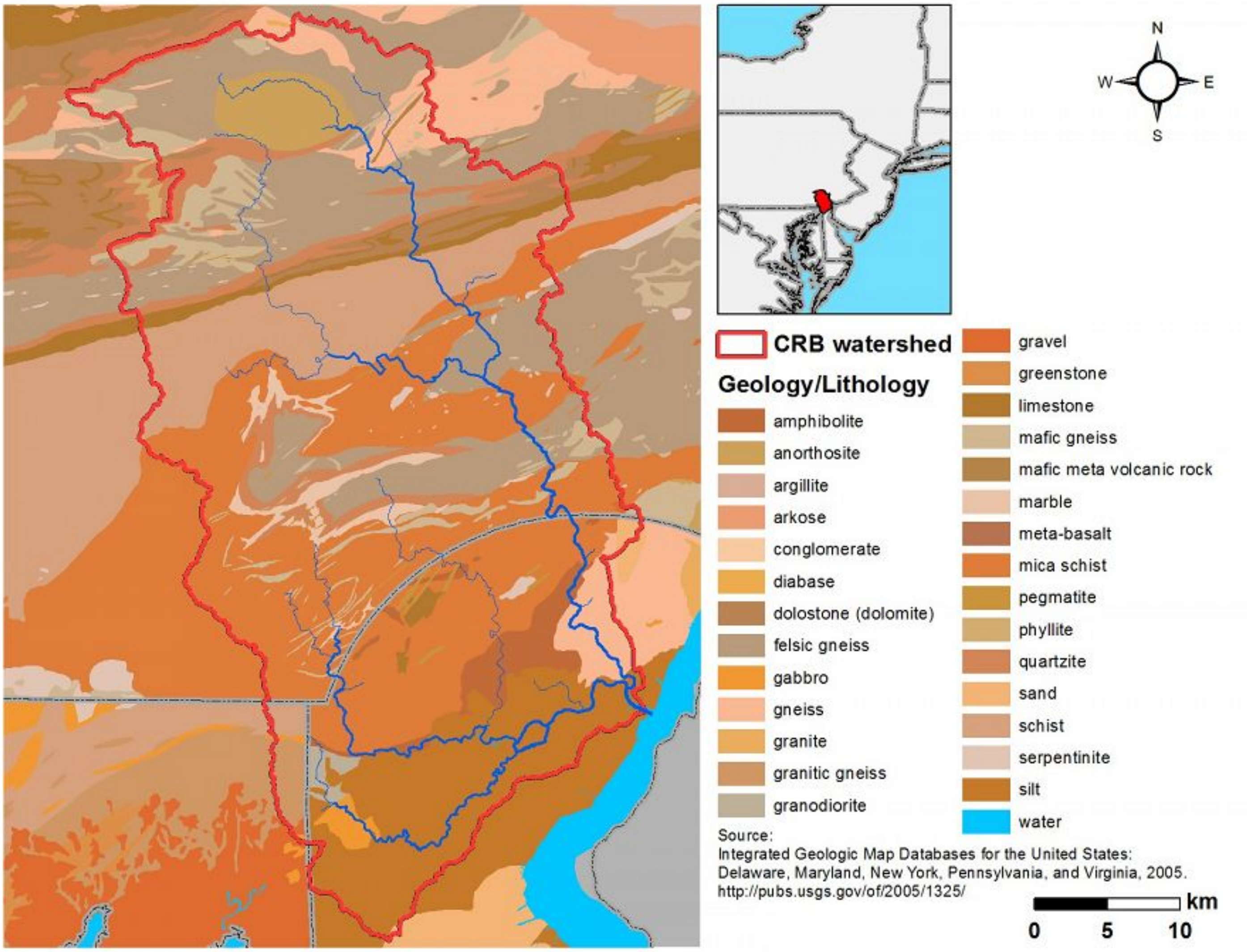

Figure 3.2: Geological map of the Christina River Basin bedrock. Source: SWRC.

3.1.2 Historic Land-Use

Land use in the mid-Atlantic Piedmont region spans back centuries and is today composed of a gradient of surface covers including mature forest, agriculture, urban, commercial, and industrial land use. Historically, the Piedmont region provided the bulk of manufacturing and agricultural goods to port cities and a large portion of the wheat and flour for mid-Atlantic shipping (Walter and Merritts, 2008). The going land rate at the end of the 18th century in Pennsylvania was 12.5 cents per acre, causing an upsurge in land purchases and clearing (Wood, 1971). In contrast to Connecticut, Pennsylvania, especially southern and central Pennsylvania, never had the widespread, broad abandonment of agriculture that Connecticut experienced.

Mid-Atlantic Piedmont valleys were the ideal size for water-powered mills. The flow of water was sufficient to turn 17th through early 20th century water wheels, yet not too high to pose engineering challenges for building and maintaining dams and mills along valley bottoms. Compared to other watersheds such as that of Lancaster County, industrialization of the Christina River Basin was less intensive and consequently did not rely on the stacked formation of dams exhibited along Lancaster County streams (Figure 3.3). Streams in the Christina River Basin were gentle and relied on mill races to divert water from the stream up to several kilometers (Figure 3.5, 3.8).

Figure 3.3: Historic map of dam locations in Lancaster, County. Dam locations are circled. Source: Franklin and Marshall College.

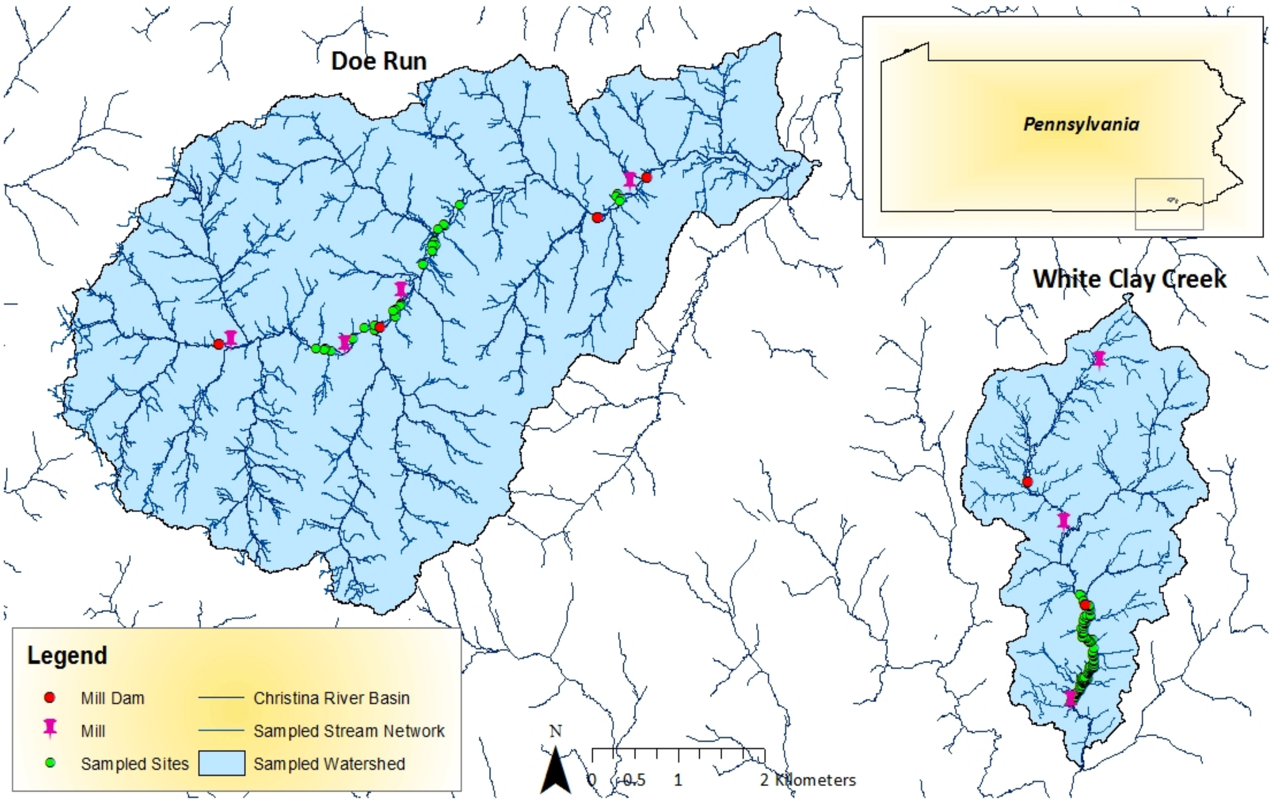

Figure 3.4: Watersheds of White Clay Creek and Doe Run study reaches located in Chester County, Pennsylvania

3.1.3 White Clay Creek

White Clay Creek is a third-order stream within the mid-Atlantic Piedmont and Atlantic Coastal Plain physiographic provinces (Figure 3.4). The majority of the stream is in the mid-Atlantic Piedmont valley, which is characterized by its low relief and tectonically inactive rolling hills, plateaus, and stream valleys (Figure 3.5). The southern portion of the stream, near Newark, Delaware, is in the Atlantic Coastal Plain, a relatively flat and tidal area. The 277-km^2 White Clay Creek watershed drains agricultural and wooded land into the Christina River (Figure 3.6). Over the past several decades, White Clay Creek has been the site of several influential stream ecological and hydrologic studies (Dunne and Leopold, 1978; Newbold et al., 1997; Kaplan et al., 2008; Karwan et al. 2011). In 2000, White Clay Creek received designation as a Wild and

Scenic River and is the only entire watershed designated within the Wild & Scenic Rivers System. The drainage area is 29.3 mi^2, with a discharge of 0.34 cubic meters per second.

Study samples were taken from the east branch of the stream, a 21.7 km stretch beginning in the West Marlborough Township and home to the long-term research watershed for the Stroud Water Research Center at approximately (N 39.8594493°, W -75.7830744°). The east branch of the stream used in the study is unique in its land management. Vegetation adjacent to the stream is maintained on an experimental basis by the Stroud Water Research Center. The upstream section is home to a riparian forest of 100 to 150-year-old trees. The downstream reach includes both a managed and wild meadow. The middle-reach of the stream is newly reforested within the last 30 years. The two-kilometer continuous study reach was selected because of the known location of three former mills within the study reach, as well as for its monitored and varying vegetation along reaches (Figure 3.7).

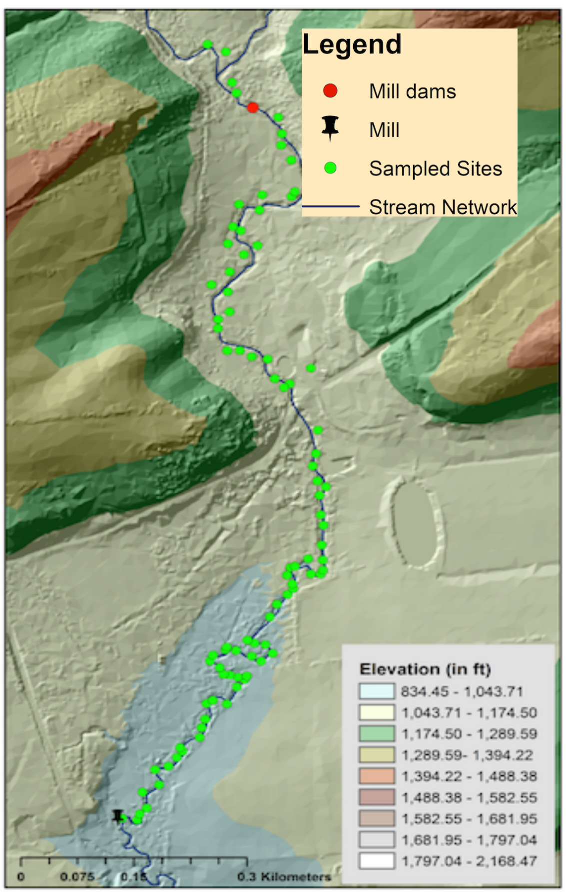

Figure 3.5: Topographic map of White Clay Creek floodplain.

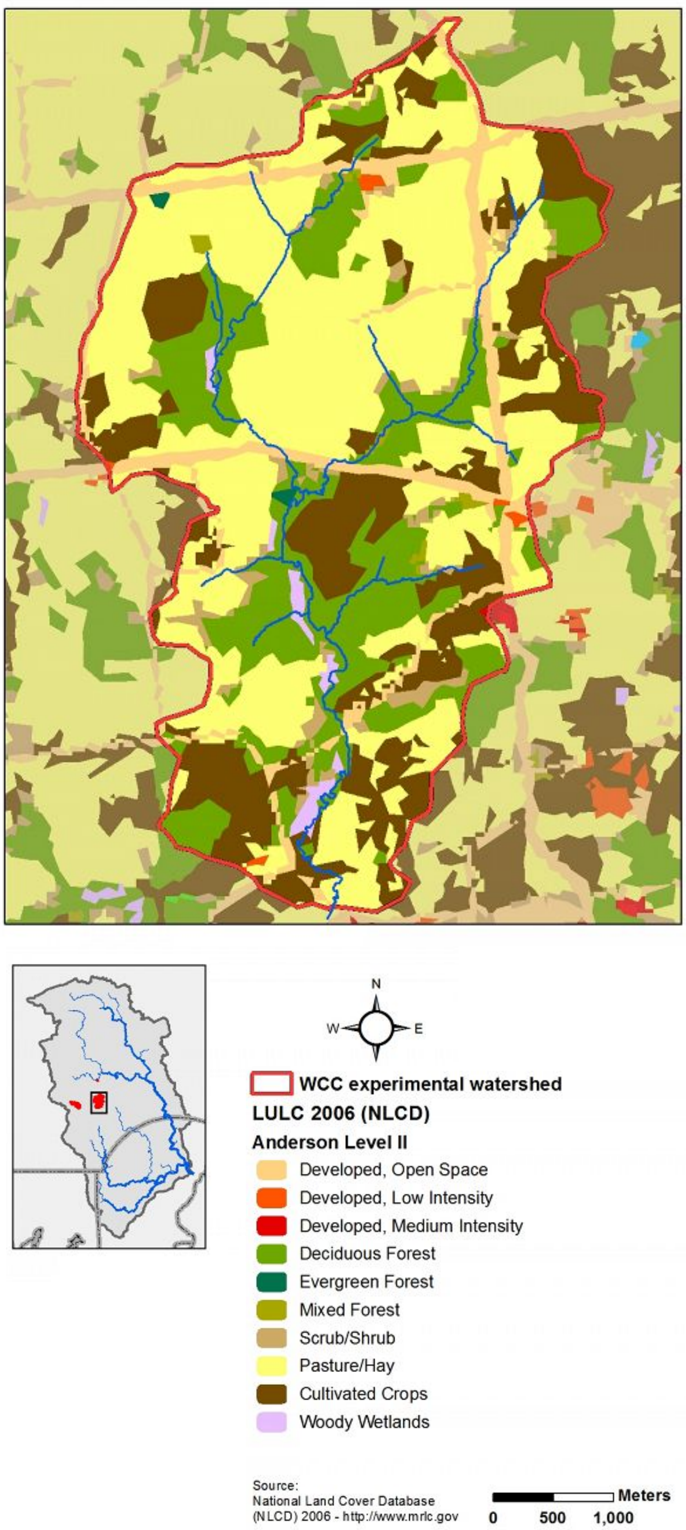

Figure 3.6: Land cover of White Clay Creek Watershed.

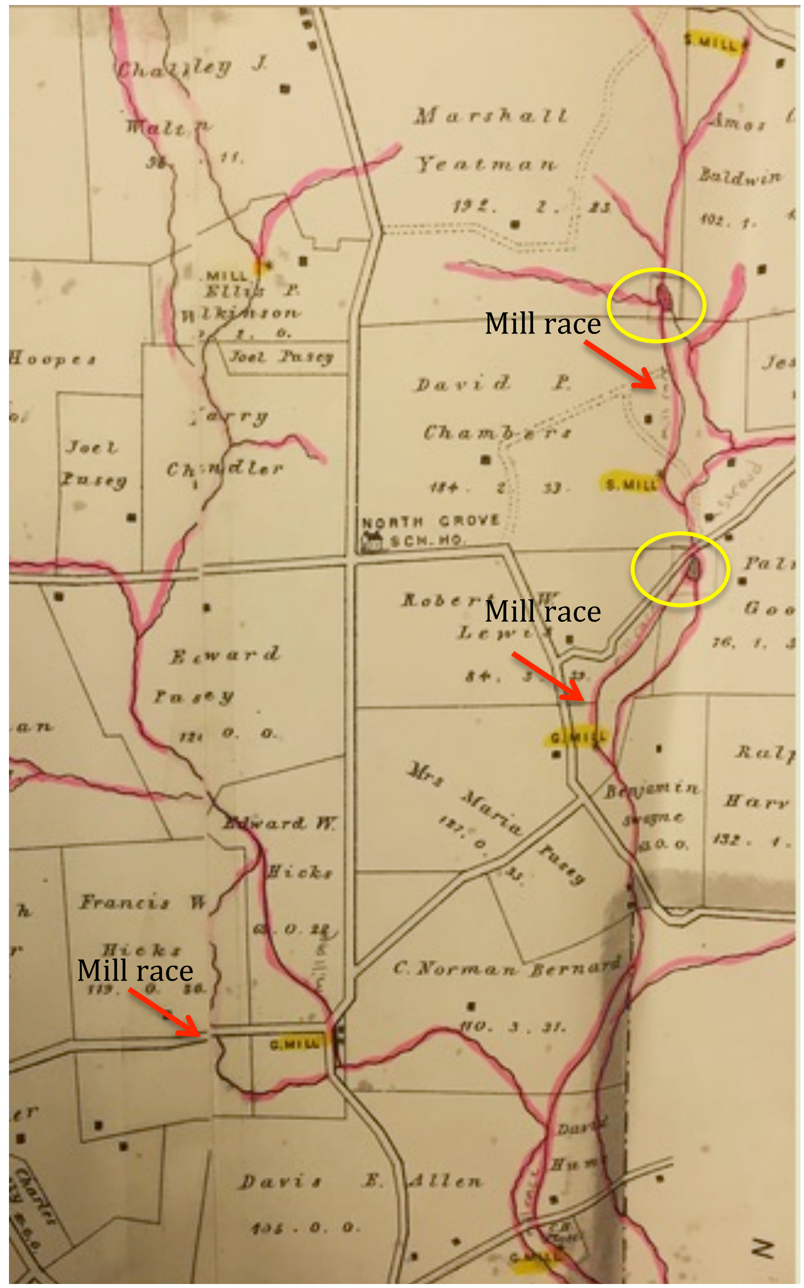

Figure 3.7: Section of 1883 map from the Chester County Historical Society of East Marlborough Twp. indicating the location of dams, mills, and mill races along the study section of White Clay Creek. Yellow circles depict dam locations and red arrows point to the diversion of the stream to mill races.

3.1.4 Doe Run

Doe Run is a 56.2 km^2 watershed and tributary to Brandywine Creek about 80 km southwest of Philadelphia and about 11 km northwest of White Clay Creek. The Brandywine flows into the Christina River, where it meets White Clay Creek, and serves as a tributary to the Delaware River. Doe Run is wider and has a greater elevation gradient than its neighboring White Clay Creek. (Figure 3.8) Water powered gristmills in the Brandywine Valley were abundant along the creek and important in developing American industry before the introduction of steam power. During the American Revolutionary War, the Battle of Brandywine was fought around the river, and from1802 to 1921 the river was the site of the DuPont gunpowder mill, one of the most successful manufacturers of explosives. Consequently, Doe Run was exposed to a higher level of industrial activity and damming than White Clay Creek.

Within the 5.8-km, discontinuous study reach, there were two known dams (Figure 3.9). The majority of land adjacent to the study reach on Doe Run was managed meadow, which was mowed in close proximity to the edge of the bank. The reach was broken into an upstream and downstream segment based on the visible presence of exposed banks and suspected legacy sediments. A narrow forested reach of the study area was not sampled due to a lack of bank exposure and thick vegetation. USGS stream gauge data is not available for Doe Run.

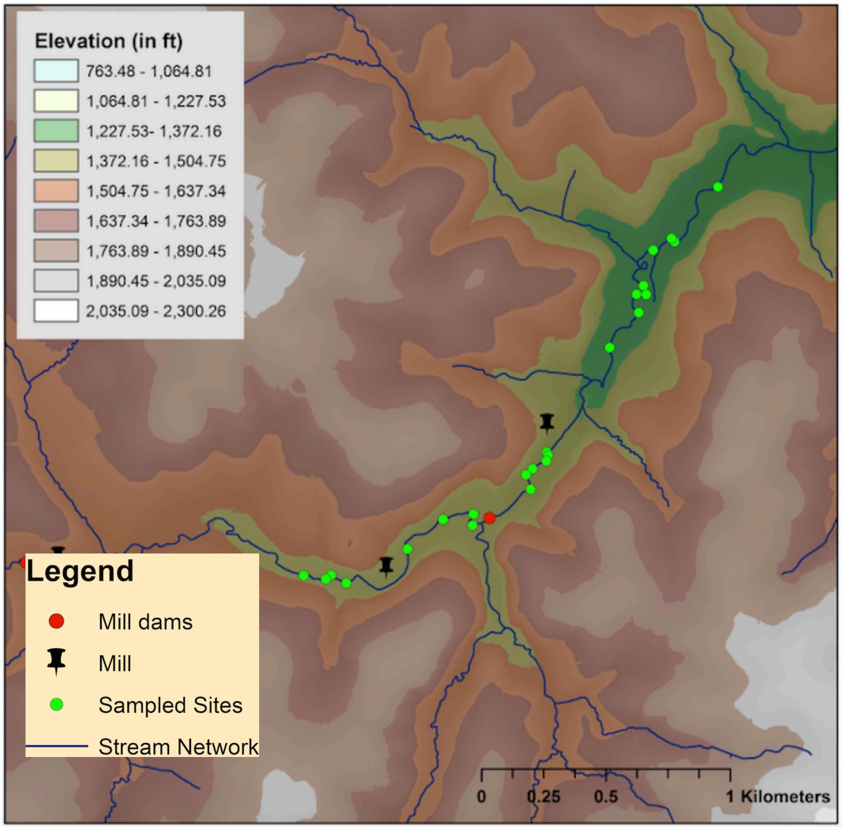

Figure 3.8: Topographic map of Doe Run floodplain.

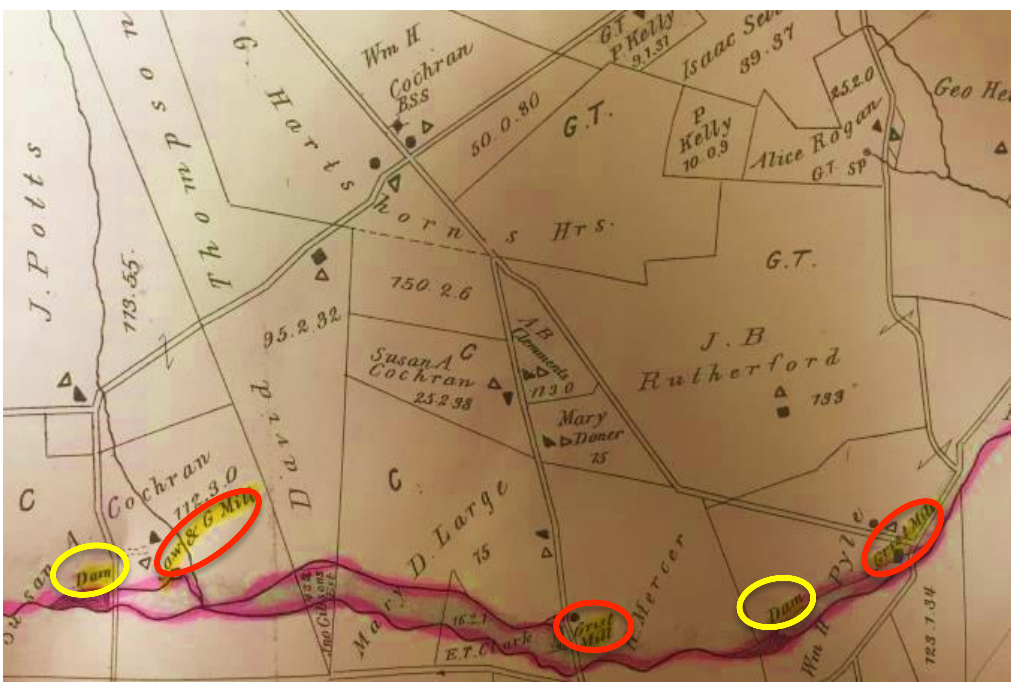

Figure 3.9: Section of 1883 map from the Chester County Historical Society of Newlin Twp. indicating the location of dams and mills along the study section of Doe Run.

3.2 Connecticut River Basin Study Sites

3.2.1 Basin Characteristics

The Connecticut River is the longest river in the New England region of the United States. The Connecticut River Basin encompasses a 29,137 km^2 area, extending from the U.S/Canadian border near Quebec to its mouth in Long Island Sound (Figure 3.10). Considerably larger in size than the Christina River Basin, the Connecticut River Basin has 148 tributaries, including 38 major rivers (Figure 3.10). The river flows through Holyoke Basalt in Connecticut with minor exposures of Triassic sandstones and siltstones (Douglas et al., 2002).

With climactic variation, vegetation along the Connecticut has changed. From 14,000 to 10,000 years ago, spruce, jack pine, and hemlock prevailed throughout New England. New England vegetation underwent large-scale changes following the retreat of glaciers. In southern New England hemlocks and hardwood trees such as oaks and chestnuts dominated the landscape. As more settlers arrived, certain tree species were favored either because of their utility or because of their inherent tolerance of a wide range of environmental conditions (Foster et al., 2004). Mature forest conditions today differ from their pre-settlement abundance. The chestnut, for instance, is no longer found in abundance due to a blight removing the species in the early 1900s.

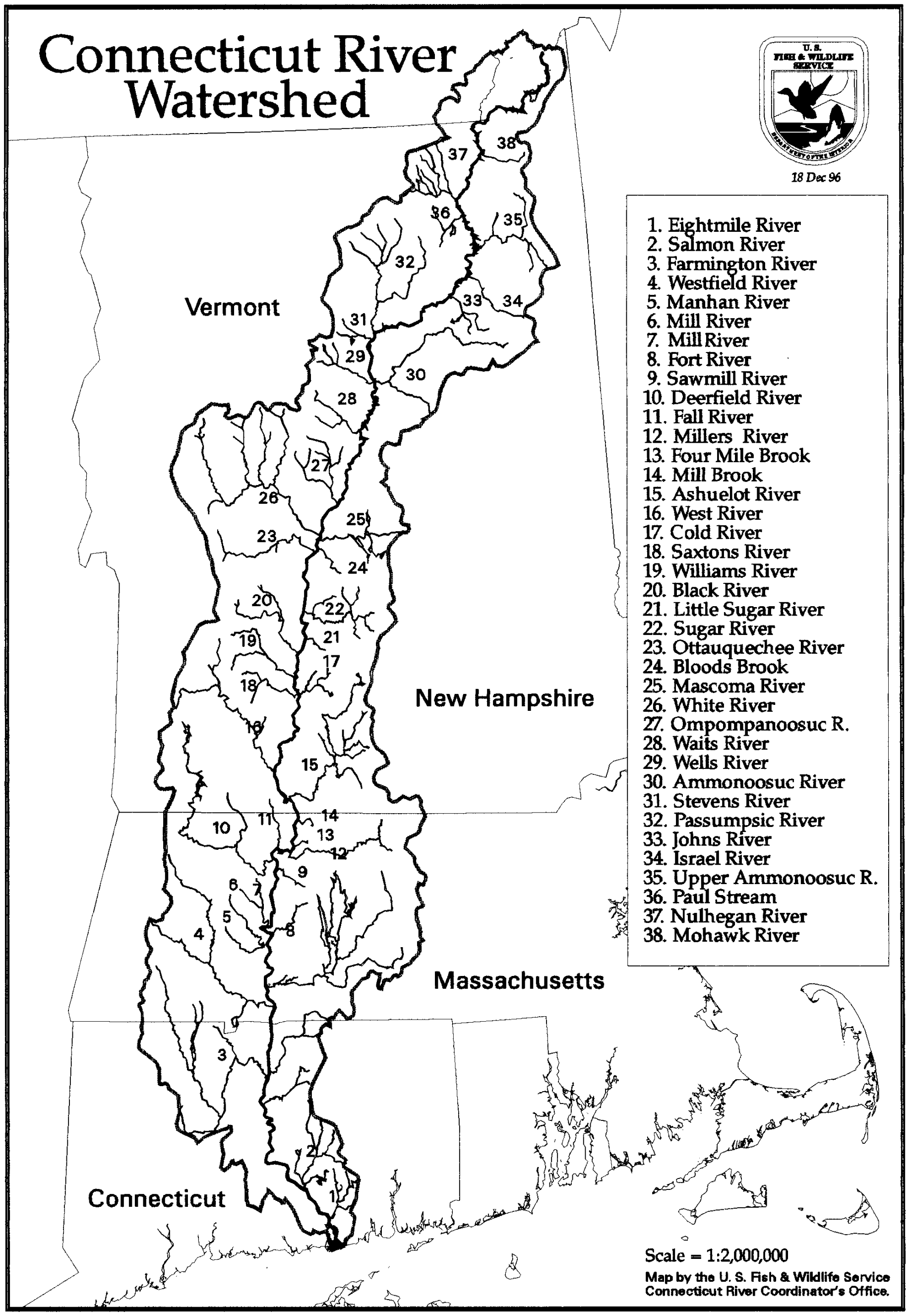

Figure 3.10: Connecticut River Watershed extending from the Canadian border down to Long Island Sound. Source: Fish and Wildlife Service.

3.2.2 Historic Land-Use

The Connecticut River Basin simultaneously experienced intensive deforestation and agricultural activity (Figure 3.11). By 1820, only 25% of Connecticut was forested (Hochholzer, 2010). An 1875 report by the U.S. Department of Agriculture stated that trees in Connecticut had been cut faster than they were grown, as field after furrowed field replaced the previously forested the landscape with an agricultural checkerboard. (Wood, 1971; Bell, 1985). In contrast to Southeastern Pennsylvania, by the turn of the 20th century, the Connecticut River valley and uplands started to reforest quickly as the soils were worn out, and many farmers abandoned New England agriculture with Westward Expansion (Bell, 1985).

Further exhausting available resources, the New England Water Resource Region had the highest historic density of dams per square kilometer (0.015 dams km^2), a legacy of the region's long history of mill dams. The structures partitioned New England watersheds into units averaging about 44 km^2 (Graf, 1999). The damming legacy of the region remains today as the Connecticut River has over a thousand dams on its tributaries and sixteen dams spanning its main stem, only twelve of which are hydropower projects (National Fish Habitat Partnership, 2015).

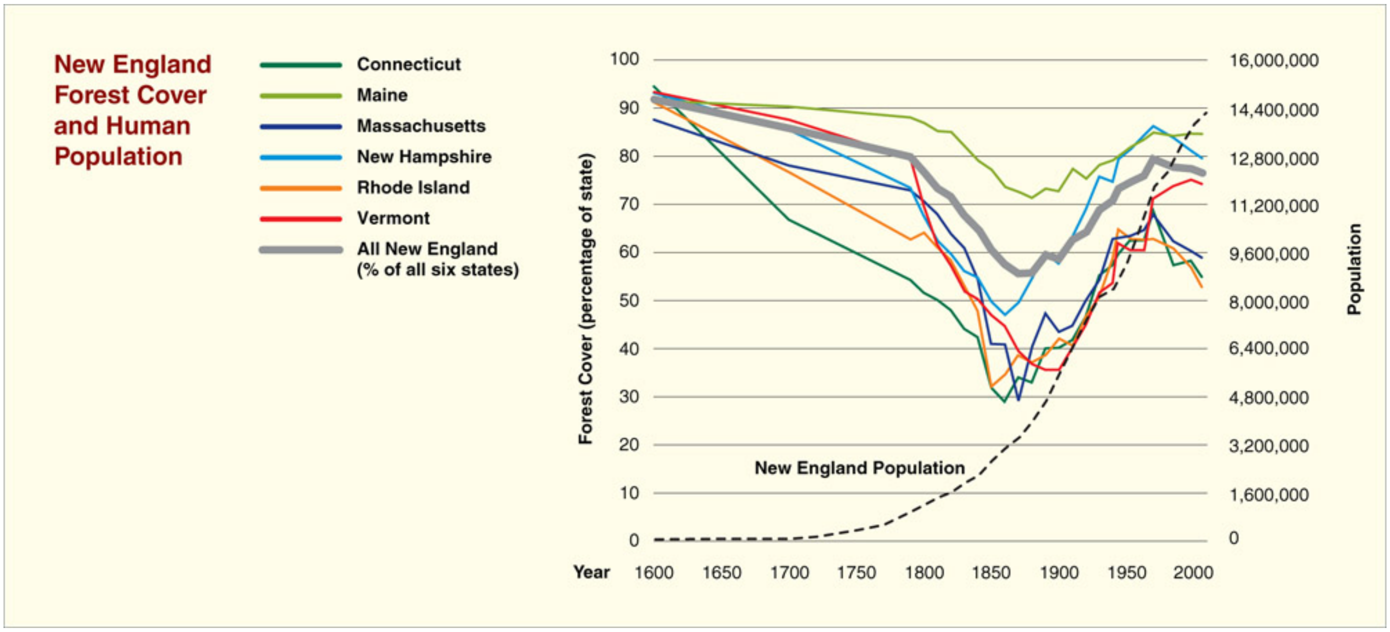

Figure 3.11: Historical changes in forest cover. Results show Connecticut forest cover was below 30% around 1850. Source: Foster et al., 2004.

3.2.3 The Salmon River

The Salmon River was chosen as a study site based off its known location of a mill dam and possible location of a second dam upstream (Figure 3.12). The presence of suspected legacy sediments upstream but a lack of any identifiable deposits downstream provided an interesting comparison in depositional characteristics. The Salmon River, located in the New England physiographic province, is formed at the confluence of the Blackledge and Jeremy rivers just west of Colchester, Connecticut (Figure 3.13). The Salmon River runs southward for 16 kilometers before joining the Connecticut River 24 kilometers upstream of Long Island Sound. The average channel slope for the Salmon River is 0.4%, bankfull widths average 25 m, and the D_{50} value of the streambed material ranges between 16 mm and 256 mm (Thompson and Hoffman, 2001). The river flows through a steep-walled, forested, valley that is dominated by a thin layer of glacial till with episodic schist and gneiss outcrops (Thompson, 2002).

Geologically, the study reach was predominantly near-ice-marginal fluvialdeltaic deposits in the lower Salmon River valley (Figure 3.14). Because the north-east-southwest trend of Salmon River valley was parallel to retreating ice margin, the southern part was most likely uncovered all at once instead of sequentially northward (Stone et al., 2005). The drainage area of the Salmon River is 259 km^2 and the discharge is on average 4.8 cubic meters per second.

Remnants of a historic dam are visible on both sides of the Salmon River upstream of the Veteran's Fishing Area (N 41.6066998°, W -72.4272193°) (Figure 3.12). The dam was constructed of rock with tiers extending into the forested bank. Approximately 200 m downstream there is an abandoned mill structure that could have utilized the dam for waterpower. The Salmon River and its tributaries each had more mills trying to operate by the middle of the nineteenth century than the water supply could support during periods of minimal precipitation (O'Keefe and Foster, 1998).

Figure 3.12: Remnant dam along the Salmon River. Arrows point to dam structure embedded in the bank.

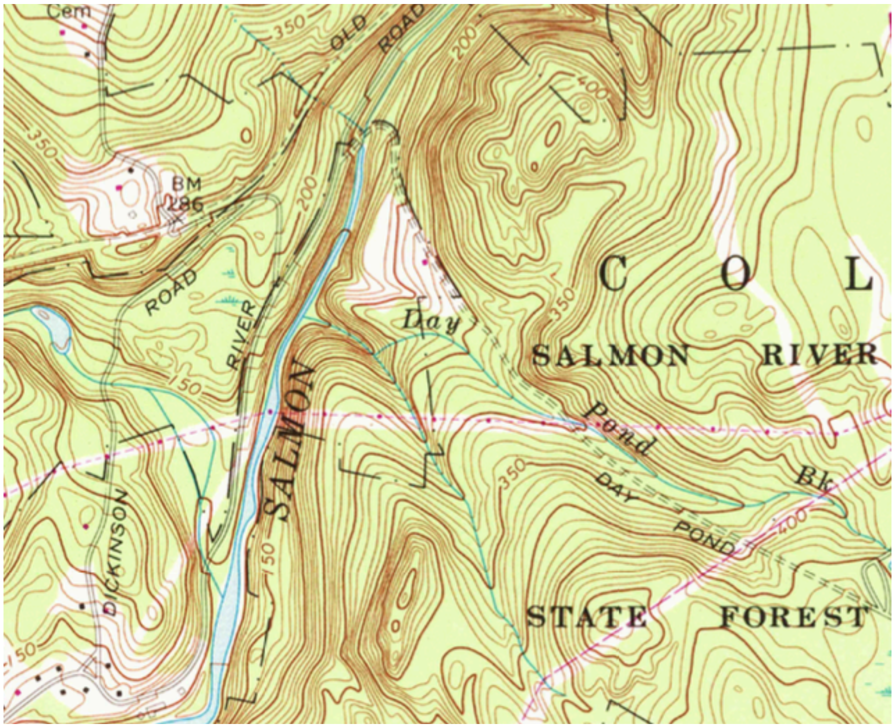

Figure 3.13: Topographic map of the Salmon River study reach. Source: USGS.

Figure 3.14: Quaternary map of Salmon River watershed. Source: USGS.

3.2.4 The Blackledge River

A 0.6-km study reach was used for the study on the Blackledge River. The Blackledge River in Marlborough, Connecticut, serves as a tributary to the Salmon River and runs for 26.4 km before joining the Salmon River. The Blackledge River flows south from an elevation of over 200 m before emptying into the Salmon River (Figure 3.15). The Salmon and Blackledge Rivers are natural trout and salmon streams of historic renown (Hunter, 1941). A small study reach along the Blackledge River was sampled in two locations. Forested vegetation was abundant up to the edge of the bank. From this point further, the Blackledge and Salmon River sites will be generally lumped together as "upstream Salmon" and "downstream Salmon" for ease of understanding in the results. The Blackledge River is periodically mentioned by name in the methods section to distinguish field reconnaissance.

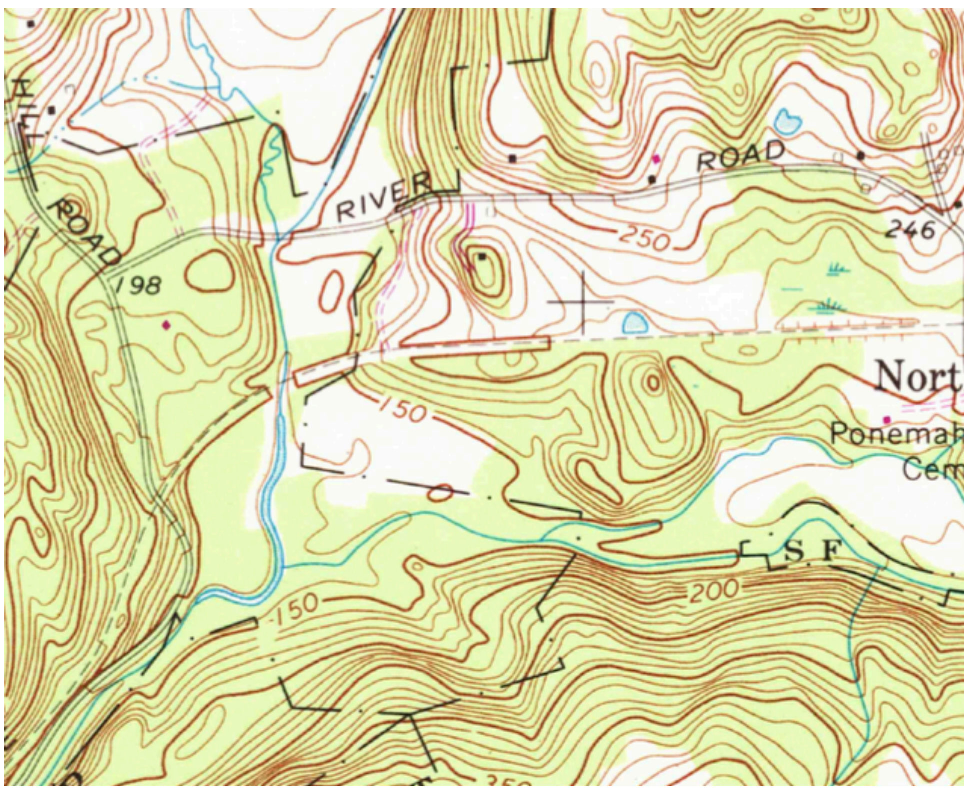

Figure 3.15: Topographic map of the Blackledge River study reach. Source: USGS.

4.0 Methodology

In order to characterize the nature and spatial variation of probable legacy sediments (PSA) and suspected buried A horizons (BS) along the floodplain continuums of the Christina and Connecticut River Basins, a combined approach of field work, laboratory sediment analysis, and GIS generated-mapping was selected as a research strategy. Spatially extensive field sampling of exposed riverbanks along White Clay Creek (PA), Doe Run (PA), and the Salmon River (CT) was carried out to identify variation in the geologically recent sediment stratification of stream banks in proximity to historic mill dams. Floodplain deposits were analyzed for organic content and grain size to determine if there was a distinguishable legacy sediment deposit and buried A horizon present. The testing of sediment samples was further intended to determine whether sediment layers were ubiquitous within and between stream sites. GIS helped to investigate correlations in spatial location of deposits with known historical mills and dams.

4.1 Mill Dam Location Reconstruction

Many historic mill dams throughout the New England and mid-Atlantic regions are no longer visible along rivers and streams today. In order to understand the relationship between dam locations and sediment deposits, an archaeological reconstruction of mill and dam locations was completed using historic maps prior to fieldwork. For White Clay Creek and Doe Run in Southeastern Pennsylvania, 1886 land-use and property maps by township were obtained from the West Chester Historical Society. These maps delineated stream locations as well as dam and mill locations prior to the start of the 19th century (Figure 3.7, Figure 3.9). Similar stylistic maps were not available at the time of study for the Salmon River. However, remnants of a mill and dam on the Salmon River downstream study reach provided visual evidence that the location was dammed. The locations of historic mill dams were used to select tributaries within the Christina and Connecticut River Basins, as well as to designate study reaches within each of the selected streams.

4.2 Fieldwork

Fieldwork along the Pennsylvania streams began in early June, 2015 with preliminary scouting to determine which reaches of the study streams would be suitable for the research objective. Two hundred forty eight samples (200 along White Clay Creek and 48 along Doe Run) were taken at exposed banks along the two streams. Banks were observed for any visible color or composition distinctions that identified layers of sediment. In particular, distinctions were made between any visually identified probable legacy sediments (hereinafter PSA), suspected buried A horizons (hereinafter BS), and sub-surface deposits. While variable between sites and riverbanks at sites, in general, PSA were identified by a light brown sediment color, uniform fine sand-grain composition, and a lack a substantial organic material. BS layers were defined by a dark grey/brown coloring as well as by the amount of organic material present. Organic material ranged from fine particulate matter to large wood. Sub-surface deposits were identified closest to the streambed and were heavily clay-dominated or matched the bed material. Samples were scraped from each identified layer using a trowel, placed into Ziploc bags, and refrigerated until further processing. The defined sediment layers at each exposed bank were measured for thickness to the nearest millimeter using a measuring tape. Measurements were taken from the marked bottom of the layer upward for each defined layer. Photographs and detailed field notes were prepared for each site with particular attention to buried organic soil composition and overall bank characterization. GPS points of exposed bank sites were taken using a Garmin 64st device. GPS points were useful to later correlate the location of specific sediment trends or differences in relation to historic milldam locations.

The same fieldwork methodology for identifying PSA and BS layers was used along the study reaches of the Salmon River, CT. Fieldwork in Connecticut took place in early October. In addition to sediment samples, a Munsell chart was used to evaluate and classify the color of the sediment at each PSA and BS layer. The Munsell chart separates the color shade components (relative to red, yellow and blue), value (lightness or darkness) and chroma (intensity or strength). Holes were bored in to the floodplain terrace using a hand-auger to further assess the presence and potential deposition of legacy sediments. At the time of field sampling, the discharge of the river was unusually low compared to average discharge measures at the downstream gauge station, permitting goof access for bank sampling.

After the leaves dropped in early November, a topographic survey was conducted along the 0.6-kilometer study reach, aimed at assessing the relative importance of the stream gradient and bank elevation and sediment deposits. Special attention was given to surveying the top of banks, thalwegs, and sediment layer heights near sample sites. There was no known benchmark elevation along the study reach, and in return a temporary benchmark was constructed. Due to the range at which the survey took place, the level of precision in the bank elevation varies, but is still considered more precise than an autolevel or LIDAR imagery.

4.3 Sediment Analysis

4.3.1 Sample Prep

Prior to any testing, all samples were baked for 24 hours in a drying oven at 60° C to remove any moisture. Upon completion of the drying process, samples were disaggregated, and crushed using a mortar and pestle. Samples were sub-divided into smaller sample bags for additional testing and stored in a desiccator to make sure the sediment remained free of moisture.

4.3.2 Grain Size

A grain-size analysis was used to observe the uniformity of sediment sizes between PSA and BS layers, both within layers and across stream sites. Since particle diameters typically span many orders of magnitude for natural sediments, testing the grain size served as a way to classify and describe the distribution of sediment. Grain size also provides evidence towards the depositional environment. A nested-dry sieve was used to distinguish the diameter of the grains for each PSA and BS sample. The mesh of each stacked sieve decreased by a set ratio equivalent to a half-phi value. Samples were sieved from course sand (2.0mm) to very fine sand (0.032mm). Histograms depicting percent frequency of particle-size occurrence were delineated from the sieving procedure. Knowledge of the particle size was critical to understand the homogeneity of grain distribution between probable legacy sediment and suspected buried A horizon deposits. A computer program called GRADISTAT was used to analyze the sieving data. GRADISTAT is written for the rapid analysis of grain-size statistics from any of the standard measuring techniques. Mean, mode, sorting, skewness and other statistics were calculated arithmetically and geometrically (in metric units) and logarithmically (in phi units) using moment and Folk and Ward graphical methods (Blott and Pye, 2001). In particular, D_{10}, D_{50}, and D_{90} values were pulled for comparison between sites. The D_{50} indicated the median value, the D_{90} indicates the point where 90 percent of the distribution was coarser than the overall sample, and the D_{10} shows where ten percent of the grains were coarser than the overall sample.

4.3.3 Organic Content

The percent organic content in each sample was critical in observing similarities or differences between the PSA and BS horizons. The organic content was measured through an ash-free dry mass method (AFDM), which indicated the loss on ignition, or percent of weighted carbon that burnt out of the greater sediment sample. It was expected that BS horizons would be richer in organic content than PSA layers.

Samples were placed in evaporating dishes and heated for one hour prior to testing in order to remove any moisture before massed empty. The dish was then filled with a sample of sediment and massed. The sediment-filled evaporating dishes were placed in a ceramic kiln to burn off any organic content. The kiln burned at 450° C to 500° C for six hours after heating to temperature. The dried samples were weighed to get the loss on ignition. The AFDM method did not take into account the weight of the organic materials' ash remaining in the dishes after coming out of the kiln.

4.4 Computer modeling of study sites

4.4.1 GIS

Study area maps for the sampled watersheds were constructed using GIS. Additionally, for the mid-Atlantic Piedmont stream sites, locations of mill dams from the 1860 historic maps were overlain in GIS with the field sampling GPS coordinates. This helped to contextualize sediment sample results within the stream system and interpret the extent to which mill dams played a role in the location and characteristics of the deposit. Isoline maps were created for Pennsylvania to show thickness differences between sediment layers in relation to mill-dam locations.

4.4.2 Sinuosity

Google Earth was used to measure the sinuosity of the each study reach. The sinuosity measure gives a better understanding of the channel characteristics and is useful in extrapolating pre-disturbance conditions. In general, straight bedrock streams that flow directly downslope have a sinuosity index of about one, and meandering streams have a sinuosity index that is greater than 1.5 (Richards, 1982; Babar 2005).

The methodology used was aimed at best distinguishing between PSA and BS layers. The chosen methodology was also necessary to understanding whether PSA sediments were historic relics of land use. The use of similar methods at each site allowed for regional comparisons to assess the importance of glacial history on PSA depositional processes.

5.0 Results

Results indicated that floodplain deposits vary greatly within and between watersheds. Thick, fine-grained deposits interpreted as legacy sediments were found at Doe Run and White Clay Creek (PA) and along the upstream Salmon River reach (CT), but were not found along the downstream Salmon River reach (CT). The PSA deposits observed most often existed with a darker, organic BS layer below. Grain-size, organic content, color, and thickness were used to distinguish between deposits, and to infer the floodplain environment at the time of deposition. Grain-size values showed greater differences between sediment layers in Connecticut, but relative uniformity in Pennsylvania. A positive relationship between low-slope, high-sinuosity, and the presence of deposits was observed at all three sites with legacy sediments. Between all three sampled sites, there was significantly more organic carbon found in the suspected buried A horizons than in the legacy sediments.

5.1 Pennsylvania Site Observations

5.1.1 Visual Observations

A visual reconnaissance of Doe Run and White Clay Creek was done prior to any sampling to understand the site conditions and identify any sediment-deposit patterns. Doe Run and White Clay Creek exhibited similar meandering, single-thread channel characteristics. The sinuosity of White Clay Creek was 1.55 and the sinuosity for Doe Run was 1.48 (Appendix C). Both streams transitioned between managed meadow and forested vegetative cover. Sampling locations on both streams displayed clear distinctions between layers of sediment at exposed banks (Figure 5.1). The thick, top layer of sediment was characteristically a larger deposit of light-brown-colored sediment lacking in any visible organic material (Figure 5.2, 5.3). Below this deposit, there was a dark-brown or black buried layer, with visible organic material. Large wood, root matter, and leaf liter was consistently found in buried-soil layers (Figure 5.2, 5.3). On two Doe Run sites, a unique re-buried organic sediment layer was found between the observed post-settlement alluvium and clay layers (Figure 5.5).

Figure 5.1: An exposed bank showing the three types of sampled sediment layers, post-settlement alluvium, buried soil, and sub-soil.

Figure 5.2: Exposed bank sampling sites along Doe Run. Arrow A points to the PSA layer. Arrow B points to the BS layer.

Figure 5.3: Exposed bank sampling sites along White Clay Creek. Arrow A points to the PSA layer. Arrow B points to the BS layer.

5.1.2 Organic Content

Percent organic carbon was used to infer the relative time sediment deposits were exposed at the surface and served as an identifier between PSA and BS layers. BS layers were consistently richer in organic content than PSA deposits. Using White Clay Creek as the standard of comparison, AFDM results were significant between all sites as well as between labeled PSA and BS samples (Appendix A). Statistical analysis suggested that all terms were significant, but PSA and BS served as the best predictors of differences (Table 5.1).

Table 5.1: AFDM whole model response comparing results by distinguished layers and by site. White Clay Creek is used as the standard.

Term	**P-value**
PSA or BS	<0.0001
Site (Doe Run)	0.0240
Site (Salmon River)	0.0080
PSA or BS (Doe Run)	0.0006
PSA or BS (Salmon River)	<0.0001

Along White Clay Creek, the percent weighted carbon was significantly higher in BS layers than in PSA layers ($P = 0.003$) (Appendix A). However, because multiple samples were taken at diffuse boundaries of distinction between the BS layers and sub-surface clay layers where sediment of the two different horizons was mixed together, statistical analysis was run for a second time without any of the mixed samples (Figure 5.4b). When statistics were run without any samples taken at diffuse boundaries, there was an even greater statistically significant difference between the White Clay Creek PSA and BS layers ($P < 0.001$). Detailed field notes taken at each site were used to identify which samples were taken at diffuse boundaries of sediment (Appendix B). Sediment samples that were run for AFDM as BS mixed with the sub-surface deposit had lower percent organic content. Similarly, PSA samples run for AFDM as PSA mixed with roots and hanging vegetation from the top of bank had higher percent organic content than those not taken at diffuse boundaries (Figure 5.4a).

The percent organic carbon was significantly higher in PSA layers than in BS layers along Doe Run ($P = 0.024$) (Table 5.1). At two Doe Run sample sites, a suspected buried A horizon was suspected below the present water level and an additional thin re-buried organic deposit was observed between the PSA and clay deposits of the same site (Figure 5.5). Samples were taken for both observed organic layers. Within and between White Clay Creek and Doe Run visible organic material ranged from fine-particulate organics to leaf litter and large wood. White Clay Creek exhibited more wood additions in the samples than Doe Run.

Figure 5.4a and 5.4b: Diffuse sediment layers showing a mixing between roots and PSA and between BS and sub-surface clay.

Figure 5.5: Doe Run sample with a BS layer below the present water level (Arrow B) and an additional thin re-buried organic deposit observed between PSA and clay deposits (Arrow A).

5.1.3 Grain Size

Results of grain size provide evidence toward changes in depositional environment and flow conditions with time. Comparison of D_{10}, D_{50}, and D_{90} values for White Clay Creek PSA and BS layers showed no statistically significant difference (Table 5.2) (Appendix A).

Table 5.2: Grain-size distributions of PSA and BS at White Clay Creek, PA.

Grain Size Distribution	P-value
D_{10}	0.3000
D_{50}	0.6014
D_{90}	0.6014

5.1.4 Thickness

Variation exists between the thickness and composition of buried organic soils and post-settlement layers. Post-settlement alluvium deposits varied widely in thickness within and between watersheds (20-160 cm), as did buried organic soils (0-80cm) (Table 5.3). No clear correlation was found at either Doe Run or White Clay Creek between post-settlement alluvium thickness and the known location of historic mills or dams (Figure 5.6a-b, 5.7a-b). No statistically significant difference was found between the thickness of sediment layers between White Clay Creek and Doe Run sites, suggesting thicknesses do not vary extensively between the two Pennsylvania sites.

Table 5.3: Comparison of mean, minimum, and maximum thickness measurements between distinguished sediment layers and sites.

	Mean (cm)	Standard Dev.	Min. (cm)	Max. (cm)
White Clay BS	35.5	15.2	13	78
White Clay PSA	70.5	24.2	24	161
Doe Run BS	24.3	12.7	13	55
Doe Run PSA	86.2	30.0	28	145

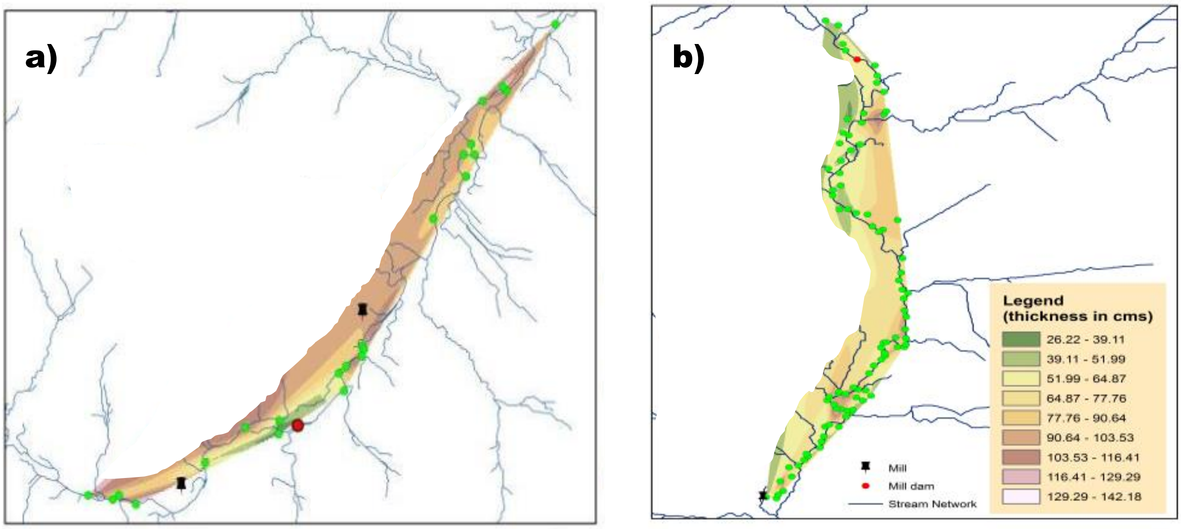

Figure 5.6a and 5.6b: Isoline of PSA concentration showing the thickness of sediment layers for studied reaches in Doe Run and White Clay Creek.

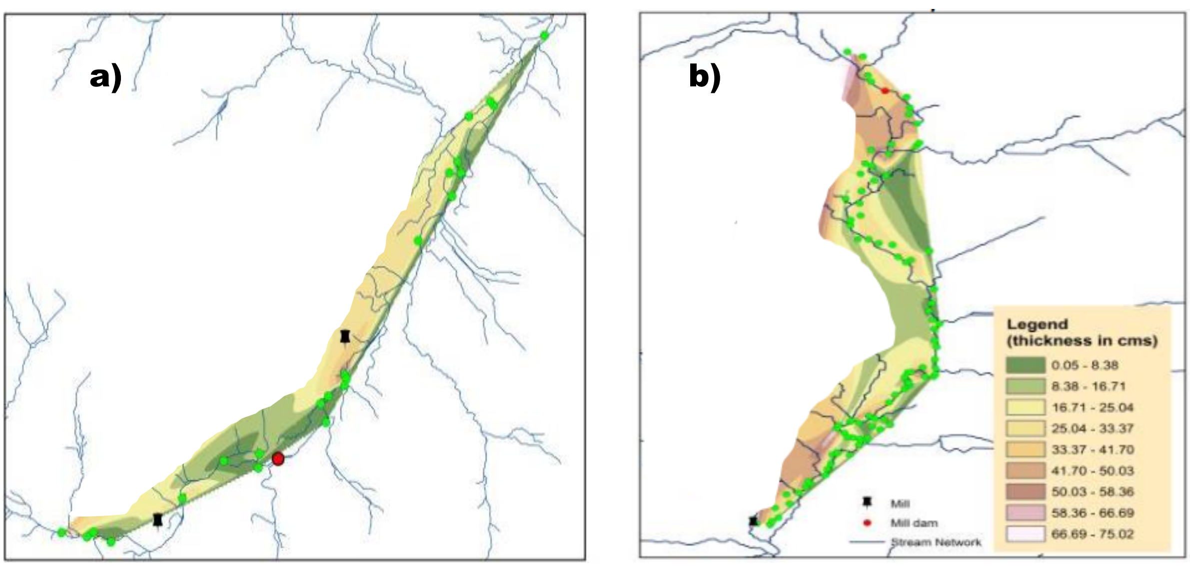

Figure 5.7a and 5.7b: Isoline of BS concentration showing the thickness of sediment layers for studied reaches in Doe Run (a) and White Clay Creek (b).

5.2 Connecticut Site Results

5.2.1 Visual observations

The upstream study reach of the Salmon River is a meandering, single-channel system with a sinuosity of 1.44 (Appendix B). Each of the four upstream Salmon River sample locations displayed clear distinctions between layers of sediment at exposed banks. The top layer of sediment was characteristically a larger deposit of light-brown colored sediment, lacking any visible organic material. These lighter colored, near-surface deposits were labeled as PSA. Below this deposit there was a dark brown or black buried layer with visible organic material labeled as BS (Figure 5.8). A paired terrace, with the left and right bank at approximately the same elevation, was observed at the furthest downstream site within the upstream Salmon River reach (Figure 5.10). The left bank of the terrace exhibited a dark sediment layer with a larger light-colored sediment deposit above it. The channel bed was far from the terrace on the right bank, but close to the left-bank terrace. The site was distinguished as a terrace by its higher bank elevation and visible soil horizons. While other terraces were observed along the study reach, they were larger and identified as Quaternary age due to size and a lack of a visible dark layer (Figure 5.9). Quaternary age terraces ranged in height from 2.7 to 3.0 m, and were measured using a laser range finder.

Figure 5.8: Sediment layer distinction and exposed banks along the upstream Salmon River location. Arrow A points to the PSA layer. Arrow B points to the BS layer.

Figure 5.9: Quaternary aged terrace along the Salmon River.

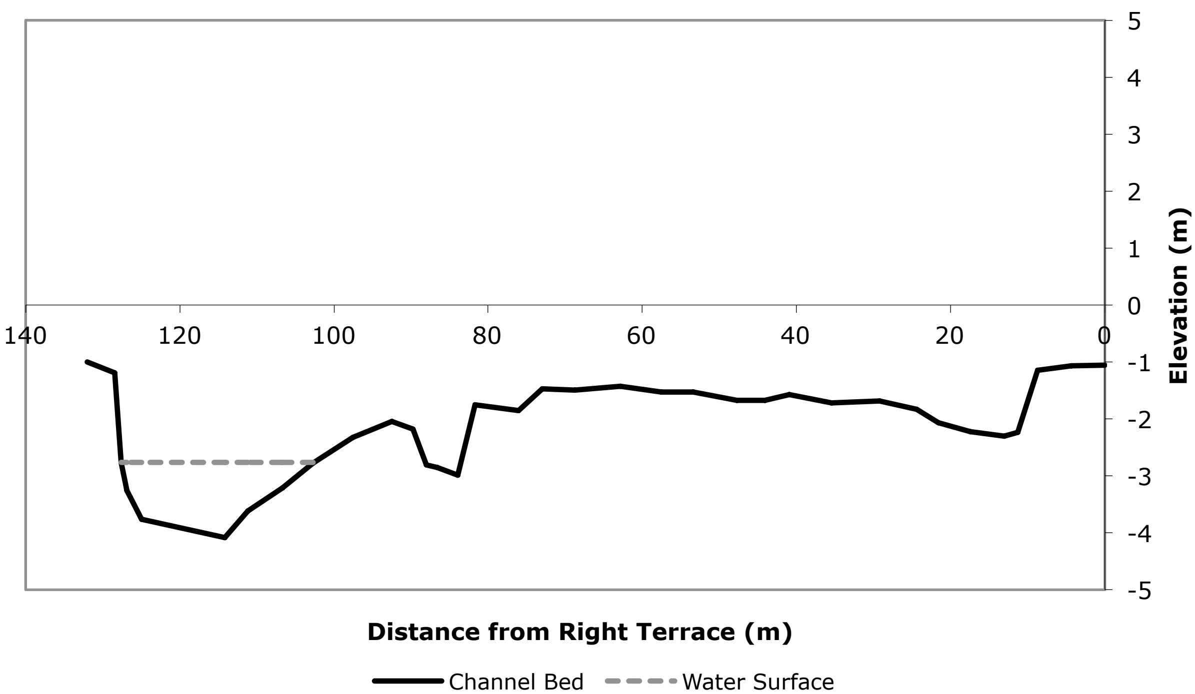

Figure 5.10: Cross-section at the furthest downstream sampling site of the upstream Salmon River study reach surveyed by Alex Iezzi, Grace Medley, and Doug Thompson (2013). Cross-section indicates a paired terrace.

Visual reconnaissance was initially done for the downstream sampling site along the Salmon River, where remnants of a mill and dam remain. The downstream sampling reach of the Salmon River is a narrow, bedrock-dominated channel, with a sinuosity of 1.04 (Figure 5.11).

One sediment sample was taken at the location. However, it was determined that the site did not include deposits of fine-grained sediments that the remaining three sites had, and thus no further data analysis was conducted at the site (Figure 5.11).

Figure 5.11: Downstream Salmon River view looking upstream and left bank dam remnants with displaying no visible fine-grained sediment deposits.

5.2.2 Color

Distinct visual differences in sediment color were observed between layers at exposed bank sites. A Munsell color chart was used to identify the color of the PSA and BS layers along the upstream study reach of the Salmon River. BS layers were identified as black 10YR 2.5/1 or 2/1 using the Munsell color chart. The PSA deposits were identified as 6/4 10YR yellowish brown or 5/4 10YR yellowish brown for all samples (Appendix B).

5.2.3 Organic Content

Percent organic content ranged from 2.9 % to 18.0 % among BS layers and 0.7 % to 2.5 % among PSA deposits (Table 5.4). The organic content of the PSA layers was significantly greater than the organic content of the BS layers at the upstream Salmon River site (P = 0.0204). Sample point AM4 was taken at a diffuse boundary between the BS and sub-surface deposit and consequently had a lower percent organic content (Appendix B). When run without the outlier point of the BS layer at AM4, the difference in percent organic material between the PSA and BS was still statistically significant (P = 0.0038) (Appendix A). Results suggest that BS layers sampled along the Salmon River were consistently higher in organic content than the BS layers along White Clay Creek and Doe Run.

Table 5.4: Percent organic content between BS and PSA layers at the upstream Salmon River reach.

	AM3	**AM4**	**AM5**	**AM6**
BS	18.0%	2.9%	9.1%	11.1%
PSA	2.5%	0.7%	0.7%	0.9%

5.2.4 Grain Size

The overall size of sediment grains between the PSA and BS layers showed that the PSA grain size was smaller in diameter than the BS below, although the difference was not statistically significant (Table 5.5). The most downstream sampling site used in the analysis (AM3) had the finest D_{90} value compared to sampling sites further upstream on the Salmon River (Appendix A). The trends in grain size for the PSA deposits were not entirely linear, but generally the finer sediments were deposited downstream and coarser sediments were found upstream. The difference in median grain size (D_{50}) between the PSA and BS layers is statistically significant (P = 0.0159), with larger median sediment size found in PSA layers. PSA layers also had a significantly larger D_{10} grain size than BS layers (P = 0.0098). No statistically significant difference was found between the D_{90} values of the two layers (P = 0.1733).

Table 5.5: Grain size results between PSA and BS layers along the Salmon River upstream and downstream reach. D_{10}, D_{50}, and D_{90} value measured in micrometers.

Sample	D_{10}	D_{50}	D_{90}
AM3PSA	68.25	166.8	334.2
AM3BS1	52.81	130	826.3
AM3BS2	51.21	109.5	480.5
AM4PSA	183	358.6	928.2
AM4BS	70.16	193.4	429.4
AM5PSA	203	454.7	1231.3
AM5BS	59.21	170.8	634.1
AM6PSA	159	370.2	1082.8
AM6BS	67.96	188.9	658.2

5.2.5 Thickness

Thick sequences of PSA deposits were found along the upstream Salmon River reach. As a general trend, the thicknesses of the PSA deposits ranged within 0.27 m of each other, with the exception of the most downstream sampling site. BS thicknesses ranged within 0.28 m of each other along the reach (Table 5.6).

Table 5.6: Thickness averages along sample sites at the upstream Salmon River reach.

Sample Point (upstream to downstream)	PSA Thickness (cm)	BS Thickness (cm)
AM3	51	39
AM4	143	20
AM5	116	48
AM6	122	41
AVERAGE	108	37.3

5.2.6 Longitudinal Profile

A longitudinal survey was used to distinguish the overall stream gradient and bank elevation of the upper Salmon River sites. Results from the longitudinal profile showed that the downstream top of the bank was roughly three meters above the thalweg and the upstream top of bank was 1.25 m above the thalweg (Figure 5.10, 5.12). The tops of the banks are at similar elevation, with one point not fitting this trend. The slope of the PSA layer is about 0.01% while the slope of the river is on average 0.4%. No thalweg measurement was taken at AM3 and AM4 because the water depth extended above 1.5 m in depth. The trend in the thalweg line indicates a high gradient of slope relative to the other measured surfaces (Figure 5.12). Unlike the top of the bank, the slope along the thalweg was not uniform and exhibited variation in depth.

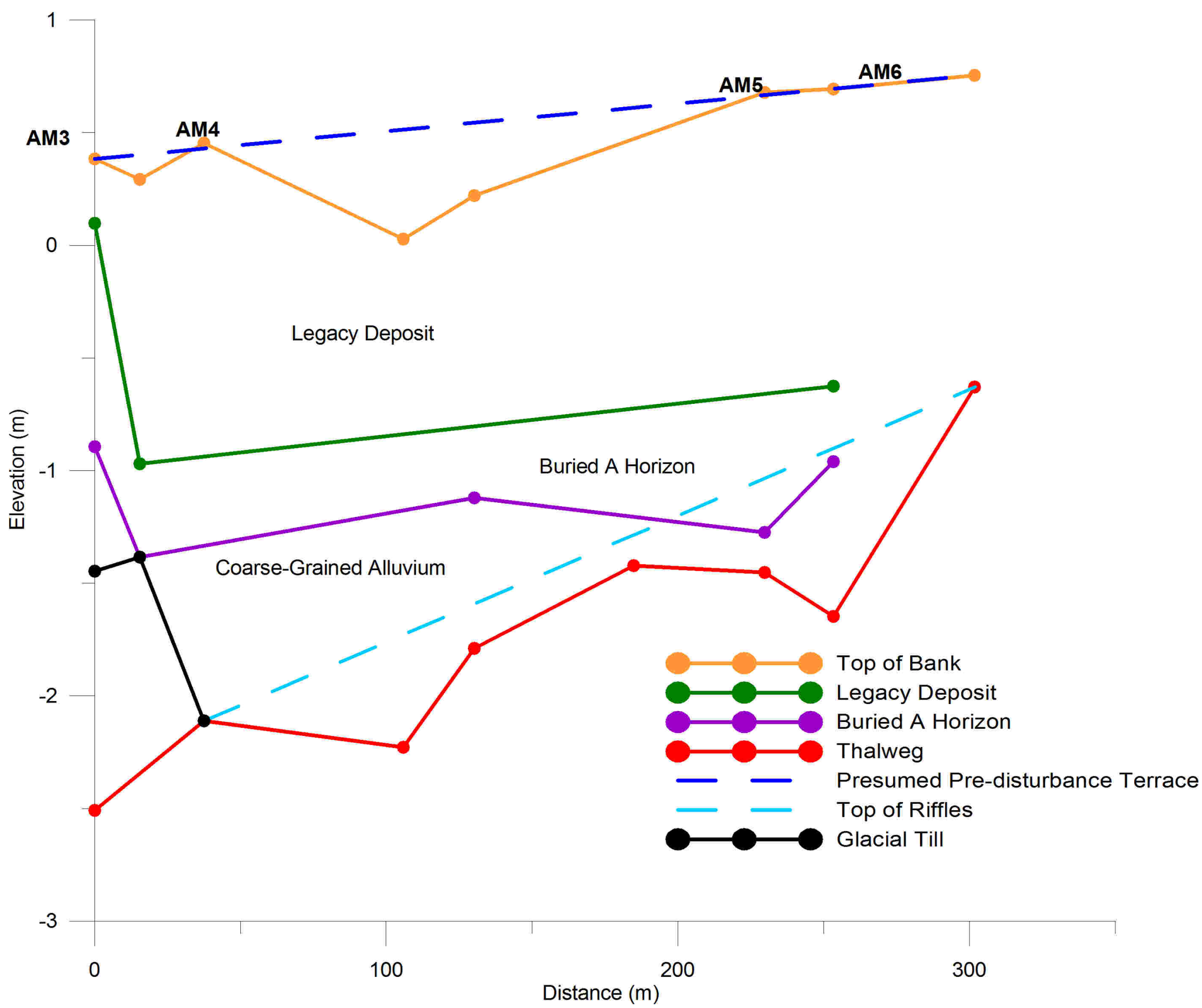

Figure 5.12: Salmon River upstream reach longitudinal profile.

Results between Connecticut and Pennsylvania sites give a sense of how fluvial systems have responded to landscape changes with time, as well as where sediments are preserved along the contemporary landscape. Comparatively, results from Connecticut sites showed significant differences between layers in the grain size and percent organic content, and results from Pennsylvania showed significant differences in organic content and color between layers. Similar depositional conditions between Pennsylvania sites correlated with somewhat similar PSA and BS characteristics between White Clay Creek and Doe Run, however there was a significant difference between all sites (Table 5.1). Consequently, the depositional environment and slope along the upstream and downstream Salmon River reaches varied, and results suggested sediment deposits were not uniformly preserved along the river. Overall, results showed a significant difference in the organic content between labeled PSA and BS layers as well as between sites, with the percent organic of the labeled BS serving as the highest measured carbon content across comparisons.

6.0 Discussion

Results from this study provide strong evidence for the presence of a buried A horizon and overlying legacy sediment layers along both streams in Pennsylvania and the upstream reach of the Salmon River in Connecticut. The downstream study reach of the Salmon River had a remnant mill and dam, but no preserved legacy deposit or buried A horizon. Statistical comparisons of soil color, organic content, and grain size of 258 sediment samples across the three sites suggests that a wide variance exists in the characteristics of floodplain deposits. Variation in the thickness and composition of sediment layers between sites suggests that deposits were not uniformly formed or preserved. It is necessary to provide interpretations of sediment layers on a regional and local scale in order to understand the impact of legacy sediments and what the pre-disturbance depositional environment looked like.

6.1 Evidence for a Buried A Horizon

The A horizon of a soil tends to be darker due to the abundance of organic material within the layer (Jenny, 1994). Visible A horizon layers along stream and river banks indicate an extensive period of exposure at the surface, which allowed the layer to form and accumulate organic matter with time. The distinguishable, dark coloring of the BS layer observed at Doe Run, White Clay Creek, and the upstream Salmon River site, provide evidence that the observed sediment layer is a former A horizon. Results from a Munsell color test of the BS layer at the upstream Salmon River site were black 10YR 2.5/1 or 2/1. A Munsell test used by Walter and Merritts (2008) to identify buried A horizons characterized the soil layers black, 10YR 2/1 as well. The coloration of the BS layers observed along White Clay Creek and Doe Run, PA were visually consistent with the upstream Salmon River site and Walter and Merritts (2008) (Figure 5.1). The similarity in color between the observed sites and Walter and Merritts (2008) characterization of a buried A horizon color provides evidence that the dark sediment layer observed in Connecticut and Pennsylvania was a buried A horizon.

Visible organics in all of the Connecticut and Pennsylvania BS samples further supported the labeling of the sediments as a buried A horizon. Organics found in White Clay Creek and Doe Run BS layers showed a range of organic composition from fine particulate organics to leaf litter and wood. Walter and Merritts (2008), on the other hand, found visible woody debris, seeds, algal mats, pollen, and peat in the buried A horizon sample sites. The upstream Salmon River site was rich in leaf litter and rotted wood. The inclusion of visible organic material in the suspected buried A horizon is evidence that the layer was exposed to the surface and accumulated vegetative cover with time. The possibility of roots extending from the surface down to the buried A horizon and adding to the organic content was considered. However, the visual observations of large wood (< 15 – 40 cm diameter) protruding from the BS layer of exposed banks suggests that the suspected buried A horizon was exposed at the surface prior to its current buried position.

The A horizon of a soil profile typically contains a higher concentration of organic material than underlying layers. Ash free dry mass results indicated that the sampled BS layers along the Salmon River ranged from 2.9% to 18.0% (Table 5.4). Comparatively, BS samples along White Clay Creek and Doe Run ranged from 1.3% to 13.8% and 2.7 to 15.7% respectively (Table 5.1). The Pennsylvania sites sampled by Walter and Merritts (2008) had an average of 2.0% to 9.0% percent weight total carbon. Results indicate that sample sites along the Salmon River were consistently higher in organic material than sediment samples taken along White Clay Creek and Doe Run in Pennsylvania as well as those observed by Walter and Merritts (2008) in Pennsylvania. This goes against the expectation that Pennsylvania soils would be higher in percent organic content due to a suspected older age of soil. Based on the comparison of percent organic content, the BS layers in Connecticut were older than those sampled in Pennsylvania. It is possible that the floodplains along White Clay Creek and Doe Run in Pennsylvania have been heavily reworked, and the soils are thus not as old as the pre-disturbance condition might otherwise be. Although the loss on ignition was lower at the two Pennsylvania sites compared to Connecticut, ash-free dry mass results from White Clay Creek and Doe Run were still higher than those measured by Walter and Merritts (2008). Between all sites, the percent carbon was statistically significant between both the identified sample layers and streams. This suggests a clear difference in carbon content and ages of soil at all sites.

6.2 Evidence for Legacy Sediments

A distinct light-colored deposit lacking in significant organic content and labeled as PSA was consistently observed above the buried A horizon and interpreted as legacy sediments. In a standard soil profile, an O horizon is found above the buried A horizon (Birkeland, 1999). However, O horizons tend to be very small (Keller, 2010) and not as thick as the observed PSA layer. The color of the PSA deposits were 10YR 6/4 yellowish brown or 10YR 5/4 yellowish brown for all samples taken in Connecticut. Walter and Merritts (2008) observed pale to yellowish brown legacy deposit, which corresponds in color with the findings in Connecticut as well as with visual observations of color along White Clay Creek and Doe Run (Figure 5.2, 5.3, 5.8). The lighter color of the observed sediment layer above the buried A horizon suggests a limited amount of organic material. The lighter coloration of the PSA soil also suggests the layer was exposed at the surface for less time than the A horizon below. Results supported this assumption, showing that the organic content of the PSA layer ranged from 0.7% to 2.5% along the upstream Salmon River site (Table 5.4), 1.0% to 6.2% along Doe Run, and 1.0% to 6.8%

along White Clay Creek (Table 5.1). Walter and Merritts (2008) found 1.0% to 2.0% percent weighted total carbon in the layer above the buried A horizon, along their study sites in Pennsylvania. The observed PSA alluvium layer above the buried A horizon was identified in this study and by Walter and Merritts (2008) as legacy sediments.

At the upstream Salmon River site, a depositional terrace was observed at the first sampling point (AM3). The site was distinguished as a depositional terrace by its higher bank elevation and visible soil horizons (Figure 5.10). The presence of a distinct buried A horizon along the terrace at AM3 suggests an older surface below the PSA deposit that did not continue to form due to the large deposit above it. The top of the PSA layer of the terrace does not have well developed soil, indicating a younger age than the A horizon below. The closeness of the channel bed to terraces on the left banks compared to terrace locations on the right bank suggests that the river migrated laterally and reworked the floodplain with time (Figure 5.10). Additional higher terraces (>3m) were observed along the study reach, but were identified as Quaternary age terraces based on size and a more uniform, low percent organic content throughout the terrace. A lack of buried A horizons and higher elevation at the other terraces on the Salmon River, further suggests they there have not been any new deposits since the initial formation.

The downstream reach on the Salmon River lacked both legacy sediments and an observable buried A horizon (Figure 5.11). A remnant dam at the site is visible evidence of human alteration to the system, however, it cannot be inferred whether the downstream sample site on the Salmon River once had a buried A horizon or legacy sediments because no deposits were preserved at the location. Downstream, the channel constricts at a narrowing in the valley. It is suspected that any legacy sediments that existed along the lower reach were either not formed or preserved due largely to the steep, narrow, bedrock dominated channel. The high energy of flow through the confined channel and valley prevents little sediment from depositing along the riverbanks beyond the constriction. The low sinuosity of the steep, bedrock-dominated channel and narrow valley at the downstream site decreases the likelihood of floodplain sediment deposition and storage. Compared to the downstream Salmon River reach, the sinuosity along the upper Salmon River, White Clay Creek, and Doe Run ranged from 1.44 to 1.58. The three sites that exhibited legacy sediments all had relatively similar sinuosity, meandering channels, and low-grade slopes. Results thus show that sinuosity and slope heavily influence the depositional environment and thus the ability for a site to store and preserve sediment.

6.3 Cause of Legacy Deposits

The cause and source of legacy deposits is not ubiquitous between sites. All four study sites have experienced a heavily modified landscape from deforestation, agriculture, and damming. White Clay Creek, Doe Run, and the downstream Salmon River site have known mill dams within the study reaches. It is suspected that the upstream Salmon River site was also dammed as evidenced by the paired terraces at the sampling site with uniform, low slope along the top of the bank (Figure 5.10, 5.12). Typically, the top of the bank corresponds with the changing slope of the river. However, the longitudinal profile for the upstream Salmon reach showed that the downstream top of the bank was roughly three meters above the thalweg and the upstream top of bank was about 1.25 m above the thalweg (Figure 5.12). It is suspected that the dip in the bank elevation at the one point on the longitudinal profile is due to post-impoundment erosion taking place since the dam was removed. This suggests a more recent reworking of the floodplain. While there was not a statistically significant difference between the grain size of the legacy sediment deposit and buried A horizon, there was enough of a difference to suggest something caused the current to slow and deposit finer material closer to AM3 (Figure 5.12,

Table 5.5). The general trend of grain size decreasing with distance downstream is characteristic of approaching slower moving water (Table 5.5). The best explanation for this was a change or block in the flow that abruptly decreased the movement of water. The low-grade slope and meandering channel provide a considerable distance to deliver sediment along. When addressing the land-use history of the region, it is likely that this block in flow was due to the placement of a dam. As water and sediment hit the dam impoundment, the channel bed was raised and coarser material deposited out further upstream. The possibility of deltaic deposits was considered as a potential influence in sediment deposition, but there was no clear evidence of deltaic deposits. Deltaic deposits often occur where a river enters a standing body of water. The sudden decrease in energy causes the river to deposit out its sediment load. The lower Salmon River site supported Walter and Merritts (2008) claim that current and former dam sites frequently exhibit little evidence for sedimentation in New England.

In Pennsylvania, no clear correlation was found between legacy-sediment thickness and the known location of historic mills or dams (Figure 5.6a-b, 5.7a-b). This is a divergent observation from the described sediment impoundments by Walter and Merritts (2008). According to Walter and Merritts (2008), in the mid-Atlantic region, thick, one to five meter, historic deposits are nearly ubiquitous at former dam sites (Walter and Merritts, 2008). Walter and Merritts (2008) observed legacy sediments as wedged deposits of fine-grained sediments behind mill dams, with finer sediment deposited closest to the dam location. This observation is congruent with observations made on the upper reach of the Salmon River (CT), but it is not representative of observed legacy deposits on White Clay Creek and Doe Run (PA). Variation between the observed legacy sediments in Pennsylvania and presence of dam impoundments from the findings of Walter and Merritts (2008) can be attributed to multiple sources. Despite the claim made by Walter and Merritts (2008) that deposits are ubiquitously found at all former dam sites in the mid-Atlantic Piedmont, the nature of damming and landscapes between the sites used by Walter and Merritts (2008) and this study are not uniform. Historical maps of Chester County from 1883 and LIDAR imagery show that local streams were diverted through a mill race, an alternative to the stacked dam method observed in Lancaster County (Walter and Merritts, 2008). Chester County was not industrialized to the same extent as Lancaster County, and instead one dam often diverted water into a race, which extended in many cases over a kilometer or fed multiple mills. The streams in Chester County were also less steep compared to the hilly topography of Lancaster, which might have resulted in more sediment deposited in the streams at the base of hillslopes. A lack of strong evidence linking legacy sediments to mill dam locations in Pennsylvania suggests local land-use might have a larger impact in the formation and storage of legacy sediments. The more developed and loose soil available on the ground surface in Pennsylvania provided a larger supply of erosional material to rivers in stream as the landscape was modified by deforestation and agriculture.

At two Doe Run sample sites, a buried A horizon was suspected below the present water level and an additional thin re-buried organic deposit was observed between the post-settlement alluvium and clay deposits (Figure 5.5). It was inferred that the uppermost re-buried sediment deposit was still legacy sediments. Several possible reasons exist for the observed variation in the legacy deposit including the presence of a dam raising the base-level and causing upstream migration of sedimentation, localized land-use change, a major flood, or period of more active deposition followed by stabilization and then re-activation.

6.4 Impact of Glacial History on Regional Differences

Differing glacial topographies between Connecticut and Pennsylvania appeared to affect the morphology of river systems. Due to glaciation in Connecticut, the overall age of soil throughout the Connecticut River Valley is geologically younger than areas of Southeastern Pennsylvania, which remained unglaciated. Results differed, however, suggesting that the soil preserved in the Salmon River buried A horizon was older than the soil composing the buried A horizons of White Clay Creek and Doe Run. The best explanation for this is likely that the floodplains along the two Pennsylvania sites were considerably reworked with time, both by natural events and human influences.

Glacial activity changed the distribution of sediment in Connecticut. The advance of ice sheets mobilized the pre-glacial fine sediments covering the landscape, and left glacial till in the river valley as the ice sheets retreated. Glacial till was observed along the downstream reach of the Salmon River at AM3 and AM4 (Figure 5.12). It is inferred that glacial till was visible at the exposed banks of AM3 and AM4 because the banks were closer to the valley wall. The downstream sampling site on the Salmon River shows clear evidence of glacial activity changing the river valley morphology. Glacial activity scraped the landscape of sediment, leaving a narrow, steep, bedrock-dominated valley. Quaternary-aged terraces were observed on the Salmon River (Figure 5.9), suggesting dams are not the sole factor in terrace formation along human-altered streams, a divergent observation from Walter and Merritts (2008). While less soil was available across the Connecticut landscape, the distance of the upstream reach provided an ideal depositional environment for the accumulation of sediment along the reach. Therefore, what was observed along the upstream Salmon River reach, represented in many ways, an ideal sediment deposit sequence. In Pennsylvania, the soil covering the landscape was not exposed to glacial activity creating a more developed and available supply of loose sediment compared to Connecticut. The observation of legacy sediments in both Pennsylvania and Connecticut suggests that regional differences and glacial history did not eliminate the possibility of legacy sediments. Rather, changes in slope, sinuosity, and depositional environment, which could be partially attributed to glacial history, appear to have a larger impact on the preservation of deposits.

6.5 Pre-disturbance Valley-bottom Conditions

The buried A horizon layer gives an indication as to the pre-colonial floodplain landscape. Variation between the grain size and weighted carbon content of buried organic soil layers between the three sites with a buried A horizon reflects a varied pre-settlement floodplain landscape. Although it has been previously suggested by Walter and Merritts (2008) that pre-settlement floodplain conditions resembled a scrub-vegetated wetland meadow across the mid-Atlantic Piedmont Valley, large wood, root matter, and leaf liter contained in buried A horizons of the two sampled Piedmont streams suggests that the landscape was far more heterogeneous and included large forested reaches along the floodplains. The higher weighted carbon values at the two Pennsylvania study reaches further suggest potential variation in the land-cover compared to the sites sampled in Pennsylvania by Walter and Merritts (2008). White Clay Creek and Doe Run exhibited flow conditions, for instance, not indicative of a swampy and braided floodplain. It is possible that the stream systems were anabranching, but no conclusive evidence was determined for the valley-bottom condition on a regional or even full-stream scale.

Upstream on the Salmon River, the percent carbon was highest upstream compared to all other sample sites, possibly suggesting a more densely forested pre-disturbance valley-bottom. The upstream, wide valley of the Salmon River is favorable to potential braided conditions.

However, downstream the Salmon River is constricted with a narrow valley and high-energy flow, a morphology not conducive to braiding or anabranching channels. Results were not conclusive as to what regional or local vegetative patterns might have existed across the valley-bottom.

6.6 Implications for Restoration

The acknowledgment of legacy sediments and a buried A horizon along select streams calls into question how the morphology of rivers has been changed by sediments. When applied to rivers, restoration attempts to return a system to a close approximation of the condition before disturbance (Wohl, 2004). Results from buried A horizon and legacy-sediment characterizations show that the morphologies and functions of pre-settlement streams are often different from those of modern streams, requiring the spatial heterogeneity between streams to be carefully accounted for in restoration efforts. The buried A horizon provides a glimpse into the pre-disturbance valley bottom, but its interpretation requires careful analysis on a site-by-site level.

Today's restoration model often assumes the meandering, eroding channel bank as the natural reference condition (Walter and Merritts, 2008). Walter and Merritts (2008) called for a reevaluation of current restoration attempts that rely on the meandering, eroding channel bank as the restoration baseline. This study echoes the restoration concerns of Walter and Merritts (2008), arguing that the large extent of legacy sediments deposited along floodplains constitutes a re-examination of natural-channel formation. When taking into account legacy deposits, a pristine stream becomes an unlikely template for restoration because the drivers of stream dynamics have all changed (Wilcock, 2008). The perspective that change is the rule, rather than the exception is important to critically understanding the restoration needs of a river system. The assumptions that changes in sediment deposition and channel morphology have been minor, and that pristine reference reaches exist that can be emulated to design stable yet "natural" reengineered reaches, should be both critically evaluated on a case-by-case basis (James et al., 2009). The generalizations made by Walter and Merritts (2008) also cannot be made on a regional level without examining the specific land-use, types of alteration, and changing sediment dynamics taking place. Contemporary alterations of river sediment constitute a legacy for the future (Wohl 2015).

Variation in floodplain characteristics at all four sites strongly suggests restoration baselines cannot be made on a regional basis, but must be determined at the local level. At the downstream Salmon River site, evidence in the straight, bedrock-dominated channel suggests that the river system was at no point a braided channel with a wide floodplain. Upstream on the Salmon River, it was deduced that the closeness of the channel bed to terraces on the left banks compared to terrace locations on the right bank was due to the river migrating laterally back and forth across the floodplain with time. As the river moved, it carved out sediment and reworked the floodplain, as exhibited in the wide spacing between the left bank and right bank terraces.

Walter and Merritts (2008) interpreted legacy findings to mean that most floodplains along mid-Atlantic streams are actually depositional terraces. However, the terraces observed in Connecticut suggest that not all terraces are dam related and that the river system had been building terraces for a long time. While the pre-disturbance condition of the upstream Salmon River is not clear, there is not strong evidence that the area was braided. In Pennsylvania, there was no conclusive evidence as to what the pre-disturbance channel morphology looked like. Walter and Merritts (2008) advocate for the regional pre–disturbance morphology to resemble a broad, shallow, braided channel landscape. However, further research is needed to understand the full extend of pre-disturbance channel morphology.

6.7 What Comes Next?

While this study provides greater understanding into the source of legacy sediments and pre-disturbance conditions, the results are ambiguous across sites as to the sole contributor to either sediment layer. Much of this study questioned the claims made by Walter and Merritts (2008) regarding both the primary cause of legacy deposits and the pre-disturbance conditions of floodplains. Walter and Merritts (2008) suggest that legacy sediments are all historic artifacts of dams. However, the lack of a strong correlation between thickness and grain size closer to mill dams along the two Piedmont study streams, suggests legacy sediments might equally be historic artifacts of land-use. The question of how much legacy sediments are attributed to dams is still unknown. Evidence of a mill dam by a fine-grained sediment wedge and paired terrace upstream on the Salmon River, nonetheless, suggests that the type and frequency of damming might play a role. However, the lack of legacy sediments at the known remnant mill dam downstream on the Salmon River site indicates that deposits are not uniformly preserved in the landscape, making it difficult to understand the full extent of buried A horizon and legacy deposits.

Percent organic content and Munsell color tests proved to be the most useful methods for distinguishing a legacy deposit and A horizon below. The statistically and visible differences between the color and organic composition of sediment layers matched the defined sediment characterizations of Walter and Merritts (2008) and suggest a strong confidence in the labeling of sampled sediments. Differences in regional responses to legacy deposits and A horizons necessitate a need for more research to understand pre-disturbance channel morphology.

7.0 Conclusion

Clear evidence of legacy sediments and a buried A horizon in both Connecticut and Pennsylvania has implications for the longstanding interpretation of a natural stream. Differences in regional and glacial histories influenced the magnitude to which sediments were stored in the floodplains, but it was slope, sinuosity, and depositional environment that appeared to most significantly impact the preservation of sediments in the landscape. As exhibited in the upstream and downstream study reaches of the Salmon River, CT, a single river can vary greatly in its depositional environment. No two study sites were alike, although Doe Run and White Clay Creek exhibited the most similar depositional environments (Appendix A). Even in a geologically young landscape, such as Connecticut, legacy sediments were found to be present. Glacial history appeared to impact the likelihood of sediment storage based on a younger geologic landscape and different valley configuration. Valley configuration and slope dramatically changed the depositional environment between upstream and downstream Salmon River sites, causing legacy sediments to be preserved in one location and not the other. The duration and intensity of damming appeared to have effect on the thickness and grain uniformity of legacy deposits near suspected mill dam sites, explaining differences between deposits observed by Walter and Merritts (2008). Walter and Merritts argued that legacy sediments are uniformly the case with proximity to mill dams. However, results suggest that for some places, especially New England, legacy sediments are not uniformly found but are possible. The depositional environment, valley configuration, and slope appeared to be the main factors determining if legacy sediments were present along rivers and streams.

The visible material of buried A horizons and higher percent carbon in both the Connecticut and Pennsylvania site, suggest an alternative perhaps valley bottom condition than the scrub wetland described by Walter and Merritts. However, results were not conclusive as to what regional or local vegetative patterns might have existed across the valley-bottom. Observed characteristics of each site suggest that some sites could have exhibited more braided characteristics (i.e. the upstream Salmon River, parts of Doe Run and White Clay Creek), while the morphology and flow of others made it highly unlikely (i.e. downstream Salmon River, parts of Doe Run and White Clay Creek).

Results necessitate the need for site-based restoration practices that take into account the deposition characteristics and historical context of floodplains. Within and between river and streams, depositional environments and valley configurations can vary dramatically. Statistical differences in the carbon content between legacy sediment and buried A horizon layers across all sites indicates different ages of soil and significant variation between the pre-disturbance condition of each stream (Appendix A). The need for site-by-site restoration thus suggests that broad sweeping conclusions should not be upheld as a restoration baseline because there is a vast amount of variation in the landscape.

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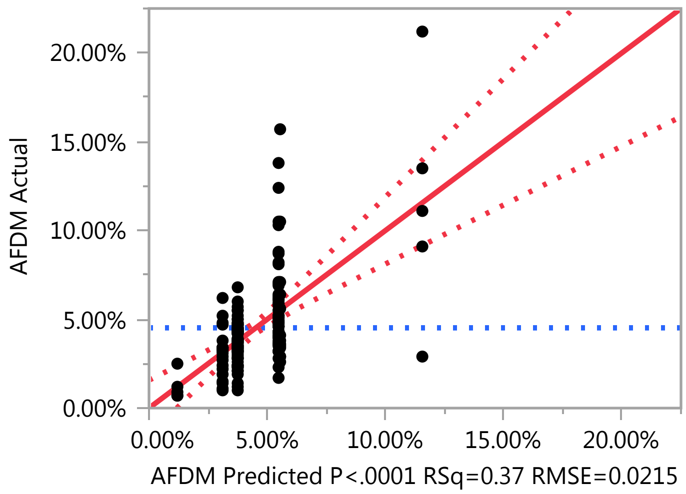
APPENDIX A

Response AFDM

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.370883
RSquare Adj	0.352159
Root Mean Square Error	0.021472
Mean of Response	0.04519
Observations (or Sum Wgts)	174

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	0.04566111	0.009132	19.8081
Error	168	0.07745363	0.000461	**Prob > F**
C. Total	173	0.12311474		<.0001 *

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0510867	0.002659	19.21	<.0001 *
PSA vs. BS[BS]	0.0242028	0.002659	9.10	<.0001 *
Site[DR]	-0.007791	0.00342	-2.28	0.0240 *
Site[SR]	0.0127133	0.004737	2.68	0.0080 *
PSA vs. BS[BS]*Site[DR]	-0.012037	0.00342	-3.52	0.0006 *
PSA vs. BS[BS]*Site[SR]	0.0275972	0.004737	5.83	<.0001 *

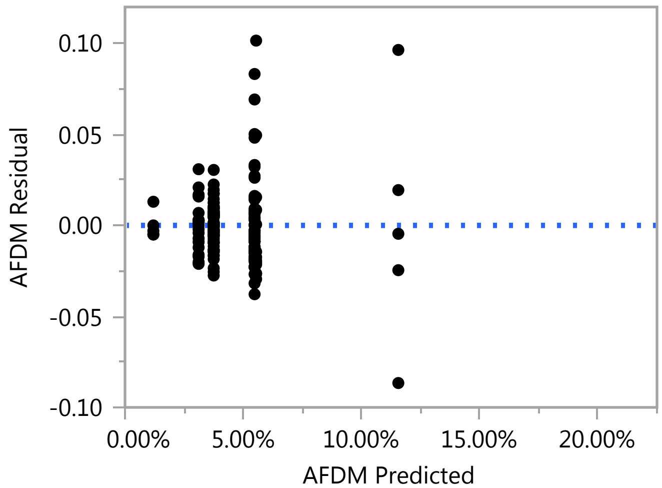
Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
PSA vs. BS	1	1	0.03820080	82.8590	<.0001 *
Site	2	2	0.00334481	3.6275	0.0287 *
PSA vs. BS*Site	2	2	0.01726398	18.7231	<.0001 *

Response AFDM

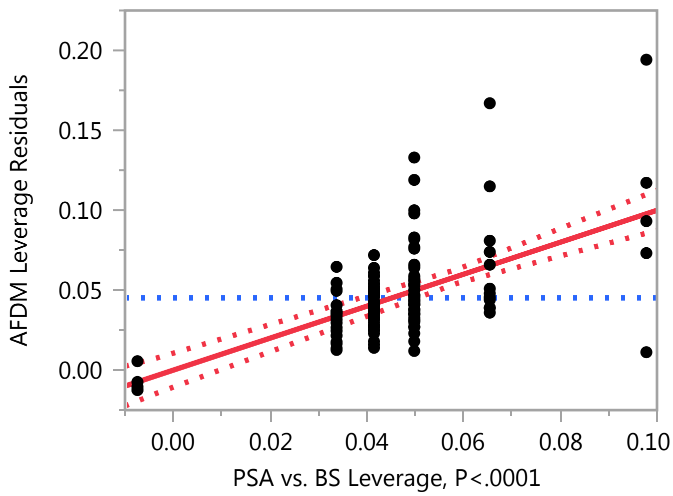
Whole Model

Residual by Predicted Plot



PSA vs. BS

Leverage Plot



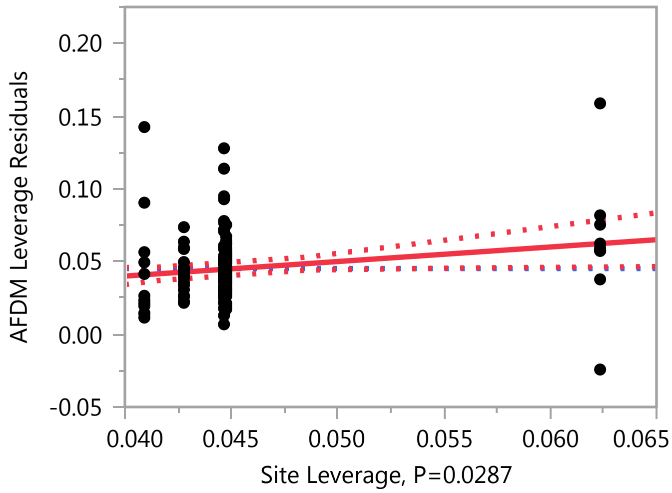
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
BS	0.07528952	0.00388386	0.058973
PSA	0.02688385	0.00363234	0.034747

Response AFDM

Site

Leverage Plot

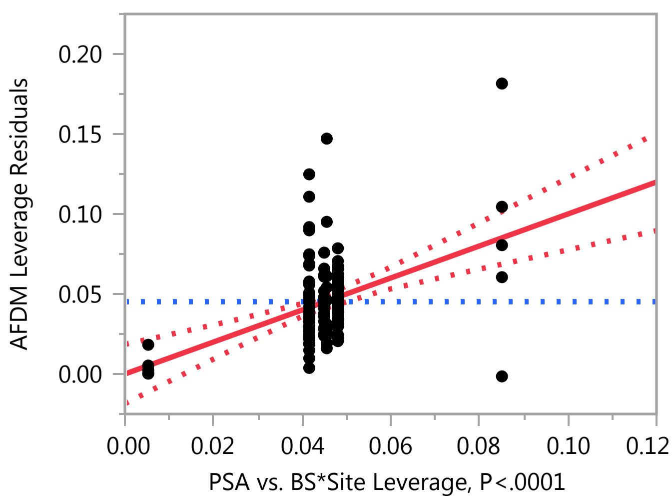


Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
DR	0.04329599	0.00372522	0.039917
SR	0.06380000	0.00678995	0.063800
WCC	0.04616407	0.00190930	0.045219

PSA vs. BS*Site

Leverage Plot



Response AFDM

PSA vs. BS*Site

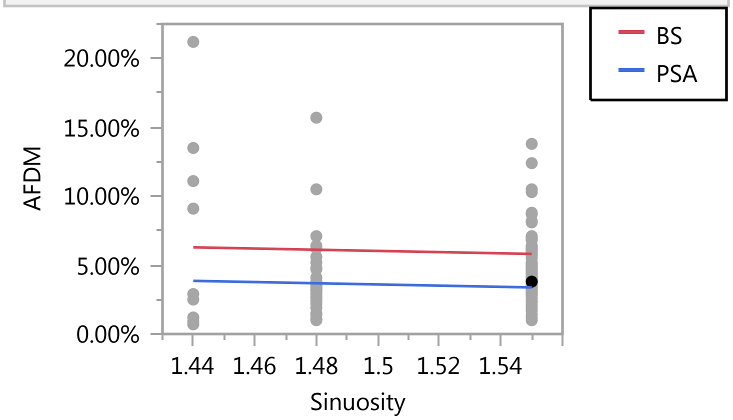
Least Squares Means Table

Level	Least Sq Mean	Std Error
BS,DR	0.05546154	0.00595518
BS,SR	0.11560000	0.00960243
BS,WCC	0.05480702	0.00284400
PSA,DR	0.03113043	0.00447716
PSA,SR	0.01200000	0.00960243
PSA,WCC	0.03752113	0.00254822

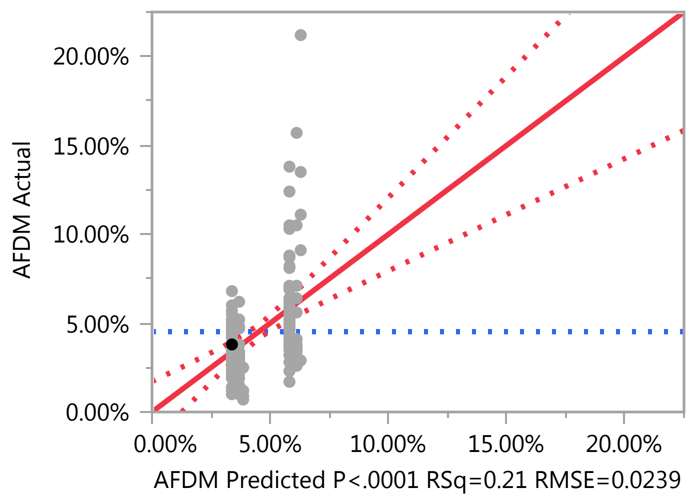
Response AFDM

Whole Model

Regression Plot



Actual by Predicted Plot



Summary of Fit

RSquare	0.206805
RSquare Adj	0.197528
Root Mean Square Error	0.023897
Mean of Response	0.04519
Observations (or Sum Wgts)	174

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	0.02546077	0.012730	22.2919
Error	171	0.09765397	0.000571	**Prob > F**
C. Total	173	0.12311474		<.0001 *

Response AFDM

Whole Model

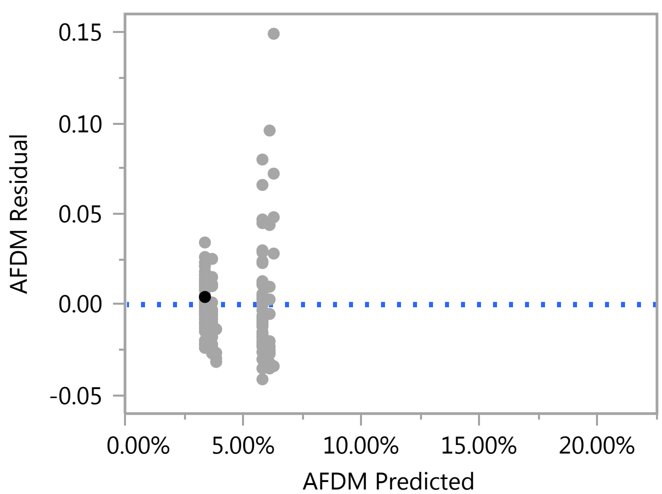
Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	3	0.02020034	0.006733	14.6051
Pure Error	168	0.07745363	0.000461	**Prob > F**
Total Error	171	0.09765397		<.0001 *
				Max RSq
				0.3709

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.1131383	0.077615	1.46	0.1468
PSA vs. BS[BS]	0.0121639	0.00183	6.65	<.0001 *
Sinuosity	-0.043337	0.050736	-0.85	0.3942

Residual by Predicted Plot



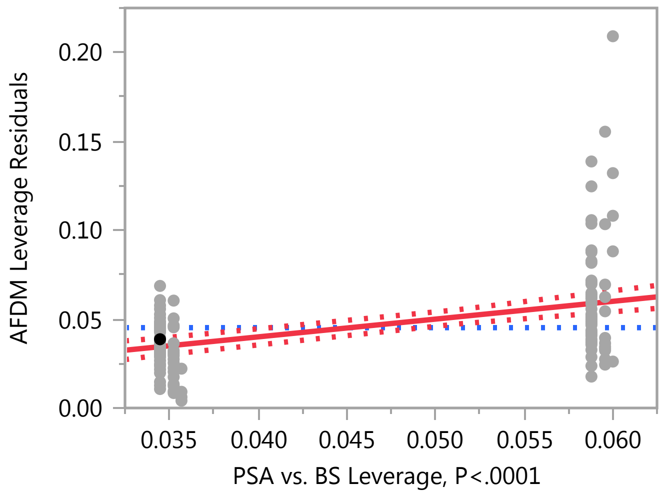
Response AFDM

Whole Model

Residual by Predicted Plot

PSA vs. BS

Leverage Plot

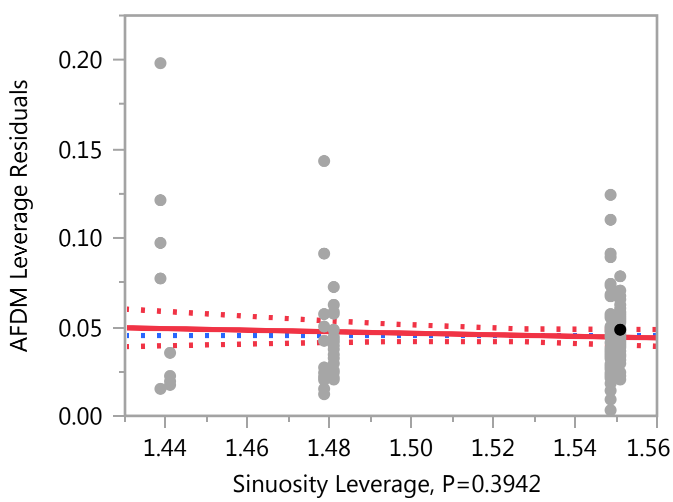


Least Squares Means Table

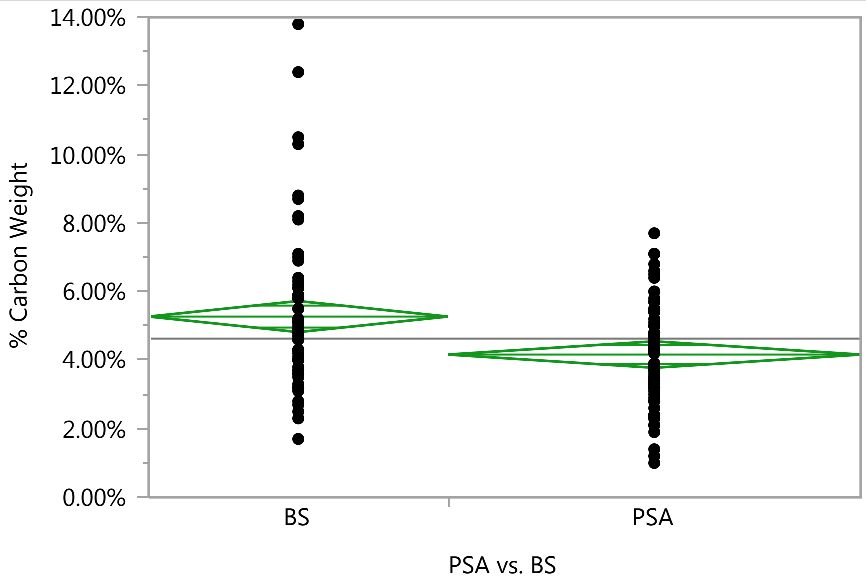
Level	Least Sq Mean	Std Error	Mean
BS	0.05903132	0.00276025	0.058973
PSA	0.03470355	0.00240231	0.034747

Sinuosity

Leverage Plot



Oneway Analysis of % Carbon Weight By PSA vs. BS



Missing Rows 2

Oneway Anova

Summary of Fit

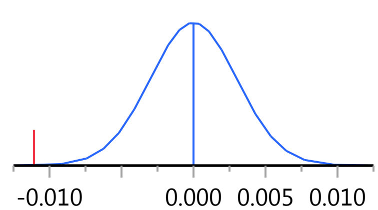
Rsquare	0.083811
Adj Rsquare	0.077621
Root Mean Square Error	0.018199
Mean of Response	0.046273
Observations (or Sum Wgts)	150

t Test

PSA-BS

Assuming equal variances

Difference	-0.01108	t Ratio	-3.6795
Std Err Dif	0.00301	DF	148
Upper CL Dif	-0.00513	Prob > |t|	0.0003 *
Lower CL Dif	-0.01703	Prob > t	0.9998
Confidence	0.95	Prob < t	0.0002 *



Analysis of Variance

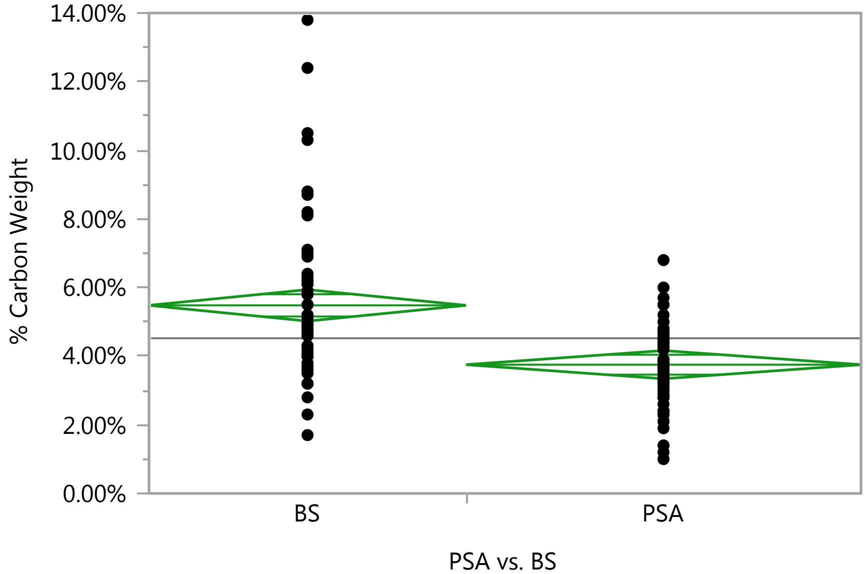
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
PSA vs. BS	1	0.00448404	0.004484	13.5387	0.0003 *
Error	148	0.04901775	0.000331		
C. Total	149	0.05350179			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
BS	63	0.052698	0.00229	0.04817	0.05723
PSA	87	0.041621	0.00195	0.03777	0.04548

Std Error uses a pooled estimate of error variance

Oneway Analysis of % Carbon Weight By PSA vs. BS



Missing Rows 22

Oneway Anova

Summary of Fit

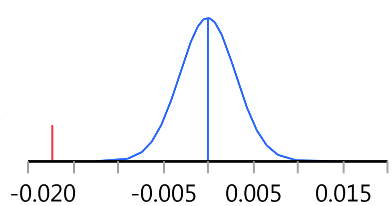
Rsquare	0.19668
Adj Rsquare	0.190304
Root Mean Square Error	0.0175
Mean of Response	0.045219
Observations (or Sum Wgts)	128

t Test

PSA-BS

Assuming equal variances

Difference	-0.01729	t Ratio	-5.55419
Std Err Dif	0.00311	DF	126
Upper CL Dif	-0.01113	Prob > |t|	<.0001 *
Lower CL Dif	-0.02344	Prob > t	1.0000
Confidence	0.95	Prob < t	<.0001 *



Analysis of Variance

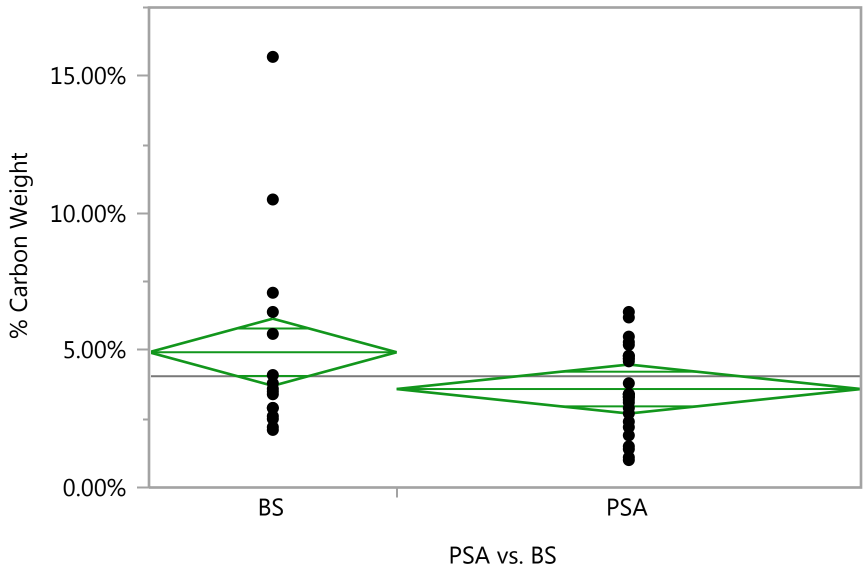
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
PSA vs. BS	1	0.00944728	0.009447	30.8490	<.0001 *
Error	126	0.03858660	0.000306		
C. Total	127	0.04803388			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
BS	57	0.054807	0.00232	0.05022	0.05939
PSA	71	0.037521	0.00208	0.03341	0.04163

Std Error uses a pooled estimate of error variance

Oneway Analysis of Column 4 By PSA vs. BS



Missing Rows 1

Oneway Anova

Summary of Fit

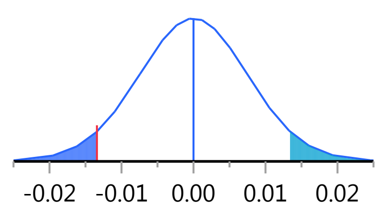
Rsquare	0.067429
Adj Rsquare	0.046234
Root Mean Square Error	0.024291
Mean of Response	0.040565
Observations (or Sum Wgts)	46

t Test

PSA-BS

Assuming equal variances

Difference	-0.01341	t Ratio	-1.78364
Std Err Dif	0.00752	DF	44
Upper CL Dif	0.00174	Prob > |t|	0.0814
Lower CL Dif	-0.02857	Prob > t	0.9593
Confidence	0.95	Prob < t	0.0407 *



Analysis of Variance

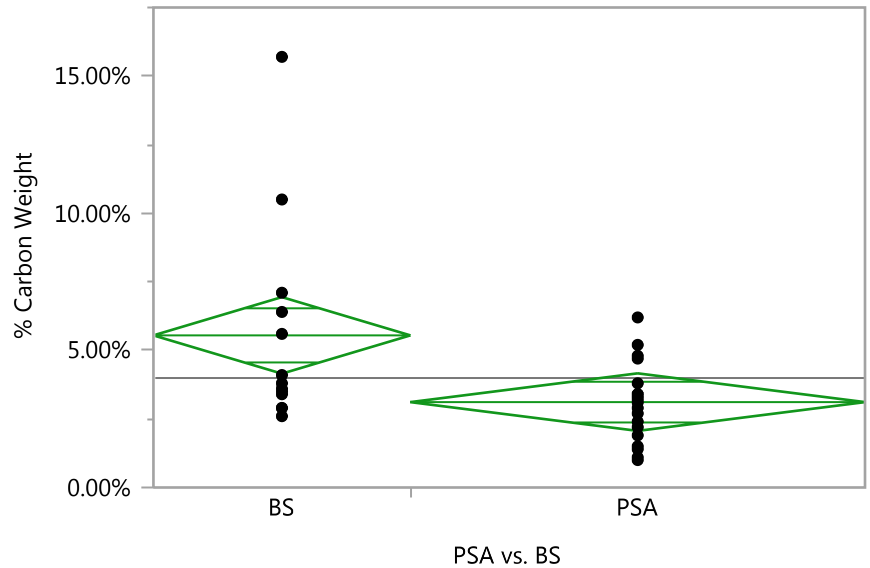
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
PSA vs. BS	1	0.00187717	0.001877	3.1814	0.0814
Error	44	0.02596214	0.000590		
C. Total	45	0.02783930			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
BS	16	0.049313	0.00607	0.03707	0.06155
PSA	30	0.035900	0.00443	0.02696	0.04484

Std Error uses a pooled estimate of error variance

Oneway Analysis of Column 4 By PSA vs. BS



Missing Rows 11

Oneway Anova

Summary of Fit

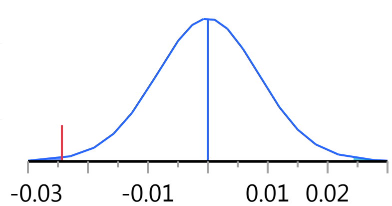
Rsquare	0.190868
Adj Rsquare	0.16707
Root Mean Square Error	0.02476
Mean of Response	0.039917
Observations (or Sum Wgts)	36

t Test

PSA-BS

Assuming equal variances

Difference	-0.02433	t Ratio	-2.83202
Std Err Dif	0.00859	DF	34
Upper CL Dif	-0.00687	Prob > |t|	0.0077 *
Lower CL Dif	-0.04179	Prob > t	0.9961
Confidence	0.95	Prob < t	0.0039 *



Analysis of Variance

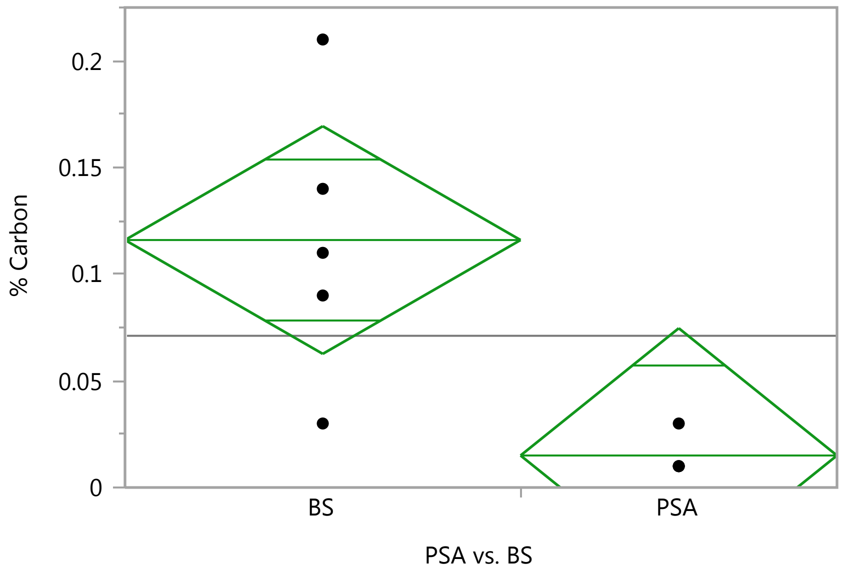
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
PSA vs. BS	1	0.00491691	0.004917	8.0204	0.0077 *
Error	34	0.02084384	0.000613		
C. Total	35	0.02576075			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
BS	13	0.055462	0.00687	0.04151	0.06942
PSA	23	0.031130	0.00516	0.02064	0.04162

Std Error uses a pooled estimate of error variance

Oneway Analysis of % Carbon By PSA vs. BS



Missing Rows 1

Oneway Anova

Summary of Fit

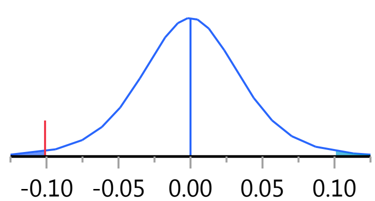
Rsquare	0.559879
Adj Rsquare	0.497005
Root Mean Square Error	0.050455
Mean of Response	0.071111
Observations (or Sum Wgts)	9

t Test

PSA-BS

Assuming equal variances

Difference	-0.10100	t Ratio	-2.98408
Std Err Dif	0.03385	DF	7
Upper CL Dif	-0.02097	Prob > |t|	0.0204 *
Lower CL Dif	-0.18103	Prob > t	0.9898
Confidence	0.95	Prob < t	0.0102 *



Analysis of Variance

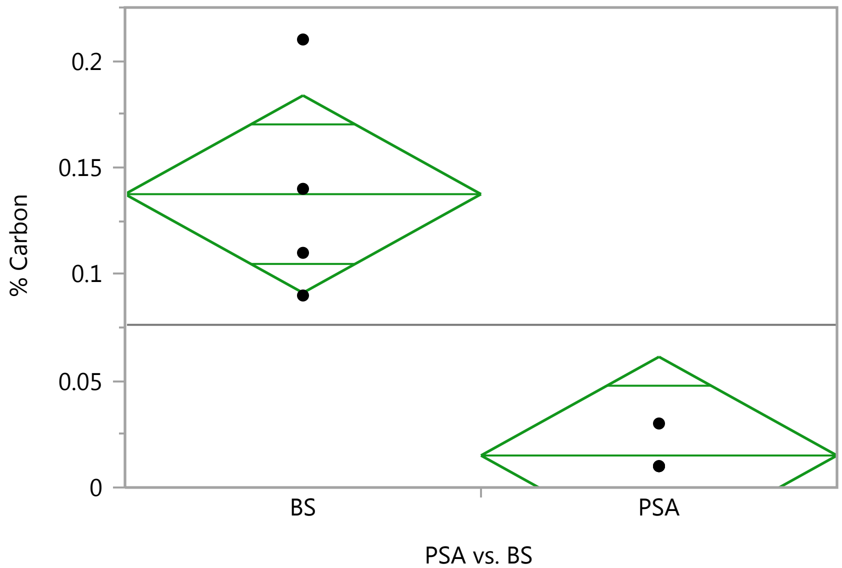
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
PSA vs. BS	1	0.02266889	0.022669	8.9047	0.0204 *
Error	7	0.01782000	0.002546		
C. Total	8	0.04048889			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
BS	5	0.116000	0.02256	0.0626	0.16936
PSA	4	0.015000	0.02523	-0.0447	0.07465

Std Error uses a pooled estimate of error variance

Oneway Analysis of % Carbon By PSA vs. BS



Missing Rows 2

Oneway Anova

Summary of Fit

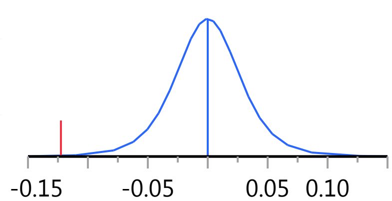
Rsquare	0.777778
Adj Rsquare	0.740741
Root Mean Square Error	0.037804
Mean of Response	0.07625
Observations (or Sum Wgts)	8

t Test

PSA-BS

Assuming equal variances

Difference	-0.12250	t Ratio	-4.58258
Std Err Dif	0.02673	DF	6
Upper CL Dif	-0.05709	Prob > |t|	0.0038 *
Lower CL Dif	-0.18791	Prob > t	0.9981
Confidence	0.95	Prob < t	0.0019 *



Analysis of Variance

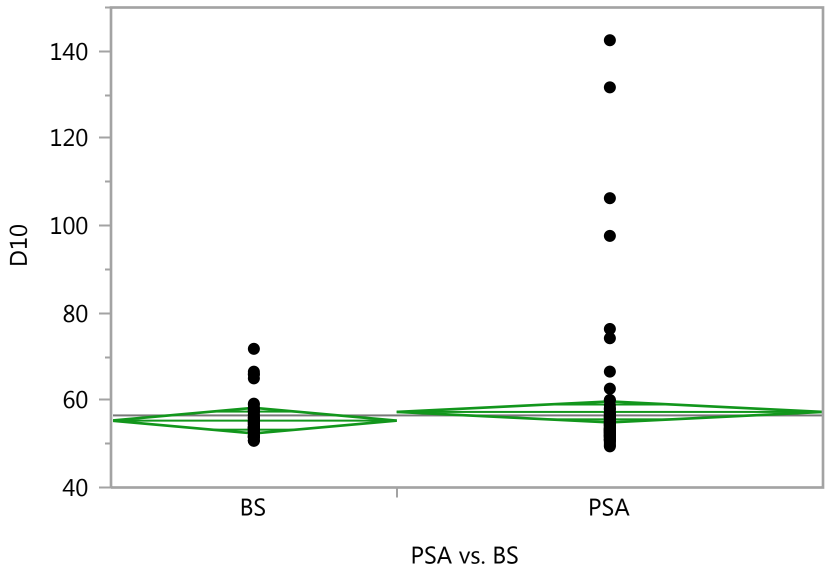
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
PSA vs. BS	1	0.03001250	0.030012	21.0000	0.0038 *
Error	6	0.00857500	0.001429		
C. Total	7	0.03858750			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
BS	4	0.137500	0.01890	0.0912	0.18375
PSA	4	0.015000	0.01890	-0.0313	0.06125

Std Error uses a pooled estimate of error variance

Oneway Analysis of D10 By PSA vs. BS



Oneway Anova

Summary of Fit

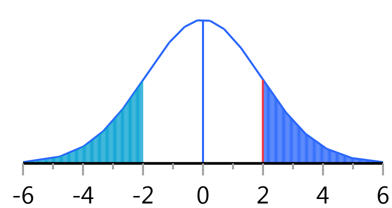
Rsquare	0.007159
Adj Rsquare	0.00054
Root Mean Square Error	11.59388
Mean of Response	56.51895
Observations (or Sum Wgts)	152

t Test

PSA-BS

Assuming equal variances

Difference	1.9952	t Ratio	1.039995
Std Err Dif	1.9185	DF	150
Upper CL Dif	5.7860	Prob > |t|	0.3000
Lower CL Dif	-1.7956	Prob > t	0.1500
Confidence	0.95	Prob < t	0.8500



Analysis of Variance

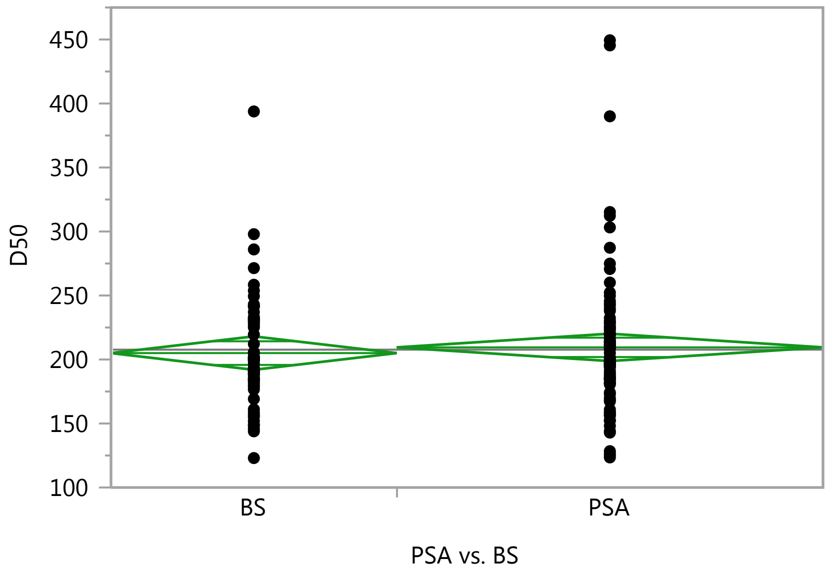
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
PSA vs. BS	1	145.385	145.385	1.0816	0.3000
Error	150	20162.703	134.418		
C. Total	151	20308.088			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
BS	61	55.3244	1.4844	52.391	58.258
PSA	91	57.3197	1.2154	54.918	59.721

Std Error uses a pooled estimate of error variance

Oneway Analysis of D50 By PSA vs. BS



Oneway Anova

Summary of Fit

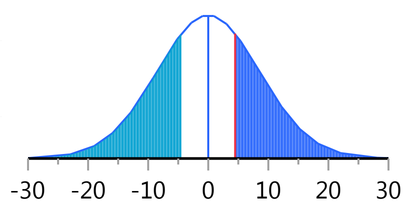
Rsquare	0.001824
Adj Rsquare	-0.00483
Root Mean Square Error	51.61683
Mean of Response	207.6789
Observations (or Sum Wgts)	152

t Test

PSA-BS

Assuming equal variances

Difference	4.472	t Ratio	0.523568
Std Err Dif	8.541	DF	150
Upper CL Dif	21.349	Prob > |t|	0.6014
Lower CL Dif	-12.405	Prob > t	0.3007
Confidence	0.95	Prob < t	0.6993



Analysis of Variance

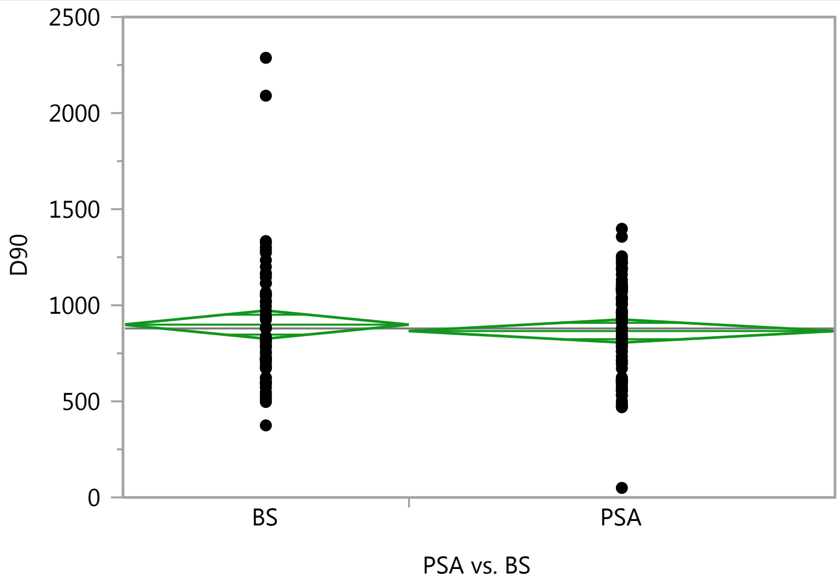
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
PSA vs. BS	1	730.35	730.35	0.2741	0.6014
Error	150	399644.65	2664.30		
C. Total	151	400374.99			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
BS	61	205.002	6.6089	191.94	218.06
PSA	91	209.474	5.4109	198.78	220.17

Std Error uses a pooled estimate of error variance

Oneway Analysis of D90 By PSA vs. BS



Oneway Anova

Summary of Fit

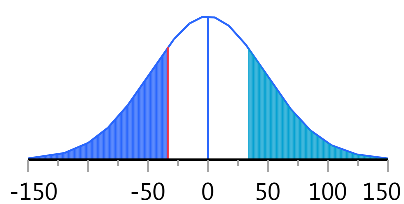
Rsquare	0.003217
Adj Rsquare	-0.00343
Root Mean Square Error	289.7146
Mean of Response	879.2326
Observations (or Sum Wgts)	152

t Test

PSA-BS

Assuming equal variances

Difference	-33.35	t Ratio	-0.69575
Std Err Dif	47.94	DF	150
Upper CL Dif	61.37	Prob > |t|	0.4877
Lower CL Dif	-128.08	Prob > t	0.7562
Confidence	0.95	Prob < t	0.2438



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
PSA vs. BS	1	40630	40630.1	0.4841	0.4877
Error	150	12590184	83934.6		
C. Total	151	12630814			

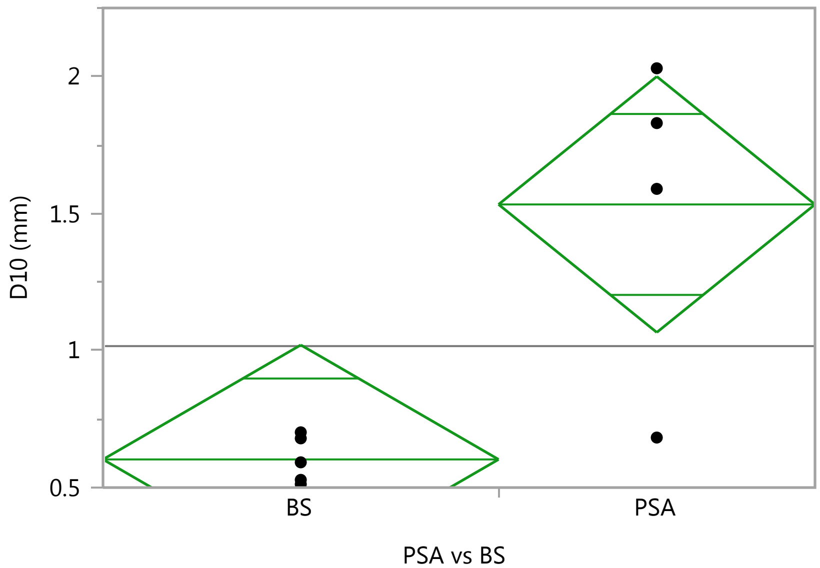
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
BS	61	899.202	37.094	825.91	972.50
PSA	91	865.847	30.370	805.84	925.86

Std Error uses a pooled estimate of error variance

Fit Group

Oneway Analysis of D10 (mm) By PSA vs BS



Missing Rows 1

Oneway Anova

Summary of Fit

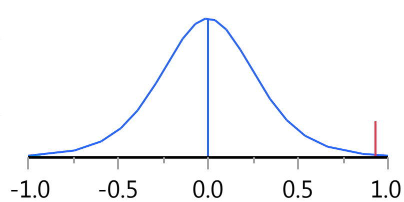
Rsquare	0.638029
Adj Rsquare	0.586319
Root Mean Square Error	0.394859
Mean of Response	1.016222
Observations (or Sum Wgts)	9

t Test

PSA-BS

Assuming equal variances

Difference	0.93043	t Ratio	3.512631
Std Err Dif	0.26488	DF	7
Upper CL Dif	1.55677	Prob > |t|	0.0098 *
Lower CL Dif	0.30408	Prob > t	0.0049 *
Confidence	0.95	Prob < t	0.9951



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
PSA vs BS	1	1.9237571	1.92376	12.3386	0.0098 *
Error	7	1.0913979	0.15591		
C. Total	8	3.0151550			

Fit Group

Oneway Analysis of D10 (mm) By PSA vs BS

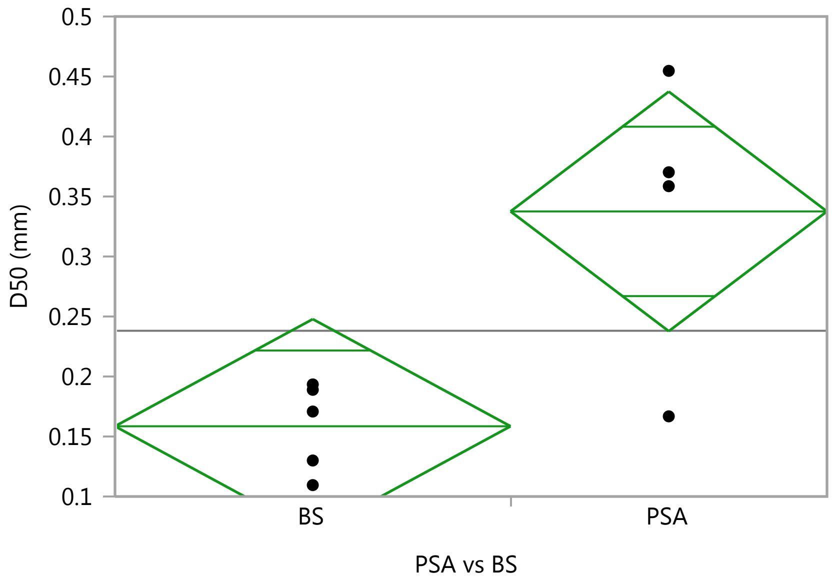
Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
BS	5	0.60270	0.17659	0.1851	1.0203
PSA	4	1.53313	0.19743	1.0663	2.0000

Std Error uses a pooled estimate of error variance

Oneway Analysis of D50 (mm) By PSA vs BS



Missing Rows 1

Oneway Anova

Summary of Fit

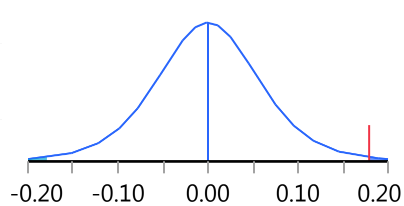
Rsquare	0.588122
Adj Rsquare	0.529282
Root Mean Square Error	0.084427
Mean of Response	0.2381
Observations (or Sum Wgts)	9

t Test

PSA-BS

Assuming equal variances

Difference	0.179055	t Ratio	3.161538
Std Err Dif	0.056635	DF	7
Upper CL Dif	0.312976	Prob > |t|	0.0159 *
Lower CL Dif	0.045134	Prob > t	0.0079 *
Confidence	0.95	Prob < t	0.9921



Fit Group

Oneway Analysis of D50 (mm) By PSA vs BS

Oneway Anova

Analysis of Variance

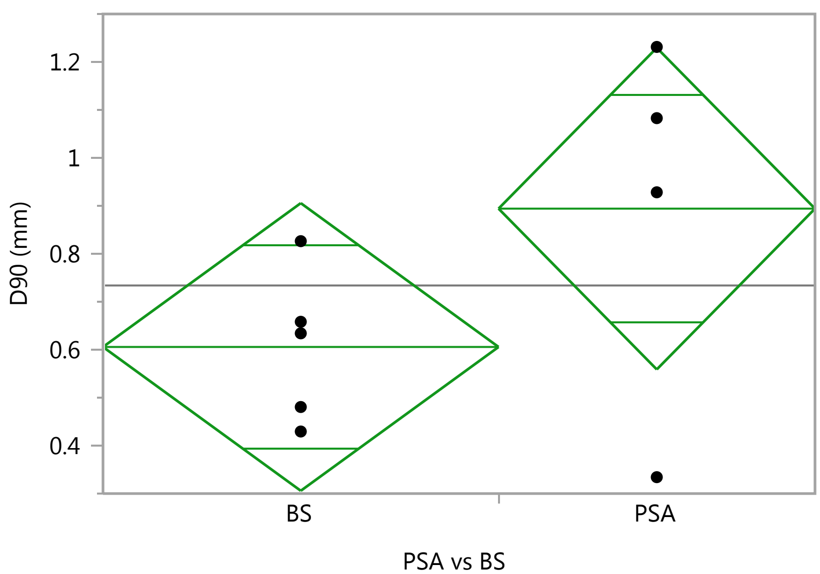
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
PSA vs BS	1	0.07124598	0.071246	9.9953	0.0159 *
Error	7	0.04989552	0.007128		
C. Total	8	0.12114150			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
BS	5	0.158520	0.03776	0.06924	0.24780
PSA	4	0.337575	0.04221	0.23776	0.43739

Std Error uses a pooled estimate of error variance

Oneway Analysis of D90 (mm) By PSA vs BS



Missing Rows 1

Oneway Anova

Summary of Fit

Rsquare	0.247208
Adj Rsquare	0.139666
Root Mean Square Error	0.283586
Mean of Response	0.733889
Observations (or Sum Wgts)	9

t Test

PSA-BS

Fit Group

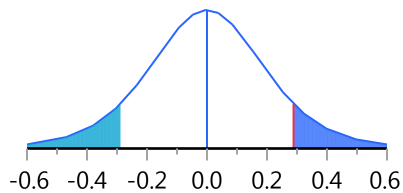
Oneway Analysis of D90 (mm) By PSA vs BS

Oneway Anova

t Test

Assuming equal variances

Difference	0.28843	t Ratio	1.51615
Std Err Dif	0.19024	DF	7
Upper CL Dif	0.73826	Prob > |t|	0.1733
Lower CL Dif	-0.16141	Prob > t	0.0866
Confidence	0.95	Prob < t	0.9134



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
PSA vs BS	1	0.18486440	0.184864	2.2987	0.1733
Error	7	0.56294625	0.080421		
C. Total	8	0.74781065			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
BS	5	0.605700	0.12682	0.30581	0.9056
PSA	4	0.894125	0.14179	0.55884	1.2294

Std Error uses a pooled estimate of error variance

APPENDIX B

Salmon River Field Data

GPS Point	Notes
AM6	BS protrudes out 219cm but is 41cm in thickness. BS very organic and dark w/ root+woody debris. PSA very sandy and eroded. Pebbles eroded down into PSA. Bank heavily vegetated. Dead grass overhanging.
AM5	Meander near split of Jeremy and Salmon. PSA=light sand deposit. Heavily vegetated bank and eroded dead grass overhanging. BS=slumping small vegetation covering. Very dark and organic. Woody debris and roots.
AM3	No veg on top. Exposed bank across from point bar. Lots of small roots exposed. Dark BS layer above and below PSA. PSA=sandy. BS2=dark soil w/ woody debris and little roots. BS1=dark soil w/ rotted roots and leaf litter. SS=pebble bed. Still pool @ bend in river upstream of small rock dam for pooling
AM2	Took a small core. Very sandy. Hit rock before able to go deeper. Looking downstream dam wall
AM1	Looking downstream dam wall
AM4	Lots of small roots extending from top of bank. Small veg along top. BS mixed with SS- sandy and dark. SS=same as bed. Silt and pebble dominated. BS mixed with SS.

GPS Point	Latitude (N)	Longitude (W)	Sample Date	Right/Left	PSA (cm)	BS (cm)	Other Layers
AM6	41.58012	72.42332	10/16/15	R	122	41	
AM5	41.58028	72.42332	10/16/15	R	116	48	
AM3	41.57853	72.42338	10/16/15	L	51	33/44.5	BS1=33. BS2=44.5
AM2	41.55529	72.44126	10/16/15	L	224		
AM1	41.55535	72.44147	10/16/15	R			
AM4	41.57856	72.42302	10/16/15	L	143	20	

White Clay Creek Field Data

GPS Point	Notes
AM13	Bank undercut. Tall grass overhanging. Gravel dominated bed. Exposed roots. No visible woody debris in BS.
AM14	BS layer extends below water. Protrudes 74cm. Wood debris in BS. Sample taken directly in front of mill. Slightly undercut. Grass overhanging.
AM15	Large sediment protrusion. Appears to be PSA that was eroded down of the bank but also potentially deposited. PSA protrusion measures 184cm from bank. Exposed roots. BS below water.
AM16	61cm slanted BS protrusion from bank. Large tree slightly upstream with roots extending above PSA. Bank undercut. Vegetation growing out of eroded PSA
AM17	45cm of BS slanting. 103cm PSA slanting. PSA eroding slope onto BS. BS protruding out and below water. Bank heavily vegetated.
AM18	PSA slanting 140cm. PSA layer has vegetated cover. PSA protrusion. BS below water level. BS layer variable along bank. Bed sand dominated with small pebbles <5cm
AM19	Bank eroded and undercut. BS layer protrudes out. Extends below water level. Aquatic vegetation along stream bed. Bed sand dominated with small pieces of gravel
AM20	Roots extending out of PSA. Grass dominated. Bed sand dominated with pebbles and cobbles
AM21	Mostly grass covered, no trees near bank, very defined BS layer. Rocks around 30cm radius.
AM22	Bank filled with grass and trees.
AM23	Bank filled with grass. Bed sand dominated with small pebbles
AM24	Bank slightly slumped. Grass growing along top of bank. Bed pebble and gravel dominated. Aquatic vegetation present but sparse
AM25	Large white clay deposit spanning left bank. Layer shows reddish coloring signs of oxidization as well as a few woody debris pieces (<2cm) suggesting a possible BS layer. No dark organic sediment was found. Clay layer is either SS with no BS layer present or BS unlike we have seen and no SS layer. Bed is pebble dominated (>10cm,<30cm) closest to bank and sand dominated along the channel and RB
AM26	Split in stream. Grass cover. Not as undercut as previous banks.
AM27	Bed is pebble dominated (>7cm, <35cm). Bank was covered by dead grass, which was cleared away prior to sampling. Site above small stream split/island.
AM28	Stream section right next to agricultural cornfield. Likely to have influenced/eroded bank. Presence of BS but buried under PSA and not distinct. Roots extend to bed. Organic content in PSA
AM29	Bank adjacent to farm field. PSA eroded over BS. Bank covered in dead grass cleared away before sampling. PSA and BS mixed together. BS was found deep into bank. Measurement taken was of entire bank height. Bed mostly sand and pebbles
AM30	43cm slanting BS. Bed silty with sand. Vegetation covering bank down to water.
AM31	Cobbled bed (>5cm, <15cm). Some small gravel close to bank. Highly vegetated

	bank. Dead grass overhanging.
AM32	Stream is meandering heavily in this reach. Bank has a very low slope that appears to serve as a path or animal access to water. BS/SS not distinguishable. Sand dominated bed
AM33	Large deposit of clay from PSA to below water level. Bed is heavily vegetated. Small roots exposed. Rapid meandering
AM34	Small pool beside glide. Bend is mostly sand, closer to bank. Grass dominated bank.
AM35	Mostly grass vegetation. Pool formation away from flow. Sand dominated near the bank.
AM36	Bank has eroded down to the bed with only PSA deposit. Deeper and forms pool. Grass dominated bank
AM37	SS measurement not clear, same as bed but mixed with BS. Grass dominated bank. Dead grass overhanging. Bed is sand and pebbles.
AM38	Bed pebble dominated. Bank highly vegetated. Roots extending down to water level. Covered with dead grass.
AM39	PSA extends to bed. PSA covering BS layer, making it not measurable. Measure taken along curve. Bank covered in grass. 4 logs sticking out of bank 32cm above bed height- suggests BS still present underneath PSA.
AM40	BS extends to bed. Grass dominated bank. Sample along bank curve. Scoured out pool 80cm below sample site. Bed is gravel and sand
AM41	BS extends to bed. Sample taken at small split in the stream with grass island in the middle. Grass dominated along top of bank but does not extend down bank extensively
AM42	Highly deposited sediment from eroded bank. Bank undercut near bank full height. Grass dominated section protected by grass bank protrusion. Cut from the glide (high flow)- forms shallow pool.
AM43	PSA extends down to bed. Part of glide. Channel very narrow and straight. Constricted flow at high velocity. Bank height is small. Heavily vegetated with grass, shrubs, and lily. Bed is pebble dominated (>5m, <20cm). PSA eroded into water/bed near bank.
AM44	SS and BS mixed below water. Wider section of stream between two glides that are constricted. Low bank. Grass dominated. Small pebble bed on RB, sand bed on LB.
AM45	White/orange clay layer resembling AM25 sample site. Bank is undercut in PSA layer but BS/SS protrudes out. Bank is grass dominated. Site upstream of riffle. Clay layer is either BS or SS. Roots extending out of PSA. Bed is large pebble dominated (>8cm, <30cm)
AM46	Bed silty sand with small gravel particles. BS mixed with PSA below water level. Extends to bed. Grass dominated bank.
AM47	Large clay protrusion overlying bed. Bed silty sand dominated. Mowed grass along top of bank. Bank is undercut in PSA layer with grass overhanging. 88cm clay (BS) protrusion. Bed heavily vegetated with aquatic plants.
AM48	BS and SS probably mixed but not measureable distinction. Deep pool with aquatic vegetation on bed. Bank is undercut in PSA layer. Bed is mostly silt. Site near benchmark
AM49	In between AM48 and AM49, there is a long stretch of straight channel covered with grass and no exposed bank. AM49- PSA is covering part of the BS, but BS is

	still measurable. Site in a glide. Bed is silty with cobbles. 3m upstream from site, large wood debris sticks out 34cm above bed on the right bank. Corresponds with BS measurement taken at AM48 and AM49.
AM50	Site downstream of riffle. Bed is gravel and cobble dominated (<20cm). Dead grass overhanging bank. BS extends down to bed. High velocity of water.
AM51	Cobble bed with small pebbles. Very small bank with small plant and grass growth. LB heavily vegetated. RB next to mowed meadow.
AM52	Grass dominated bank down to water. Bank undercut at PSA with dead grass overhanging. Large cobbles for bed (<25cm, >8cm). SS mixed with BS. BS entirely submerged below water.
AM53	Site shallow pool to glide going through heavily vegetated tall grasses upstream. BS extends to bed. Forms step out of hard clay. Bed is gravel with medium sized pebbles. Top of bank is mowed grass.
AM54	Clay heavy bank. Forms step-like feature. Bed pebble dominated (>8cm,<20cm). High flow but bank protected by grass buffer. Channel incised. Site downstream of riffle
AM55	Large rocks (>15cm, <35cm) in bank and in channel bed. Forming riffle downstream. Bank has low grass along top and dead grass draping over. Difficult to dig due to rocks. BS extends down to bed.
AM56	Subsoil and BS mixed below water level. Clearly defined BS and PSA. Mowed grass along top of bank. Bed gravel dominated with some sand and pebbles (<8cm). Bank eroded.
AM57	Large 25 cm diam wood coming out of bank. Roots exposed.
AM58	Large log extending out of BS (30 cm diam). SS might be eroded PSA or slumping BS. Sandy bed; grass above bank
AM59	Large clay deposit in bank (33.5cm). Top of bank vegetated. Undercut PSA bank.
AM60	BS extended down to bed. BS below water covered in deposited SS. Pebble dominated bed.
AM61	Bank heavily vegetated and eroded. Sand bar (121cm). Left bank has multiple logs sticking out of BS.
AM62	Below water level BS is mixed with PSA and immeasurable. Few large rocks (>30cm). Sandy bed with pebbles
AM63	Lots of dead grass hanging over bank. BS has small ~12cm diam logs coming out of bank. Narrow channel. Pebbly bed.
AM64	Channel is constricted and part of a glide. Bank vegetated; grass mowed up to bank. Pebbly bed.
AM65	Short bank very vegetated. Silty sandy bed.
AM66	PSA down to large white clay deposit (37.5cm to bed). Dead grass overhanging bank. PSA undercut. Rocky bed. Below riffle.
AM67	Short bank. Top mowed to streamside. PSA layer eroded and deposited on top of BS. Silty and pebbly bed.
AM68	PSA very undercut and has deposited sediment onto BS. Narrow channel w/ quick flow.
AM69	Short vegetated bank. PSA extends to bed with large rock inclusions in bank. Sandy bed w/ large rocks.

AM70	Short vertical bank; grass mowed to streamside. Large rock streambed. Exposed roots.
AM71	Very vegetated bank. First point taken in forested area. Rock embedded bank.
AM72	BS extends down to bed. Small roots exposed and overhanging from top of bank. Low, dense shrub vegetation (leafy). Bed silty sand. Large roots extending out of PSA.
AM73	BS has lots of medium sized rocks embedded in bank. BS extends to bed. Heavily eroded. Pebbly bed.
AM74	Grassy bank w/ two trees (~40cm diam). Exposed roots on bank; PSA undercut. SS is claylike layer extending to bed. Silty pebbly bed.
AM75	Eroded PSA deposited on top of BS causing it to mix (also mixed with bed sediment). Short bank. Exposed roots. Leaf deposits on bank.
AM76	Short vertical bank. Exposed roots. Undercut BS. Sand bar in middle of stream.
AM77	Clear difference between BS and underlying layer. BS shows no organic material- very sandy. Medium rocky bed.
AM78	Short bank. Large tree overhanging stream. Roots exposed at bank. Slumped moss. Undercut PSA (eroded down over BS). Silty bed w/ medium rocks.
AM79	Below riffle. Large clay layer between PSA and BS. Undercut PSA; exposed roots. BS submerged and extends to bed. Silty sand bed w/ medium rocks.
AM80	Low bank with moss and small veg overhanging. Straight channel below riffle. Bed cobbled. BS buried under PSA for all of bank. Small wood debris extends out of bank below water level about 15cm above bed.
AM81	Giant tree has carved out pool-like formation in bed and curve in bank. Large tree roots exposed. Low bank with dense shrub vegetation.
AM82	BS layer covered by PSA eroded sediment. Extends below water level. BS and SS mix below water. Short bank short grasses and small vegetation. Bed is sandy silt with gravel and small pebbles (<10cm)
AM83	PSA layer eroded down on BS layer. Undercut near the top of overhanging. Short and dense. Vegetation small trees one meter from the bank. Bed dominated by small pebbles and silty near the bank.
AM84	Below small rock dam. Channel widens before channelized glide downstream. Medium roots overhanging. Small shrubs on top of bank. BS extends to bed. Large pebble bed with sand underlying.
AM85	The bed is silt with medium sized pebbles. Bank is short in height and densely vegetated with grass and small plants. Clay deposit mixed with BS. Small gravel intrusion in bank.
AM86	PSA is eroded down to BS. Medium sized root expose from PSA. Small trees about a meter height. Bed is sandy-silt dominated with medium sized pebbles. Clay/SS extends to bed.
AM87	BS buried very deep below PSA and was not measurable. Sample taken along curve/slip in the bank. Bed is silty-sand. Low bank with short grass. PSA is heavily eroded over the BS.
AM88	BS extends down to bed. PSA eroded down over PSA and deposited. Clear definition of layers. Short bank but tall and dense grass overtop. Small roots and dead grass overhanging. Medium roots through middle of PSA layer. Medium trees 2-3 meters from bank. Sandy gravel bed with some medium cobbles.

AM89	BS extends to bed but covered with PSA. PSA layer undercut possibly due to erosion and exposed roots. PSA is only present in the roots. Bed is sandy silt with medium and small cobbles. BS layer protrudes below water level and forms steps.
AM90	Downstream of 1st bridge. Bank eroded but not undercut. Small vegetation extending down bank. One small tree 1 meter from bank. Bed is sand dominated with a few small pebbles. BS mixed with SS
AM91	Small gravel and pebble bed. Very clear. No loose sediment. Medium roots extend along top of bank. Large tree upstream 1.5m from bank edge. Exposed roots. Low vegetation.
AM92	Bank is all PSA. Bed is gravel and small pebbles. Bank is short and vertical. Small grass along top. PSA layer eroded a little but not undercut. No exposed roots. Trees >3m away.
AM93	BS extends down to bed. Mixed with SS as bed. BS 3cm behind PSA. Bank is vertical and slightly eroded. Small roots exposed. Top of bank is short grass. Bed sandy silt.
AM94	BS extends to bed. Bank eroded down and deposited on top of BS. Moss covering bank with medium shrubs 12cm from edge. Bed is sandy silt with small pebbles.
AM95	BS extends to bed. Tree with 1.5m exposed roots. Top of bank is small vegetation and grass. Bed is sand, gravel and small pebble dominated. Small woody debris (20cm) extends our from BS
AM96	SS may be mixed with BS. PSA eroded down over BS, but it is measurable. BS is sandy at base. Bank cover is short grass. Bank has root exposure. Bed is sand, gravel, and pebbles.
AM97	BS is lighter in color and more clay-like but there is a distinct different between the SS and BS. Medium root extending at bank. Heavily vegetated with grass and medium sized trees. Bed is sand, pebbles, and cobbles.
AM98	Bank is highly vegetated with exposed roots. All sediment layers have organic material. Bed is cobble, pebble, and gravel. Shrubs down to water level and medium sized trees located 1.5m from bank.
AM99	PSA and clay combined layer between PSA and BS layers (20cm). SS is mixed with BS, down to the bed. Short bank with small exposed roots. Bank with small and medium bushes. Bed is sandy-silt
AM100	PSA and clay combined layer between PSA and BS layers (27.5cm). BS extends to bed. BS below water has a lot of woody debris in it. PSA eroded and deposited on clay. Thick dense shrub. Big cobbles on bed.
AM101	Highly vegetated bank with a big tree and roots exposed on bank. PSA extends up to roots only. Bed is cobbles and large pebbles. Bank is undercut and held by the roots.

Sample Date	GPS Point	Right/ Left	Latitude (N)	Longitude (W)	PSA (cm)	BS (cm)	SS (cm)	Corrected
23-Jun-15	AM13	R	39.85918	75.78304	91.6		8.6	BS (8.6)=SS, SS original (12.9)=bed
23-Jun-15	AM14	R	39.85313	75.78615	44	54	16	
23-Jun-15	AM15	L	39.8531	75.78591	103	22		

23-Jun-15	AM16	R	39.85318	75.78587	58	33	7	
23-Jun-15	AM17	L	39.85326	75.78576	91		23	BS(23)=SS
23-Jun-15	AM18	R	39.85347	75.78582	112	32.4		
23-Jun-15	AM19	L	39.85357	75.78556	64	41		
23-Jun-15	AM20	R	39.85378	75.78561	70.5	26.5		
23-Jun-15	AM21	L	39.85382	75.78541	71	34.5		
23-Jun-15	AM22	L	39.85394	75.78527	69.2	19.1	8	
23-Jun-15	AM23	R	39.85402	75.78519	70.5	22		
23-Jun-15	AM24	R	39.85407	75.78522	69.7	62		
23-Jun-15	AM25	L	39.8542	75.78491	27		64.3	Definite white clay but has organic. BS switched to SS after EA test
23-Jun-15	AM26	R	39.85434	75.78487	70.3	18.4		After drying- layer has clay
23-Jun-15	AM27	R	39.85445	75.78481	50	17.2		After drying- layer has clay
23-Jun-15	AM28	L	39.85466	75.78479	52.5			
23-Jun-15	AM29	L	39.8547	75.78469	66.5			
23-Jun-15	AM30	L	39.85465	75.78448	67	39		
24-Jun-15	AM31	R	39.85487	75.78432	67.3	31.4		
24-Jun-15	AM32	R	39.85498	75.78419	36			
24-Jun-15	AM33	L	39.85502	75.78415	31		106	Old BS=clay…moved to SS
24-Jun-15	AM34	R	39.85501	75.78429	84.5	21.4	24	
24-Jun-15	AM35	R	39.85504	75.78442	82.5	30.5		
24-Jun-15	AM36	R	39.85505	75.78452	161			
24-Jun-15	AM37	R	39.85514	75.78457	91	27		
24-Jun-15	AM38	R	39.85524	75.78472	63	78		
24-Jun-15	AM39	L	39.85531	75.78467	107			
24-Jun-15	AM40	R	39.85538	75.78447	81	28		
24-Jun-15	AM41	R	39.85542	75.78445	61	57		
24-Jun-15	AM42	L	39.85537	75.78431	134			
24-Jun-15	AM43	R	39.85529	75.78407	71			
24-Jun-15	AM44	R	39.85522	75.78392	58	42		SS and BS mixed in sample
24-Jun-15	AM45	L	39.85532	75.78374	42		81	BS(81)=SS
24-Jun-15	AM46	R	39.85544	75.78385	87			
24-Jun-15	AM47	R	39.85546	75.78402	93	24		
24-Jun-15	AM48	R	39.85551	75.78413	87	39		
24-Jun-15	AM49	R	39.85582	75.78377	67	39		
24-Jun-15	AM50	R	39.85598	75.78365	87	33		

24-Jun-15	AM51	R	39.85611	75.78349	40	17		
24-Jun-15	AM52	L	39.8562	75.78339	112.4	17.5		
24-Jun-15	AM53	R	39.85625	75.78341	51.5		74	BS(74)=SS
24-Jun-15	AM54	R	39.85638	75.78349	49		108	BS(108)=SS
24-Jun-15	AM55	R	39.85648	75.78343	77	30		
24-Jun-15	AM56	R	39.85649	75.78336	68	54		
25-Jun-15	AM57	R	39.85659	75.78316	77.5	47.4		
25-Jun-15	AM58	L	39.85638	75.78312	96.5	58.5		BS measure=SS (24.5)+BS (34)
25-Jun-15	AM59	L	39.85638	75.78297	69		104.5	BS(71)=SS…SS+clay deposit(33.5)=104.5
25-Jun-15	AM60	L	39.85643	75.78293	74	37		
25-Jun-15	AM61	R	39.85658	75.78293	99.5			
25-Jun-15	AM62	L	39.85678	75.78294	114			
25-Jun-15	AM63	L	39.85704	75.78291	70	38.5		
25-Jun-15	AM64	R	39.85719	75.78294	110			
25-Jun-15	AM65	R	39.85745	75.78294	56.5	25		
25-Jun-15	AM66	L	39.85756	75.78285	74.5		37.5	Clay deposit=SS
25-Jun-15	AM67	R	39.85764	75.78298	53	31		
25-Jun-15	AM68	L	39.85785	75.78304	65		43	BS(43)=SS
25-Jun-15	AM69	R	39.85802	75.78299	87			
25-Jun-15	AM70	L	39.85834	75.78295	65	19.5		
25-Jun-15	AM71	L	39.85897	75.78337	86	50.5		
25-Jun-15	AM72	R	39.85892	75.78346	74	37		
25-Jun-15	AM73	R	39.85904	75.7836	98	18		
25-Jun-15	AM74	L	39.85931	75.78371	83	31	24.5	
25-Jun-15	AM75	R	39.85935	75.78395	46	20.5		
25-Jun-15	AM76	L	39.85944	75.78413	39.4	45.5		
25-Jun-15	AM77	R	39.85944	75.78432	37.5	17		PSA heavily mixed with BS
25-Jun-15	AM78	L	39.85974	75.78446	62	14		
25-Jun-15	AM79	L	39.85986	75.78446	53	30.5		
26-Jun-15	AM80	L	39.85996	75.78428	46.5	26	13.5	
26-Jun-15	AM81	R	39.86034	75.78455	53	13	17	
26-Jun-15	AM82	L	39.86023	75.78429	65	32	2	
26-Jun-15	AM83	R	39.8605	75.78426	46	43		
26-Jun-15	AM84	R	39.86073	75.78403	53	26		
26-Jun-15	AM85	L	39.86086	75.78382	46		26.5	old BS=SS
26-Jun-15	AM86	R	39.86089	75.78428	63.4	21	56.5	

26-Jun-15	AM87	L	39.86106	75.78407	61.5		19	
26-Jun-15	AM88	R	39.86111	75.78419	65	35.5		
26-Jun-15	AM89	R	39.86142	75.78409	24	51		
26-Jun-15	AM90	L	39.86134	75.78378	84	78	7.3	
26-Jun-15	AM91	R	39.86154	75.78372	74	45		
26-Jun-15	AM92	R	39.86151	75.78327	130			
26-Jun-15	AM93	R	39.86158	75.78322	67	36	15	
26-Jun-15	AM94	R	39.862	75.78326	86	49		
26-Jun-15	AM95	R	39.86221	75.78341	62.5	49		
26-Jun-15	AM96	L	39.86236	75.78339	59.5	52		
26-Jun-15	AM97	L	39.86259	75.78345	49	40.5	35	
26-Jun-15	AM98	L	39.86293	75.78409	63.5	29		
26-Jun-15	AM99	L	39.86307	75.78415	56.5	27		
26-Jun-15	AM100	L	39.86349	75.78423	51	31.5		
26-Jun-15	AM101	L	39.86359	75.78452	41	75.5		
16-Jul-15	AM102	L	39.89389	75.8757	83.5	43		

Doe Run Field Data

GPS Point	Notes
AM102	PSA mixed with BS. BS extends to bed and has dark clay content. Top of bank is mowed grass. Undercut bank along a meander, under a riffle
AM103	BS is buried under PSA and below water level. PSA layer has slumped down. Grass is mowed over bank. Veg is encroaching on the bank. Rock toppled over the bank. BS sample taken but not measurable
AM104	Grass mowed bank. PSA extends to bed and mixed with grey clay. Sampled at a riffle
AM105	There is no BS. Bank is covered with grass and overhanging veg. PSA is clayey. PSA is cemented below water with small rock inclusions. Located at a glide. PSA was a mix of clay and PSA layer throughout until below water surface
AM106	SS is a light clay layer, which extends to bed. Grass is mowed to bank. Site below a riffle.
AM107	SS is a light clay layer, which extends to bed. Grass is mowed to bank. Channel is a deep pool
AM108	SS=clay. Small shrub vegetation. Moss/algae extending down bank. Medium grey clay deposit to bed w/ orange coloring. Stagnant water/not in stream flow
AM109	SS=Clay. BS below water level. Clay deposit between BS+PSA. Overhanging tall grass and plants. Sample along meander. Sand and small pebble bed. Clay slightly lighter grey color than BS and has no organic matter
AM110	Clay=45cm and between PSA+BS. PSA eroded down to bed and over BS. Deep pool with a few boulders (1-2m). Bank is heavily eroded. Small roots exposed and grass mowed to bank. Bank is rocky at clay layer
AM111	SS=Clay. Short bank. Medium grass and small overhanging roots. PSA, clay, BS=order of layers. BS extends to bed and is below water. Bed is small cobbles dominated. Clay layer has some gravel inclusions. All layers mixed with PSA. BS more sandy but has organic
AM112	All PSA. Short bank downstream of bridge. PSA extends to bed. Gravel and pebble inclusions in bank. Medium grass to bank. Cobble stream bed
AM113	Grass mowed to bank. Site just upstream of bridge on Fernwood rd. SS is clay and extends to bed. Small wood roots overhanging. Bed is cobble dominated with small pebbles.
AM114	Short bank mowed to edge. BS extends to bed. PSA has clay particles mixed in slightly. BS=clay rich and could be possible SS. Vines overhanging. Site along glide.
AM115	Tall grass along bank w/tree plantings. BS extends to bed. Site along riffle
AM116	SS=Clay. Bank cemented with rock. Site is just downstream of a big riffle, away from the river. Bank is mowed grass. Large rock intrusions. PSA is more reddish. Exposed roots
AM117	PSA is reddish and very eroded over the lower 1/2 of bank. SS is 14cm in beneath PSA and very cemented. Exposed steep bank. Dark, sandy, clay beneath PSA (SS) that is grey in color. Mowed grass. There are rock intrusions (<8cm) in bank, site in pool. Larger pebbles below, over-hanging roots.
AM118	SS measurement=74 from bed, 51 above water, and a 100cm step protrusion. Grassy bank in the form of a step that goes down to the bed. Rock-cemented in steps. Silt at

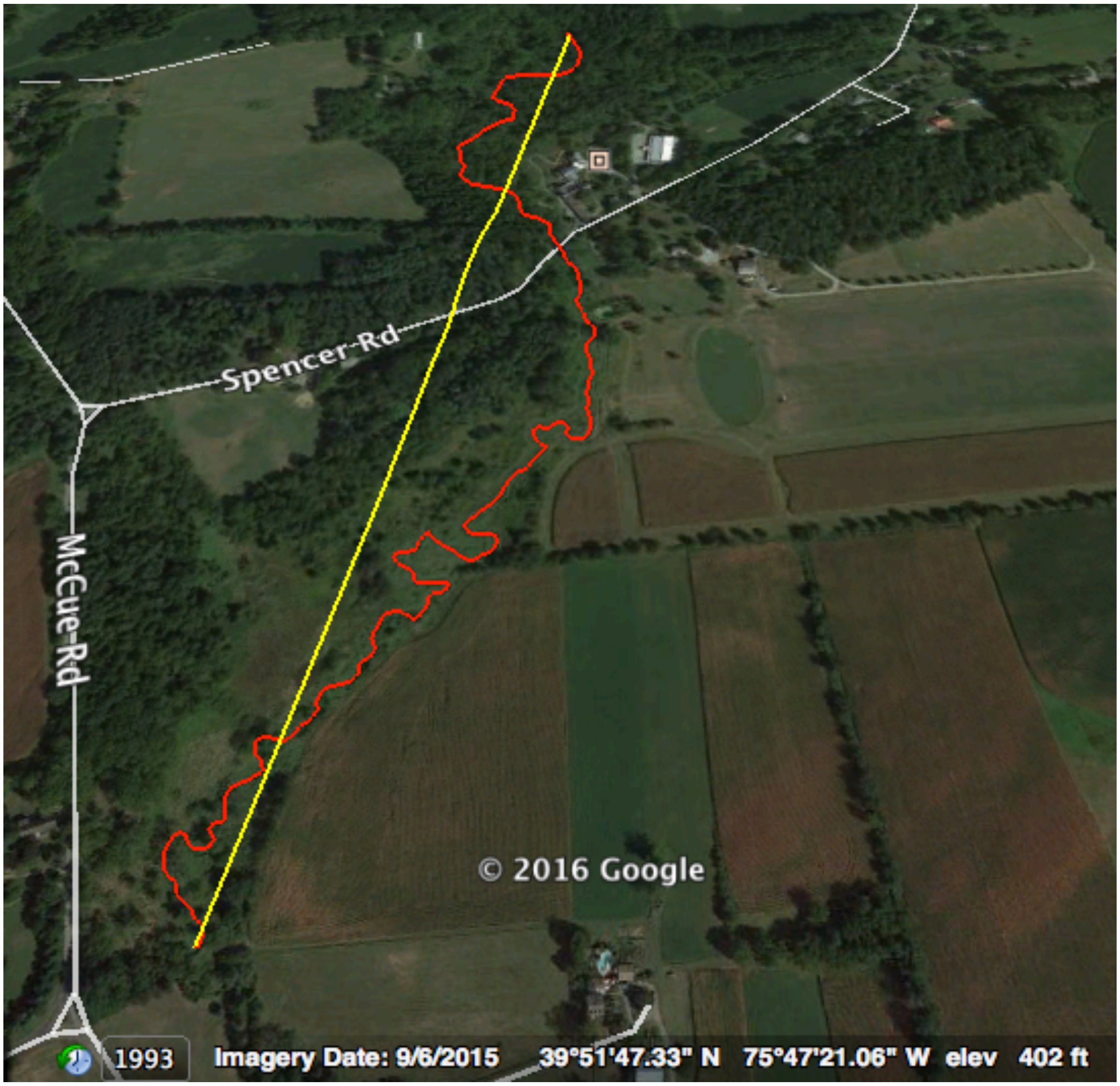
	pool
AM119	Undercut bank. Medium dense grass along top of bank. Small overhanging roots. BS is clay-like but darker than SS/clay layer below. Very thin. BS layer with very little organic matter. Bed is pebble and cobble dominated
AM120	32cm clay protrusion below water. SS grey+orange clay layer heavily cemented with small rocks. Mowed to bank edge. Tree roots exposed through PSA layer. Below riffled cobble bed.
AM121	Darker clay layer between PSA and lighter clay but without very much organic matter. Similar to AM119. Short grass bank. Tree roots exposed. Bed is medium pebbles and silt. Clay protrusion below water level.
AM122	SS is present but not measurable (sinking mud). BS is visibly mixed with PSA. Gravel inclusions in lower portion of bank. PSA mixed with BS below water level, but mostly PSA. Short grass bank
AM123	BS very thin and unevenly distributed across bank. Small stick embedded in BS layer. Short grass bank and small veg overhanging. Bed is large cobble and sand
AM124	BS1 layer slightly clay but has very little wood. BS2 layer large old wood w/ some gravel inclusions. Tall exposed bank w/ short grass below riffle. New BS (BS1) doesn't have organic matter that is substantial. Refer to field notebook for diagram.
AM125	Clay/SS extends to bed. Protrudes below water level. Grass mowed to bank. Bed is gravel and small pebbles.
AM126	Grass mowed to bank. Clay/SS layer extends to bed. Small pebble and large cobble stream bed.
AM127	BS=darker clay layer but little organic content. SS=white/orange clay. Short grass and veg overhanging
AM128	Grass mowed to bank (meadow). Small roots overhanging. Clay layer slightly protruding below water. SS has a few pieces of isolated woody debris

Sample Date	GPS Point	Right/ Left	Latitude (N)	Longitude (W)	PSA (cm)	BS (cm)	SS (cm)	Corrected
16-Jul-15	AM103	R	39.89378	75.87563	145			
16-Jul-15	AM104	R	39.89358	75.87572	110.5			
16-Jul-15	AM105	L	39.8933	75.87638	102		25.5	
16-Jul-15	AM106	R	39.89256	75.87649	59.5		67.5	
16-Jul-15	AM107	L	39.89309	75.87669	54		63	
16-Jul-15	AM108	R	39.89131	75.87925	28		94	PSA mixed with clay
16-Jul-15	AM109	L	39.89171	75.8792	45.5	13	93	BS mixed with clay
16-Jul-15	AM110	L	39.89153	75.88064	112.5	23		PSA and BS mixed
16-Jul-15	AM111	R	39.8905	75.88234	48.5	25	31	Clay heavily mixed with PSA
16-Jul-15	AM112	R	39.88931	75.88525	128			PSA mixed with clay
16-Jul-15	AM113	L	39.8896	75.88596	69		73	

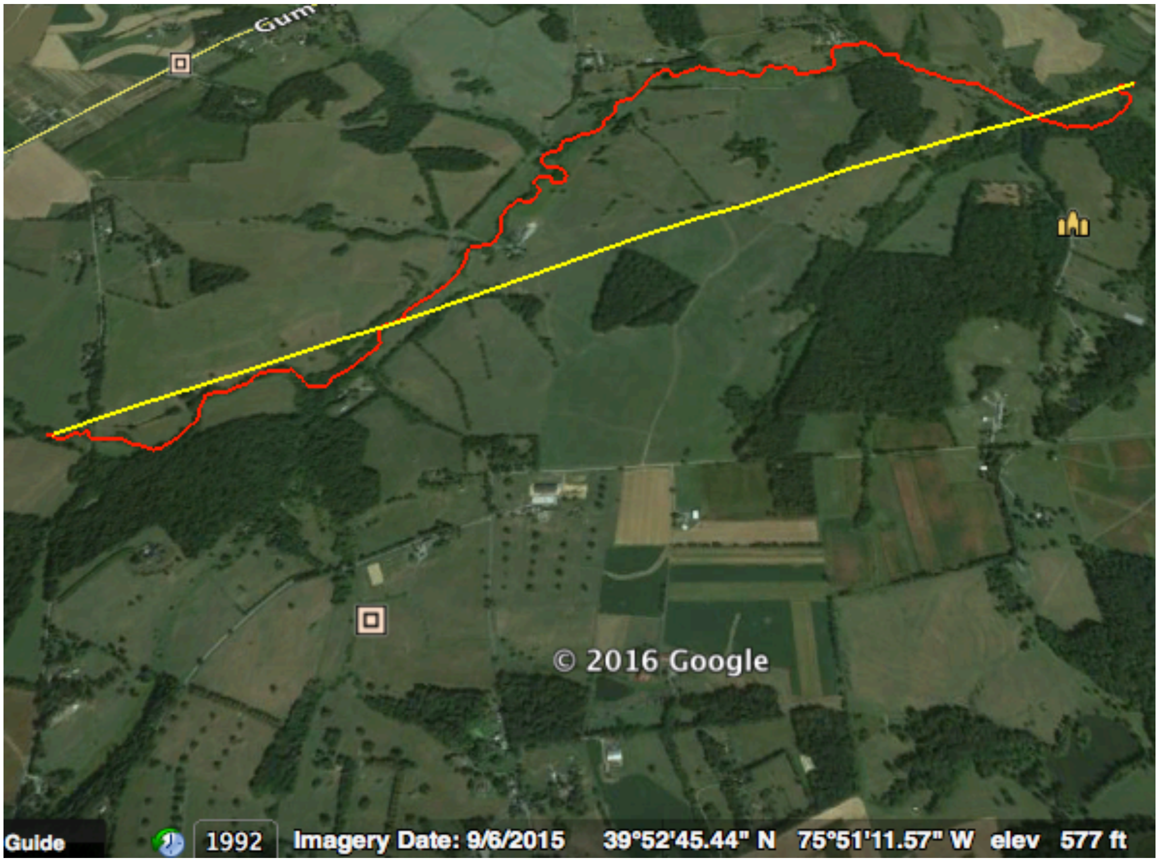
16-Jul-15	AM114	R	39.88947	75.88621	89	55		
16-Jul-15	AM115	R	39.88961	75.88724	113	27		
17-Jul-15	AM116	R	39.90417	75.846	134		58	
17-Jul-15	AM117	R	39.9039	75.84614	108		72.5	
17-Jul-15	AM118	L	39.90368	75.84565	62.5		74	
17-Jul-15	AM119	R	39.90342	75.84569	50	14	61	
17-Jul-15	AM120	R	39.90337	75.86738	92		28	
17-Jul-15	AM121	R	39.90142	75.86948	98	18	49	
17-Jul-15	AM122	R	39.90154	75.86962	131	15		BS+PSA
17-Jul-15	AM123	L	39.90113	75.87049	88	15	32	BS2= 17cm
17-Jul-15	AM124	L	39.89764	75.87263	82	21	29	
17-Jul-15	AM125	R	39.89985	75.87099	75		91	
17-Jul-15	AM126	R	39.89953	75.87086	66		66	
17-Jul-15	AM127	L	39.89954	75.87132	90	22	39	
17-Jul-15	AM128	R	39.89888	75.87123	77		39	

APPENDIX C

White Clay Creek, PA



Doe Run, PA


Gum
© 2016 Google
Guide
1992
Imagery Date: 9/6/2015
39°52'45.44" N
75°51'11.57" W
elev 577 ft

Upstream Salmon River, CT

Downstream Salmon River, CT