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USING GIS TO DELINEATE HEADWATER STREAM ORIGINS IN THE APPALACHIAN COAL-BELT REGION OF KENTUCKY

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USING GIS TO DELINEATE HEADWATER STREAM ORIGINS IN THE APPALACHIAN COAL-BELT REGION OF KENTUCKY

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in
Biosystems and Agricultural Engineering in the College
of Engineering at the University of Kentucky

By

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Agricultural Engineering

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2013

ABSTRACT OF THESIS

USING GIS TO DELINEATE HEADWATER STREAM ORIGINS IN THE APPALACHIAN COAL-BELT REGION OF KENTUCKY

Human activity such as surface mining can have substantial impacts on the natural environment. Performing a Cumulative Hydrologic Impact Assessment (CHIA) of such impacts on surface water systems requires knowing the location and extent of these impacted streams. The Jurisdictional Determination (JD) of a stream's protected status under the Clean Water Act (CWA) involves locating and classifying streams according to their flow regime: ephemeral, intermittent, or perennial. Due to their often remote locations and small size, taking a field inventory of headwater streams for surface mining permit applications or permit reviews is challenging. A means of estimating headwater stream location and extent, according to flow regime using publicly available spatial data, would assist in performing CHIAs and JDs. Using headwater point-of-origin data collected from Robinson Forest in eastern Kentucky along with data from three JDs obtained via a Freedom of Information Act (FOIA) request to the U.S. Army Corps of Engineers (USACE), headwater streams in the Appalachian Coal Belt were characterized according to a set of spatial parameters. These characteristics were extrapolated using GIS to delineate headwater streams over a larger area, and the results were compared to the National Hydrography Dataset (NHD).

KEYWORDS: GIS, headwaters, surface mining, Appalachia, hydrology

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USING GIS TO DELINEATE HEADWATER STREAM ORIGINS IN THE APPALACHIAN COAL-BELT REGION OF KENTUCKY

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For my grandmother.

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CHAPTER 1: INTRODUCTION

1.1 HEADWATER STREAMS AND JURISDICTIONAL DETERMINATIONS

Anthropogenic activities, such as mining, substantially alter the natural landscape. In Appalachia, surface mining adversely impacts headwater streams, many of which are ephemeral or intermittent in nature. Mountaintop removal, for instance, leads to the burial of headwater streams through the disposal of overburden, which is the soil and rock overlying a coal seam, into the valleys (i.e. valley fills) in which these ephemeral, intermittent and perennial headwater streams lie. In the state of West Virginia, for example, it is estimated that valley fills (median size of 4.9 ha, maximum size of 194.2 ha) have resulted in the loss of over 1,360 km of intermittent and perennial streams from 1984 to 2009 (Paybins, 2003). Note that this total does not include ephemeral streams (Shank, 2010); if it did, the total would be substantially larger (Leopold et al., 1964). Ephemeral, intermittent, and perennial classifications refer to the flow permanence or flow regime of a stream. Presently, a number of definitions exist for these stream types; however, for consistency, the following definitions will be used. Ephemeral streams are defined as those that flow only in direct response to precipitation meaning the streambed is always above the local water table. Intermittent streams are those which flow for a portion of the year when the local water table is above the streambed. With perennial streams, the water table is typically above the streambed for the entire year meaning these streams flow continuously during a normal year (405 KAR 16:001).

Despite their small size, headwater streams account for a substantial portion of the stream network. About 53% of total stream miles in the continental U.S. are classified as headwater streams, many of which are intermittent or ephemeral in nature (USEPA, 2013). In mountainous areas such as the Appalachian Coal Belt region, ephemeral streams account for about 80% of total channel length (Shreve, 1969). Headwater streams are vital to larger downstream reaches through the many functions they provide such as nutrient cycling and removal (Peterson et al., 2001). Macroinvertebrate populations located in headwater streams are essential to the breakdown of organic material as well as the growth and survival of larger aquatic and terrestrial organisms. Furthermore, much of the water, sediment, and organic matter inputs to downstream reaches originate in headwater catchments. Because of this, headwater streams are primary determinants of flooding, water quality, aquatic habitat, erosion control, and other factors in lowland streams (Vannote et al., 1980; Gomi et al., 2002). Although the geomorphology and hydrology of headwater streams is complex and may vary based on regional and local factors, research has long shown that even the smallest ephemeral channels in a wide range of locations exhibit consistent and often predictable equilibrium relationships between drainage area and factors such as discharge, slope, width, and depth (Leopold and Miller, 1956; Schumm, 1979). These and other observations indicate that headwater streams exhibit regular and consistent flow regimes over time and therefore may deserve greater protection from human activities under the law (USEPA and USACE, 2011). The extent, characteristics, importance, and protection of headwater streams have been sources of ongoing research and litigation (Carabell v. U.S. Army Corps of Engineers 2004; United States v. Rapanos 2004).

In light of the ecological importance of headwater streams, the regulatory community has re-evaluated their methodology for assessing the effects of large scale anthropogenic disturbances, such as surface coal mining, on headwater stream systems. As a result of a Memorandum of Understanding (MOU) between the U.S. Environmental Protection Agency (USEPA) and the U.S. Army Corps of Engineers (USACE), USACE Section 404 applications for surface mining permits require a Clean Water Act (CWA) review. This review involves completion of a Jurisdictional Determination (JD), an accounting of the location and extent of waterways that will be impacted by the proposed mining activity, and an approval of the JD by state and federal regulators. The completion of these JDs, as part of the CWA review, comprises part of a Cumulative Hydrologic Impact Assessment (CHIA) of human activity on the aquatic environment. The premise of a CHIA is that while individual, localized impacts may be relatively insignificant in a large watershed, the cumulative impact of multiple activities on the hydrologic behavior of an ecosystem may be quite significant. Obtaining a complete picture of the cumulative hydrologic impact requires knowing the location and extent of all the streams that will be impacted (Gandolfi and Bischetti, 1997). However, performing a complete inventory of headwater streams, especially in large watersheds such as the North Fork of the Kentucky River, is time and labor-intensive. This is especially true in the Appalachian Coal Belt region where the headwater stream system is quite mature meaning both the drainage density and topographic relief are high (Davis, 1899). For these reasons, developing, reviewing, and approving surface mining permit applications is challenging.

To date, regulatory authorities have relatively little information available to help determine the accuracy and completeness of JDs outside of conducting thorough field visits of proposed permit areas. Development of a geographical information system (GIS) based model for the Appalachian Coal Belt region to help predict the origin and extent of headwater streams would assist regulatory personnel in screening permit applications for completeness and accuracy.

1.2 OBJECTIVES

The goal of this study is to use publically-available spatial information to characterize and delineate ephemeral, intermittent and perennial headwater streams in the Appalachian Coal Belt region of Kentucky. Specific objectives are to:

1. Identify the stream and basin characteristics, based on a review of the literature, most likely to influence flow regimes.
2. Determine the stream and basin characteristics for field collected point-of-origin data, and evaluate relationships between these parameters and stream flow regime types.
3. Compare the stream and basin characteristics from field collected point-of-origin data to point-of-origin data from three JD permits within 60 km of the project area.
4. Extrapolate selected stream flow regime type delineation parameters to the Buckhorn Creek watershed.

Another aspect which is related to but separate from this thesis is the ongoing monitoring and analysis of flow regime data and precipitation data from the University of Kentucky's Robinson Forest. These data will be used by the U.S. Geological Survey to assess the predictive capabilities of their Water Availability Tool for Environmental Resources (WATER) program for classifying the flow regime of headwater streams.

1.3 ORGANIZATION OF THESIS

Chapter 1 is the introduction to the thesis. It contains background information on the research and outlines the objectives of the thesis. Chapter 2 reviews available literature, including a discussion of stream definitions and field identification methods. Chapter 3 describes the methodology and procedures for the thesis, including GIS and statistical analysis techniques. Chapter 4 presents and discusses the results of the analyses and their application. Chapter 5 discusses conclusions that can be drawn from this study while Chapter 6 presents a framework for future research opportunities. Appendices A through X include raw data and maps of the selected parameters, maps of stream origin points and their respective catchments, detailed results of the statistical analysis, and other data not included in the body of the thesis.

CHAPTER 2: LITERATURE REVIEW

2.1 ECOLOGICAL IMPORTANCE OF HEADWATER STREAMS

Assessing the cumulative hydrologic impact of land disturbance activities such as mining, urbanization, or agriculture requires an understanding of the ways that streams of different orders and flow regimes are mutually dependent. This interdependence occurs at chemical, biological, and physical levels. Organizations of stream networks in the landscape evolve hierarchically in such a way as to minimize the total expenditure of energy and maximize the efficiency and stability of the system (Leopold, 1974). Headwater streams, being the source of most energy input to river systems in the form of precipitation, impose spatial constraints on the potential head loss (in the form of possible flow paths) in the system and thus have significant impacts on the type, quantity, and location of energy available to less constrained downstream reaches (Leopold and Langbein, 1962; Huang et al., 2007). The result is that collectively headwater streams strongly influence the behavior of larger aquatic systems in the form of important biological, physical, and chemical processes over geologic time and due to discrete threshold geomorphic events and landscape alterations (Schumm, 1979).

The River Continuum Concept suggests that in natural stream systems, communities of organisms are organized temporally and spatially, from the headwaters to the outlets, so as to maximize the efficient use of organic material as energy (Vannote et al., 1980). As a result, biological communities establish a dynamic equilibrium with the physical forms of streams and rivers, which spans the entire length of a channel network from the lowest to the highest steam orders. Headwater streams, for instance, which Vannote et al. (1980) describe as orders 1 through 3, are primary sources of organic material in the form of vegetative debris. These headwater streams are thus inhabited by a higher proportion of "shredder" species which disperse the carbon energy into smaller particles that are then more efficiently consumed by "collector" species located further downstream. Assessing the ecological importance of headwater streams is complex. For example, biological diversity is often viewed as an indicator of ecological health. Vannote et al. (1980) observed, however, that in highly physically stable stream systems total biotic diversity may be low while still maintaining a stable stream ecosystem because a smaller variety of physical conditions requires a smaller variety of organisms in response. From an evolutionary standpoint, it is likely that terrestrial organisms such as insects first migrated from land to water in headwater reaches since headwaters have the greatest interface between terrestrial and aquatic habitat (Vanotte et al., 1980). Based on the river continuum concept, it is expected that alterations to headwater streams will lead to complex changes in the rest of the downstream drainage network as the system seeks to reestablish dynamic equilibrium (Leopold and Miller, 1956; Schumm, 1979; Vannote et al., 1980).

Principles of continuity and mass-balance in stream systems indicate that since headwater streams are the most common streams in the United States, they contribute significantly to both water quantity and quality in downstream reaches (USEPA, 2011). In defining the "waters of the U.S." to include tributaries, the USACE stated that regulating sources of water pollution must consider all waters that comprise an aquatic ecosystem, since pollution in one part of the system will impact water quality elsewhere (42 Fed. Reg. 37, 122; 37, 128). This principle remains the basis of USEPA and USACE protections under the CWA to the present day. Federal law seeks to protect "the many tributary streams that feed into the tidal and commercially navigable waters…since the destruction and/or degradation of the physical, chemical, and biological integrity of each of these waters is threatened by the unregulated discharge of dredged or fill material (42 Fed. Reg. 37, 123)." Headwater streams trap sediment, remove nutrients, control water temperatures, provide habitat and migration corridors for fish and other animals, maintain baseflow further downstream, mitigate downstream flooding and erosion, and perform many other important chemical, biological, and physical functions (USEPA and USACE, 2011).

2.2 SIGNIFICANT NEXUS DETERMINATION

Headwater streams are typically classified in three ways according to flow permanence: ephemeral, intermittent, or perennial. Depending on the regulatory authority, the definitions can differ, particularly with regards to intermittent streams. The USEPA (2013) defines ephemeral streams as those that flow only in direct response to rainfall, intermittent streams as those that flow when ephemeral streams are flowing and when groundwater provides enough water for stream flow, and perennial streams as those which flow year-round and receive most of their water from smaller upstream waters or groundwater as opposed to runoff from rainfall or snowmelt. The Kentucky Administrative

Regulations (405 KAR 16:001) define an ephemeral stream as one that flows only in response to precipitation and has a channel bottom always above the local water table. The definition of an intermittent stream differs from that of the USEPA as Kentucky law specifies a minimum drainage area, derived from older federal mining regulations. An intermittent stream is defined as one with a drainage area of at least one square mile or lacks year-round flow, has a streambed that is below the local water table for at least some part of the year, and obtains its flow from both surface runoff and groundwater sources. A perennial stream is defined as one that flows year-round as a result of groundwater discharge or surface runoff. Jurisdictional determinations prepared for surface mining permit applications all use a flow regime classification system to identify and locate streams that will be affected by valley fills, slurry impoundments, and other mining structures or activities, but the definition and identification of these flow regimes, as well as which ones qualify for jurisdiction under the CWA, is inconsistent.

In April of 2011, the USEPA and the USACE released draft guidance to explain which types of waters are protected under the CWA, and therefore require inclusion in JDs as part of Section 404 permit applications for surface mining activities. This guidance is considered non-binding (and thus does not constitute a legal requirement), and once it is finalized it will supersede previous guidance documents issued in 2003 and 2008. Discussion of JDs in this thesis will refer to the 2011 draft version. The most relevant aspects of the 2011 guidance document relate to how headwater streams are defined under the CWA. The 2011 guidance document states that the CWA has jurisdiction over any waters that have a "significant nexus" to traditional navigable waters (TNW) or interstate waters. The USEPA (2011) defines waters with a significant nexus as those that "either alone or in combination with similarly situated waters in the region, significantly affect the chemical, physical, or biological integrity of traditional navigable waters or interstate waters." Headwater streams, as noted by numerous scientific studies, arguably have a significant nexus to downstream reaches (Duncan et al., 1987; USNRC, 1997; Dieterich and Anderson, 1998; Hall and Anderson, 1988; Alexander et al., 2000; Lieb and Carline, 2000; Meyer and Wallace, 2001; Peterson et al., 2001; Gomi et al., 2002; Pitt, 2002; Ohio EPA, 2003; Lowe and Likens, 2005; Dunnivant and Anders, 2006; Freeman et al., 2007; Meyer et al., 2007).

2.3 FIELD IDENTIFICATION OF HEADWATER STREAM ORIGINS

Conducting a complete assessment of headwater streams for use in the JD process requires knowledge of the points-of-origin of headwater streams. In many instances, for purposes of preparing JD assessments, one-time field surveys are performed to identify the channel head or point-of-origin[1] for headwater streams in the area of interest. According to the 2011 guidance from the USEPA and USACE, time-series documentation of site-specific flow permanence data is not required, and a direct field observation may not be necessary as long as documentation of factors influencing hydrologic flow permanence, such as drainage area and typical annual rainfall, from a study of similar waters in the same region is utilized.

Assuming a field survey is conducted to identify the points-of-origin of headwater streams, a standardized identification protocol, such as that developed by Fritz et al. (2006) is used. The presence of surface flow at channel heads is due to a variety of factors such as water table fluctuations (Blythe and Rodda, 1973; Stanley et al., 1997) and connectivity to groundwater. As such, a single observation may have limitations with regards to hydrologic permanence at this scale, particularly for intermittent and perennial streams. In years of drought, for example, the lowering of the water table would indicate point-of-origins for intermittent and perennial streams that are further down-gradient than in normal rainfall years. Characteristics of the valley surrounding the channel head, such as slope and geology, guide the evolution of the channel over time and therefore determine the location of the channel point-of-origin (Dietrich and Dunne, 1993; Montgomery, 1999). Points-of-origin for headwater streams are likely to be relatively constant over the timeframe of a typical study or project (i.e. 1-2 years) but may change significantly due to various erosive events over longer periods of time (Fritz et al., 2006).

The 2011 guidance document issued by the USEPA and USACE states that when analyzing a tributary for a significant nexus, the observer should first identify a bed and bank and an ordinary high water mark (OHWM). USACE regulations define an OHWM as, "that line on the shore established by the fluctuations of water and indicated by physical characteristics such as a clear, natural line impressed on the bank, shelving, changes in the character of the soil, destruction of terrestrial vegetation, the presence of litter and debris, or other appropriate means that consider the characteristics of the surrounding areas (33 C.F.R. Part 328)." If the tributary has these characteristics, the observer must determine if the

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[1] The terms channel head and point-of-origin will be used interchangeably in this thesis.

tributary drains, by itself or as a network of similar tributaries, into a downstream TNW. These determinations suggest that the stream is then likely to significantly affect the chemical, physical, or biological integrity of downstream TNWs. Determination of whether the tributary eventually flows into a TNW should be made via direct observation or other information such as topographic maps or aerial photography.

Once a stream is positively identified as a tributary by the above definitions, the guidance states that field staff should document its flow characteristics, functions, and hydrologic relationship to the nearest downstream TNW. This documentation may include actual flow data in response to precipitation events, physical indicators of flow, topographic maps, soil surveys, watershed studies, statistical data, literature citations, references from pertinent studies, personal observations, field reports, expert statements, and other sources. Determining an OHWM itself involves examining the stream and floodplain for recent evidence of flow such as changes in soil and/or vegetation or the presence of litter and debris. Note that it is not necessary for the observer to document actual flow data using stream gages or other monitoring techniques.

The 2011 USEPA and USACE guidance document also states that contextual factors influencing hydrology, such as drainage area and typical annual rainfall, may be utilized. As long as this type of documentation is available, it is not necessary for a field worker to directly observe the tributary in order to make a significant nexus determination. It is not required that this documentation is specific to the waters under consideration. For example, regional studies of similar waters can be used to document a significant nexus JD if they are applicable to the stream(s) in question. In cases where a previous significant nexus JD has been established for a similarly situated water with a similar flow regime (i.e. ephemeral, intermittent, or perennial), staff can apply that determination to any additional waters that are documented and established to be of the same type and in the same watershed.

States such as Georgia and North Carolina along with the USEPA provide guidance to help determine the likely flow regime of a headwater stream based upon field observations. The Georgia Department of Natural Resources (GDNR, 2006), for instance, describes a methodology for stream classification according to flow regimes in its *Field Guide for Determining the Presence of State Waters that Require a Buffer*. In cases where the presence or absence of base flow is not obvious, other typical characteristics are provided for each flow regime. The guide defines a perennial stream as one with riffle and pool structures, a sinuous channel, fluctuating high water marks, evidence of scouring, wetland vegetation in the channel or along the banks, hydric soils in the bank material, and exposed rock, gravel, or sand in a nearly continuous low lying channel. The guide defines an intermittent stream as one that may or may not exhibit baseflow at the time of observation but is otherwise characterized similarly to a perennial stream except without clear riffle and pool structures, and it may lack sinuosity. Ephemeral streams are characterized by no evidence of baseflow, a channel that is nearly always straight and flattens at the bottom, absence of fluctuating OHWMs, evidence of leaf litter and debris jams in the flow channel, sparse wetland vegetation, and soils with a more loamy texture than the surrounding landscape. The guide suggests that the presence or absence of hydric indicators in bank soil, as evidenced by gray or black soil and other factors, is the most reliable means of differentiating between intermittent and ephemeral streams respectively, but not all areas exhibit hydric soils even in intermittent and perennial reaches. This is an example of one regional factor that leads to the necessity for state-by-state or even more localized guidance within a state for field classification of streams. The Georgia guidance document itself makes some distinctions between the North Georgia, Piedmont, and Coastal regions with respect to the three major flow regimes (GDNR, 2006).

In North Carolina, the Division of Water Quality (NCDWQ) has issued the *Methodology for Identification of Intermittent and Perennial Streams and Their Origins* revised as version 4.11 effective September 2010. This guidance document provides a wide range of geomorphic, hydrologic, and biological indicators with which to assess likely flow regimes and points-of-origin for headwater streams. North Carolina Administrative Code (NCAC) defines an ephemeral stream as one that carries only stormwater in direct response to precipitation, may or may not have a well-defined channel, the bed is always above the water table, and typically lacks the biological, hydrological, and physical characteristics commonly associated with the continuous or intermittent conveyance of water. Intermittent streams are well-defined channels that typically contain water only during the winter and spring months when the bed is below the seasonal high water table and often lack the biological and hydrological characteristics commonly associated with the continuous conveyance of water. Perennial streams are well-defined channels that contain water during all of a typical rainfall year, where groundwater is the primary source of water, and exhibit the typical biological, hydrological, and physical characteristics commonly associated with the continuous conveyance of water. The guidance document details the typical characteristics that define each stream type and, like Georgia, North Carolina notes the distinction between flow regimes by landscape and geology, distinguishing between the Mountain, Piedmont, and Coastal Plain regions. This guidance document makes the important observation that practitioners should familiarize themselves with a variety of headwater streams and their typical characteristics prior to making flow-regime based classifications (NCDWQ, 2010). As noted by the 2011 USEPA and USACE guidance document, the long-term knowledge possessed by experts and local residents about the behavior and characteristics of headwater streams can often be among the most reliable sources of information.

Fritz et al. (2006) in *Field Operations Manual for Assessing the Hydrologic Permanence and Ecological Condition of Headwater Streams* provides a detailed procedure for identifying headwater stream points-of-origin. The procedure involves hiking upstream along a given reach and observing the slope of the streambed and banks relative to the adjacent hillslopes. Channels convey water between banks that are characterized by steeper gradients than those of the surrounding valley and channel bottom. Points-of-origin can be abrupt or gradual. Abrupt origins, often called knickpoints or headcuts, are step-like transitions from the valley slope above to the channel bed itself. Above this point in the valley, a readily identifiable channel bed or bank is typically absent. The transition is often characterized by the presence of a rich soil layer above the knickpoint and exposed bedrock or boulders below. Fritz et al. (2006) noted that headcut features can occur within a continuous channel reach, in which case defined bed and banks will continue upslope from the headcut, and its location does not imply a point-of-origin. Gradual channel heads are characterized by a less abrupt transition between the steep slope of a bank and the valley above it. The field surveyor must make the distinction as to where there are no longer defined bed and banks, and this location defines the channel origin. When an observer is in doubt as to whether a channel continues above a location without clearly defined bed and banks, the presence of bedrock and boulder material exposed by surface flow suggests that the channel head may lay further upland.

2.4 HEADWATER STREAM CHARACTERISTICS

Paybins (2003) characterized intermittent and perennial headwater streams in the mountaintop coal-mining region of southern West Virginia. Ephemeral streams were not examined. Each stream reach was walked until the upstream limit of continuous surface flow was identified, and these coordinates were marked using a portable GPS receiver. Stream basin characteristics were identified including drainage area, point-of-origin elevation, mean drainage area slope, drainage area aspect, and dominate underlying rock type. The study concluded that drainage area, basin slope, and rock type were useful parameters for predicting the flow regime of streams. As seen in Table 2.1, the median drainage area for the intermittent channels was 5.9 ha (14.5 acres) and ranged from 2.5 to 18.3 ha (6.3 to 45.3 acres). The median drainage area for the perennial channels was 16.5 ha (40.8 acres) and ranged from 4.2 to 60.7 ha (10.4 to 150.1 acres). The median basin slope for the intermittent channels was 7.4% and ranged from 3.5% to 11.7%. The median basin slope for the perennial channels was 9.8% and ranged from 4.4% to 12.6%.

Table 2.1: Median characteristics of southern West Virginia headwater streams (Paybins 2003).

Parameter	Stream Flow Type	
	Intermittent	Perennial
Drainage Area (ha)	5.9	16.5
Basin Slope (%)	7.4	9.8

Svec et al. (2005) catalogued channel geometry parameters including bankfull width, bankfull mean depth, bankfull cross-sectional area, width-to-depth ratio, sinuosity, stream slope, floodprone width, and entrenchment ratio, as well as the watershed characteristics of drainage area, upland hillslope, and depth to bedrock for 23 headwater streams in the Eastern Coalfield Region of Kentucky. Twelve of the 23 streams were located in the University of Kentucky's Robinson Forest. Streams were classified as ephemeral if flowing <10% of the time observed, intermittent if flowing between 10-90%, and perennial if >90%. Flow durations of less than 53% of the time were not observed, and no streams met the definition of ephemeral. The authors suggest a range of 1 to 10 ha (2.5 to 24.7 ac) for ephemeral drainage areas, 1 to 100 ha (2.5 to 246 ac) for intermittent, and 5 to over 100 ha (12.4 to 247 ac or larger) for perennial streams. A "best fit" statistical model was developed to predict flow duration, and the authors found that flow duration was directly proportional to watershed size and inversely proportional to width-to-depth ratio, stream slope, and entrenchment ratio (Table 2.2).

Table 2.2: Stream classification guidelines from the Eastern Coalfields Region of Kentucky (Svec et al., 2005).

Area (ha)	Width:Depth	Slope (%)	Entrenchment Ratio	Channel class
1-5	1-25	<30	<2	Intermittent
	>25	>30	>2	Ephemeral
5-10	1-3	1-2	<1.5	Perennial
	3-50	2-30	1.5-4	Intermittent
	>50	>30	>4	Ephemeral
10-25	1-6	1-3	<1.5	Perennial
	6-50+	3-30+	1.5-5+	Intermittent
25-100	1-30	1-10	<3	Perennial
	>30	10-30+	>3	Intermittent
100+	Any value	Any value	Any value	Perennial

Hansen (2001) surveyed stream characteristics within the Chattooga River watershed spanning regions of Georgia, South Carolina, and North Carolina. Approximately 190 streams were characterized as ephemeral, intermittent, or perennial. Data including presence of defined channel, estimated flow duration, streambed water level, presence of aquatic insects, material movement, and channel materials were collected for each stream. The author found that the key indicators of flow regime were degree of erosion into the landscape and the presence or absence of aquatic insects (Table 2.3). At the 1:24K scale, 28% of streams were classified as perennial, 17% as intermittent, and 55% as ephemeral. Ephemeral streams were mostly first order with some second order, intermittent streams were mostly second order with some first order, and perennial streams were mostly third order or greater. While drainage areas were not provided according to flow regime, first-order streams had drainage areas ranging from 0.26 to 6.2 ha (0.64 to 15.3 ac). For second order streams, drainage areas ranged from 2.6 to 65 ha (6.42 to 161 ac).

Table 2.3: Field criteria for determining stream type in the Blue Ridge Mountains (Hansen 2001).

Criteria	Stream Flow Type		
	Perennial	Intermittent	Ephemeral
Channel bed and banks	Defined	Defined	Not defined
Flow duration	Almost always	Extended, but interrupted	Storm flow only
Streambed water level	Above channel	Near channel surface	Below channel
Aquatic insects	Present	Few, if any	None
Material Movement	Present	Present, less obvious	Lacking or limited
Channel materials	Scoured, flow sorted; no organic buildup	Scoured or flow sorted; lacks organic buildup	Mostly soil materials; organic buildup

Fritz et al. (2008) examined a number of physical indicators of hydrologic permanence at 113 sites across 10 forests in nine different states in an attempt to identify characteristics of ephemeral, intermittent, and perennial streams that could be used to help with JDs. Drainage area, the Ohio EPA Headwater Habitat Evaluation Index (HHEI), and the NCDWQ Stream Classification Method (NCSC) were found to be the most useful indices for distinguishing ephemeral from intermittent and perennial sites. Entrenchment ratio was the most useful parameter for distinguishing between intermittent and perennial sites. Drainage areas for ephemeral streams ranged from 0.04 to 79.8 ha (0.1 to 197.2 ac), 0.1 to 256.5 ha (0.25 to 633.8 ac) for intermittent, and 6.9 to 241.1 ha (17.1 to 595.8 ac) for perennial across all 113 sites. Looking at results from Indiana, Kentucky, south-central Ohio, and southeastern Ohio only, ephemeral drainage areas ranged from 1.7 to 13.2 ha (4.2 to 32.6 ac), 1.9 to 256.5 ha (4.7 to 633.8 ac) for intermittent, and 6.9 to 241.1 ha (17.1 to 595.8 ac) for perennial. Fritz et al. (2008) observed that these ranges are very large with considerable overlap. The authors suggested that drainage area is most likely to be an important factor in determining stream flow characteristics within a single ecoregion or hydrologic landscape region (HLR) (Wolock et al., 2004; Fritz et al., 2008). Drainage area did appear to be an important variable to discriminate between ephemeral, intermittent, and perennial streams in the core study forests, which include observations made in Kentucky.

2.5 DELINEATION OF HEADWATER STREAMS AND THE NHD

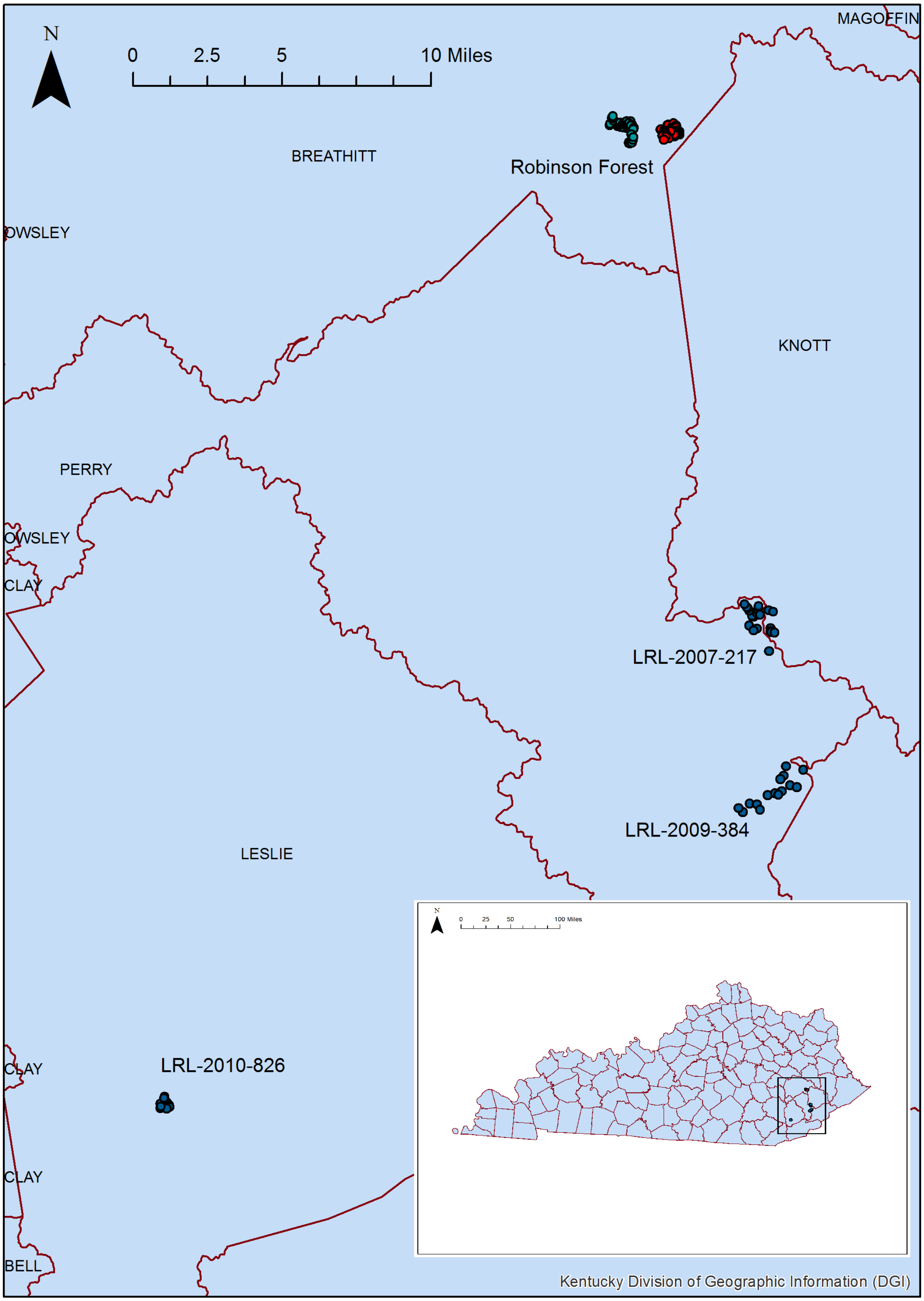
The National Hydrography Dataset (NHD) is often used when making regulatory decisions with respect to flow regimes (Leopold, 1994; Paybins, 2003) and is the primary digital stream map in the U.S. (Fritz et al., 2013). Several studies have observed that the NHD and the USGS topographic contour maps, from which the NHD is derived, tend to significantly underestimate the extent of headwater streams (Hansen, 2001; Paybins, 2003; Childers et al., 2006; Fritz et al., 2013). Using a combination of data from GIS flow accumulation models and field surveys to assess flow permanence, Hansen (2001) observed that USGS topographic contour maps only identified 50-75% of perennial streams depending on scale, and 14-21% of the entire ephemeral, intermittent and perennial stream network. Childers et al. (2006) developed a flow accumulation GIS model using the National Elevation Dataset (NED) and median drainage areas from Paybins (2003) in southern West Virginia. The GIS model revealed a perennial network with 70% greater length than the NHD showed and an intermittent network with 158% greater length than the NHD showed. Fritz et al. (2013) looked at data from 29 headwater streams in nine U.S. forests and observed that seven of the nine were predicted to have more than 200% greater channel length than was shown in the high-resolution version of the NHD. The authors also concluded that most streams identified as first order on the medium resolution NHD were actually second order streams. Most first order channels were not even depicted on the medium resolution NHD. Fritz et al. (2013) estimated that the percentage of first order streams with ephemeral or intermittent flow in the study areas may be 68%-75% or even greater, and the medium resolution NHD may only depict as few as 0%-15% of these channels in some forested areas.

CHAPTER 3: MATERIALS AND METHODS

3.1 STUDY SITES

Developing the dataset for this thesis involved first obtaining the coordinates for headwater stream points-of-origin of ephemeral, intermittent, and perennial flow permanence. As the intent was to compare streams delineated in the surface mining permit applications to those identified in a controlled environment, points were obtained via field reconnaissance in the University of Kentucky's Robinson Forest using a similar methodology outlined in Fritz et al. (2006). The team identifying points-of-origin was led by Carmen Agouridis, Ph.D., P.E., and included other staff from the University of Kentucky Dept. of Biosystems & Agricultural Engineering including Alex Fogle. To obtain data suitable for a comparison to the Robinson Forest data set, a Freedom of Information Act (FOIA) request was submitted to the USACE to obtain JDs for three randomly chosen surface mining permit applications in areas near Robinson Forest. The resulting dataset included 142 headwater stream points-of-origin in the Appalachian Coal Belt region of Kentucky (Figure 3.1). At Robinson Forest, 33 data points were from the Little Millseat watershed, 6 from the Field Branch watershed and, 46 from the Falling Rock watershed (Figures 3.2-3.3). All three watersheds in Robinson Forest are considered reference watersheds for the Commonwealth of Kentucky due to lack of recent anthropogenic disturbance (~100 years), stream stability, and aquatic habitat quality. For the JDs, 32 were from USACE Permit LRL-2007-217, 16 from the LRL-2009-384 permit, and 9 from the LRL-2010-826 permit (Figures 3.4-3.6). The coordinates of the Robinson Forest and JD dataset are bounded by -83.4 to -83.0 degrees longitude and 37.0 to 37.5 degrees latitude.

Figure 3.1: Overview of stream locations in Breathitt, Perry, and Leslie counties, eastern Kentucky, USA.



Kentucky Division of Geographic Information (DGI)

Figure 3.2: Locations of headwater stream points-of-origin in the Little Millseat and Field Branch watersheds of Robinson Forest. *DEM indicates digital elevation model. Flow indicates flow regime (E=ephemeral, I=intermittent, P=perennial).*

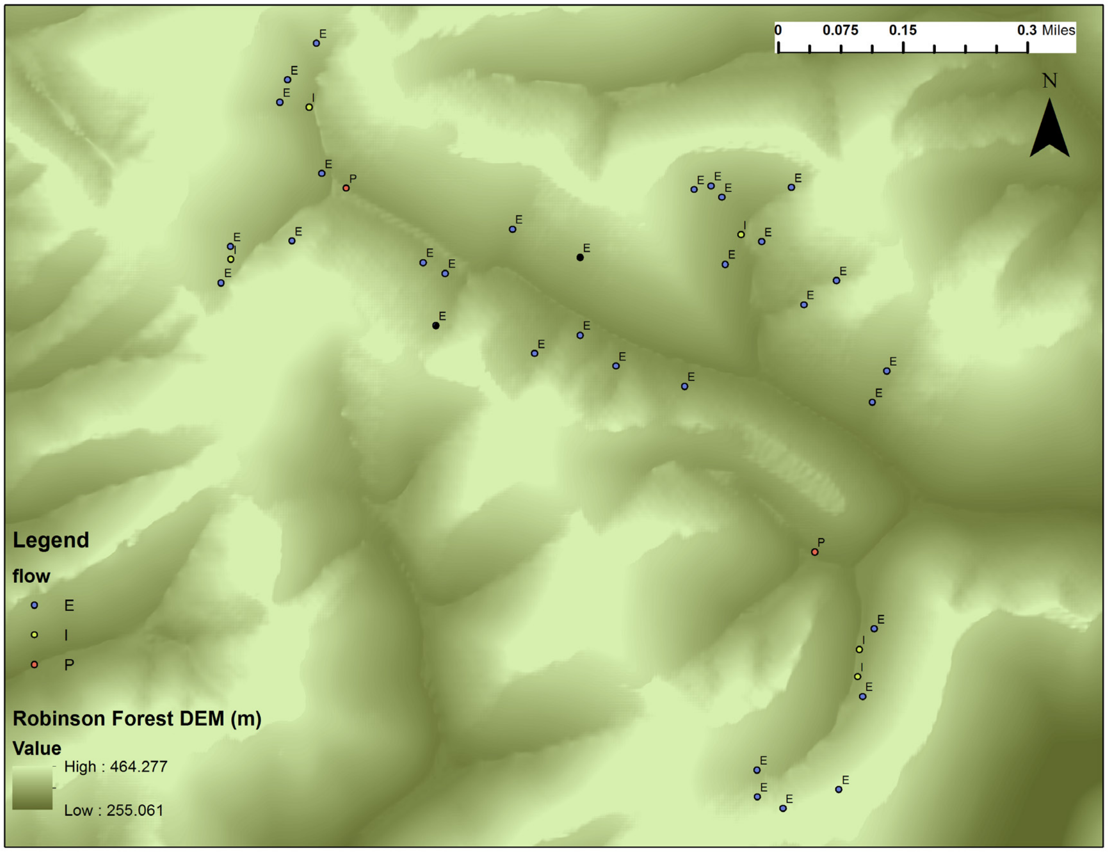


Figure 3.3: Locations of headwater stream points-of-origin in the Falling Rock watershed of Robinson Forest. *DEM indicates digital elevation model. Flow indicates flow regime (E=ephemeral, I=intermittent, P=perennial).*

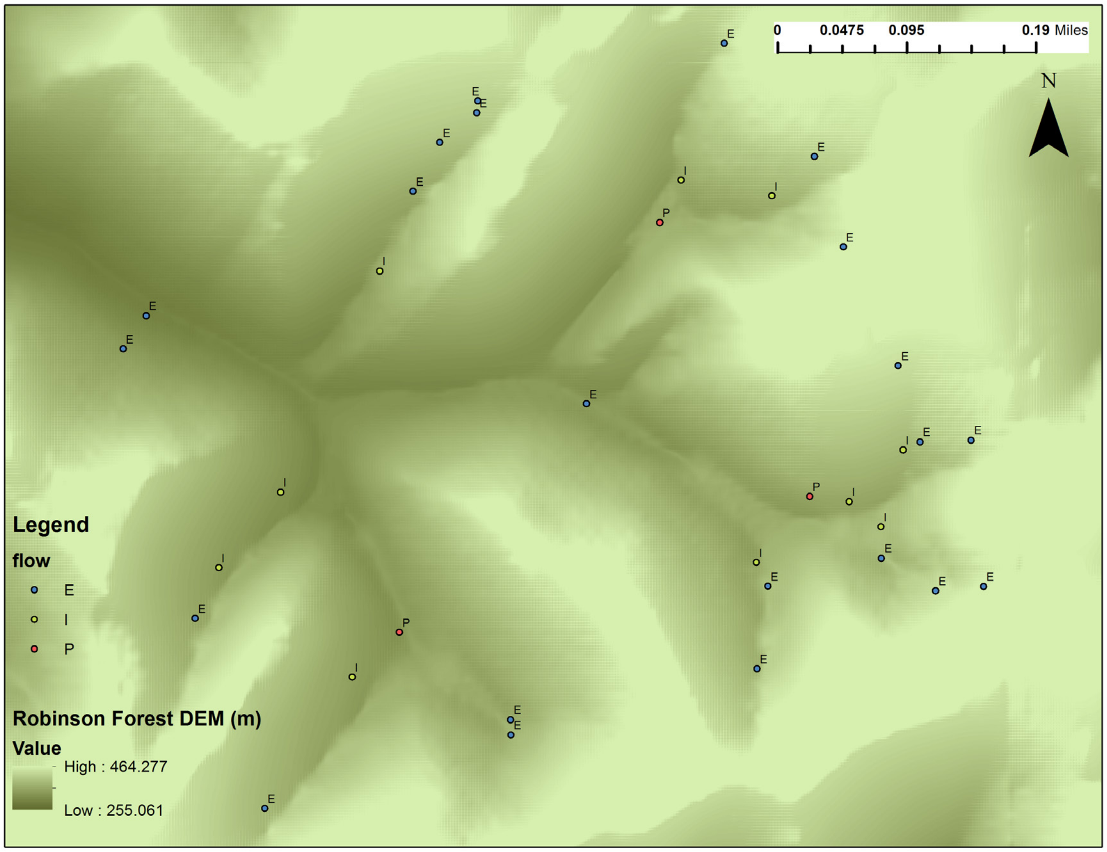


Figure 3.4: Detail of headwater stream points-of-origin from permit no. LRL-2007-217. *DEM indicates digital elevation model. Flow indicates flow regime (E=ephemeral, I=intermittent, P=perennial).*

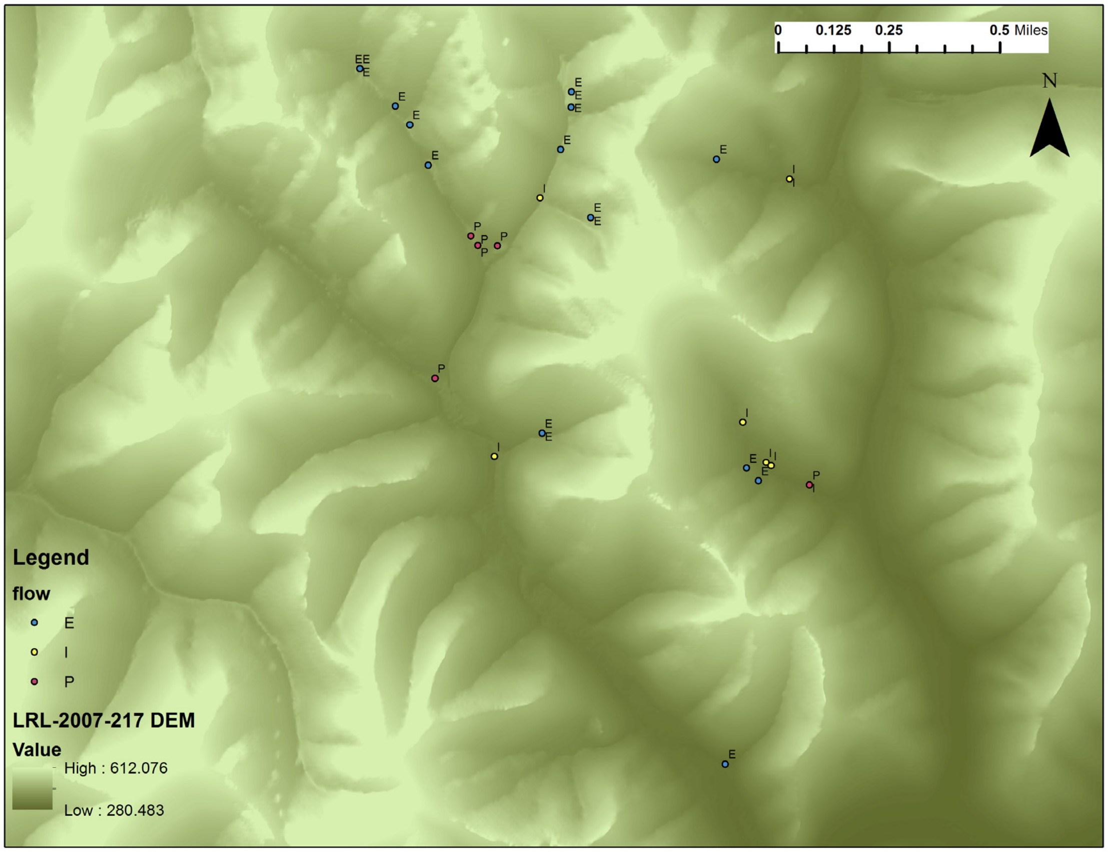


Figure 3.5: Locations of headwater stream points-of-origin from permit no. LRL-2009-384. DEM indicates digital elevation model. *Flow indicates flow regime (E=ephemeral, I=intermittent, P=perennial).*

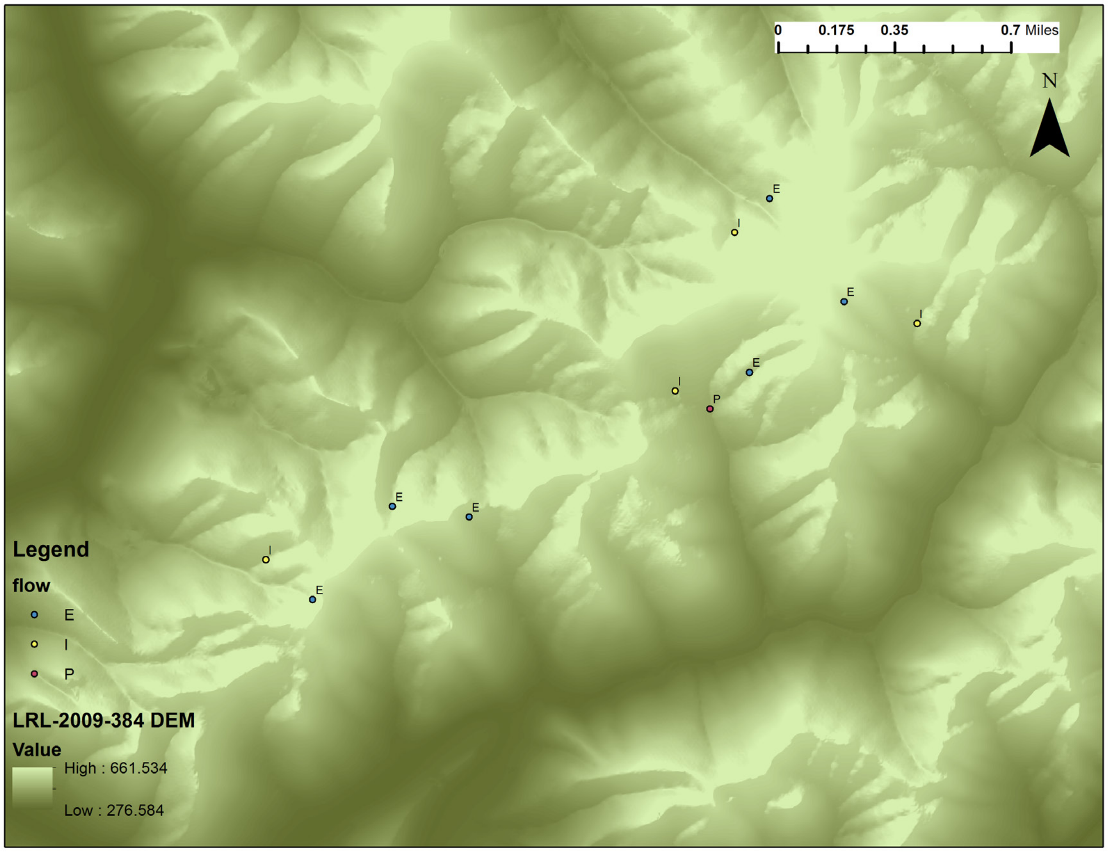
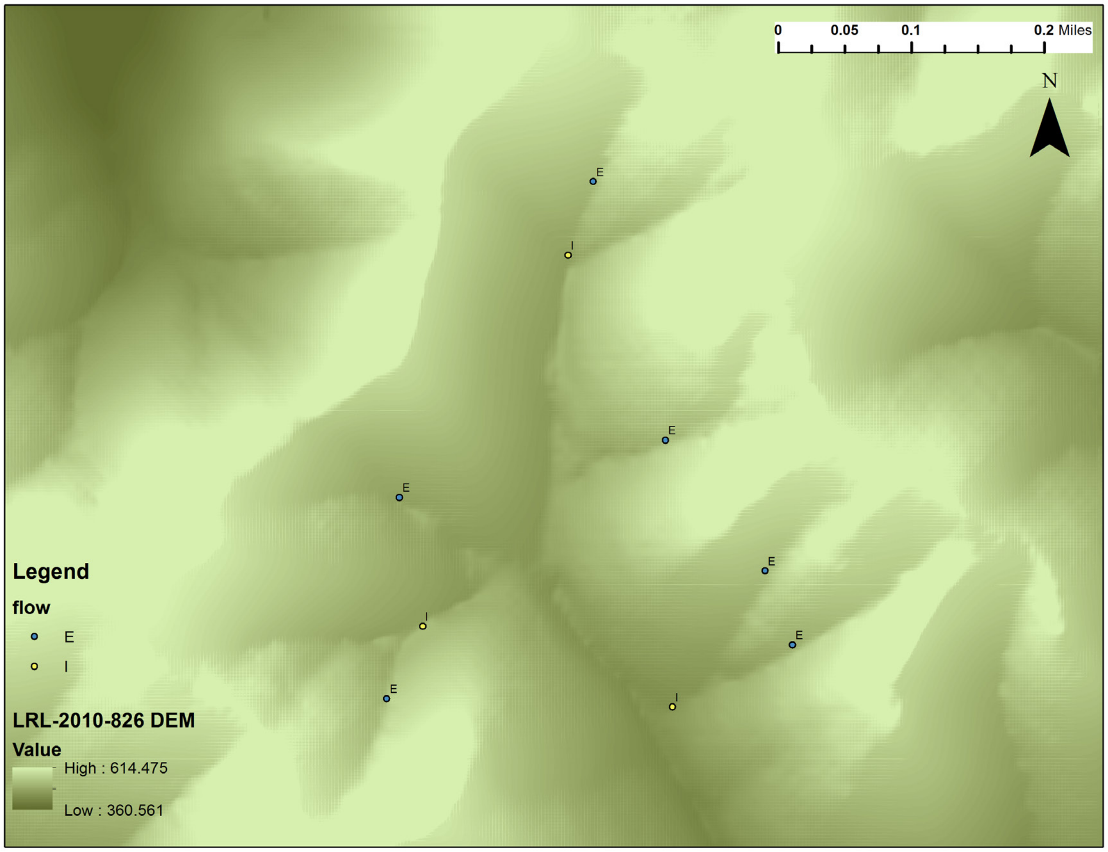


Figure 3.6: Location of headwater stream points-of-origin from permit no. LRL-2010-826. DEM indicates digital elevation model. *Flow indicates flow regime (E=ephemeral, I=intermittent, P=perennial).*



3.1.1 Climate

The climate near the project site is humid and temperate. The average annual rainfall (1981-2010) is 123 cm with the maximum occurring during the month of May (13.2 cm) and the minimum occurring during the month of October (9.4 cm). Monthly mean temperatures range from 1.61°C in January to 23.6°C in July with an annual average of 13.6°C (NCDC, 2013).

Table 3.1: Monthly precipitation normal data (1981-2010) in inches for Jackson Julian Carroll Airport, KY station (NCDC, 2013). *'Precipitation probabilities' indicates probability that precipitation will be equal to or less than the indicated amount.*

	Totals	Mean Number of Days				Precipitation Probabilities		
	Means	Daily Precipitation				Monthly Precipitation vs. Probability Levels		
Month	Mean	>=0.01	>=0.1	>=0.5	>=1.0	0.25	0.50	0.75
1	3.61	14.1	7.3	2.4	0.8	2.46	3.32	5.10
2	3.75	13.1	7.8	2.4	0.8	2.88	3.44	4.46
3	4.12	14.0	8.5	2.7	0.9	2.71	3.36	5.29
4	3.83	12.4	8.2	2.7	0.7	2.67	3.55	4.91
5	5.20	13.8	9.7	3.4	1.4	3.61	5.00	6.28
6	4.70	12.3	8.5	3.4	1.1	3.22	4.29	6.18
7	4.65	12.4	8.3	3.4	1.0	3.74	4.32	6.13
8	3.69	9.6	6.0	2.5	1.2	2.50	3.42	4.39
9	3.46	8.4	5.7	2.2	1.0	2.03	2.77	4.88
10	3.19	8.8	5.7	2.1	0.8	1.69	2.71	4.64
11	3.96	11.5	7.2	2.8	0.9	2.73	3.46	5.22
12	4.18	14.0	8.2	2.7	1.0	2.73	3.62	4.92
Summary	48.34	144.4	91.1	32.7	11.6	32.97	43.26	62.40

3.1.2 Geology

According to USGS Geologic Quadrangle 500K maps, all of the point-of-origin data lie within the Breathitt Coal Formation (Upper, Middle, & Lower parts) (Figure 3.7). The 24K dominant lithology of all point locations is mixed clastics. All points lie in either the Princess Formation or Four Corners 24K geologic formations (Figures 3.8-3.12). Points lie above or below a variety of coal seam formations depending on their elevations and locations. The LRL-2007-217 permit lies above of a large number of abandoned underground mines (Figure 3.13). Abandoned underground mines are also located underneath a small number of points in the Little Millseat watershed in Robinson Forest

(Figure 3.14) and the LRL-2009-384 site (Figure 3.15). None of the other points or their watersheds lie directly above previous or current underground mining activity.

Figure 3.7: Geologic formations (USGS 500K) at the study sites.

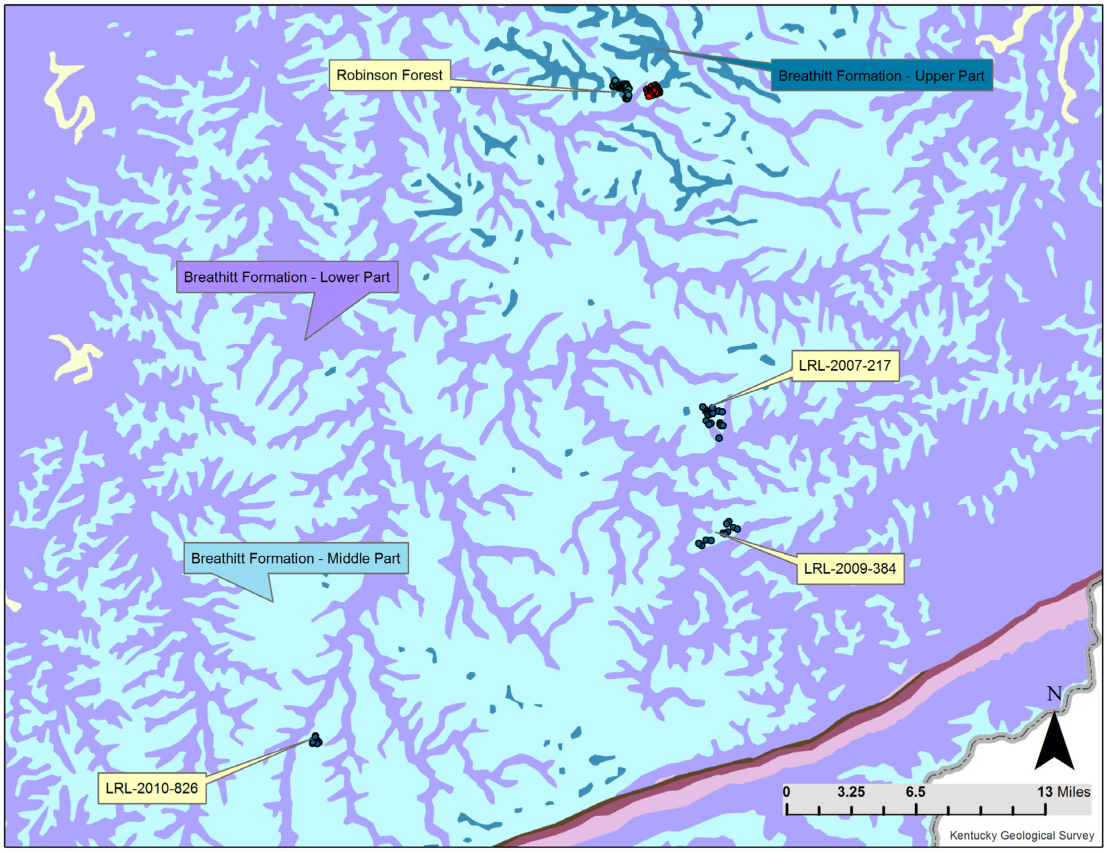


Figure 3.8: 24K geologic formations, coal beds, and geologic contacts, Little Millseat and Field Branch watersheds, Robinson Forest. *E, I and P indicate ephemeral, intermittent, and perennial, respectively.*

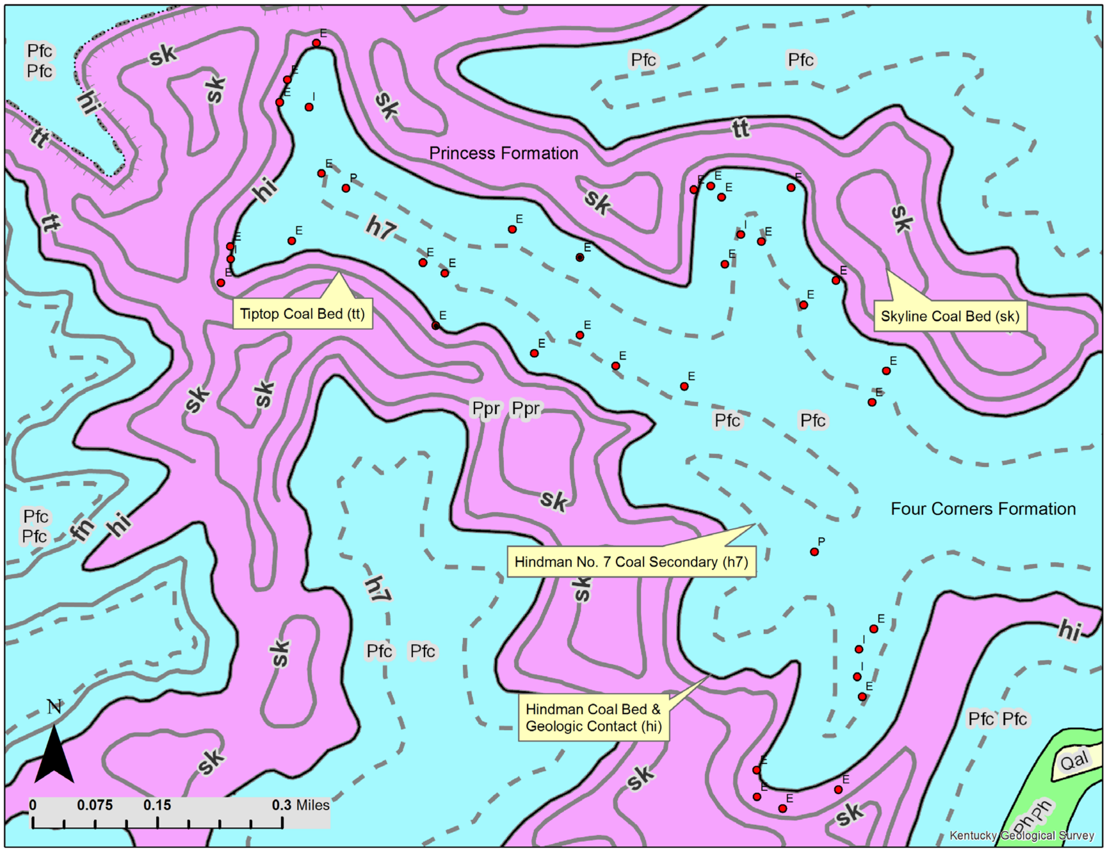


Figure 3.9: 24K geologic formations, coal beds, and geologic contacts, Falling Rock watershed, Robinson Forest. *E, I, and P indicate ephemeral, intermittent, and perennial, respectively.*

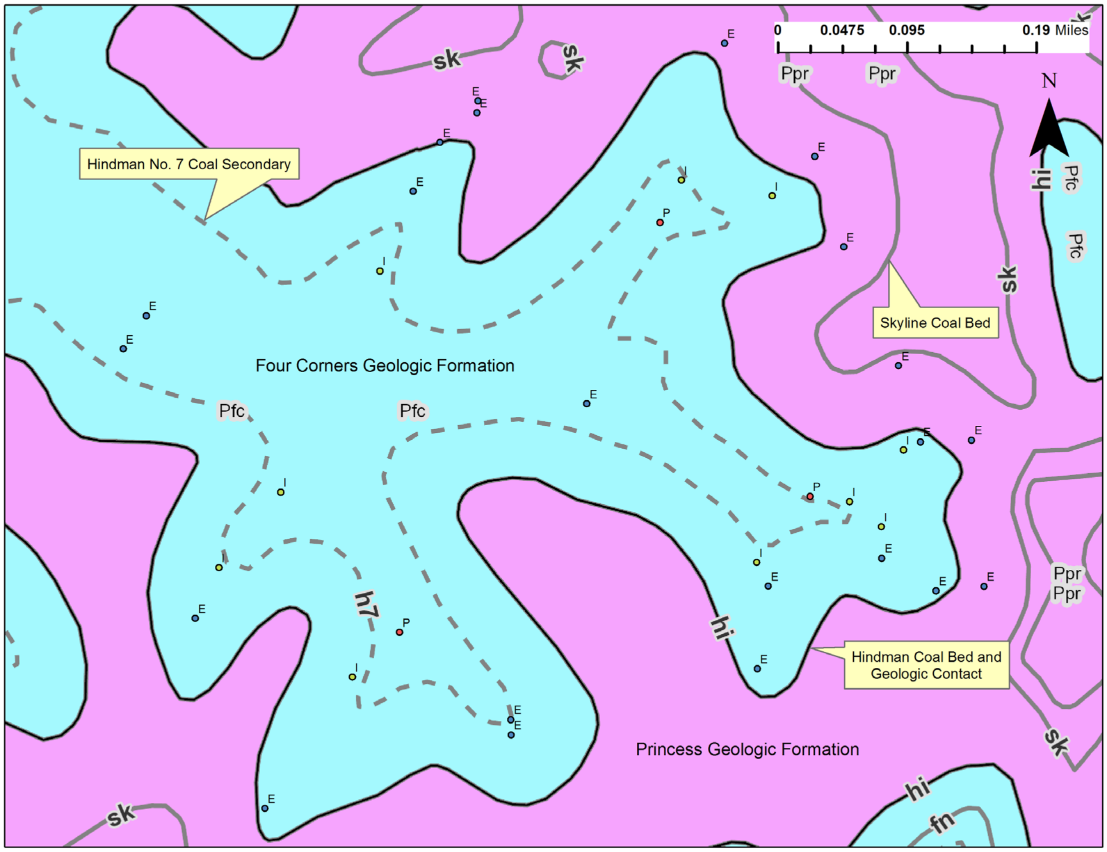


Figure 3.10: 24K geologic formations, coal beds, and geologic contacts, permit no. LRL-2007-217. *E, I, and P indicate ephemeral, intermittent, and perennial, respectively.*

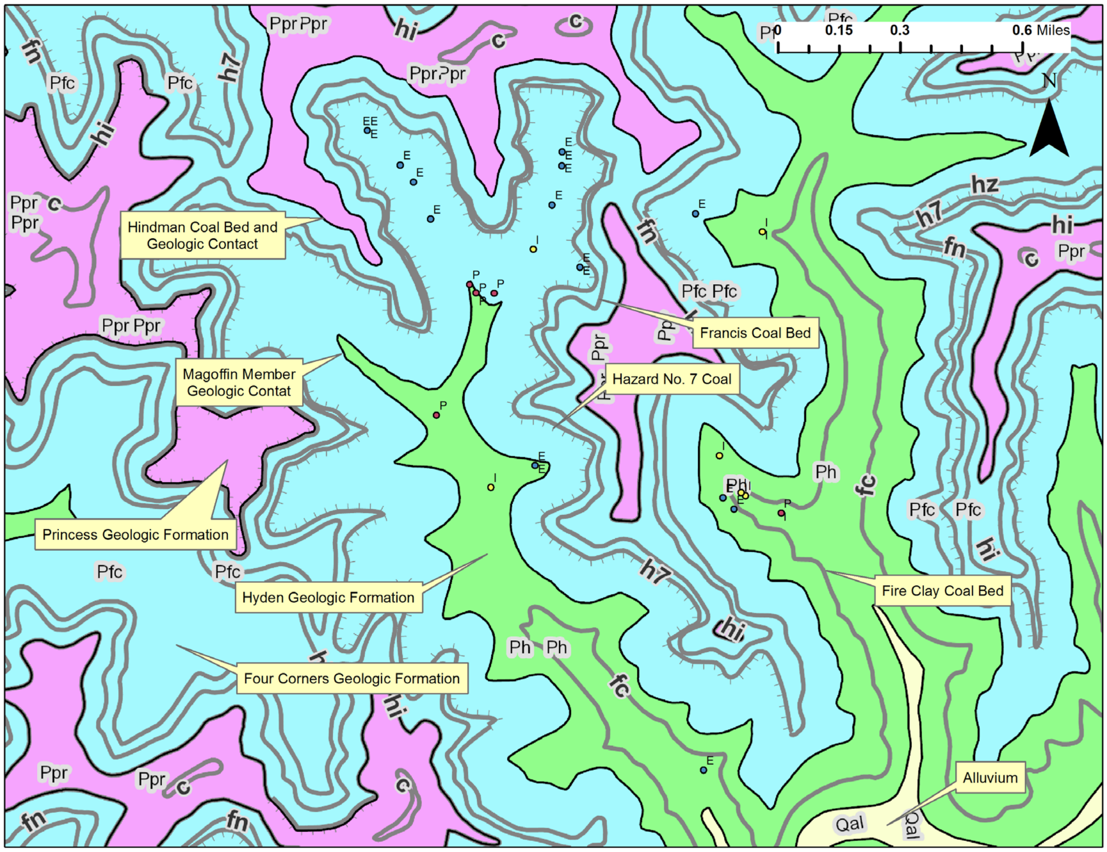


Figure 3.11: 24K geologic formations, coal beds, and geologic contacts, permit no. LRL-2009-384. *E, I, and P indicate ephemeral, intermittent, and perennial, respectively.*

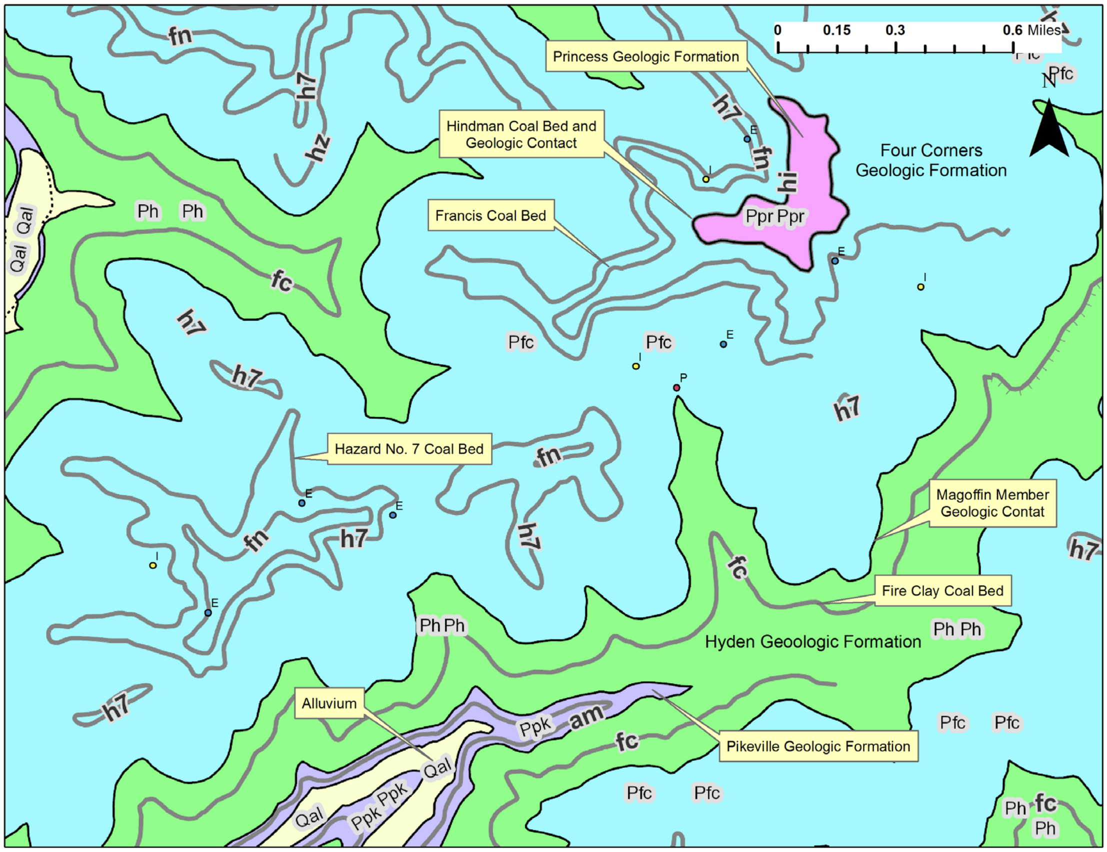


Figure 3.12: 24K geologic formations, coal beds, and geologic contacts, permit no. LRL-2010-826. *E, I, and P indicate ephemeral, intermittent, and perennial, respectively.*

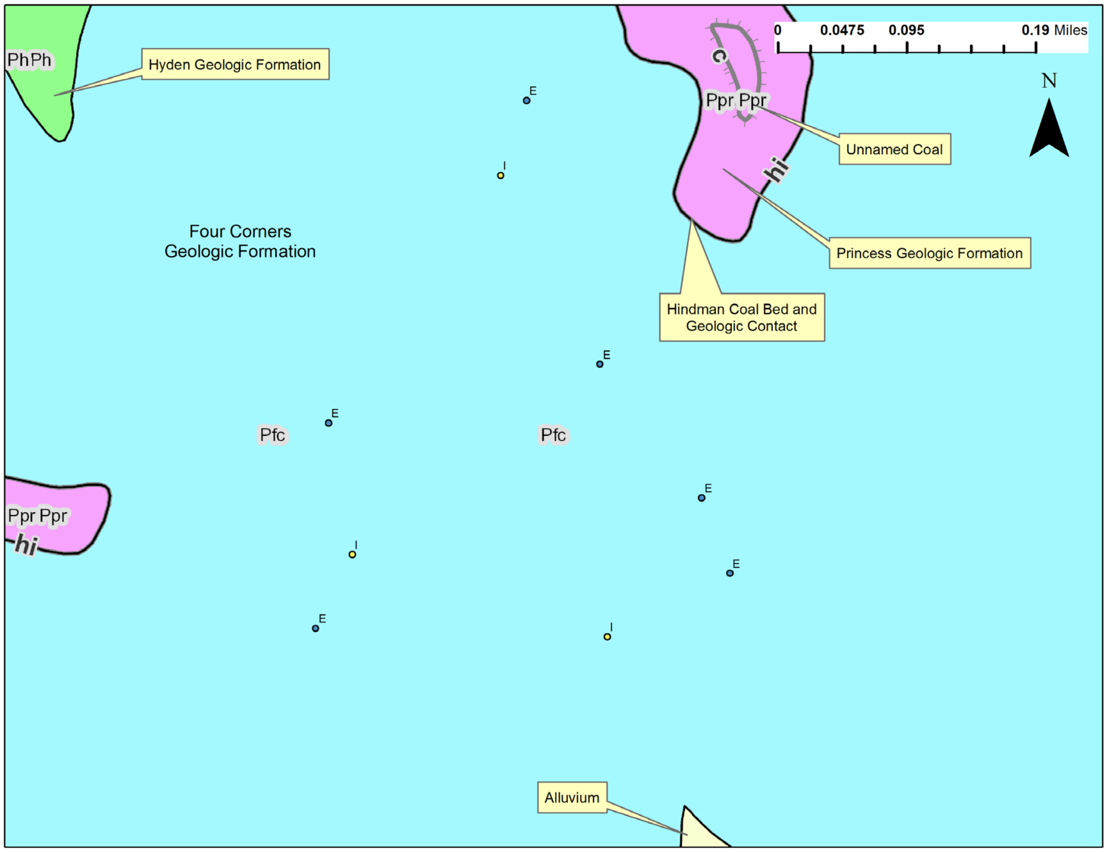


Figure 3.13: Abandoned underground mining areas, permit no. LRL-2007-217. DEM indicates digital elevation model. E, I and P indicate ephemeral, intermittent, and perennial, respectively.

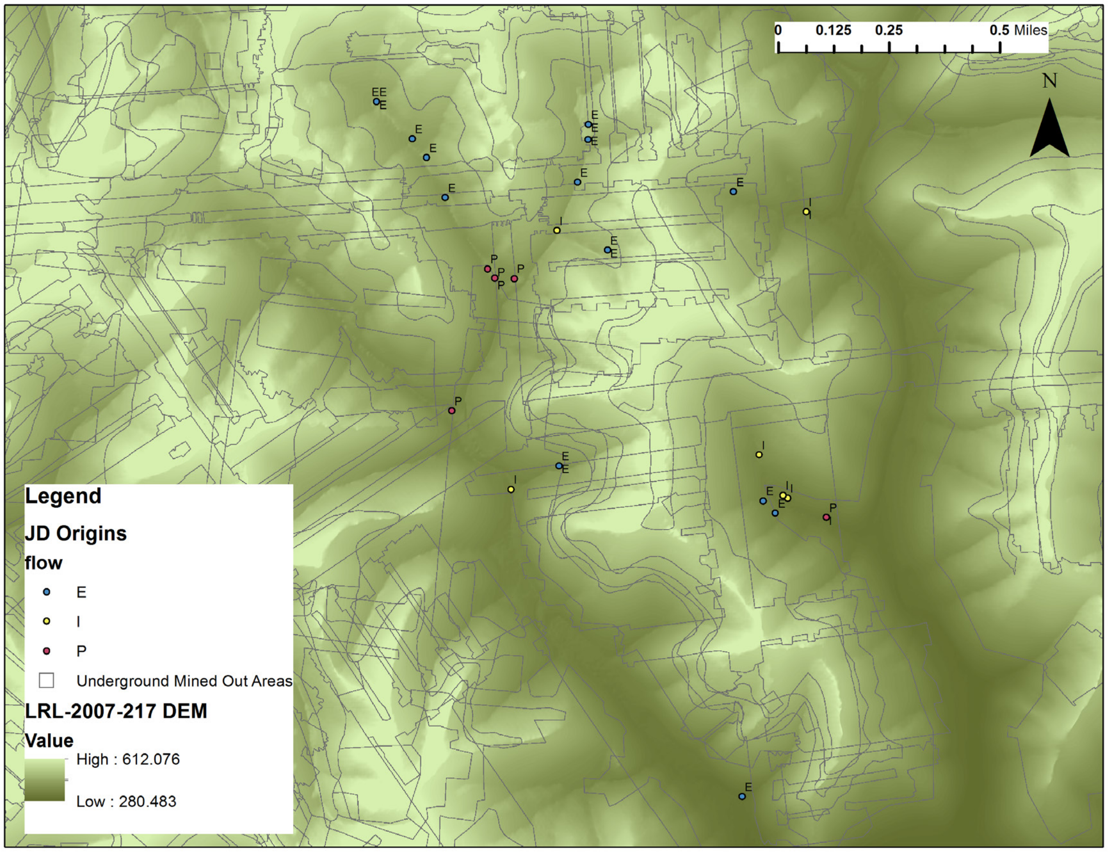


Figure 3.14: Abandoned underground mining areas, Little Millseat and Field Branch watersheds, Robinson Forest. *DEM indicates digital elevation model. Flow indicates flow regime (E=ephemeral, I=intermittent, P=perennial).*

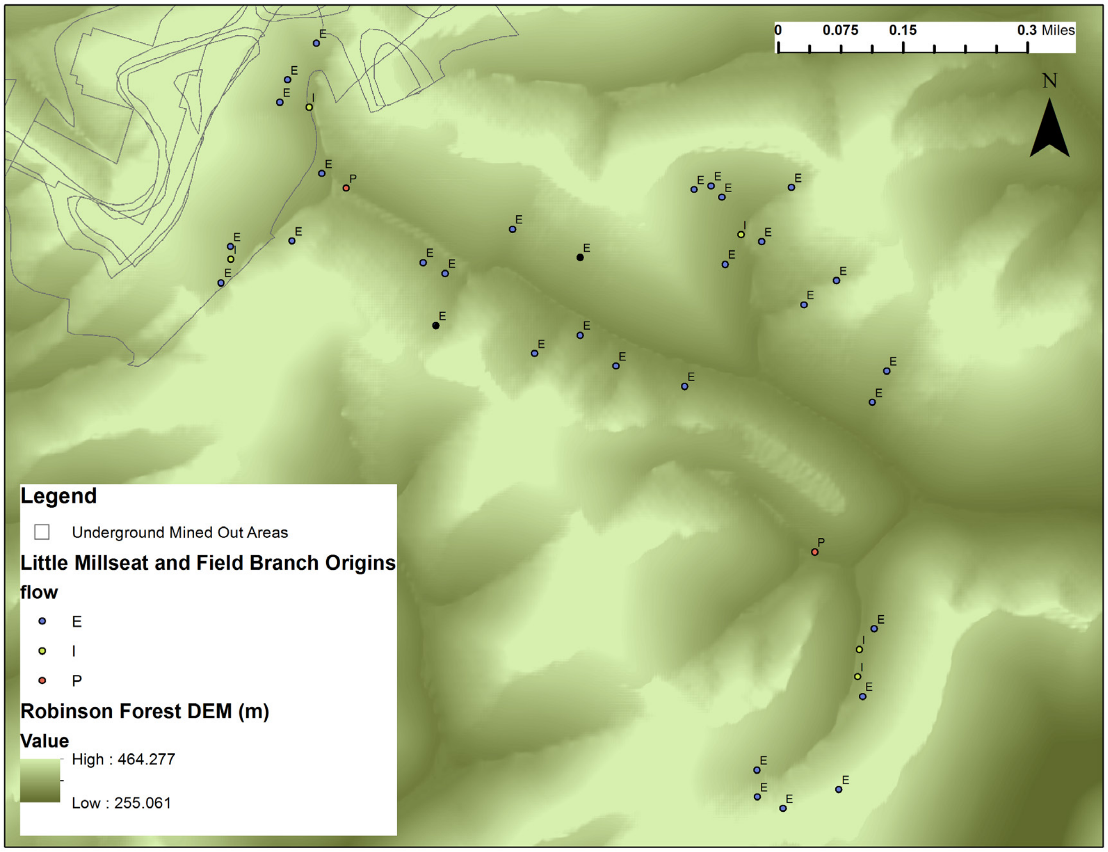
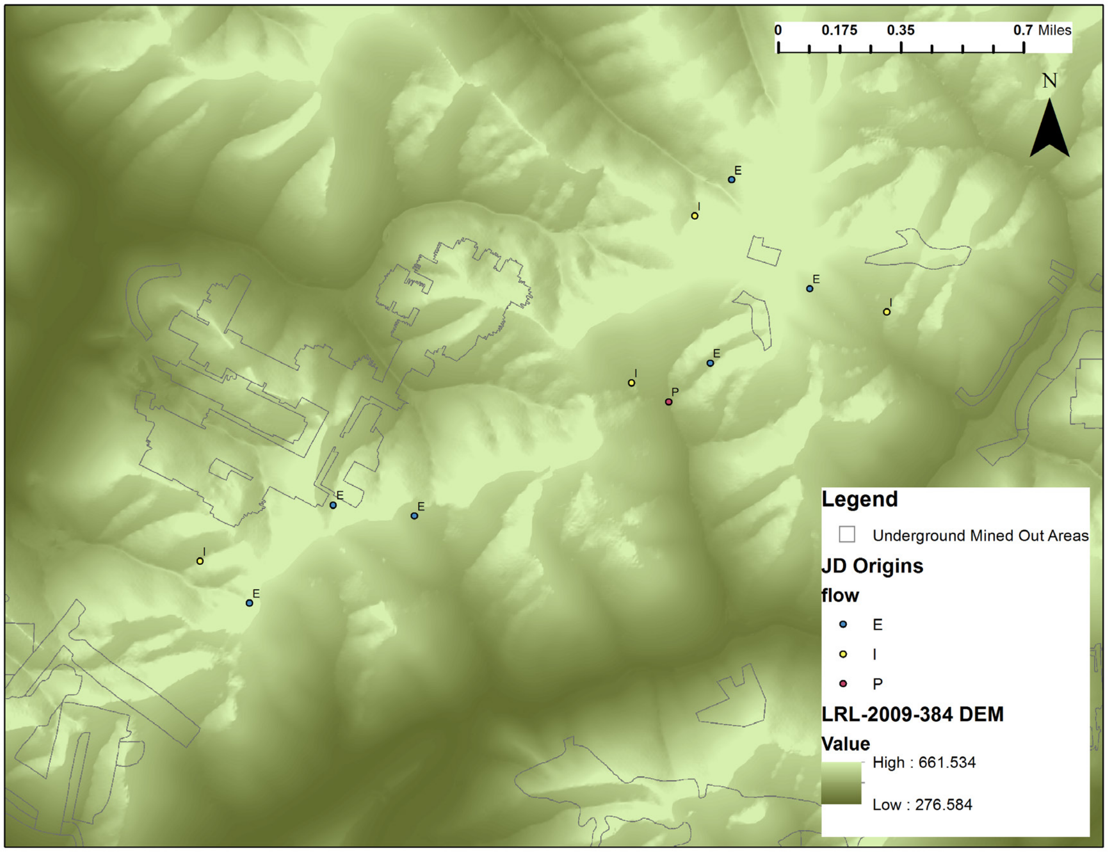


Figure 3.15: Abandoned underground mining areas, permit no. LRL-2009-384. DEM indicates digital elevation model. Flow indicates flow regime (E=ephemeral, I=intermittent, P=perennial).



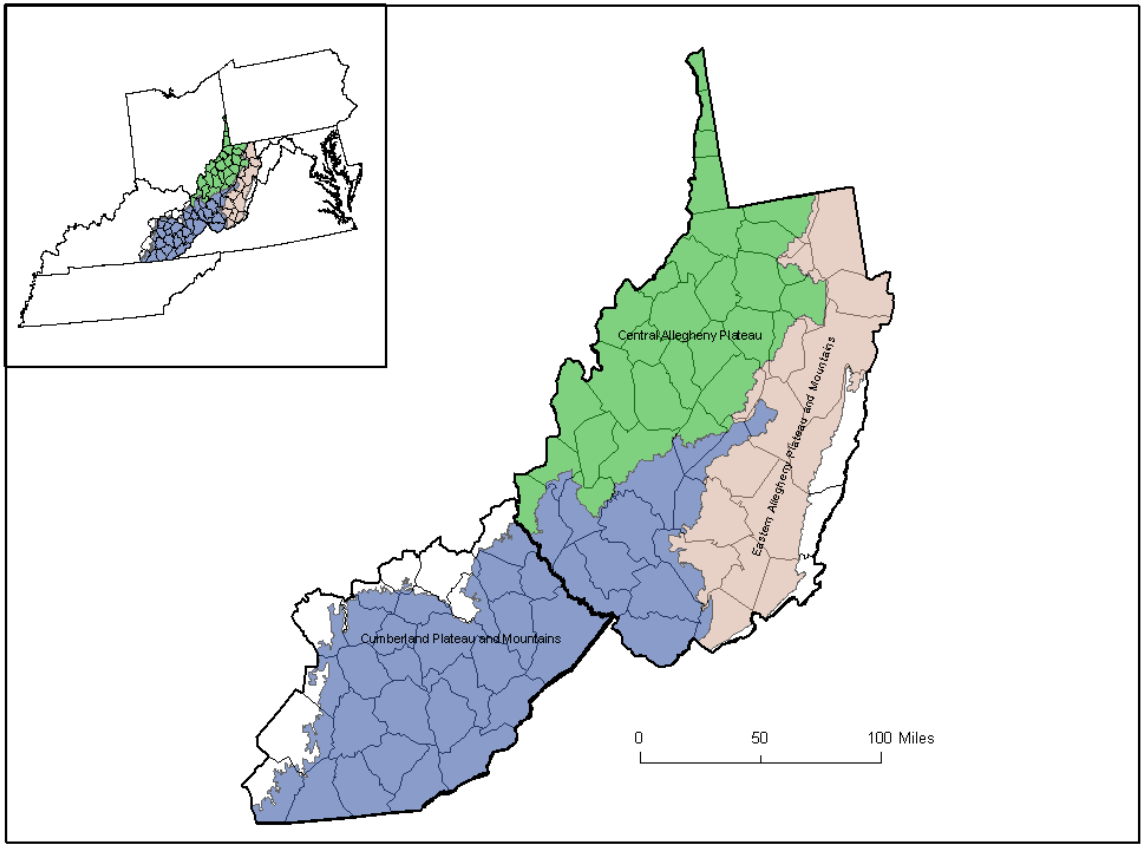
3.1.3 Major Land Resource Areas

All of the headwater streams examined in this thesis lie within Major Land Resource Area (MLRA) 125, Cumberland Plateau and Mountains, which is a section of the Appalachian Plateaus Province of the Appalachian Highlands. According to the USACE (2010) *Operational Draft Regional Guidebook for the Functional Assessment of High-gradient Ephemeral and Intermittent Headwater Streams in Western West Virginia and Eastern Kentucky*, the maximum geographic extent of similarly situated ephemeral and intermittent streams could include "much of the Appalachian Plateau from Pennsylvania to Tennessee." This area is generally encompassed by MLRAs 125, 126, and 127 (Figure 3.16). This guidebook characterizes the study area as having, " … narrow, level valleys and narrow, sloping ridgetops that are separated by long, steep and very steep side slopes dissected by numerous stream channels with no or very narrow stream floodplains" with local relief ranging from 50 to 100 m (160 to 330 ft). Average precipitation ranges from 86-130 cm (34-51 in.) and increases with elevation, with highest rainfall volume in midsummer as high-intensity thunderstorms and lowest in fall and early winter. While precipitation generally exceeds potential evapotranspiration for most of the year, deficits usually occur in summer.

3.1.4 Hydrologic Landscape Regions

The U.S. is divided into 20 Hydrologic Landscape Regions (HLR), each of which is expected to exhibit similar hydrologic characteristics according to a GIS and statistical analysis of land-surface form, geologic texture (soil and bedrock permeability), and climatic parameters (Wolock et al., 2004). HLRs with more similar numbers exhibit more similar characteristics (i.e. HLR 1 is very unlike HLR 20, and HLR 10 is much like HLR 11). HLRs are defined by a variety of characteristics analyzed on the scale of watersheds approximately 212 km^2. These characteristics include aquifer permeability (AQPERM, 1=lowest and 7=highest), slope (SLOPE), mean annual temperature (TAVE), mean annual precipitation (PPT), mean annual evapotranspiration (PET), sand content of soil (SAND), mean annual precipitation minus potential evapotranspiration (PMPE), minimum elevation with respect to mean sea level (MINELE), topographic relief (RELIEF, maximum elevation in a watershed minus minimum elevation in a watershed), total flat land (PFLATTOT, less than

Figure 3.16: Major Land Resource Areas (MLRA) 125 - Cumberland Plateau and Mountains, 126 - Central Allegheny Plateau, and 127 - Eastern Allegheny Plateau and Mountains (NRCS, 2006; USACE, 2010).



1% slope), flat land in the lowland portions of the watershed (PFLATLOW), and flat land in the upland portions of the watershed (PFLATUP).

All study locations lie within HLR 16 (Figure 3.17a-b). HLR 16 is characterized by "humid mountains with permeable soils and impermeable bedrock" with the primary hydrologic flow path being shallow groundwater as opposed to primarily overland flow or deep groundwater (Wolock et al., 2004). HLR 16 occupies the western section of the Appalachian Mountains ranging from northern Georgia and Alabama through far eastern Kentucky, southern and central West Virginia (roughly coincident with MLAs 125 and 126), western Pennsylvania, and encompassing most of upstate New York and the New England states (Figure 3.18). HLR 16 also characterizes part of northern California and southern Oregon, far western Wisconsin, part of northern Arkansas, and far western North Carolina and Virginia. Table 4 contains the HLR characteristics for the study sites.

Table 3.2: Hydrologic landscape region characteristics of the study site watersheds.

Parameter[1]	Robinson Forest	Permit no. LRL-2007-217	Permit no. LRL-2009-384	Permit no. LRL-2010-826
AQPERM	2	2	2	2
SLOPE (%)	2.2	3.4	3.8	3.9
TAVE (°C)	12.4	12.6	12.6	12.7
PPT (cm yr^{-1})	116.6	116.8	119.6	123.4
PET (cm yr^{-1})	73.9	74.4	74.4	74.7
SAND (%)	23.7	24.3	23.7	23.2
PMPE (cm yr^{-1})	42.7	42.4	45.2	48.8
MINELE (m)	319	311	311	379
RELIEF (m)	159	338	413	354
PFLATTOT (%)	14	6	4	5
PFLATLOW (%)	12	4	3	2
PFLATUP (%)	2	2	1	3

[1] AQPERM=aquifer permeability (1=lowest and 7=highest), SLOPE=slope, TAVE=mean annual temperature, PPT=mean annual precipitation, PET=mean annual evapotranspiration, SAND=sand content of soil, PMPE=mean annual precipitation minus mean annual evapotranspiration, MINELE=minimum elevation, RELIEF=topographic relief, PFLATTOT=total flat land (<1% slope), PFLATLOW= flat land in the lowland portions of the watershed, and PFLATUP= flat land in the upland portions of the watershed.

Note that these data refer to the HUC-12 scale watersheds used to characterize HLRs according to the selected parameters (Figure 3.17b). The smaller watersheds from which the selected point-of-origin data are derived may exhibit some variations from these values. For instance, the percent of flat land in the larger HLR watershed encompassing the Robinson Forest study sites (14%) is likely higher than the percentage in Robinson Forest itself, which has very little flat land. Other characteristics such as precipitation and evapotranspiration values however should be fairly consistent throughout the larger watersheds.

Figure 3.17a: Broad view of study site watersheds, all of which are located in the hydrologic landscape region (HLR) 16.

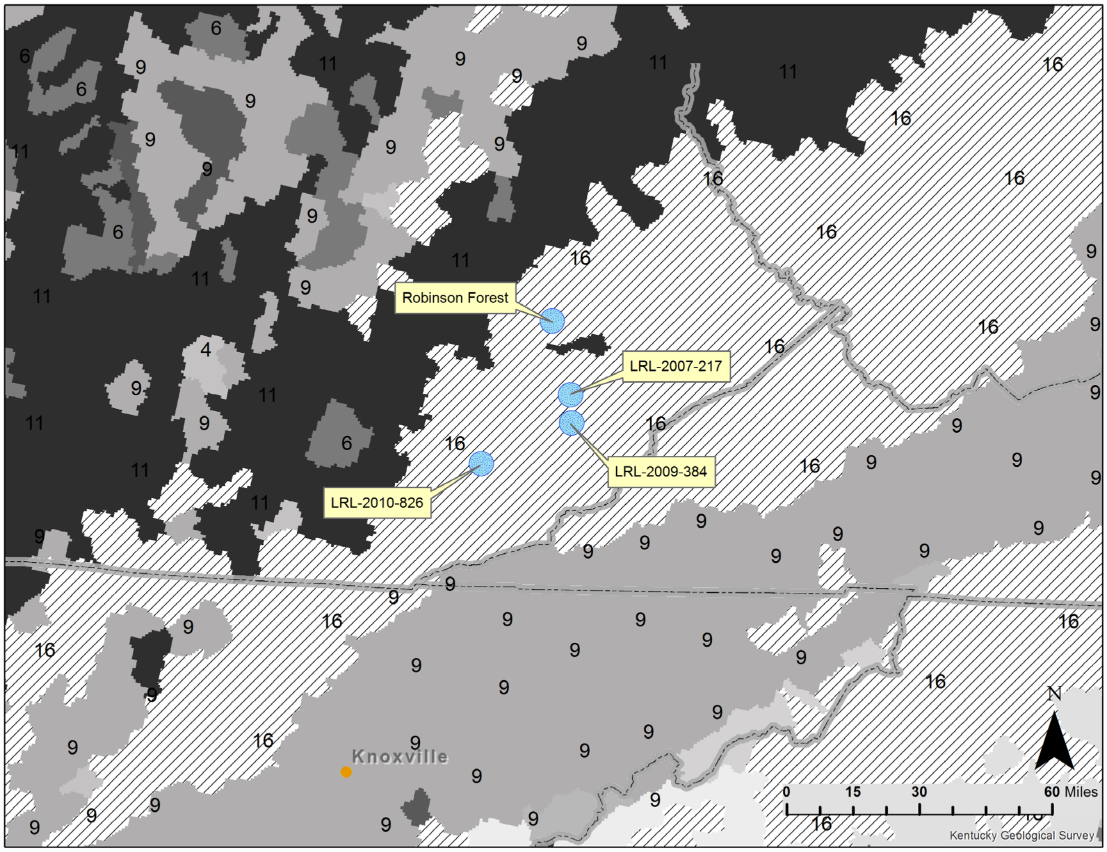


Figure 3.17b: Detailed view of study site watersheds, all of which are located in the hydrologic landscape region (HLR) 16.

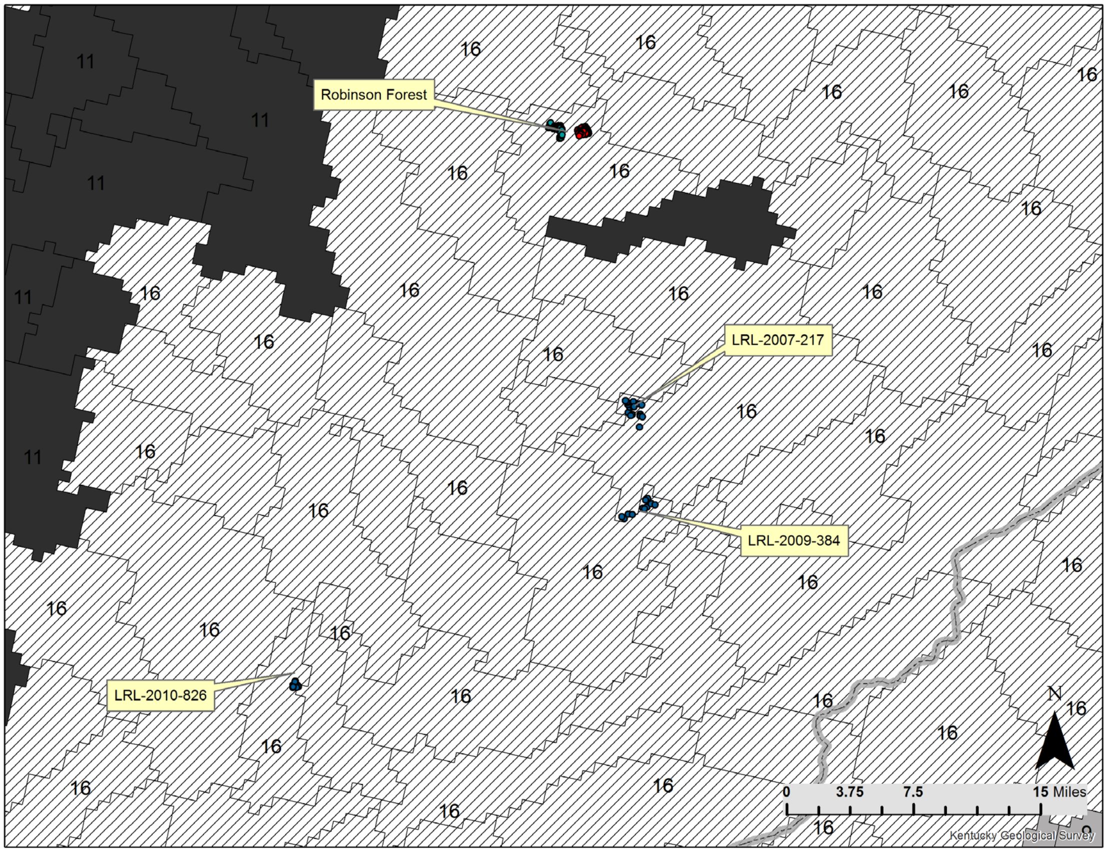
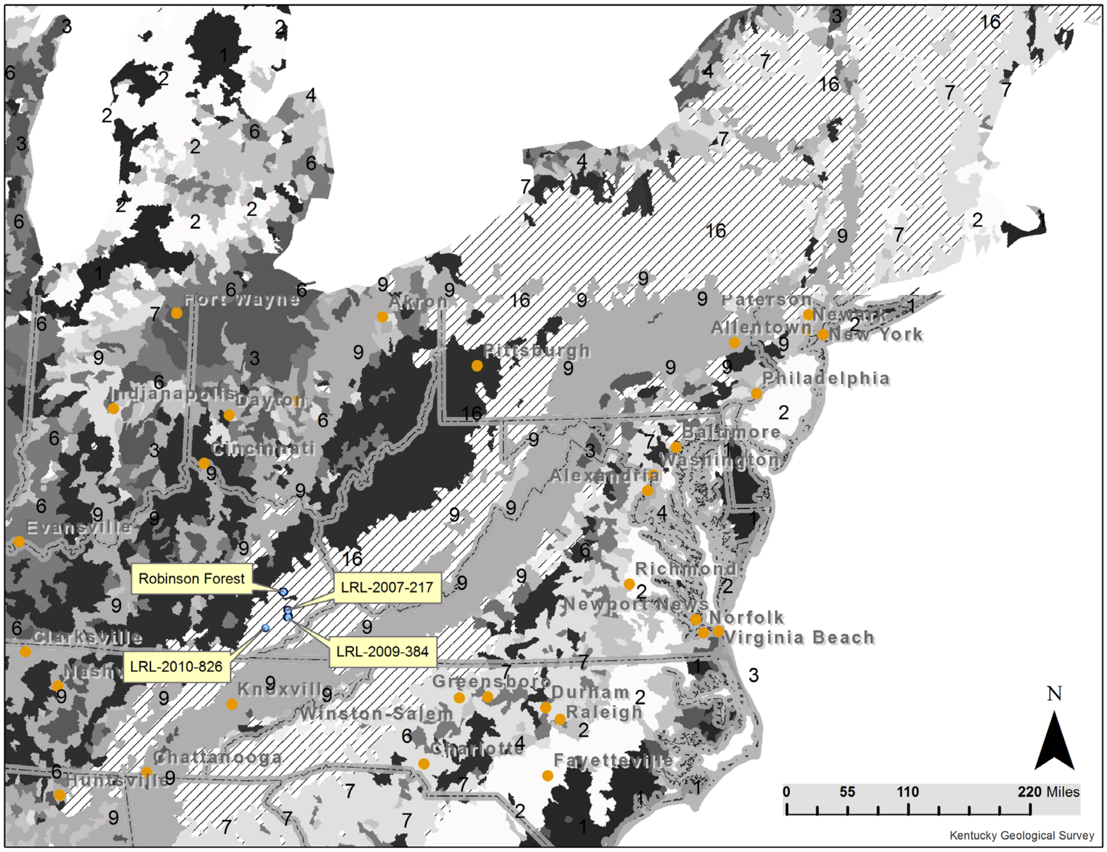


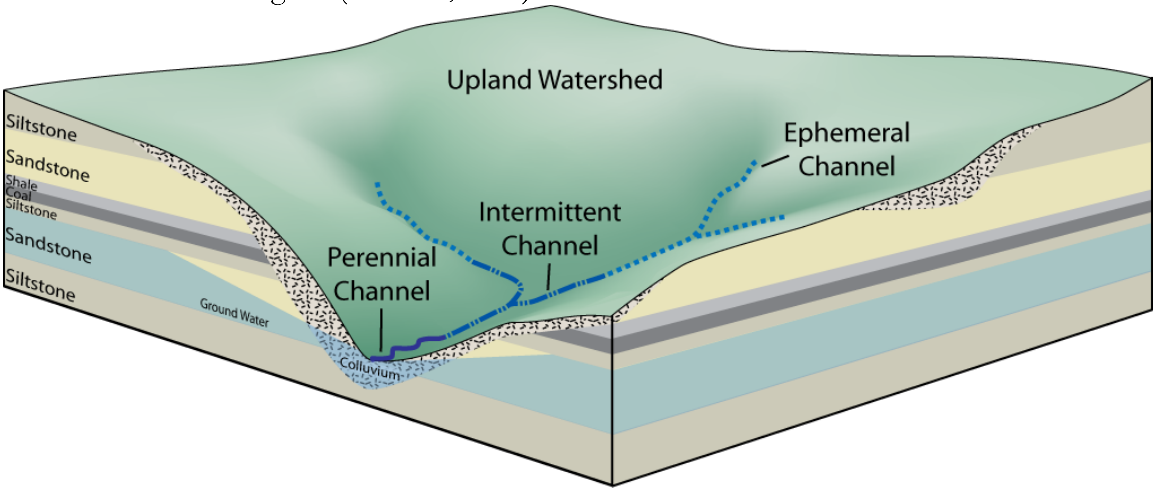
Figure 3.18: Extent of contiguous hydrologic landscape region (HLR) 16 in the eastern United States, as represented by the diagonal stripes.



3.2 FIELD IDENTIFICATION OF HEADWATER STREAMS

Identification of the points-of-origin of ephemeral, intermittent and perennial streams in Robinson Forest was done using the procedures described by Fritz et al. (2006). Field assessments were conducted in mid-to-late February 2011, and point-of-origin coordinates were recorded with a Garmin Oregon 550T portable GPS receiver (accuracy ±10 m). Figure 3.19 depicts typical ephemeral, intermittent and perennial configurations in eastern Kentucky. Intermittent streams eastern Kentucky are described by USACE (2010) as having low sinuosity, common-to-many step pool complexes, and would likely classify as A or B channels in the Rosgen stream classification system with gravel or cobble channels within Type I valleys (Rosgen, 1996). Drainage basins for ephemerals are described as small (0.4 ha or 1 ac) with many channels absent on standard 1:24,000 USGS topographic maps. Ephemeral channels may either grade into intermittent channels or flow directly into a perennial channel. Intermittent channels typically flow into perennials. Ephemeral streams

Figure 3.19: Location of ephemeral, intermittent, and perennial channels in eastern Kentucky and western West Virginia (USACE, 2010).



in this region are usually first-order, while intermittent streams are typically first or second-order. The points-of-origin of perennial headwater streams in Robinson Forest had been previously identified through other unpublished research efforts.

3.3 PARAMETER SELECTION

Parameters for characterizing each known point-of-origin location were selected based on data availability, relevance to site hydrology, and likely correlation to channel formation based on the literature review. Ideally, the selected parameters would be easily obtainable from publically available databases to enhance repeatability of the process. The parameters chosen for development of this GIS model are thus spatial rather than time-series in nature. As such, the flow regime of the streams (e.g. ephemeral, intermittent, or perennial) is a fixed input variable for purposes of model development.

The parameters considered for the GIS model are categorized as topography-based parameters and geology/soils-based parameters. From a geomorphologic and hydrologic standpoint, the topographic parameters associated with channel head locations represent a watershed's response to precipitation over a long timescale. The geology/soils parameters can be viewed similarly, except they are more likely to represent causative aspects of historical hydrology and geomorphology rather than the results (Dietrich and Dunne 1993; Montgomery 1999; Wolock et al. 2004; Fritz et al. 2006). Taken together, it is hypothesized that topographic, geologic, and soils landscape characteristics can highlight meaningful and useful relationships between flow permanence, which is difficult to characterize and extrapolate for large headwater systems (e.g. North Fork of the Kentucky River), and readily-available spatial data. Knowledge of such relationships could simplify and expedite the process of assessing cumulative hydrologic impacts due to surface mining and other anthropomorphic activity.

One difficulty that arises with respect to soils and geology, when examining points within similar terrain, is the lack of variance within the dataset. For instance, hydric soils are often viewed as a useful factor for determining headwater points-of-origin (GDNR, 2006), but all of the soils underlying the known point-of-origin data in this thesis were found to be non-hydric. Also all of the points-of-origin lie within geologic areas that are non-karst and overlie the same larger geologic formation and one of two smaller geologic formations (Four Corners and Princess Formations). After consulting with staff at the Kentucky Geologic Survey (KGS) and examining data from USGS Geologic Quadrangle maps and Soil Survey Geographic (SSURGO) Database from the U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS), a set of parameters was selected that provided the best available combination of variety within the dataset and relevance to hydrology and erosion potential. Considering the topography related variables, parameters were chosen that involved well-established relationships to headwater flow regimes and could be readily derived from publicly-available elevation data using GIS (Leopold and Miller 1956; Paybins 2003; Rivenbark & Jackson 2004; Svec et al., 2005; Bent and Steeves 2006; Fritz et al. 2008). Table 3.3 contains the parameters selected for the GIS model.

Table 3.3: Selected GIS model parameters.

Parameter	Units
Aspect	°
Elevation	m
Local Valley Slope	%
Drainage area	m^2
Soil infiltration rate	mm h^{-1}
K_w	--
K_f	--
T-factor	t ha^{-1}
% sand	%
% silt	%
% clay	%

3.3.1 Topographic Parameters

The parameter aspect refers to the compass direction of the valley face (0°=east, 90°=north, 180°=west, and 270°=south). The direction of the valley face was measured as the orientation in degrees from the channel point-of-origin to the next downstream confluence. The parameter elevation is in relation to mean sea level as determined by the DEM. The parameter local valley slope is the change in elevation of the valley divided by the linear distance along the valley from grid cells adjacent to the point-of-origin upstream and downstream of the point (as extracted from the ArcHydro Slope function). The drainage area parameter is the area of the contributing catchment upstream of the known point-of-origin as determined by the ArcHydro Point Delineation functions.

3.3.2 Soil Parameters

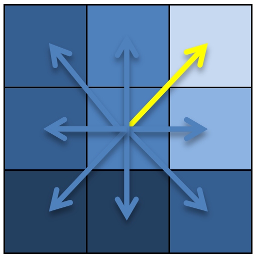
The parameter soil infiltration rate is the weighted average of the mean soil infiltration rate – a measure of soil's ability to infiltrate water from rainfall or snowmelt – for ranges established for hydrologic soil groups associated with the portions of the soil matrix underlying each known point-of-origin. K_w and K_f are soil erodibility factors that quantify soil detachment by runoff and raindrop impact. The higher the value of K_f or K_w, the more susceptible the soil is to sheet and rill erosion by rainfall. These parameters consider soil properties that affect soil erodibility such as texture, organic matter content, structure size class, and the saturated hydraulic conductivity of the subsoil. The parameter K_f is a variable used in the Revised Universal Soil Loss Equation (RUSLE) that indicates the susceptibility of the fine-earth fraction (material less than 2 mm in size) of the soil to sheet and rill erosion by rainfall. Rocks and rock fragments in the soil are not considered, unlike the parameter K_w. The parameter K_w is the same as K_f, but it is modified to consider the presence of rock and rock fragments in the soil profile. Experimentally determined values of K_w have ranged from 0.02 to 0.69. The parameter T-factor is the soil loss tolerance, and ranges from 2.4 to 12.0 metric tons per hectare. It is defined as the maximum amount of erosion at which the quality of a soil as a medium for plant growth can be maintained. This quality of the soil to be maintained is threefold in focus. It includes maintaining the surface soil as a seedbed for plants, the atmosphere-soil interface to allow the entry of air and water into the soil and still protect the underlying soil from wind and water erosion, and the total soil volume as a reservoir for water and plant nutrients, which is preserved by minimizing soil loss. The parameters % sand, % silt, and % clay are weighted averages of the constituent material composition of the component soil types underlying the known points-of-origin.

3.4 GEOGRAPHIC INFORMATION SYSTEMS (GIS) ANALYSIS

Version 10.1 of the ArcMap desktop GIS software suite along with ArcHydro Tools for ArcGIS 10.1 (version 10.1) by ESRI were used to delineate catchments and extract data on the selected parameters (Table 3.3) corresponding to the point-of-origin data from the study sites. The raw data input to the software includes: (1) a DEM (a raster representation of a topographic contour map) which was obtained from the NED via the USGS Seamless Web Server Viewer, now *The National Map* Viewer and Download Platform (http://viewer.nationalmap.gov/viewer), (2) SSURGO soils data from the USDA NRCS Soils Data Mart (http://soildatamart.nrcs.usda.gov), and (3) NHDPlus version 2 data obtained from Horizon Systems Corporation (http://www.horizon-systems.com/NHDPlus/NHDPlusV2_05.php). The DEM data resolution was 1/3 arc-second or approximately 9.42 m per grid cell. The DEM data, point-of-origin coordinates from the study sites, NHDPlus data, SSURGO soils data (joined to the corresponding Access database), USGS Geologic Quadrangle maps, high-resolution orthoimagery, Kentucky Geological Survey (KGS) resources, HLR data, and all other spatially referenced data utilized in the GIS analysis were projected to the NAD_1983_UTM_Zone_17N spatial reference (Datum: D_North_American_1983). The AGREE method for "burning-in" NHDPlus blue-line stream features to force flow convergence along certain paths was not used in this analysis.

ArcHydro Tools uses a "pour-point" model to generate a system of potential drainage paths given DEM topographic data. Each square grid cell in the DEM represents an area of terrain and a corresponding elevation. Water is assumed to flow only in the direction of steepest descent as determined by comparing the elevations of each grid cell to its eight surrounding cells (Figure 3.20). Each time a cell is marked as receiving flow from another cell according to this method, it increments a flow index for that cell. The result is a "flow accumulation grid" in which each cell (representing a roughly 10 m x 10 m area) is represented by the flow index indicating its total accumulation of flow from contributing upslope cells. This flow accumulation grid can then be used to delineate a hierarchical ordered stream network by selecting a grid cell threshold (GCT) corresponding to the smallest drainage area for which a stream will be drawn. For example, if a GCT value of 100 is selected as the threshold for delineation, given a DEM resolution of approximately 10 m (100 m^2 per cell), streams will be delineated at all points receiving flow contribution from at least 100 upland grid cells or 10,000 m^2 (1 ha).

Figure 3.20: In the GIS flow accumulation grid model, water can only flow in one direction: the direction of steepest descent (i.e., to the lowest adjacent elevation – the lightest blue square in this example) from one grid cell to an adjacent grid cell.



At this stage in the analysis, it is not necessary that the selected GCT exactly matches the thresholds for delineating catchments at actual ephemeral, intermittent or perennial points-of-origin. This theoretical stream network along with its associated grid of catchments is used to facilitate the delineation of drainage areas using the known point-of-origin coordinates from the six study sites. It is helpful, however, if the GCTs used are similar to those representing the actual drainage areas of the points being analyzed. This is because ArcHydro will only delineate the intended drainage areas for points that lie along the 'longest flow path' or 'main flow path' for a catchment as predicted by the model at a given GCT. Catchments for field-sourced points that lie outside this predicted path will be improperly delineated, and since the predicted flow paths may change based on the GCT chosen, it is important that the catchment for each point be delineated using a GCT that represents the likely flow accumulation at the scale of the actual site topography. Since drainage areas for actual headwater channels will vary in size even at the local level, a variety of GCTs were used to create delineation frameworks for each of the six study sites. It was found that a 75 GCT or 100 GCT (0.75 ha or 1.0 ha) was typically most appropriate. Using these GCTs (as opposed to significantly larger or smaller ones) minimized the delineation of extraneous channels and provided flow paths that minimized the need to make X-Y plane adjustments to the point-of-origin data.

Some manual adjustment of the field-derived points was still required, such as moving a point to lie along the predicted flow path in the intended catchment, to ensure proper delineation of drainage areas according to the ArcHydro model. Adjustment was done manually for each point (as opposed to using the ArcHydro "snapping" function which automatically moves points based on an input raster and may result in undesirable lengthening or shortening of channels) in consideration of the proper GCT and an attempt to minimize both lateral and vertical alterations to the original coordinate data. In a small number of cases where the best adjustment was not immediately obvious, first-order channel cross-sections were examined for presence of a potential headcut as an indicator of the intended point-of-origin observation. For this process, a headcut was defined as a change in elevation greater than or equal to approximately 5 m between adjacent grid cells (NCDWQ, 2005; Fritz 2006). In some instances, the field-sourced point-of-origin could not be adjusted without introducing an unacceptable variation from the original point, or the field-sourced point did not appear to accurately reflect the topography according to the DEM. In these cases the points were not adjusted and were not utilized in collecting data for the model.

3.5 STATISTICAL ANALYSIS

The dataset of 100 ephemeral, intermittent, and perennial points-of-origin was divided into two larger groupings: a control group of 48 points from Robinson Forest and 52 points from three permitted sites. The control group was used to develop the GIS model while the permitted sites were used for comparison. These datasets were further subdivided according to the three watersheds in Robinson Forest (Little Millseat, Field Branch, and Falling Rock) and the three permitted sites obtained from the FOIA request (LRL-2007-217, LRL-2009-384, and LRL-2010-826).

3.5.1 Descriptive Statistics

SigmaPlot 12 was used to compute descriptive statistics (minimum, maximum, median, mean and standard deviation) for each study site (Robinson Forest and permitted) as well as each individual watershed within the study sites (Little Millseat, Field Branch, Falling Rock, LRL-2007-217, LRL-2009-384, and LRL-2010-826) based on stream type flow regimes (e.g. ephemeral, intermittent, and perennial).

3.5.2 Study Site Comparisons

One-way ANOVAs were used to compare hydrologic and geologic/soil parameters, for a given stream flow regime, within a study site (e.g. Little Millseat v. Field Branch v. Falling Rock and LRL-2007-217 v. LRL-2009-384 v. LRL-2010-826). Student's t-tests were used to compare hydrologic and geologic/soil parameters, within a stream flow regime type, between the watersheds at Robinson Forest and those at the permitted sites. A significance level of p=0.05 was used.

3.5.3 Pearson Correlation Analysis

Pearson correlation analysis was performed to look for correlations among variables within each study site across groupings of flow regimes including ephemeral only (E), ephemeral and intermittent together (EI), and ephemeral, intermittent, and perennial together (EIP) using SAS version 9.3. These combinations were used because expected relationships between parameters, for example local valley slope and elevation, are likely to be observed primarily across a range of flow regimes and not within a single regime. This is because the different regimes typically occur at different landscape scales. The heterogeneity of point-of-origin locations and characteristics within a particular flow regime type may or may not be sufficient to detect correlations between parameters, if such correlations exist. A significance level of p=0.05 was used.

3.5.3.1 Hypotheses

Based on previous research and knowledge of the control location, it was hypothesized that from among the selected representative parameters, drainage area and local valley slope, and to a lesser extent elevation, would be most likely to uniquely characterize distinct stream flow regime types at a given site (Paybins, 2003; Fritz et al., 2008). This is because ephemeral stream origins were observed in the field to occur at higher elevations with higher slopes and smaller upland contributing areas as compared to their intermittent and perennial counterparts. However ephemeral origins, which comprised the majority of total observations, occurred at a variety of elevations within and across watersheds depending on local topographic relief, baseline (i.e. perennial origin) elevation, and other factors. Therefore it was difficult to hypothesize an a priori relationship between absolute elevation itself and the presence of a particular flow regime. Based on Schumm (1979), an inverse correlation between drainage area and local valley slope as well as between drainage area and elevation across a range of stream flow regime types was expected. Similarly, a positive correlation was expected between local valley slope and elevation based on the dendritic mountainous terrain of the Appalachian Plateau region, where valley slope tends to increase with increasing elevation and upland area or drainage area tends to decrease with increasing elevation. The nature of this relationship, however, as evidenced by the degree of possible correlation between drainage area and local valley slope, drainage area and elevation, and local valley slope and elevation, may provide a more detailed hydrologic characterization of the landscape than that provided by consideration of topographic relief alone, as utilized in determining HLRs.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 TYPICAL STREAM CHARACTERISTICS

4.1.1 Robinson Forest Descriptive Statistics

Descriptive statistics for stream points-of-origin from Robinson Forest are presented separately for each of the three flow regimes (ephemeral, intermittent, and perennial) for the three study watersheds (Little Millseat - LMS, Field Branch - FB, and Falling Rock - FR) as well as combined. One-way ANOVAs were used to compare each parameter between these three control watersheds when enough data were available for a particular flow regime.

4.1.1.1 Ephemeral Descriptive Statistics

As seen in Table 4.1 and Figures 4.1-4.3, the median drainage area for the ephemeral streams examined in Robinson Forest is 0.64 ha with a median local valley slope of 44.1% and a median elevation of 374.8 m. Drainage areas are smaller in Field Branch (median=0.50 ha) as compared to Little Millseat (median=0.62 ha) and Falling Rock (median=0.92 ha) (Tables 4.2-4.3; Figure 4.4). Local valley slopes are steepest in Field Branch (median=48.4%) followed by Little Millseat (median=41.6%) and Falling Rock (median=42.0% (Figure 4.5). The point-of-origin occurrence is highest for Field Branch (387.8 m) followed by Falling Rock (376.3 m) and Little Millseat (374.1 m) (Figure 4.6). For all three watersheds, the soil type was loam. None of the hydrologic or geologic/soil parameters differed between the three sites with respect to ephemeral points-of-origin (Table 4.5).

Table 4.1: Robinson Forest ephemeral descriptive statistics (all sites, n=33).

Parameter	Min.	Max.	Median	Mean	Std. Dev.
Elevation (m)	331.8	419.9	374.8	374.8	21.8
Local Valley Slope (%)	26.3	55.6	44.1	42.6	7.2
Drainage Area (ha)	0.17	2.24	0.64	0.73	0.48
Infiltration Rate (mm hr^{-1})	5.33	5.84	5.84	5.59	0.25
K_w	0.26	0.29	0.29	0.27	0.01
K_f	0.27	0.30	0.30	0.30	0.00
T-Factor (t ha^{-1})	4.8	9.6	9.6	9.5	0.8
% Sand[1]	35.0	41.1	35.0	36.9	2.0
% Silt	42.1	45.4	45.4	43.9	1.7
% Clay	15.3	19.6	19.6	19.3	0.7

[1]Soil type = loam

Figure 4.1: Robinson Forest mean and median drainage areas by flow regime. *E, I and P indicate ephemeral, intermittent, and perennial, respectively.*

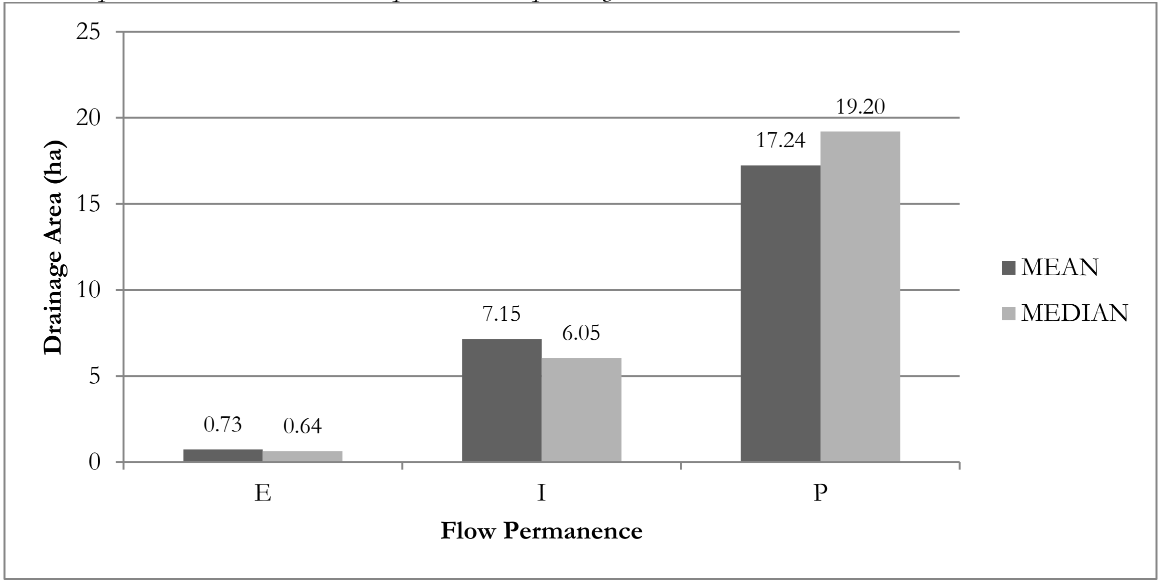


Figure 4.2: Robinson Forest mean and median local valley slope by flow regime. *E, I and P indicate ephemeral, intermittent, and perennial, respectively.*

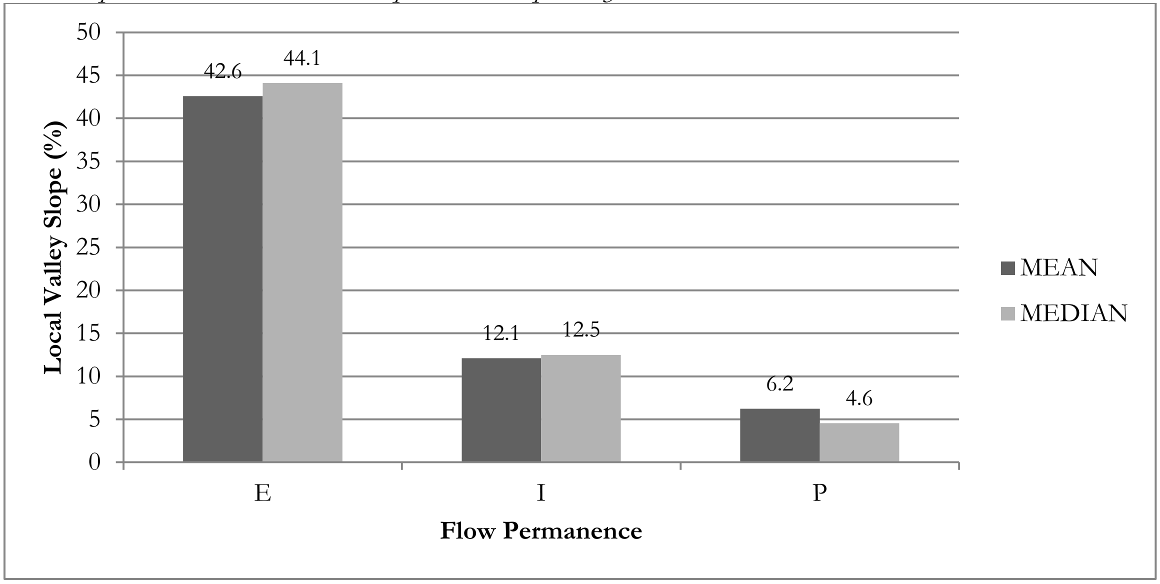


Figure 4.3: Robinson Forest mean and median point-of-origin elevation by flow regime. *E, I and P indicate ephemeral, intermittent, and perennial, respectively.*

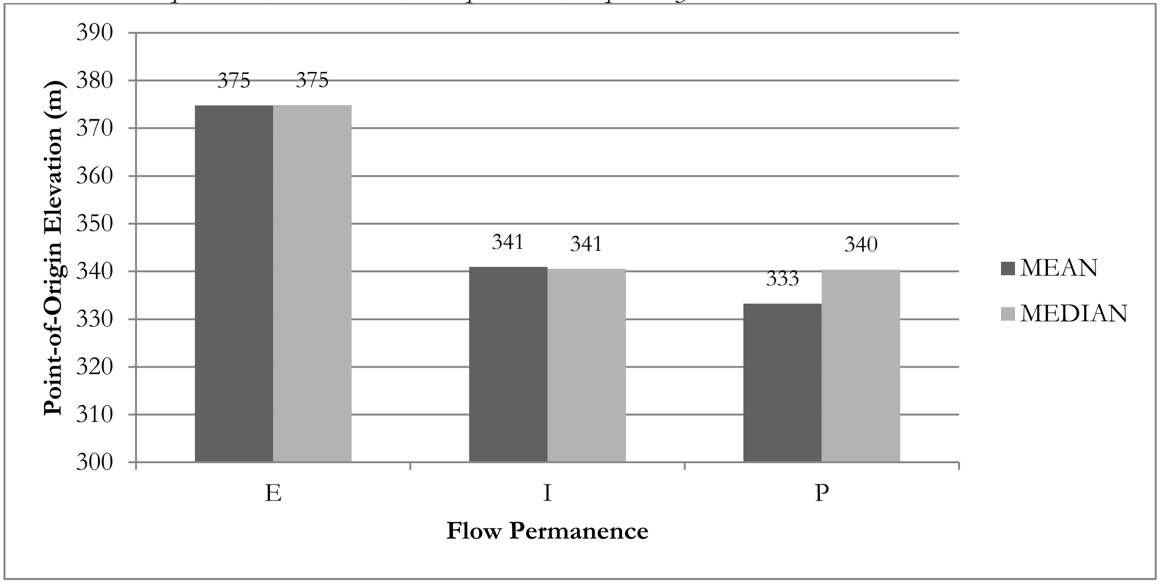


Table 4.2: Little Millseat ephemeral descriptive statistics (n=15).

Parameter	Min.	Max.	Median	Mean	Std. Dev.
Elevation (m)	335.8	391.5	374.1	371.2	17.0
Local Valley Slope (%)	31.6	51.8	41.1	41.6	6.4
Drainage Area (ha)	0.27	1.11	0.64	0.62	0.28
Infiltration Rate (mm hr^{-1})	5.30	5.72	5.72	5.56	0.16
K_w	0.26	0.29	0.29	0.28	0.01
K_f	0.30	0.30	0.30	0.30	0.00
T-Factor (t ha^{-1})	9.6	9.6	9.6	9.6	0.00
% Sand[1]	35.0	38.7	35.0	36.7	1.9
% Silt	42.1	45.4	45.4	43.9	1.7
% Clay	19.1	19.6	19.6	19.4	0.2

[1] Soil type = loam

Table 4.3: Field Branch ephemeral descriptive statistics (n=4).

Parameter	Min.	Max.	Median	Mean	Std. Dev.
Elevation (m)	347.5	399.0	387.8	380.5	23.1
Local Valley Slope (%)	43.6	54.1	47.9	48.4	4.3
Drainage Area (ha)	0.17	0.81	0.51	0.50	0.26
Infiltration Rate (mm hr^{-1})	5.41	5.72	5.56	5.56	0.18
K_w	0.26	0.29	0.27	0.27	0.01
K_f	0.30	0.30	0.30	0.30	0.00
T-Factor (t ha^{-1})	9.6	9.6	9.6	9.6	0.00
% Sand[1]	35.0	38.7	36.9	36.9	2.2
% Silt	42.1	45.4	43.8	43.8	1.9
% Clay	19.1	19.6	19.4	19.4	0.3

[1] Soil type = loam

Table 4.4: Falling Rock ephemeral descriptive statistics (n=14).

Parameter	Min.	Max.	Median	Mean	Std. Dev.
Elevation (m)	331.8	419.9	376.3	376.9	26.5
Local Valley Slope (%)	26.3	55.6	44.4	42.0	8.2
Drainage Area (ha)	0.18	2.24	0.67	0.92	0.64
Infiltration Rate (mm hr^{-1})	5.41	5.72	5.72	5.59	0.16
K_w	0.26	0.29	0.27	0.27	0.01
K_f	0.27	0.30	0.30	0.30	0.01
T-Factor (t ha^{-1})	4.8	9.6	9.6	9.4	1.2
% Sand[1]	35.0	41.1	36.9	37.0	2.2
% Silt	42.1	45.4	44.5	43.9	1.6
% Clay	15.3	19.6	19.4	19.1	1.1

[1] Soil type = loam

Table 4.5: Results of comparison of ephemeral stream characteristics at Robinson Forest.

Parameter	LMS[1]	FB	FR
Elevation (m)	371.2 a[2]	380.5 a	376.9 a
Local Valley Slope (%)	41.6 a	48.4 a	42.0 a
Drainage area (ha)	0.62 a	0.50 a	0.92 a
Infiltration Rate (mm hr^{-1})	5.56 a	5.56 a	5.59 a
K_w	0.28 a	0.27 a	0.27 a
K_f	0.30 a	0.30 a	0.30 a
T-Factor (t ha^{-1})	9.6 a	9.6 a	9.4 a
Sand (%)	36.7 a	36.9 a	37.0 a
Silt (%)	43.9 a	43.8 a	43.9 a
Clay (%)	19.4 a	19.4 a	19.1 a

[1] LMS=Little Millseat; FB=Field Branch; FR=Falling Rock.

[2] Rows with same letters are not significantly different (*p*=0.05).

Figure 4.4: Robinson Forest mean drainage areas by flow regime and watershed. *E, I and P indicate ephemeral, intermittent, and perennial, respectively. LMS indicates Little Millseat, FB indicates Field Branch, and FR indicates Falling Rock.*

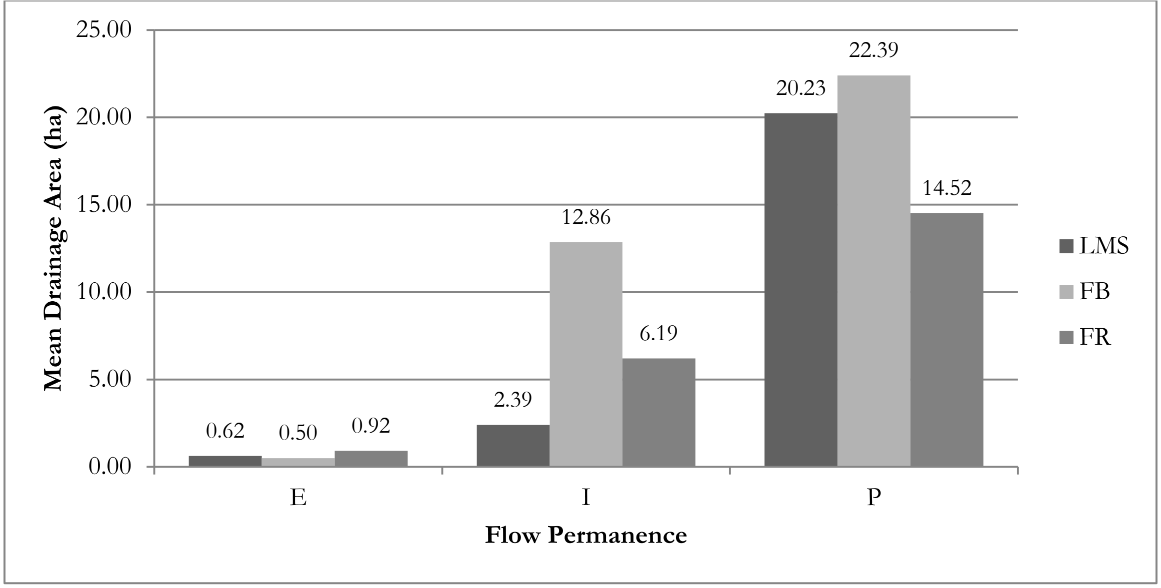


Figure 4.5: Robinson Forest mean local valley slope by flow regime and watershed. *E, I and P indicate ephemeral, intermittent, and perennial, respectively. LMS indicates Little Millseat, FB indicates Field Branch, and FR indicates Falling Rock.*

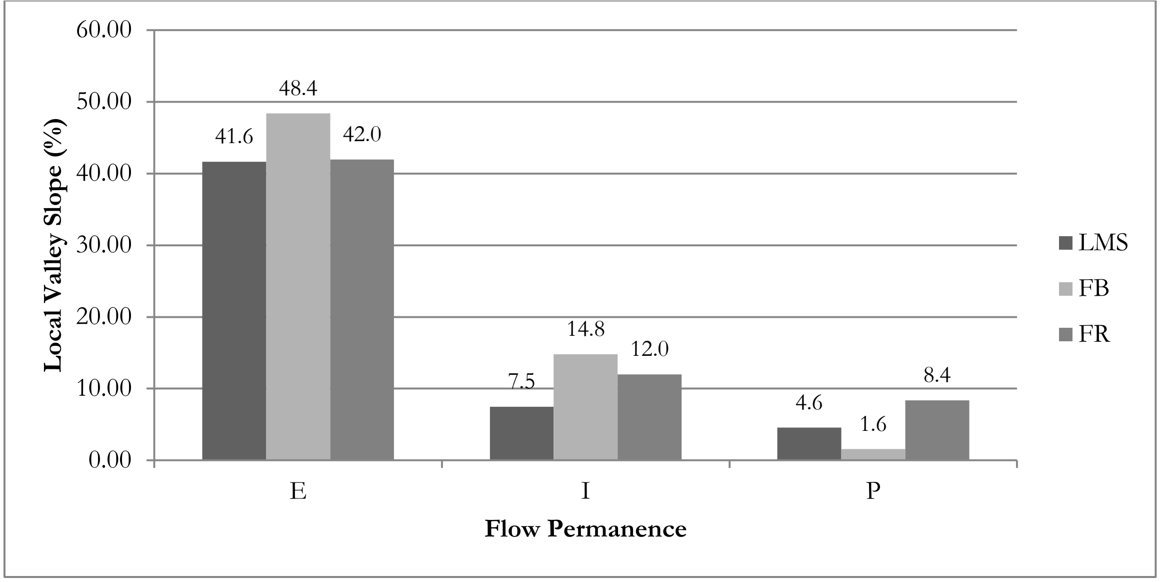
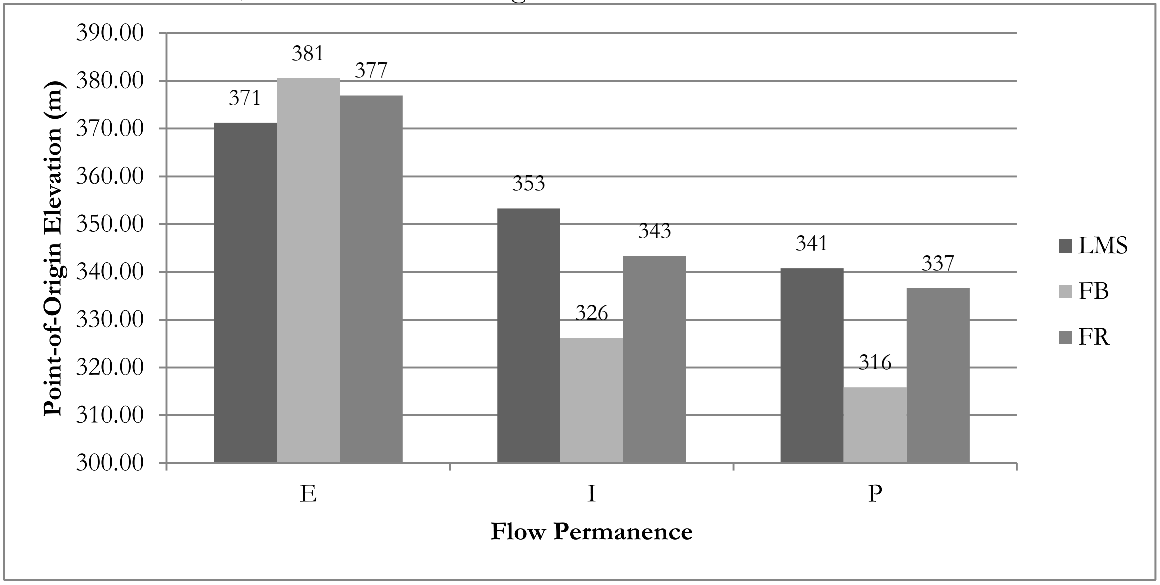


Figure 4.6: Robinson Forest mean point-of-origin elevation by flow regime and watershed. *E, I and P indicate ephemeral, intermittent, and perennial, respectively. LMS indicates Little Millseat, FB indicates Field Branch, and FR indicates Falling Rock.*



4.1.1.2 Intermittent Descriptive Statistics

As seen in Table 4.6 and Figures 4.4-4.6, the median drainage area for the intermittent streams examined in Robinson Forest is 7.15 ha with a median local valley slope of 12.5% and a median point-of-origin elevation of 340.6 m. Drainage areas are smaller in Little Millseat (median=2.39 ha) as compared to Falling Rock (median=5.84 ha) and Field Branch (median=12.86 ha) (Tables 4.7-4.9) (Figure 4.4). Local valley slopes are steepest in Field Branch (median=14.8%) followed by Falling Rock (median=11.2%) and Little Millseat (median=7.5%) (Figure 4.5). The point-of-origin occurrence is highest for Little Millseat (353.3 m) followed by Falling Rock (340.7 m) and Field Branch (326.2 m) (Figure 4.6). For all three watersheds, the soil type was loam. Since only one intermittent stream was present in Little Millseat, between watershed statistical comparisons were not performed.

Table 4.6: Robinson Forest intermittent descriptive statistics (all sites, n=10).

Parameter	Min.	Max.	Median	Mean	Std. Dev.
Elevation (m)	323.9	360.2	340.6	340.9	11.6
Local Valley Slope (%)	1.4	22.0	12.5	12.1	5.9
Drainage Area (ha)	2.39	13.84	6.05	7.15	3.59
Infiltration Rate (mm hr^{-1})	5.33	5.84	5.84	5.59	0.25
K_w	0.26	0.29	0.29	0.28	0.01
K_f	0.30	0.30	0.30	0.30	0.00
T-Factor (t ha^{-1})	9.6	9.6	9.6	9.6	0.00
% Sand[1]	35.0	38.7	35.0	36.1	1.8
% Silt	42.1	45.4	45.4	44.4	1.6
% Clay	19.2	19.6	19.6	19.5	0.2

[1] Soil type = loam

Table 4.7: Little Millseat intermittent descriptive statistics (n=1).

Parameter	Min.	Max.	Median	Mean	Std. Dev.
Elevation (m)	353.3	353.3	353.3	353.3	-
Local Valley Slope (%)	7.5	7.5	7.5	7.5	-
Drainage Area (ha)	2.39	2.39	2.39	2.39	-
Infiltration Rate (mm hr^{-1})	5.72	5.72	5.72	5.72	-
K_w	0.29	0.29	0.29	0.29	-
K_f	0.30	0.30	0.30	0.30	-
T-Factor (t ha^{-1})	9.6	9.6	9.6	9.6	-
% Sand[1]	35.0	35.0	35.0	35.0	-
% Silt	45.4	45.4	45.4	45.4	-
% Clay	19.6	19.6	19.6	19.6	-

[1]Soil type = loam

Table 4.8: Field Branch intermittent descriptive statistics (n=2).

Parameter	**Min.**	**Max.**	**Median**	**Mean**	**Std. Dev.**
Elevation (m)	323.9	328.6	326.2	326.2	3.3
Local Valley Slope (%)	13.8	15.8	14.8	14.8	1.4
Drainage Area (ha)	11.88	13.84	12.86	12.86	1.4
Infiltration Rate (mm hr^{-1})	5.72	5.72	5.72	5.72	0.0
K_w	0.29	0.29	0.29	0.29	0.0
K_f	0.30	0.30	0.30	0.30	0.0
T-Factor (t ha^{-1})	9.6	9.6	9.6	9.6	0.0
% Sand[1]	35.0	35.0	35.0	35.0	0.0
% Silt	45.4	45.4	45.4	45.4	0.0
% Clay	19.6	19.6	19.6	19.6	0.0

[1]Soil type = loam

Table 4.9: Falling Rock intermittent descriptive statistics (n=7).

Parameter	**Min.**	**Max.**	**Median**	**Mean**	**Std. Dev.**
Elevation (m)	329.3	360.2	340.7	343.4	9.8
Local Valley Slope (%)	1.4	22.0	11.2	12.0	7.1
Drainage Area (ha)	4.49	9.44	5.84	6.19	1.83
Infiltration Rate (mm hr^{-1})	5.41	5.72	5.72	5.59	0.16
K_w	0.26	0.29	0.29	0.28	0.01
K_f	0.30	0.30	0.30	0.30	0.00
T-Factor (t ha^{-1})	9.6	9.6	9.6	9.6	0.0
% Sand[1]	35.0	38.7	35.0	36.6	2.0
% Silt	42.1	45.4	45.4	44.0	1.8
% Clay	19.1	19.6	19.6	19.4	0.2

[1]Soil type = loam

4.1.1.3 Perennial Descriptive Statistics

As seen in Table 4.10 and Figures 4.4-4.6, the median drainage area for the perennial streams examined in Robinson Forest is 17.2 ha with a median local valley slope of 6.2% and a median point-of-origin elevation of 340.4 m. Drainage areas are smaller in Falling Rock (median=14.5 ha) as compared to Little Millseat (median=20.2 ha) and Field Branch (median=22.4 ha) (Tables 4.11-4.13) (Figure 4.4). Local valley slopes are steepest in Falling Rock (median=5.1%) followed by Little Millseat (median=4.6%) and Field Branch (median=1.6%) (Figure 4.5). The point-of-origin occurrence is highest for Falling Rock (340.4 m) followed by Little Millseat (328.0 m) and Field Branch (315.9 m) (Figure 4.6). For all three watersheds, the soil type was loam. Since only one perennial stream was present in Little Millseat, between watershed statistical comparisons were not performed.

Table 4.10: Robinson Forest perennial descriptive statistics (all sites, n=5).

Parameter	Min.	Max.	Median	Mean	Std. Dev.
Elevation (m)	315.9	340.8	340.4	333.3	11.1
Local Valley Slope (%)	1.6	18.0	4.6	6.2	6.7
Drainage Area (ha)	11.0	22.4	19.2	17.2	4.8
Infiltration Rate (mm hr^{-1})	5.33	5.84	5.84	5.59	0.25
K_w	0.26	0.29	0.29	0.28	0.01
K_f	0.30	0.30	0.30	0.30	0.00
T-Factor (t ha^{-1})	9.6	9.6	9.6	9.6	0.0
% Sand[1]	35.0	38.7	35.0	35.8	1.7
% Silt	42.1	45.4	45.4	44.8	1.5
% Clay	19.2	19.6	19.6	19.5	0.2

[1]Soil type = loam

Table 4.11: Little Millseat perennial descriptive statistics (n=1).

Parameter	Min.	Max.	Median	Mean	Std. Dev.
Elevation (m)	328.0	328.0	328.0	328.0	-
Local Valley Slope (%)	4.6	4.6	4.6	4.6	-
Drainage Area (ha)	20.2	20.2	20.2	20.2	-
Infiltration Rate (mm hr^{-1})	5.72	5.72	5.72	5.72	-
K_w	0.29	0.29	0.29	0.29	-
K_f	0.30	0.30	0.30	0.30	-
T-Factor (t ha^{-1})	9.6	9.6	9.6	9.6	-
% Sand[1]	35.0	35.0	35.0	35.0	-
% Silt	45.4	45.4	45.4	45.4	-
% Clay	19.6	19.6	19.6	19.6	-

[1]Soil type = loam

Table 4.12: Field Branch perennial descriptive statistics (n=1).

Parameter	Min.	Max.	Median	Mean	Std. Dev.
Elevation (m)	315.9	315.9	315.9	315.9	-
Local Valley Slope (%)	1.6	1.6	1.6	1.6	-
Drainage Area (ha)	22.4	22.4	22.4	22.4	-
Infiltration Rate (mm hr^{-1})	5.72	5.72	5.72	5.72	-
K_w	0.29	0.29	0.29	0.29	-
K_f	0.30	0.30	0.30	0.30	-
T-Factor (t ha^{-1})	9.6	9.6	9.6	9.6	-
% Sand	35.0	35.0	35.0	35.0	-
% Silt	45.4	45.4	45.4	45.4	-
% Clay	19.6	19.6	19.6	19.6	-

[1]Soil type = loam

Table 4.13: Falling Rock perennial descriptive statistics (n=3).

Parameter	Min.	Max.	Median	Mean	Std. Dev.
Elevation (m)	328.5	340.8	340.4	336.6	7.0
Local Valley Slope (%)	2.0	18.0	5.1	8.4	8.5
Drainage Area (ha)	11.0	19.2	13.4	14.5	4.2
Infiltration Rate (mm hr^{-1})	5.41	5.72	5.72	5.61	0.18
K_w	0.26	0.29	0.29	0.28	0.01
K_f	0.30	0.30	0.30	0.30	0.00
T-Factor (t ha^{-1})	9.6	9.6	9.6	9.6	0.0
% Sand	35.0	38.7	35.0	36.3	2.2
% Silt	42.1	45.4	45.4	44.3	1.9
% Clay	19.1	19.6	19.6	19.4	0.3

[1]Soil type = loam

4.1.1.4 Point-of-Origin Elevation Relationship to Coal Beds

Figures 3.8-3.12 show the locations of stream origin points with respect to the elevation contours of various coal beds and coal outcroppings. While additional survey sites and a controlled study would be needed to confirm the theory, Figure 3.8 in particular appears to show a strong relationship between origin points (ephemeral and intermittent in particular) and the presence of the Hindman Coal Bed and Geologic Contact (hi, elevation=385 m) and the Hindman No. 7 Coal Secondary (h7, elevation=348 m). The clustering of points around these coal seams may or may not be related to the difference in permeability/hydraulic conductivity between the coal seam layers and the adjacent rock types as a cross-section of the terrain. Coal outcroppings also may or may not affect channel formation by influencing the location and degree of surface soil erosion resulting from overland flow. Anecdotally, miners and other people familiar with the Appalachian coal belt region have observed a link between the presence of a coal outcropping and water features such as seeps, springs, and channel heads. Again, there is insufficient data in this study to confirm or deny these theories, but the question is ripe for further study.

4.1.2 Comparison of Robinson Forest Stream Characteristics to Prior Work

4.1.2.1 Ephemeral Stream Comparisons

Previous studies noted ephemeral drainage areas ranging from 1 to 10 ha (2.5 to 24.7 acres) (Svec et al., 2005) and 0.04 to 79.8 ha (0.1 to 197.2 acres) (Fritz et al., 2008), and first-order stream drainage areas[2] ranging from 0.26 to 6.19 ha (0.64 to 15.3 acres) (Hansen, 2001). This broad range reflects the wide range of spatial and temporal factors that may influence headwater channel formation at the local level. In this study, the median drainage areas found for ephemeral streams at Robinson Forest (median=0.64 ha) are at the lower end of the range. Although Paybins (2003) did not evaluate ephemeral streams, it is most closely related to this study in terms of results and study site characteristics excluding Svec et al. (2005). While Svec et al. (2005) evaluated ephemeral streams in Robinson Forest, the typical ephemeral drainage areas found in this thesis fell below the range found in that study. The headwater catchments in the Paybins (2003) are forested and mostly free from previous coal mining activity. Also coincident with the methodology of this thesis, the collected points-of-origin were mapped in ArcGIS and verified by comparison to existing elevation datasets. Unlike the digital elevation model used in this thesis, the version of the National Elevation Dataset utilized for verification and analysis in the Paybins (2003) was accurate to a resolution of 30 horizontal meters, while the version utilized in this study is accurate to a resolution of approximately 10 meters. At the intermittent and perennial scales, however, this resolution difference is not as significant as it is for mapping typical ephemeral channels in the region. Paybins (2003) also collected a variety of data relating to field-sourced stream locations including drainage area, point-of-origin elevation, local valley slope, aspect, and geologic characteristics.

4.1.2.2 Intermittent Stream Comparisons

Paybins (2003) found a median drainage area for intermittent channels of 5.9 ha (14.5 ac), which is 0.2 ha (0.6 ac) less than the median drainage area computed for the intermittent streams in the three studied watersheds at Robinson Forest (Figure 4.7). Drainage areas at Robinson Forest ranged from 2.4 to 13.8 ha (5.9 to 34.1 ac), which is comparable to the results by Paybins (2003). The authors noted drainage areas ranging from 2.5 to 18.3 ha (6.3 to 45.3 ac) for intermittent streams in southern WV. With regards to basin slopes, the values recorded at Robinson Forest for local valley slope (median of 12.5% and range from 1.4% to 22.0%) are similar to those found by Paybins (2003) for basin slope (Figure 4.8). The authors noted a median basin slope of 7.4% and a smaller range of 3.5 to 11.7%. The differences in slopes may be due in part to differences in the methodologies

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[2] All ephemeral streams found in Robinson Forest for this thesis were first-order streams, but not all first-order streams were ephemeral streams.

used to determine these values in addition to natural variation in terrain within and between study sites. It should be noted that Paybins (2003) distinguished between the northeastern and southwestern parts of the study area, wherein the northeastern intermittent points exhibited larger median drainage areas and less steep median basin slopes (8.3 ha and 6.1%, respectively) than those in the southwestern part of the study area (5.2 ha and 8.8%, respectively). The median values for the southwestern study section are more similar to those found in this thesis than the ones from the northeastern section, which coincides with expectations as the southwestern part of West Virginia is closer to Robinson Forest. Median elevation for intermittent points overall is 321 m, 528 m in the northeastern section, and 308 m in the southwestern section, compared to approximately 340 m for intermittent points in Robinson Forest (Figure 4.9).

4.1.2.3 Perennial Stream Comparisons

Paybins (2003) found a median drainage area of 16.5 ha (40.8 ac) for perennial channels in West Virginia. The median drainage area at Robinson Forest is 19.2 ha (47.4 ac) which is a difference of 2.7 ha (6.6 ac). The range of perennial drainage areas in Paybins (2003) was 4.2 to 60.7 ha (10.4 to 150.1 ac) compared to the range of 11.0 to 22.4 ha (27.2 to 55.4 ac) at Robinson Forest (Figure 4.7). As with intermittent channels, the range of drainage area values was narrower at Robinson Forest than in Paybins (2003). This difference is likely due to the fact that the Robinson Forest locations are within a smaller geographic area than those in Paybins (2003) which came from a range of counties across the southern part of West Virginia. Paybins (2003) reported the median basin slope for perennial channels was 9.8% with a range of 4.4% to 12.6%. At Robinson Forest, the median of 4.6% is lower and the range of 1.6% to 18% is larger (Figure 4.8). Perennial points in the northeastern part of the study area, as with intermittent points, had larger median drainage areas and less steep median basin slopes (26.8 ha and 8.4% respectively) than those in the southwestern part of the study area (14.1 ha and 10.7%). Median elevation for perennial points overall is 305 m, 458 m in the northeastern section, and 280 m in the southwestern section, compared to approximately 340 m for perennial points in Robinson Forest (Figure 4.9).

Figure 4.7: Comparison of median intermittent and perennial point-of-origin drainage areas from West Virginia as reported in Paybins (2003) and Robinson Forest.

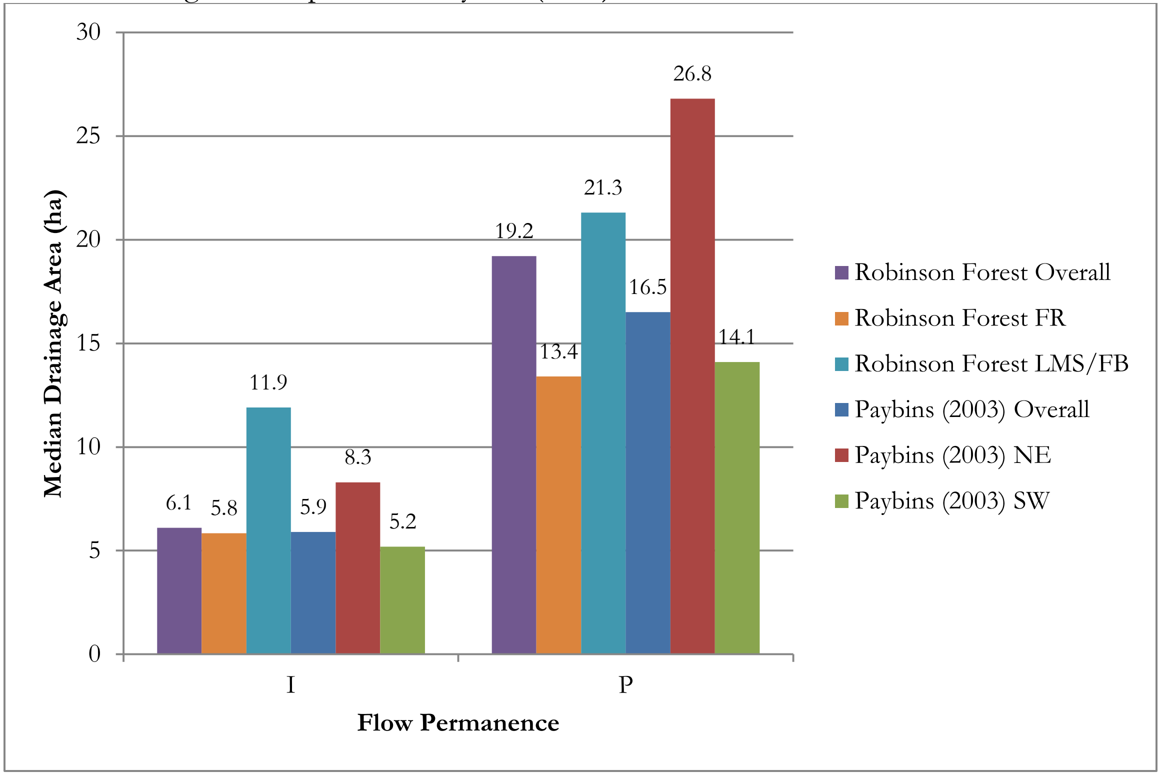


Figure 4.8: Comparison of median intermittent and perennial point-of-origin basin slopes from West Virginia as reported in Paybins (2003) and Robinson Forest local valley slopes.

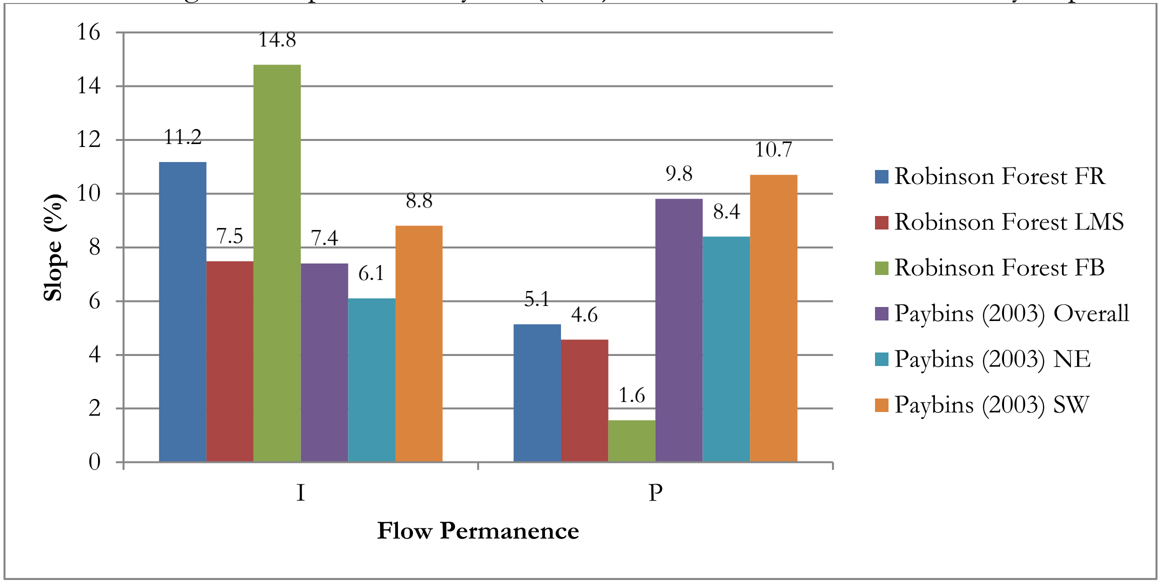
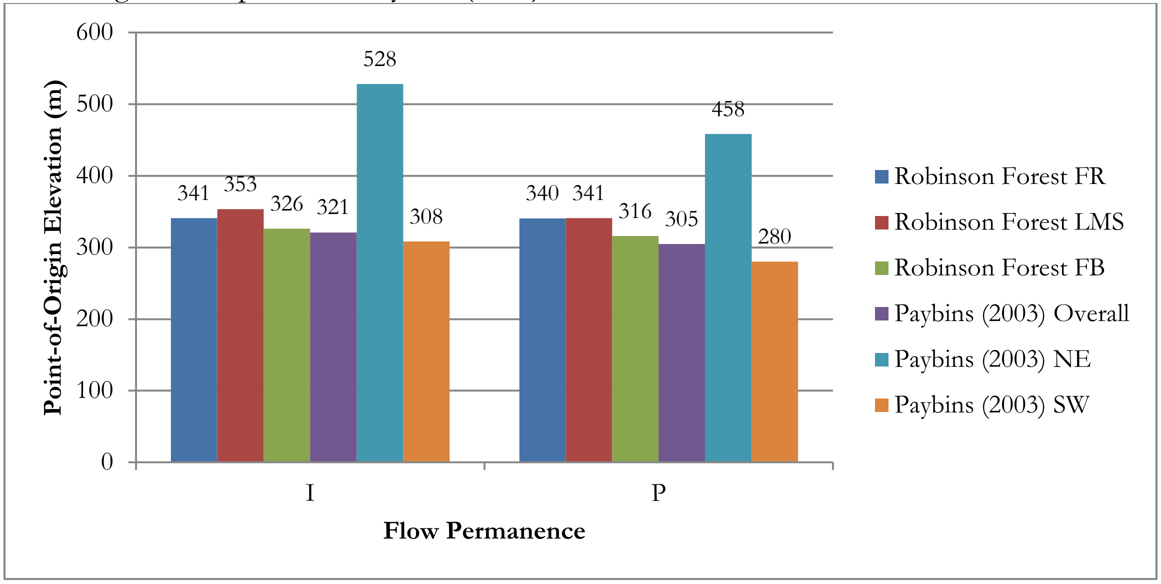


Figure 4.9: Comparison of median intermittent and perennial point-of-origin elevations from West Virginia as reported in Paybins (2003) and Robinson Forest.



4.1.3 Jurisdictional Determination (JD) Descriptive Statistics

Descriptive statistics for stream points-of-origin from JDs are presented separately for each of the three flow regimes (i.e. ephemeral, intermittent, and perennial) for the three study watersheds considered both together and separately. Henceforth, LRL-2007-217 will be referred to as 2007, LRL-2009-384 as 2009, and LRL-2010-826 as 2010. Each parameter between the three watersheds was compared when enough data was available for a particular flow regime.

4.1.3.1 Ephemeral JD Descriptive Statistics

As seen in Table 4.14 and Figures 4.10-4.12, the median drainage area for the ephemeral streams in the JDs is 2.55 ha with a median local valley slope of 32.2% and a median elevation of 426.0 m. Drainage areas are smaller in 2009 (median=0.99 ha) as compared to 2010 (median=1.57 ha) and 2007 (median=4.1 ha) (Tables 4.15-4.17; Figure 4.10). Local valley slopes are steepest in 2010 (median=39.9%) followed by 2009 (median=36.8%) and 2007 (median=24.5%). The point-of-origin occurrence is highest for 2009 (median=522 m) followed by 2010 (median=516 m) and 2007 (median=398 m). For all three watersheds, the soil type was silt loam though it was almost a loam. As expected from the median values for drainage area, local valley slope and elevation, 2007 differed significantly from 2009 and 2010 (Table 4.18). With the exception of K_f, none of the geologic/soil parameters differed between the sites. In summary, the 2007 JD posted a larger median drainage area (approximately 400-500%), flatter local valley slope, and lower elevation for the ephemeral stream point-of-origins. No significant differences were noted between 2009 and 2010 except for infiltration rate which was smaller for 2009.

Table 4.14: JD ephemeral descriptive statistics (all sites, n=30).

Parameter	**Min.**	**Max.**	**Median**	**Mean**	**Std. Dev.**
Elevation (m)	303.9	546.6	426.0	446.3	67.5
Local Valley Slope (%)	2.4	51.0	32.2	30.0	12.0
Drainage Area (ha)	0.31	14.28	2.55	3.77	3.57
Infiltration Rate (mm hr^{-1})	2.54	6.10	4.83	4.83	1.02
K_w	0.20	0.31	0.31	0.29	0.04
K_f	0.27	0.55	0.32	0.35	0.08
T-Factor (t ha^{-1})	7.2	12.0	9.6	9.8	1.1
% Sand[1]	27.0	39.7	28.4	30.7	3.6
% Silt	43.3	54.0	53.2	51.3	3.0
% Clay	16.5	19.0	18.4	17.9	0.8

[1]Soil type = silt loam (almost a loam)

Figure 4.10: JD mean drainage area by flow regime and permit number. *E, I and P indicate ephemeral, intermittent, and perennial, respectively.*

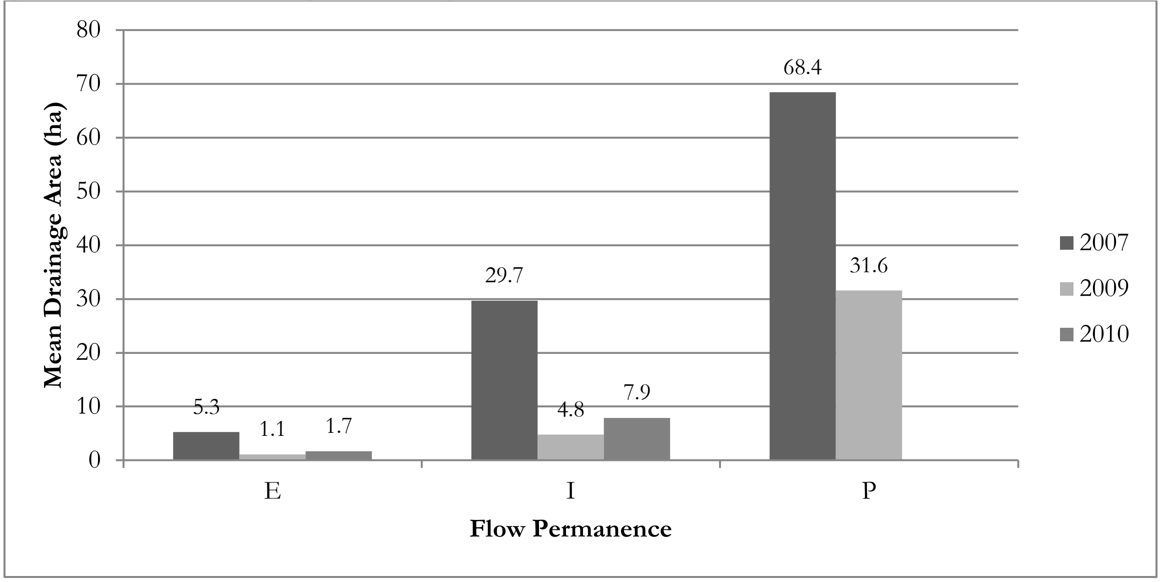


Figure 4.11: JD mean local valley slope by flow regime and permit number. *E, I and P indicate ephemeral, intermittent, and perennial, respectively.*

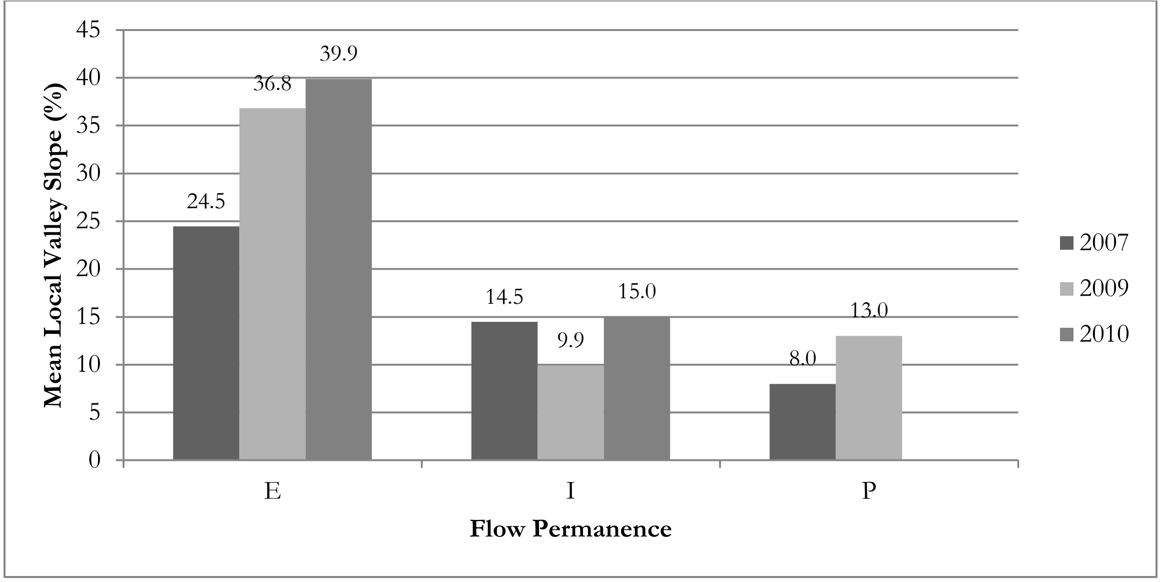


Figure 4.12: JD mean point-of-origin elevation by flow regime and permit number. *E, I and P indicate ephemeral, intermittent, and perennial, respectively.*

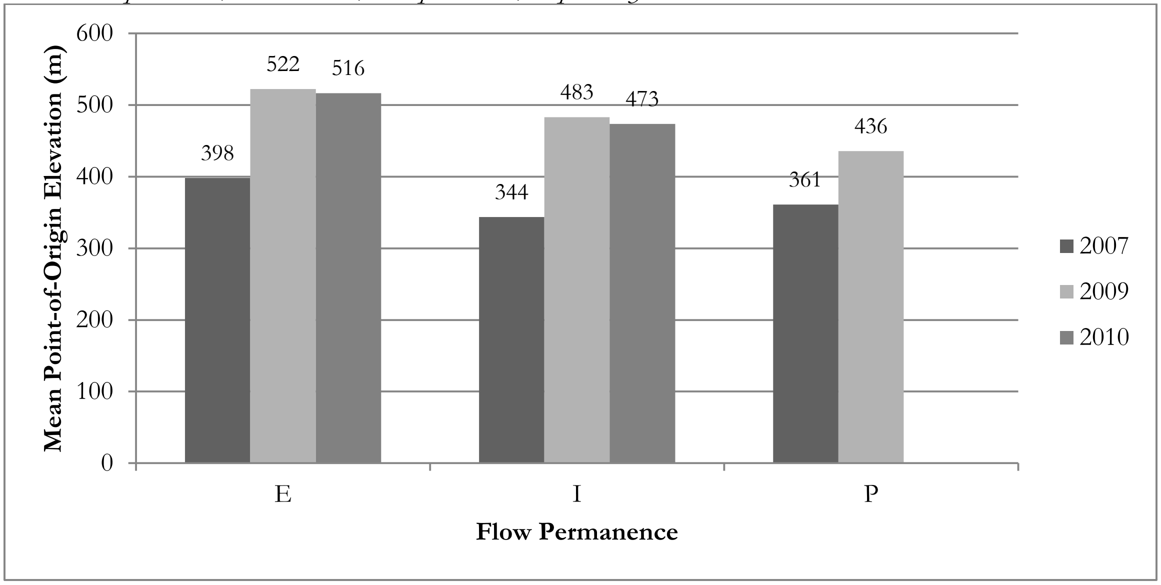


Table 4.15: LRL-2007-217 ephemeral descriptive statistics (n=18).

Parameter	Min.	Max.	Median	Mean	Std. Dev.
Elevation (m)	303.9	445.4	407.6	397.5	36.6
Local Valley Slope (%)	2.4	39.2	25.1	24.4	11.4
Drainage area (ha)	1.8	14.3	4.1	5.3	3.8
Infiltration Rate (mm hr^{-1})	4.93	5.72	4.93	5.18	0.38
K_w	0.20	0.31	0.31	0.29	0.04
K_f	0.27	0.32	0.32	0.31	0.02
T-Factor (t ha^{-1})	9.6	9.6	9.6	9.6	0.0
Sand (%)[1]	28.4	34.6	28.4	30.3	2.7
Silt (%)	48.9	53.2	53.2	51.9	2.0
Clay (%)	16.5	18.4	18.4	17.9	0.8

[1] Soil type = silt loam (almost a loam)

Table 4.16: LRL-2009-384 ephemeral descriptive statistics (n=6).

Parameter	Min.	Max.	Median	Mean	Std. Dev.
Elevation (m)	507.8	546.6	519.4	522.3	14.4
Local Valley Slope (%)	26.8	51.0	37.2	36.8	8.2
Drainage area (ha)	0.30	2.36	0.99	1.12	0.77
Infiltration Rate (mm hr^{-1})	2.54	6.02	2.54	3.71	1.80
K_w	0.23	0.28	0.28	0.26	0.3
K_f	0.38	0.55	0.55	0.50	0.9
T-Factor (t ha^{-1})	7.2	12.0	12.0	10.3	2.4
Sand (%)[1]	27.0	39.7	27.0	31.2	6.6
Silt (%)	43.3	54.0	54.0	50.4	5.5
Clay (%)	17.0	19.0	19.0	18.3	1.1

[1] Soil type = silt loam (almost a loam)

Table 4.17: LRL-2010-826 ephemeral descriptive statistics (n=6).

Parameter	Min.	Max.	Median	Mean	Std. Dev.
Elevation (m)	491.8	534.3	515.8	516.4	15.1
Local Valley Slope (%)	31.1	45.9	41.5	39.9	5.5
Drainage area (ha)	0.55	3.04	1.57	1.69	0.96
Infiltration Rate (mm hr^{-1})	4.93	5.72	5.72	5.46	0.41
K_w	0.31	0.31	0.31	0.31	0.00
K_f	0.32	0.32	0.32	0.32	0.00
T-Factor (t ha^{-1})	9.6	9.6	9.6	9.6	0.00
Sand (%)[1]	28.4	33.3	33.3	31.7	2.5
Silt (%)	49.4	53.2	49.4	50.7	2.0
Clay (%)	17.4	18.4	17.4	17.7	0.5

[1] Soil type = silt loam (almost a loam)

Table 4.18: Results of comparison of ephemeral stream characteristics at JD sites.

Parameter	2007[1]	2009	2010
Elevation (m)	397.5 b[2]	522.3 a	516.4 a
Local Valley Slope (%)	24.4 b	36.8 a	39.9 a
Drainage area (ha)	5.3 a	1.12 b	1.69 b
Infiltration Rate (mm hr^{-1})	5.18 a	3.71 b	5.46 a
K_w	0.29 a	0.26 a	0.31 a
K_f	0.31 b	0.50 a	0.32 a
T-Factor (t ha^{-1})	9.6 a	10.3 a	9.6 a
Sand (%)	30.3 a	31.2 a	31.7 a
Silt (%)	51.9 a	50.4 a	50.7 a
Clay (%)	17.9 a	18.3 a	17.7 a

[1] 2007= LRL-2007-217; 2009= LRL-2009-384; 2010= LRL-2010-826.

[2] Rows with same letters are not significantly different (*p*=0.05).

4.1.3.2 Intermittent JD Descriptive Statistics

As seen in Table 4.19 and Figures 4.10-4.12, the median drainage area for the intermittent streams in the JDs is 13.99 ha with a median local valley slope of 8.7% and a median point-of-origin elevation of 397.4 m. Drainage areas are smallest for 2009 (median=4.8 ha) and 2010 (median=7.9 ha) but increase substantially for 2007 (median=2007 ha) (Tables 4.20-4.22; Figure 4.10). Local valley slopes are steepest for 2010 (median=15.0%) and 2007 (median=14.5%) and flattest for 2007 (median=9.9%) (Tables 4.20-4.22; Figure 4.11). With regards to elevation, both 2009 (median=483 m) and 2010 (median=473 m) are similar with 2007 (median=344 m) much lower (Tables 4.20-4.22; Figure 4.12). As seen in Table 4.23, the intermittent points-of-origin for the 2007 JD site have significantly lower elevations, larger drainage areas (approximately 400-600% larger), and a lower percentage of clay than the other two JD sites. This observation mirrors that for ephemeral points-of-origin with respect to elevation and drainage area. The data also show that there is no statistically significant difference between the 2009 and 2010 JDs with respect to any parameter, which is also in line with results from the ephemeral dataset.

Table 4.19: JD intermittent descriptive statistics (all sites, n=15).

Parameter	Min.	Max.	Median	Mean	Std. Dev.
Elevation (m)	315.8	497.7	397.4	407.1	72.4
Local Valley Slope (%)	2.1	28.3	8.7	13.5	9.1
Drainage Area (ha)	3.30	48.25	13.99	18.56	14.28
Infiltration Rate (mm hr^{-1})	4.83	5.84	5.84	5.59	0.25
K_w	0.20	0.31	0.31	0.28	0.05
K_f	0.27	0.32	0.32	0.30	0.03
T-Factor (t ha^{-1})	9.6	9.6	9.6	9.6	0.00
% Sand[1]	28.4	34.6	33.3	32.2	2.7
% Silt	48.9	53.2	49.4	50.4	2.0
% Clay	16.5	18.4	17.4	17.4	0.8

[1]Soil type = silt loam (almost a loam)

Table 4.20: LRL-2007-217 intermittent descriptive statistics (n=8).

Parameter	Min.	Max.	Median	Mean	Std. Dev.
Elevation (m)	315.8	397.4	339.2	344.3	24.2
Local Valley Slope (%)	2.1	20.9	7.1	8.7	5.4
Drainage area (ha)	13.99	48.25	31.51	29.4	10.7
Infiltration Rate (mm hr^{-1})	4.93	5.72	5.72	5.59	0.32
K_w	0.20	0.31	0.20	0.24	0.06
K_f	0.27	0.32	0.27	0.28	0.03
T-Factor (t ha^{-1})	9.6	9.6	9.6	9.6	0.0
Sand (%)[1]	28.4	34.6	34.6	33.4	2.5
Silt (%)	48.9	53.2	48.9	49.7	1.7
Clay (%)	16.5	18.4	16.5	16.9	0.8

[1]Soil type = silt loam (almost a loam)

Table 4.21: LRL-2009-384 intermittent descriptive statistics (n=4).

Parameter	Min.	Max.	Median	Mean	Std. Dev.
Elevation (m)	461.6	497.7	486.4	483.0	15.3
Local Valley Slope (%)	5.0	9.8	6.4	6.9	2.2
Drainage area (ha)	3.30	7.34	4.29	4.81	1.75
Infiltration Rate (mm hr^{-1})	4.93	5.72	4.93	5.13	0.39
K_w	0.31	0.31	0.31	0.31	0.00
K_f	0.32	0.32	0.32	0.32	0.00
T-Factor (t ha^{-1})	9.6	9.6	9.6	9.6	0.00
Sand (%)[1]	28.4	33.3	28.4	29.6	2.4
Silt (%)	49.4	53.2	53.2	52.3	1.9
Clay (%)	17.4	18.4	18.4	18.1	0.5

[1]Soil type = silt loam (almost a loam)

Table 4.22: LRL-2010-826 intermittent descriptive statistics (n=3).

Parameter	Min.	Max.	Median	Mean	Std. Dev.
Elevation (m)	450.7	485.7	484.1	473.5	19.8
Local Valley Slope (%)	3.7	15.4	13.1	10.7	6.2
Drainage area (ha)	6.37	9.06	8.26	7.88	1.36
Infiltration Rate (mm hr^{-1})	5.72	5.72	5.72	5.72	0.0
K_w	0.31	0.31	0.31	0.31	0.0
K_f	0.32	0.32	0.32	0.32	0.0
T-Factor (t ha^{-1})	9.6	9.6	9.6	9.6	0.0
Sand (%)[1]	33.3	33.3	33.3	33.3	0.0
Silt (%)	49.4	49.4	49.4	49.4	0.0
Clay (%)	17.4	17.4	17.4	17.4	0.0

[1] Soil type = silt loam (almost a loam)

Table 4.23: Results of comparison of intermittent stream characteristics at JD sites..

Parameter	2007[1]	2009	2010
Elevation (m)	344.3 b[2]	483.0 a	473.5 a
Local Valley Slope (%)	8.7 a	6.9 a	10.7 a
Drainage area (ha)	29.4 a	4.81 b	7.88 b
Infiltration Rate (mm hr^{-1})	5.59 a	5.13 a	5.72 a
K_w	0.24 a	0.31 a	0.31 a
K_f	0.28 a	0.32 a	0.32 a
T-Factor (t ha^{-1})	9.6 a	9.6 a	9.6 a
Sand (%)	33.4 a	29.6 a	33.3 a
Silt (%)	49.7 a	52.3 a	49.4 a
Clay (%)	16.9 b	18.1 a	17.4 ab

[1] 2007= LRL-2007-217; 2009= LRL-2009-384 ; 2010= LRL-2010-826 .

[2] Rows with same letters are not significantly different (p=0.05).

4.1.3.3 Perennial JD Descriptive Statistics

As seen in Table 4.24 and Figures 4.10-4.12, the median drainage area for the perennial streams in the 2007 and 2009 JDs is 62.17 ha with a median local valley slope of 10.5% and a median point-of-origin elevation of 373.2 m. No perennial streams were present in the 2010 JD. Drainage areas are larger for the 2007 JD (median=64.17 ha) as compared to the 2009 JD (median=31.57 ha) (Tables 4.25-4.26; Figure 4.10). Local valley slopes were steeper for the 2009 JS (median=13.0%) as compared to the 2007 JD (median=9.0%) (Tables 4.25-4.26; Figure 4.11). The point-of-origin elevation was highest for the 2009 JD (median=435.6 m) versus the 2007 JD (median=373.2 m). Since only one perennial stream was present in the 2009 JD, between watershed statistical comparisons were not performed. It is important to note that the median drainage area for the perennial points-of-origin in the 2007 JD is approximately 100% larger than that of the 2009 JD. Typical elevations and local valley slopes are somewhat smaller for 2007 than for 2009, which is in keeping with observations for ephemeral and intermittent streams in the JD dataset.

Table 4.24: JD perennial descriptive statistics (all sites, n=7).

Parameter	Min.	Max.	Median	Mean	Std. Dev.
Elevation (m)	315.8	435.6	373.2	371.6	35.7
Local Valley Slope (%)	2.5	13.0	10.5	8.7	3.9
Drainage Area (ha)	31.57	103.99	64.17	63.16	21.98
Infiltration Rate (mm hr^{-1})	2.54	5.84	2.54	3.81	1.78
K_w	0.20	0.31	0.28	0.28	0.04
K_f	0.27	0.55	0.55	0.44	0.13
T-Factor (t ha^{-1})	9.6	12.0	12.0	11.0	1.3
% Sand[1]	27.0	34.6	27.0	29.9	3.6
% Silt	48.9	54.0	54.0	52.0	2.6
% Clay	16.5	19.0	19.0	18.2	1.1

[1] Soil type = silt loam (almost a loam)

Table 4.25: LRL-2007-217 perennial descriptive statistics (n=6).

Parameter	Min.	Max.	Median	Mean	Std. Dev.
Elevation (m)	315.8	377.3	373.2	360.9	24.0
Local Valley Slope (%)	2.5	12.1	9.0	8.0	3.8
Drainage area (ha)	48.25	103.99	64.17	68.43	18.63
Infiltration Rate (mm hr^{-1})	2.54	5.72	2.54	3.61	1.64
K_w	0.20	0.31	0.28	0.27	0.04
K_f	0.27	0.55	0.55	0.46	0.13
T-Factor (t ha^{-1})	9.6	12.0	12.0	11.3	1.2
Sand (%)[1]	27.0	34.6	27.0	29.3	3.6
Silt (%)	48.9	54.0	54.0	52.4	2.5
Clay (%)	16.4	19.0	19.0	18.3	1.1

[1] Soil type = silt loam (almost a loam)

Table 4.26: LRL-2009-384 perennial descriptive statistics (n=1).

Parameter	Min.	Max.	Median	Mean	Std. Dev.
Elevation (m)	435.6	435.6	435.6	435.6	--
Local Valley Slope (%)	13.0	13.0	13.0	13.0	--
Drainage area (ha)	31.57	31.57	31.57	31.57	--
Infiltration Rate (mm hr^{-1})	5.72	5.72	5.72	5.72	--
K_w	0.31	0.31	0.31	0.31	--
K_f	0.32	0.32	0.32	0.32	--
T-Factor (t ha^{-1})	9.6	9.6	9.6	9.6	--
Sand (%)[1]	33.3	33.3	33.3	33.3	--
Silt (%)	49.4	49.4	49.4	49.4	--
Clay (%)	17.4	17.4	17.4	17.4	--

[1] Soil type = silt loam (almost a loam)

4.1.4 Comparison of Robinson Forest Stream Characteristics to JDs

Because of the large differences noted between the 2007 JD and both the 2009 and 2010 JDs, the stream characteristics from Robinson Forest were compared 1) to all JD sites and 2) to the 2007 data set and the combined 2009/2010 data set separately (α=0.05).

4.1.4.1 Ephemeral Streams

As seen in Table 4.27 for the ephemeral streams, significant differences were found between all of parameters except T-factor. Overall, the ephemeral streams at Robinson Forest started at a lower elevation and smaller drainage areas than those of the JD sites. Table 4.27 shows that the 2007 JD had the largest number of significant differences. The elevation was higher, the local valley slopes were flatter, and the drainage area larger for the 2007 JD suggesting that the point of origin of these ephemeral streams was identified further down-gradient than those at Robinson Forest and the other JD sites (Tables 4.1 and 4.18; Figures 4.13-4.15). With regards to soils, the infiltration rate was lower for all JD sites as compared to Robinson Forest which agrees with the soils at the JD sites having a lower sand content (Table 4.27 and Figures 4.16-4.20).

Table 4.27: Robinson Forest (all sites) and JD ephemeral comparison (median values presented).

Parameter	Robinson Forest	JD (all sites)	JD (2009/2010)	JD (2007)
Elevation (m)	374.8	426.0*[1]	516.5*	407.6*
Local Valley Slope (%)	44.1	32.1*	37.5	25.1*
Drainage area (ha)	0.64	2.55*	1.34*	4.07*
Infiltration Rate (mm hr^{-1})	5.72	4.93*	5.33*	4.93*
K_w	0.29	0.31*	0.29	0.31*
K_f	0.30	0.32*	0.35*	0.32*
T-Factor (t ha^{-1})	9.6	9.6	9.6	9.6
Sand (%)[1]	35.0	28.4*	30.8*	28.4*
Silt (%)	45.4	53.2*	51.3*	53.2*
Clay (%)	19.6	18.4*	17.9*	18.4*

[1]* indicates significantly different from Robinson Forest

4.1.4.2 Intermittent Streams

For the intermittent streams, the only significant differences between Robinson Forest and the JD sites (all together) occurs with the percentage of sand, silt and clay in the soil (Table 4.28). However, when looking at 2007 alone, significant differences are noted with drainage area. The median drainage area for the 2007 JD is 5.2 times that of the median drainage area at Robinson Forest (Figure 4.14). For the 2009 and 2010 combined JDs, significant differences were noted for the parameters K_w and K_f although in magnitude these differences are small.

Table 4.28: Robinson Forest (all sites) and JD intermittent comparison (median values presented).

Parameter	Robinson Forest	JD (all sites)	JD (2009/2010)	JD (2007)
Elevation (m)	340.6	397.4	485.1*[1]	339.2
Local Valley Slope (%)	12.5	7.5	7.5	9.0
Drainage area (ha)	6.05	13.99	6.37	31.51*
Infiltration Rate (mm hr^{-1})	5.72	5.72	5.72	5.72
K_w	0.29	0.31	0.31*	0.20
K_f	0.30	0.32	0.32*	0.27
T-Factor (t ha^{-1})	9.6	9.6	9.6	9.6
Sand (%)[1]	35.0	33.3*	33.3*	34.6*
Silt (%)	45.4	49.4*	49.4*	48.9*
Clay (%)	19.6	17.4*	17.4*	16.5*

[1]* indicates significantly different from Robinson Forest

4.1.4.3 Perennial Streams

For perennial streams, six parameters are significantly different between Robinson Forest and all of the JDs: elevation, drainage area, K_f, and soil components (Table 4.29). The biggest difference was with drainage area, which was driven by the 2007 JD (Figure 4.14). The median drainage area for the 2007 JD is 3.3 times larger than the median drainage area for Robinson Forest.

Table 4.29: Robinson Forest (all sites) and JD perennial comparison (median values presented).

Parameter	Robinson Forest	JD (all sites)[2]	JD (2009)[3]	JD (2007)
Elevation (m)	340.4	373.2*[1]	435.6	373.2
Local Valley Slope (%)	4.6	10.5	13.0	9.0
Drainage area (ha)	19.20	64.17*	31.57	64.17*
Infiltration Rate (mm hr^{-1})	5.72	2.54	5.72	2.54
K_w	0.29	0.28	0.31	0.28
K_f	0.30	0.55*	0.32	0.55
T-Factor (t ha^{-1})	9.6	12.0	9.6	12.0
Sand (%)[1]	35.0	27.0*	33.3	27.0*
Silt (%)	45.4	54.0*	49.4	54.0*
Clay (%)	19.6	19.0*	17.4	19.0*

[1] * indicates significantly different from Robinson Forest

[2] No perennial streams in the 2010 JD

[3] Only one stream in the 2009 JD, so statistical comparisons to Robinson Forest streams were not made.

Figure 4.13: Median point-of-origin elevation by flow regime and study site.

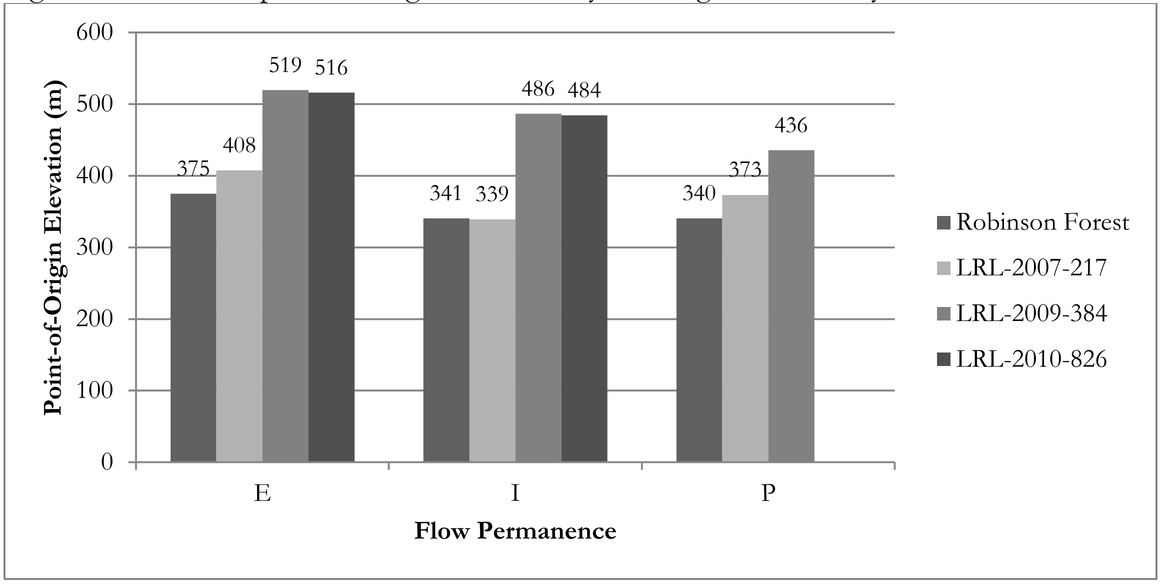


Figure 4.14: Median drainage area comparison by flow regime and study site.

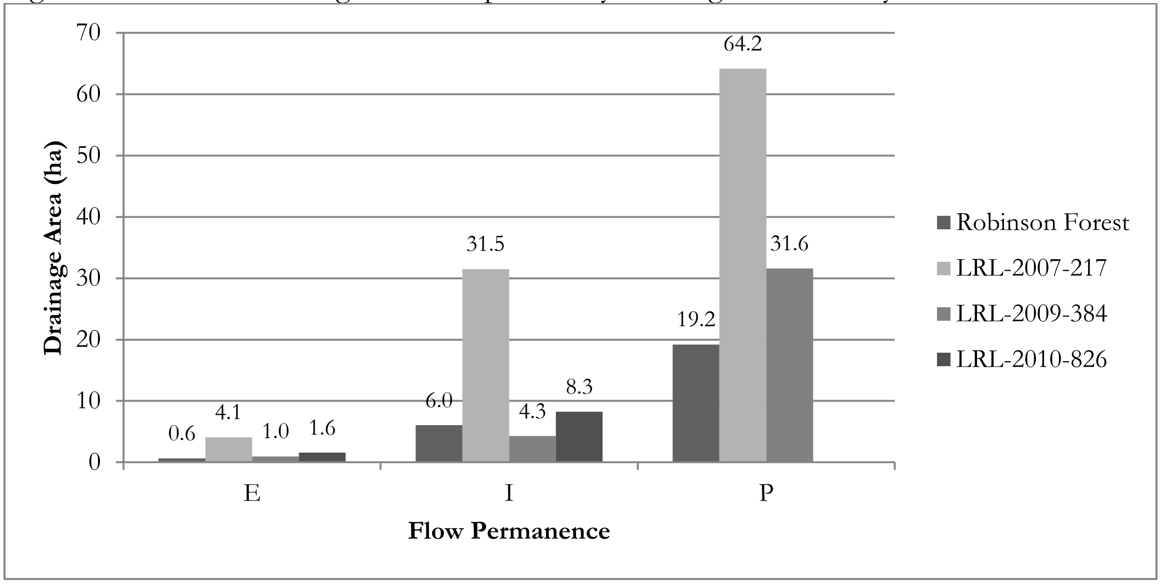


Figure 4.15: Median local valley slope comparison by flow regime and study site.

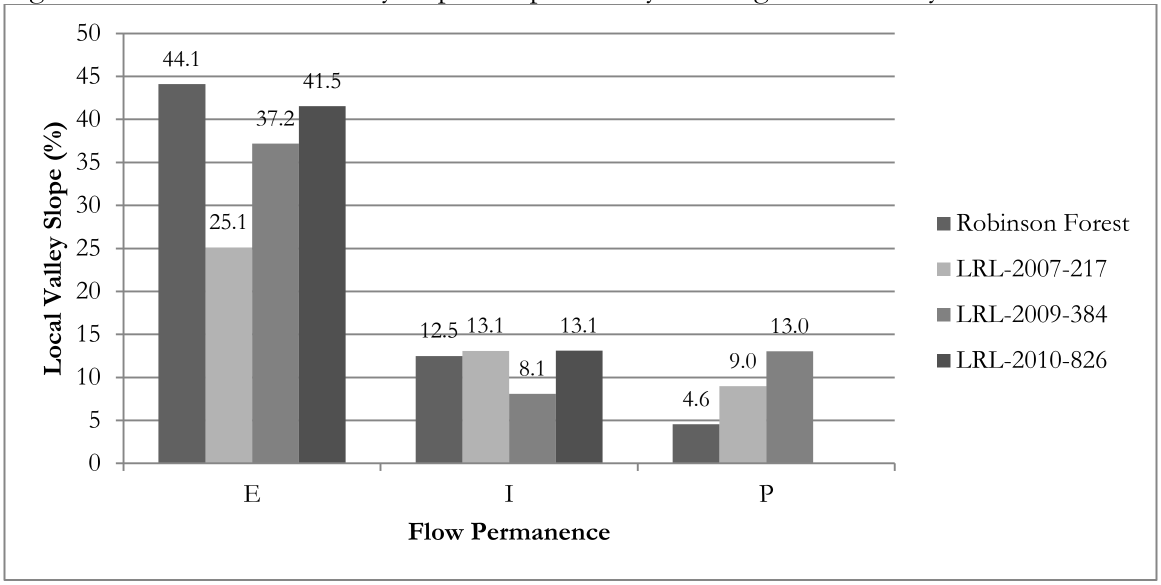


Figure 4.16: Median infiltration rate comparison by flow regime and study site.

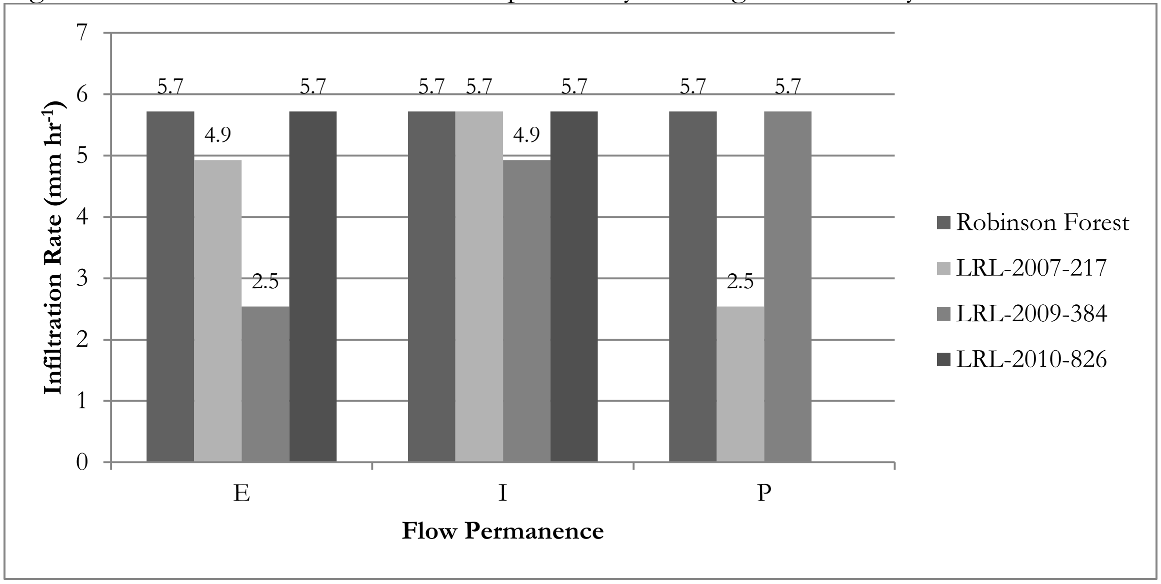


Figure 4.17: Median K_f value comparison by flow regime and study site.

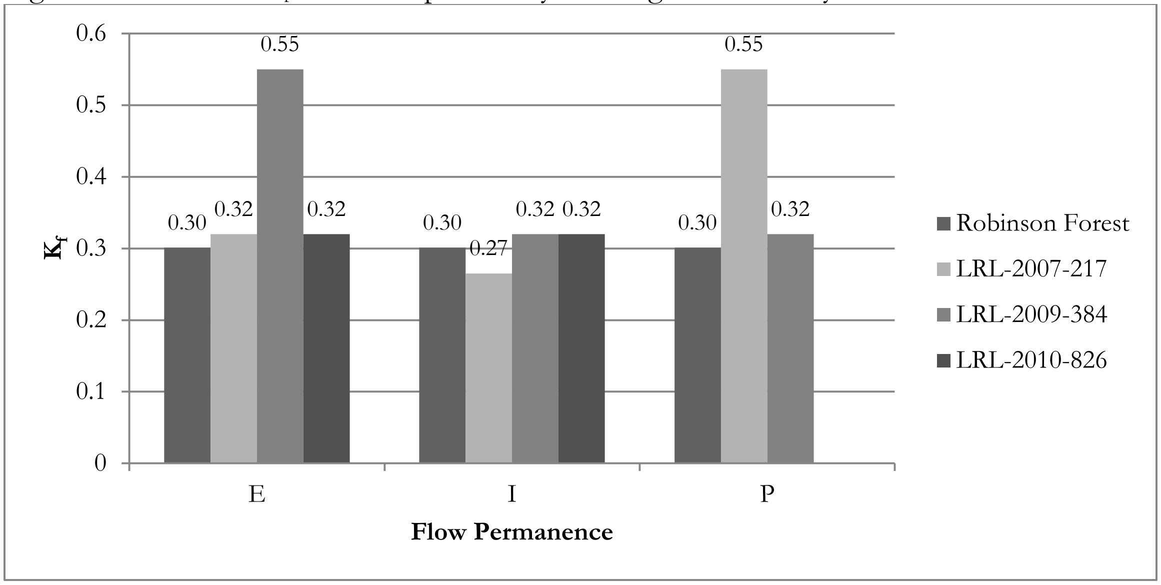


Figure 4.18: Median % sand comparison by flow regime and study site.

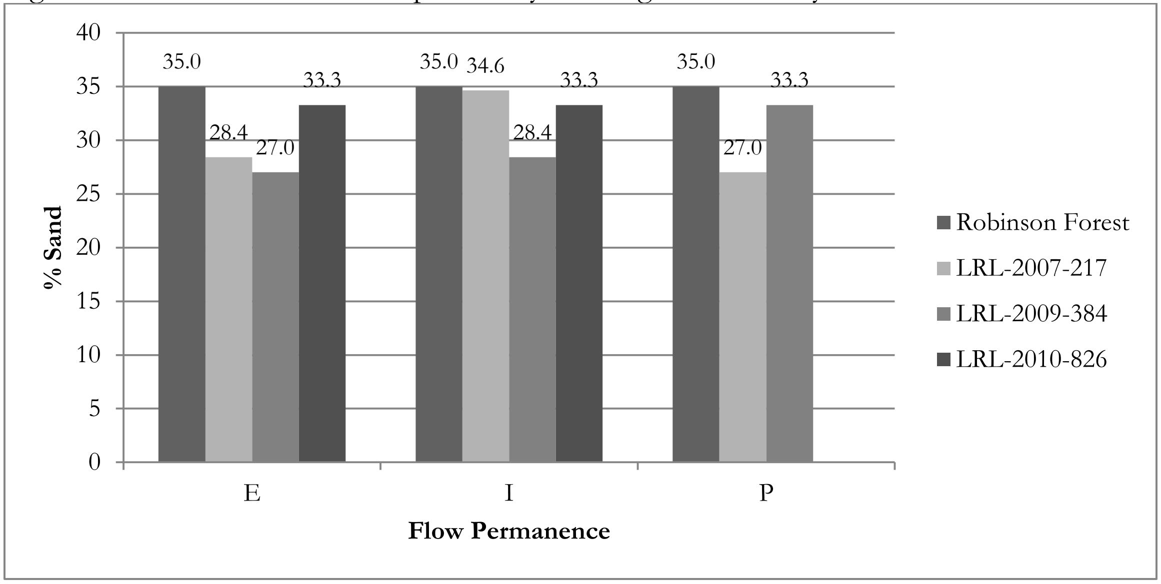


Figure 4.19: Median % silt comparison by flow regime and study site.

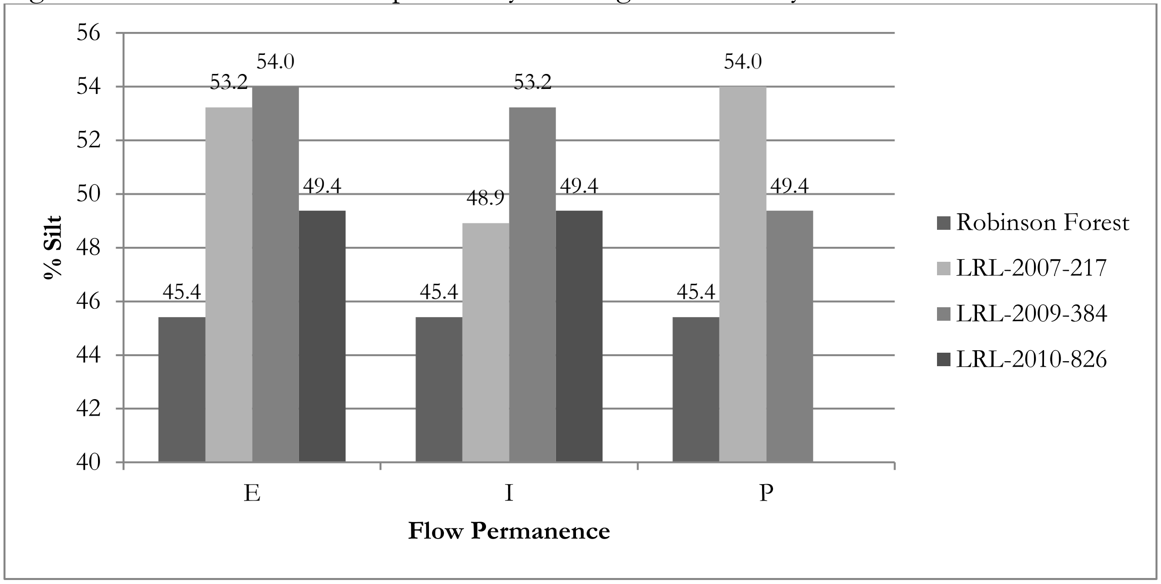
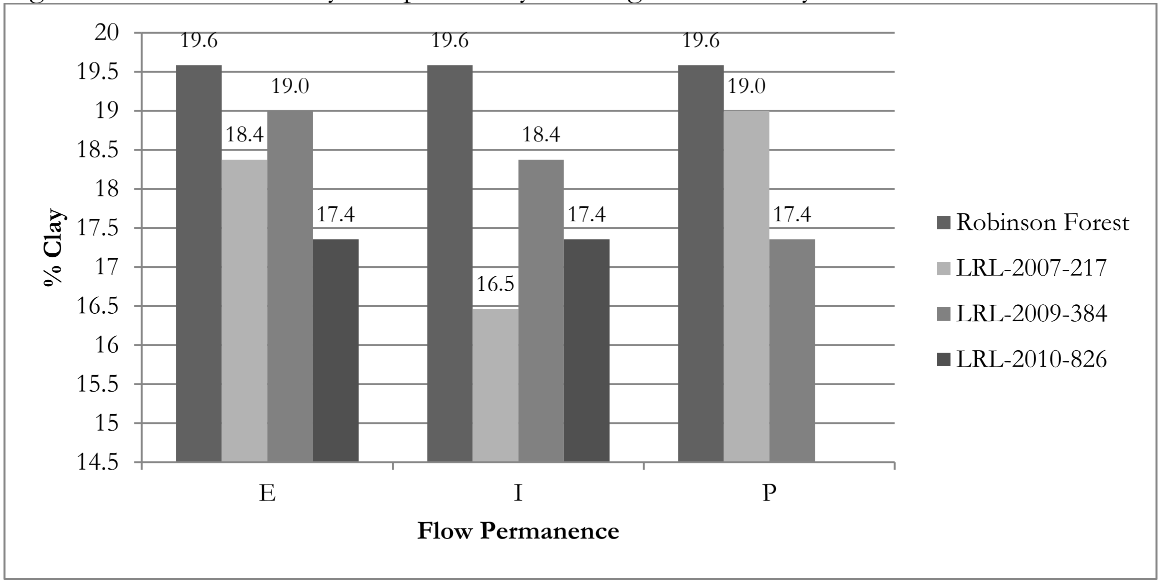


Figure 4.20: Median % clay comparison by flow regime and study site.



4.1.5 Parameter Correlation Analysis

Results of the Pearson correlation analysis found significant relationships for local valley slope and drainage area, elevation and drainage area, and elevation and local valley slope.

4.1.5.1 Local Valley Slope vs. Drainage Area

A significant and strong correlation is present between local valley slope and drainage area for the streams at Robinson Forest (Table 4.30). As drainage area increases, local valley slope decreases as seen in Figure 4.21. This relationship was expected based upon the work by Schumm (1979). A similar result is seen with the stream at the JD sites (Figure 4.22) although the correlation is not as strong (Table 4.30).

Table 4.30: Pearson correlations comparing local valley slope and drainage area.

Stream Orders[1]	**Correlation Coefficient**	***p*-value**
	-----Robinson Forest-----	
E and I (n=43)	-0.742	<0.0001
E, I, and P (n=48)	-0.812	<0.0001
	-----JDs-----	
E (n=30)	-0.663	<0.0001
E and I (n=45)	-0.478	0.0009
E, I, and P (n=52)	-0.542	<0.0001

[1] E=ephemeral, I=intermittent, and P=perennial

Figure 4.21: Local valley slope vs. drainage area at Robinson Forest (all flow regimes).

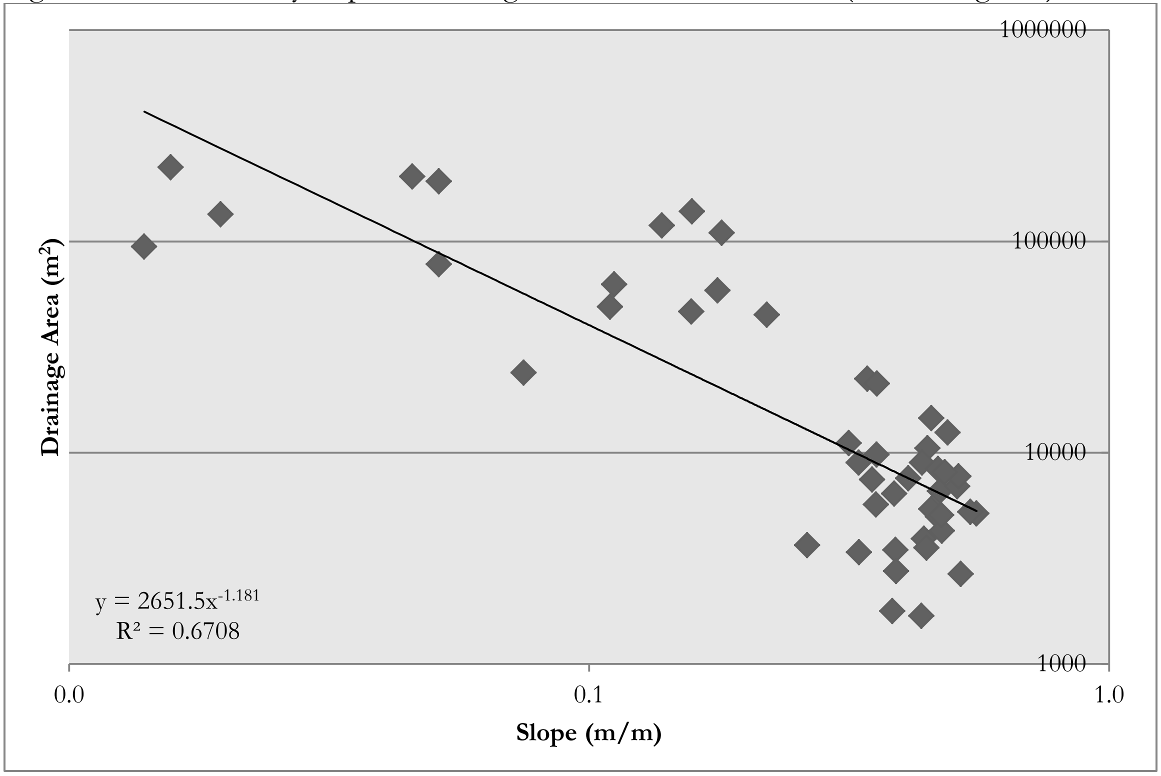
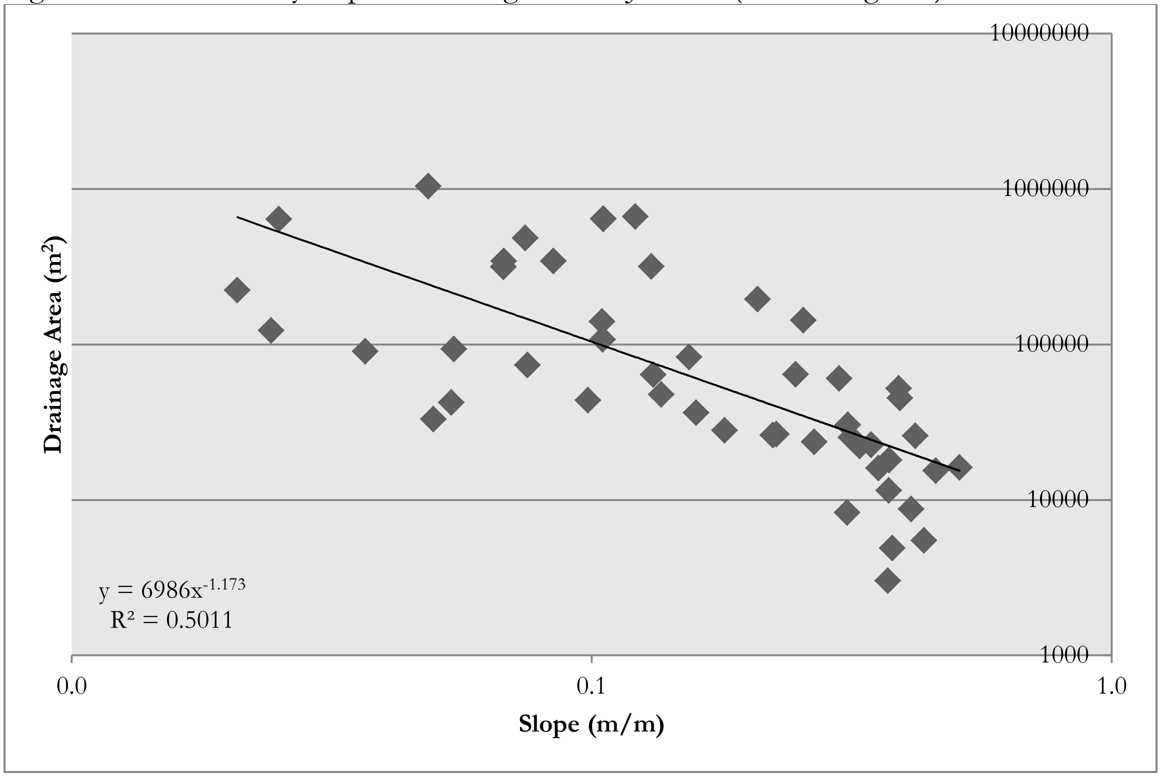


Figure 4.22: Local valley slope vs. drainage area at JD sites (all flow regimes).



Although drainage area remains the most suitable parameter to use when performing stream delineations using GIS, the data show that for Robinson Forest a typical local valley slope of approximately 43% is associated with ephemeral streams (consistent with Svec et al. (2005) which indicated ephemeral streams in eastern Kentucky typically have valley slopes greater than 30%), 17% for intermittent streams, and 5% for perennial streams. This observation is significant because even small channel incisions are usually identifiable on topographic maps in this region. As such, knowledge of the typical local valley slope for a given stream order enables one to make a reasonable first guess as to the location of a likely point-of-origin using only a raw DEM and the associated slope raster in GIS, or from a standard topographic map using a local (10 m) valley slope calculation. Such knowledge could prove useful to practitioners performing a similar analysis, including the verification of GIS-derived catchments and pour-point/origin locations, as well as to those whose job it is to review permit applications such as JDs. Performing digital or manual calculations of drainage areas from topographic data can be time consuming, and a known slope-drainage area relationship such as this could provide a useful starting point and means of verifying field-sourced data. It is important to consider, however, that while slope and elevation may yield significant results and correlations in the aggregate over many observations, there is substantial variance in these parameters at the scale of local topography. Similar or even identical local valley slopes may occur throughout nearby watersheds depending on local conditions. This is one reason why local valley slope alone cannot be used in lieu of drainage area for predicting channel heads in the landscape.

4.1.5.2 Elevation vs. Drainage Area

A significant and moderate correlation is present between elevation and drainage area for the streams at Robinson Forest (Table 4.31). As drainage area increases, elevation decreases as seen in Figure 4.23. This result was expected as higher local elevations in a dendritic, fractal valley system are associated with smaller upland contributing areas. A similar result is seen with the stream at the JD sites (Figure 4.24). For the intermittent streams at the JD sites, this relationship is very strong. The reason for this is unknown.

While local valley slope, being a differential measure of elevation, may be more likely to exhibit similar behavior throughout a given topographic region, elevation alone is significant only at a local scale. While two different catchments upstream of two different perennial points-of-origin may exhibit similar or identical behavior with respect to local valley slope – that is, they may look identical when overlaid on one another – the baseline elevation of the perennial origin, and thus the elevation of every upland point, may be substantially different. Therefore it is both unsurprising to observe significant inverse correlation between elevation and drainage area and unhelpful to extrapolate a typical elevation for a given stream type from one catchment to another.

The correlation that is observed from these data, and the fact that it appears consistent across a variety of datasets and scales, is fundamentally a confirmation that there is a similar pattern to the topography in the Robinson Forest and the JD datasets. This observation suggests that such a correlation may be useful as a measure of the applicability of results from one region to another with respect to spatial analysis of flow networks. While factors such as geology, soils, and topographic relief may be the same or similar across large areas, as evidenced by the vast area encompassed by HLR 16, a more "high resolution" characterization of the landscape may be useful for extrapolating the results of this thesis to other areas in GIS.

Table 4.31: Pearson correlations comparing elevation and drainage area.

Stream Orders[1]	**Correlation Coefficient**	***p*-value**
	-----Robinson Forest-----	
E (n=33)	-0.562	0.0007
E and I (n=43)	-0.632	<0.0001
E, I, and P (n=48)	-0.656	<0.0001
	-----JDs-----	
E (n=30)	-0.578	0.0008
E and I (n=45)	-0.673	<0.0001
E, I, and P (n=52)	-0.561	<0.0001

Figure 4.23: Elevation vs. drainage area at Robinson Forest (all flow regimes).

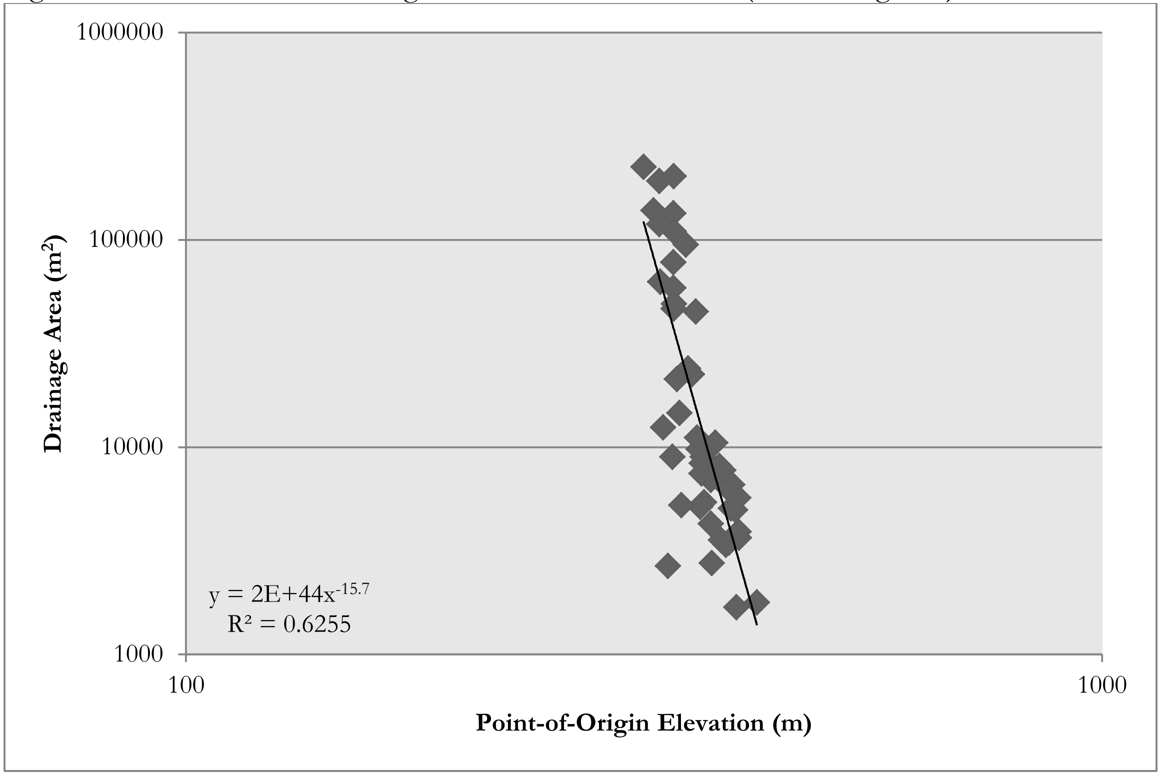
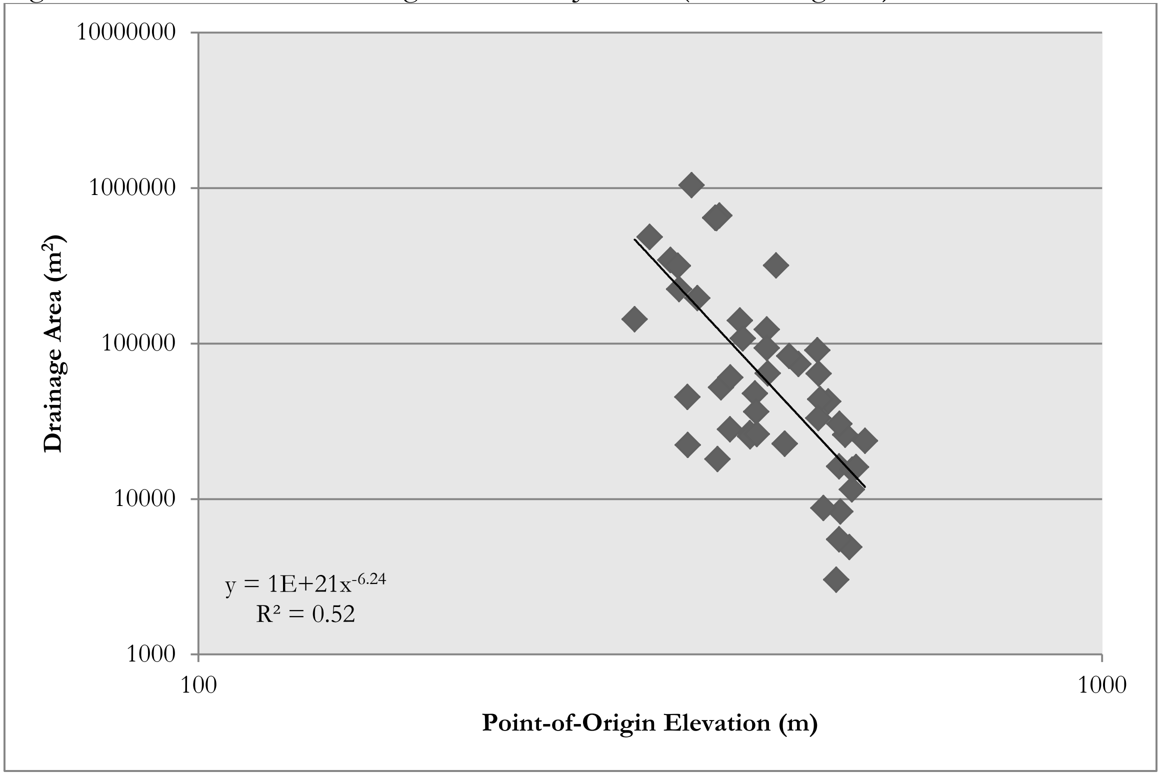


Figure 4.24: Elevation vs. drainage area at the JD sites (all flow regimes).



4.1.5.3 Elevation vs. Local Valley Slope

A significant and weak to moderate correlation is present between elevation and local valley slope for the streams at Robinson Forest (Table 4.32). As elevation increases, local valley slope increases as seen in Figure 4.25. A similar result is seen with the stream at the JD sites (Figure 4.26). These results agree with the intuition that slope increases with elevation in mountainous terrain.

Table 4.32: Pearson correlations comparing elevation and local valley slope.

Flow Regimes	**Correlation Coefficient**	***p*-value**
	-----Robinson Forest-----	
E and I (n=43)	0.417	0.0055
E, I, and P (n=48)	0.547	<0.0001
	-----JDs-----	
E (n=30)	0.407	0.0256
E and I (n=45)	0.347	0.0196
E, I, and P (n=52)	0.425	0.0017

Figure 4.25: Elevation vs. local valley slope at Robinson Forest (all flow regimes).

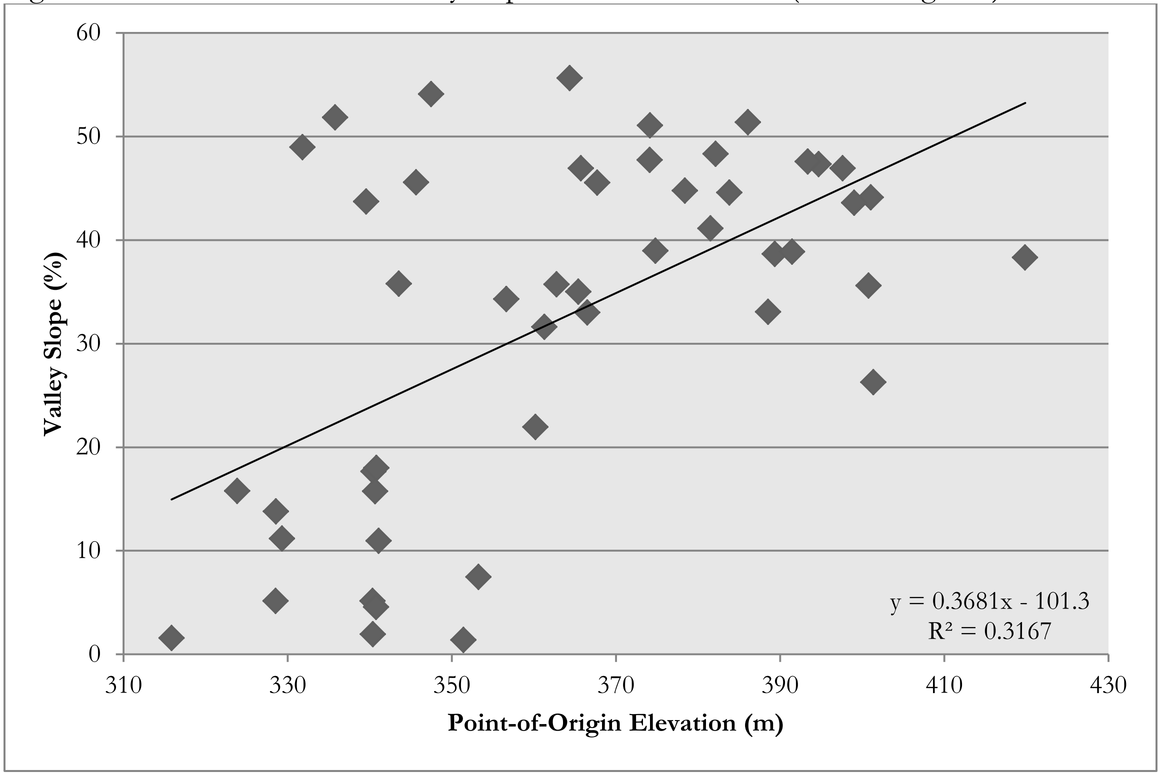
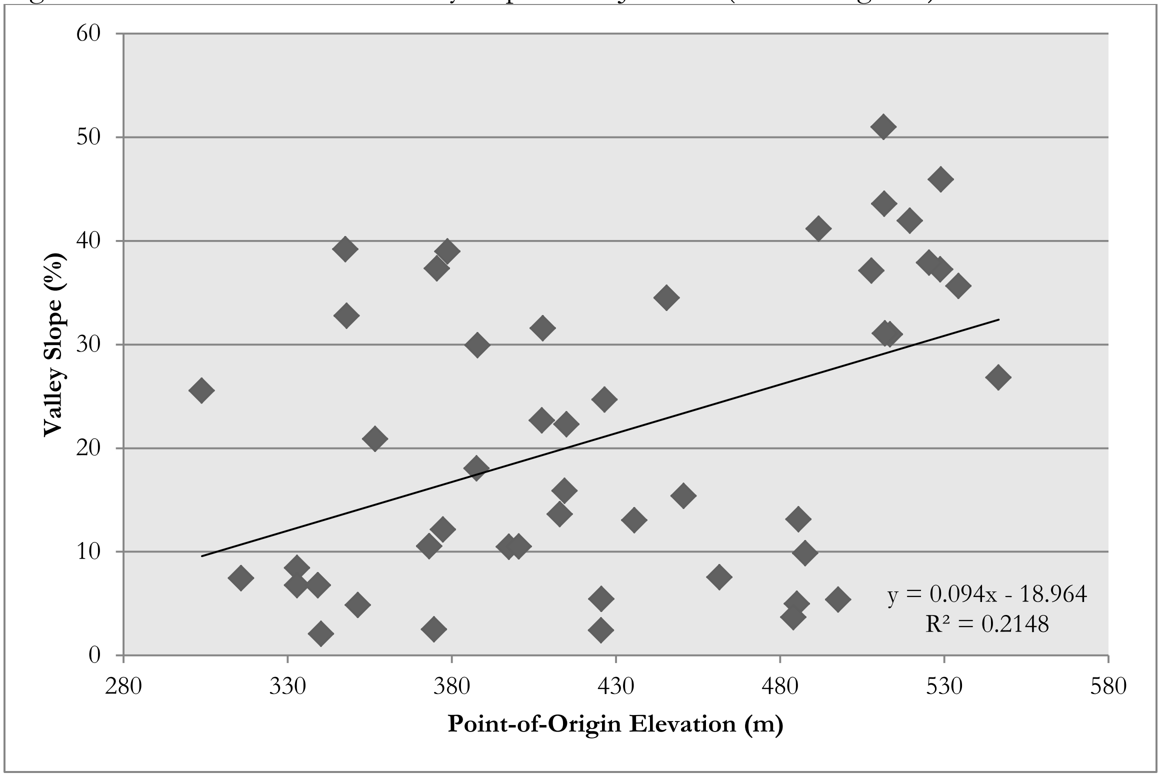


Figure 4.26: Elevation vs. local valley slope at the JD sites (all flow regimes).



4.1.5.4 Soil Parameter Correlations

While the regression analyses involving combinations of local valley slope, elevation, and drainage area do tend to show significant relationships, the regression analyses involving the various soil characteristics (infiltration rate, T-factor, K_w, K_f, % Sand, % Silt, and % Clay) show a lesser degree of correlation depending on the variable. The difficulty in uncovering consistent and significant statistical relationships involving the soil parameters is likely due to a lack of variety in the soils types underlying the available point-of-origin data.

With regards regression analysis of soil infiltration rate and drainage area, while no statistically significant relationship was found for any combination of stream orders within either dataset, almost every analysis revealed at least a weak positive correlation. Correlations of approximately 0.26 at levels of significance near 0.07 were obtained in both datasets when ephemeral and intermittent orders were combined. While it is not possible to draw firm conclusions from the available data, there are some indications that a mild positive relationship may exist between infiltration rate and drainage area for headwater streams. Pearson correlation analysis was also run on infiltration rate against both local valley slope and elevation, and while no significant relationships were found in either dataset between infiltration rate and local valley slope, analysis of the JD dataset for infiltration rate versus elevation showed a correlation of -0.399 at the 0.0291 level of significance for ephemeral streams alone.

Considering Pearson correlation analyses involving K_w and K_f, similar results were obtained for both of these variables with slightly stronger correlations observed for K_w than for K_f. Looking at K_w and K_f versus drainage area, correlations on the order of approximately -0.4 at levels of significance ranging from 0.0012 to 0.0133 were found in the JD dataset when ephemeral and intermittent streams were combined. However for K_w and drainage area, a correlation of 0.287 at significance level 0.0482 was found for the Robinson Forest dataset when all stream orders are considered together. No significant relationships were found in either dataset between K_w or K_f and local valley slope. Considering K_w and K_f versus elevation, correlations on the order of -0.35 at 0.01 significance are observed for the Robinson Forest data when ephemeral and intermittent streams were combined, while correlations on the order of 0.40 or higher at 0.01 significance or better are seen in the JD data set.

For the remainder of the soils-derived parameters – T-factor, % silt, % sand, and % clay – no consistent significant correlations between these and the spatial parameters were found. In several cases, a significant correlation was discovered in the JD dataset when only intermittent streams are considered, and this correlation was often the inverse of a correlation found in the Robinson Forest dataset. For example, correlations between % clay and elevation on the order of -0.4 at 0.01 or better significance were found throughout the Robinson Forest data, regardless of how stream types are grouped, while correlations ranging from 0.36 to 0.73 at significance 0.01 or better are found in the JD data, also regardless of how stream types are grouped. This and other similar observations suggest that the soils in the two datasets simply have different characteristics with respect to the variables in question. Ultimately, no firm conclusions can be drawn from these soils data. While these were the most robust data that could be identified, and there is some indication of a positive correlation between infiltration rate and drainage area, there is simply too little variety in the dataset and too few observations with inadequate controls to identify any additional functional relationships involving these soil characteristics.

4.2 GIS MODEL DEVELOPMENT

Based on the results of this study along with results from previous studies (Gandolfi et al., 1998; Paybins, 2003; Childers, 2006), drainage area and local valley slope were identified as the most useful spatial parameters for predicting and delineating headwater streams using GIS. The typical values of drainage area and local valley slope for headwater points-of-origin obtained from Robinson Forest were validated by both previous studies (Paybins, 2003; Fritz et al., 2008) and the JD dataset (excluding JD site 2007). Additionally, drainage area and local valley slope are very convenient parameters for use with the ArcHydro model in ArcGIS. Drainage area can be directly related to the GCT used to delineate streams in ArcHydro, and local valley slope can be quickly and easily obtained from any DEM using built-in ArcHydro functions. As such, drainage area can be used as the parameter to estimate the location and extent of a particular flow regime, while local valley slope can be used (along with elevation to look for potential headcuts), if necessary, to help validate the results of the prediction.

The values of drainage area and local valley slope used for delineations in ArcGIS for each of the three flow regimes are shown in Table 4.33. Using a 1/3 arc-second DEM resolution, each grid cell is approximately 9.421 m on a side, or 88.76 m^2 in area. This results in GCTs for each flow regime as shown in Table 4.34. Different DEM resolutions (i.e. 1 arc-second or 1/9 arc-second) will have different GCTs that correspond to the typical drainage areas shown in Table 4.33. After the appropriate DEM preprocessing has been completed in ArcHydro (fill sinks, etc.), these GCTs can be used to delineate dendritic flow networks for each flow regime. Each network will delineate a stream at all points with a drainage area equal to or greater than the GCT for that flow regime, so the total linear extent of streams in a given regime will be equal to the difference in total extent between regimes.

Table 4.33: Typical drainage areas and local valley slopes (by flow regime) for headwater streams in Robinson Forest.

	Ephemeral	**Intermittent**	**Perennial**
Drainage Area (ha)	0.7	7.2	17.2
Local Slope (%)	43	12	6

Table 4.34: Grid Cell Thresholds (GCTs) for stream delineation by flow regime (1/3 arc-second DEM resolution).

	Ephemeral	**Intermittent**	**Perennial**
Grid Cell Threshold	79	811	1938

For example, the length of ephemeral streams will be estimated to equal the difference between the total length of streams delineated using the ephemeral GCT and those delineated using the intermittent GCT, while the length of intermittent streams will be the difference between the length of streams delineated using the intermittent GCT and those delineated using the perennial GCT. The length of the total network delineated using the perennial GCT should equal the estimate of total length for the perennial flow regime, since all points downstream of the perennial point-of-origin threshold should also exhibit perennial flow.

In order to estimate the location and extent of streams with ephemeral, intermittent, and perennial flow regimes based on the drainage area thresholds identified, a stream network should be created in ArcHydro using each of the three GCTs presented. ArcGIS can then be used to calculate the length of stream features in each of the resulting layers. Using the procedure described, the length of streams can then be determined for each flow regime.

4.3 EXTRAPOLATION OF RESULTS AND COMPARISON TO NHD

In order to test the applicability of the developed GIS model for predicting the location and extent of headwater flow regimes, the procedure described was applied to the Buckhorn Creek 12-digit Hydrologic Unit Code (HUC-12) 051002010506 that encompasses the Robinson Forest study watersheds. This area was selected because the Buckhorn Creek HUC-12 is relatively small (117.6 km^2 or 29,058 ac), facilitating GIS processing, and it is expected to have the greatest similarity of any HUC-12 to the study area from which the model GCTs were derived. This provides the highest possible degree of confidence in the precision of the results and facilitates accurate comparison to the published high-resolution NHD stream features in the same HUC-12.

Stream networks were delineated for the Buckhorn Creek HUC-12 using the model GCTs from Robinson Forest. The total length exclusive to each flow regime was calculated. The high-resolution NHD data from The National Map Viewer was analyzed and the total length of streams identified as intermittent and perennial were calculated. The high-resolution NHD data did not include ephemeral streams. Flow paths for a small portion of the Buckhorn Creek HUC-12, including Buckhorn Lake and an area that has been extensively surface mined, was initially delineated by the GIS model, but all delineated flow paths in the area for which streams were not shown in the high-resolution NHD dataset were removed from the GIS model results to provide a consistent basis for comparison (approximately 14.7 km of total length from the GIS model delineation of intermittent and perennial streams together).

Table 4.35: Total stream length by flow regime (HUC 051002010506, Buckhorn Creek).

	Ephemeral	**Intermittent**	**Perennial**	**Intermittent and Perennial**
GIS Model (km)	317.2	81.2	185.9	267.1
High-res NHD (km)	0.0	74.1	64.1	138.2
Difference (%)	*100*	*8.7*	*65.5*	*48.3*

The high-resolution NHD for the Buckhorn Creek HUC-12 identified approximately 140 km of total intermittent and perennial stream length, compared to 267.1 km from the GIS model, a difference of 122.1 km (48.3%). The high-resolution NHD showed 64.1 km of perennial stream length, compared to 185.9 km from the GIS model, a difference of 121.8 km. The high-resolution NHD showed 74.1 km of intermittent stream length, compared to 81.2 km from the GIS model, a difference of 7.1 km. The high-resolution NHD shows approximately 65.5% less perennial stream extent and 8.7% less intermittent stream extent than the GIS model. Of the overall difference between the high-resolution NHD and the GIS model, the majority (95.0%) is due to differences in perennial stream length. The high-resolution NHD and the GIS model appear to have good agreement on the total length of intermittent channels. While the high-resolution NHD does not account for ephemeral channels, they account for 54.3% of total channel length in the Buckhorn Creek HUC-12 according to the GIS model. Assuming the stream network that should be considered in CHIAs includes ephemeral streams, the high-resolution NHD may underrepresent the total stream network length in the Buckhorn Creek HUC-12 by as much as 77% (though it should be reiterated that the high-resolution NHD data does not claim to include ephemeral channels).

Table 4.36: Percentage of total channel length in each flow regime (GIS model, Buckhorn Creek HUC-12 and Hansen (2001) from USGS 1:24K topographic maps, Chattooga River watershed – Georgia, South Carolina, and North Carolina).

Channel Length (%)	**Ephemeral**	**Intermittent**	**Perennial**
GIS Model	54.3	13.9	31.8
Hansen (2001)	55	17	28

Hansen's (2001) GIS model found that USGS topographic contour maps (1:24K) only identified 75% of perennial streams and 21% of the entire ephemeral, intermittent and perennial stream network. For comparison, the high-resolution NHD identifies approximately 35% of perennial streams delineated by the GIS model in this thesis and 23% of the entire ephemeral, intermittent, and perennial network. The GIS model developed by Childers et al. (2006) revealed a perennial network with 70% greater length than the NHD showed, compared to 65.5% in this thesis.

Figure 4.27: Buckhorn Creek HUC-12, high-resolution NHD intermittent and perennial stream delineation (*StreamRiver*).

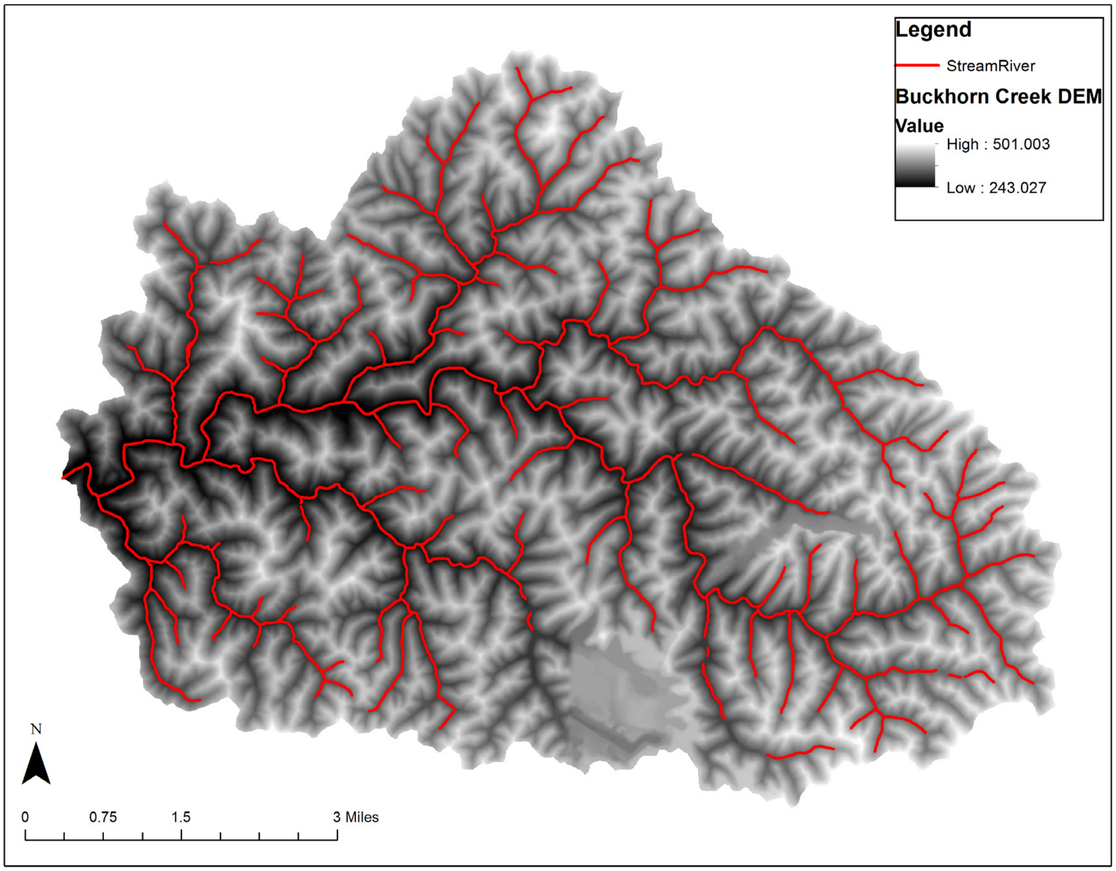


Figure 4.28: Buckhorn Creek HUC-12, high-resolution NHD intermittent and perennial stream delineation (*StreamRiver*) and GIS model perennial stream delineation (*GIS Model: P*).

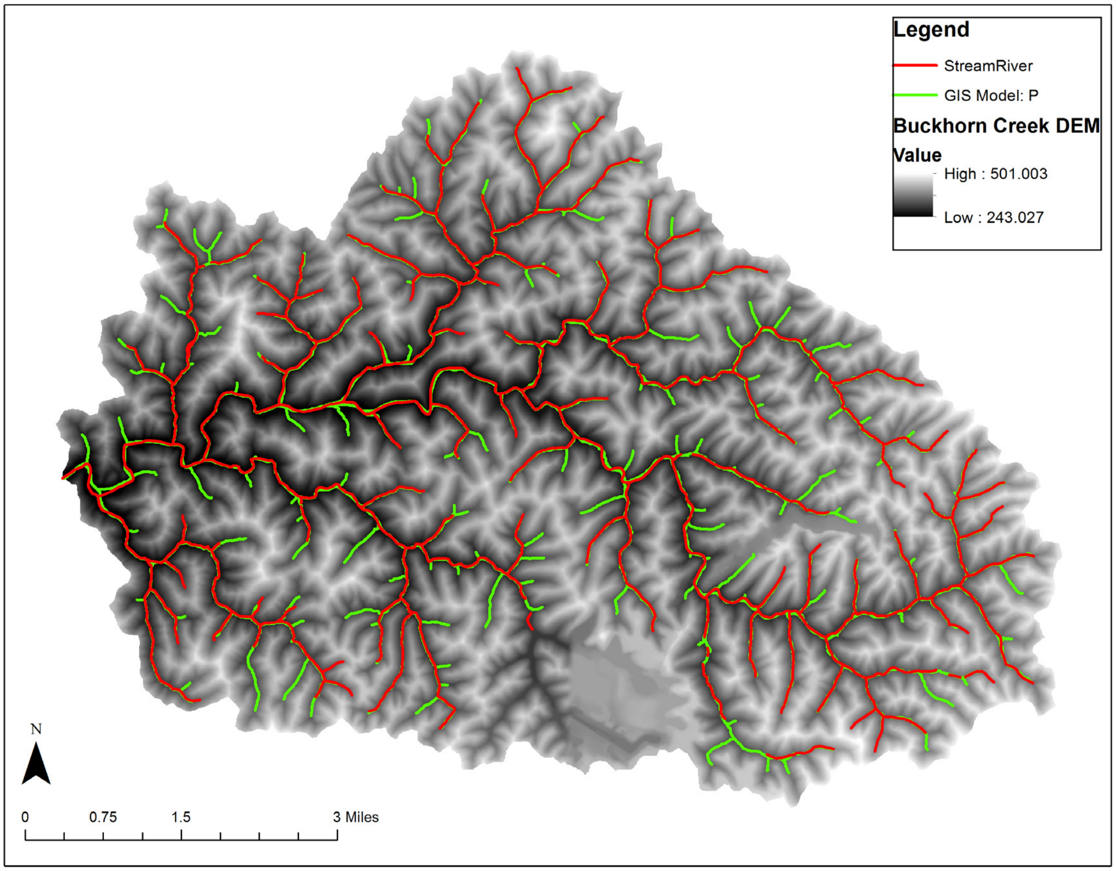


Figure 4.29: Buckhorn Creek HUC-12, high-resolution NHD intermittent and perennial stream delineation (*StreamRiver*) and GIS model intermittent and perennial stream delineation (*GIS Model: I and P*).

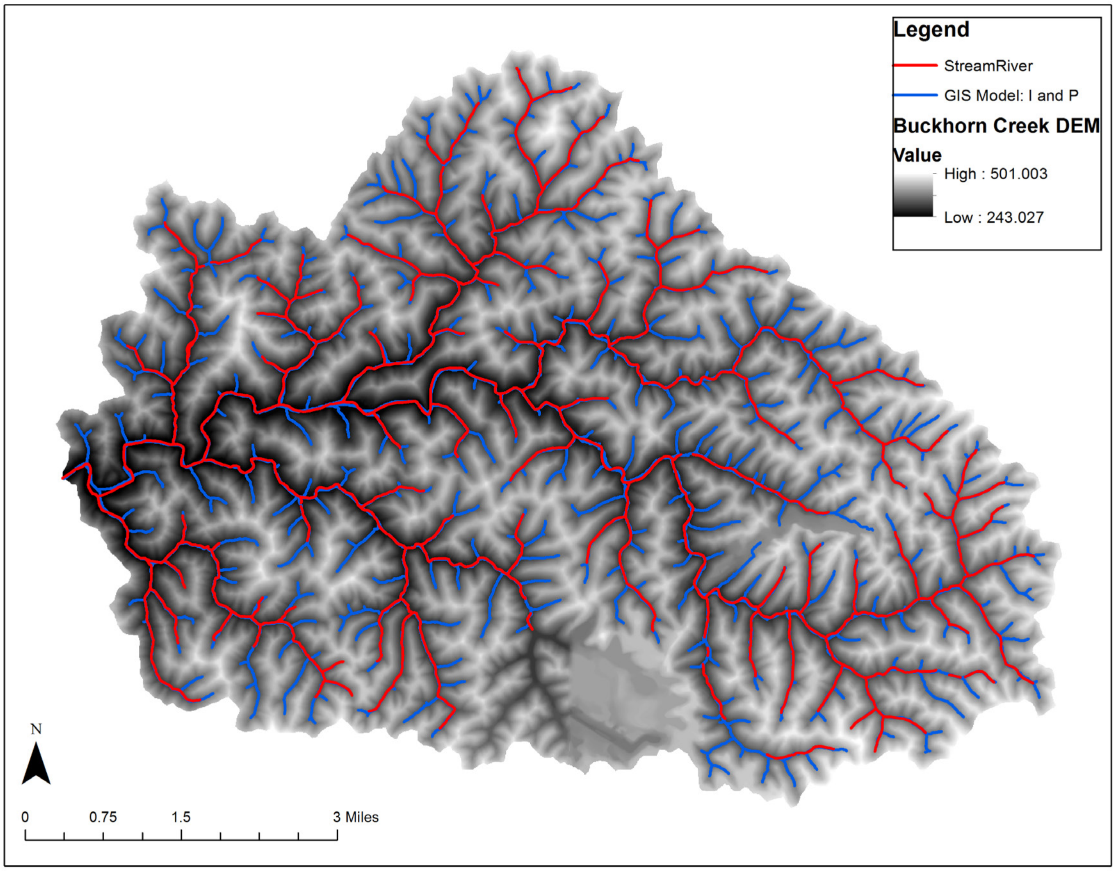


Figure 4.30: Buckhorn Creek HUC-12, high-resolution NHD intermittent and perennial stream delineation (*StreamRiver*) and GIS model ephemeral, intermittent, and perennial stream delineation (*GIS Model: E, I, and P*).

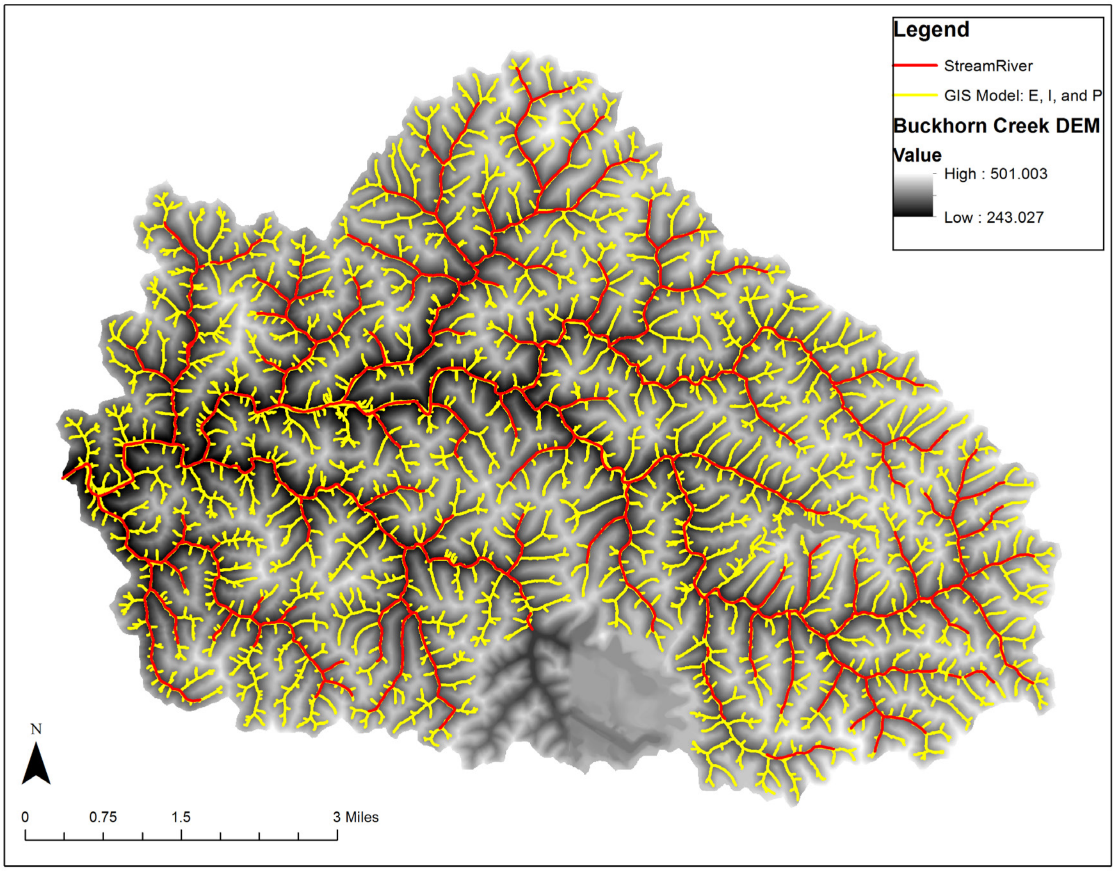


Figure 4.31: Buckhorn Creek HUC-12, high-resolution NHD intermittent and perennial stream delineation (*StreamRiver*) and GIS model perennial stream delineation (*GIS Model: P*) and intermittent with perennial stream delineation (*GIS Model I and P*).

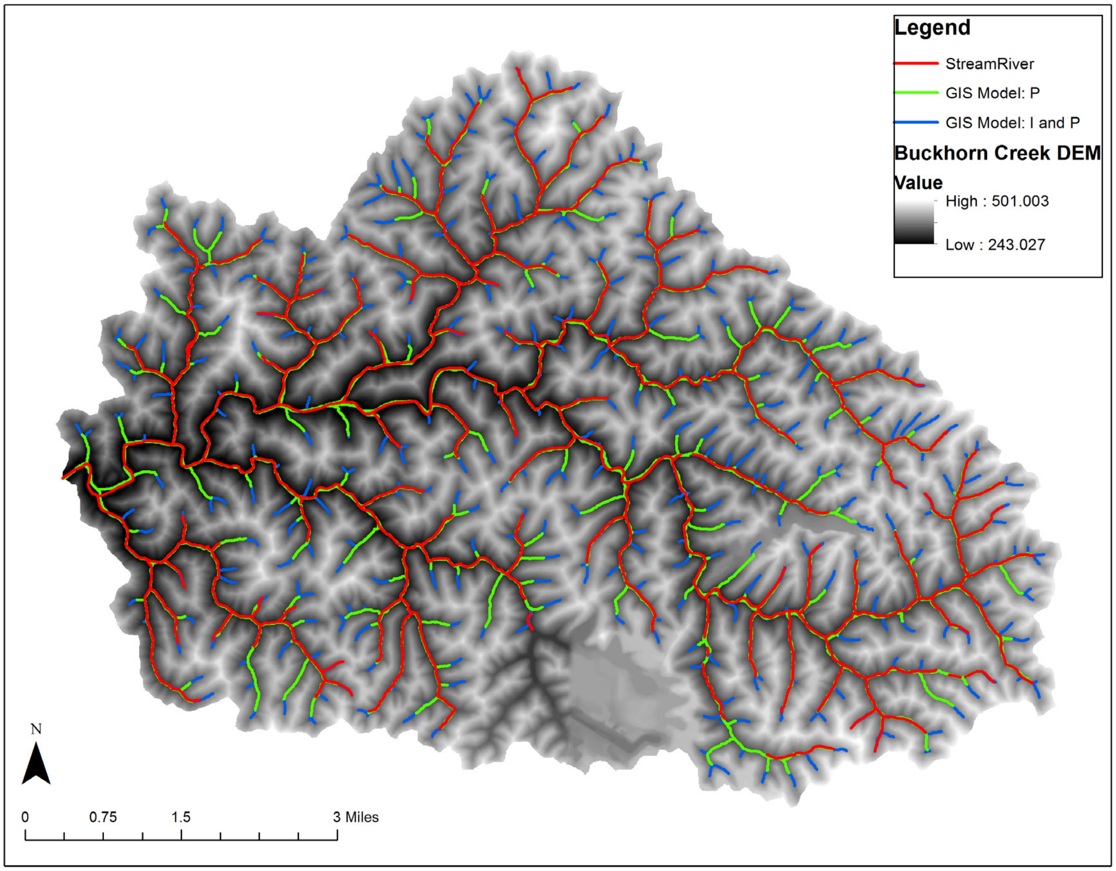
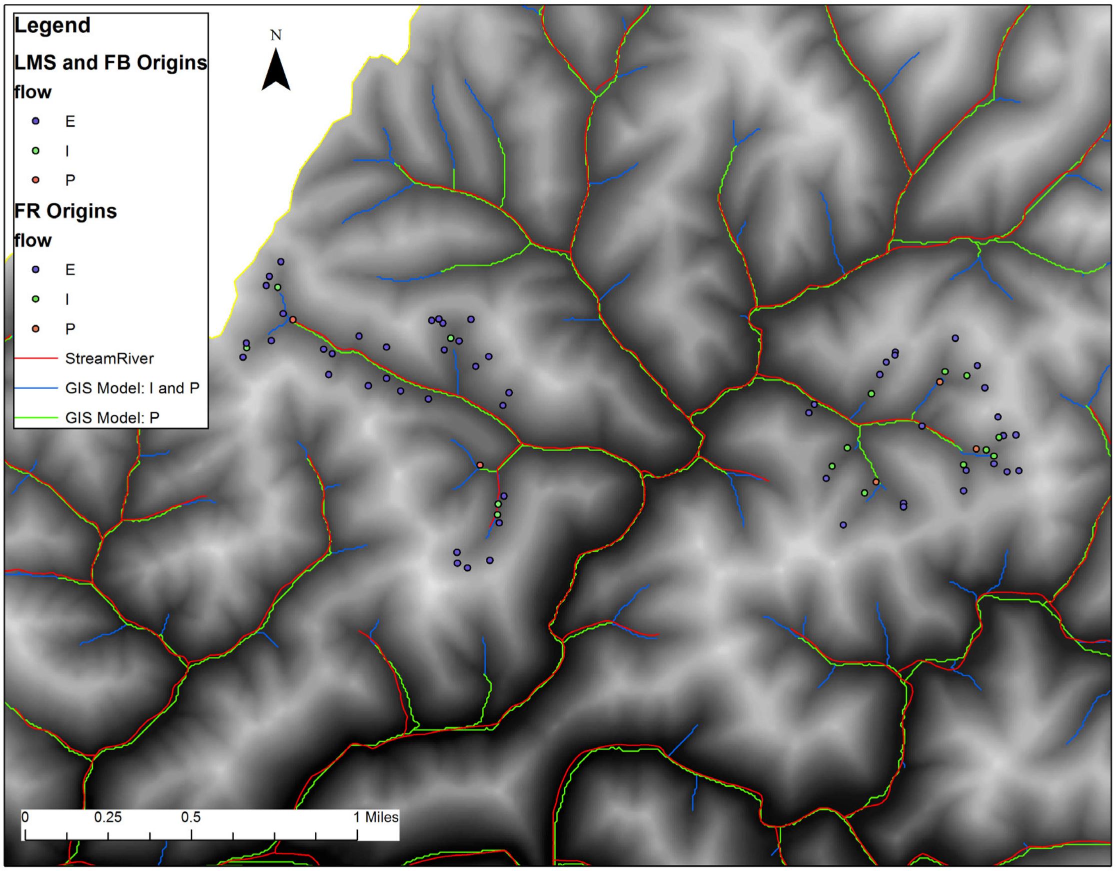


Figure 4.32: Buckhorn Creek HUC-12, Robinson Forest area detail, high-resolution NHD intermittent and perennial stream delineation (*StreamRiver*), GIS model perennial stream delineation (*GIS Model: P*) and intermittent with perennial stream delineation (*GIS Model: I and P*). *Flow indicates flow regime (E=ephemeral, I=intermittent, P=perennial). LMS=Little Millseat, FB=Field Branch, FR=Falling Rock.*



Figures 4.27 through 4.32 illustrate the differences between the high-resolution NHD intermittent and perennial stream delineation (red lines) and the delineation of intermittent and perennial streams based on the GIS drainage area threshold model (blue lines). Note how the GIS model delineation generally coincides with the location of intermittent stream points-of-origin (green dots), while the high-resolution NHD delineation coincides more closely with the location of perennial stream points-of-origin (pink dots). The GIS model intermittent and perennial stream delineation (and sometimes even the perennial-only delineation) generally extends further upland into the drainage network than the NHD, resulting in a greater total stream length shown by the GIS model.

CHAPTER 5: CONCLUSIONS

Recent draft guidance from the USEPA (2011) explains that streams with a significant physical, biological, or chemical nexus to TNWs should be included in JDs for surface mining permit applications. Performing a CHIA of mining's impact on the aquatic environment requires knowing the location and extent of all streams with a significant nexus in a given project area. Previous studies indicate that streams with an ephemeral or intermittent flow regime, despite lacking year-round flow, do have a significant physical, biological, and chemical nexus to their downstream perennial counterparts (Duncan et al., 1987; USNRC, 1997; Dieterich and Anderson, 1998; Hall and Anderson, 1988; Alexander et al., 2000; Lieb and Carline, 2000; Meyer and Wallace, 2001; Peterson et al., 2001; Gomi et al., 2002; Pitt, 2002; Ohio EPA, 2003; Lowe and Likens, 2005; Dunnivant and Anders, 2006; Freeman et al., 2007; Meyer et al., 2007). The results of this thesis and previous studies (Hansen, 2001) indicate that ephemeral streams can account for over fifty percent of total stream length in mountainous regions such as the Appalachian Coal Belt. This thesis and other studies (Hansen, 2001; Paybins, 2003; Childers et al., 2006; Fritz et al. 2013) also indicate that existing nationwide stream inventories used by regulatory agencies and researchers such as the high-resolution NHD and USGS 1:24K topo maps not only fail to indicate ephemeral streams, they may significantly underestimate the extent of intermittent and perennial streams as well.

This thesis sought to characterize headwater streams in the Appalachian Coal Belt according to readily-available spatial data and develop a digital model to extrapolate these results to other areas using existing GIS stream delineation software. It is anticipated that this model will be of use to researchers, engineers, and government regulators seeking a means of validating field-sourced data and predicting the extent of headwater flow regimes across broad geographic areas within the Appalachian Coal Belt and Hydrologic Landscape Region 16. One hundred headwater channel points-of-origin including ephemeral, intermittent, and perennial flow regimes were identified in the field according to techniques specified in USEPA guidance documents (Fritz, 2006). The GIS model was developed from point-of-origin data collected in the University of Kentucky's controlled research forest, Robinson Forest. Points from three JDs obtained via a FOIA request to the USACE were used for validation of the model and assessment of the accuracy of JDs with respect to delineating the extent of headwater channels. Data were collected for each point-of-origin according to two broad classifications: topographic and soils parameters. Parameters were chosen considering the availability and consistency of data across geographic regions, likely flow regime prediction capability, and usefulness in GIS spatial analysis.

The parameters underwent statistical analyses for measures of central tendency and correlation, and ultimately it was decided that drainage area and local valley slope were the most useful variables for developing and implementing the desired GIS model. Streams in Robinson Forest and the JDs were characterized according to the selected parameters, and the results appeared to coincide very closely to those from previous studies in similar areas (Hansen, 2001; Paybins, 2003; Svec et. al, 2005; Fritz et. al, 2008). This not only helps to validate the typical values of parameters such as drainage area and local valley slope found in this thesis, but it also suggests that drainage area in particular may have the potential to remotely estimate the origins, locations, and extent of headwaters according to flow regime. The results of this thesis and those obtained by Paybins (2003) in West Virginia indicate a relatively small range of drainage areas within discrete flow regime classifications compared to previous studies (Svec et. al, 2005; Fritz et. al, 2008), and the median drainage areas from this thesis agree exceptionally well with those from Paybins (2003). There was also remarkable similarity between the results of this thesis, Paybins (2003), and the results obtained from two of the three JDs. Taken together, the similar results obtained from these field-sourced data points taken from disparate areas of the Appalachian Coal Belt region suggest that a consistent and useful relationship may exist between drainage area and flow regime across topographically and hydrologically homogenous terrain.

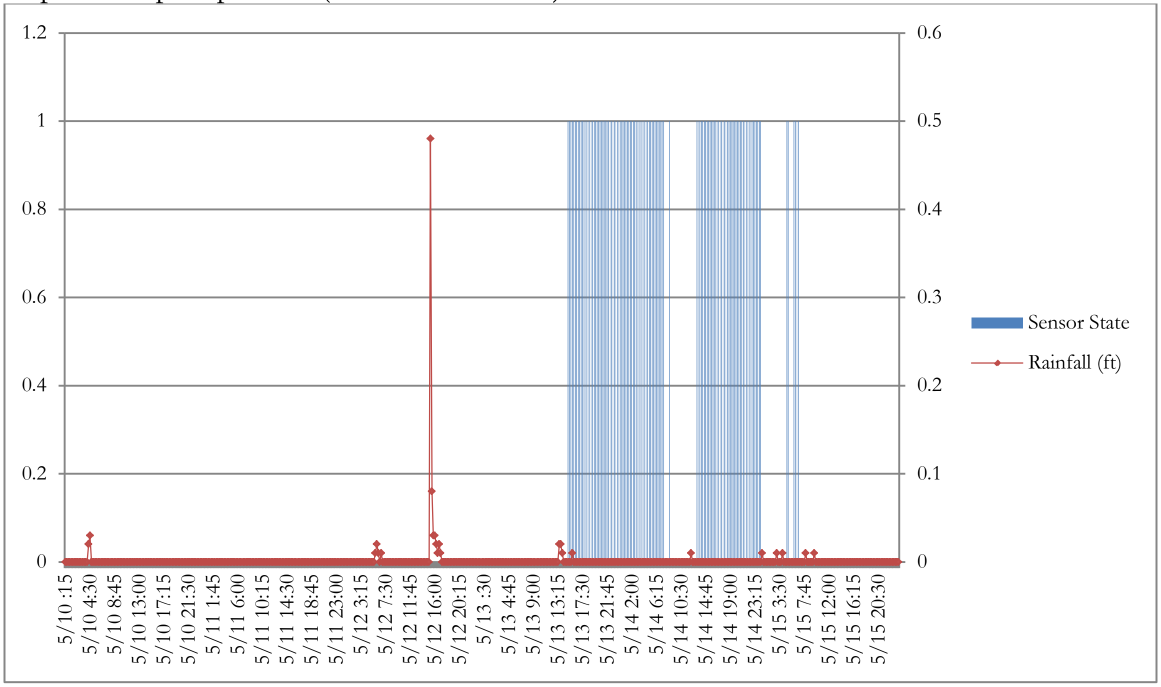
The data collected for this thesis indicated consistent drainage areas for ephemeral, intermittent, and perennial streams in the study area. The mean drainage area was found to be 0.7 ha (1.7 ac) for ephemeral streams, 7.2 ha (17.8 ac) for intermittent streams, and 17.2 ha (42.5 ac) for perennial streams. These drainage areas were converted into GCTs according to the resolution of available DEM data, and these GCTs were used in ArcGIS with the ArcHydro extension to extrapolate the results to the larger HUC-12 catchment encompassing the source data points. The delineation resulting from the GIS model was compared to the current NHD obtained from The National Map Viewer and Download Platform. The comparison showed that the NHD shows approximately nine percent fewer intermittent streams and sixty-six percent fewer perennial streams than predicted by the GIS model. While the NHD does not include ephemeral streams, the GIS model indicated that approximately 54% of total channel length in the study catchment is made up of streams with ephemeral flow regimes according to the selected drainage area thresholds. While it is possible that the GIS model somewhat overestimates the total length of ephemeral streams due to local artifacts as a result of inadequate DEM resolution, the results for intermittent and perennial streams are expected to be more accurate (since the effect of low DEM resolution is lessened at larger drainage areas). Therefore the different extents of intermittent and perennial streams predicted by the NHD and the GIS model are probably not a result of the GIS model overestimating stream length due to lack of DEM resolution. The different channel extents most likely result from other differences between the NHD and the GIS model such as differences in delineation technique, criteria for classifying flow regimes, source DEM data, post-processing (i.e. line simplification) in the NHD, or other factors.

Also while the results of the GIS model for intermittent and perennial channels is thought to be accurate for the drainage area thresholds utilized, it is unknown exactly how precise the extrapolation of results from Robinson Forest will be over larger areas. Extrapolating results to the same HUC-12 from which the original data were sourced should, however, provide the most reliable and precise opportunity possible to compare the predictions of the GIS model to existing databases such as the NHD.

CHAPTER 6: FUTURE WORK

The objectives, methods, and results of this thesis provide several opportunities for future research. Approximately 30 flow-state sensors were installed with the intent of documenting the presence or absence of flow in a sampling of the Robinson Forest headwater channels analyzed in this thesis. Data were collected from May 2011 to November 2012. The USGS, as part of a Precision Resource Management Special Grant, are using this data along with time series precipitation data and the WATER (Water Availability Tool for Environmental Resources) program to compare the flow permanence predicted by the WATER model to that evidenced by the flow-state sensors. Rainfall intensity data are available for Robinson Forest in fifteen minute increments, and the flow-state data can be plotted to show the presence or absence of flow over those same fifteen minute intervals in order to gauge the stream's response to rainfall. The WATER program combines topographic and hydrologic analysis techniques, and it presents an opportunity to help validate both field observations and GIS model predictions of flow permanence (Williamson et al., 2006). Approximately half of the sensors first installed in Robinson Forest suffered damage that prevented them from sampling continuous data at some point during the observation period either from rodents chewing through sensor cabling or water inundating the sensor bottle. In total, approximately 15 sensors have collected between six and eighteen months of viable flow-state data available for use in future analysis of flow permanence in Robinson Forest and calibration of the WATER software. Future attempts to collect additional flow permanence data from Robinson Forest or other locations should follow the methodology described by Fritz et. al (2006) for building, installing, and maintaining flow-state sensors in the field so as to help prevent the problems associated with unshielded cabling and inadequate waterproofing.

Figure 6.1: Example of flow-state data plotted with rainfall intensity for an ephemeral channel in the Falling Rock watershed of Robinson Forest showing flow in the channel in response to precipitation (5/10/11-5/15/11).



In addition to the WATER program and flow-permanence analysis, numerous opportunities exist to collect additional point-of-origin data and explore the relationships between channel origins and the topographic/hydrologic characteristics of the terrain in which they exist. Additional channel points-of-origin can be identified from Robinson Forest, from additional JDs via FOIA requests to the USACE, and from other sources and locations. The methodology described in this thesis can be replicated to compile further data on typical drainage area, valley slope, elevation, and other characteristics for known points-of-origin in various flow regimes. While the results of this thesis agree well with previous studies in the region and suggest a consistent and useful relationship between flow permanence and drainage area in the Appalachian Coal Belt Region, the landscape characteristics that determine the precise nature of this relationship need to be further researched.

The Hydrologic Landscape Region (HLR) terrain classification system discussed in this thesis provides a good starting point for analyzing the consistency of the drainage area-flow permanence relationship across a variety of geographic areas. The data analyzed in this thesis all derive from HLR 16, as do those from Paybins (2003), which suggests that the

HLR unit might prove to be an effective means of characterizing this relationship between topography and flow permanence. Analysis of soils characteristics in this thesis as well as exploring the relationships between factors such as slope, drainage area, and elevation provides a foundation for identifying such relationships across a broader geographic area. Similar characteristics are used to classify the various HLRs, which explains in part the relatively low variance of these parameters, especially considering soils and geology. In other words, the homogeneity of landscape characteristics which presumably lead to a consistent drainage area-flow permanence relationship in a certain area (i.e. HLR 16 or the Appalachian Coal Belt) also makes it difficult to characterize this relationship across a range of dissimilar areas. This thesis identified clear and expected correlations between topographic parameters for instance, but using these parameters to characterize landscapes with respect to the drainage area-flow permanence relationship will require analyzing data from a variety of regions with significantly different topography. Similarly, the uniformity of soils and geology in this thesis makes it difficult to quantify the effect of these variables on the theorized drainage area-flow permanence relationship. Analyzing channel origins across a range of HLRs may be a good way to test this theory, as would collecting data from different areas with characteristics that control specifically for one or more variables (i.e. areas with similar soils and geology but with a significantly different slope-area relationship or topographic relief). The HLR regime considers a variety of these factors together in an attempt to characterize the hydrologic behavior of large landscape regions, but it is also important to consider the influence of the individual parameters that define a HLR in order to determine whether or not the HLR is or is not an appropriate system by which to classify a drainage area-flow permanence relationship, and if so, to what extent.

The ultimate objective of this thesis and future research along similar lines is to develop an empirical model to simplify the complex process of identifying and delineating streams according to their typical flow regime for purposes of scientific research, engineering practice, and government oversight. While implementing full hydrologic response and water-deficit models such as WATER will be useful in continuing to develop and validate such techniques, the goal is to enable practitioners to utilize simpler techniques and less onerous datasets to arrive at adequate, if not fully precise, estimations of flow permanence and channel extent in a given region. The simplest and fastest way to achieve this objective is to collect and analyze empirical data on channel origins over a wide range of terrain and climate characteristics with an eye towards controlling for important variables and testing for hypothesized relationships. Further work with the WATER program and other models will help establish these hypotheses and lend additional confidence to field determinations of flow permanence, among other benefits. This thesis establishes a straightforward and replicable methodology by which future researchers can continue to refine and expand empirical modeling of the drainage area-flow permanence relationship.

APPENDIX A: MASTER POINT-OF-ORIGIN DATASET

RF=Robinson Forest; LRL-2007-217=07; LRL-2009-384=09; LRL-2010-826=10

FR=Falling Rock; LMS=Little Millseat; FB=Field Branch

E=ephemeral; I=intermittent; P=perennial

ID	Type	Loc.	Asp.	Elev. (m)	Slope (%)	Drain Area (ha)	Infil. Rate (mm hr^{-1})	K_w	K_f	T (t/ha)	Sand (%)	Silt (%)	Clay (%)
FR-01	E	RF	45	331.8	49.0	1.24	5.84	0.29	0.30	9.6	35.0	45.4	19.6
FR-05	E	RF	315	364.4	55.6	0.51	5.33	0.26	0.30	9.6	38.7	42.1	19.1
FR-08	E	RF	225	401.4	26.3	0.36	5.33	0.26	0.30	9.6	38.7	42.1	19.1
FR-14	E	RF	221	397.6	46.9	0.50	5.33	0.26	0.30	9.6	38.7	42.1	19.1
FR-15	E	RF	226	400.8	35.6	0.57	5.33	0.26	0.30	9.6	38.7	42.1	19.1
FR-17	E	RF	158	394.7	47.3	0.66	5.33	0.26	0.30	9.6	38.7	42.1	19.1
FR-18	E	RF	270	419.9	38.3	0.18	5.84	0.26	0.27	4.8	41.1	43.6	15.3
FR-21	E	RF	270	378.4	44.7	1.05	5.33	0.26	0.30	9.6	38.7	42.1	19.1
FR-23	E	RF	134	374.1	51.1	0.69	5.84	0.29	0.30	9.6	35.0	45.4	19.6
FR-24	E	RF	163	401.1	44.1	0.39	5.84	0.29	0.30	9.6	35.0	45.4	19.6
FN-31	E	RF	90	366.5	33.0	0.90	5.84	0.29	0.30	9.6	35.0	45.4	19.6
FR-43	E	RF	61	356.7	34.3	2.24	5.84	0.29	0.30	9.6	35.0	45.4	19.6
FR-46	E	RF	180	345.6	45.6	1.46	5.84	0.29	0.30	9.6	35.0	45.4	19.6
FR-47	E	RF	90	343.6	35.8	2.12	5.84	0.29	0.30	9.6	35.0	45.4	19.6
LMS-01	E	RF	68	335.8	51.8	0.27	5.84	0.29	0.30	9.6	35.0	45.4	19.6
LMS-02	E	RF	68	339.6	43.7	0.90	5.84	0.29	0.30	9.6	35.0	45.4	19.6
LMS-04	E	RF	59	365.7	46.9	0.83	5.84	0.29	0.30	9.6	35.0	45.4	19.6
LMS-05	E	RF	66	383.8	44.6	0.36	5.84	0.29	0.30	9.6	35.0	45.4	19.6
LMS-09	E	RF	27	388.6	33.1	0.34	5.84	0.29	0.30	9.6	35.0	45.4	19.6

ID	Type	Loc.	Asp.	Elev. (m)	Slope (%)	Drain Area (ha)	Infil. Rate (mm hr^{-1})	K_w	K_f	T (t/ha)	Sand (%)	Silt (%)	Clay (%)
LMS-10	E	RF	337	389.4	38.6	0.64	5.84	0.29	0.30	9.6	35.0	45.4	19.6
LMS-12	E	RF	346	386.1	51.4	0.77	5.84	0.29	0.30	9.6	35.0	45.4	19.6
LMS-14	E	RF	247	391.5	38.9	0.35	5.84	0.29	0.30	9.6	35.0	45.4	19.6
LMS-15M	E	RF	257	362.8	35.7	0.98	5.33	0.26	0.30	9.6	38.7	42.1	19.1
LMS-16	E	RF	241	367.7	45.5	0.54	5.33	0.26	0.30	9.6	38.7	42.1	19.1
LMS-18C	E	RF	320	365.4	35.0	0.75	5.33	0.26	0.30	9.6	38.7	42.1	19.1
LMS-19	E	RF	315	374.8	39.0	0.28	5.33	0.26	0.30	9.6	38.7	42.1	19.1
LMS 20	E	RF	202	374.1	47.7	0.43	5.33	0.26	0.30	9.6	38.7	42.1	19.1
LMS22	E	RF	204	381.5	41.1	0.75	5.33	0.26	0.30	9.6	38.7	42.1	19.1
LMS-24	E	RF	242	361.3	31.6	1.11	5.33	0.26	0.30	9.6	38.7	42.1	19.1
FB-03	E	RF	0	382.1	48.3	0.81	5.84	0.29	0.30	9.6	35.0	45.4	19.6
FB-04	E	RF	43	393.4	47.6	0.51	5.84	0.29	0.30	9.6	35.0	45.4	19.6
FB-05	E	RF	85	399.0	43.6	0.17	5.33	0.26	0.30	9.6	38.7	42.1	19.1
FB-07	E	RF	180	347.5	54.1	0.52	5.33	0.26	0.30	9.6	38.7	42.1	19.1
FR-04I	I	RF	232	340.5	17.7	5.84	5.33	0.26	0.30	9.6	38.7	42.1	19.1
FR-13I	I	RF	257	340.7	15.7	4.65	5.33	0.26	0.30	9.6	38.7	42.1	19.1
FR-16C	I	RF	180	360.2	22.0	4.49	5.33	0.26	0.30	9.6	38.7	42.1	19.1
FR-26I	I	RF	180	351.4	1.4	9.44	5.84	0.29	0.30	9.6	35.0	45.4	19.6
FR-30I	I	RF	74	341.1	11.0	4.90	5.84	0.29	0.30	9.6	35.0	45.4	19.6
FR-41I	I	RF	41	329.3	11.2	6.26	5.84	0.29	0.30	9.6	35.0	45.4	19.6
FR-49I	I	RF	49	340.4	5.1	7.78	5.84	0.29	0.30	9.6	35.0	45.4	19.6
LMSI-02	I	RF	291	353.3	7.5	2.39	5.84	0.29	0.30	9.6	35.0	45.4	19.6
FB-02IL	I	RF	90	323.9	15.8	13.84	5.84	0.29	0.30	9.6	35.0	45.4	19.6
FB-02IU	I	RF	90	328.6	13.8	11.88	5.84	0.29	0.30	9.6	35.0	45.4	19.6
FR-12P	P	RF	233	340.4	2.0	13.39	5.33	0.26	0.30	9.6	38.7	42.1	19.1

ID	Type	Loc.	Asp.	Elev. (m)	Slope (%)	Drain Area (ha)	Infil. Rate (mm hr^{-1})	K_w	K_f	T (t/ha)	Sand (%)	Silt (%)	Clay (%)
FR-28P	P	RF	153	340.8	18.0	10.97	5.84	0.29	0.30	9.6	35.0	45.4	19.6
FR-45P	P	RF	119	328.5	5.1	19.20	5.84	0.29	0.30	9.6	35.0	45.4	19.6
LMSP-01	P	RF	328	340.8	4.6	20.23	5.84	0.29	0.30	9.6	35.0	45.4	19.6
FB-01P	P	RF	29	315.9	1.6	22.39	5.84	0.29	0.30	9.6	35.0	45.4	19.6
Per UT Stacy Branch	P	07	289	351.4	4.8	103.99	5.84	0.31	0.32	9.6	33.3	49.4	17.4
Per RF UT Stacy Branch	P	07	290	373.2	10.5	64.17	2.54	0.28	0.55	12.0	27.0	54.0	19.0
Per LF UT Stacy Branch	P	07	290	373.2	10.5	64.17	2.54	0.28	0.55	12.0	27.0	54.0	19.0
Int RF UT Stacy Branch	P	07	226	377.3	12.1	66.33	2.54	0.28	0.55	12.0	27.0	54.0	19.0
Int LF UT Stacy Branch	P	07	290	374.6	2.5	63.64	2.54	0.28	0.55	12.0	27.0	54.0	19.0
UT 1R Eph Stacy Branch	E	07	211	303.9	25.5	14.28	5.84	0.31	0.32	9.6	33.3	49.4	17.4
UT 2R Eph Stacy Branch	E	07	206	375.5	37.3	1.80	5.84	0.31	0.32	9.6	33.3	49.4	17.4
UT 3R Eph Stacy Branch	E	07	206	378.7	38.9	5.19	5.84	0.31	0.32	9.6	33.3	49.4	17.4
UT 2R Int Stacy Branch	I	07	273	340.2	2.1	22.31	5.84	0.31	0.32	9.6	33.3	49.4	17.4
UT 1R Int RF UT Stacy Branch	I	07	233	397.4	10.5	13.99	4.83	0.31	0.32	9.6	28.4	53.2	18.4
UT 1R Eph RF UT Stacy Branch	E	07	159	445.4	34.5	2.26	4.83	0.31	0.32	9.6	28.4	53.2	18.4
UT 3R Eph RF UT Stacy Branch	E	07	247	407.5	22.7	2.64	4.83	0.31	0.32	9.6	28.4	53.2	18.4
UT 4R Eph RF UT Stacy Branch	E	07	267	426.5	24.7	6.40	4.83	0.31	0.32	9.6	28.4	53.2	18.4
UT 5R Eph RF UT Stacy Branch	E	07	267	425.4	2.4	12.28	4.83	0.31	0.32	9.6	28.4	53.2	18.4
UT 1L Eph RF UT Stacy Branch	E	07	267	425.5	5.4	9.34	4.83	0.31	0.32	9.6	28.4	53.2	18.4
UT 1L Eph LF UT Stacy Branch	E	07	221	387.5	18.0	2.80	4.83	0.31	0.32	9.6	28.4	53.2	18.4
UT 1R Eph LF UT Stacy Branch	E	07	220	400.4	10.5	10.76	4.83	0.31	0.32	9.6	28.4	53.2	18.4
UT 2L Eph LF UT Stacy Branch	E	07	224	407.8	31.5	2.52	4.83	0.31	0.32	9.6	28.4	53.2	18.4
UT 3L Eph LF UT Stacy Branch	E	07	270	412.9	13.6	4.75	4.83	0.31	0.32	9.6	28.4	53.2	18.4
UT 4L Eph LF UT Stacy Branch	E	07	0	415.0	22.3	2.61	4.83	0.31	0.32	9.6	28.4	53.2	18.4
UT 2R Eph LF UT Stacy Branch	E	07	45	414.4	15.9	3.63	4.83	0.31	0.32	9.6	28.4	53.2	18.4

ID	Type	Loc.	Asp.	Elev. (m)	Slope (%)	Drain Area (ha)	Infil. Rate (mm hr^{-1})	K_w	K_f	T (t/ha)	Sand (%)	Silt (%)	Clay (%)
Int Sugar Branch	I	07	340	315.8	7.5	48.25	5.84	0.20	0.27	9.6	34.6	48.9	16.5
UT 1L Int Sugar Branch	I	07	333	332.9	8.4	34.23	5.84	0.20	0.27	9.6	34.6	48.9	16.5
UT 2L Int Sugar Branch	I	07	333	332.9	6.8	34.23	5.84	0.20	0.27	9.6	34.6	48.9	16.5
Eph Sugar Branch	I	07	282	356.7	20.9	19.49	5.84	0.20	0.27	9.6	34.6	48.9	16.5
UT 2L Eph Sugar Branch	E	07	0	347.6	39.2	4.51	5.84	0.20	0.27	9.6	34.6	48.9	16.5
UT 1L Eph Sugar Branch	E	07	45	348.0	32.8	2.22	5.84	0.20	0.27	9.6	34.6	48.9	16.5
UT 1L Int Yellow Creek	I	07	356	339.2	6.8	31.51	-	-	-	-	-	-	-
UT 1L Eph Yellow Creek	E	07	337	387.9	29.9	6.03	5.84	0.20	0.27	9.6	34.6	48.9	16.5
UT 2R Eph RF UT Stacy Branch	E	07	159	445.4	34.5	2.26	4.83	0.31	0.32	9.6	28.4	53.2	18.4
Sugar Branch Perennial	P	07	340	315.8	7.5	48.25	5.84	0.20	0.27	9.6	34.6	48.9	16.5
UT 1L of Yellow Creek Perennial	I	07	356	339.2	6.8	31.51	-	-	-	-	-	-	-
HF#2 Area, UT Ephemeral Tributary #1 and UT Intermittent Tributary #1	E	09	250	513.5	31.0	0.83	2.54	0.28	0.55	12.0	27.0	54.0	19.0
HF#3 Area, UT Ephemeral Tributaries No. 1 through 4	E	09	211	507.8	37.1	0.30	6.10	0.23	0.38	7.2	39.7	43.3	17.0
HF#5 Area, UT Ephemeral Tributaries No. 1 through 4	I	09	72	497.7	5.4	4.22	4.83	0.31	0.32	9.6	28.4	53.2	18.4
HF#5 Area, UT Intermittent Tributaries No. 1 through 4	I	09	6	461.6	7.5	7.34	5.84	0.31	0.32	9.6	33.3	49.4	17.4
HF#5 Area, UT Perennial Tributary No. 1	P	09	270	435.6	13.0	31.57	5.84	0.31	0.32	9.6	33.3	49.4	17.4
HF#6 Area, UT Ephemeral Tributaries No. 1 through 7	E	09	160	546.6	26.8	2.36	2.54	0.28	0.55	12.0	27.0	54.0	19.0
HF#6 Area, UT Intermittent Tributaries No. 1 through 5	I	09	207	487.7	9.8	4.37	4.83	0.31	0.32	9.6	28.4	53.2	18.4
HF#7 Area, UT Ephemeral Tributaries No. 1 & 2	E	09	309	511.6	51.0	1.62	2.54	0.28	0.55	12.0	27.0	54.0	19.0
HF#7 Area, UT Intermittent Tributaries No. 1 & 2	E	09	223	528.8	37.2	1.14	2.54	0.28	0.55	12.0	27.0	54.0	19.0

ID	Type	Loc.	Asp.	Elev. (m)	Slope (%)	Drain Area (ha)	Infil. Rate (mm hr^{-1})	K_w	K_f	T (t/ha)	Sand (%)	Silt (%)	Clay (%)
HF#9 Area, UT Ephemeral Tributaries No. 1 through 8	E	09	297	525.4	37.9	0.49	6.10	0.23	0.38	7.2	39.7	43.3	17.0
HF#9 Area, UT Intermittent Tributaries No. 1 through 3	I	09	237	485.1	5.0	3.30	4.83	0.31	0.32	9.6	28.4	53.2	18.4
Unnamed Ephemeral #1	E	10	77	511.7	43.6	0.55	5.84	0.31	0.32	9.6	33.3	49.4	17.4
Unnamed Ephemeral #2	E	10	281	491.8	41.2	0.87	5.84	0.31	0.32	9.6	33.3	49.4	17.4
Unnamed Ephemeral #3	E	10	255	529.0	45.9	1.54	5.84	0.31	0.32	9.6	33.3	49.4	17.4
Unnamed Ephemeral #4	E	10	200	519.6	41.9	2.58	5.84	0.31	0.32	9.6	33.3	49.4	17.4
Unnamed Ephemeral #5	E	10	252	534.3	35.6	1.60	4.83	0.31	0.32	9.6	28.4	53.2	18.4
Unnamed Ephemeral #6	E	10	208	512.0	31.1	3.04	4.83	0.31	0.32	9.6	28.4	53.2	18.4
Unnamed Intermittent Trib. #1	I	10	270	485.7	13.1	6.37	5.84	0.31	0.32	9.6	33.3	49.4	17.4
Unnamed Intermittent Trib. #2	I	10	33	450.7	15.4	8.26	5.84	0.31	0.32	9.6	33.3	49.4	17.4
Unnamed Intermittent Trib. #3	I	10	33	484.1	3.7	9.02	5.84	0.31	0.32	9.6	33.3	49.4	17.4

APPENDIX B: POINT-OF-ORIGIN CATCHMENT DELINEATIONS

Figure B.1: Robinson Forest, Little Millseat watershed, ArcGIS/ArcHydro catchment delineations. *Original (GPS) points shown (labeled) adjacent to adjusted point-of-origin locations.*

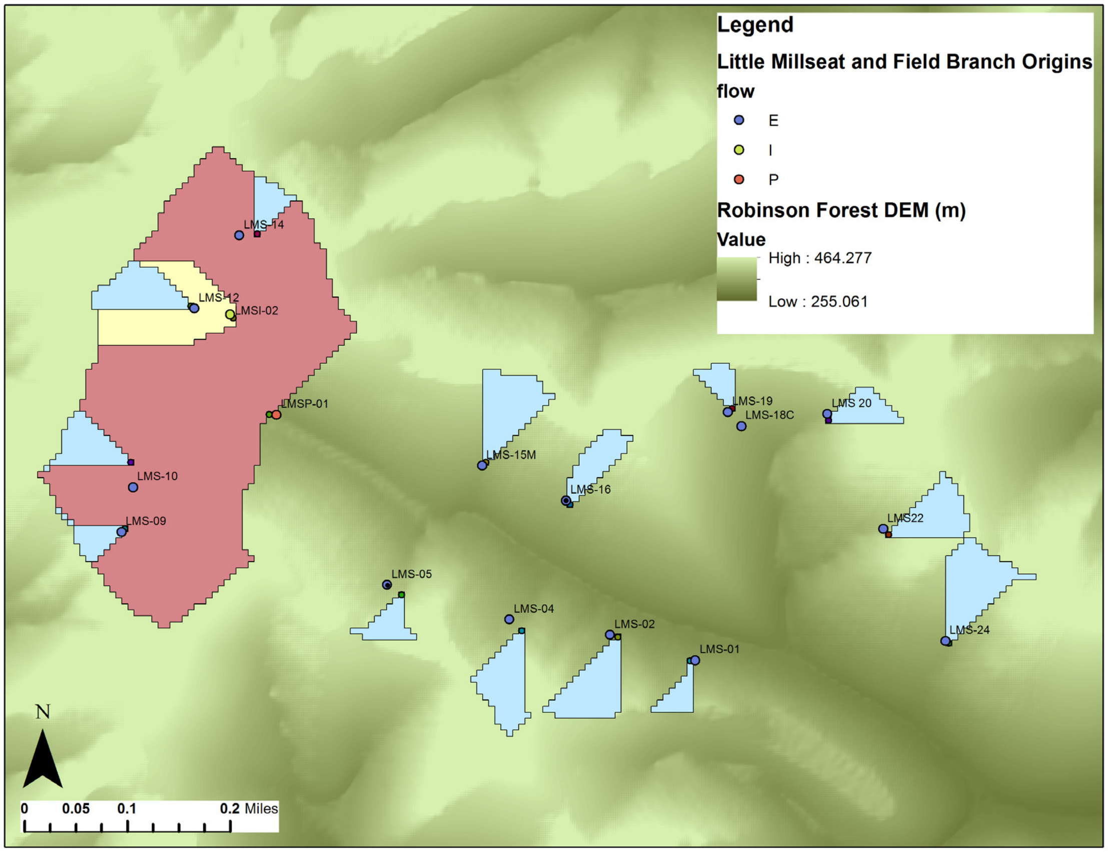
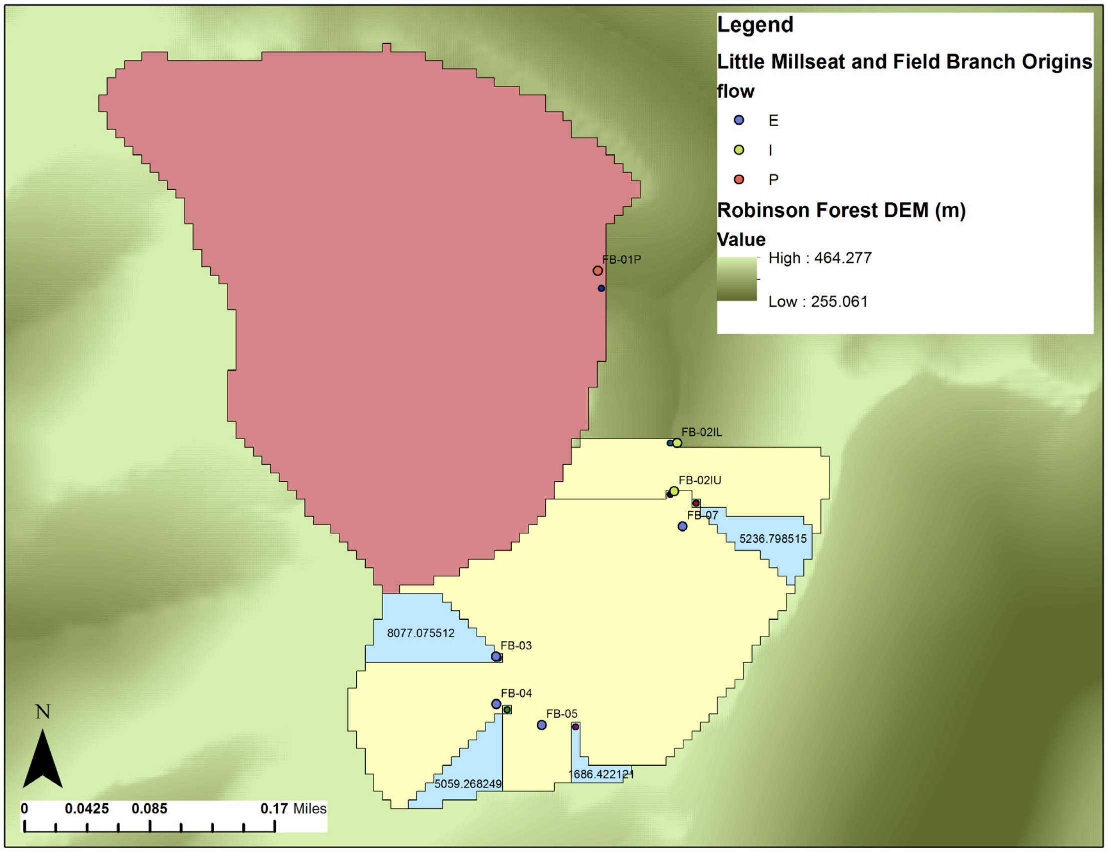


Figure B.2: Robinson Forest, Field Branch watershed, ArcGIS/ArcHydro catchment delineations. *Original (GPS) points shown (labeled) adjacent to adjusted point-of-origin locations.*



Points FB-02IL and FB-02IU are two possible point-of-origin locations for the same intermittent stream. A large debris obstruction appeared to have resulted in a relatively recent alteration in the channel. While the difference in key characteristics between the two origin locations (i.e. drainage area, local valley slope) is minimal, both points were included in the analysis to account for the apparent influence of the obstruction on the channel's geomorphology.

Figure B.3: Robinson Forest, Field Branch watershed, ArcGIS/ArcHydro catchment delineations. *Original (GPS) points shown (labeled) adjacent to adjusted point-of-origin locations.*

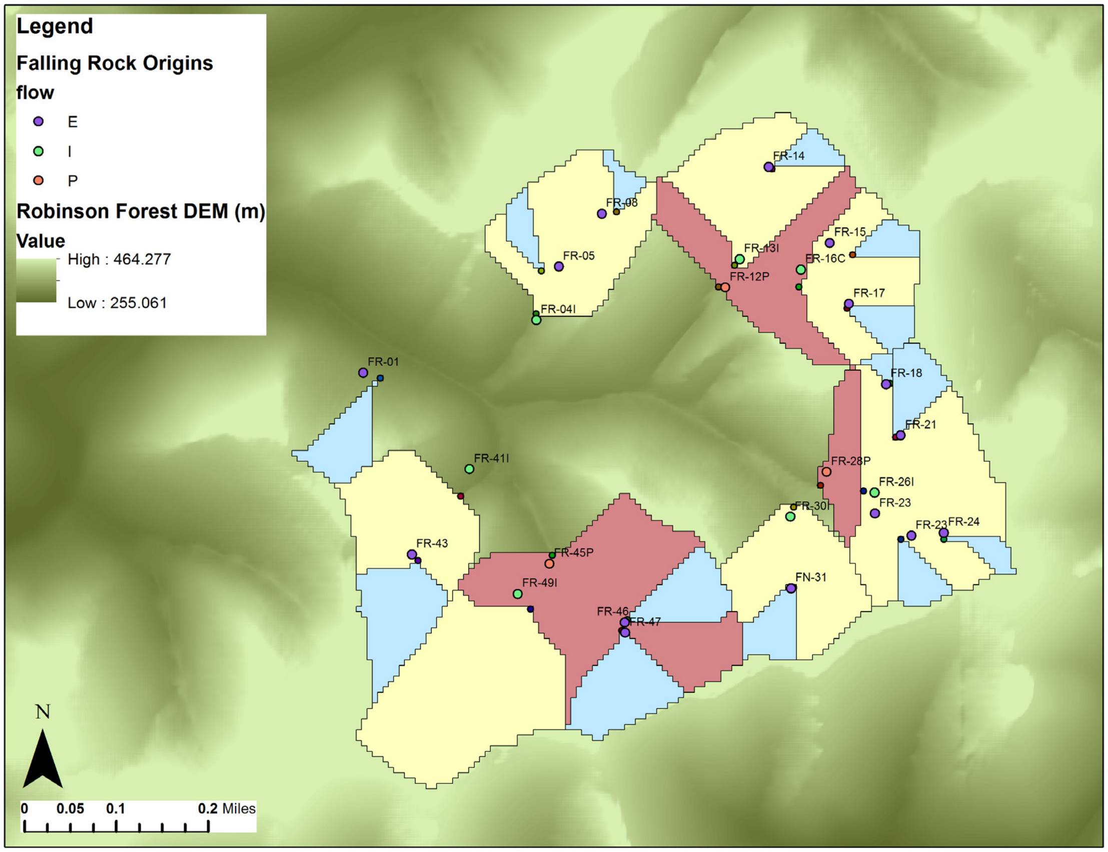


Figure B.4: JD, Permit LRL-2007-217, ArcGIS/ArcHydro catchment delineations. Original JD points shown (labeled) adjacent to adjusted point-of-origin locations.

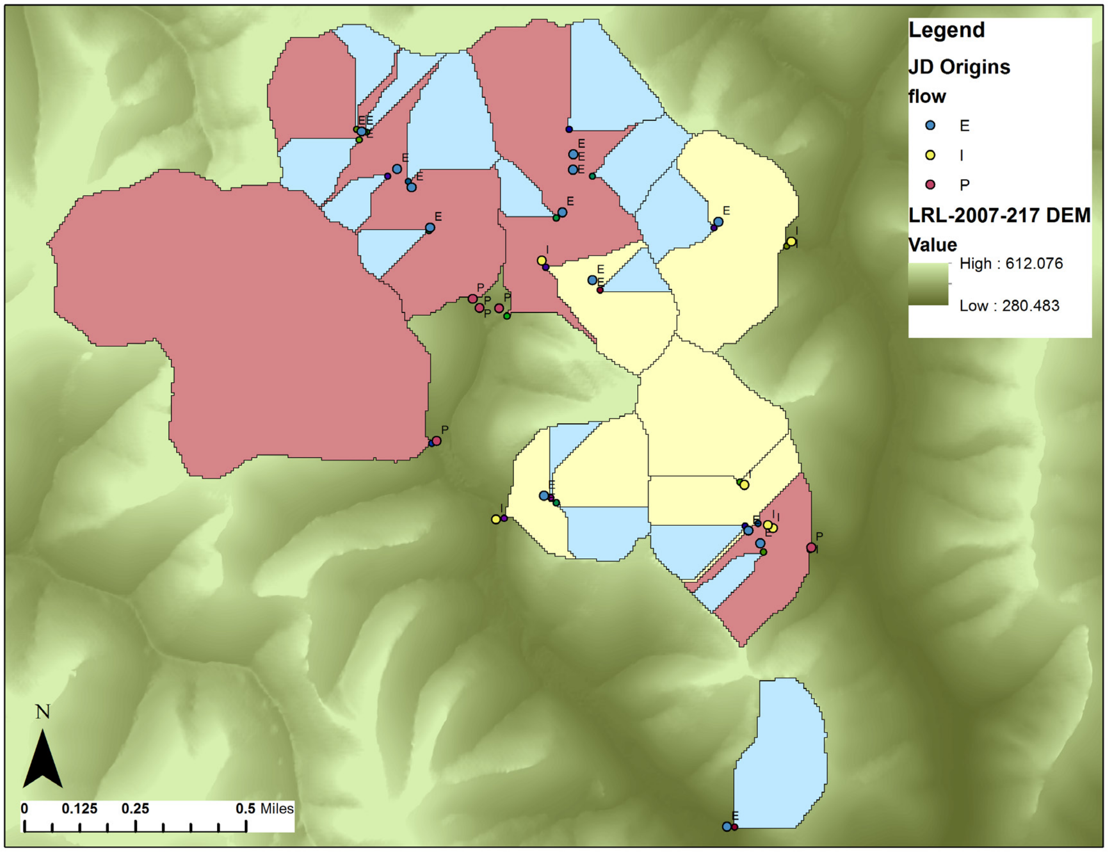


Figure B.5: JD, Permit LRL-2009-384, ArcGIS/ArcHydro catchment delineations. Original JD points shown (labeled) adjacent to adjusted point-of-origin locations.

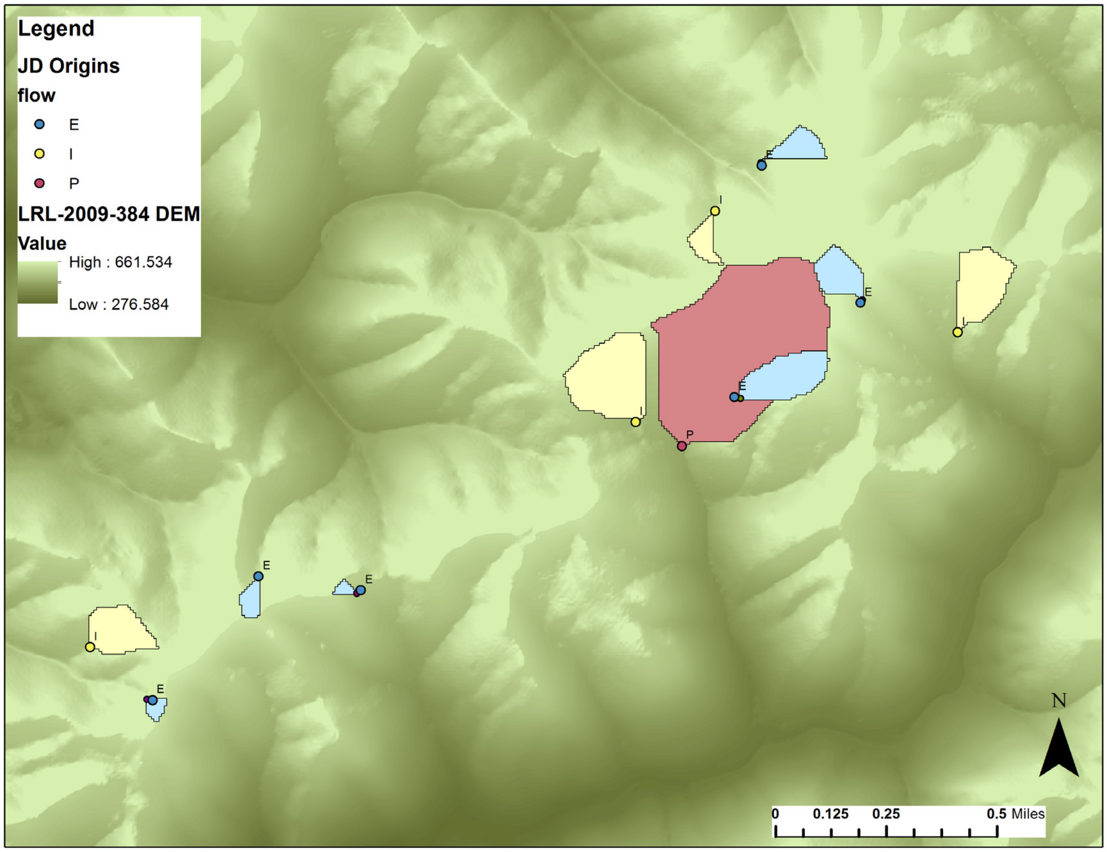
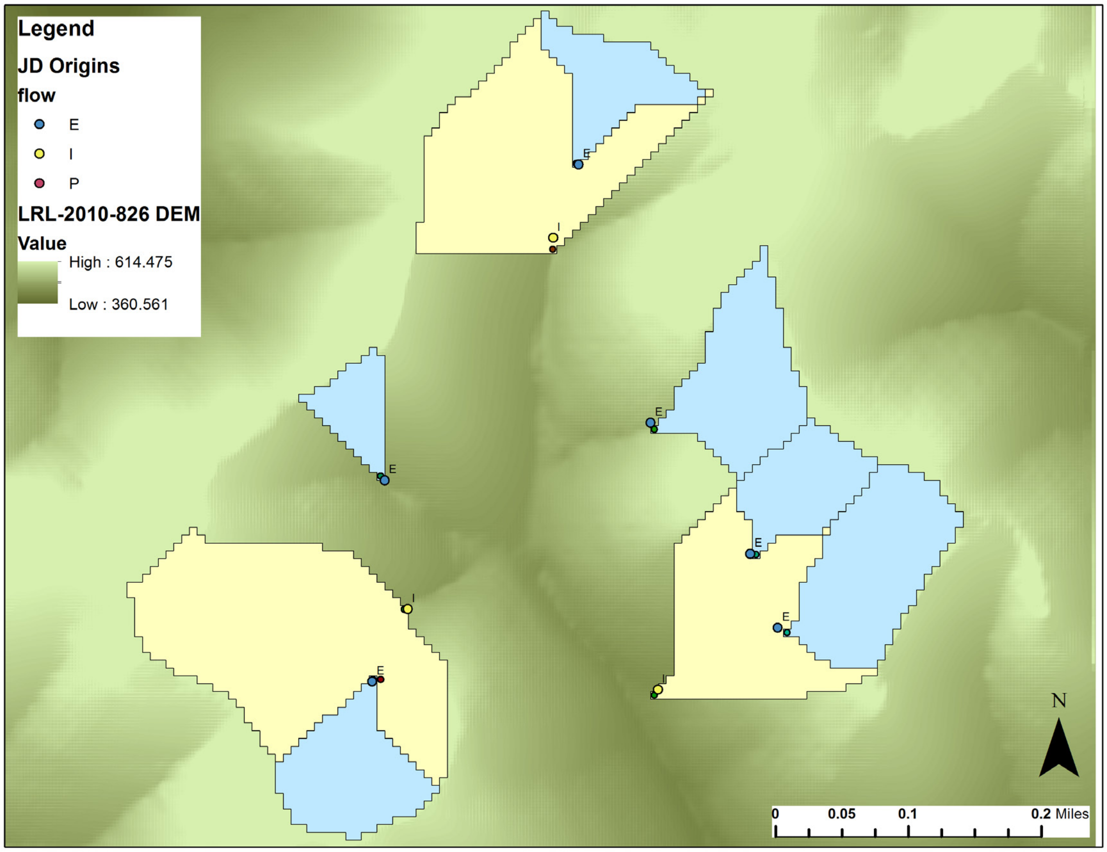


Figure B.6: JD, Permit LRL-2010-826, ArcGIS/ArcHydro catchment delineations. Original JD points shown (labeled) adjacent to adjusted point-of-origin locations.



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