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Field Guide to Identifying the Upper Extent of Stream Channels

Rebecca K. Rossi and Gabrielle C.L. David

March 2022



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Field Guide to Identifying the Upper Extent of Stream Channels

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Abstract

The upper extent of a channel is a transition zone from the hillslope to the beginning of the stream channel. Accurately and consistently identifying the upper extent of a channel in the field and locating where hillslope processes transition to stream-channel processes can be a difficult task. Physical characteristics located at the beginning of a channel (i.e., channel head), including geomorphic, sediment, and vegetation indicators, can vary significantly across different landscapes in the United States. Remote tools are useful for examining the upper extent of channels, but these remote tools have limitations for identifying the beginning of channels. Even as the resolution of remote data continues to increase, field observations are necessary to validate the remote data on the ground and to accurately and consistently identify and locate the transition from the hillslope to the stream channel. Use of a combination of remote and field evidence is likely the most successful strategy for identifying channel heads. This report presents a case study that demonstrates how a weight-of-evidence approach can combine field and remote evidence to locate the different parts of the transition and ultimately to identify the channel-head location.

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Contents

Abstract	ii
Figures and Tables	v
Preface	ix
1 Introduction	1
1.1 Background	1
1.2 Objectives	7
1.3 Approach	8
1.4 Definitions	10
2 Remote Examination of the Upper Extent of Stream Channels	19
2.1 Remote-tools workflow	22
2.1.1 <i>Model My Watershed</i>	22
2.1.2 <i>The National Map Viewer</i>	29
2.1.3 <i>Google Earth</i>	36
2.1.4 <i>Additional remote tools</i>	38
2.2 Limitations of remote data and tools	42
3 Field Identification of the Upper Extent of Stream Channels	46
3.1 Overview of identifying stream-channel characteristics	52
3.1.1 <i>Geomorphic indicators</i>	53
3.1.2 <i>Sediment indicators</i>	62
3.1.3 <i>Vegetation indicators</i>	67
3.2 Variation in stream-channel indicators	68
3.3 Overview of identifying channel-head characteristics	69
3.3.1 <i>Geomorphic indicators</i>	71
3.3.2 <i>Sediment indicators</i>	71
3.3.3 <i>Vegetation indicators</i>	72
3.3.4 <i>Additional channel-head indicators</i>	76
3.4 Variation in channel-head indicators	78
3.5 Overview of identifying hillslope characteristics	79
3.5.1 <i>Geomorphic indicators</i>	80
3.5.2 <i>Sediment indicators</i>	88
3.5.3 <i>Vegetation indicators</i>	89
3.6 Variation in hillslope indicators	90
3.7 Variation in channel-head location caused by land use and disturbance	93
4 Weight-of-Evidence Approach to Identifying the Upper Extent of Stream Channels in the Field	96
4.1 WoE steps	96
4.1.1 <i>Step 1: Compile data layers to remotely examine the field-survey area (chapter 2)</i>	96
4.1.2 <i>Step 2: Initial site conditions during the field survey (assemble evidence)</i>	98

4.1.3	Step 3a: List field evidence systematically.....	99
4.1.4	Step 3b: Weight each line of evidence and weigh body of evidence	100
4.1.5	Step 4: Describe rationale for the location of the channel head	102
4.2	Identifying a channel head in the field using WoE.....	102
4.2.1	Online examination using remotely available data	102
4.2.2	Field survey.....	109
5	Summary.....	114
	References	116
	Acronyms and Abbreviations	121
	Report Documentation Page.....	122

Figures and Tables

Figures

1	Factors that control the variation of channel-head characteristics across the U.S.	2
2	Variation seen across the hillslope-to-stream-channel transition in the field throughout five different ecoregions (Level IV) across the U.S.....	5
3	Field site locations referenced in this report overlaying annual precipitation for each region of the country.	9
4	Types of drainage basins and parts of a watershed	11
5	Example of a channel head that is located at the upper extent of a first-order stream channel in the Upper Buckhorn Creek Subwatershed in Colorado.....	15
6	Channel-head examples from across the U.S.....	18
7	Example workflow for compiling remote data layers and examining the watershed and stream channel of interest.	21
8	Subwatershed (HUC-12) of the Smoky Hill River Watershed in Kansas with displayed stream network.....	23
9	Example of mean monthly temperature (A) and precipitation (B) climate data derived from the Model My Watershed remote tool for warm semiarid (AZ), cold semiarid (KS), and humid (TN) watersheds	25
10	Subwatershed (HUC-12) of the Smoky Hill River Watershed in Kansas with stream network and headwater stream slope and length statistics derived from NHDplusV2 data	26
11	Model My Watershed soils map for two headwater streams in adjacent subwatersheds in the Smoky Hill River Watershed in Kansas.....	27
12	Model My Watershed land cover types (NLCD 2011) for the example headwater stream located in the subwatershed of the Smoky Hill River Watershed.....	28
13	Usage of the National Map Viewer (USGS 2017) to examine a headwater stream within the headwater area of the City of Marana-Santa Cruz River Watershed by examining the slope map (A) and identifying land-use patterns (B)	30
14	Examination of surface characteristics observed on lidar for an example site in Kansas	33
15	The National Map Viewer geology layer	35
16	Google Earth tools used to investigate the upper extent of stream channels in the Upper Buckhorn Creek Subwatershed in Colorado	37
17	Map of Buckhorn Creek Watershed and stream network generated from the EPA WATERS GeoViewer tool	39
18	Subwatershed of the Upper Buckhorn Creek Watershed delineated in the StreamStats tool with streamflow statistics, including reoccurrence intervals of streamflow.....	41
19	Web Soil Survey portal interface showing information about local soil characteristics	42

20	Comparison of channel-head location with field observation, lidar, and NHD dataset	43
21	Comparison of headwater streams derived from field data versus NHD stream delineations.....	44
22	Location of a small bedrock tributary stream in Tennessee.....	45
23	Small channel characteristic (i.e., break in slope) that is difficult to find on (A) Google Earth (adapted from Google 2018) and (B) lidar but is apparent from the field survey (C and D).....	45
24	Field-survey path including (1) the direction of the field-survey path, (2) the location of the river junction, (3) the path of the mainstem of the stream, (4) the path of the tributary that leads to the channel head, and (5) the location of the convergence zone (i.e., colluvial hollow) and hillslope characteristics upslope of the channel head.....	47
25	Examples of channel-head types and longitudinal characteristics of the hillslope-to-stream-channel transition.....	50
26	Steps for examining the landscape and identifying the upper extent of a stream channel	51
27	Examples of streamflow indicators in a nonperennial stream in Arizona with isolated patches of drought-tolerant vegetation (i.e., mesquite tree, grass, and moss) bordering or located in the stream channel.....	54
28	Flow direction indicators in different environments.....	55
29	Cascade stream-channel morphology in a vegetated, nonperennial stream in the Upper Buckhorn Creek Watershed in Colorado and in an unvegetated, nonperennial stream in California	58
30	Step-pool stream-channel morphology in arid and humid environments.....	59
31	Plane-bed morphology in North Carolina and Vermont.....	60
32	Pool-riffle and pool morphology in Tennessee and Kansas streams	61
33	Stream-channel-bed sediment types, including a bedrock stream channel. The streams are ordered from high gradients (e.g., large-cobble/small-boulder-bedded channel in California) to low gradients (e.g., fine-sediment/clay-bedded channel in Kansas)	63
34	Examples of rounding and scouring of bed sediment by flowing water	64
35	Differences in sorting and appearance of sediment sorted by wind versus water in Arizona	65
36	Examples of sediment sorting on a hillslope versus by water (Colorado stream) and comparisons of bank versus bed sediment (Kentucky and Arizona streams)	66
37	Channel indicators where there is lack of defined banks: dense vegetation in the channel/floodplain and shallow slopes (e.g., Kansas and Colorado)	68
38	Examples of discontinuous stream-channel banks in humid and arid landscapes.....	69
39	Schematic of the transport of water and sediment to a convergence zone where the stream channel starts. The two examples show a difference in the runoff paths in landscapes with hillslopes containing high and low gradients.....	70
40	Break in slope of channel-head wall and sides	72

41	Example of the noticeable transition in vegetation (e.g., color, type, and density) from the stream-channel bed to the surrounding hillslopes in a nonperennial stream in Kansas	75
42	Variation of the upper extent of a stream channel seen through distinct, linear vegetation patches in a stream in Kansas	76
43	Examples of springs, seeps, and macropores at a channel head in Colorado	77
44	Examples of channel-head initiation from a wetland that is caused by a shallow groundwater table or saturation excess overland flow, or both, in the Piedmont regions of North Carolina and Vermont	78
45	Example of multiple sequential headcuts that are more defined (i.e., steep, relatively narrow, and deep headcut faces) toward the stream channel and less defined (i.e., shallow, relatively wide) at the actual channel head	79
46	Comparison of sheetflow and channelized flow indicators across different landscapes in Arizona, Hawaii, and Kentucky	82
47	Anatomy of a small debris flow that occurred in the wildfire burn scar in Santa Cruz in 2021	84
48	Anatomy of a talus slope and two examples of talus sediment in Colorado and Maine. The thick layer of lichen on the Maine talus sediment indicates that the sediment is less mobile	85
49	Examples of rills and a gully in a semiarid environment	87
50	End members of sediment sorting types. Angular, poorly sorted sediment is strong evidence for sediment transported by hillslope processes. Rounded, poorly sorted sediment is strong evidence for sediment transported by concentrated flowing water	89
51	Variations of typical convergence-zone indicators across different landscapes	92
52	Seasonal differences in the appearance of Hubbard Brook, New Hampshire	93
53	Characteristics of a hillslope-to-stream-channel transition in a landscape disturbed by mining. An engineered channel (i.e., groin drain) adds variation to the characteristics of the hillslope-to-stream-channel transition	95
54	The location of the study area within the watershed (A) and the proposed field-survey path to the channel head of interest based upon aerial imagery and the NHD stream delineation using the National Map Viewer remote tool (B)	105
55	Revised field-survey path based on observations from lidar using the National Map Viewer remote tool	106
56	Example of areas of interest to investigate in the field, selected by examining the lidar-derived hillshade and associated elevation profile by using the National Map Viewer (USGS 2017) remote tool	108
57	Example of using the WoE approach to determine the location of the stream channel, channel head, and hillslope by using multiple, weighted lines of evidence while walking along the field-survey path in the upstream direction	111

Tables

1	Basic types of runoff and where they occur	17
2	Climate classifications used in Fig. 6 for the channel-head examples found in this report	18

3	Summary of remote resources for viewing the upper extent of channels	20
4	General relationships between rock type, runoff type, and stream channel and channel-head characteristics. Note that there are other possibilities of channel-head characteristics depending on geology	36
5	Montgomery and Buffington (1997) stream-channel-morphology classifications	57
6	Questions to consider about the presence of a stream channel, a channel head, and hillslope characteristics along the field-survey path (e.g., Fig. 24).....	100
7	Example of how to apply the WoE technique to a specific site (Fig. 57). The description of weights is described in relation to this specific site	112

Preface

This study was conducted for Headquarters, U.S. Army Corps of Engineers (USACE), through the Wetlands Regulatory Assistance Program (WRAP) under AMSCO 088893, funding account U4378481, project 2016-ERD-0350-0001, “Characterizing the Upper Extent of Streams.” The technical monitor was Mr. Kyle Gordon.

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1 Introduction

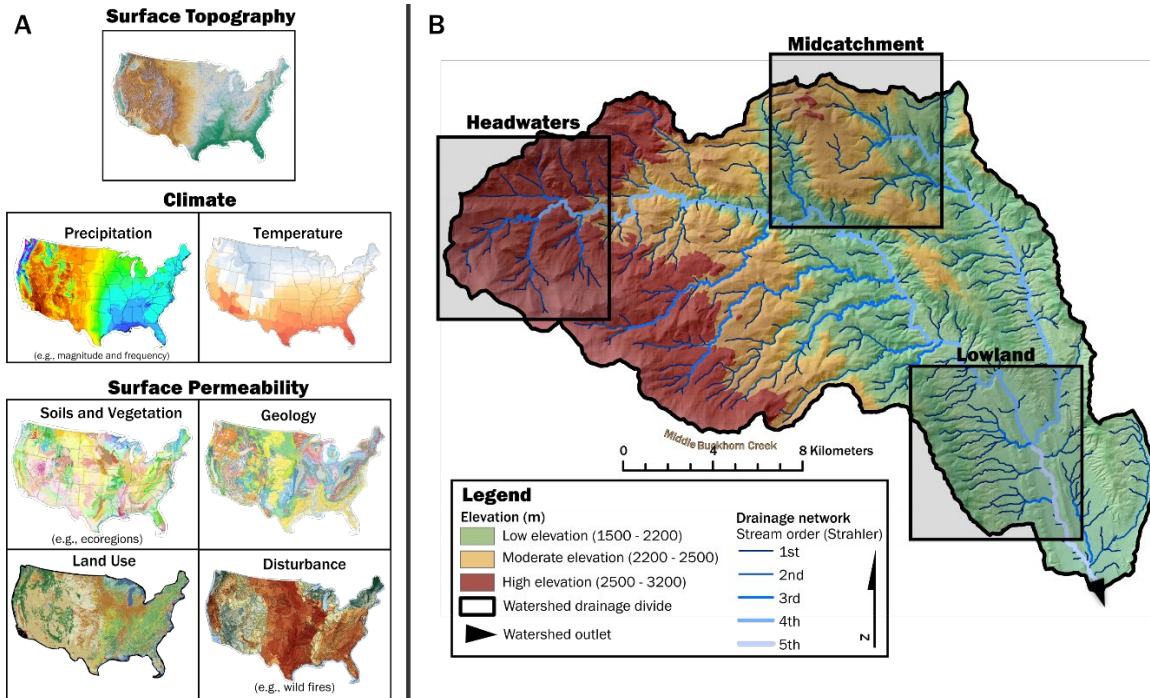
1.1 Background

Section 404 of the Clean Water Act requires accurate, consistent, and repeatable delineation of river channels (U.S. Congress 1977). This includes the delineation of the longitudinal and lateral extents of headwater streams (i.e., first through second or first through third order) which comprise 60%–80% of the total length of a watershed (Benda et al. 2005). *Stream channel* is a general term for either a stream or river channel and is defined as a linear characteristic formed primarily by a concentrated path of flowing water and sediment and contains a defined shape, or morphology, with identifiable stream bed and banks at least shortly after a precipitation event (Dietrich and Dunne 1993). This current report focuses on headwater streams and the location of stream-channel initiation at the outer- and upper-most extent of a watershed or catchment. At the upper extent of a stream channel, there is a transition zone between the hillslope and the beginning of the stream channel. The *upper extent* is a general term that includes the whole area (e.g., the area adjacent to the beginning of the stream) prior to getting to the channel head and also the channel head itself. The channel head is located at the upstream-most point of a stream, where water converges into a flow path of concentrated water and sediment to erode and initiate a stream channel with definable bed and banks (Montgomery and Dietrich 1988, 1989). The channel head demarks the end of the hillslope and the beginning of a stream channel and can be challenging to consistently identify across the U.S. because of the variation of factors that influence how and where channel heads start (E. Wohl 2018).

Figure 1 summarizes the factors that control the variation of channel-head characteristics across the U.S. Channel-head initiation depends on how surface and subsurface runoff from the hillslope converges into a flow path of concentrated water and sediment to erode and initiate a stream channel. How water moves, is trapped, or is slowed while flowing downslope through soil, vegetation, and the local geology ultimately controls how flow converges to erode and thus form a channel head. The material and density of the soil and the openings and pathways throughout the soil (e.g., macropores or pipes) determine how flow will converge to a downslope

channel-initiation point. Figure 1A shows the factors (i.e., surface topography, climate, and surface permeability) that influence the type of runoff and ultimately flow convergence to a channel head.

Figure 1. Factors that control the variation of channel-head characteristics across the U.S.: (A) factors that control flow convergence and surface/subsurface runoff and (B) examples of the process domains of headwater streams throughout the Buckhorn Creek Watershed in the headwaters, midcatchment, and lowland areas of the watershed.



Ecoregions are regions throughout the U.S. with similar geology, land-forms, soils, vegetation, climate, land use, and hydrology (Omernik 1987) that integrate several surface permeability factors. Information about topography, climate, and surface permeability can be extracted from online resources that provide summary information about landscapes. For example, geology provides additional information for how runoff is likely to flow overland or be trapped (e.g., perched water table) in the surface and subsurface. Additionally, understanding precipitation type (rain or snow), intensity, and magnitude through regional climatic data can provide further information on expected stream-channel characteristics. The magnitude and frequency of precipitation controls the degree of flow convergence that forms a localized channel head. For example, a monsoonal, desert thunderstorm can cause intense precipitation that, combined with low soil permeability, will result in high flow convergence and erosive potential to initiate a nonperennial channel. Lastly, land use and

disturbance, such as wildfire, alter the surface permeability, which can alter flow-convergence locations on hillslopes. For example, wildfire can alter the properties of soil to have water repellent characteristics that decrease soil permeability and increase flow convergence and erosion potential for channel initiation (Shakesby and Doerr 2006). Therefore, gathering online information about land use and recent disturbances prior to site visits can aid in understanding field observations. Chapter 2 describes in more detail extracting and examining online resources.

Understanding variability in processes on the landscape, in terms of process domains, can assist in understanding variability in the channel-head characteristics and channel-initiation points. Process domains are spatially identifiable areas of a watershed that contain similar geomorphic processes and the resultant geomorphic characteristics (Montgomery 1999). The spatial distribution of physical disturbances (e.g., wildfires or dams) that change the localized processes of water and sediment transport in an area of a watershed causes spatially differentiated process domains in headwater streams. Process domains can also vary longitudinally throughout the headwater streams of a watershed. For example, Figure 1B shows the Buckhorn Creek Watershed in Colorado with a stream network that drains from the edges of the watershed or drainage divide to the mouth (or outlet) of the watershed. In the steeper headwater areas of the watershed (Figure 1B), streams are likely located in a process domain dominated by more hillslope processes, such as rockfalls and debris flows (i.e., fast-moving, water-laden landslides). Rockfalls and debris flows generate a sediment source with higher rates of coarse sediment erosion downslope and at the entryways of stream channels in confined valleys (i.e., higher hillslope-channel connectivity). The process domain located in the midcatchment headwater streams area of the watershed (e.g., Figure 1B) is likely dominated by sediment transported in streams with moderate slope where there may be less coarse sediment and more mixed-sized sediment transport. Finally, the process domain in the lowland headwater stream area of the watershed (e.g., Figure 1B) consists of rivers with low slope where fine sediment is more likely deposited, erosion rates are low, and there is low hillslope-channel connectivity. If a wildfire occurs in the steeper headwater region, then the result may be flooding and debris flows. Alternatively, if a wildfire occurs in a lowland region, it could result in increased flooding, but debris flows would be less likely. Therefore, there are different processes at play in these different areas of a watershed.

Examining maps that show surface topography can assist in understanding the steepness of sites, hillslope connections, and floodplain extents prior to a site visit.

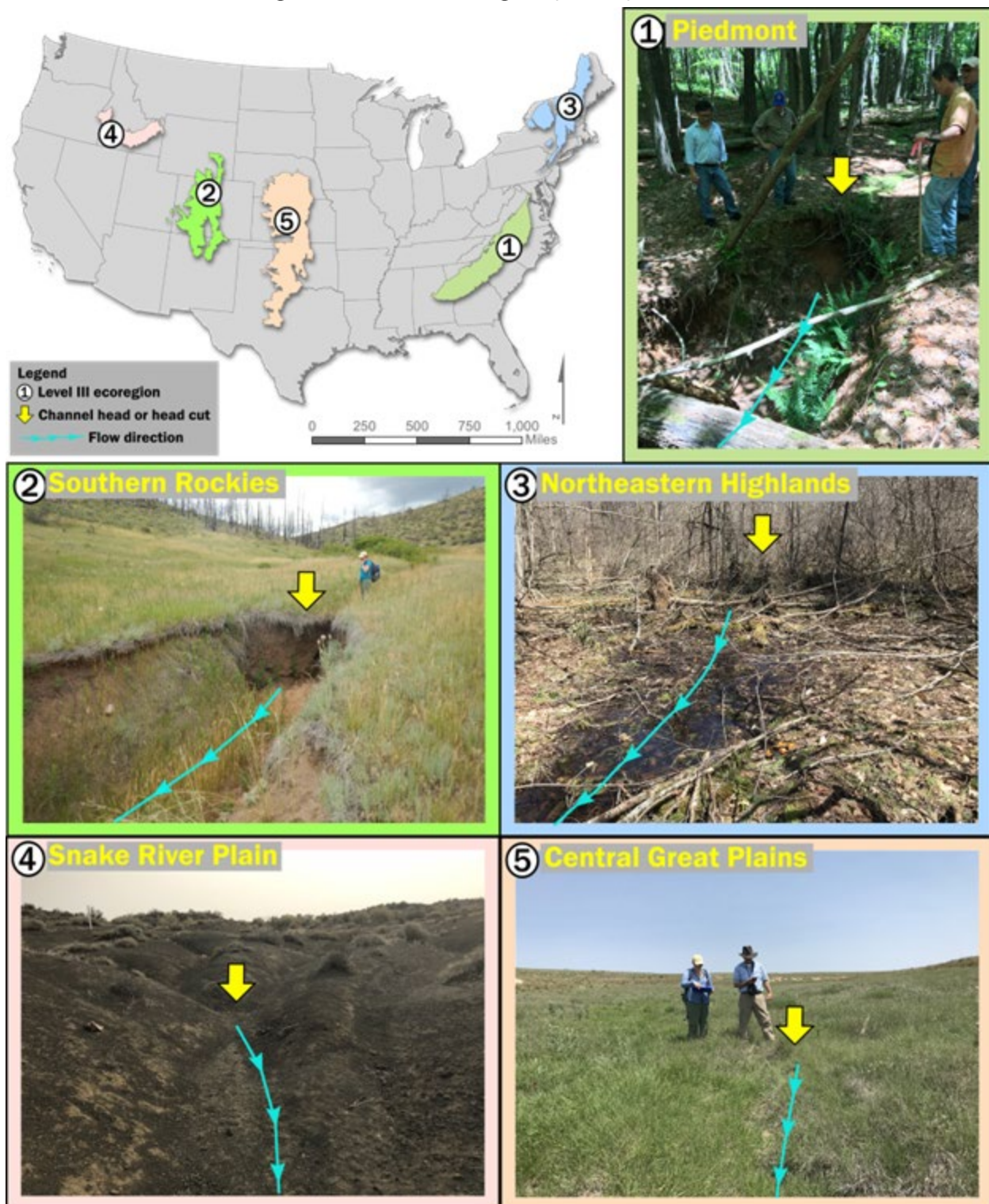
The variation in channel-head characteristics across different landscapes often results in the vast difference in appearance of channel heads in the field. Figure 2 shows the variation of channel-head characteristics in the field for five different ecoregions across the U.S. Most research has focused on localized, abrupt and well-defined channel heads in mountainous landscapes. Less research has characterized channel heads on low slopes, which are characterized by a gradational and extended transition in the longitudinal direction from the hillslope to the stream channel.

The transition from the hillslope to the stream channel can be characterized by an abrupt channel head (i.e., the traditional channel-head characteristics originally described by Dietrich and Dunne 1993). An abrupt headcut can take the form of (1) a single steep and deep headcut where there is a sharp change in channel slope from either a vertical drop or a short steep section of channel that flattens out in the downstream direction (e.g., Figure 2, Piedmont ecoregion; Osterkamp 2008) or (2) a sequence of distinct headcuts (e.g., Figure 2, Southern Rockies ecoregion). A channel head with an abrupt headcut also often has a visible break in vegetation.

Where the water table is low and the ground is saturated, the channel head can have a more gradual headcut (e.g., Figure 2, Northeastern Highlands ecoregion) or no headcut and instead initiate from a depression or wetland. In more arid areas with less vegetation, channel heads may be localized, small abrupt headcuts (e.g., Figure 2, Snake River Plain ecoregion).

In areas with low slopes, dense vegetation, and subsurface flow, channel heads can have small or subtle headcuts (e.g., Figure 2, Central Great Plains ecoregion). These low-gradient landscapes can contain gradational or discontinuous channel heads where discontinuities in subsurface flow cause the stream channel to start and stop at multiple headcuts over some distance downstream (E. Wohl 2018). Field observations and channel heads in different regions of the U.S. are described throughout chapter 3.

Figure 2. Variation seen across the hillslope-to-stream-channel transition in the field throughout five different ecoregions (Level IV) across the U.S.



Remote techniques are useful for investigating the upper extent of stream channels but remain limited for consistently and accurately identifying

channel heads within and across landscapes (E. Wohl 2018). Chapter 2 describes in detail finding remotely available data and extracting information that can inform a field survey of a site. Channel heads are localized, small features; and inconsistencies in the delineation of stream channels at their upper extent is often because of the spatial resolution of the remote data and the current inability to “see” the beginning of these small channel heads. With a large field dataset of mapped channel heads in the Colorado Front Range, Henkle, Wohl, and Beckman (2011) showed that the field channel-head locations were significantly lower down the hillslope than the locations that were derived remotely from a regional slope-area relationship curve. Additionally, land-use practices can cause channel heads to migrate up or down the hillslope at a rate of weeks to months (Thorne 1999). Without high temporal resolution, remote methods are limited in capturing fast rates of channel-head migration. Making consistent interpretations of channel-head locations from multiple lines of evidence from remote data layers is also difficult. Lastly, the variability in physical processes at the upper extent of stream channels can cause gradational stream channels that span some longitudinal distance downslope. Categorizing the dominant physical processes along this longitudinal distance is challenging with remote data alone because there is limited information about the physical processes.

Ultimately, direct field observations of the topography, hydrology, geomorphology, and sedimentology are necessary to accurately and consistently identify the beginning of a stream (chapter 3). Although there are challenges with identifying channel heads in the field (e.g., using GPS devices to locate channel heads in forested terrain; Rodríguez-Pérez, Álvarez, and Sanz-Ablanedo 2007), there are few substitutes for physically following streams to the channel head, making observations of where the hillslope transitions to the channel, and locating the channel head and other characteristics with a GPS device.

Previous field observations of channel heads fixated particularly on steep, mountainous landscapes in the western U.S. (E. Wohl 2018). Therefore, predictions of channel-head locations, mostly based upon slope and drainage area relationships, are also skewed to the western part of the U.S. (E. Wohl 2018). Because the development of predictive methods focused heavily on mountainous western landscapes, without additional field investigation, caution should be used when applying these relationships to

other landscapes. Many studies have shown the variability in these relationships depends on geologic, vegetative, climatic, and land-use differences (Poesen et al. 2003; Montgomery and Dietrich 1994). Although many areas are not easily accessible or the resources are simply unavailable for a field investigation, many channel heads are located in lower-gradient landscapes that do not require difficult traverses. Field investigations to channel heads should especially be considered in these areas.

The transition from material on a hillslope being predominantly moved by gravity versus material being predominantly moved by water can sometimes be difficult to consistently identify in the field across landscapes. A weight-of-evidence approach (WoE) is one method for evaluating multiple lines of field evidence to arrive at a defensible conclusion. This approach considers the “relevance, strength, and reliability” of each line of field evidence. The WoE process involves (1) assembling evidence; (2) weighting the relevance, strength, and reliability of the individual lines of evidence; and (3) weighing the body of evidence by integrating and interpreting the weighted individual lines of evidence (Suter, Cormier, and Barron 2017; Linkov et al. 2009). A WoE approach provides a logical method for assessing and integrating lines of evidence to support a conclusion on the location of the upper extent of the channel. Chapter 4 describes the WoE approach in the context of assembling evidence on which processes and characteristics (i.e., geomorphic, sediment, and vegetation) are predominant in which locations (e.g., stream, channel head, or hillslopes). The WoE approach can be helpful for determining where the channel head is located. The chapter presents one case study in the field to test the WoE approach.

1.2 Objectives

An understanding of how channel heads vary over different landscapes of the U.S. is critical for improving consistency in field identification of channel heads. Therefore, the primary objective of this report is to provide guidelines on how to identify the characteristics found at the upper extent of stream channels where there is a transition between hillslope and stream-channel processes. This report has the following aims:

1. Describe the variation of geomorphic, sedimentologic, and vegetative characteristics at the upper extent of channels across different landscapes throughout the U.S.

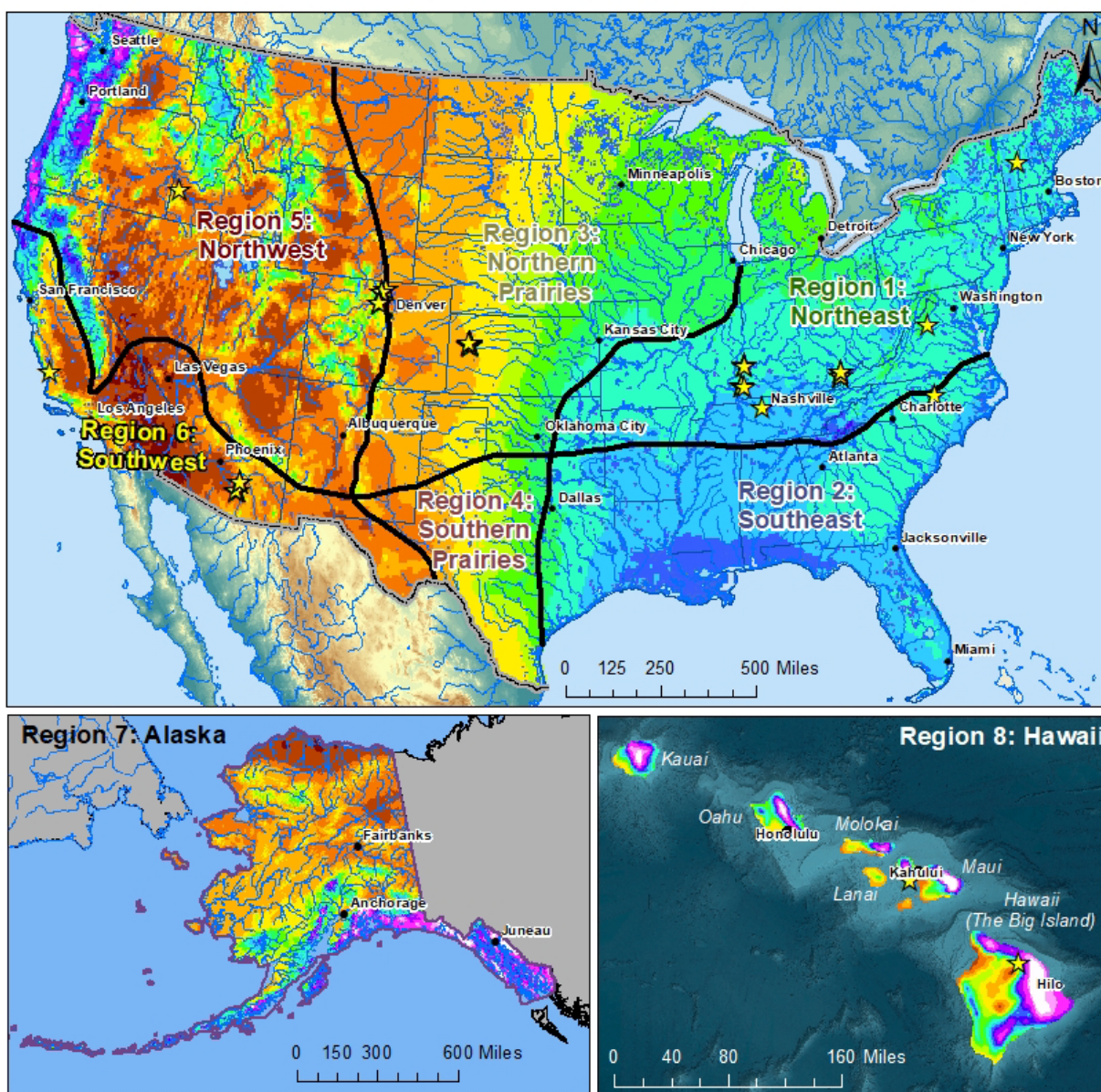
2. Provide indicators on how to physically identify where stream channels begin using field descriptions collected from the various landscapes, hydrological regimes, ecoregions, and land-use types across the U.S. Stream channels, along with the channel heads, can be difficult to physically identify in the field because of variations in controls on the formation of channel head and the transition zone from the hillslopes to the initiation of the stream. This report provides field examples of how to identify geomorphic characteristics that are dominantly formed in different parts of this hillslope-to-stream-channel transition across various landscapes.
3. Provide recommendations on how to assess the accuracy of channel-head locations with both remotely sensed evidence and field observations using a WoE approach.

1.3 Approach

This field guide is an applied extension of the E. Wohl (2018) channel-head literature review, which established a baseline understanding of the upper extent of channels. The approach for this field guide was to characterize the hillslope-to-stream-channel transition zone in seven of the eight regions of the U.S. (i.e., field sites in Colorado, Hawaii, Kansas, Kentucky, Vermont, North Carolina, and Tennessee). Channel heads were not investigated in Alaska because of the difficulty in accessing remote headwater streams in this region. These eight regions are differentiated based upon vegetation types and climate and are the same regions used for Ordinary High Water Mark identification and delineation (Figure 3; E. Wohl et al. 2016).

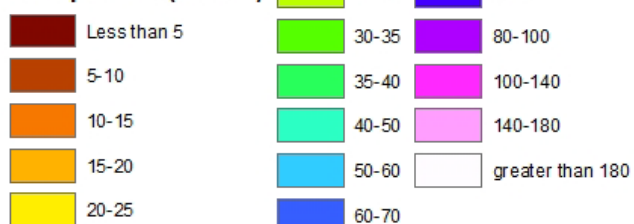
A GPS was used to tag channel-head locations in each of these regions to compare with remote data. Field observations were collected of the transition between hillslope characteristics and stream characteristics in each of these regions. Field data collection allowed for evaluation of variations of channel-head initiation (distance from the drainage divide) in relation to climate, geology, and vegetation. Further investigation provided the opportunity to determine how useful each of the channel-head indicators was for determining the upper extent of stream channels. Field data were also used to compare to remote methods for viewing the upper extent of channels. These methods included simply estimating the channel head based on physical signatures identified in aerial imagery and using a digital elevation model (DEM)–based approach that attempts to use topography to identify the transition from overland to channelized flow.

Figure 3. Field site locations referenced in this report overlaying annual precipitation for each region of the country. Regional boundaries are defined in E. Wohl et al. (2016).



Legend

Precipitation (inches)



- ★ Channel Head Field Sites
- Major Cities
- Regional Boundaries (Wohl et al. 2016)
- ~ Streams

The field-delineated channel-head locations were compared with delineated channel heads from other data sources, including the National Hydrography Dataset (NHD) and soil survey maps. The comparison of channel-head locations identified in the field with remote data illustrates the limitations in the exclusive usage of remote methods to identify channel heads. Finally, the last chapter of this guide presents a step-by-step WoE approach with a field case study to demonstrate how to identify the transition zone from hillslope to stream-channel characteristics at the upper extent of stream channels in different landscapes.

For the purposes of this report, streams are divided into perennial and nonperennial. Stream channels at the upper extent are often nonperennial, unless they are spring fed. The described indicators of streamflow found in this report do not provide information on flow regime. These indicators can exist whether a stream is ephemeral or intermittent (i.e., nonperennial) or perennial undergoing drought conditions. Other resources are being developed to identify streams based on flow regime, such as the regional streamflow duration assessment methods being developed by the Environmental Protection Agency (EPA; Mazor et al. 2021).

1.4 Definitions

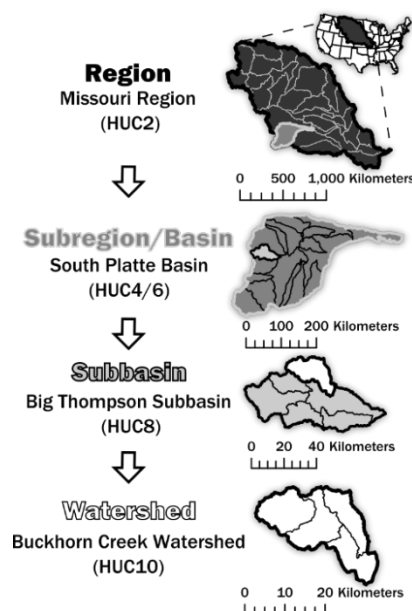
This section defines basic terminology and concepts that are useful for understanding where a channel begins. An understanding of the terminology and concepts is essential to any remote investigation or field identification of physical characteristics associated with the upper extent of stream channels.

The surface of the earth contains numerous landscapes with various levels of surface roughness (e.g., mountains and plateaus). *Topography* is a term used to describe this surface roughness, and *topographic relief* is the amount of topographic change from the highest point to the lowest point within a particular area. High topographic relief results from large topographic changes over a small area (e.g., steep mountain range in the Colorado Rockies), whereas low topographic relief results from small topographic changes over a large area (e.g., flat grasslands in Kansas). *Elevation* is another widely used term to quantify the height of a point on the earth's surface above a fixed reference point (e.g., height above sea level).

Topographic characteristics and the acceleration due to gravity control how precipitation flows as runoff at and below the surface of the earth. A *drainage divide* is a linear, topographically higher characteristic on the

landscape that separates the adjacent drainage basins. Although drainage divides are more easily visible in mountain ranges with high relief, drainage divides can have low topographic relief. As precipitation falls to the surface, it flows to a lower elevation (i.e., either side of the drainage divide) in the drainage basin. The USGS delineates drainage basins based on the size of the contributing area upslope of a drainage outlet point (Figure 4). The USGS assigns a hydrologic unit code (HUC) to each drainage-basin type. A HUC is akin to a drainage-basin address. Figure 4 shows an example of the hierarchy of hydrological scales defined by the USGS, starting with the Missouri regional-scale delineation (e.g., 300,000 km²) and ending with the Buckhorn Creek watershed-scale delineation (e.g., 300 km²).¹ According to the HUC hierarchy, *regions* contain drainage basins of major rivers (e.g., Missouri River), whereas *watersheds* contain a single drainage basin with streams that drain to a single watershed output point (i.e., lowest elevation in the watershed). HUCs are often used in scientific studies as a way to identify and compare areas of similar size.

Figure 4. Types of drainage basins and parts of a watershed. Hierarchical drainage-basin delineation, starting with the largest area (i.e., regional scale) and ending with the smallest area (i.e., watershed scale).



¹ For a full list of the spelled-out forms of the units of measure used in this document and their conversions, please refer to *U.S. Government Publishing Office Style Manual*, 31st ed. (Washington, DC: U.S. Government Publishing Office, 2016), 245–252, <https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf>.

There are several key parts of a watershed (Figure 1B). Each watershed consists of a *drainage network* where water flowing from the hillslopes is concentrated into interconnected paths of flowing water that create stream channels. A *stream channel* is a linear characteristic formed primarily by a concentrated path of flowing water and sediment and contains a defined shape, or *morphology*, with identifiable stream bed and banks at least shortly after a precipitation event (Dietrich and Dunne 1993). Streams flow, longitudinally from upstream to downstream, through the drainage network to the lowest elevation or outlet point of the watershed.

Stream channels within a drainage network are commonly categorized with a systematic, size-ordering scheme that is also indicative of the position of the stream within the watershed. One example is the Strahler stream-order system where a stream increases in order when joined by a channel of equal order (Strahler 1952). Moving down the watershed from the drainage divide to the lowest watershed output point, two first-order streams join, forming a second-order stream; and as two second-order streams join, a third-order stream is formed (Strahler 1952). All stream-order classification systems are primarily based on map products and depend on map resolution (Benda et al. 2005).

The scientific definition of a *tributary* is the stream of lower order that joins or feeds into a higher-order stream. The first- through second-order or first- through third-order streams are called headwater streams (Meyer et al. 2007; Figure 1B). This scientific definition may be broader than some of the various regulatory definitions used across the U.S. Therefore, use of *tributary* in this report will follow the scientific definition and not the regulatory one. Regulations define headwaters as

non-tidal rivers, streams, and their lakes and impoundments, including adjacent wetlands, that are part of a surface tributary system to an interstate or navigable water of the United States upstream of the point on the river or stream at which the average annual flow is less than five cubic feet per second (U.S. Congress 1977). The [District Engineer] may estimate this point from available data by using the mean annual area precipitation, area drainage-basin maps, and the average runoff coefficient, or by similar means. For streams that are dry for long periods of

the year, [District Engineers] may establish the point where headwaters begin as that point on the stream where a flow of five cubic feet per second is equaled or exceeded 50 percent of the time.²

Headwater streams can be found in the upper (i.e., headwaters), middle (i.e., midcatchment), or lower (i.e., lowlands) parts of a watershed at the outermost and uppermost part of a watershed, in closest proximity to the drainage divide (Figure 1B; Brierley and Fryirs 2005).

Streamflow can vary in space (i.e., longitudinally) and time (e.g., seasonally) because of different hydrological factors. A stream channel that flows year-round is a *perennial stream* and contains “flowing water continuously during a year of normal rainfall, often with the streambed located below the water table for most of the year. Groundwater typically supplies the baseflow for perennial reaches, but the baseflow may also be supplemented by stormwater runoff and/or snowmelt” (Mazor et al. 2021, 1). There are two types of nonperennial streams, intermittent and ephemeral. *Intermittent streams* “contain sustained flowing water for only part of the year, typically during the wet season, where the streambed may be below the water table and/or where the snowmelt from surrounding uplands provides sustained flow. The flow may vary greatly with stormwater runoff” (Mazor et al. 2021, 1). Lastly, *ephemeral streams* “flow only in direct response to precipitation. Water typically flows only during and/or shortly after large precipitation events, the streambed is always above the water table, and stormwater runoff is the primary water source” (Mazor et al. 2021, 1). Perennial streams can sometimes become nonperennial over time. For instance, land-use changes, such as groundwater pumping or urban development, can sometimes cause a stream that was once perennial to become nonperennial. Droughts can also cause perennial streams to dry up temporarily over the course of the drought. A drainage network can also consist of stream channels with discontinuous streamflow because of geological controls such as limestone topography (i.e., karst) with surface depressions or holes where the subterranean streamflow disappears and reappears from the surface. All of these flow regimes can result in similar stream characteristics. Therefore, descriptions throughout this report focus on the indicators formed by streamflow rather than on flow regime.

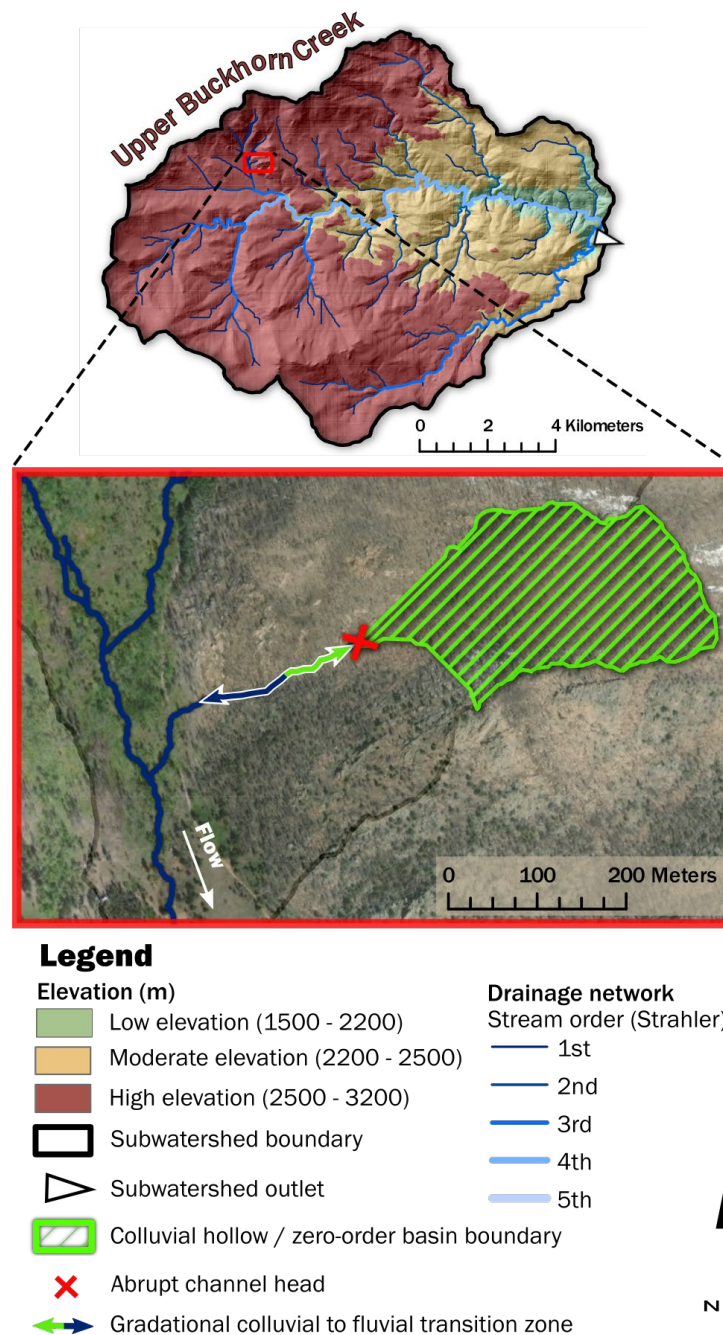
² Nationwide Permit Program, 33 C.F.R. § 330.2(d) (2020), 460, <https://www.govinfo.gov/contest/pkg/CFR-2020-title33-vol3/pdf/CFR-2020-title33-vol3.pdf>.

The *channel head* is the single most-used geomorphic characteristic to demarcate the beginning of a stream channel. The channel head is located at the upstream-most point of a stream, where water converges into a flow path of concentrated water and sediment to erode and initiate a stream channel with definable bed and banks (Montgomery and Dietrich 1988, 1989). The channel head is a specific type of knickpoint (i.e., headcut) located at the farthestmost upslope point. *Knickpoints* are simply a location in the channel network with a sharp change in channel slope where the channel bed is resisting erosion. A *headcut* is a specific type of knickpoint where there is a sharp change in channel slope from either a vertical drop or a short, steep section of channel that flattens out in the downstream direction. Headcuts often migrate rapidly and contain areas of increased erosion (E. E. Wohl 1999; Robinson et al. 2000). Headcuts are then a rapidly migrating knickpoint that is most often found near the headwaters of a stream. Headcuts represent a transition point between a depositional environment upstream and erosional environment downstream. Headcuts can occur where the channel starts but can also occur farther downstream and migrate toward the channel head. A *stream head*, or the initial point of perennial streamflow, can occur at the same location as the channel head or farther downstream. Depending on the topographic relief, the small, upslope drainage area of a channel head where sediment accumulates is defined as a *colluvial hollow* or *zero-order basin* (e.g., ~0.05 km²; Figure 5). In landscapes with low topographic relief (e.g., Great Central Plains), a colluvial hollow may not be physically apparent.

The *upper extent of a stream channel* can include a single, abrupt channel head, which characterizes the start of the headwater stream; but in multiple landscapes, it is likely that the upper extent of a stream channel is characterized by a gradational hillslope-to-stream-channel transition zone over a longer longitudinal distance with potentially multiple, discontinuous headcuts (Figure 5; Dietrich and Dunne 1993; E. Wohl 2018).

Upslope of the channel head, diffusive hillslope processes dominate and form *hillslope* characteristics, whereas downstream of the channel head, stream processes dominate and form *stream-channel* characteristics (Figure 5). *Hillslope* characteristics are created by the downslope movement of material by gravity. For instance, sediment is transported from the hillslope through the process of debris flows and rockfalls, forming hillslope deposits.

Figure 5. Example of a channel head that is located at the upper extent of a first-order stream channel in the Upper Buckhorn Creek Subwatershed in Colorado (adapted from Google 2019). The colluvial hollow, or zero-order basin, is located upslope of the channel head and is also the source area of water and sediment for the beginning of the stream channel. The channel head can be a single, abrupt, localized break in slope that demarks the beginning of the channel. The channel head can also be a gradational zone where the colluvial hollow and dominant hillslope processes transition more gradually to the beginning of the stream channel where stream-channel processes dominate. This hillslope-to-stream-channel transition zone can consist of shallow breaks in slope, multiple headcuts in succession that extend longitudinally in the downstream direction, or both.



Stream-channel characteristics are created by the downslope movement of material by water (e.g., distinct stream channel; Dietrich and Dunne 1993). Geomorphic processes that transport sediment, such as *sheetflow* or *rain splash*, where surface runoff is dispersed downslope, are considered diffusive hillslope processes until the surface runoff is concentrated into a preferential flow path of channelized flow.

A stream channel downstream of a channel head is distinguishable from a rill or gully because a stream channel is a persistent characteristic on the landscape through and after a precipitation event. A *rill* is a small erosional, nonperennial characteristic that can be destroyed by tillage or natural processes such as frost action (Schumm, Harvey, and Watson 1984; Kirkby and Bracken 2009). Rills are a result of overland flow and often appear as parallel characteristics on sides of slopes, particularly roadcuts. Rill erosion is an intermediate erosional process occurring between sheetflow and gully erosion (Casalí et al. 2006). A *gully* is a relatively deep, nonperennial (ephemeral or intermittent) or perennial feature that has eroded material away from the valley bottom or valley side, developing a channel where a well-defined channel did not previously exist (Patton and Schumm 1975; Schumm, Harvey, and Watson 1984; Kirkby and Bracken 2009). Gullies are transitional features that often occur when land use or climatic changes have caused increased erosion. A gully can eventually become an established extension of the stream network.

Climate and hydrology control variations in the type of runoff (Table 1) and flow magnitude and frequency, which cause different channel-head sizes and shapes (Dietrich and Dunne 1993, Fig. 7.6). For example, in regions with precipitation occurring regularly year-round, at the upper extent of the stream channel where the soil is saturated, precipitation during storm events causes *saturation overland flow* from the channel-initiation point. This type of surface hydrology, saturation overland flow, can also cause the channel to initiate from a wetland on the surface (Henkle, Wohl, and Beckman 2011), whereas channel heads located in areas with underlying limestone or karst geology may initiate at longitudinally discontinuous springs. The channel head likely starts at a small spring on the surface (e.g., a hole in the rock) with less water or evidence for flow, and then the channel extends to the subsurface until resurfacing again as a perennial spring (i.e., stream head) farther downstream. The magnitude and frequency of precipitation cause a range of colonization rates of vegetation at the channel head, resulting in variable thresholds for bank erosion. Lastly,

a stream can start at a wetland and may form a stream within a wetland for a period downslope.

Table 1. Basic types of runoff and where they occur.

Runoff Type	Description	Regional Examples
Infiltration excess overland flow (Horton 1945)	• Uncommon in natural, vegetated watersheds unless there is an extreme precipitation event • Certain arid soils (e.g., high clay content) and disturbed soils (e.g., water repellent soils from forest fire) cause infiltration excess overland flow because the water is not able to penetrate and permeate into the soil	Arid shrubland
Saturation excess overland flow (Dunne and Black 1970a, 1970b)	• Dependent on recent soil moisture conditions (i.e., antecedent soil moisture) • Dependent on porosity and permeability of the subsurface (i.e., how easily the water can pass through connected spaces in the soil; Montgomery and Dietrich 2002) • Flows in direct proximity to the stream channel	Temperate grassland
Shallow subsurface flow	• Similar dependencies to saturation excess overland flow • Travels from farther up on the hillslope through soil and leaf litter	Humid forest

Ecoregions, which are defined independently from *process domains*, are regions throughout the U.S. with similar geology, landforms, soils, vegetation, climate, land use, and hydrology (Omernik 1987) that are useful to pair with process domain investigations. There are different levels of ecoregions, but at the highest level (i.e., Level IV) there are 967 uniquely defined ecoregions in the conterminous U.S. (Omernik 1987). Within the single state of Tennessee, there are 25 different Level IV ecoregions. Ecoregion descriptions are useful for collecting regional information on the main factors (i.e., subsurface permeability, flow convergence, climate, and surface topography) that control runoff type (Figure 6; Table 2). The type of runoff is directly related to the channel-head type and channel-head characteristics. For example, in the Cumberland Mountains and Northern Outer Piedmont, the humid climate, high flow convergence, moderate surface topography, and high subsurface permeability cause saturation excess overland flow. This type of runoff can cause channel heads that initiate from wetlands.

Figure 6. Channel-head examples from across the U.S. (A) and corresponding runoff types (B; E. Wohl 2018). The colors of the ecoregions in (A) correspond to the colors of the runoff types plotted in (B).

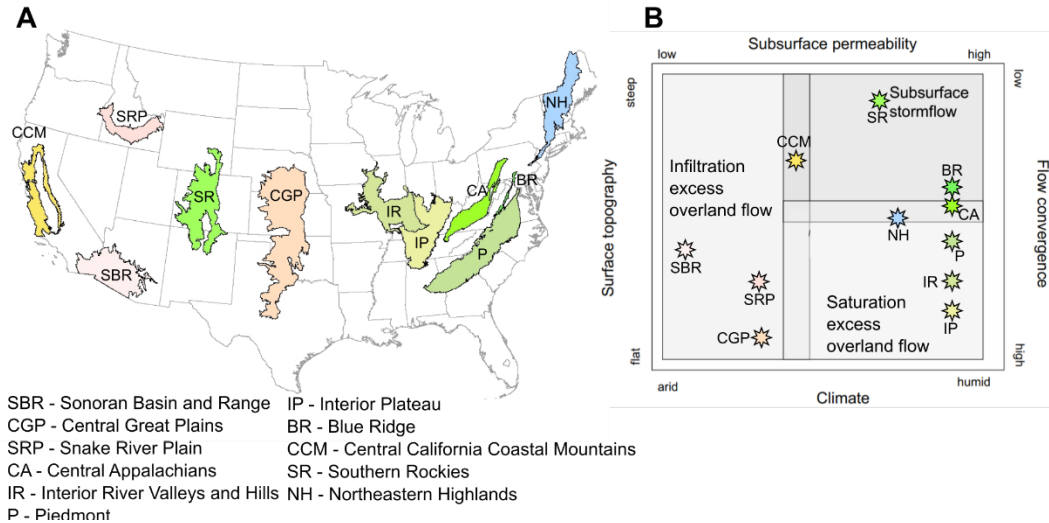


Table 2. Climate classifications used in Fig. 6 for the channel-head examples found in this report.

State	Ecoregion (Level III) ^a	Main Climate ^b	Precipitation ^b	Temperature ^b
Arizona	Sonoran Basin and Range	Warm Semi-arid	Steppe	Hot Arid
Kansas	Central Great Plains	Cold Semi-arid	Steppe	Cold Arid
Idaho	Snake River Plain	Cold Semi-arid	Steppe	Cold Arid
Kentucky (Defeated Creek, Big Everidge Branch)	Central Appalachians	Humid Subtropical	Fully Humid	Hot Summer
Kentucky (John James Audubon State Park)	Interior River Valleys and Hills	Humid Subtropical	Fully Humid	Hot Summer
North Carolina	Piedmont	Humid Subtropical	Fully Humid	Hot Summer
Tennessee	Interior Plateau	Humid Subtropical	Fully Humid	Hot Summer
Virginia	Blue Ridge	Humid Subtropical	Fully Humid	Hot Summer
Hawaii (Mana Road, Big Island; Opunaha Gulch, Maui)	Unavailable	Oceanic	Fully Humid	Warm Summer
California	Central California Coastal Mountains	Temperate Mediterranean	Dry Summer	Warm Summer
Colorado (Gordon Creek)	Southern Rockies	Humid Continental	Fully Humid	Warm Summer
Vermont	Northeastern Highlands	Humid Continental	Fully Humid	Warm Summer
Colorado (Buckhorn Creek, Saint Vrain Creek)	Southern Rockies	Cool Continental	Fully Humid	Cold Summer

^aOmernik and Griffith (2014)

^bPeel, Finlayson, and McMahon (2007) Köppen climate classification

2 Remote Examination of the Upper Extent of Stream Channels

The goal of the remote examination is to gather information about the study area before entering the field. This includes compiling remotely available data layers pertaining to the stream-channel-to-hillslope transition, including drainage networks, topography, hydrology, vegetation, and land use. Table 3 provides examples of these remote-tool resources, including data layers collected remotely (lidar and satellite imagery) and other resources available online, such as geologic maps and topographic maps. Section 2.1 provides an example workflow for using specific online tools to compile remotely available data layers applicable to the study area and to evaluate questions pertaining to the stream-channel-to-hillslope transition at the upper extent of the stream channel and to the potential location of the channel head (Figure 7). Section 2.1.4 describes additional tools, but the example workflow was designed specifically for users to efficiently compile the available online information with minimal experience using geographic information systems (GIS). The example workflow in section 2.1 includes remotely available data applied to multiple channel-head sites. The case study in chapter 4 steps through questions about the study area that are directly linked to the WoE approach, which uses the compiled remote evidence from section 2.1.

Topographic data layers, including DEMs derived from lidar, provide a model of the bare-earth surface and can reveal visible breaks in slope, linear surface depressions, and other important surface characteristics (e.g., bedrock, stream-channel banks, and accumulation or erosion of sediment). Slope maps generated from lidar-derived DEMs also provide valuable information on breaks in slope and can help narrow the potential location of the channel head. As the characteristics at the upper extent are small (i.e., submeter to meter scale), high-resolution DEMs (1 to 10 m scale) are the most effective surface data to remotely view physical characteristics at the upper extent of stream channels. Lidar-derived products, including DEMs and slope maps, have become more widely available across the U.S. to view and download. The most robust online remote tool to view lidar-derived DEMs and slope maps is the USGS National Map Viewer and should be the starting place for the remote examination.

Table 3. Summary of remote resources for viewing the upper extent of channels.

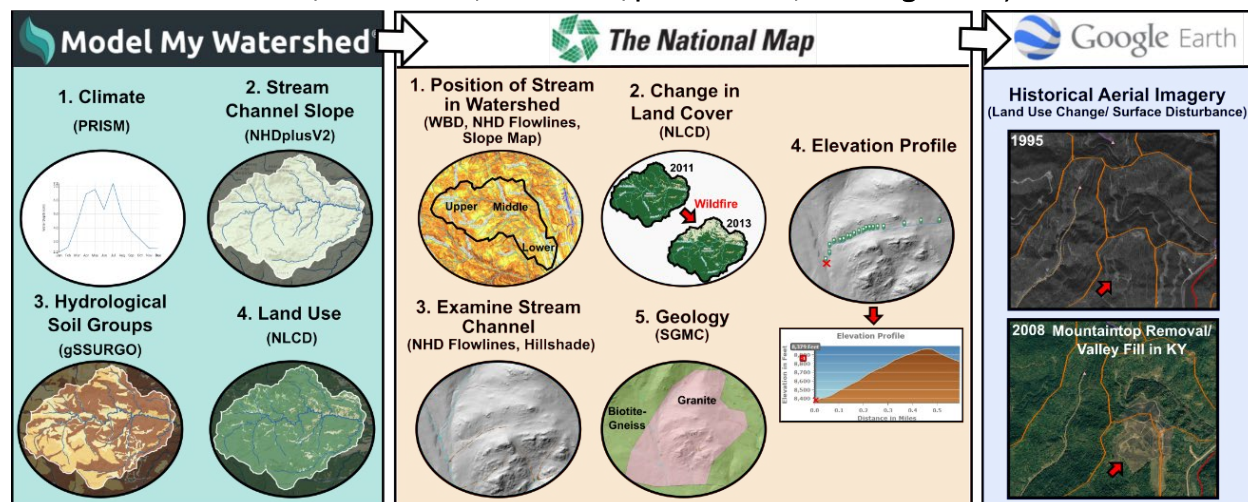
Application Name	Application Type	Available Data	Website
Model My Watershed	Viewer with watershed analysis tools	• Climate (mean temperature and precipitation) • Length and slope of headwater stream channels in user-delineated watershed • National Land Cover Database (NLCD) 2011 data layer • gSSURGO soil type distribution layer	https://modelmywatershed.org/
National Map Viewer	Viewer with limited tools	• Topographic maps (7.5 × 7.5 minute) • NHD • Stream types • Flow direction • USGS stream gage locations • Watershed Boundary Dataset (WBD) • USGS HUC2–HUC16 drainage-basin boundaries • Slope map • Combined lidar/hillshade surfaces • Elevation profiles • Land-use classifications	https://viewer.nationalmap.gov/advanced-viewer/
National Map Data Download	Data download portal	• Downloaded data layers from the National Map Viewer to use in external GIS (e.g., ArcGIS, QGIS)	https://viewer.nationalmap.gov/basic/
Google Earth	Viewer with limited tools	• Historical aerial imagery • Topography • Elevation profiles • Imported .kmz data layers for the U.S. (e.g., NHD, geology, soils)	https://www.google.com/earth/ example .kmz download for California soils: https://casoilresource.lawr.ucdavis.edu/soilweb-apps
Lidar	Data portals and data sources vary by state	• High-resolution surface elevation data (e.g., 1 m resolution)	Depends on state. Some states house more accessible data download portals than others (e.g., https://lidar.unh.edu/map/)
Web Soil Survey	Viewer	• Local soil composition • Local soil depth • Local lithology • Basic climate statistics (precipitation and temperature)	https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx
StreamStats	Streamflow calculations	• Delineation of subwatersheds • Streamflow magnitude, duration, and frequency statistics	https://streamstats.usgs.gov/ss/

Table 3 (cont.). Summary of remote resources for viewing the upper extent of channels.

Application Name	Application Type	Available Data	Website
EnviroAtlas	Interactive Map	- Raindrop tool - Shows the flow path of a drop of water anywhere on the surface - Water supply, runoff, and flow data layers (e.g., number of dams located in a watershed)	https://www.epa.gov/enviroatlas
Ecoregions	PDF map and shapefiles	Descriptions of climate, terrain, and streams for areas within a watershed	https://www.epa.gov/ecoresearch/ecoregions
USGS Earth Explorer	Data download portal	- Aerial imagery - DEM	https://earthexplorer.usgs.gov/
EPA WATERS GeoViewer	Viewer	Similar layers to the National Map Viewer	https://www.epa.gov/waterdata/waters-geoviewer

Note: Website addresses are subject to change.

Figure 7. Example workflow for compiling remote data layers and examining the watershed and stream channel of interest. The Buckhorn Creek and Upper Buckhorn Creek Watersheds are featured in the figure along with a watershed in Kentucky. (Images reproduced with permission from Stroud Water Resource Center 2017, CC BY-SA 3.0; USGS 2017, public domain; and Google 2008).



Although remotely available data layers that are used to view the upper extent of stream channels are relatively easy and fast to construct, they contain temporal and spatial errors (see limitations of remote-sensing tools in section 2.2). Therefore, while map products derived from remote data are useful tools to help guide an investigator to a field location, they should not be considered completely representative of reality. In fact, the data layers are temporal and spatial interpretations of what is actually present at the surface and could be outdated or misrepresentative. For example,

wildfires that occurred after the remote data were collected could significantly alter the appearance of the surface characteristics. In all, online data are useful for reconnaissance of the area of interest prior to a field investigation but typically need to be validated with direct field observations in real time. Also, mapping of stream networks by using online tools such as NHD are only as accurate and precise as the remote data used to generate them. The quality (i.e., the spatial and temporal resolution) of the remote data can vary greatly depending on the data source and location and can result in higher or lower accuracy of the map products and ultimately the expected location of the stream-channel-to-hillslope transition.

2.1 Remote-tools workflow

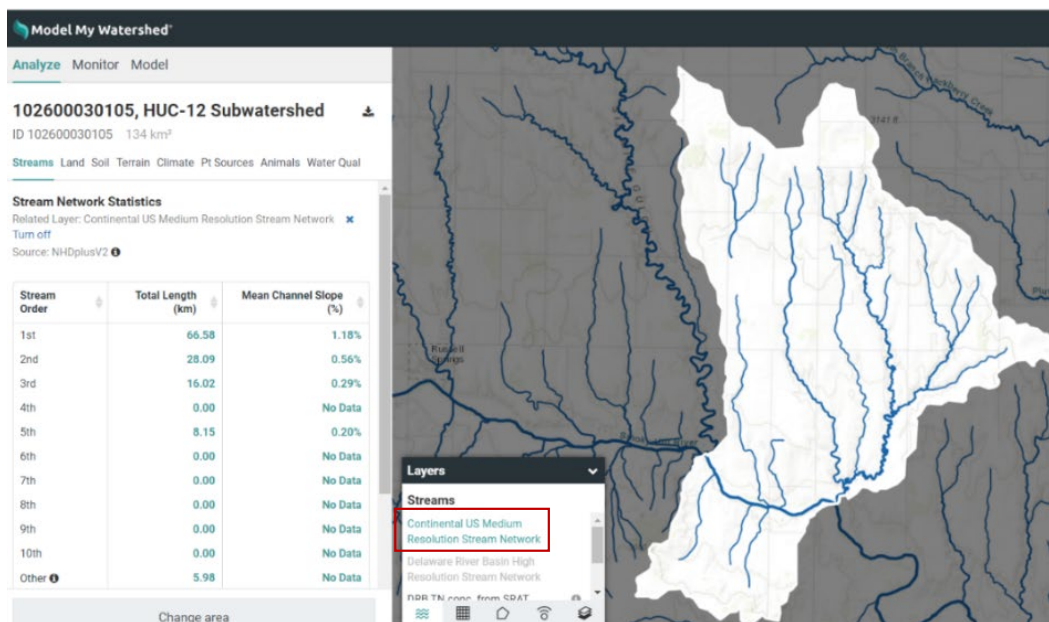
2.1.1 Model My Watershed

The first step in the remote-tool workflow is to use the Model My Watershed tool to gather general information on climate, hydrology, and soil for the watershed of interest. The main goal of starting with the Model My Watershed tool in the remote-tool workflow is to provide general information about the watershed of interest, which can help develop expectations for the type of runoff and the associated channel-head type that is potentially present at the upper extent of the stream channel of interest. However, even subwatersheds are large areas, and the information should not be used as truth for any particular location within the watershed.

1. **Navigate to the Model My Watershed website:**
<https://modelmywatershed.org/>
2. **Find the study area** within the map of the U.S. by (a) manually zooming in to the area or (b) typing a state, river name, address, or HUC code into the search bar.
3. **Select the USGS subwatershed unit (HUC-12) boundary and turn on the streams layer.**
 - a. Click on the Get started button at the bottom left side of the page.
 - b. Click on the Select boundary drop-down button on the left side of the page. If the Select boundary button is not visible, zoom in closer to the area of interest to activate the options under the Select boundary button.

- c. Click on USGS Subwatershed unit (HUC-12). The HUC-12 subwatershed boundaries should appear on the map. USGS Watershed unit (HUC-10) can also be used but will be an even larger area of interest.
- d. Click on the subwatershed boundary on the map. The subwatershed should stand out among the adjacent subwatersheds, and there should be a new window on the left side of the page with information on streams, land, soil, terrain, climate, etc.
- e. Turn on the streams layer by clicking on Continental US Medium Resolution Stream Network in the layers menu (Figure 8).

Figure 8. Subwatershed (HUC-12) of the Smoky Hill River Watershed in Kansas with displayed stream network. (Image reproduced from Stroud Water Research Center 2017. CC BY-SA 3.0.)



1. **Gather information from the analysis summary.** Information from the Model My Watershed tool that can be used to develop expectations for the types of runoff and the appearance of channel heads present at the upper extent of a stream channel of interest is located under the Climate, Streams, Land, and Soil tabs:
 - a. Click on the Climate tab and toggle between the Mean Precipitation in centimeters and Mean Temperature in degrees Celsius to determine the climate of the watershed. A helpful climate reference is the Peel, Finlayson, and McMahon (2007) climate classification (e.g., Table 2)

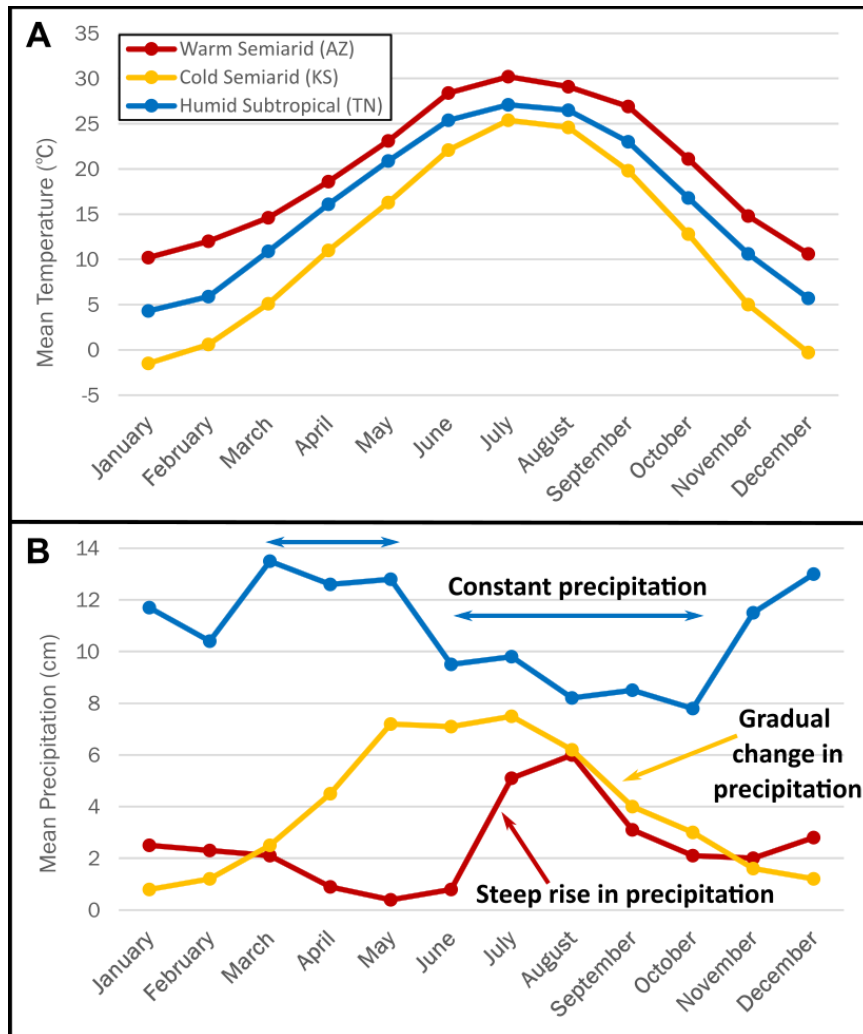
that can be used to categorize the mean precipitation and temperature values from the Model My Watershed tool. **Based upon the mean precipitation and temperature, what is the climate of the subwatershed?**

What are the monthly patterns of precipitation? For example, what months out of the year is the precipitation high or low? Finally, what hydrological regime can be determined from the mean annual precipitation and temperature? Figure 9 shows example temperature (A) and precipitation (B) plots of downloaded data from three different watersheds in Arizona, Kansas, and Tennessee with warm semiarid, cold semiarid, and humid subtropical climates, respectively. The temperature data show similar trends in temperature throughout the year (e.g., cooler in the winter months and warmer in the summer months) for all three watersheds with the arid watershed having the highest temperatures.

Mean monthly precipitation provides more information about the hydrological regime of the watershed and is helpful for determining the potential runoff type in the watershed. For example, the warm semiarid watershed has a steep rise in precipitation from June to July, which is evidence of a flashy hydrological regime. In other words, the monsoonal rain season occurs during the summer to early fall and brings intense precipitation. In an arid or semiarid climate, the soils are not likely to quickly absorb precipitation during an intense event, and the runoff type is likely to be infiltration excess overland flow. The subtropical humid watershed is likely to experience more constant precipitation year-round, resulting in a surface that is saturated. During precipitation events, saturation overland flow is likely to occur near the stream in this watershed. In the cold semiarid watershed, there are periods throughout the year with low and moderate precipitation, resulting in a mix of runoff types occurring.

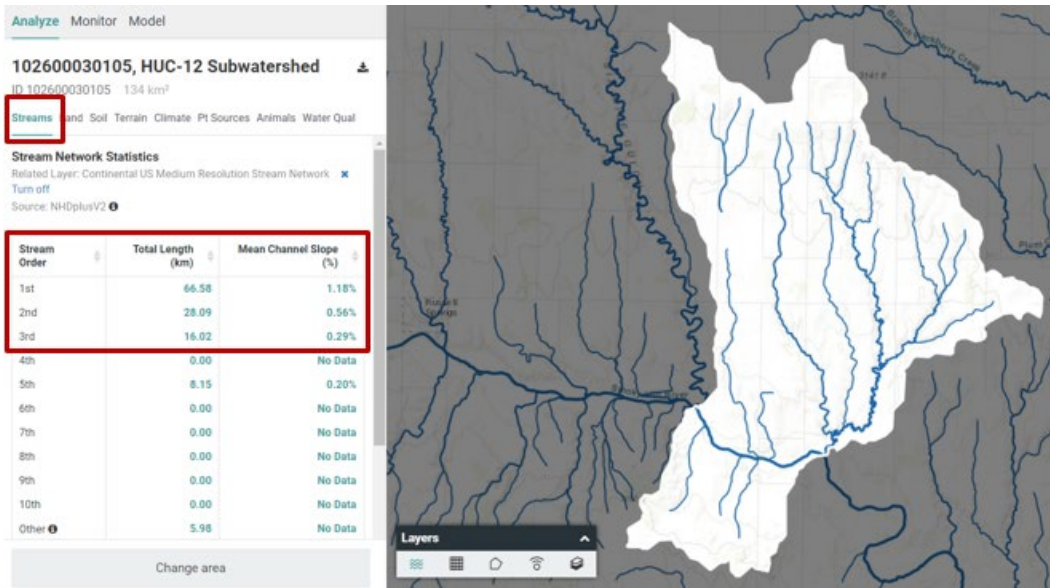
Looking at the combination of both mean temperature and precipitation, the presence and abundance of vegetation can also be generally determined for the watershed of interest. For example, in an arid or semiarid climate, isolated patches of less dense vegetation are likely present. The field investigation is more likely to have full visibility of the channel head because of exposed sediment. However, in a humid climate, dense vegetation may obstruct channel-head characteristics.

Figure 9. Example of mean monthly temperature (A) and precipitation (B) climate data derived from the Model My Watershed remote tool for warm semiarid (AZ), cold semiarid (KS), and humid (TN) watersheds (Stroud Water Research Center 2017). Patterns in mean precipitation (B) can be used to deduce hydrological regime and runoff type of the watershed of interest, which can be useful for developing expectations of channel-head characteristics in the field.



- b. Click the Streams tab to show the Mean Channel Slope (%) of the first-, second-, and third-order streams (Figure 10). **Do the slopes of the headwater stream channels contain low (e.g., less than 2%), medium or high (e.g., greater than 3%) values?** Low mean channel-slope values (e.g., 0.29% to 1.18%) are likely to have channel heads without steep, abrupt faces and sides, whereas high mean channel-slope values of the first-, second-, and third-order streams (e.g., 3.14% to 9.06% in Colorado mountain streams) are more likely to have abrupt, steep channel heads.

Figure 10. Subwatershed (HUC-12) of the Smoky Hill River Watershed in Kansas with stream network and headwater stream slope and length statistics derived from NHDplusV2 data. (Image reproduced from Stroud Water Research Center 2017. CC BY-SA 3.0.)

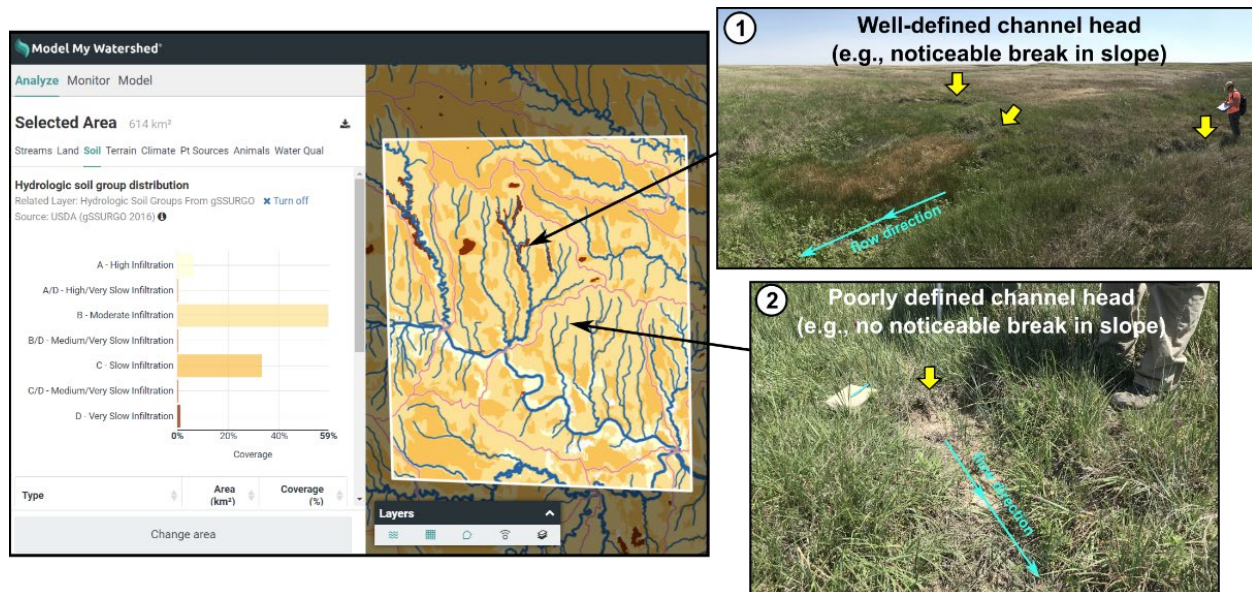


- c. Click the Soil tab and click on the text “Hydrologic Soils Groups from gSSURGO” to turn on the soils map layer (Figure 11). The soil map shows more localized information about the different soil types (e.g., soil type A, B, C, and D) and the corresponding infiltration rates.

Are there any soils with high infiltration, moderate infiltration, or very slow infiltration? If so, where are these soils located on the soils map? Soils with very slow infiltration are likely to have high clay content or be underlain by impervious rock types that contain high clay content, such as shale. Channel heads that are located where soils contain very slow infiltration rates and high clay content are likely to have a more defined shape (e.g., steeper sides and faces) because of the cohesive properties of clay and may be more identifiable in the field even if the channel head is vegetated and contains a low slope. For example, Figure 11, compares channel-head characteristics for two headwater streams in adjacent subwatersheds of the Smoky Hill River in Kansas. The expectation is that because these two headwater streams are located in adjacent watersheds, they contain a similar climate and therefore the channel heads should have similar characteristics. Examining the Model My Watershed soils map shows a difference in soil type for these two headwater streams. In fact, the channel heads for the two headwater streams appear differently in the field (Figure 11). At

the beginning of the first stream, there is a localized soil type of very slow infiltration, which is likely causing the well-defined break in slope of the channel head. In the second headwater stream, the soil type has moderate infiltration, and the channel head lacks a well-defined break in slope. The channel head for the second headwater stream was difficult to identify in the field without a noticeable break in slope or distinctive changes in vegetation.

Figure 11. Model My Watershed soils map for two headwater streams in adjacent subwatersheds in the Smoky Hill River Watershed in Kansas. (Left image reproduced from Stroud Water Research Center 2017. CC BY-SA 3.0.) The first channel-head location contains soils with very slow infiltration, whereas the second channel-head location contains soils with moderate infiltration. The first channel head contains characteristics that are more likely to occur with poor soil infiltration and high clay content because the soil is more cohesive and breaks in slope are maintained. The second channel head lacks a large break in slope and exhibits more subtle channel-head characteristics (e.g., small break in vegetation and exposed channel-bed sediment).

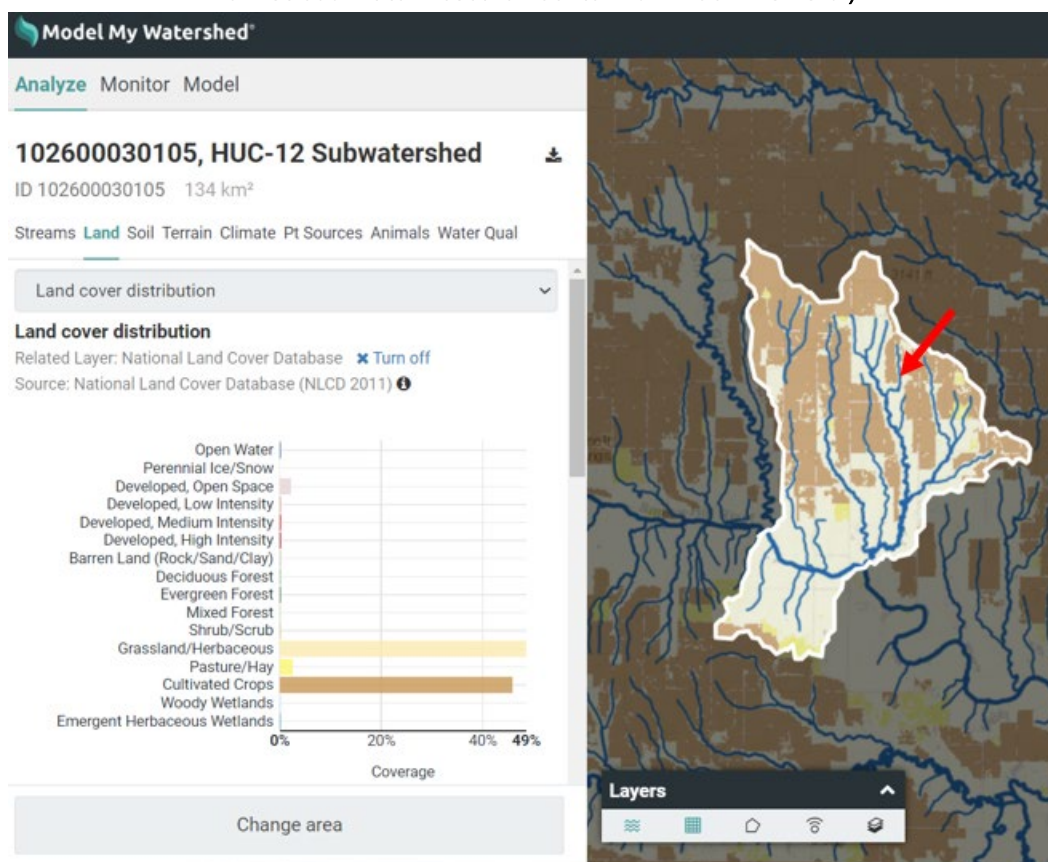


- d. Click the Land tab and click the Turn on the National Land Cover Database layer. Similar to the soils layer, the land-use layer also provides more localized information about the different land cover types. Model My Watershed is a good starting place for answering basic questions about land use.

What land cover category is present in the watershed or stream of interest? How can this land cover category affect the surface around the stream of interest? For example, in the Smoky Hill River Subwatershed example in Figure 12, the stream of interest is located in an area with grassland/herbaceous land cover. The surrounding area is also cultivated crop land. In

this example, the surface properties (e.g., the natural soil and grass-land) could be altered by farming practices. There are additional man-made influences that accompany farming practices, such as irrigation structures (e.g., agricultural ponds and dams) and groundwater pumping, that can significantly alter runoff processes and where runoff forms a stream channel. This is good information to be aware of during field investigation. Model My Watershed includes land cover types for only a single year (2011), and it is important to combine land cover information from Model My Watershed with additional land cover data sources (e.g., see sections on the National Map Viewer and Google Earth) that provide temporal changes in land cover that will be useful to determine if the area of interest has been affected by a land-use disturbance over time (e.g., wildfire).

Figure 12. Model My Watershed land cover types (NLCD 2011) for the example headwater stream located in the subwatershed of the Smoky Hill River Watershed. (Image reproduced from Stroud Water Research Center 2017. CC BY-SA 3.0.).



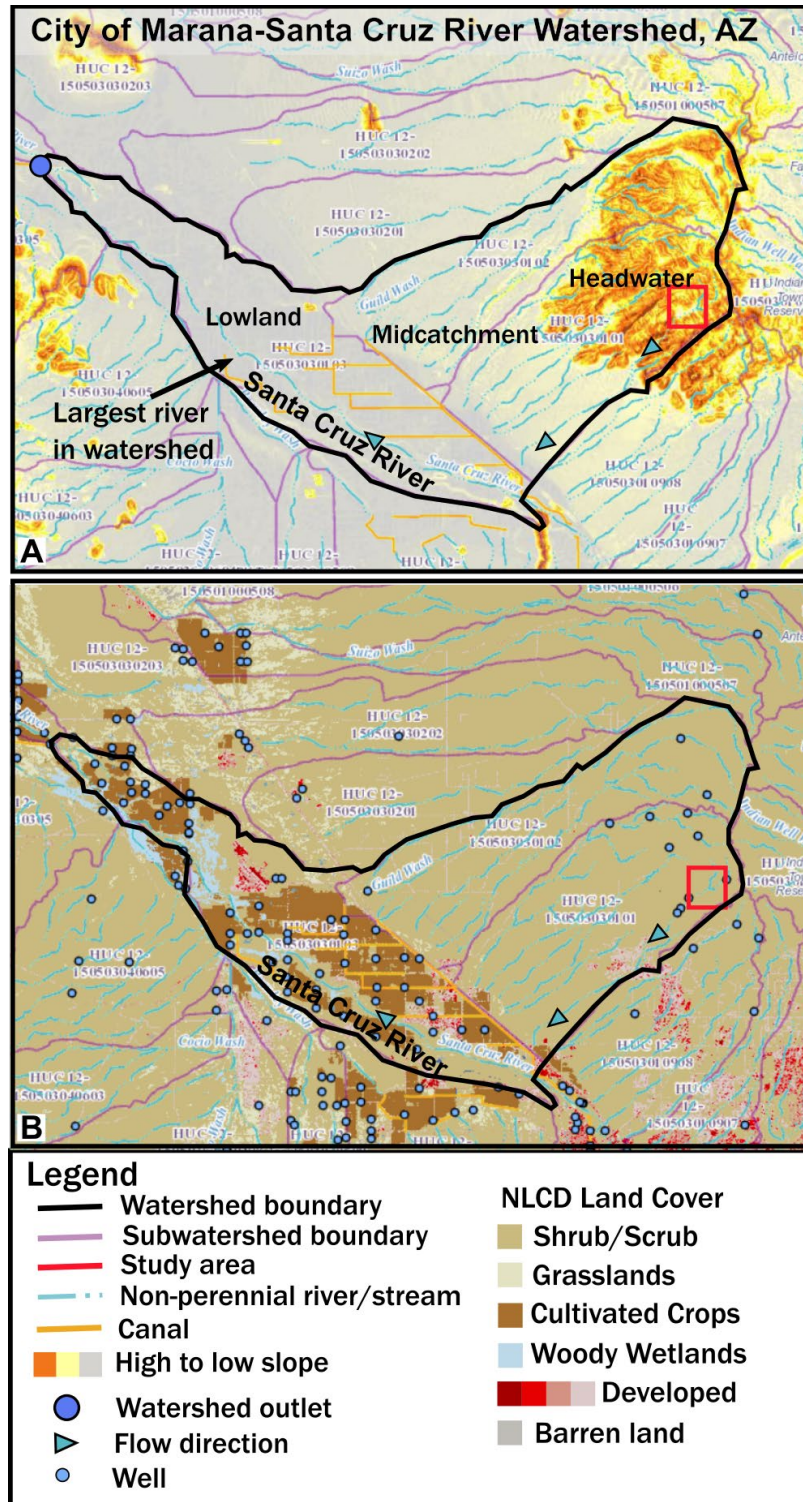
2.1.2 The National Map Viewer

The USGS National Map Viewer is the second tool in the remote workflow and contains more data layers that will help constrain the stream-channel-to-hillslope transition and provide potential channel-head locations. The USGS National Map Viewer is also the most robust online remote tool to view the bare-earth surface across the U.S. because it contains widespread coverage of high-resolution lidar-derived DEMs and slope maps. The National Map Viewer also has numerous available data layers that are helpful for the remote examination of the study area. Lastly, the National Map Viewer has the capability to add outside remote data layers along with other resources (e.g., GPS site shapefiles, comma-delimited files, and Google Earth .kml files). This gives the user the ability to record specific GPS coordinates to investigate in the field and also to bring back GPS coordinates from the field and place them in the context of the data layers. The National Map Viewer workflow contains the following steps:

1. **Navigate to the website:** <https://apps.nationalmap.gov/viewer/>.
2. **Find the study area** within the map of the U.S. by (a) manually zooming in to the area or (b) typing in a state, river name, or address into the search bar.
3. **View the Layer List** by clicking on the  [Layer List](#) icon.
4. **Determine the position of the stream channel within the watershed. In other words, is the stream channel located in the lower (i.e., lowlands), middle (i.e., midcatchment) or headwater portion of the watershed (Figure 13A)?**
 - a. Check on the [National Hydrography Dataset \(NHD\)](#) layer
 - b. Check on the [Watershed Boundary Dataset \(WBD\)](#) layer.

Note: Features, which may include blue stream lines and purple polygon boundaries, may become visible on the map. If not, make sure the nested boxes are checked on. The different-sized drainage basins are viewed by zooming in and out of the map, and additional information about each drainage basin (e.g., basin area and HUC number) is viewed by clicking on the drainage-basin boundary. The higher the HUC code, the smaller the drainage basin.

Figure 13. Usage of the National Map Viewer (USGS 2017) to examine a headwater stream within the headwater area of the City of Marana-Santa Cruz River Watershed by examining the slope map (A) and identifying land-use patterns (B). The midcatchment and lowland areas of the watershed are also labeled based on elevation in (A).

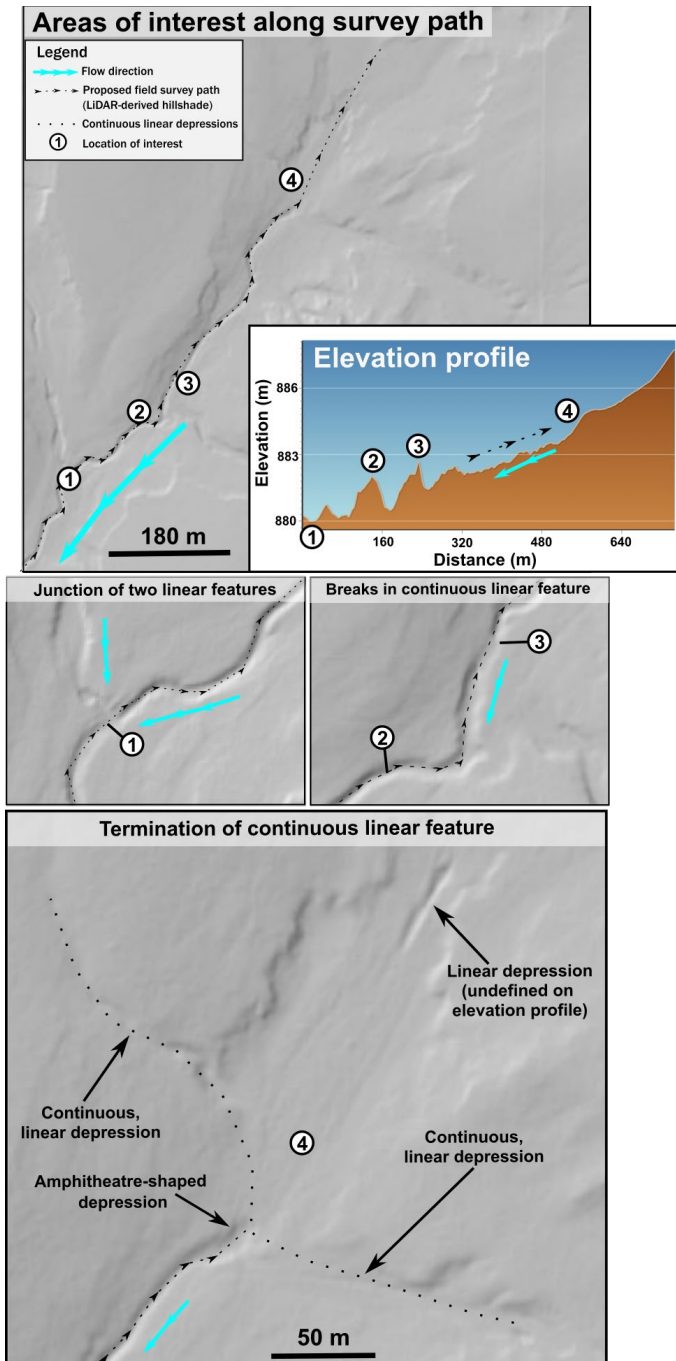


- a. Check on the 3DEP Elevation - Slope Map layer.
 - b. Locate the largest river or stream flowing through the watershed of interest and examine the direction of flow of the largest river to identify the outlet of the watershed. The NHD flowline layer should already be visible. Flow direction is indicated by small blue arrows along the blue stream lines upon zooming in. The subwatersheds that are farther from the mouth of the watershed are located at the upper part of the watershed. The slope map can also show areas of the watershed with low, moderate, and high slopes. It can be challenging, especially in low-gradient landscapes such as Kansas or the Atlantic and Gulf Coastal Plain, to determine which subwatersheds are higher in elevation in the watershed and which are lower in elevation in the watershed.
5. **Examine the watershed of interest and the surrounding watersheds for natural (e.g., wildfire) or man-made (e.g., agricultural land use) disturbances.**
 - a. Click on the NLCD Land Cover layer and identify the land-use cover from the pull down legend. This layer contains general information on the land cover type, including general vegetation cover. General land-use changes can be identified by toggling off different land cover layers for the different years. **Does the land use change over time for the watershed of interest? The surrounding watersheds?**
 - b. Click on the Imagery (NAIP Plus) layer. This is helpful to identify other land-use indicators (e.g., agricultural) or man-made structures within the watershed. For example, the clearing of vegetation by wildfire or for logging can be clearly evident in the aerial imagery.
6. **Examine the stream channel of interest and note any changes to the channel on the lidar-derived hillshade layer and follow it to the beginning of the NHD stream delineation.**
 - a. Click on the 3DEP Elevation - Hillshade Stretched layer and zoom all the way into the stream channel until surface depressions are clearly visible. The Elevation Contours layer is also helpful to have checked on.
 - b. If the NHD layer indicates that the stream channel contains segments of perennial (solid blue line) and nonperennial stream (dashed blue or

brown line), identify where the NHD stream delineation changes from a perennial to nonperennial stream channel. Examine the hillshade layer at this location to see if there are any differences in the surface appearance between the perennial and nonperennial NHD stream delineation. **For example, does the channel become wider or more defined, or both, where the NHD stream is delineated as a perennial stream? Or does this occur farther upstream?**

- c. By having the 3DEP Elevation - Slope Map layer checked on and toggling the hillshade layer on and off, the slope layer can aid in identifying breaks in slope associated with the beginning of the stream channel according to the NHD delineation.
 - d. **Are there any indicators on the hillshade layer that the stream channel is discontinuous? For example, does the stream channel abruptly disappear and then reappear farther downstream when viewing the hillshade or imagery (e.g., Figure 14)?**
7. **Draw an elevation profile that follows the stream of interest to the beginning of the drainage divide. Examine the elevation profile (e.g., breaks in slope and profile shape) to generally locate the stream-channel-to-hillslope transition and potential locations for the channel head.** Draw a line segment from the main stem of the main tributary junction upstream along the stream of interest to the delineated drainage divide derived from the WBD. If the stream channel contains multiple tributaries, start by drawing the line up one of the tributaries; and then repeat the next steps to examine the other tributaries.
- a. Click the  Profile icon.
 - b. Click the  Measure Distance icon under the Elevation Profile tab.
 - c. Draw a line that follows the stream on the hillshade as closely as possible in the upstream direction across the drainage divide (e.g., watershed boundary in the WBD layer).

Figure 14. Examination of surface characteristics observed on lidar for an example site in Kansas. Areas of interest on the lidar can be identified by drawing an elevation profile along the proposed survey path in the National Map Viewer (USGS 2017). Breaks in slope along the elevation profile, and the coordinates of the breaks in slope can be used as areas of interest to investigate in the field survey.

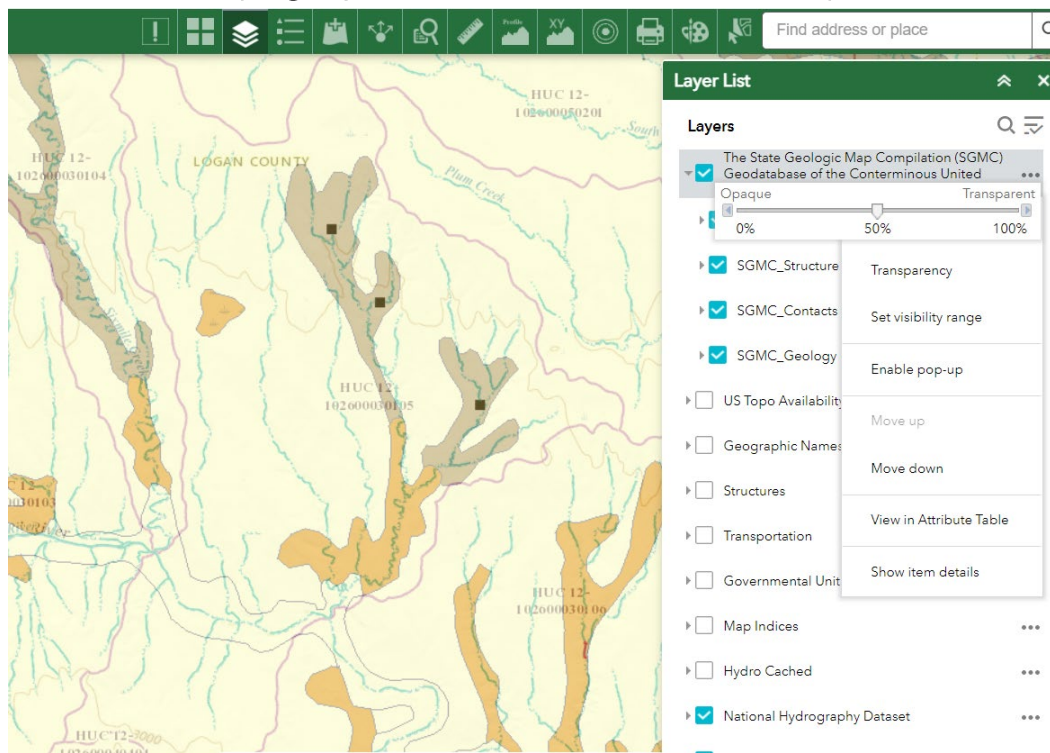


- d. Mark where there are significant changes in slope. **For example, where are the depressions on the profile? Specifically, is**

there a concave section of the profile from the hilltop/drainage divide to the beginning of the stream channel (i.e., colluvial hollow)? Where are the high points on the profile? This exercise can be used to draw estimated boundaries of where the stream channel begins at the channel head and where the convergence zone, or colluvial hollow, are located (i.e., concave depression on the elevation profile). A common coordinate format for GPS units is degrees, minutes, seconds, which is a coordinate format option on the map. Coordinates of these transition points can be recorded by hovering over the point of interest on the map. These point coordinates can then be input into a GPS and investigated in the field. Also, coordinates collected in the field with a GPS can be brought back and imported as a data layer (e.g., zipped shapefile extension) to compare to data layers in the National Map Viewer.

8. Import the geology shapefile and examine the geology types within the watershed and across the stream-channel-to-hillslope transition.
 - a. Click on the  Add Data icon.
 - b. In the search bar, search for “state geologic map.”
 - c. Click the ADD button under the option labeled “The State Geologic Map Compilation (SGMC) Geodatabase of the Conterminous U.S.” Note that this is a large layer that can take a few minutes to appear on the map. Also, if the geology layer is not appearing on the map, try clicking the layer off and on.
 - d. Switch back to the Layer List icon, and click the three dots to the right of the layer. Then click the Transparency button. Then slide the transparency bar to 50% to view the underlying stream and watershed boundary (Figure 15).
 - e. Click on the different colors on the map to identify the major rock and sediment types that underlie the stream-channel-to-hillslope transition zone. Note that clicking on a location on the map that is represented with multiple layers requires scrolling through or using the arrows at the top of the pop-up box to toggle between the layers to find the geology information for that area.

Figure 15. The National Map Viewer geology layer.
(Image reproduced from USGS 2017. Public domain.)



- f. **What are the main rock types, and where are they located in relationship to the stream channel of interest?** “The State Geologic Map Compilation (SGMC) Geodatabase of the Conterminous U.S.” layer is useful to find the major rock and sediment types that underlie the stream channel of interest. Specific rock types are likely to control the type of runoff in the area, which is related to the stream channel and channel-head characteristics that may be present in the field (Table 4). For example, limestone and shale geology are more erodible by groundwater and are likely to have underground pathways where subsurface runoff can disappear from the surface and reappear some distance downstream, causing a discontinuous stream channel. In mountainous areas underlain by rocks such as granite, the groundwater can become trapped by impervious crystalline rock; and a perched water table forms. Perched water tables can create springs, which can also be the locations of channel heads. Lastly, the geology layer can also be used to identify faults in the area that can cause subsurface flow to become exposed at the surface as a channel head.

Table 4. General relationships between rock type, runoff type, and stream channel and channel-head characteristics. Note that there are other possibilities of channel-head characteristics depending on geology.

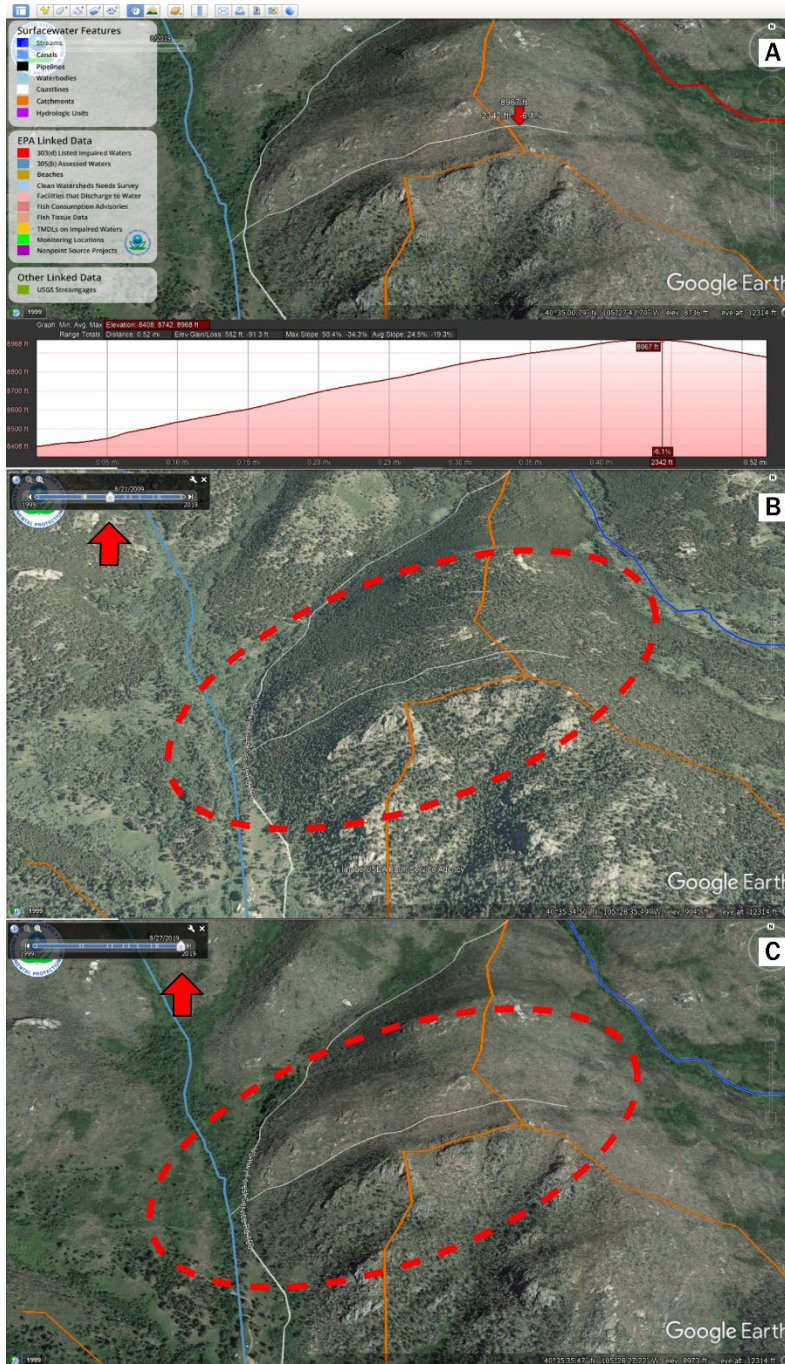
SGMC Rock Types	Runoff Type	Expected Stream Channel and Channel-Head Characteristics
Sedimentary (e.g., undifferentiated, carbonate, chemical, clastic, and evaporate)	Subsurface stormflow	Discontinuous stream channel
Metamorphic (e.g., amphibolite, gneiss, granitic, intrusive, and igneous)	Subsurface stormflow	Spring channel heads surrounded by dense, bright-green vegetation

2.1.3 Google Earth

The third step in this example remote-tool workflow is to view historical imagery of the stream channel of interest in Google Earth. Model My Watershed and the National Map Viewer contain more general land cover data that may span a few years, but Google Earth allows the user to quickly view more-detailed satellite imagery of the earth's surface from multiple scales before and after disturbance events (e.g., wildfire). Layers and locations (e.g., point, line, or polygon files) can also be added to the surface in Google Earth, including the NHD and WBD layers. Similar to the National Map Viewer, there is a tool to draw a transect across the surface and plot an elevation profile. For example, in Figure 16A, a transect is plotted from the base of the headwater stream to the drainage divide, and the corresponding elevation profile is plotted below with an interactive cursor that points out the location in the elevation profile on the surface.

The level of error in longitudinal profiles generated by both the National Map Viewer and Google Earth vary based on the topography. For example, elevation data derived from Google Earth for applications with lower, flatter topography are highly accurate with only meters of positional error (Wang et al. 2017). Conversely, the topography associated with headwater streams can result in more positional error in the elevation profiles generated by the National Map Viewer and Google Earth. Again, the elevation profiles are a useful guide for field work but should not be considered the true location or exact elevation profile.

Figure 16. Google Earth tools used to investigate the upper extent of stream channels in the Upper Buckhorn Creek Subwatershed in Colorado: (A) elevation profile (red arrow) of a headwater stream overlaid with the NHD layers (e.g., subwatershed boundary), (B) aerial imagery of the same headwater stream in 2009 prior to disturbance (red arrow indicates the timeline for dates with available images), and (C) aerial imagery of the same headwater stream in 2019 following wildfire disturbance (red arrow indicates that the image was from 2019). (Images adapted from Google 2019.)



Google Earth also provides a time series of satellite imagery. For example, Figure 16B and C show imagery of this first-order stream in the Upper Buckhorn Creek Subwatershed in 2009 and 2019. Just by examining the satellite imagery through two satellite images at this site, a distinct difference in vegetation from vegetated to unvegetated is clear. This difference is due to forest fires in the Buckhorn Creek Watershed in Colorado that occurred in 2013 and again in 2020, which could impact the physical indicators associated with locating the channel head. The exact dates of the historical imagery in Google Earth are not always shown correctly on the Google Earth page; however, exact dates and metadata can be checked for the aerial imagery by downloading the aerial images from the USGS Earth explorer.

2.1.4 Additional remote tools

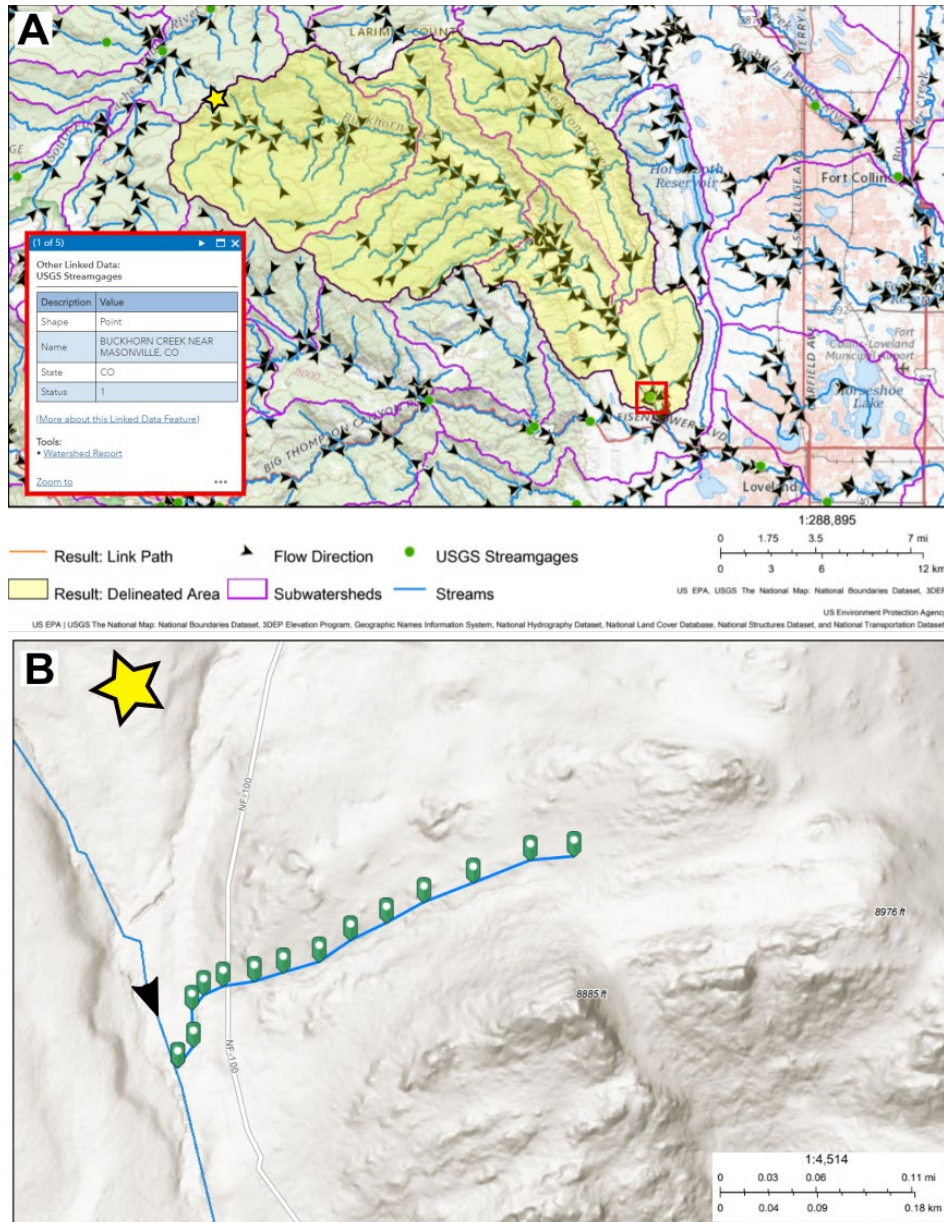
There are many other remote tools that can provide information similar to that from the example remote workflow (Table 3).

2.1.4.1 EPA WATERS GeoViewer

The EPA WATERS GeoViewer tool can also be used to quickly view the area of interest, hydrologic units (i.e., regions, subregions, basins, sub-basins, watersheds, and subwatersheds), and the stream network. Also, general maps of the study area are easy to generate in PDF format (Figure 17A). Another helpful characteristic of the EPA WATERS GeoViewer is the USGS stream gage layer that displays the nearest locations of long-term stream gage records throughout the U.S. (Figure 17A). These stream gage locations are linked directly to the time series of USGS streamflow gage records. Lastly, there is a “terrain with labels” basemap layer that allows users to view an approximately 1 m resolution terrain (Figure 17B). Small geomorphic characteristics located at the upper extent of stream channels are visible within this layer, and there is also a measurement tool to calculate the length of characteristics or path distances (Figure 17B). The limitation of the EPA WATERS GeoViewer for viewing the upper extent of the stream channels is the low resolution of the stream network and associated lack of capability to delineate small zero-order basins. This tool also only references streamflow resources and provides minimal ability to calculate hydrology and streamflow statistics for the area of interest.

Figure 17. Map of Buckhorn Creek Watershed and stream network generated from the EPA WATERS GeoViewer tool (EPA 2021). (A) A key characteristic is the linked USGS stream gage layer that allows the user to view the closest stream gage to the area of interest and access the USGS stream gage record directly. The *red boxes* show an example of a stream gage location and associated gage information. (B)

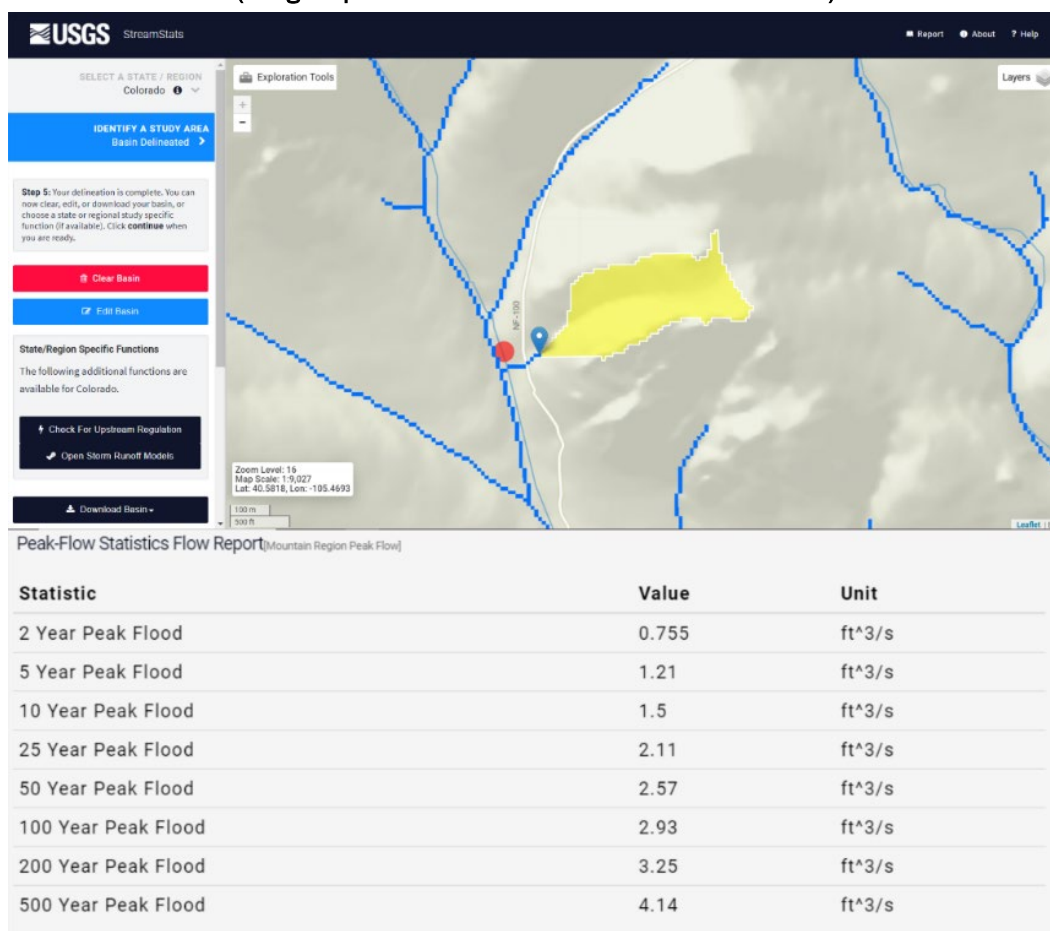
This inset view of panel A (referenced with *star*) shows a small intermittent headwater stream located at the Upper Buckhorn Creek Watershed. There is a path drawn next to this small stream that measures 440 m. The small stream channel is visible with the terrain layer and can be followed to its probable starting location where the linear characteristic tapers off into the upslope colluvial hollow.



2.1.4.2 *StreamStats*

StreamStats is an open-source, online application that is useful specifically for obtaining streamflow statistics on ungaged streams. It is not included in the example workflow because streamflow data can be more complicated to interpret without additional training. However, StreamStats can be used to delineate subwatersheds for user-selected stream sites. Without direct streamflow information from a USGS stream gage, StreamStats provides information on the site streamflow with relationships between regional streamflow and drainage area. The application returns hydrological characteristics about the magnitude, duration and frequency of streamflow at the user-selected stream site by using regional regression equations. These equations relate streamflow characteristics that are computed for a group of regionally selected stream gages to basin characteristics that were measured for the corresponding stream gages. For example, Figure 18 shows the delineated subwatershed of a headwater stream (i.e., yellow polygon) and the streamflow statistics that are returned from the application. Note that the different recurrence interval flows, especially those around the 1.5-year recurrence interval flood, commonly associated with the flows that form and maintain the shape of the stream channel are useful in determining the hydrology of the subwatershed. This tool also provides information on the magnitude of extreme floods. Both delineated watershed areas and streamflow statistics are useful for estimating the size of the streamflow and its drainage area. The magnitude, duration, and frequency of flow aid in understanding the hydrology of the stream, which can help in identifying channel heads that are shaped by particular hydrologic regimes. For example, in an arid environment, the magnitude of monsoonal rains is high, resulting in intense flooding; but the frequency of these flooding events is low. Channel heads in this environment may have a distinct vertical slope because of the infrequent intense overland flow without subsequent reworking of the channel head.

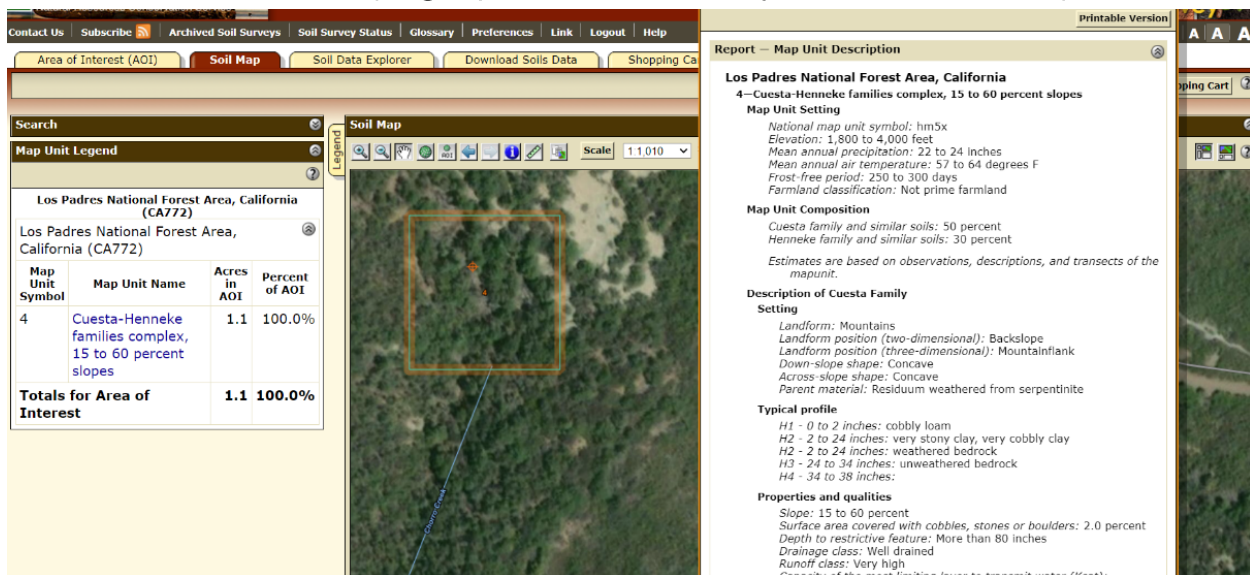
Figure 18. Subwatershed of the Upper Buckhorn Creek Watershed delineated in the StreamStats tool with streamflow statistics, including recurrence intervals of streamflow. (Image reproduced from USGS 2015. Public domain.)



2.1.4.3 Web Soil Survey

The Web Soil Survey portal provides more-detailed information on soils than the Model My Watershed tool. Again, this level of detail about soils in the Web Soil Survey portal does not necessarily add to the interpretation of the soils and runoff types that are adjacent to the stream and is therefore not included in the example remote workflow. The Web Soil Survey portal, which the USDA Natural Resources Conservation Service (NRCS) operates and maintains, provides a user interface where a selected location of interest within the U.S. returns detailed information on the area of interest, including soil profile composition, surface slope, geology, mean annual precipitation and air temperature, and land-use history (Figure 19). This application also includes additional resources on soils under the [Soil Data Explorer](#) tab.

Figure 19. Web Soil Survey portal interface showing information about local soil characteristics. (Image reproduced from Soil Survey Staff, n.d. Public domain.)



2.1.4.4 EnviroAtlas

One additional Interactive Map tool to mention is the Raindrop tool in EnviroAtlas. This tool is useful when determining the path that flowing water will take from the adjacent hillslopes to the stream channel. This could also be helpful for identifying where flow would be draining to at the beginning of a stream that may also correspond with breaks in slope seen on the map surface in EnviroAtlas.

2.2 Limitations of remote data and tools

Remote data and the products derived from them (e.g., stream types delineated in the NHD) are a proxy for the actual characteristics on the ground. Therefore, remote data and the derived data products have limitations when it comes to locating actual characteristics in the field. The ability to see surface characteristics from lidar-derived products is dependent on the resolution of the lidar. Increased density or closer spacing of surface measurements results in higher lidar resolution (e.g., 1 m resolution) and more remote visibility of surface characteristics. But even with high-resolution lidar DEMs (e.g., 1 m) the actual characteristics in the field may be too small to locate on the lidar DEM, which will result in discrepant locations between field and remote data. In Figure 20, the actual location of the channel head that was identified in the field is more than 90 m above the channel head that was chosen by simply viewing the characteristics on the high-resolution lidar DEM. The channel-head location from the NHD is

closer to the actual channel-head location but is still around 50 m downslope of it. Also, different tools are likely to result in different representations of the watershed and drainage network, which can introduce variability in characteristic locations. Figure 21 compares Colorado (Figure 21A) and Kansas (Figure 21B) streams and channel heads delineated and demarcated using the NHD versus using field data and an advanced hydrology toolkit in ArcGIS. At both the Colorado and Kansas sites, the NHD underestimates the length of the streams.

There are major limitations for locating small channel heads and headcut characteristics by solely using remote data. Whether channel heads are visible on lidar can also depend on the landscape and how the breaks in slope are resolved. But even within the same landscape, the visibility of small characteristics can vary. Comparisons between characteristics in the field and lidar illustrate what is visible on lidar and what limitations exist for viewing small characteristics such as a channel at the upper extent. Figure 22 shows a small bedrock tributary in Tennessee that is visible in Google Earth (Figure 22A) and on lidar (Figure 22B). Figure 23 shows another small bedrock channel that is located in an adjacent watershed to the bedrock tributary in Figure 22C, with a 1–2 m tall break in slope that is observed in the field (Figure 23C and D) but is not visible in Google Earth (Figure 23A) or on the lidar (Figure 23B). The limitations of remote data prevent consistent and accurate identification and location of channel heads and other characteristics at the upper extent of channels. Without field data for validation, the investigator is subject to the limitations of the remote data, which is likely to contain error.

Figure 20. Comparison of channel-head location with field observation, lidar, and NHD dataset: (A) field-observed location at the base of the *yellow arrow* and (B) locations determined from lidar (*brown star*), NHD (*blue star*), and field observation (*top of yellow arrow*).

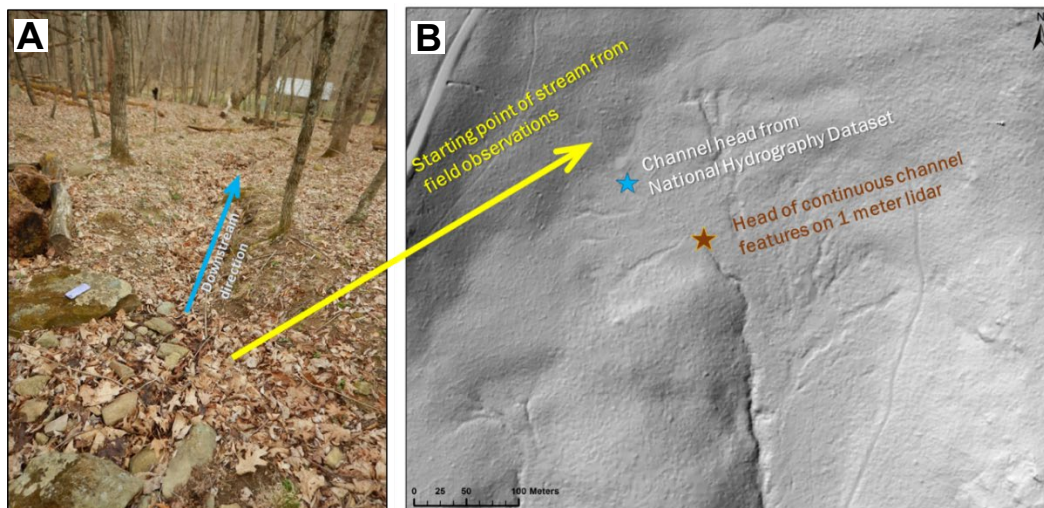


Figure 21. Comparison of headwater streams derived from field data versus NHD stream delineations: (A) watershed in Colorado and (B) watershed in Kansas. The *red arrows* indicate where the channel head is located in the field.

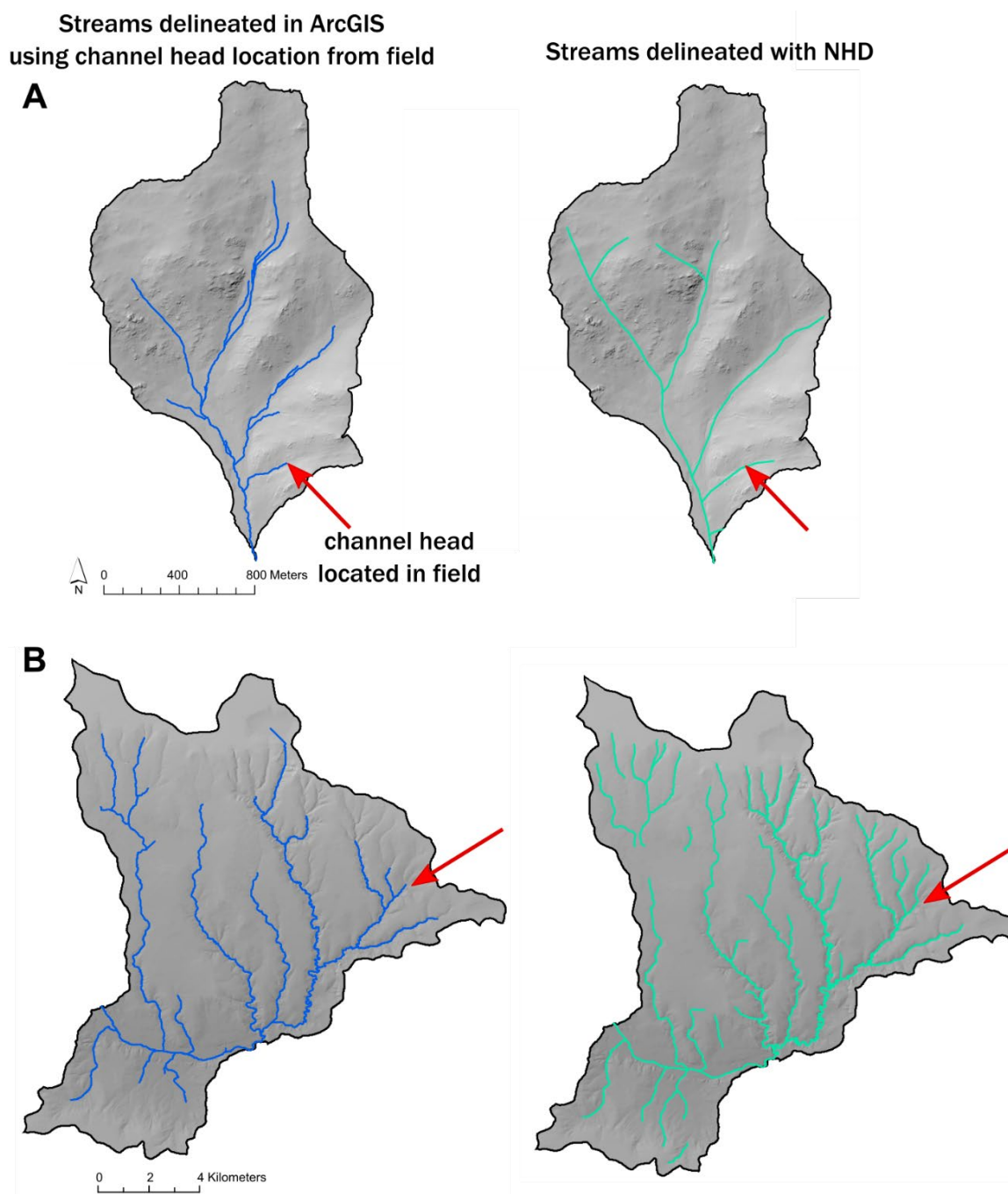


Figure 22. Location of a small bedrock tributary stream in Tennessee. Note that this tributary can be seen in (A) Google Earth imagery (adapted from Google 2018) and (B) with lidar (1 m resolution). (C) Photograph of the tributary shown in (A) and (B). Flow direction in (C) is from top to bottom in the photo.

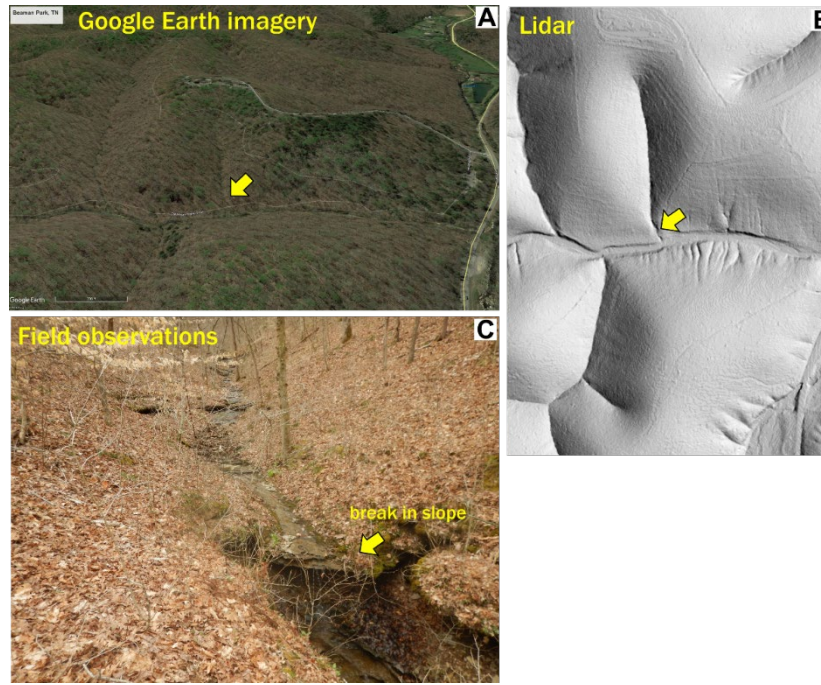
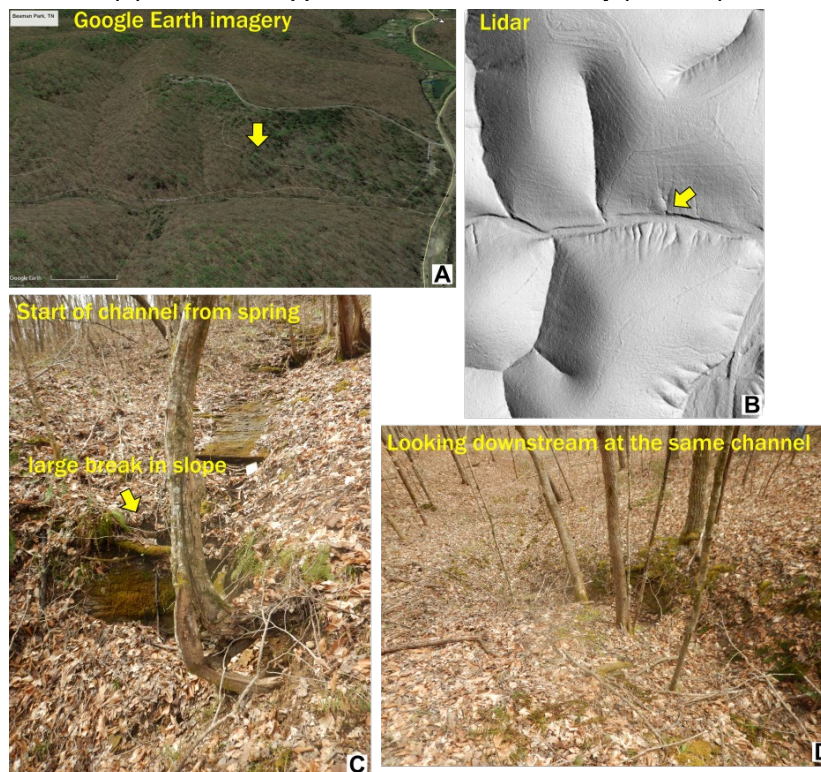


Figure 23. Small channel characteristic (i.e., break in slope) that is difficult to find on (A) Google Earth (adapted from Google 2018) and (B) lidar but is apparent from the field survey (C and D).

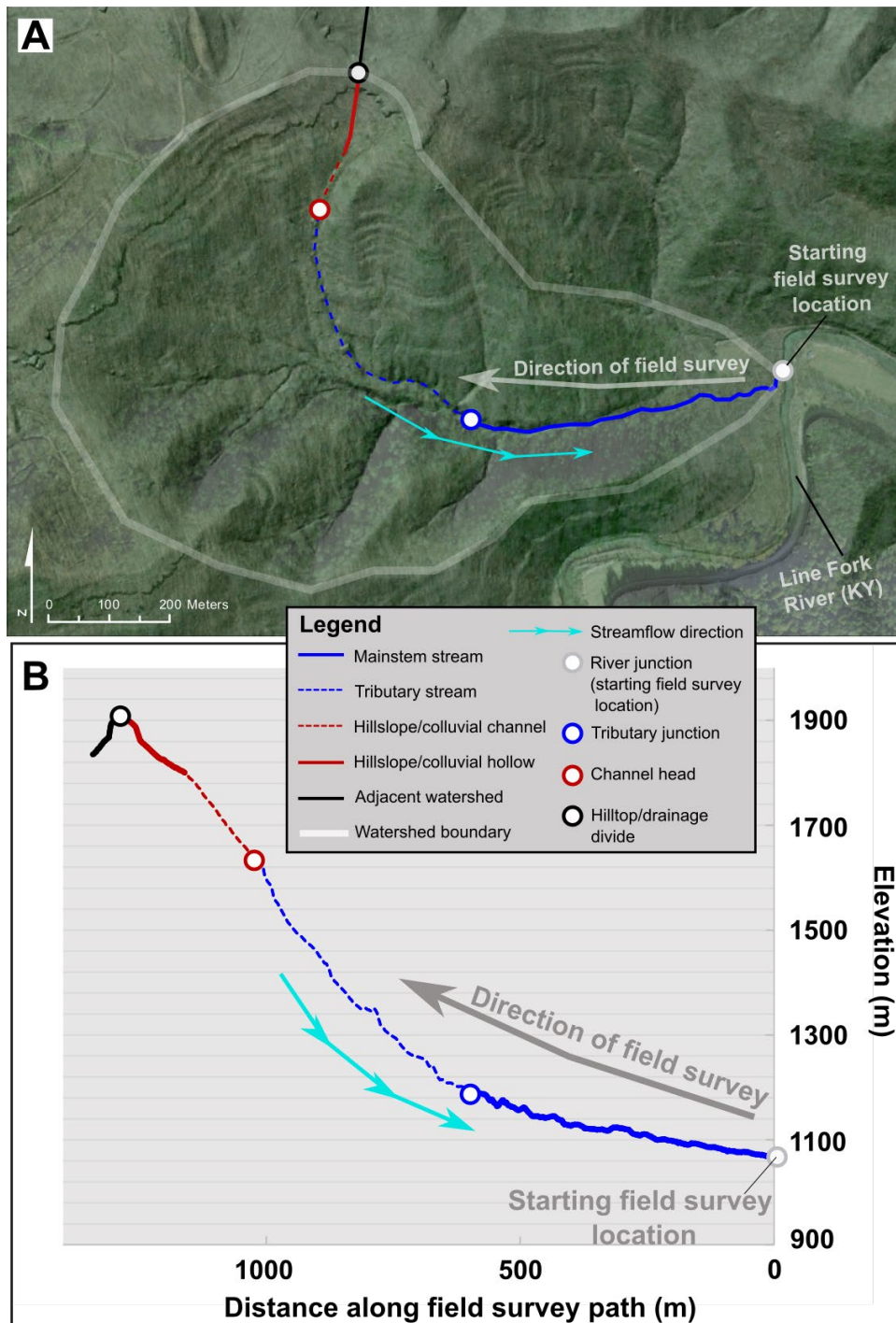


3 Field Identification of the Upper Extent of Stream Channels

This section provides guidelines on how to identify the upper extent of a stream channel with evidence collected in the field. The layout of the sections in chapter 3 reflects the survey path of the field investigator that follows the stream channel (section 3.1) to the channel head (section 3.3) in the upstream direction and investigates the hillslope located upslope of the channel head (section 3.5; Figure 24). Figure 24 shows two types of views of an example field-survey path. Figure 24A shows the map or plan view of the watershed, looking down on the field-survey path. Figure 24A also has the lidar imagery (1.5 m resolution) where small features (e.g., channel, large boulders, etc.) on the surface are clearly visible. If lidar is available, it is worth the time to download and create a map (e.g., Figure 14) to locate features in the field. Figure 24B shows the longitudinal profile view of the survey path line in the top panel. Both views are helpful to have available in the field. The elevations of the longitudinal profile are extracted from the lidar surface and show breaks in slope (e.g., between the colluvial channel and colluvial hollow; Figure 24B).

The starting location and path of a field survey to a channel head are critical. The most efficient field-survey path starts at the mainstem of the stream, if accessible, and follows the stream to the channel head (Figure 24). The collection of field observations along this type of field-survey path is the most systematic strategy. Also, there is an opportunity to revisit locations of interest and the hillslope-to-stream-channel transition along the field-survey path on the way back. The most ideal viewing angle for identifying stream characteristics is looking upstream where the shape or morphology of the stream bed is the most defined. Field investigations can also start at the drainage divide at the top of the hillslope or somewhere on the hillslope that is adjacent to the stream channel. These types of field-survey paths are more difficult to traverse while collecting systematic observations. For example, if dropping in from the drainage divide is steep, it is likely that the primary concern will be navigating the steep slope instead of taking detailed field notes. Also, if the field-survey path diverges laterally from the stream channel, other linear features can be misinterpreted as streams. For example, the surface of the forest may contain linear features that appear to be stream channels but are linear depressions from a past logging operation or other past land use.

Figure 24. Field-survey path including (1) the direction of the field-survey path, (2) the location of the river junction, (3) the path of the mainstem of the stream, (4) the path of the tributary that leads to the channel head, and (5) the location of the convergence zone (i.e., colluvial hollow) and hillslope characteristics upslope of the channel head. (A) The plan view of the example field-survey path. (B) The corresponding longitudinal profile view of the example field-survey path with corresponding categorized segments (i.e., stream channel, channel head, and hillslope).



Logistical limitations in the field are likely to affect the interpretation of a channel-head location. Depending on the location, spatial extent, conditions, and accessibility (e.g., terrain and vegetation cover) of the field sites, the field investigation is likely to not extend to the drainage divide or top of the hillslope. Furthermore, steep terrain in mountainous-headwater systems or arid-canyon systems can prevent investigators from following streams to the drainage divide. Lastly, there may be limitations in terms of access to land, scope of project, or amount of time available for the field investigator. Being aware of these limitations and the positional uncertainty they introduce to the channel-head location will aid in determining the amount of positional error that exists with the channel head location and the associated level of confidence the field investigator has with its location. The error associated with identifying the location of a channel head is related to sources of uncertainty in the distance upslope and downstream from the identified channel head to the actual location. If there are limitations in terms of the size and scope of the field investigation, resources in chapter 2 can assist in evaluating whether the channel head is likely to be farther upstream from the observed point in the field. Chapter 3 provides a full description of observations so that field investigators can better understand their observations along these upper extents of stream channels in different regional environments.

Identifying hillslope and stream-channel characteristics in the field provides one technique to spatially constrain the upper and lower extents of the hillslope-to-stream-channel transition, thereby reducing the spatial extent for investigating the location of the channel head. Upslope of the hillslope-to-stream-channel transition, hillslope sediment is predominantly transported by forces driven by gravity. Downstream of the hillslope-to-stream-channel transition, where flow is concentrated into a stream channel, fluid forces dominate, initiating transport of water and sediment on the bed and banks of the stream channel. Gravity and water-driven forces drive physical processes that can result in distinctive geomorphic characteristics, but often hillslope and stream-channel characteristics can be difficult to differentiate in the field because they spatially overlap within the hillslope-to-stream-channel transition zone. Although both characteristic types, hillslope and stream channel, are likely present at the upper extent of the stream channel, it is important to be able to distinguish the dominant processes and associated characteristics at the location under investigation within the transition zone.

Consistently identifying this hillslope-to-stream-channel transition in the field, across different landscapes, is challenging because differences in regional climate, hydrology, vegetation, geology, soil, and land use cause variation in the characteristics of the channel-head transition zone (E. Wohl 2018). Figure 25 illustrates variation in physical characteristics across the hillslope-to-stream-channel transition zone from field observations across three different landscapes. In the steep Upper Buckhorn Creek Subwatershed in Colorado, the channel head is located at a small bedrock seep that is caused by subsurface runoff and a break in surface slope. Looking upslope from the bedrock seep, there is a clearly defined colluvial hollow in the upslope direction. Looking downstream of the bedrock seep, there is evidence for stream processes, and the hillslope transitions to the channel are relatively abrupt. The channel-head transition extends only minimally until there is a more defined stream channel at a large spring. In the moderate gradient Gordon Creek Watershed in Colorado, the channel head is gradual and extends over hundreds of meters with a sequence of deep headcuts (i.e., up to several meters deep). The stream-channel characteristics are also discontinuous, where there are clearly defined segments of stream channel followed by open grassland where the stream disappears into the subsurface. Looking upslope from the channel head, there is a small, less distinct colluvial hollow. Lastly, in the low-gradient Upper Smoky Hills Subwatershed in Kansas, there is a gradual channel head that extends hundreds of meters. The channel head is the point of convergence of several small drainage features where there is a noticeable break in slope. Looking upslope from the channel head, there is minimal evidence for a defined colluvial hollow. This area is characterized by discontinuous islands of vegetation. Downstream of the channel head, the stream channel is discontinuous with long segments disappearing into the subsurface (i.e., karst geology) and reappearing farther downstream at small headcuts.

Figure 26 summarizes the steps needed to identify the upper extent of a stream channel in the field. The following sections describe the characteristics of the stream channel, the channel head, and the hillslope in the field.

Figure 25. Examples of channel-head types and longitudinal characteristics of the hillslope-to-stream-channel transition.

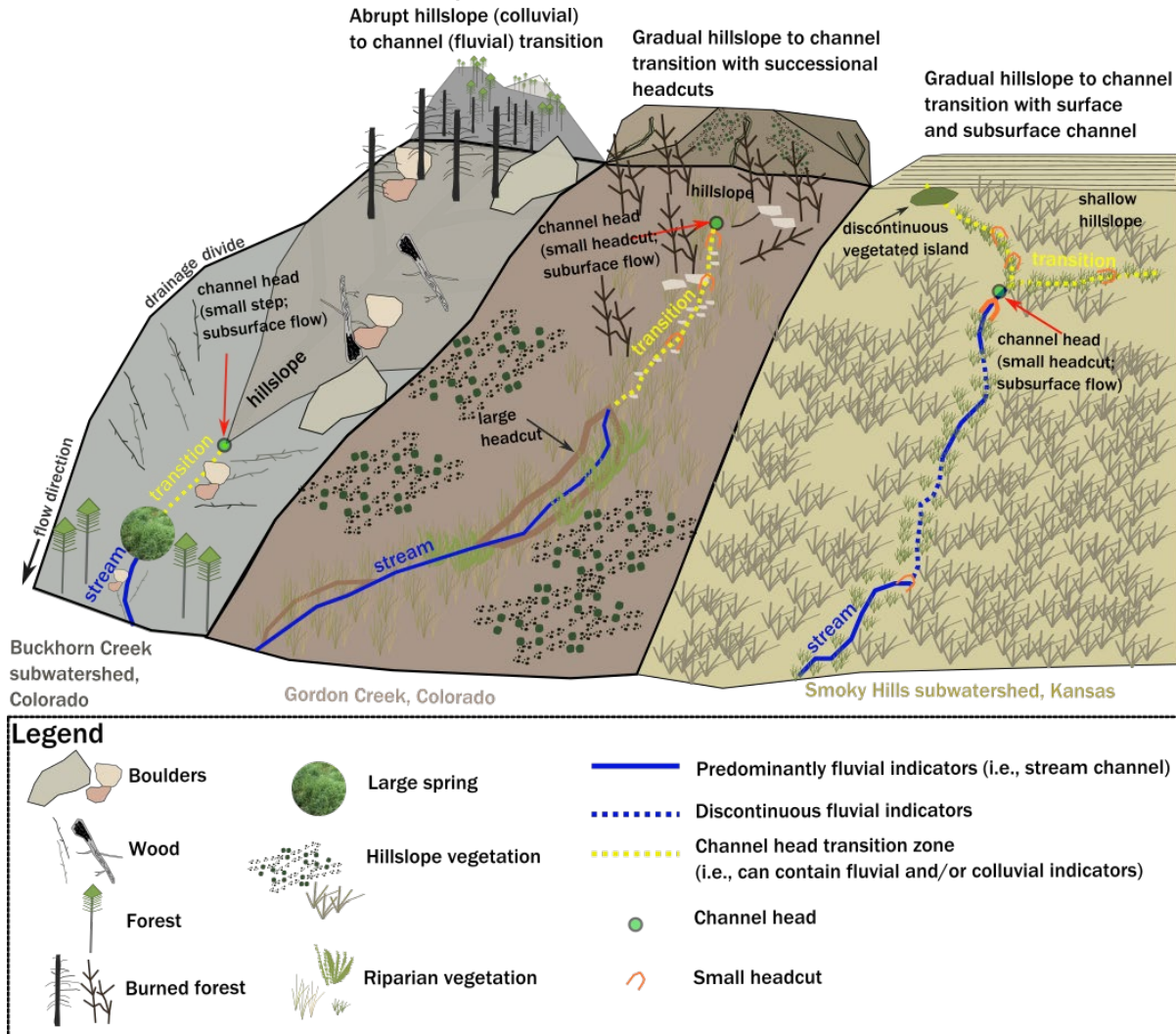


Figure 26. Steps for examining the landscape and identifying the upper extent of a stream channel.



3.1 Overview of identifying stream-channel characteristics

A stream starts when there is enough water concentrated on a portion of the hillslope to transport sediment and form the observable stream characteristics. The amount of water in the stream channel is described as streamflow, or discharge. Streamflow is a fundamental factor influencing the shape, or morphology, of the bed and banks of a stream channel. Therefore, there are distinct geomorphologic, sedimentologic, and vegetative indicators generated by streamflow. Information on the climatologic and hydrologic regime of the field-survey area provides an expectation of the type of streamflow present and how the stream channel is shaped during different types of precipitation events over a period of time. Nonperennial streams (e.g., common in arid and semiarid environments) generate streamflow that shapes the channel during rare, intense precipitation events. This type of streamflow, particularly streams that flow only during precipitation events, can often leave physical indicators that are frozen in time and well defined but that may have been further modified by other types of erosion (e.g., wind erosion) before the field investigation takes place. Furthermore, physical indicators on nonperennial streams in humid environments can end up being obscured by vegetation growth. In contrast, perennial streams (e.g., common in humid environments with frequent precipitation) generate streamflow that can maintain the shape of the stream channel. This type of streamflow can often leave well-developed physical indicators, including well-developed banks, bed morphology, and bedforms.

Downstream of the channel head, processes controlled by concentrated, flowing water and transported sediment on the bed and banks of the stream channel predominate. Just as hillslope indicators vary across regions, stream-channel indicators can look different across regions. The stream channel indicators described in this section include (a) flow confined to a stream channel; (b) the development of stream-channel banks and bed, including changes in vegetation type and density; (c) sediment sorting on the stream-channel bed; and (d) the development of stream-channel morphology and bedforms. Most importantly, not all types of stream-channel indicators may be present in every headwater stream channel, and often flowing water is not present at the time of investigation. Therefore, it is critical to consider different types of stream-channel indicators (if present) in determining if stream-channel indicators dominate in the area where the field investigation occurs.

3.1.1 Geomorphic indicators

3.1.1.1 *Indicators of flow confined to a stream channel*

Flow indicators provide evidence for the presence of channelized, flowing water through indirect evidence of vegetation and sediment transport. In arid environments, rare precipitation events result in short inundation periods that significantly wet the path of the nonperennial channel. Isolated clumps of drought-tolerant vegetation that border nonperennial streams are referred to as xeroriparian vegetation and can be an indicator of past streamflow through a nonperennial channel (Johnson, Carothers, and Simpson 1984). Figure 27 shows the presence of xeroriparian vegetation (e.g., mesquite tree, grass, and moss) that indicates the presence of streamflow in a nonperennial stream in Arizona.

Often, whether in arid or humid environments, transitions in vegetation species, density, and age along a channel boundary can assist with identifying zones that are more frequently disturbed by flowing water.³ Because vegetation varies by region, it is helpful to investigate regional resources that provide information on vegetation communities in the riparian zones. For instance, information about vegetation in arid environments can be found in the streamflow duration assessment method for the arid west (Mazor et al. 2021). Hydrophytic plant species are common in riparian zones and in some cases may grow on the bed of the channel. The National Wetland Plant List (U.S. Army Corps of Engineers 2020) is another resource that can provide regional information on hydrophytic plants. Note that it is important to understand species characteristics within a region because the same plant may have a different rating based on the region.

Organic litter or flood debris, or both, can accumulate on the stream-channel bed or around the stream-channel banks. For example, Figure 28 shows for a nonperennial stream channel in Arizona the base of a grass cluster that is bent and elongated in the direction of streamflow and wrapped around the base of the boulder. There can also be organic litter or flood debris that is accumulated on the upstream side of larger rocks in the channel, indicating that the streamflow slowed down on the upstream side

³ G. C. L. David, K. M. Fritz, T.-L. Nadeau, B. J. Topping, A. O. Allen, S. Kichefski, P. H. Trier, L. A. James, E. Wohl, and D. Hamill, *National Ordinary High Water Mark Field Delineation Manual for Rivers and Streams* (Hanover, NH: U.S. Army Engineer Research and Development Center, forthcoming).

of the protruding rock, causing the organic litter to accumulate on the up-stream side of the rock.

Figure 27. Examples of streamflow indicators in a nonperennial stream in Arizona with isolated patches of drought-tolerant vegetation (i.e., mesquite tree, grass, and moss) bordering or located in the stream channel.

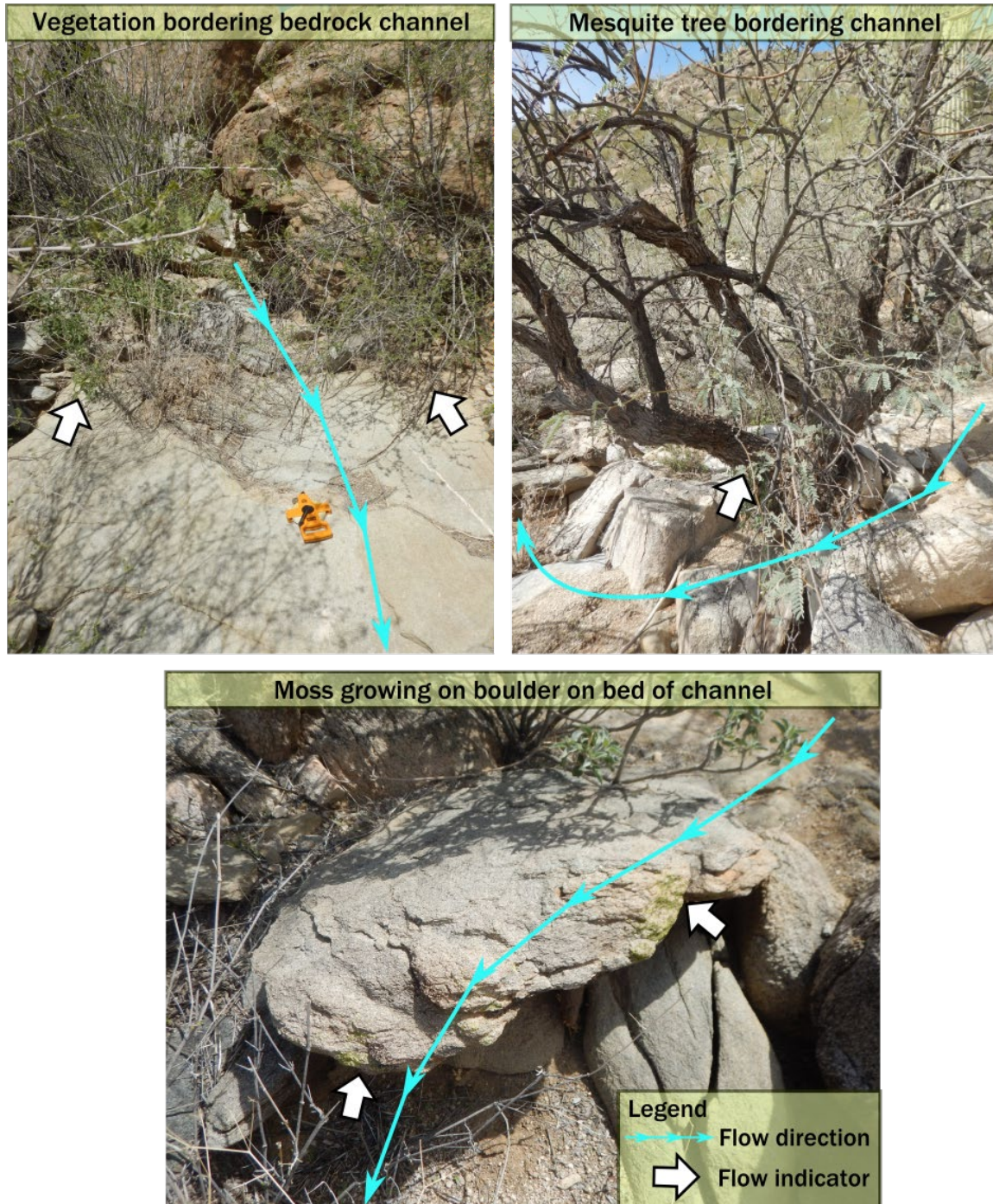


Figure 28. Flow direction indicators in different environments.



Also, the direction of flowing water can be determined from how organic litter is arranged (i.e., orientation of leaves moved by flowing water). Lastly, organic-litter accumulations can also indicate the level or stage the flow reached during the flooding event. For example, in Figure 28, a small stream in Tennessee has cleared the leaf litter, exposing the gravel-sized sediment on the bed of the channel; and further, the streamflow has forced the leaves to accumulate against the small tree (blue pencil for scale). Pieces of organic litter can also be displaced and organized by sheet flow, which is described later in this document as a type of runoff that occurs on hillslopes. Differentiating between organic indicators of streamflow and sheetflow may be difficult and will likely require additional indicators to determine the flow type (e.g., visible organization of sediment or defined channel banks indicate streamflow).

3.1.1.2 Development of banks and bed

The stream-channel banks can be defined by (a) a visible break in slope on one or both sides of the channel and (b) distinct differences in vegetation and sediment characteristics on the stream-channel banks compared to the channel bed. Stream-channel banks can be challenging to identify at the upper extent, and multiple lines of evidence are likely necessary to identify a stream channel across different landscapes. A visible break in slope often occurs both at the bottom of the bank and the top of the bank. The breaks are the transitions between a flatter bed surface; a steeper bank surface; and, after the top of bank, a flatter floodplain surface. In the upper extent, the height of the banks can be very small, sometimes less than a few centimeters tall; therefore, these transitions in slope can be at a small scale.

3.1.1.3 Channel morphology

The characteristics of stream channels, including the slope, width, depth, and bed grain size and grain organization (i.e., the stream-channel morphology) usually vary along a stream channel. It is helpful to link stream-channel characteristics with defined stream morphology classification types. For example, Montgomery and Buffington (1997) provide a simple stream-channel-morphology classification that provides stream-channel characteristics and the corresponding stream-channel-morphology types (Table 5). This table provides expectations of what stream characteristics are likely present in stream channels with particular slope ranges. The table also provides the likely spacing of pools, indicating sequences of morphology types that are repeated along the stream channel. Sequences, or a pattern, of morphology types (e.g., step-pool sequence) are easier to identify in the field because the shape of the stream channel and the organization of bed sediment are repeated in a pattern. Bed grain size, which the next subsection discusses further, also includes how the particles are arranged, interlocked, embedded, winnowed, or organized on the stream-channel bed (i.e., architecture of the bed) and what patterns the grains may be organized in when traveling in the downstream direction. Sediment is systematically sorted within the different stream-channel-morphology types. For example, fine sediment is found in pools, whereas steps contain larger clasts (e.g., cobbles and boulders).

Table 5. Montgomery and Buffington (1997) stream-channel-morphology classifications.
(Table reproduced from Bunte and Abt 2001. Public domain.)

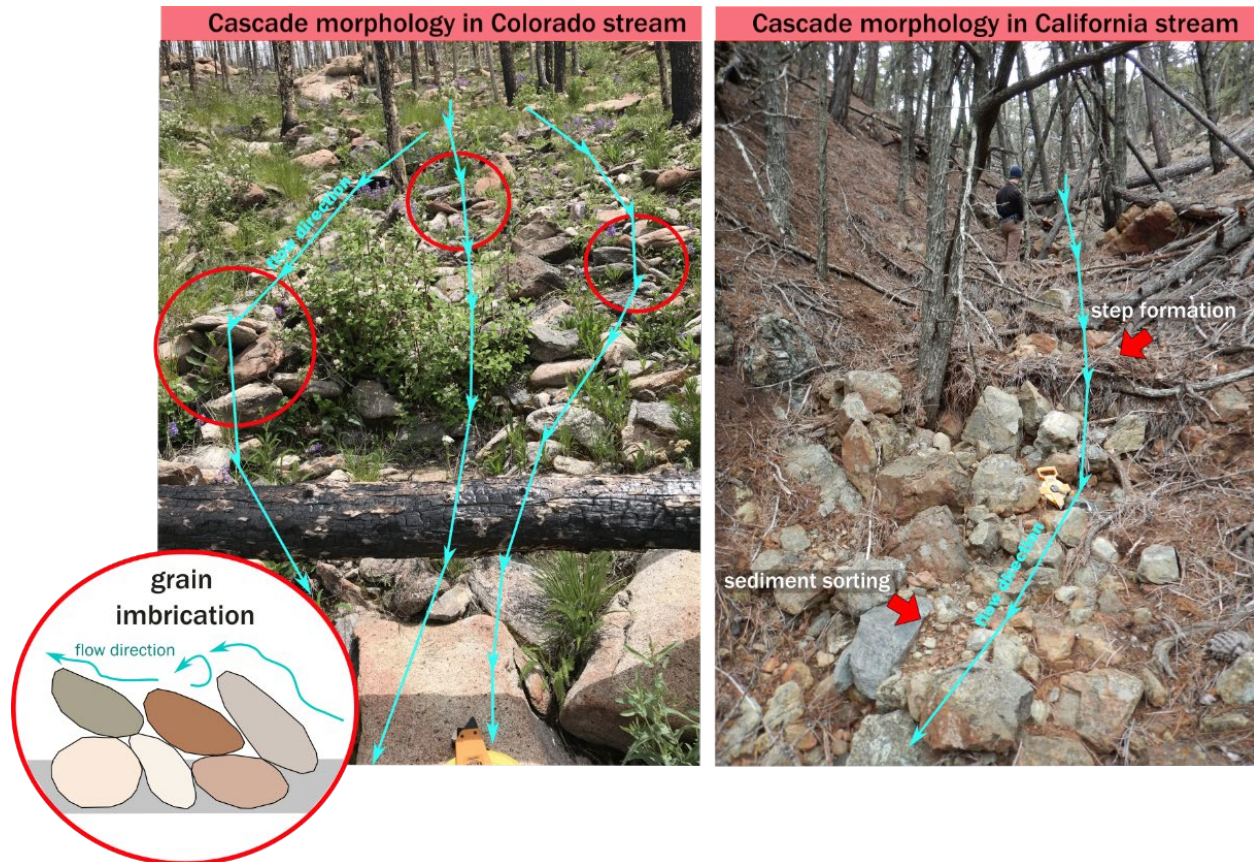
Stream Gradient, Range and Mode (m/m)	Stream Type	Typical Bed Material	Dominant Sediment Source	Dominant Sediment Storage	Typical Pool Spacing ^a
0.03–0.20 (0.08–0.20)	Cascades	Cobble-boulder	Fluvial, hillslopes, debris flows	Around-flow obstructions	<1
0.02–0.09	Step-pool	Cobble-boulder	Fluvial, hillslopes, debris flows	Bedforms	1–4
<0.02–0.05 (0.02–0.04)	Plane-bed, forced pools	Gravel-cobble	Fluvial, bank failure, debris flows	Overbank	None
<0.0001–0.03 (0.01)	Pool-riffle	Gravel	Fluvial, bank failure	Overbank, bedforms	5–7
<0.001	Dune-riffle	Sand	Fluvial, bank failure	Overbank, bedforms	5–7

Note: Values in parentheses are the modes of the observed stream gradient distribution.

^a In terms of channel widths.

Cascade morphology occurs on steep slopes (i.e., 0.03 to 0.20 m/m) in narrowly confined valleys (Montgomery and Buffington 1997). Therefore, the channel has less floodplain area and is less likely to migrate laterally onto its floodplain because it is confined by bedrock on one or both sides of its channel. Flow is characterized as continuous tumbling flow around individual large clasts. Therefore, cascades have multiple paths of flowing water. If small pools exist, they do not span the width of the channel. Again, in the Colorado stream in Figure 28, the flattened grass around the stream-channel sediment on such a steep slope is evidence for cascading flow. Cascades have high-energy flows that can move boulders and cobbles on top of each other, pointing in the direction of flow (i.e., imbricated grains; Figure 29). Grain imbrication can occur in different stream-channel-morphology types but is particularly evident in cascade streams where cobbles and boulders move on top of grains downstream; and over time these large, perched grains create clusters or small steps within the cascade (Figure 29). The presence of vegetation and the sediment rock type can cause differences in how cascades appear in the field. For example, in Figure 29, vegetation has grown between individual flat-shaped grains in the cascade in the Upper Buckhorn Creek watershed in Colorado, indicating a more persistent cascade over time. In contrast, the grains are less imbricated and rounded in the nonperennial stream in California, but sediment sorting and step formation are present (Figure 29).

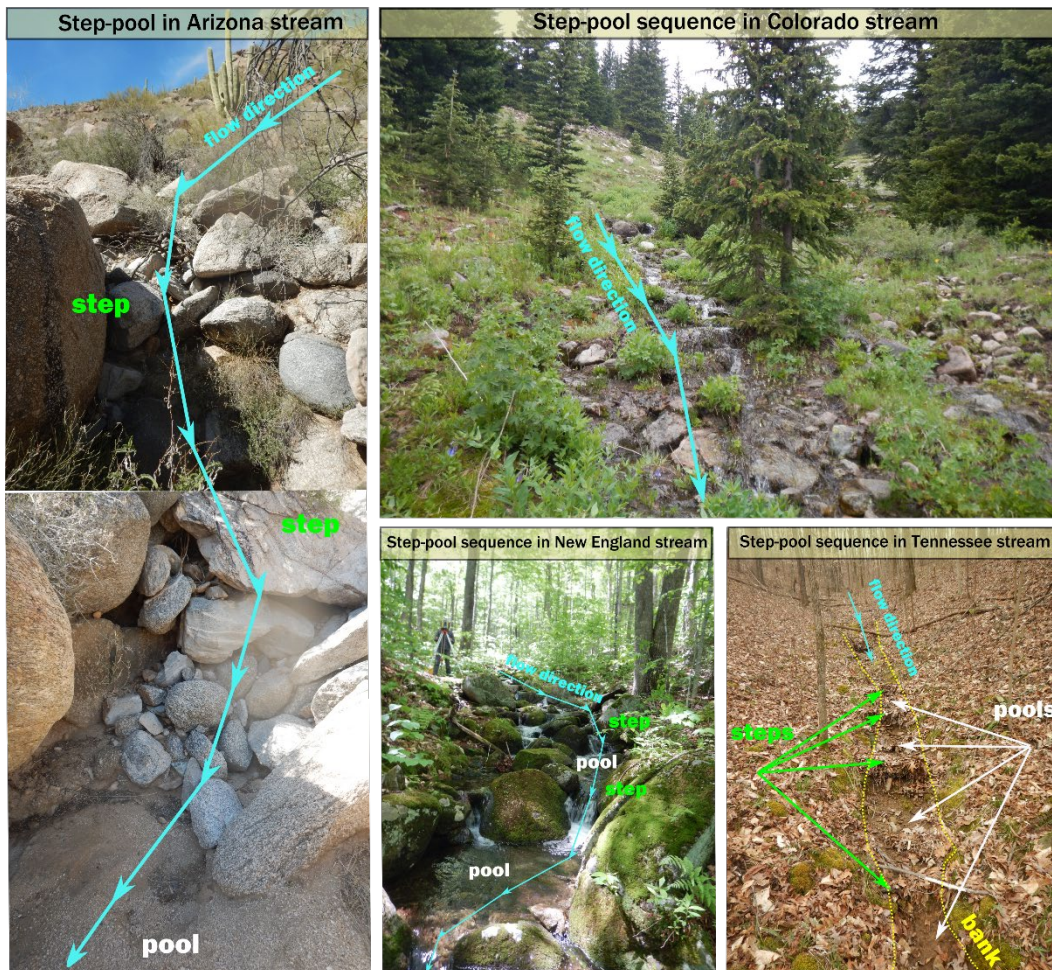
Figure 29. Cascade stream-channel morphology in a vegetated, nonperennial stream in the Upper Buckhorn Creek Watershed in Colorado and in an unvegetated, nonperennial stream in California. The Colorado stream has visible imbricated grains, showing the downstream flow direction. The *red circles* indicate imbrication.



Step-pool morphology contains shallower slopes than cascades (i.e., 0.02 to 0.09 m/m) and more-defined steps in the longitudinal direction but persists in laterally confined valleys like cascades (Montgomery and Buffington 1997). Usually step-pools are found in steep mountain stream channels that have larger cobble- and boulder-sized grains; but smaller-sized step-pools can form in steep, sandy channels (Montgomery and Buffington 1997). The steps also span the entire channel in the lateral direction. The steps and pools have distinctive sediment morphology and size differences, with steps having larger-sized clasts clustered together in a convex form and pools having fine-grained sediment in a concave form. There are many variations of step-pools, including the spacing of pools along the reach. The pool spacing in step-pool channels is approximately one to four channel widths (Grant, Swanson, and Wolman 1990). The stream-channel segment may only have a few large step-pools, or there may be many sequences of small step-pools. For example, Figure 30 shows a large step-

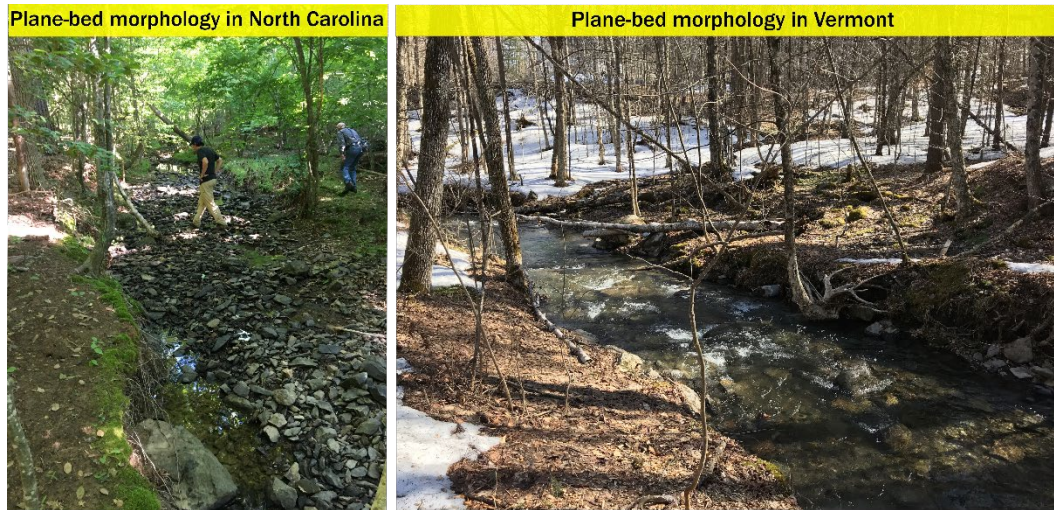
pool in a nonperennial stream in Arizona with a coarse-grained step containing large cobbles and boulders. Below the step is a large pool with fine sand and small gravels. The steps can also contain organic matter, including wood, leaf litter, and debris as seen in the small step-pool sequence in Tennessee in Figure 30. In-stream wood can also force a step-pool morphology at lower slopes than are necessarily expected (Grant, Swanson, and Wolman 1990).

Figure 30. Step-pool stream-channel morphology in arid and humid environments.



Plane-bed stream-channel morphology (Figure 31) occurs on moderate slopes with gravel and cobble-bed sediment. The cross-sectional shape of a plane-bed stream channel is rectangular and flume-like (i.e., constant width and depth). The bed grain size is also distinctly uniform across and down the bed, with some clusters of grains that form localized patches of turbulent flow.

Figure 31. Plane-bed morphology in North Carolina and Vermont.

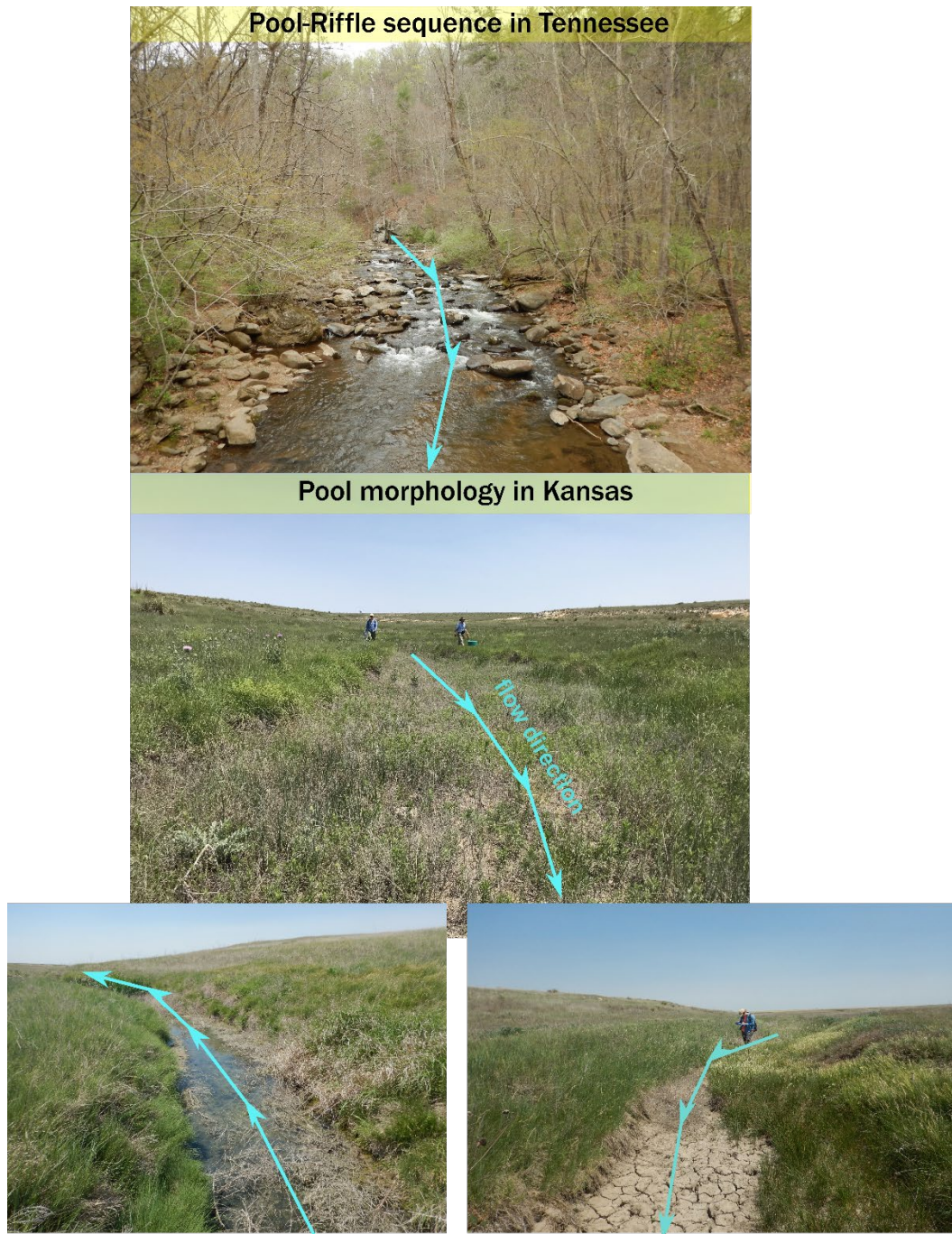


Pool and pool-riffle stream-channel morphology occur on streams with low slopes. Pools have a concave shape and generally contain smaller grain sizes. The examples of large pools in the Kansas stream in Figure 32 show distinctive changes in vegetation from a large pool. Mud cracks are often present in a nonperennial stream channel with pool morphology (e.g., Kansas stream in Figure 32). There are also pools that are forced by objects that protrude into the stream channel, like large pieces of wood or bedrock. The streamflow scours out bed sediment around these objects and forms forced pools. Pool-riffle stream-channel morphology (e.g., Tennessee stream in Figure 32) alternates between concave-shaped pools with finer sediment and calmer streamflow and steeper riffles that have larger-sized sediment and more turbulent flow.

Although the Montgomery and Buffington (1997) stream-channel-morphology types provide a basic framework, it is worth noting that many variations of these basic stream-channel morphology types exist, especially across landscapes with lower slopes. For example, in a landscape with lower slopes, even the headwater streams could have only a pool-riffle morphology without cascade, step-pool, or plane-bed stream-channel-morphology types. There are other bedform features at lower slopes that can be similar to a pool-riffle morphology but in much finer-grained material. For instance, streams flowing through silt and clay may form more of a pool-run morphology, rather than a distinct riffle. The example from Kansas in Figure 32 is closer to this channel type. Streams flowing through

fine-grained material such as sand may form more of a dune-ripple morphology, where the stream forms dunes or ripples on the channel bed. Pools can also be found in this channel type.

Figure 32. Pool-riffle and pool morphology in Tennessee and Kansas streams.



Other common channel forms, such as a meandering planform (i.e., view from above rather than in cross section) can be evident as well in headwater streams. Meandering is a distinct stream feature and therefore can assist in identifying where fluvial processes are still dominating. Headwater streams with lower slopes that are located within unconfined valleys are able to form bends or meanders in the alluvium. As streamflow enters the bend, forces erode the outside of the bend, forming a cut bank; and the eroded bank sediment is transported to the inside of the bend, forming a bar where the water streamflow speed is slower. The development of channel bars is another distinct channel feature. This is a form of sediment sorting between the faster-flowing, deeper part of the channel and the area where water is depositing sediment because it is flowing slowly.

3.1.2 Sediment indicators

3.1.2.1 *Bed sediment*

Stream-channel-bed sediment can vary in grain size from mud to sand to gravel to cobble- to boulder-sized grains. Stream-channel-bed sediment can also be a mix of grain sizes, or the stream channel can be lined with bedrock (Figure 33). Bed grain size depends on stream-channel gradient and also the type of sediment that is available to transport. In headwater mountain streams, the grain size is predominantly larger-sized grains (i.e., gravel, cobbles, and boulders) sourced from debris flows, whereas flat headwater streams with limestone bedrock contain fine clay and silt grains on the stream bed. Conversely, in an arid stream in Arizona, for example, the channel bed likely consists of sand.

A common characteristic of bed-sediment texture is the rounded or smoothed surface of the bedrock-lined channel or the bed sediment. Rounded and smoothed characteristics on the bed of a stream channel indicate the transport of water and sediment. There are different types of sediment transport on the bed of a stream that result in rounding of the stream-channel-bed sediment. Suspended-sediment transport occurs when abundant fine-grained sediment supplied to the stream channel travels in suspension during a high flow event. The suspended sediment can erode bedrock, leaving smooth, scoured surfaces or potholes in bedrock (Figure 34, e.g., Hawaii and Idaho streams). Bedload transport occurs when individual particles are transported on the bed of a stream through bouncing or sliding. Over time, this type of sediment transport results in rounding of large-sized grains along the bed of a stream channel during a

flood. For example, Figure 34 shows stream channels in Hawaii and Kentucky with rounded boulder-bedded sediment.

Figure 33. Stream-channel-bed sediment types, including a bedrock stream channel. The streams are ordered from high gradients (e.g., large-cobble/small-boulder-bedded channel in California) to low gradients (e.g., fine-sediment/clay-bedded channel in Kansas).



Figure 34. Examples of rounding and scouring of bed sediment by flowing water.

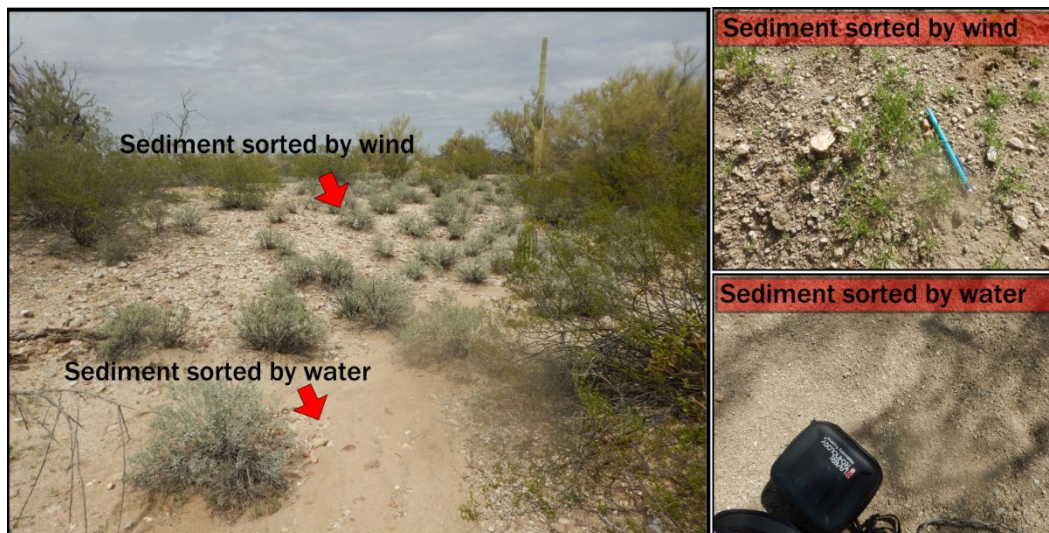


3.1.2.2 Sediment sorting on stream-channel bed

An additional characteristic of bed sediment is the sorting of the grains on the bed of the channel. Stream-channel-bed sediment varies in size and texture from the stream channel to the surrounding floodplain or hillslope. Flowing water rounds bed sediment and sorts it into patches of like-sized grains. There are visible differences in the texture of sediment moved and

sorted in the stream channel compared to sediment transported and re-worked by wind adjacent to the stream channel on the banks, floodplain, or hillslope (Figure 35). For example, in Figure 35, there is a distinct difference in the coarser, poorly sorted (i.e., range of sediment sizes) sediment on the adjacent hillslope that was sorted by wind and the fine, well-sorted (i.e., grains are the same size) sand in the stream-channel bed that was sorted by water. Another characteristic of sediment sorted by wind in an arid landscape is the winnowing or separation of fine grains from the larger grains as seen in Figure 35. The coarse grains protrude up from the surface, remaining in place as the fine grains are transported away by wind.

Figure 35. Differences in sorting and appearance of sediment sorted by wind versus water in Arizona.



3.1.2.3 Bank versus bed sediment

The bank sediment along a channel can be made up of a variety of material, depending on the landscape of the stream. Bank sediment can be composed of alluvium, which is material that was previously deposited by the stream, or it can be composed of exposed bedrock. Alluvium itself has a variety of characteristics, depending on if the material was previously deposited in a floodplain or on the channel bed. Finer-grained sediment in the bank can indicate an old floodplain deposit versus coarse grain that may have been an old channel bed. At the upper extent, the stream could be flowing through old debris flows, landslides, material that is part of an alluvial fan, or sedimentary layers that were deposited in the very distant past. Therefore, bank material may appear different from the bed material because it was formed and deposited from different landscape processes.

It is the source material for the sediment on the channel bed, but that sediment may appear different because it has now been sorted by flowing water. For instance, if there is a mixture of fine and coarse-grained sediment on the channel bank, then the coarse-grained material may be the sediment that is left behind on the channel bed.

Figure 36 shows additional examples comparing bed and bank sediment texture and sediment sorting for different landscapes. In humid, mountainous landscapes, the difference between sediment sorted by water and sediment on the banks can be more difficult to identify than in arid landscapes because there is more-compacted soil. In the example from the Upper Buckhorn Creek Watershed, the streamflow cleared a small path in the vegetation and sorted fine-grained sediment on the stream-channel bed in Colorado.

Figure 36. Examples of sediment sorting on a hillslope versus by water (Colorado stream) and comparisons of bank versus bed sediment (Kentucky and Arizona streams).

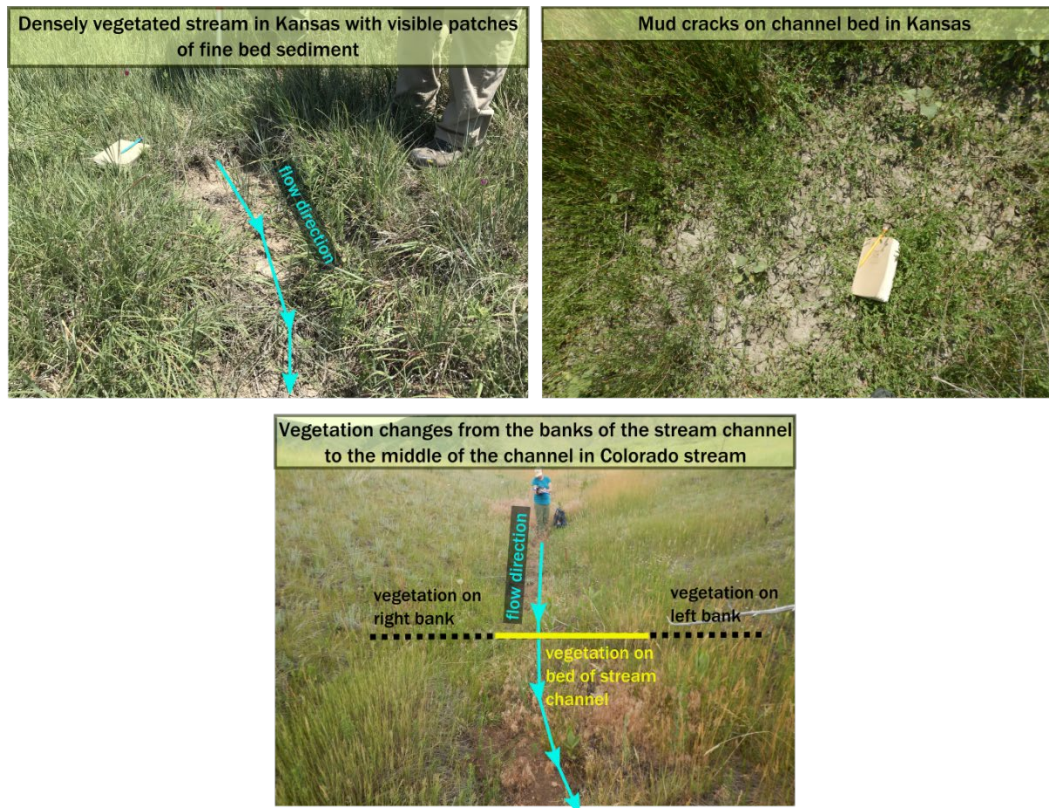


In comparison, the hillslope sediment associated with that stream has a coarser grain size, has been transported by wind and gravity, and has a more compacted texture with darker-brown sediment color. In the stream from Kentucky, the channel-bed sediment is lighter in color than the dark, organic-rich soil that is located outside of the channel. Lastly, Figure 36 shows an example of patchy vegetation established on the banks of the Arizona stream, and there is sorting of the sand in the adjacent channel bed. The color of the bank sediment is also slightly darker and browner than the sandy channel bed.

3.1.3 Vegetation indicators

Vegetation can be an indicator of channel location. A change in vegetation can include one or a combination of changes in species, density, and age. There can be vegetation changes moving perpendicularly to flow across the channel from the channel banks to the channel bed. In humid regions with abundant grass cover, defined banks may not be visible because they are completely covered with vegetation or the gradient of the bank is too gradual, but the channel bed may be visible as patches of exposed sediment or mud (Figure 37). The distribution of vegetation from the channel bed to banks may vary and provide an indicator that flowing water is present where more herbaceous vegetation is growing versus more woody vegetation on the banks or adjacent floodplain. For example, in Figure 26 (e.g., “Changes in vegetation type and density”) there is dense, hydrophytic, herbaceous vegetation directly adjacent to either side of the stream channel. The stream channel itself is clear of dense vegetation, and the hillslope has less-dense vegetation of a different type. Cracks on the surface of the dry stream bed, known as mud cracks, indicate that the channel bed was saturated in the recent past and dried out quickly, causing the mud to expand and then crack (Figure 37).

Figure 37. Channel indicators where there is lack of defined banks: dense vegetation in the channel/floodplain and shallow slopes (e.g., Kansas and Colorado).

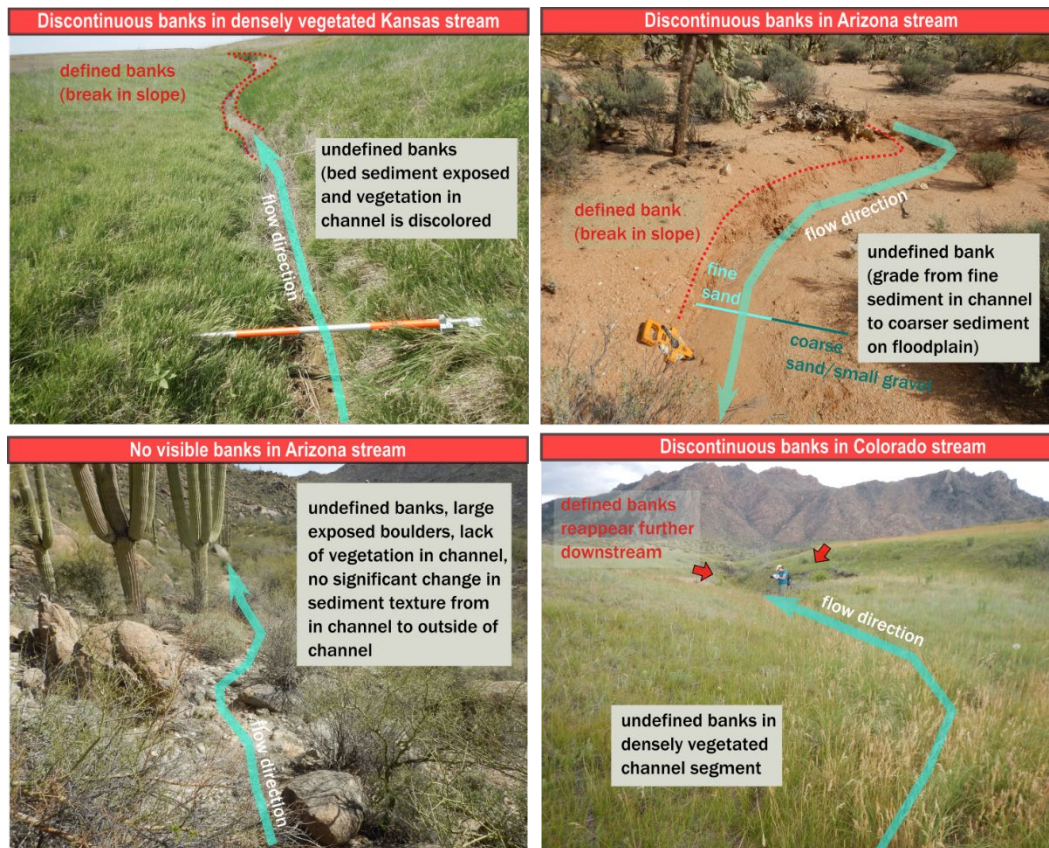


3.2 Variation in stream-channel indicators

Channel banks can be discontinuous along the stream channel and therefore are difficult to identify across multiple landscapes. Using additional bank indicators in the stream (e.g., differences in color of vegetation in the channel versus vegetation on the floodplain or mud cracks on the stream bed), the investigator can follow the channel until banks are identified again farther upstream or downstream (Figure 38). There also may be changes in sediment texture, including sediment grain size and sorting of the grains from the sediment in the channel to outside of the channel. In arid landscapes that may lack vegetation indicators, differences in the texture of sediment located in the channel versus the texture of sediment located in areas outside of the channel are helpful indicators of the stream channel in the absence of well-defined, continuous banks (Figure 38). Or, especially in arid environments, there may be no visible banks for long stream segments (Figure 38). In arid environments, there may be only subtle indicators of the lack of vegetation in the channel. Lastly, in densely vegetated landscapes, there may be no indicators of the stream channel (e.g., stream banks, channel-bed sediment, or change in vegetation density

or color) for long segments until banks emerge abruptly either upstream or downstream. For example, in Gordon Creek Watershed in Colorado, the channel is discontinuous for several hundred meters before additional headcuts and banks that are defined by large breaks in slope indicate a channel. In the Gordon Creek example, the sequence of emergent banks to dense grass cover to emergent banks occurs along the majority of the stream channel.

Figure 38. Examples of discontinuous stream-channel banks in humid and arid landscapes.

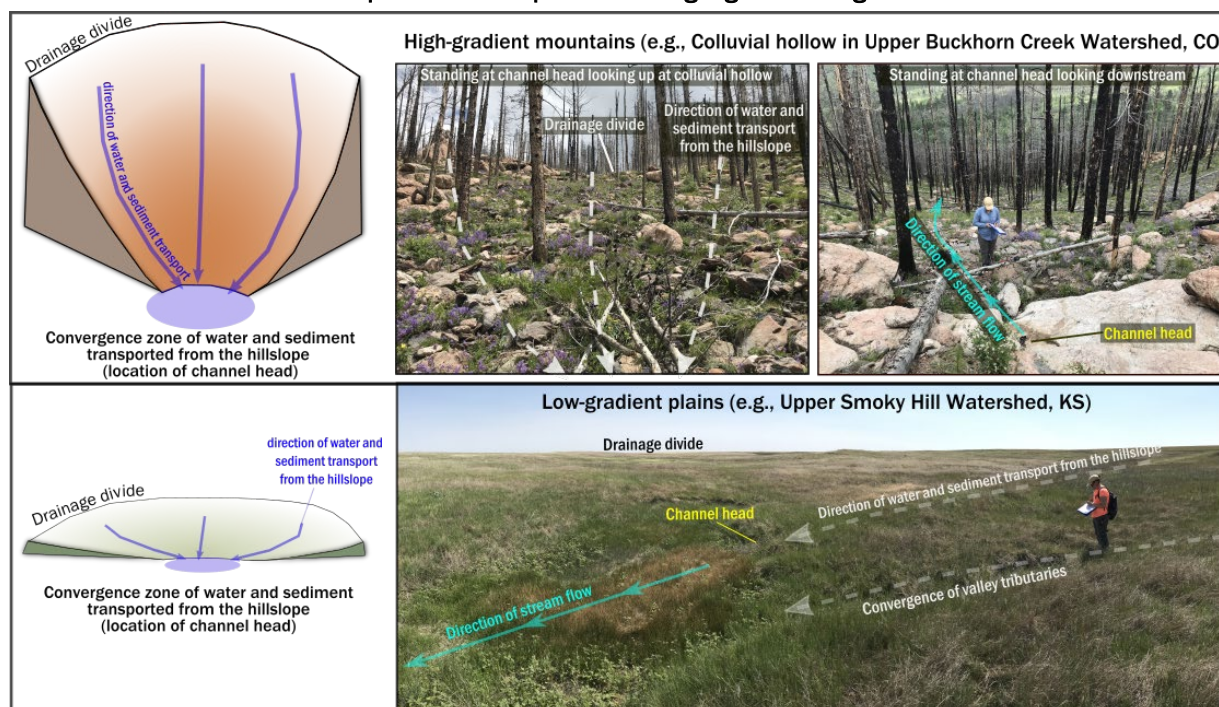


3.3 Overview of identifying channel-head characteristics

Channel-head initiation depends on how surface and subsurface runoff from the hillslope converges into a flow path of concentrated water and sediment to initiate a stream channel (Figure 39). Walking up the stream channel, the field investigator will be looking for a noticeable terminus of the stream channel marked by one or more of the following: (a) a single break in slope (i.e., headcut) or a sequence of headcuts, (b) changes in sediment across the headcut, (c) transition in vegetation across the headcut, and (d) additional indicators of the dominant runoff type (e.g., springs). Dietrich and Dunne (1993) and other authors that have described channel

heads lack descriptions about (a) low-gradient channel heads and (b) how channel heads can vary in the longitudinal direction across different regions. This is problematic because field investigations are often required in headwater streams in low-gradient areas.

Figure 39. Schematic of the transport of water and sediment to a convergence zone where the stream channel starts. The two examples show a difference in the runoff paths in landscapes with hillslopes containing high and low gradients.



The stream-channel-to-hillslope transition can be abrupt or gradual and can contain segments of stream channel that are discontinuous (e.g., Figure 38). In other words, without traversing the stream channel in the longitudinal direction, the field investigator may misidentify these starts and stops of the stream channel. Patton and Schumm (1981) describe a mechanism for the initiation and subsequent termination of a stream channel in sequence that helps explain the starting and stopping of the stream channel. The stream channel initiates at a headcut because of erosion, and then the eroded sediment is transported downslope, filling in the valley and subsequently terminating the stream channel. The location and frequency of the starting and stopping points along the stream channel may also be caused by the underlying geology. For example, in an area underlain by limestone geology, streamflow can appear from and disappear to the subsurface at small headcuts. Additionally, the land-use history of the watershed can affect the channel-head location. For example, forest fires

weaken the structure of underlying soils, which can lead to an increased abundance of erosional headcuts or the upslope migration of headcuts (E. Wohl 2013). The concept of a discontinuous transition from the stream channel to the hillslope and discontinuous-stream-channel segments even downstream of the channel head is extremely important when accurately and consistently identifying the hillslope-to-stream-channel transition in the field.

3.3.1 Geomorphic indicators

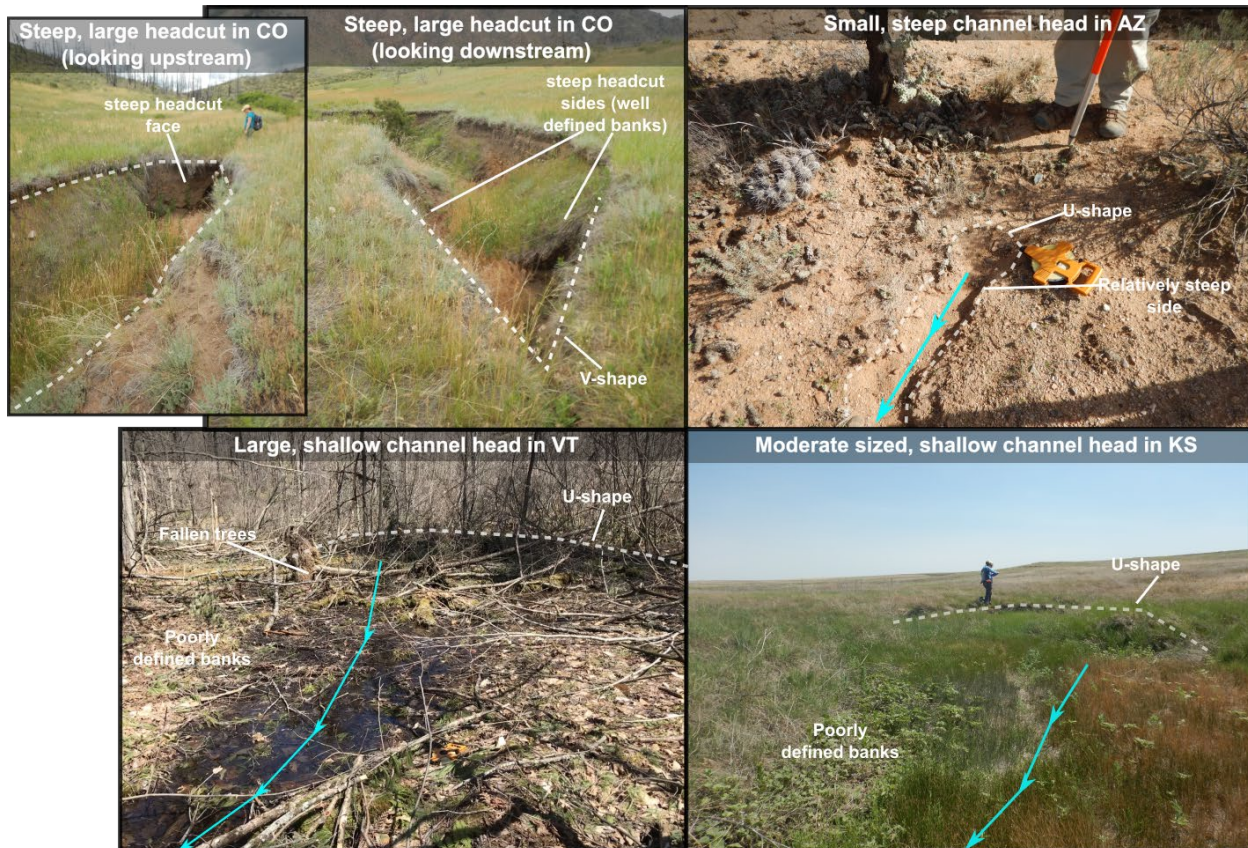
The most common characteristic of a channel head is a noticeable break in slope, where runoff is accumulating in the convergence zone and causing sediment displacement and erosion. Depending on the underlying soil and sediment type, infiltration excess overland flow can cause areas of highly concentrated, localized flow that can form a channel head with a visible break in slope (e.g., Figure 40, Arizona example). Two common types of channel-head slope breaks are abrupt, narrow, and steep (e.g., meters deep; Figure 40, Colorado example) and shallow and wide (e.g., the headcut is shaped like an amphitheater; Figure 40, Vermont and Kansas examples). In low-gradient, vegetated landscapes with subsurface stormflow and saturation excess overland flow, the channel head is more likely to contain a wider, shallower amphitheater-shaped channel-head morphology because of the low gradient (e.g., Figure 40, Vermont and Kansas examples). Headcuts can have up to three visible slope breaks that form a U- or V-shaped channel head with one break in slope at the head of the channel and two breaks in slope on either side of the channel head that can also form the banks of the stream channel.

3.3.2 Sediment indicators

In addition to the noticeable break in slope of a channel head, the morphology, or shape, of the channel head depends on the underlying sediment and soil type. Underlying soils and sediment that contain higher clay content are more likely to sustain vertical, cleanly exposed faces (e.g., Figure 40, Colorado example). Channel heads can also undergo headward migration where the channel head erodes in the upslope direction over time. In areas underlain by clay-rich soil and sediment, as the channel migrates upslope, large cohesive blocks of sediment can detach from the headcut and are deposited just downstream of the headcut (e.g., Figure 40, Colorado example). The sediment that is detached and deposited downstream from the channel head is often colonized by vegetation, making it difficult

to identify headward erosion of the channel head in the field. Even with dense vegetation, there are still visible rough patches with some sediment exposed and a visible break in slope at the channel head (e.g., Figure 40, Colorado and Kansas examples). In areas with sandy soils and less clay content, the channel-head shape can be smaller and less defined because sand is not as cohesive and the sides of the channel head are more likely to collapse or become eroded (e.g., Figure 40, Arizona example). Although lower-gradient landscapes can contain shallower and wider channel-head morphology, if the underlying sediment is clay rich, there is often some definition on the channel head that can be identified in the field (e.g., Figure 40, Vermont and Kansas examples).

Figure 40. Break in slope of channel-head wall and sides.



3.3.3 Vegetation indicators

When investigating a densely vegetated channel head in the field, it may be easier to identify the channel-head location from prominent changes in vegetation rather than from a noticeable break in slope or sedimentological indicators. When investigating the channel head in the field, the transition in vegetation can be identified walking in a line from the stream

channel, over the channel head, and up the hillslope (i.e., colluvial hollow) or from either side of the channel head (i.e., stream banks), lateral to the hillslopes (Figure 41). The change in vegetation color, density, and species across the stream-channel-to-hillslope transition is controlled by the proximity to converging flow. Generally, upslope of the channel head and on the surrounding hillslopes there are drier areas with different vegetation species that are less dense. Usually, near the channel head, there is a localized area that is currently or previously wet that contains denser vegetation with different species than upslope. Then, further downstream of the channel head, there is different vegetation located in the channel and on the channel banks that varies in density. Channel heads in arid environments often lack characteristics associated with vegetation because the vegetation may be present in only isolated patches, may be less present, or both. David et al. provide additional detailed examples of the transition in vegetation from the channel to the adjacent floodplain and hillslope across different landscapes throughout the U.S.⁴

Walking up the stream channel, the field investigator will eventually reach the beginning of the stream channel. Depending on the region of the country, vegetation may be growing on both the bed and banks. This type of vegetation located on the stream bed undergoes nonperennial streamflow conditions, which include shorter periods of full inundation and longer dry periods. As a result, the vegetation growing on the stream bed may be a different type of vegetation than the surrounding bank and hillslope vegetation, and the density of the surrounding vegetation can vary. Lower density of vegetation on the bed of the stream channel can also allow the field investigator to see the stream-channel-bed sediment (e.g., mud cracks). Figure 41 shows an example of vegetation growing on both the bed and over the channel head on a stream in the plains in Kansas. A distinct transition in vegetation species, color, and density occurs between the bed of the channel and up to the top of the channel head.

⁴ G. C. L. David, K. M. Fritz, T.-L. Nadeau, B. J. Topping, A. O. Allen, S. Kichefski, P. H. Trier, L. A. James, E. Wohl, and D. Hamill, *National Ordinary High Water Mark Field Delineation Manual for Rivers and Streams* (Hanover, NH: U.S. Army Engineer Research and Development Center, forthcoming).

As the field investigator looks upslope to the banks on all three sides of the channel head (i.e., face and left and right sides of the channel head), there will likely be changes in the vegetation on the banks compared to the vegetation on the surrounding hillslopes (e.g., Figure 41). Bank vegetation can often be denser and greener than the vegetation on the surrounding hillslopes. The brighter-green color is caused by a higher local abundance of water coming directly from the convergence zone. Upslope of the channel head, the vegetation can have similar densities or may be less dense. The hillslope vegetation can be a different color or type than the bank vegetation because the hillslope vegetation has less access to water and the soil is dryer. For example, in Figure 41, the bank vegetation and hillslope vegetation are different species of grasses though they contain similar densities. However, the grass on the hillslopes is a pale-brown color and appears slightly less dense because it is partially dried out because it is farther away from the water source.

There can be vegetation changes at the upper extent of a stream channel that are less common across landscapes, but these vegetation changes can inform the field investigator that the channel head is close. An example of these vegetation indicators are discontinuous, linear patches or islands of green vegetation that extend in length nearing a larger zone of flow convergence (e.g., Figure 42). These linear segments of vegetation can be associated with karst topography where the concentrated flow moves from near surface to subterranean to the surface. The movement of concentrated flowing water can leave these distinct patterns of vegetation. These distinctive patterns of vegetation can guide the field investigator to the nearest zone of flow convergence and provide an indicator that hillslope processes will dominate upslope of these vegetated islands.

Figure 41. Example of the noticeable transition in vegetation (e.g., color, type, and density) from the stream-channel bed to the surrounding hillslopes in a nonperennial stream in Kansas.

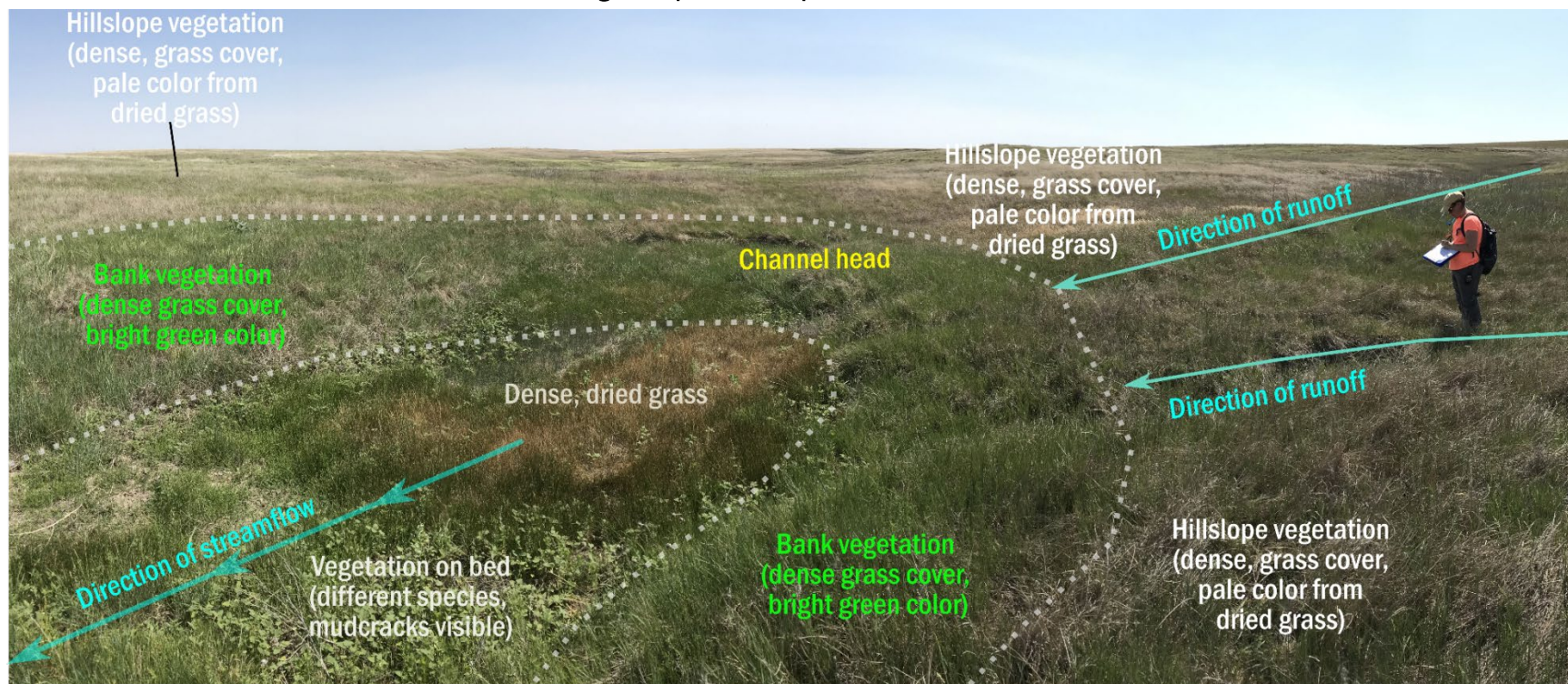
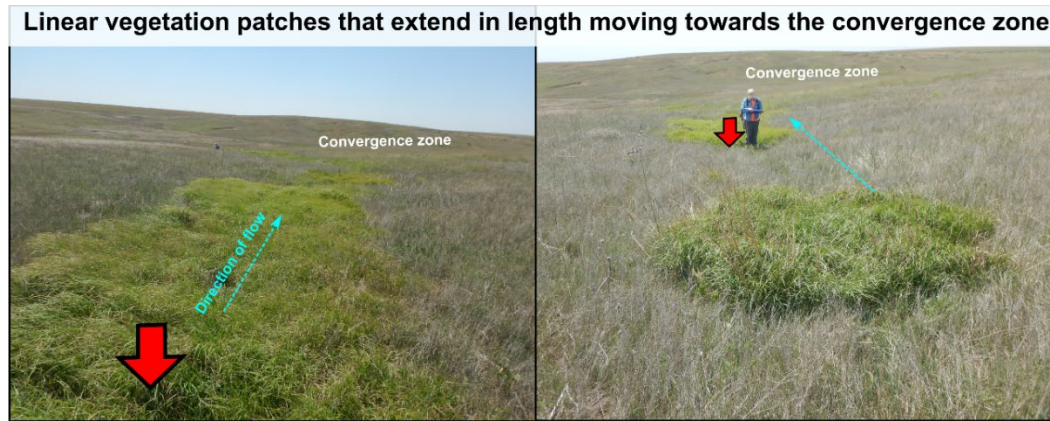


Figure 42. Variation of the upper extent of a stream channel seen through distinct, linear vegetation patches in a stream in Kansas. This distinct vegetation pattern indicates that the channel head is close and that upslope of the vegetated islands, hillslope processes are likely to predominate. The *red arrows* indicate the same position in both photos.



3.3.4 Additional channel-head indicators

When following the stream channel to the channel head, subsurface runoff can be flowing out of springs, seeps, or macropores at the channel head (Figure 43). In mountainous landscapes, springs usually occur where there is an open pathway through a fracture in the underlying bedrock. The groundwater table can also be perched on a hillslope with water flowing from an opening in bedrock (i.e., bedrock seep) that is buttressed against the groundwater table. Springs can demark the channel head or occur farther downstream (Figure 43). Similar to sequential headcuts, there can be multiple springs or bedrock seeps before reaching the channel head. It is important for the field investigator to continue walking in a linear path upslope of the first visible spring to determine if there is another spring upslope that is the actual channel head.

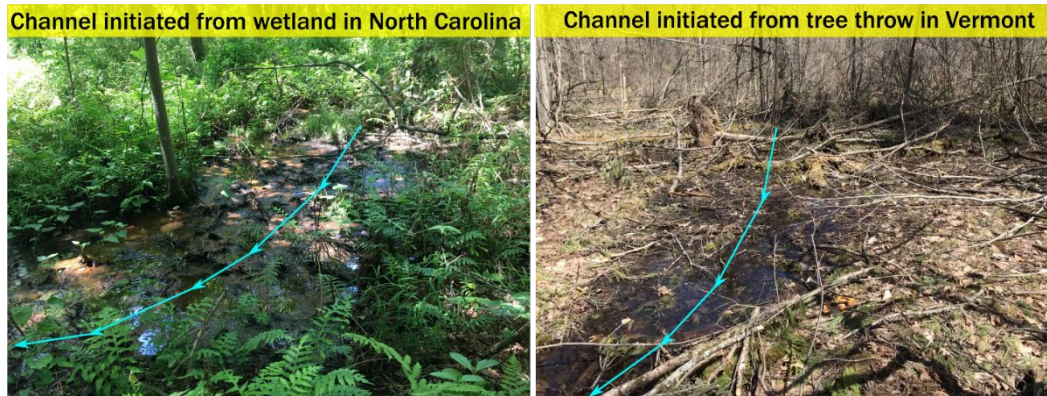
Bedrock seeps do not contain dense vegetation because there are not developed soils covering the vertical faces of the bedrock. Even in arid environments, bedrock seeps lack abundant, dense vegetation. If vegetation is present on a bedrock seep in an arid environment, there is a striking contrast in color between the dull gray-yellow bedrock and the bright-green vegetation (e.g., Figure 27, “Vegetation bordering bedrock channel”). In wetter environments, springs and macropores are surrounded by abundant, lush vegetation that dissipates moving away from the spring. The opening around the spring can have some detritus that is hanging over the face of the spring opening (e.g., Figure 43, “Macropore with flowing water” and “Spring marking channel heads”).

Figure 43. Examples of springs, seeps, and macropores at a channel head in Colorado.



The channel head can also initiate from a flat area or depression of ponded water. The ponded water can develop and persist from a shallow groundwater table, from saturation excess overland flow, or both (Figure 44). This type of channel head is often located in humid environments. Depressions in the ground surface can be created by toppled trees, which can expose the groundwater table. The area of the ponded water associated with these types of channel heads is likely to change with seasonal fluctuations. For example, in the Northeast region, ponded areas located around the channel head may be smaller in the summer than in the spring or fall. It is important to recognize in the field that a stream channel can initiate from a wetland; or the stream channel, located farther downstream from the channel head, may have segments where the stream channel passes through a wetland.

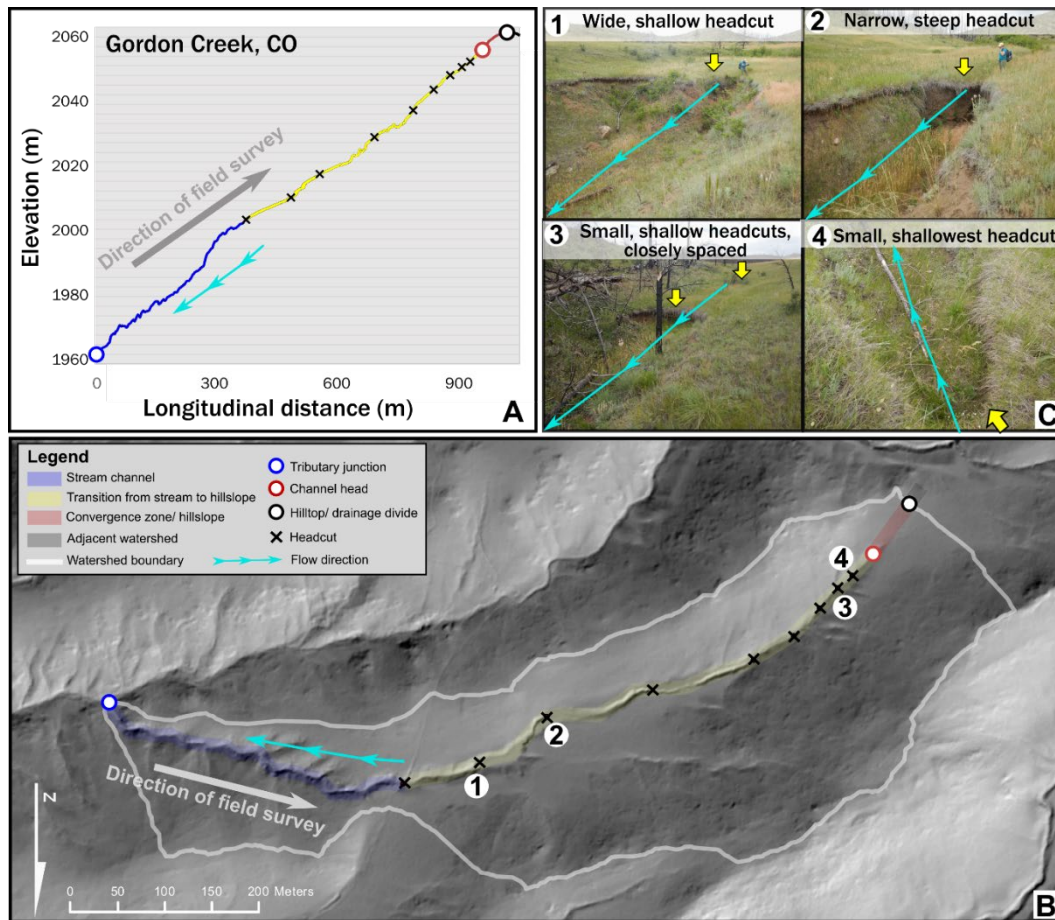
Figure 44. Examples of channel-head initiation from a wetland that is caused by a shallow groundwater table or saturation excess overland flow, or both, in the Piedmont regions of North Carolina and Vermont.



3.4 Variation in channel-head indicators

Particularly in low-gradient landscapes, there can also be a sequence of multiple small or large headcuts that span a linear distance of several hundred meters toward the convergence zone or the hillslope. As the field investigator traverses up the stream channel, it is important, if access is permitted, to continue walking past the first visible headcut to avoid falsely identifying the channel head. If access is not possible, then the resources described in chapter 2 can be used to further investigate landscape features remotely. It is recommended to approximately measure the distance or count the number of steps, or both, between successional headcuts because the density of headcuts along the traverse can increase toward the actual channel head (Figure 45A and B). Additionally, the first headcut that is encountered in the field can be wide and deep, but there may be successional smaller or narrower headcuts, or both, that are located upslope (Figure 45C).

Figure 45. Example of multiple sequential headcuts that are more defined (i.e., steep, relatively narrow, and deep headcut faces) toward the stream channel and less defined (i.e., shallow, relatively wide) at the actual channel head. The elevation profile (A) contains the field-survey path, and the plan view map (B) shows the same field-survey path across the stream-channel-to-hillslope transition. (C) Four photographs of different shapes, sizes, and densities of headcuts found along the field-survey path.



3.5 Overview of identifying hillslope characteristics

A fundamental hillslope process is the transport of water and sediment down the hillslope to a zone of sediment and flow accumulation or convergence (Figure 39). This zone of sediment and flow accumulation is where the stream initiates from the channel head. The goal of the field investigation is to identify the channel head and the associated convergence zone. An investigation of the area upslope of the channel head is helpful because it will provide validation of predominant hillslope processes and will confirm that the channel-head location is accurate.

The physical processes that occur on a hillslope are defined as diffusive processes because the water and sediment that are transported down the

hillslope are (a) generally transported at a slower rate than the processes that occur in streams and (b) predominantly transported by the force of gravity. Diffusive processes result in common characteristics across all hillslopes, which are useful as hillslope field indicators. These common hillslope characteristics include those associated with the landscape-scale shape of the hillslope and primarily hillslope sediment indicators. A profile of a hillslope shows the downslope shape of the hillslope, whereas the planform view shows the degree of convergence of the hillslope toward the valley bottom (Figure 39). The convergence of water and sediment down a hillslope most often results in a concave-shaped profile from the top to the base of a hillslope. This depression is known as a colluvial hollow, or zero-order basin. Sediment indicators are associated with how the sediment is eroded and accumulated on the hillslope and at the base of the hillslope.

The visibility of hillslope characteristics in the field can vary across landscapes, mostly because of differences in topographic relief. Generally, landscapes with high topographic relief contain more-visible hillslope indicators compared to landscapes with low topographic relief. For example, in Figure 39, the steep slope angle in a mountainous landscape results in more-pronounced hillslope processes that are likely to have greater visibility in the field when compared to a lower-relief landscape where hillslope processes are muted because the slope is gradual. Nevertheless, in any landscape, hillslope indicators can be difficult to identify or differentiate from stream processes in the field. This section provides an overview of how to investigate hillslope indicators upslope of the channel head and convergence zone.

3.5.1 Geomorphic indicators

3.5.1.1 Convergence zone

To initially find the stream channel, the field investigator will follow the stream to the estimated channel-head location, which is also the convergence zone. The point of convergence will likely be difficult to identify in the field without the context of the surrounding topography. The topographic context is best derived from digital topographic and lidar maps or contours on a GPS that are brought into the field (see section 2.1). These maps will aid in identifying the low point or depression of the colluvial hollow. The close-up perspective of the convergence zone in the field will likely obstruct the view of the converging hillslope topography. In addition, the hillslopes may be completely forested, obstructing the underlying

convergent topography. Once the convergence zone is roughly located, the field investigator can start to search for hillslope indicators.

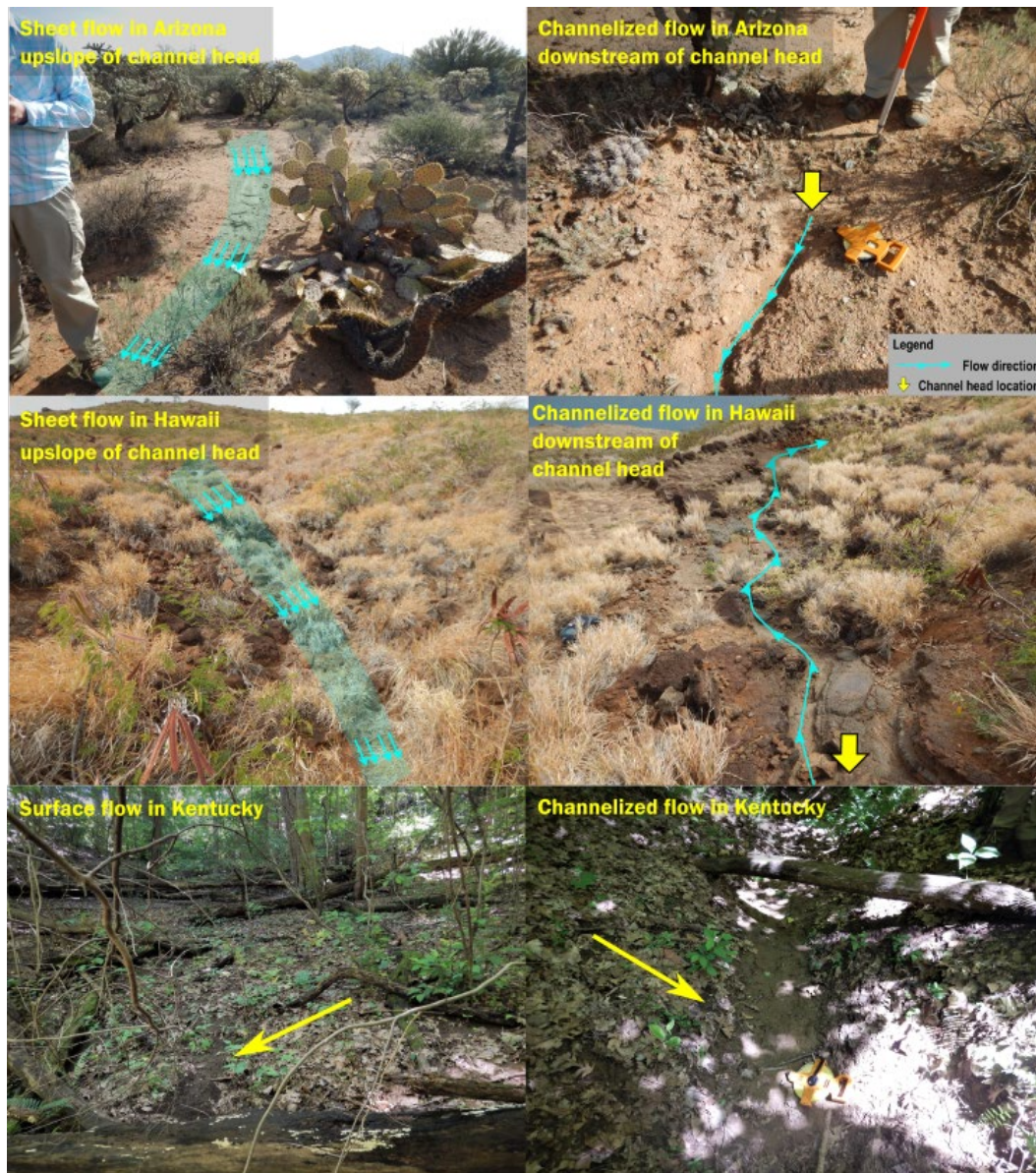
3.5.1.2 Diffusive processes

When inspecting hillslopes for the convergence zone, it can be useful to understand the common characteristics of a hillslope that has been developed by diffusive processes. The relative differences between the hillslope and channel characteristics can assist in identifying where those channel-head characteristics start. Over years to hundreds of years, significant volumes of sediment are gradually eroded and transported down the hillslope to the convergence zone through diffusive processes. These diffusive processes include rain splash, soil creep, sheetwash, and sheet flow. Rain splash occurs during rainstorms when individual rain droplets displace hillslope sediment, which is then gradually transported in the downhill direction. Rain splash is more likely to displace sediment in an arid landscape than on a densely vegetated hillslope because a large area of sediment is exposed compared to a densely vegetated area that can absorb the impact of the rain droplets. Therefore, rain splash is likely to be a visible hillslope indicator in arid environments where the sandy surface is exposed and the individual rain splash impacts can be preserved between prolonged periods without precipitation. There are multiple mechanisms for the incremental downslope creep of soil on the hillslope, including the constant freezing and thawing of the soil on the hillslope to the loosening of the soil because of bioturbation. Gravity then causes all these materials to slowly move downslope. On steep slopes in high-relief landscapes, indicators of soil creep are the bent base of the tree trunks where the tree is trying to remain growing upright while its roots are gradually forced downslope.

Sheetflow occurs during a heavy precipitation event that spreads out over the ground surface as overland flow without a preferential flow path. Sheetflow is difficult to identify in the field because it leaves subtle physical indicators that are transient. Alternatively, channelized flow leaves more permanent and persistent indicators due to the erosion of sediment by the more concentrated flow (e.g., identifiable banks and bed-sediment organization and sorting). Section 3.1 provides more details about stream-channel indicators. It is helpful to view examples of sheetflow versus channelized flow across different landscapes because these two different types of indicators can appear similar in the field. For example, Figure 46 compares sheetflow and channelized flow across three different landscapes

with different sediment and vegetation or organic-litter cover. In the Arizona example, sheetflow is visible upslope of a channel head where preferential flow paths and signs of erosion of sediment by concentrated flow are nonexistent. Similar to rain splash, indicators of sheetflow can be more visible in arid landscapes where the sediment is undisturbed for long periods between precipitation events.

Figure 46. Comparison of sheetflow and channelized flow indicators across different landscapes in Arizona, Hawaii, and Kentucky.



In the Hawaii example, it is difficult to identify sheetflow, but notice the difference in the position of the vegetation between the area with sheetflow and the channelized example. The channel is clear of vegetation, and

the exposed channel bed has sorted sediment. The Kentucky example shows water flowing from a small hill where the water has cleared organic litter but is not channelized and has not sorted the sediment. The Kentucky channel has created a clear, linear stream with banks; and the sediment on the channel bed has been organized and sorted by the flow.

3.5.1.3 *Mass movements*

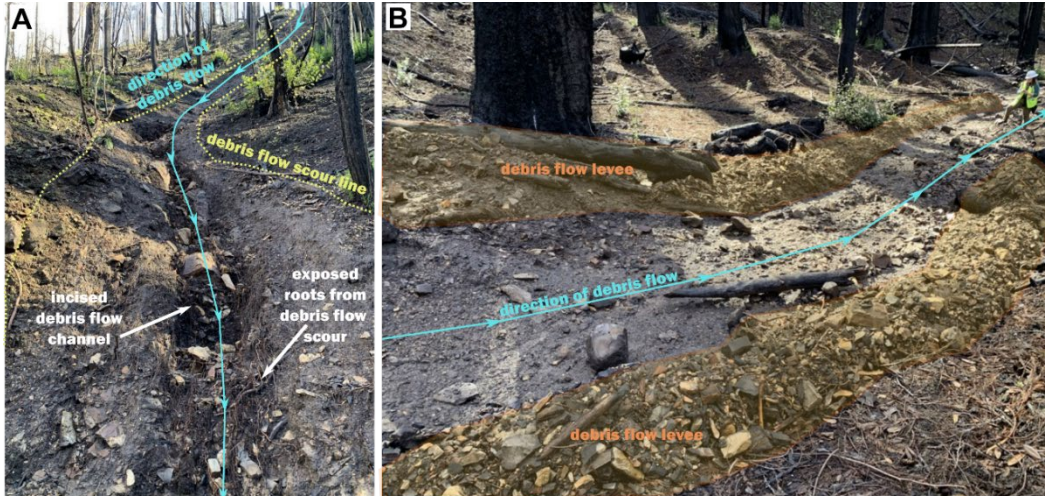
Large amounts of sediment and woody debris accumulated in the convergence zone can be displaced downslope through mass movements such as landslides, debris flows, and rockfalls. In landscapes with moderate to high gradients, mass movement can occur at or near the beginning of the stream channel, which makes it challenging to differentiate between channels formed by mass movement (e.g., channels formed by debris flows) and stream processes. Debris flows are common mass movements in mountainous landscapes and transport a large volume of mixed-sized sediment. Debris flows can also commonly occur in areas that have had recent forest fires. The water-laden properties of debris flows result in characteristics of stream channels, but there are key characteristics of debris-flow channels that can help in the field to differentiate them from stream channels.

The example of a debris-flow channel in Santa Cruz California in Figure 47 shows that debris-flow channels can appear similar to small headwater streams. However, the channel that a debris flow forms is (a) more incised than a stream channel because a large volume of sediment, debris, and water quickly scours the surface over a relatively short amount of time, indicated by the deep scoured-out channel (Figure 47A; e.g., tree roots are scoured and exposed in the channel), and (b) has unique deposits on the sides of the channel, known as debris-flow levees (Figure 47B). Debris-flow levees form on the sides of the channel as an accumulation of coarser particles and act to contain and direct the slurry of water and finer materials downslope. Debris-flow levees are shaped like linear mounds of sediment and woody debris along the sides of the channel. The layering within the debris-flow levee is also diagnostic of a debris-flow deposit because coarser sediment is layered on top of finer sediment within a debris-flow levee (Figure 47B).

It is especially important to investigate for debris-flow deposits in areas that are affected by wildfire, located on steep slopes, or are likely to have large precipitation events because the conditions needed to trigger a debris

flow are more favorable (e.g., weakened soil strength from burned vegetation). Debris flows can also scour hillslopes to the bedrock to form the beginning of a stream channel (Dietrich, Wilson, and Reneau 1986). Debris flows that scour to the bedrock often have distinct scour lines where there is a sharp, abrupt transition from the soil to the scoured bedrock channel or there are roots exposed from the scour (Figure 47A). Evidence of a recent debris flow (e.g., Figure 47A and B) includes minimal weathering of the surface (i.e., debris-flow features are intact) and exposure of the surface without dense vegetation cover. Older debris-flow channels and deposits that are densely vegetated can be especially difficult to identify in the field because there is no access to see the layers or the top of the sediment within the deposit. Additional debris-flow indicators in a densely vegetated environment may be scour marks that are visible at a similar height to each other along a stand of trees where large sediment within the debris flow can remove parts of the tree bark.

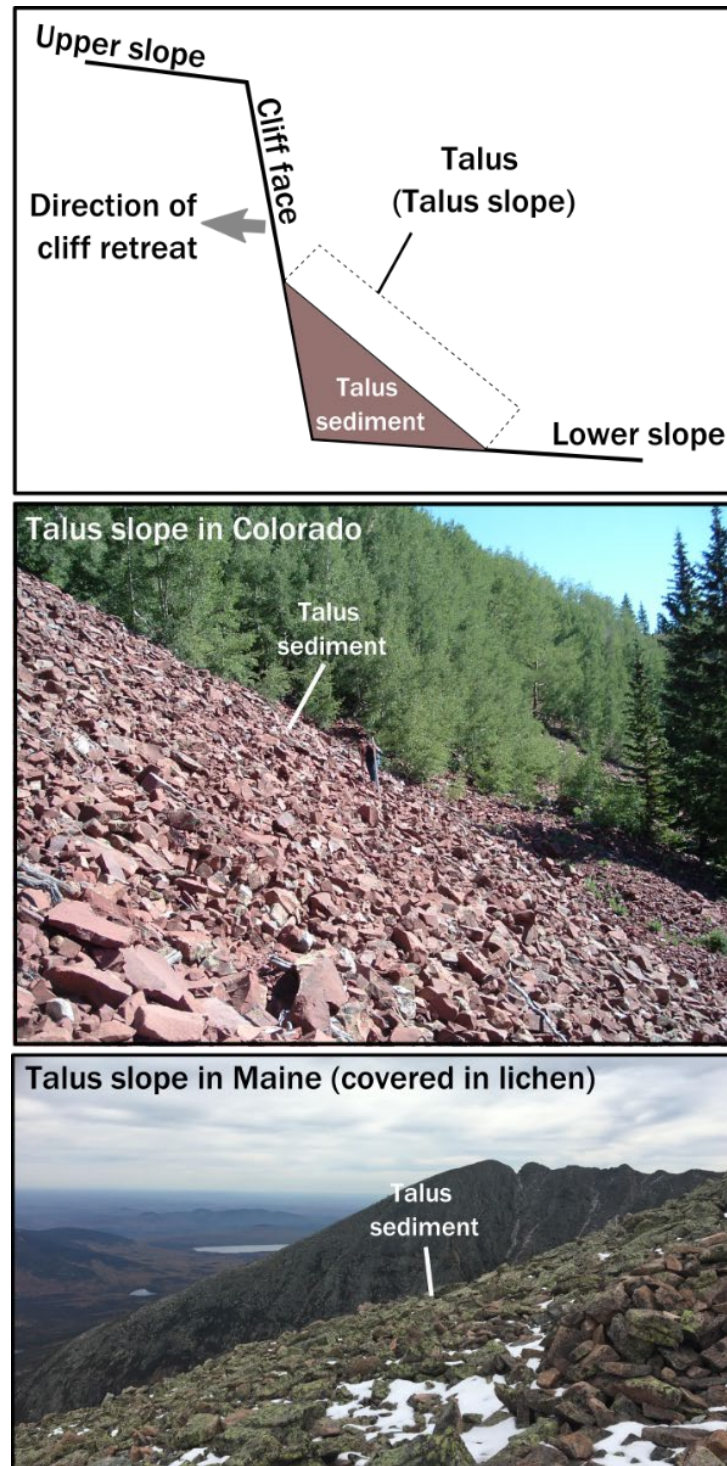
Figure 47. Anatomy of a small debris flow that occurred in the wildfire burn scar in Santa Cruz in 2021. Both the incision (A) and the coarsely armored debris-flow levees (B) differentiate this debris-flow channel from a stream channel. (Photographs modified with permission from Amy East.)



Rockfall, or the rapid detachment of bedrock from a hillslope, often forms a talus slope, which is a type of loose, hillslope sediment that is eroded or detached from exposed bedrock cliff faces. The loose hillslope sediment accumulates into a wedge-shaped cone at the base of the cliff (Figure 48). Once new sediment accumulates on the talus cone, sediment is transported downslope to maintain the slope angle (Figure 48). Talus slopes are often found in glaciated areas where glaciers carved steep slopes out of the bedrock. When traversing across a talus slope in the field, the grains that

make up the talus slope are often angular with freshly broken surfaces and are unstable underfoot.

Figure 48. Anatomy of a talus slope and two examples of talus sediment in Colorado and Maine. The thick layer of lichen on the Maine talus sediment indicates that the sediment is less mobile.



3.5.1.4 *Nonstream conveyances*

Many nonstream conveyances, such as rills, gullies, or other similar features (e.g., talus slopes), will be observed on hillslopes when searching for the start of a stream channel (Figure 49). Also, many can eventually become established channels, which can make differentiating between nonstream conveyances and stream channels challenging.

It is important to be able characterize these nonstream conveyances because they can often be in the transition zone between the hillslope and the stream channel. The nonstream conveyances discussed here are at the initiation point of the stream, but they can also be observed farther down in the stream network. Nonstream conveyances are not considered stream channels because (a) they are not formed exclusively by stream processes, (b) they are transient characteristics on the landscape (E. Wohl 2018), and (c) they generally erode at a faster rate than stream channels (Schumm, Harvey, and Watson 1984; Kirkby and Bracken 2009). When differentiating nonstream conveyances from stream channels in the field, it is important to note that the erosive formation of nonstream conveyances generally results in more incised and entrenched conveyance morphologies. The transient nature of nonstream conveyances may be present in the field where there are multiple nonstream conveyances imprinted on or intersecting each other. With such fast migration rates through hillslope sediment, there is likely evidence, in arid and semiarid environments, of unstable walls of the conveyance itself where the conveyance walls consist of sediment that is crumbling and noncohesive. In humid environments, nonstream conveyances can be densely vegetated but generally have more incised and entrenched morphologies that are distinguishable from stream channels.

A rill is a small erosional channel that is formed by overland flow and often appears as an incised, parallel channel on the sides of slopes (e.g., Figure 49). Rill erosion is an intermediate process between erosion caused by sheetflow and gully erosion (Casalí et al. 2006). Therefore, in the field, if there is evidence for sheetflow, it is likely that rill erosion is also present on the hillslope.

Figure 49. Examples of rills and a gully in a semiarid environment.



Gullies (e.g., Figure 49) are hillslope channels that are larger and deeper than rills and can be continuous or discontinuous. A continuous gully is a gully that is directly linked to the rest of the drainage network. A discontinuous gully can occur at any point along a hillslope; its start is signified by an abrupt headcut (Heede 1976). This is particularly problematic when trying to identify channel heads, another type of headcut, in the field. Again, the sediment forming gully headcuts, especially in an arid to semiarid environment, will be less stable, crumbling, and noncohesive. In other words, the gully walls are likely to collapse underfoot. Again, it is especially challenging in humid environments to distinguish between a vegetated gully headcut and the vegetated headcut of a channel head. Vegetated gullies, like vegetated rills, contain more evidence of erosion, where there are exposed areas of the gully that have freshly eroding sediment in contrast to the banks of a stream channel that have been shaped by multiple flows. Gullies and rills can be difficult to differentiate from stream channels, especially because, in some landscapes, gullies and rills can eventually form the beginning of stream channels. Therefore, gullies and rills will likely need to be paired with other hillslope indicators to confirm that they are associated with hillslope processes, particularly when the gullies and rills are located along the slope within the convergence zone and if there are multiple rills and gullies present. Rills and gullies are more transient features but may be highly abundant as rill or gully networks, or both, on the hillslopes in some landscapes. Rills and gullies can be more abundant in some landscapes with erosional land-use practices

(e.g., agriculture). Rills and gullies are also often associated with roads and culverts where there is increased runoff and erosion (Figure 49).

Human and natural disturbances such as land-use practices and wildfire can cause, maintain, or increase erosion of nonstream conveyances (E. Wohl 2018). It is important to gather information on any disturbance history of the field area and to spend time searching the field area for evidence of past disturbances. For example, if wildfires frequent the study area, it is likely that the hillslope sediment is clear of stabilizing vegetation and rills and gullies are more likely to form or rapidly migrate upslope. This would suggest that locating the headcut at the channel head may be more difficult with abundant nonstream conveyances on the landscape.

3.5.2 Sediment indicators

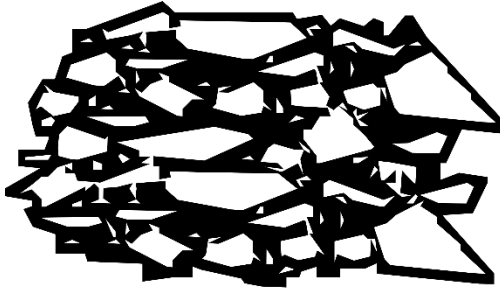
The primary characteristic differentiating hillslope and stream-channel-bed sediment pertains to the individual grains that make up the hillslope sediment, including grain size, shape, and organization. Generally, hillslope sediment consists of sediment with a coarser grain-size distribution than sediment that is sorted by stream processes downstream. This coarse grain-size difference in sediment is often noticeable (e.g., large boulders distributed throughout the colluvial hollow) but can be less pronounced in areas with lower slopes or fewer weathered-bedrock sediment sources. For example, in an arid environment (e.g., Arizona) with a low to moderate slope, grain size is not the best field indicator to differentiate hillslope sediment from stream-channel sediment because they contain similar grain sizes of sand. It is also similar for a densely vegetated, flat grassland environment (e.g., Kansas) where there are no differences in the grain size of the hillslope and stream-channel sediment (e.g., clay).

Although the grain size of the hillslope sediment can vary, the texture of the individual grains within the hillslope sediment is generally unrounded or angular in shape, contains low sphericity, and is poorly sorted because the sediment (a) is close to the sediment source and has not been transported far and (b) has been transported by gravity and not rounded by channelized, flowing water and contact with the stream bed during transport (Figure 50). Another characteristic of hillslope sediment that is related to poor sediment sorting is that the sediment lacks characteristics that were organized by channelized flowing water. For example, hillslope sediment lacks sediment that is organized into sequential step-like structures, or sediment that is overlapping in the flow direction. It is important

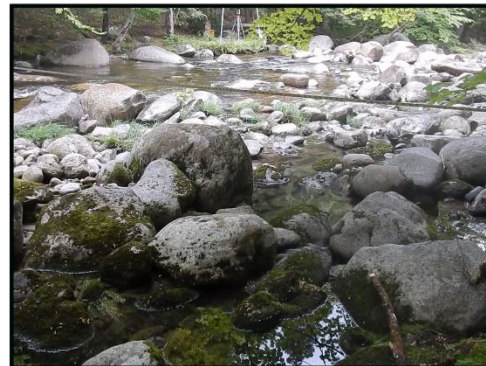
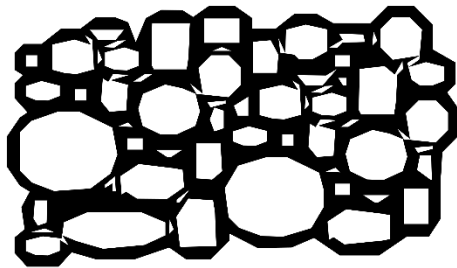
to note that, in some cases, the channel sediment could still be fairly angular, but it might be less angular than on the surrounding hillslopes.

Figure 50. End members of sediment sorting types. Angular, poorly sorted sediment is strong evidence for sediment transported by hillslope processes. Rounded, poorly sorted sediment is strong evidence for sediment transported by concentrated flowing water.

Angular, poorly sorted
(hillslope processes predominate)



Rounded, poorly sorted
(fluvial processes predominate)



3.5.3 Vegetation indicators

There is a transition in vegetation characteristics from the channel head to the hillslope in the longitudinal direction and also from the channel bed and banks to the hillsides in the lateral direction. Vegetation indicators include changes in vegetation type (e.g., differences in species of vegetation), abundance, and density. These differences are controlled by multiple factors, including slope, land use, underlying rock, sediment and soil type, and the presence of and proximity to a water source. Generally, there is a riparian vegetation corridor surrounding the stream, and the lateral width of this vegetation corridor varies across landscapes. Therefore, the appearance of the transition from the riparian-corridor vegetation to the hillslope vegetation can vary. This vegetation transition can be marked by an obvious change in vegetation (e.g., change in species of vegetation) that is

known to colonize stream banks versus surrounding hillslope, or there may be less subtle changes in vegetation (e.g., similar species of vegetation on the banks and hillslope but variation in vegetation density across the transition). David et al. provide additional detailed examples of the transition in vegetation from the channel to (1) the adjacent floodplain and (2) the hillslope across different landscapes throughout the U.S.⁵

3.6 Variation in hillslope indicators

Although there are common convergence-zone indicators across different landscapes with moderate to steep slopes (e.g., larger hillslope sediment with angular grains), it is useful to recognize how these convergence-zone indicators found on moderate to steep gradients can appear slightly different in the field because of factors such as differences in bedrock, soil type, and vegetation cover. Landscapes with moderate to steep gradients in arid climates have large boulder-sized, detached bedrock within the convergence zone (e.g., Figure 51, convergence zone in Arizona). The detached bedrock is mostly exposed but can have patches of vibrant-green vegetation where springs flow from the subsurface (e.g., Figure 51, convergence zone in Arizona). Springs are likely present where there is an accumulation of detached bedrock, which creates a break in slope. The spring is exiting the subsurface where the slope is transitioning from a high to a low gradient. This accumulation of exposed, detached bedrock is a type of steep headcut found on moderate to steep hillslopes in arid landscapes. In the field, reaching the first detached bedrock headcut may mislead the investigator into thinking this hillslope feature is either located in the convergence zone or is the channel head when, in reality, this is the first of a sequence of many detached bedrock headcuts before reaching the actual channel head and convergence zone. Although these headcuts are difficult to climb over directly, it is informative either to hike around these hillslope features beyond the first bedrock headcut or to search for these large bedrock headcuts on lidar, or both. This may not be permissible without field access.

Subtle differences in geology across different landscapes can also change the appearance of the hillslope sediment in the convergence zone. For example, in Figure 51, although the landscapes in Kentucky and Colorado have moderate to steep hillslopes that are vegetated, the rock types and the

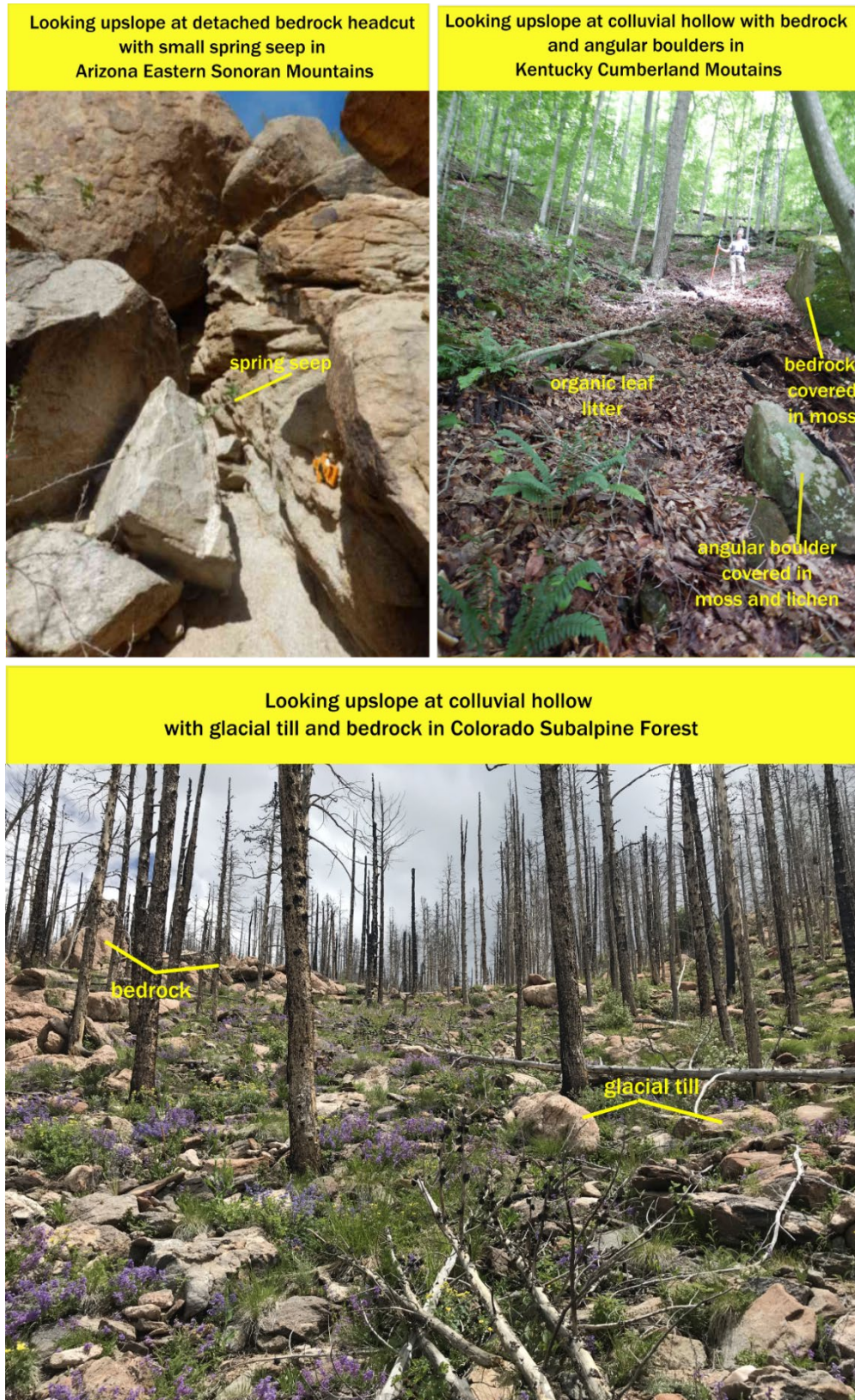
⁵ G. C. L. David, K. M. Fritz, T.-L. Nadeau, B. J. Topping, A. O. Allen, S. Kichefski, P. H. Trier, L. A. James, E. Wohl, and D. Hamill, *National Ordinary High Water Mark Field Delineation Manual for Rivers and Streams* (Hanover, NH: U.S. Army Engineer Research and Development Center, forthcoming).

way the bedrock was weathered are different, resulting in a slightly different appearance of the hillslope sediment within the convergence zone. The quartz-rich bedrock within the Colorado example's convergence zone was weathered in the distant past by glaciers, which were able to physically break down the rock into poorly sorted and somewhat rounded sediment (i.e., glacial till) on the hillslope. In contrast, the Kentucky site's bedrock is a softer rock type (i.e., sandstone) than Colorado's, but there were no glaciers to weather and break down the bedrock into smaller-sized grains. Therefore, the convergence zone at the Kentucky site has large bedrock outcrops and large angular boulders that are covered in moss and lichen (Figure 51). Moss and lichen growth on large boulders on a hillslope can be a useful indicator that sediment has not been transported by streamflow and that the investigator is upslope of the channel head. But although moss and lichen can aid in identifying a hillslope location upslope of the channel head, these indicators can occur in multiple environments (e.g., in association with streams) and should be paired or confirmed with other hillslope indicators.

Vegetation and organic litter can also cover hillslope sediment within the convergence zone, making it especially difficult to identify diffusive processes such as sheetflow because the organic litter (e.g., leaf litter) can move around easily from wind or animals (Figure 51, the convergence zone in Kentucky, for example). Again, indicators of sheetflow will likely need to be paired with other hillslope indicators to confirm the presence of sheetflow (i.e., hillslope process) versus streamflow (i.e., stream process).

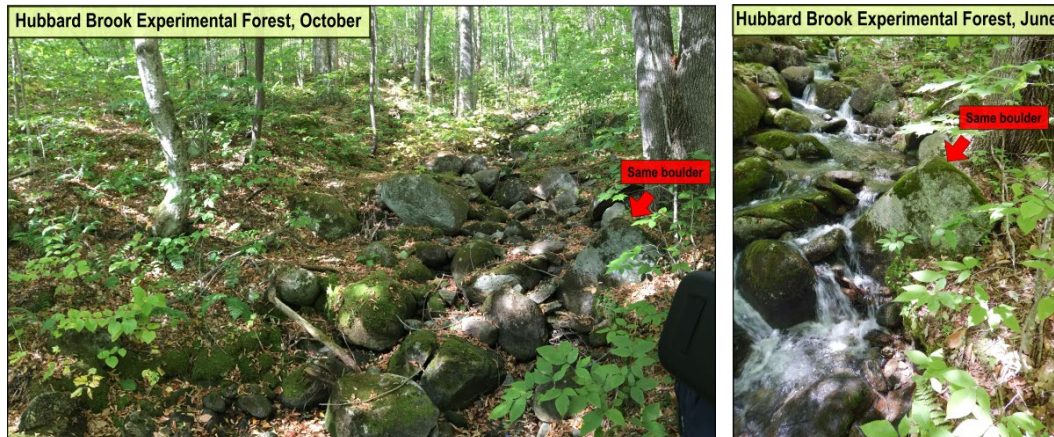
Not all convergence zones have well-defined, concave-shaped morphology and noticeable changes in grain size, shape, and sorting from the hillslope to the stream-channel transition (Figure 39). Landscapes with low to moderate gradients or that contain dense vegetation cover, or that have both, typically have poorly defined or less visible convergence zones (Figure 39). Compared to hillslope indicators, which may be less defined in convergence zones with low to moderate gradients, channel-head indicators (described in the next section) are more likely to help indicate where the channel starts. It is important to note that hillslope processes are occurring even in headwater streams with low slope and dense vegetation; but the range, spatial distribution, and definition of these hillslope indicators can be limited in the field.

Figure 51. Variations of typical convergence-zone indicators across different landscapes.



Seasonal changes to the appearance of hillslope and stream-channel characteristics can also contribute to inconsistencies in field identification. For example, leaf litter can sometimes help with finding boundaries (where it is removed) but in some cases can hide the channel (Figure 52). Depending on the season, there can also be drastic differences in vegetation cover.

Figure 52. Seasonal differences in the appearance of Hubbard Brook, New Hampshire.



3.7 Variation in channel-head location caused by land use and disturbance

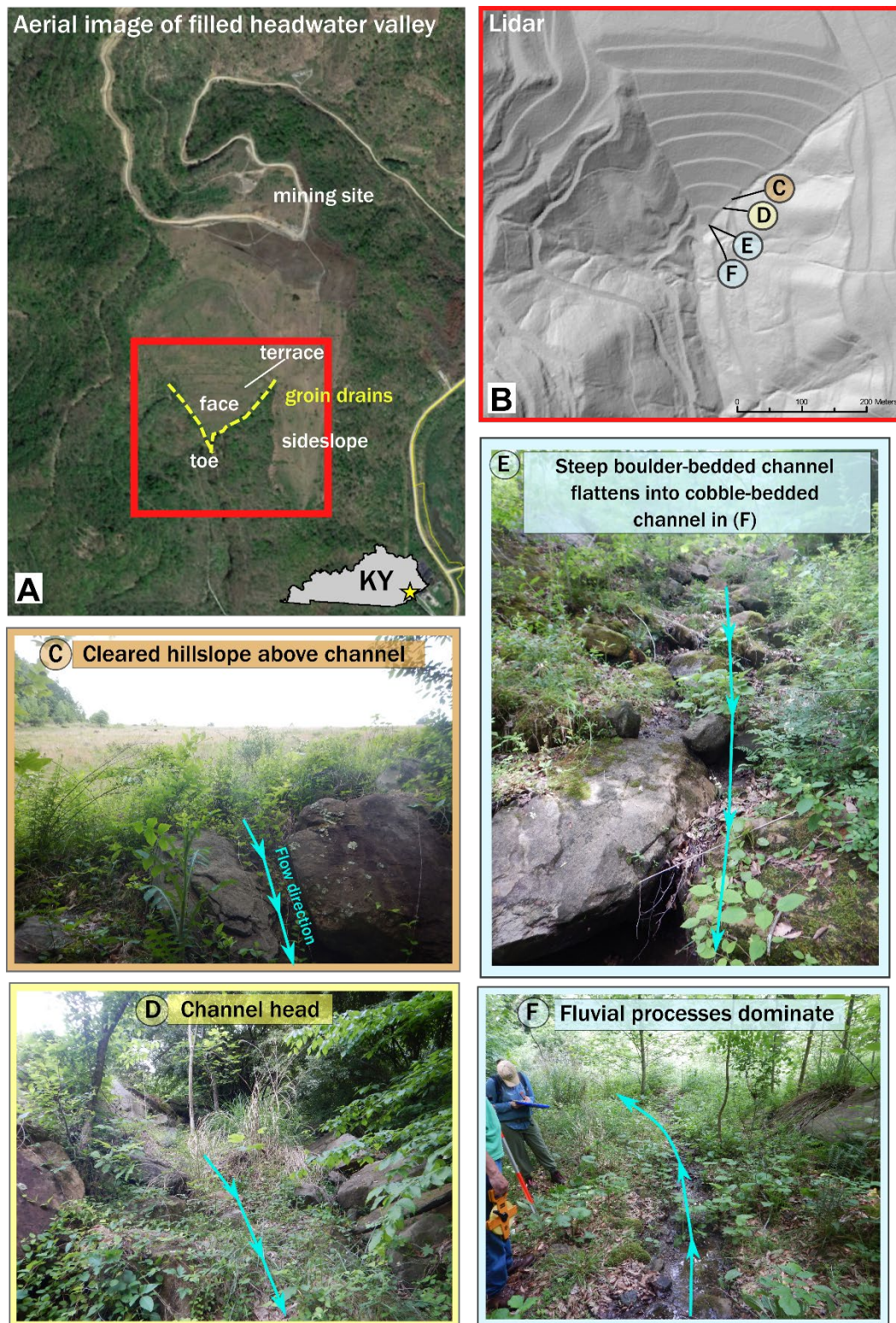
Land use (e.g., wildfire, logging, mining dam emplacement or removal, agriculture, or ground-water disturbance) can significantly change the position of channel heads within the hillslope-to-stream-channel transition. For example, wildfires alter the structure of the underlying soils, leading to more easily erodible sediments. More abundant channel heads can form faster in more easily erodible sediments (e.g., Gordon Creek site in Colorado). Logging and subsequent regrowth of the forest can result in a sequence of channel-head migration postlogging and relict characteristics that are no longer the start of the channel after regrowth. For example, in the Piedmont ecoregion in Figure 2, this large headcut could have been activated by historic logging practices in the area, but is not currently migrating from stream processes (i.e., relict feature on the landscape).

Identifying where a stream begins in a landscape with land-use alteration can be challenging because parts of the hillslope-to-stream-channel transition may contain engineered or artificial channel characteristics, whereas other parts of the stream may contain stream indicators. An example of the impact that land use has on the hillslope-to-stream-channel transition

and how this affects the identification of this transition is shown for an unnatural channel located in the Carr Fork–North Fork Kentucky River Watershed (671 km²; Figure 53). This site contains engineered channels (i.e., groin drains) that were built to manage excess sediment from mining operations and to convey stormwater runoff draining from the hillslope (Figure 53A). These engineered headwater valleys are ubiquitous landscape features that can be seen on lidar (Figure 53B) across West Virginia and Kentucky and can alter channel-head indicators in the field (Zipper, Daniels, and Bell 1989).

The artificially constructed stream appears as a well-defined channel on the lidar DEM and aerial imagery, but portions of the drainages are not actively conveying stormwater runoff. The field survey traversed one of the groin drains on the eastern side of the filled headwater valley up until there were indicators of a channel head created by stormflow runoff. The channel head was located only partially (~150 m) up the groin drain where there was an open area without dense woody vegetation or trees in the channel (Figure 53D). The fill terraces are apparent looking out from the top of the channel head (Figure 53C). Above the channel head, the groin drain continues for another 300 m as seen on the lidar, but stormflow is no longer accessing this drain as seen by the dense forest vegetation and no cleared channel. As runoff flows down from the channel head, there is evidence of stream-channel processes, including sediment sorting in small step-pools. But the steep slope and coarse boulders of the engineered channel bed cause some of the stormflow to enter the subsurface, forming a discontinuous stream channel on the surface. As the slope flattens out, the water table rises to the level of the surface, and the stream channel reemerges. Farther downstream, as the channel slope continues to flatten, the grain size decreases from boulder bedded to cobble bedded (Figure 53E to Figure 53F). Defined banks and stream-channel processes predominate.

Figure 53. Characteristics of a hillslope-to-stream-channel transition in a landscape disturbed by mining. An engineered channel (i.e., groin drain) adds variation to the characteristics of the hillslope-to-stream-channel transition.



4 Weight-of-Evidence Approach to Identifying the Upper Extent of Stream Channels in the Field

The WoE approach uses evidence collected from downstream of the channel head (i.e., where stream-channel characteristics predominate), directly at the channel head, and upslope of the channel head (where hillslope characteristics predominate) to determine the location of the channel head in the field. The lines of evidence are then weighted according to the relevance, strength, and reliability of the evidence and combined to justify a final determination of the channel-head location.

4.1 WoE steps

The WoE approach to identifying the upper extent of a stream channel starts in the office. The field investigator compiles information about the channel head of interest by using online remote tools to examine the drainage network and to gather information on the dominant runoff type, climate, hydrography, geology, soil types, and land use (chapter 2). This remote examination provides initial expectations of what characteristics of the stream channel, channel head, and hillslope may be present in the field before stepping foot in the field. The remote examination also provides logistical information for planning the field survey. Field plans include calculating the time it will take to traverse the terrain and reach the channel head as well as formulating secondary survey plans for unanticipated challenges in the field (e.g., routes around obstacles blocking the survey path). The limitations of remote data prevent consistently and accurately identifying and locating channel heads and other characteristics at the upper extent of channels. Without field data for validation, the investigator is subject to the limitations of the remote data, which is likely to contain error.

4.1.1 Step 1: Compile data layers to remotely examine the field-survey area (chapter 2)

While compiling available remote data layers, consider the following two categories of questions about the stream-channel-to-hillslope transition:

1. Watershed characteristics: climate, land cover, stream networks, and hydrology and runoff types:

- a. Based on precipitation, what is the climate of the watershed or subwatershed (reference the Köppen climate categorization in Peel, Finlayson, and McMahon 2007)?
 - b. What are the monthly patterns of precipitation? For example, what months out of the year is the precipitation high? Finally, what hydrological regime can be determined from the mean annual precipitation and temperature?
 - c. Do the slopes of the headwater stream channels contain low (e.g., <2%), medium, or high (e.g., >3%) values?
 - d. Are there any soils with very slow infiltration, slow infiltration, or medium infiltration? If so, where are these soils located?
 - e. What land cover category is present in the watershed or stream of interest? How can this land cover category affect the surface around the stream of interest?
2. Remote examination of proposed field-survey path following the stream channel to the hillslope:
 - a. Is the stream channel located in the lower, middle, or upper portion of the watershed?
 - b. What land cover is adjacent to the field-survey path?
 - c. Does the stream channel become wider or more defined where the NHD stream is delineated as a perennial or nonperennial stream? Or is there a change in stream-channel width farther upstream or downstream of the NHD stream delineation?
 - d. Are there any stream channels that are delineated by the NHD as discontinuous (e.g., the stream-channel line has a large gap in it)?
 - e. Are there any indicators on the high-resolution DEM or hillshade that indicate the stream channel is discontinuous? For example, does the stream channel abruptly disappear?

- f. Where are the depressions on the field-survey path and elevation profile following the stream? Specifically, is there a concave area up slope of the profile from the hilltop and drainage divide to the beginning of the stream channel (i.e., colluvial hollow)? Where are the high points on the profile?
- g. What are the major rock types and where are they located in relationship to the stream channel of interest (section 2.1.2)?
- h. When comparing multiple years of imagery, how has the vegetation adjacent to the transect changed (section 2.1.3)?

4.1.2 Step 2: Initial site conditions during the field survey (assemble evidence)

Following evaluation of the remote data and tools, complete the following steps:

1. Identify the starting point of the stream channel to follow to the channel head.
 - a. Identify flow confined to a channel.
 - b. Identify defined stream-channel banks and bed.
2. At the starting field location and when following the stream in the upstream direction, note any adjacent land use or surface disturbances in the area surrounding the stream channel that may influence interpretation of the channel-head location:
 - a. Are there obvious man-made alterations to the stream channel or surrounding area?
 - b. Are there man-made (e.g., bridges, dams, or culverts) or natural structures (e.g., bedrock outcrops or large wood jams) that will influence or control flow?
 - c. Is there evidence of wildfire (e.g., burned soils or trees) or logging (e.g., relict channels)?

4.1.3 Step 3a: List field evidence systematically

Identifying the channel head requires collecting systematic observations of changes in characteristics from the stream channel to the channel head to the hillslope. Ultimately, the field investigator will determine which characteristics (i.e., stream channel, channel head, or hillslope) predominate based upon the discussion found in chapter 3. Following the field-survey path up the stream channel of interest, the field investigator should collect systematic observations and map and record GPS coordinates on the elevation profile (e.g., Figure 24) for the following situations:

- a. There is a continuation of stream characteristics (e.g., collect a set of points where stream indicators are located along a continuous segment).
- b. The stream characteristics may disappear and reappear at a point, along a line segment, or both.
- c. Channel-head characteristics are located at a point or along a line segment.
- d. There is a continuation of hillslope characteristics upslope of the channel head that is ideally followed to the drainage divide.

With time permitting, following the field-survey path from the hillslope to the stream channel, collect a second set of GPS coordinates to confirm for the following situations:

- a. There is a continuation of hillslope characteristics to the convergence zone and channel head.
- b. There are channel-head characteristics that are located at a point or along a line segment.
- c. Stream characteristics clearly dominate. Remember that stream characteristics may be discontinuous.
- d. There is a clear continuation of dominant stream characteristics.

Table 6 lists questions to consider about the presence of a stream channel, a channel head, and hillslope characteristics.

Table 6. Questions to consider about the presence of a stream channel, a channel head, and hillslope characteristics along the field-survey path (e.g., Fig. 24).

Characteristics	Stream Channel	Channel Head	Hillslope
Geomorphic	Are defined bed and banks present? Are bedforms present on the stream-channel bed (e.g., pools and riffles)?	Is there a zone of converging flow? Is there a noticeable break in slope, or is there a sequence of breaks in slope associated with the decrease in stream-channel characteristics?	Is there a colluvial hollow with concave hillslopes that direct flow and sediment to the convergence zone and channel head? Is there evidence of diffusive processes (e.g., sheetflow)?
Sediment and Soil	Is sediment sorting present on the stream-channel bed?	Is there a change in sediment across the break in slope?	Is there a relative increase in sediment size from the channel head to the hillslope? Is the sediment on the hillslope relatively poorly sorted and angular compared to the stream-channel-bed sediment?
Vegetation	Is there vegetation growing on the channel bed? Has any vegetation been flattened by streamflow?	Is there a change in vegetation across the break in slope? (e.g., type and density)?	Is there a different species of vegetation that is less dense?
Additional	Is there evidence that the stream channel flows into or out of the subsurface as a discontinuous channel?	Are springs (e.g., bedrock seeps or saturated macropores) located at the terminus of the stream channel or farther upslope in line with the stream channel?	Is there evidence of mass movement (e.g., debris flows)? Is there evidence of other colluvial channels (e.g., rills and gullies)?

4.1.4 Step 3b: Weight each line of evidence and weigh body of evidence

Note that the WoE method assigns and combines qualitative weightings to arrive at a decision. Weight each indicator by considering its importance based on the following:

1. Relevance:
 - a. Is the indicator likely to occur in the climate, topography, and hydrology of the watershed?⁶
 - b. Is the indicator likely to occur at the identified elevation along the field-survey path?
2. Strength:
 - a. Is this indicator persistent across the immediate surrounding area?
 - (1) Look at the surrounding area to see if the same indicator is present at multiple locations along the field-survey path.
 - (2) Is the indicator continuous for a long distance? Or is the indicator discontinuous, where it disappears and then reappears?
 - (3) Can this indicator (e.g., stream-channel indicator) be completely distinguished from other indicators present (e.g., channel-head and hillslope indicators)? Or are there a mix of indicators?
3. Reliability:
 - a. Is this indicator persistent on the landscape over time? Will this indicator still persist across seasons? This can be difficult to determine for some indicators and may be specific to climatic region (in terms of persistence of vegetation) and history of land use or other natural disturbances.
4. Weigh body of evidence:
 - a. Combine weights by integrating the weighted line of evidence (relevance, strength, and reliability) of each indicator.
 - b. For each of the observed indicators, which are more heavily weighted? Where do high-value indicators co-occur along the field-survey path?

⁶ Landscape context from Step 1 can help determine the relevance, strength, and reliability of the characteristic (i.e., stream, channel head, or hillslope) observed in the field.

4.1.5 Step 4: Describe rationale for the location of the channel head

These steps are used to explain the rationale for determining the location of the channel head:

1. Why do the combination of indicators represent the channel head?
2. If there are multiple possibilities for the channel head, explain why there are two (or more) possibilities and the reasoning behind the final decision. Include any relevant discussion on why specific indicators were not included in the final decision.

4.2 Identifying a channel head in the field using WoE

This section presents a case study applying the WoE approach to collect and weight evidence of stream channel, channel head, and hillslope characteristics and indicators to ultimately determine the location of the channel head. The channel-head example is for a headwater stream in the Six-Mile Creek–Smoky Hill River Watershed in Elkader, Kansas (i.e., HUC1026000301). This Kansas example was also used in chapter 2 for the remote examination. The field investigator collected observations along the field-survey path by using the WoE approach. Although the WoE approach provides a framework for how to identify a channel head, channel heads can be difficult to identify in the field even with this approach.

4.2.1 Online examination using remotely available data

To gain more understanding of the general watershed climate, topography, hydrology, and runoff type, the investigator used the Model My Watershed remote tool to collect remote evidence for a subwatershed (i.e., HUC102600030105) of the Six-Mile Creek–Smoky Hill River where the stream of interest is located. The Model My Watershed analysis results of the subwatershed were used to answer the list of questions in Step 1 of the WoE approach. Step 1 outlines questions that assist in gathering online resources to use in developing expectations prior to the field visit for where the stream channel, channel head, and hillslope characteristics are likely located.

The subwatershed receives 46.9 cm of annual precipitation on average and has a mean annual temperature of 11.7°C. Mean annual temperature

and precipitation are higher in the summer months and gradually decrease in the winter months. From referencing the Peel, Finlayson, and McMahon (2007) Köppen climate classification, the area has a cold semi-arid climate, resulting in semiarid vegetation, such as grasslands. The hydrological regime and runoff type are difficult to determine exclusively from the mean precipitation and temperature of this particular subwatershed. Additional information on geology and land cover could help determine the dominant runoff type in this area and therefore the expected channel-head characteristics.

From the Model My Watershed tool, the slopes of the headwater streams are extremely flat (i.e., first-order streams have a mean channel slope of 1.18%). The headwater stream channels that contain low slopes likely result in less distinctive hillslope processes that are occurring at a slower rate over a larger area (Figure 39). Furthermore, the low mean channel slopes and the lack of hillslope definition can result in a less defined transition from the stream channel to the hillslope. Therefore, the channel head is likely to be less defined on a larger scale. Additionally, as seen in Figure 11, type D soils surround the stream of interest. This group of soils has slow infiltration rates and high clay content, which is more cohesive. The cohesiveness could indicate that a distinct channel-head wall will occur, despite the low slopes. Lastly, according to the NLCD 2011 land cover layer, grassland and herbaceous vegetation surround the stream channel. The land cover of the surrounding land is also heavily cultivated cropland. Dense grasses can obstruct low-gradient breaks in the slope of headcuts. But changes in the species, density, and color of different grasses can also be helpful for providing indicators of the presence or absence of streamflow. The systematic and widespread cultivated cropland indicates that there could be disturbance to the surface because of agricultural practices, which could alter the appearance and location of the channel head and could increase erosion of the channel head. Additionally, irrigation practices, such as small agricultural dams and reservoirs, could affect the amount, timing, and intensity of streamflow in the headwater streams in this location.

By examining the streams layer, without additional geological information, there is evidence for breaks in the stream line layer. This could indicate that the streamflow is disappearing to and reappearing from the subsurface because of the underlying geology (e.g., karst geology). Sink holes and subterranean flows are common in karst terrain. Any prior knowledge of

discontinuous stream channels is critical when identifying channel heads. Discontinuous channels can result in falsely identifying the channel head.

The next step in the remote investigation requires a closer examination of the subwatershed. In this example, the National Map Viewer remote viewer tool was used. After examining the six subwatersheds within the Six-Mile Creek–Smoky Hill River watershed and identifying the direction of flow of the Smoky Hill River, the stream of interest was located in the lowland area of the watershed (Figure 54A). As previously mentioned, low-gradient headwater channel heads located in the lowland part of a watershed can be especially difficult to identify because there are likely undefined hillslope characteristics that gradually transition over a long distance from above and below the channel head, resulting in difficulties identifying an abrupt boundary demarking the channel head. There are also cultivated crop changes in the headwater stream of interest and abundant small dams and reservoirs (e.g., flow direction shows artificial paths where reservoirs are located). All of these land-use practices could alter the appearance of the stream-channel and channel-head characteristics. For example, a small headwater reservoir could be mistaken for a large pool of a stream channel, or the beginning of the headwater stream could be truncated by agricultural practices.

The investigator initially produced a field-survey-path map (Figure 54B) by using the aerial imagery layer in the National Map Viewer but later revised it upon further examination of the lidar-derived hillshade layer (Figure 55). The initially mapped field-survey path extends past the channel head that is defined by the NHD layer to the drainage divide (Figure 54B). However, the lidar-derived hillshade layer in the National Map Viewer shows a defined channel (i.e., continuous linear depression in the lidar that represents a confined stream channel) that does not appear until much farther downstream of the channel head delineated from the NHD layer (Figure 55). After examining the lidar, the field investigator shortened the field-survey path to the estimated channel-head location. By creating a field-survey path from the NHD stream delineation, the planned traverse would be 2.5 kilometers longer. The final proposed field-survey path distance is around 2 km round trip to reach the estimated channel head from the car and back.

Figure 54. The location of the study area within the watershed (A) and the proposed field-survey path to the channel head of interest based upon aerial imagery and the NHD stream delineation using the National Map Viewer remote tool (B).

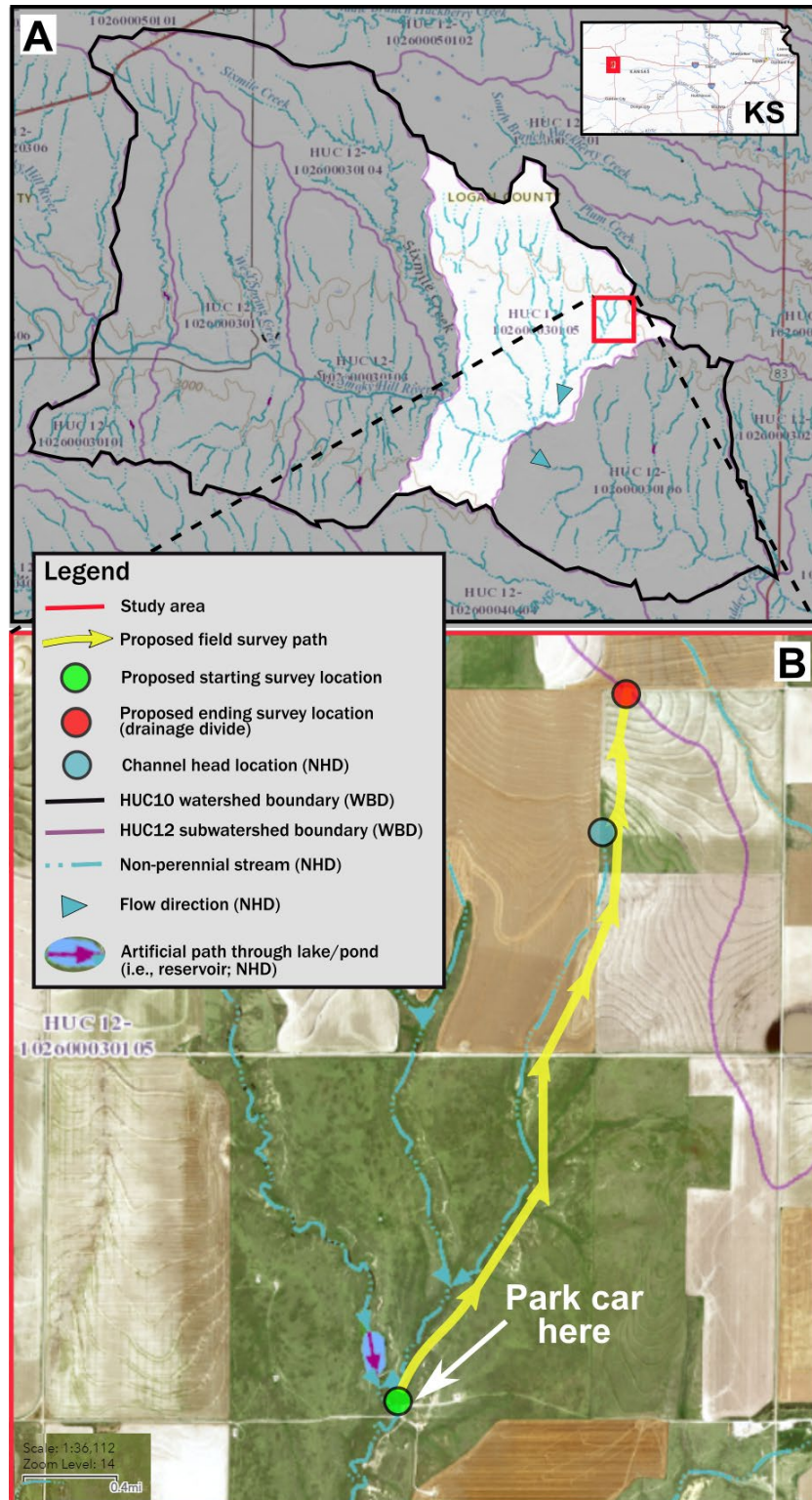
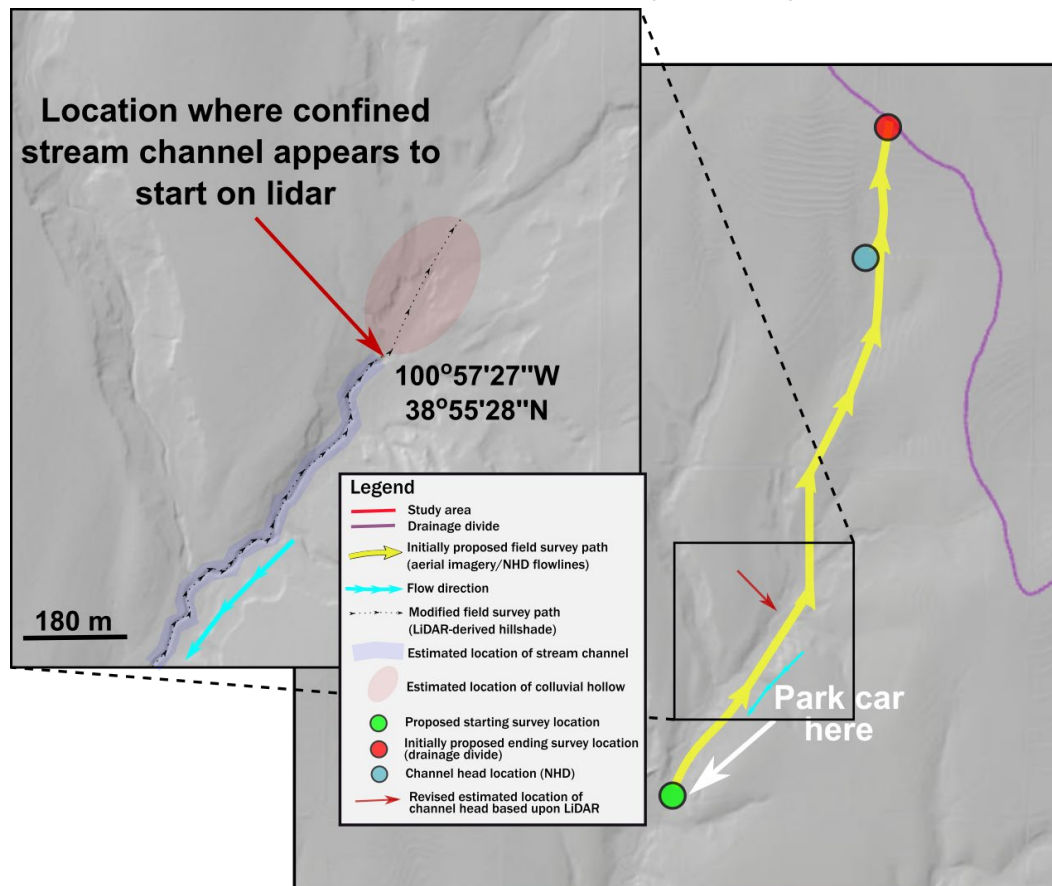


Figure 55. Revised field-survey path based on observations from lidar using the National Map Viewer remote tool (USGS 2017).

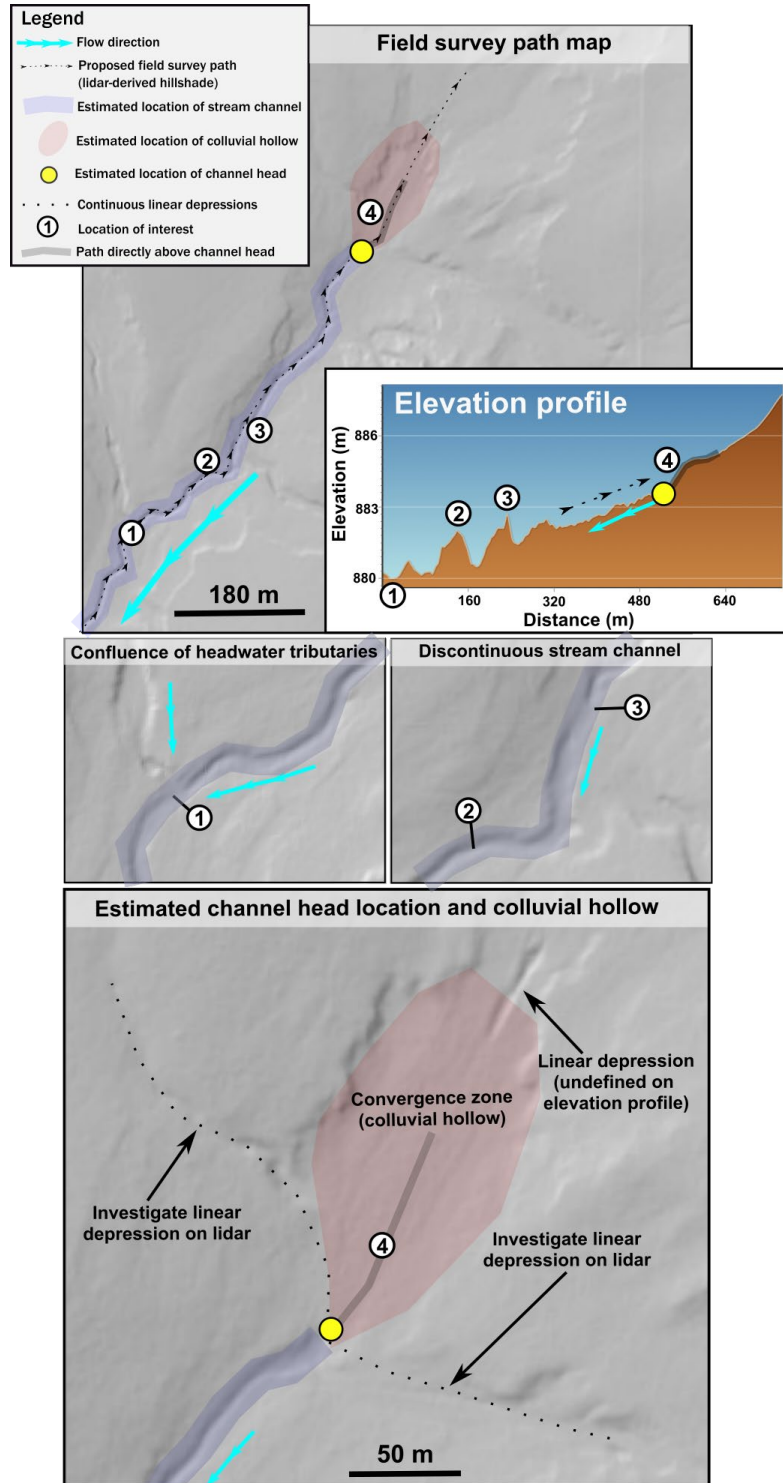


On closer examination of the lidar-derived hillshade in the National Map Viewer, the field investigator identified areas of interest along the field-survey path and extracted the corresponding elevation profile within the National Map Viewer (Figure 56). The elevation profile contains vertical exaggeration, which results in an unrealistic picture of the actual slope (i.e., the channel slope is low in this location, and variation in slope along the field-survey path is likely indistinguishable in the field). But the vertically exaggerated elevation profile is useful to find potential breaks in slope that could be headcuts or even the channel head. The first area of interest appears to be a location where a tributary joins the stream of interest. The confluence of the two suspected stream channels appears to be filled in. This is unexpected for a tributary confluence; where two stream channels meet, there are likely erosive processes occurring, resulting in a depression on the lidar. This may indicate land-use practices, such as a small dam that is located on the tributary, or the filled in confluence could be a result of the underlying geology.

Moving up the field-survey path to the second and third areas of interest, a stream channel is defined on the lidar-derived hillshade, but there are what appear to be gaps in the stream channel (i.e., linear depression appears to be filled in; Figure 56). In addition to the observation at the downstream confluence, these gaps in what is likely stream-channel banks could be evidence for a discontinuous channel. The discontinuous stream channel also parallels the underlying karst geology that was found in the previous watershed remote examination. The elevation profile also indicates that there are breaks in slope where the stream channel disappears and reappears on the lidar-derived hillshade. The breaks in slope are likely headcuts and should be investigated in the field. The stream channel appears to continue upstream from the second and third areas of interest along the suspected stream channel. Therefore, it is critical to continue to investigate upstream of these headcuts to avoid falsely identifying the channel head as a headcut farther downstream.

Lastly, the fourth area of interest is located around the estimated locations of the channel head and convergence zone, or colluvial hollow. On the lidar-derived hillshade, there is a clear depression and termination of the stream-channel banks (Figure 56). The estimated beginning of the stream channel contains a rounded, amphitheater shape with banks on all three sides (i.e., break in slope of the face and sides of the estimated channel-head location). There is also a break in slope on the elevation profile at the estimated channel-head location. This is further evidence that flow is converging to the estimated channel-head point and that the channel does not extend continuously upslope. Evidence for a convergence zone is seen on the concave profile from the estimated channel-head location to farther upslope. There is a linear depression that is located above the channel head that should also be investigated, but it does not appear to contain a headcut on the lidar-derived hillshade. Also, there are two shallow linear depressions that join at the estimated channel-head location. These could terminate at a different channel-head location, or they could also be discontinuous stream segments. To confirm the location of the estimated channel head, it is important to follow these shallow linear depressions farther in the field if there is access to the area.

Figure 56. Example of areas of interest to investigate in the field, selected by examining the lidar-derived hillshade and associated elevation profile by using the National Map Viewer (USGS 2017) remote tool.



4.2.2 Field survey

The field investigator located the starting point of the stream channel (i.e., flowing water confined to a channel) from the road and followed the field-survey path upstream. The field investigator explored the areas of interest along the field-survey path from the remote examination and collected lines of evidence (i.e., geomorphic, sediment, and vegetation). The field investigator then assigned weights based upon the relevancy, strength, and reliability of each line of evidence (Figure 57; Table 7). At the starting location of the field-survey path, there was an agricultural dam, which indicated that the stream channel of interest may also be impacted by agricultural land-use practices farther upstream. Up until the first area of interest, there were multiple different types of evidence for a stream channel, including (a) continuously defined stream-channel banks and bed (i.e., geomorphic indicator), (b) exposed patches of the stream bed that contained mud cracks (i.e., sediment indicator), and (c) vegetation density and color change across the stream channel (i.e., vegetation). The geomorphic line of evidence was weighted the highest in comparison to the sediment and vegetation indicators, but all three indicators have high weights. These results lead to the conclusion that there is a continuous stream channel up until the first area of interest (Figure 57, area 1).

The second and third areas of interest contained similar lines of evidence, including geomorphic, sediment, and vegetation indicators; but there was an evident change in the stream-channel indicators. For example, the line of evidence for continuously defined banks was less apparent and weighted with a lower strength (Figure 57; Table 7). Vegetation indicators were weighted more strongly because the vegetation is clearly different inside and outside of the channel. There were also small headcuts where the stream channel reappears at the surface, and this geomorphic line of evidence is weighted with a lower relevancy score because the expected channel-head location from the remote examination is located much farther upstream. Therefore, there was evidence that the second and third areas of interest contain a discontinuous channel that flows into the subsurface and that there is a break in slope or headcut where the stream channel reappears.

Following the field-survey path upstream revealed a landscape-scale depression where multiple branching linear depressions lead into the fourth area of interest. As the field investigator followed the survey path to the

fourth area of interest, the geomorphic indicators included a change or termination of the banks on both the sides and face of the discontinuous stream channel. There were also gradual but noticeable breaks in slope at the termination of the discontinuous stream channel. These geomorphic indicators were assigned a high weight because they contain high relevancy (Figure 57; Table 7). The sediment indicators of the stream channel were rated with a low strength because they were not as visible on the channel bed. The vegetation indicators, including a change in density and type of vegetation over and around this depression were assigned a high weight because they distinctly indicate where the stream banks and bed are and where the hillslope is located. There was a change in vegetation (i.e., pale-yellow color) from upslope of the depression, and also there was a concave landscape shape upslope of the depression. These lines of evidence were used to identify the convergence zone, or colluvial hollow, directly upslope of the identified depression.

Lastly, the field investigator examined the shallow linear depressions in the fifth area of interest and found a lack of geomorphic and sediment indicators in these areas. However, there were clear linear patches of bright-green vegetation that extended up the shallow linear depressions. The linear patches became discontinuous moving upslope and eventually terminated. Based on the defined and confined linear patches of vegetation and the assigned weights, these shallow linear depressions were identified as discontinuous streamflow.

Figure 57. Example of using the WoE approach to determine the location of the stream channel, channel head, and hillslope by using multiple, weighted lines of evidence while walking along the field-survey path in the upstream direction. Following the field-survey path, the areas of interest are displayed with field images in the counter-clockwise direction. Table 7 (*below*) corresponds to the different lines of evidence in this figure.

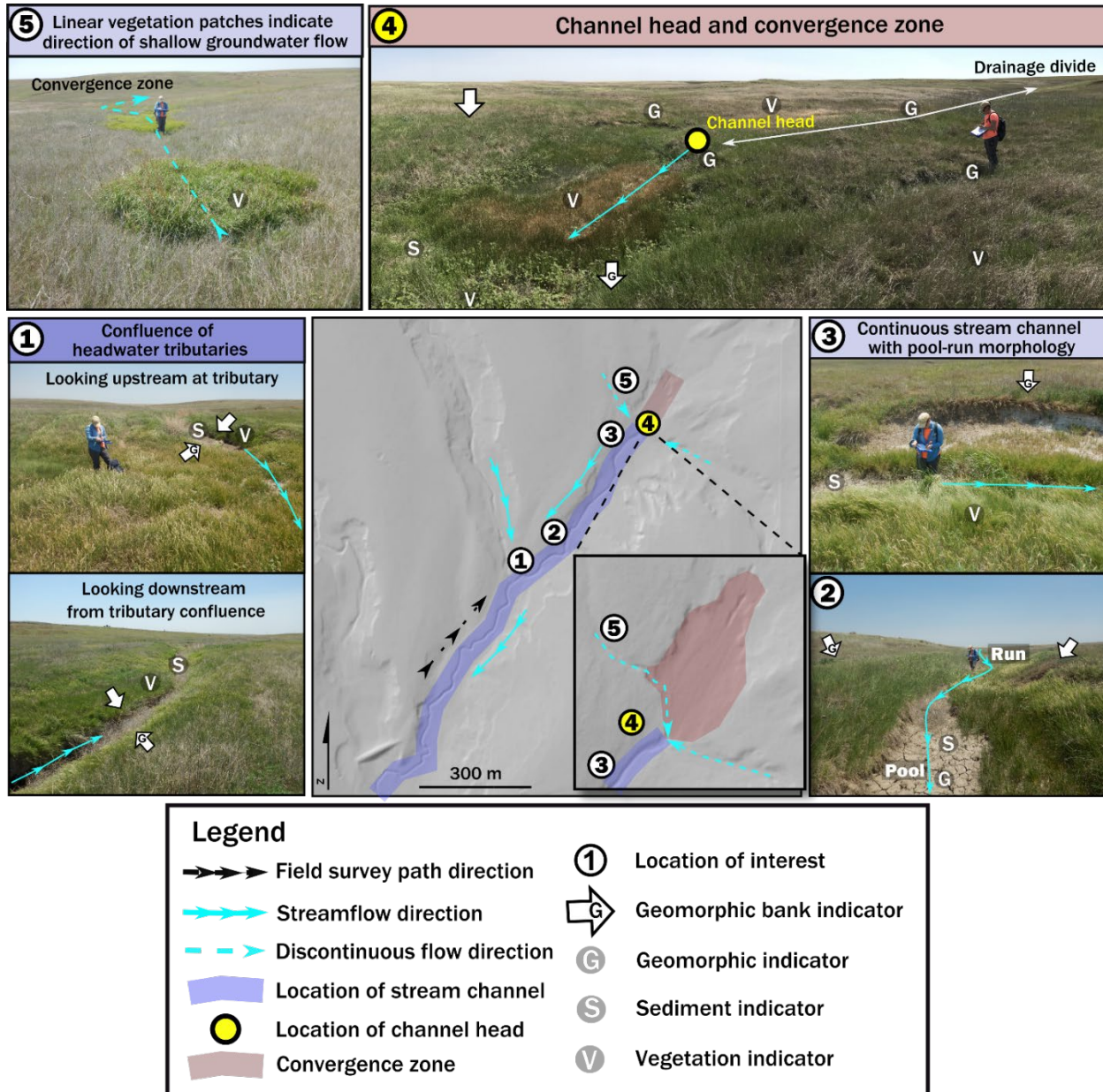


Table 7. Example of how to apply the WoE technique to a specific site (Fig. 57). The description of weights is described in relation to this specific site. The evidence, strength, and reliability of specific evidence are site dependent. All the evidence discussed in this table has already been determined to be relevant, therefore it is not included as a separate column in the description of weights.

Indicator Name ^a	Description of Field Indicator	Description of Weights		Description of Remote Evidence	Location Decision Based on Field and Remote Evidence ^b		
		Strength of Field Indicator (persistent over space)	Reliability of Field Indicator (persistent over time)		SC	CH	HS
1G	Continuous, defined channel bank and bed formation	Strong evidence of stream-channel morphology	Reliable, but banks can erode and become less visible over time	Continuous, defined linear depression on lidar	X		
1S	Exposed, fine sediment on bed; mud cracks on bed	Strong evidence of stream-channel morphology	Less reliable as bed sediment can quickly become vegetated; mud cracks are temporarily exposed		X		
1V	Difference in color and density of vegetation on banks vs. bed	Evidence for presence of stream channel	Less reliable as vegetation color and density can quickly change		X		
2/3G	Less-defined channel banks along particular segments	Less strength because may be more difficult to identify	Reliable, but banks can erode and become less visible over time	Defined linear depression on lidar with some locations that appear filled, but linear depression extends farther upstream from this point	X		
2/3S	Exposed, fine sediment on bed; mud cracks on bed	Strong evidence of stream-channel morphology	Less reliable as bed sediment can quickly become vegetated; mud cracks are temporarily exposed		X		
2G	Sequence of depressions and filled in segments (there are breaks in slope at the beginning of depressions)	Strong evidence of a stream-channel morphological sequence (i.e., pool-run-pool)	Reliable (long-term) stream-channel characteristic of sediment scouring a pool and filling in the following run morphology		X		
3V	Difference in vegetation type in channel vs. banks	Secondary evidence for presence of a stream channel	Less reliable as vegetation type can change with water abundance		X		

^a G = Geomorphic, S = Sediment, V = Vegetation.

^b SC = Stream Channel, CH = Channel Head, HS = Hillslope.

Table 7 (cont.). Example of how to apply the WoE technique to a specific site (Fig. 57).

Indicator Name ^a	Description of Field Indicator	Description of Weights		Description of Remote Evidence	Location Decision Based on Field and Remote Evidence ^b		
		Strength of Field Indicator (persistent over space)	Reliability of Field Indicator (persistent over time)		SC	CH	HS
4G	Continuous, defined channel bank and bed formation	Strong evidence of stream-channel shape	Potentially less reliable as banks can erode and become less visible over time	The continuous, linear depression terminates at this location on the lidar (i.e., linear depression does not extend upslope)		X	
4S	Exposed, fine sediment on bed; mud cracks on bed	Strong evidence of stream-channel shape	Less reliable as bed sediment can quickly become vegetated; mud cracks are temporary			X	
4V	Difference in color, type, density of vegetation on banks vs. bed	Evidence for presence of stream channel	Less reliable as vegetation color, type and density can quickly change			X	
4G	Break in slope and dense vegetation (headcut)	Strong evidence of channel-head shape	Less reliable as headcuts are prone to migration and erosion; with dense vegetation and low slope they may be difficult to identify			X	
4V	Difference in color, type and density of vegetation below and above headcut	Evidence for transition from above to below the channel head	Less reliable as vegetation color, type and density can quickly change			X	
4G	Concave-up profile upslope of headcut	Strong evidence of the profile shape of a convergence zone	Reliable landscape characteristic	Elevation profile shows concave-up profile shape with faint, discontinuous linear depression			X
5G	No visible channel banks or bed	Poor evidence for a stream channel; strong evidence for a convergence zone	Less likely that streams will be introduced in this location				X
5S	No visibly exposed bed sediment	Poor evidence for a stream channel; strong evidence for a convergence zone	Less likely that streams will be introduced in this location				X
5V	Discontinuous, linear patches of bright-green vegetation	Some evidence for concentrated shallow groundwater flow	Less reliable as this type of vegetation is subject to seasonal changes in shallow groundwater flow	Faint, discontinuous linear depression pointing in the direction of the convergence zone			X

^a G = Geomorphic, S = Sediment, V = Vegetation.

^b SC = Stream Channel, CH = Channel Head, HS = Hillslope.

5 Summary

The delineation of river and stream channels requires the accurate, consistent and repeatable identification of the upper extent of the stream channel. At the upper extent of a stream channel, there is a transition zone between the hillslope and the beginning of the stream channel. The channel head is located at the upstream-most point of a stream, where water converges into a flow path of concentrated water and sediment to erode and initiate a stream channel with definable bed and banks (Montgomery and Dietrich 1988, 1989). The channel head demarks the end of the hillslope and the beginning of a stream channel and can be challenging to consistently identify across the U.S. because of the variation of factors that influence how and where channel heads start (E. Wohl 2018). Channel-head initiation depends on how surface and subsurface runoff from the hillslope converges into a flow path of concentrated water and sediment to erode and initiate a stream channel.

Stream channels, along with the channel heads, can be difficult to physically identify in the field because the factors that control the formation of channel heads and the transition zone from the hillslopes to the initiation of the stream vary. Therefore, this report accomplishes the following to assist with this identification:

- Describes the variation of geomorphic, sediment, and vegetation characteristics at the upper extent of channels, at each part of the transition zone (i.e., stream channel, channel head, and convergence zone), across different landscapes throughout the U.S.
- Provides an easily accessible remote-examination workflow to answer questions pertaining to the estimated location of the channel head and to develop expectations for what geomorphic, sediment, and vegetation indicators are likely to be present in the field
- Summarizes geomorphic, sediment, and vegetative indicators that help to more consistently and accurately identify where stream channels begin by using field descriptions that were collected from the various landscapes, hydrological regimes, ecoregions, and land-use types across the U.S.

- Includes a field-survey plan that describes how to observe changes in geomorphic, sediment, and vegetation indicators when surveying from the stream channel to the channel head to the convergence zone
- Presents a WoE approach to assess the accuracy of the channel-head location with both remotely sensed evidence and field observations

Channel heads remain challenging to identify in the field even with the remote guidance of estimated locations derived from high-resolution lidar. These challenges include limited access to field-survey paths and variation in geomorphic, sediment, and vegetation indicators across landscapes. Variation in the indicators can be caused by several factors, including land-use change. While this report presents and applies the WoE approach to a case study, testing the WoE approach on field-survey paths across various landscapes would provide additional descriptions of the variation in indicators across the various landscapes. The additional descriptions from future research are necessary to more widely apply the WoE approach to identifying the upper extent of the stream channel using the geomorphic, sediment, and vegetation indicators at each part of the transition from the stream channel to the hillslope.

Describing the upper extent of a stream channel is paramount for identifying the channel head. Therefore, this report provides tools and technical approaches to more reliably and consistently identify the channel head for the purposes of the Clean Water Act.

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Acronyms and Abbreviations

CWA	Clean Water Act
DEM	Digital Elevation Model
EPA	Environmental Protection Agency
GIS	Geographic Information System
HUC	Hydrologic Unit Code
NHD	National Hydrography Dataset
NLCD	National Land Cover Database
NRCS	Natural Resources Conservation Service
SGCM	State Geologic Map Compilation
WBD	Watershed Boundary Dataset
WoE	Weight of Evidence

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