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Wetlands Regulatory Assistance Program (WRAP)

National Ordinary High Water Mark Field Delineation Manual for Rivers and Streams

Interim Version

Gabrielle C. L. David, Ken M. Fritz, Tracie-Lynn Nadeau, Brian J. Topping, Aaron O. Allen, Patrick H. Trier, Steven L. Kichefski, L. Allan James, Ellen Wohl, and Daniel Hamill

November 2022

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Interim Version

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Abstract

The ordinary high water mark (OHWM) defines the lateral extent of non-tidal aquatic features in the absence of adjacent wetlands in the United States. The federal regulatory definition of the OHWM, 33 CFR 328.3(c)(7), states the OHWM is "that line on the shore established by the fluctuations of water and indicated by physical characteristics such as [a] clear, natural line impressed on the bank, shelving, changes in the character of soil, destruction of terrestrial vegetation, the presence of litter and debris, or other appropriate means that consider the characteristics of the surrounding areas." This is the first manual to present a methodology for nationwide identification and delineation of the OHWM. A two-page data sheet and field procedure outline a weight-of-evidence (WoE) methodology to organize and evaluate observations at stream sites. This manual presents a consistent, science-based method for delineating the OHWM in streams. It also describes regional differences and challenges in identifying the OHWM at sites disturbed by human-induced or natural changes and illustrates how to use remote data to structure field inquiries and interpret field evidence using the principles of fluvial science. The manual demonstrates that, in many landscape settings, the OHWM may be located near the bankfull elevation.

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Contents

Figures, Tables, and Boxes

Figures

Tables

Boxes

Preface

This study was conducted for the US Army Corps of Engineers (USACE) Headquarters through the Wetlands Regulatory Assistance Program (WRAP) under project, “Testing OHWM Nationally,” funding account U438116, AMSCO 088893. The technical monitor was Mr. Kyle Gordon.

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1 Introduction

1.1 Background

The ordinary high water mark (OHWM) defines the lateral extent of non-tidal aquatic features in the absence of adjacent wetlands in the United States. The federal regulatory definition of the OHWM, 33 CFR 328.3(c)(7), states, “The term ordinary high water mark means that line on the shore established by the fluctuations of water and indicated by physical characteristics such as [a] clear, natural line impressed on the bank, shelving, changes in the character of soil, destruction of terrestrial vegetation, the presence of litter and debris, or other appropriate means that consider the characteristics of the surrounding areas.” The OHWM has been used to delineate the jurisdictional limits of certain aquatic features since the Rivers and Harbors Act of 1899. The OHWM defines the jurisdictional limits for both streams and lakes, but this manual focuses solely on a methodology for identifying and delineating the OHWM in streams. In this context, *identification* refers to recognizing evidence at places along the stream, and *delineation* refers to connecting the evidence to arrive at an OHWM determination. Throughout the document, the term *stream* refers to both streams and rivers. Physical features are used as surrogate indicators for identifying the upper limits of semifrequent high-flow events in flowing waters. *Physical features* refers to physical characteristics on the landscape, including flora and geomorphic features shaped by fluvial processes.

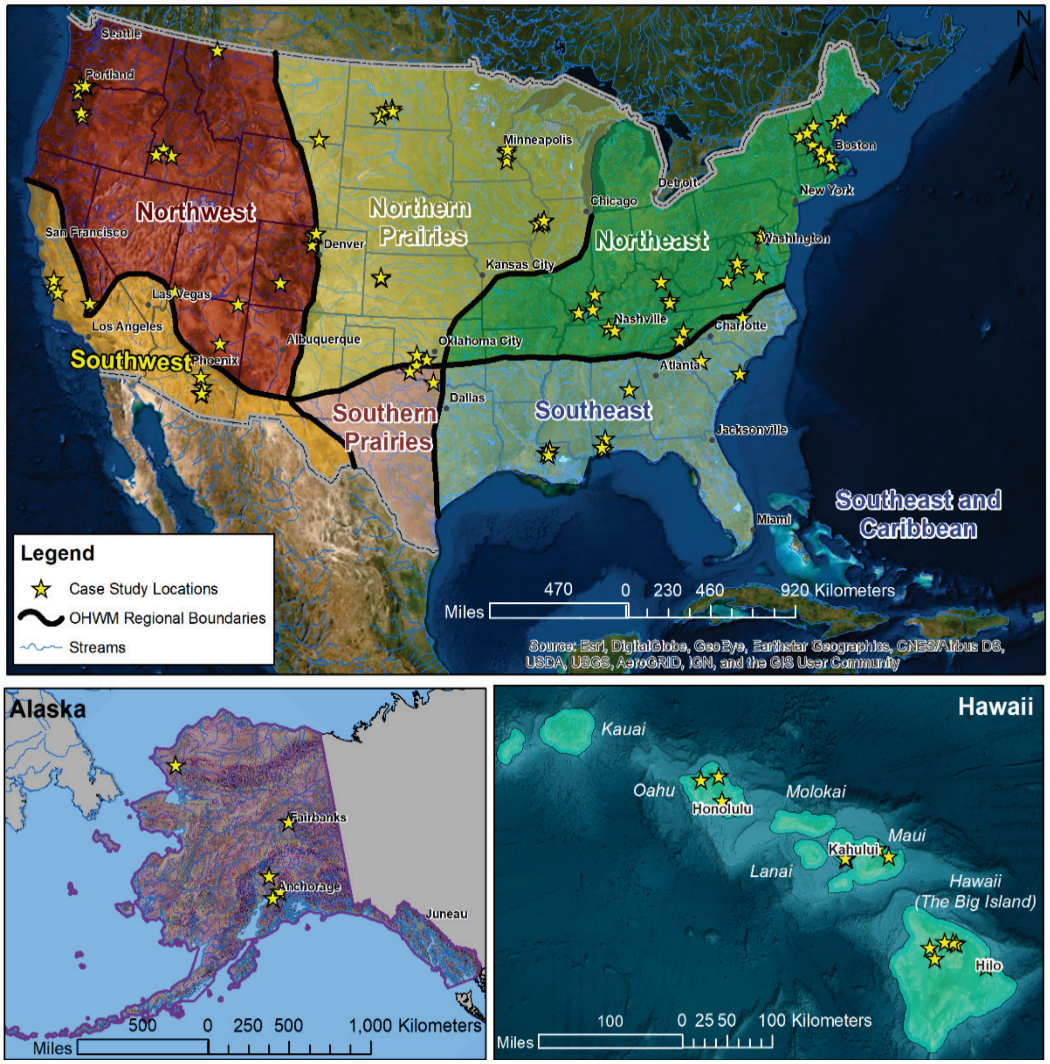
This is the first manual to describe a consistent approach for identifying these physical features in different climatic regions nationwide to support OHWM delineation, and it is the result of several years of effort by the standing National Technical Committee (NTC-OHWM) and extensive nationwide field work. Previous technical reports on OHWM identification and delineation covered only a portion of the United States, mainly the arid and mountainous West (Lichvar and Wakeley 2004; Lichvar and McColley 2008; Mersel and Lichvar 2014), and lacked explanations of how the physical features that characterize the OHWM can differ in different climatic and geographic regions of the country. In 2016, a technical report, *Synthesizing the Scientific Foundation for the Ordinary High Water Mark Delineation in Fluvial Systems* (Wohl et al. 2016), provided the foundational science underlying the processes that control the formation of the physical features that are used to identify the OHWM. The NTC-OHWM produced this scientific synthesis report to provide a scientific foundation for the development of the current manual and planned regional manuals. In this synthesis report, the country was divided into eight regions: Northeast, Southeast and Caribbean, Northern Prairies, Southern Prairies, Northwest, Southwest, Alaska, and Hawaii. These OHWM regions were determined based on climatic and vegetation boundaries. Figure 1 shows the regional boundaries and the location of the case studies presented throughout this manual.

This manual will improve the consistency of OHWM identification within regions by

- providing consistent definitions of OHWM indicators (Chapter 2);
- outlining a clear, step-by-step process for identifying the OHWM using a weight-of-evidence (WoE) approach (Suter 2016; Chapter 3 and Appendix B of this text);
- providing a data sheet for logging information at a site (Box 1 and Appendix B);
- describing how to put streams and the observed physical features in a landscape context to better interpret observations (Chapter 4); and
- providing examples of how to include further support for difficult OHWM delineations (Chapters 5, 6, and 7).

Geomorphic and ecological complexity, and the intensity and timing of both natural and anthropogenic disturbances, can contribute to uncertainty in OHWM identification. Therefore, additional lines of evidence can be integrated with field data to support OHWM identification at challenging sites. *Natural disturbances* include flooding, landslides, debris flows, and fires, whereas *anthropogenic disturbances* include activities such as damming, mining, channelization, urbanization, logging, agriculture, and cattle grazing. Chapters 6 and 7 contain examples of OHWM delineation at locations that recently experienced these disturbances. Before covering each of these topics, Sections 1.1.1 and 1.1.2 provide some background on why OHWM varies between regions and define some commonly used terminology. Project objectives, how this manual was developed, and the approach used for identifying the OHWM are in Sections 1.2 and 1.3.

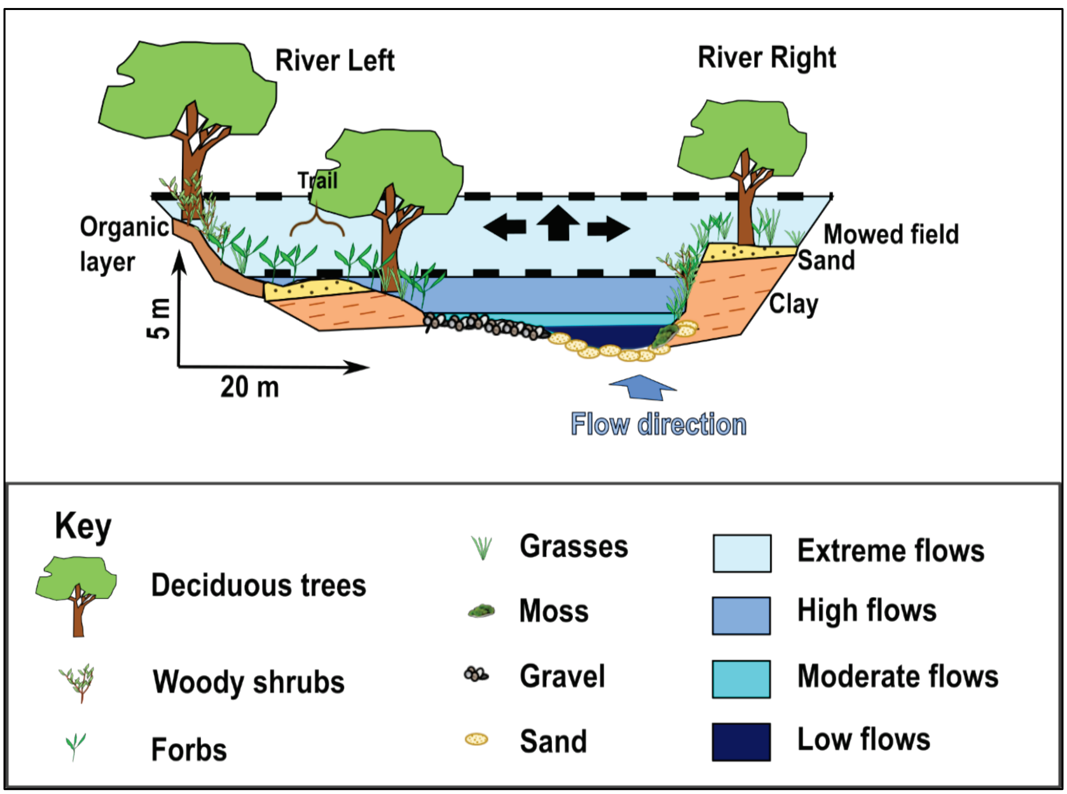
Figure 1. Regional boundaries for identification of the ordinary high water mark (OHWM) in streams across the United States. Boundaries are based on climate and vegetation. *Stars* indicate the locations of case study sites used throughout this manual.



1.1.1 Understanding why there is variability in the ordinary high water mark (OHWM)

The complications in delineating the OHWM are due to site-specific variability in landscape processes, vegetation, geology, topography, and land use that cause the physical characteristics described in the federal definition to be expressed on the landscape in very different ways. Channel shape can be influenced by location within the watershed, the dominant types of precipitation events that occur, sediment loads and characteristics, and past and present natural and anthropogenic disturbance events. Similar to bankfull, the physical characteristics used to identify the OHWM are often shaped by a variety of flows in a channel, not just the flows corresponding with the OHWM (Figure 2). Therefore, these physical characteristics are generally considered *flow indicators* because they can be created on the landscape from low, moderate, high, and extreme flows. High-water marks are the physical characteristics that are connected to high flows, rather than low or extreme flows, and are the assembled evidence for identifying the elevation of the OHWM. Seasonal changes in vegetation, snow cover, and ice can further complicate delineations made during different times of year. These factors explain why the OHWM and its position in channel corridors vary across sites. Therefore, this manual provides a method for investigating site-specific characteristics and aids in the decision-making process required for identifying the OHWM.

Figure 2. Flow categories within a stream cross section, represented as low, moderate, high, and extreme flows. The *solid black lines* between the flows were determined from analyzing USGS streamgage and Hydrologic Engineering Center's River Analysis System (HEC-RAS) flow modeling (Hamill and David 2021). The *dashed line* between the high and extreme flows was determined using geomorphic evidence at a site and represents a potential high-flow boundary. The *upper dashed line* represents an arbitrary maximum extreme flood. The *arrows* represent that extreme flows can be larger than the maximum represented in the cross section.



Despite being used as a regulatory boundary for over a century, the federal definition of OHWM does not refer to a specific frequency of high water.

Previous work on characterizing the OHWM and relating it to flood frequency showed that relying on physical indicators leads to greater consistency in identifying the OHWM (Curtis et al. 2011). Nevertheless, flood frequency can be useful for estimating the types of flows that are forming the physical marks left on the landscape. The definition points toward an ordinary high water (OHW) elevation, which excludes extreme flows but includes high flows or small, frequent flood flows that fill a river or stream to capacity and often go overbank. Small, frequent flood flows are defined based on the hydrologic definition of high flows being at the lower end of a flood-frequency curve; therefore, they are not necessarily all overbank flows, as the term *flood* implies (Hamill and David 2021).

Figure 2 shows the general flow categories that will be represented in stream cross sections throughout this manual. There can be confusion in terminology and in describing flows; therefore, the following descriptions characterize flows used throughout this manual. Generally, flows are divided into categories defined as low, moderate, high, or extreme. *Extreme flows* are defined as relatively rare events that generally overtop stream banks and deeply submerge the floodplain. However, there are many cases in stream channels in which flows that overtop a bank are not extreme. Therefore, the upper boundary of high flows in Figure 2 is shown only as a potential upper boundary of high flow, where flows are beginning to submerge the floodplain on river left. The extreme-flow category is a gradient of high to extreme flows in any given stream channel, and the transition from one flow category to the other is more of a gradual transition than a fixed line and can be better understood by examining flood-frequency curves (Section 5.4). Stream–wetland complexes (SWCs) are examples of the dynamic nature of stream systems and represent cases in which small, frequent flood flows regularly submerge a floodplain (Chapter 6). *High flows*, which include small flood flows that go overbank, submerge the greatest percentage of the cross section to the top, and sometimes over the top, of the banks. Determinations of whether flows are within the channel or overbank should consider that channel banks are often subtle and inset within larger terraces. Therefore, overbank flows may be confined within a higher set of bank-like geomorphic features that are above the active channel (Section 2.3.1.1). Because higher flows in streams usually occur in response to a storm event and rise and fall quickly, low and moderate flows occur most of the time. *Low flows* and *moderate flows* include base flows, with the division between low and moderate flows being drawn at the mean annual flow elevation. The predominance of low flows throughout the year results in the average flow being pulled toward the lower end of the range of flow magnitudes measured at a location. The mean annual flow most often takes up less than half of a bankfull cross section. Exceptions to this are ephemeral streams, in which larger, infrequent discharges pull the average flow toward the upper end of the range of measured flow magnitudes. Identifying evidence of these high flows is key to conducting a field identification of the OHWM. Additional descriptions of the field methods used to measure these cross sections and the flow modeling used to determine the elevations of the low, moderate, and high flows can be found in Chapter 5 of this text and in Hamill and David (2021).

The lateral extent and spatial distribution of low and high flows can exhibit very different appearances based on the relative area inundated in different channel types. For instance, a braided channel may have a much wider area that is inundated during a high-flow event, whereas high flows in anastomosing or meandering channels may access secondary channels or just fill the stream to the top of the banks. Figure 3 provides examples of three different channel types at a low- and high-flow stage. The high-flow stage would likely be at, or near, the OHWM, active channel, and bankfull channel in each of these simplified channel types.

Figure 3 shows flows that are mostly contained within the channel or that sometimes go just above the lip of the top of the bank in braided, anastomosing, and meandering systems. Streams are dynamic and diverse systems, so there will be special cases in which high flows are not always contained within the more obvious channel banks and, therefore, the OHWM will be above the active channel. For instance, there are special cases, such as SWCs (Figure 4), aggrading channels, or runoff-enhanced urbanizing watersheds, in which high flows frequently overtop stream banks and, therefore, the OHWM occurs high up on the floodplain, rather than near the tops of the stream bank. Many of these special cases and the evidence supporting OHWM identification beyond the channel banks are described in more detail in Chapters 6 and 7.

Figure 3. Low- and high-flow stages in braided, anastomosing, and meandering channels. The high-flow stage encompasses the active channel in each of these systems. (Braided channel image adapted from Suazo-Davila et al. 2013)

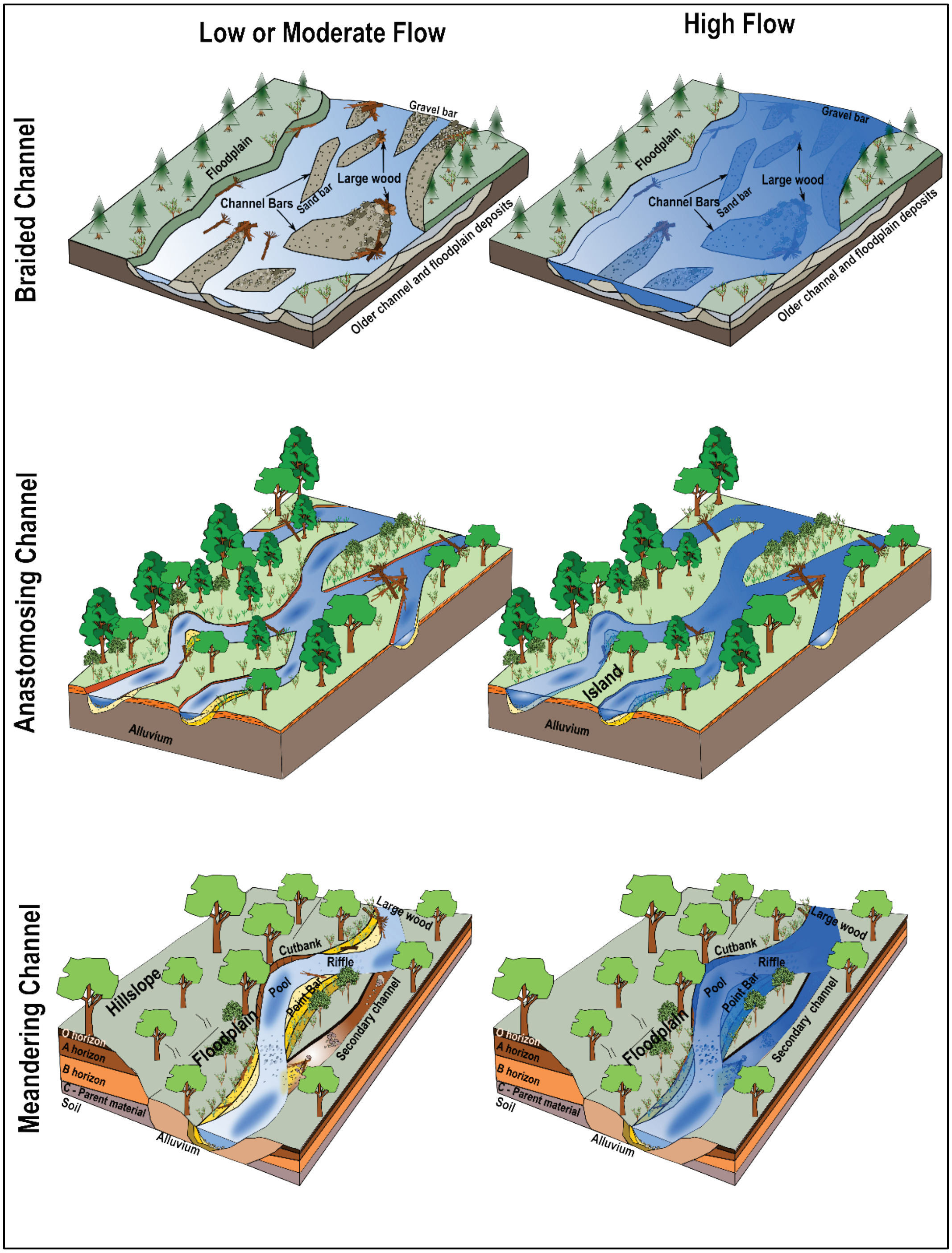
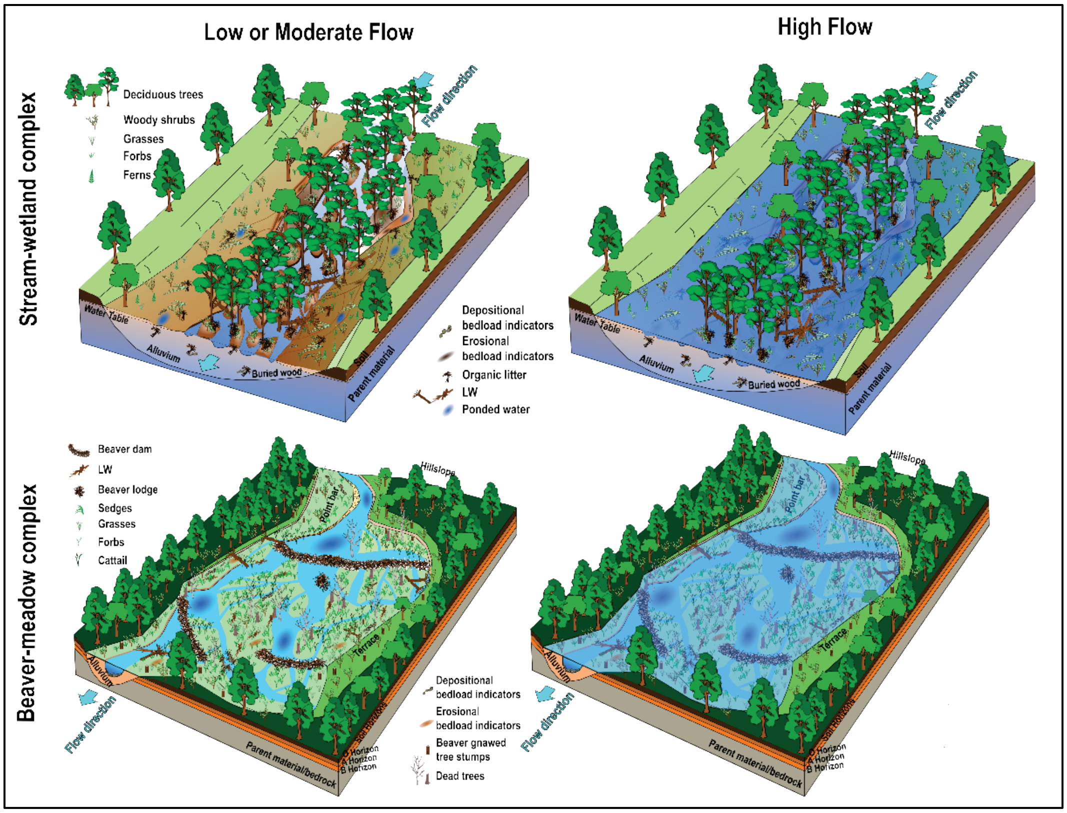


Figure 4. Low-or-moderate- and high-flow stage in two different types of stream–wetland complexes (SWCs).

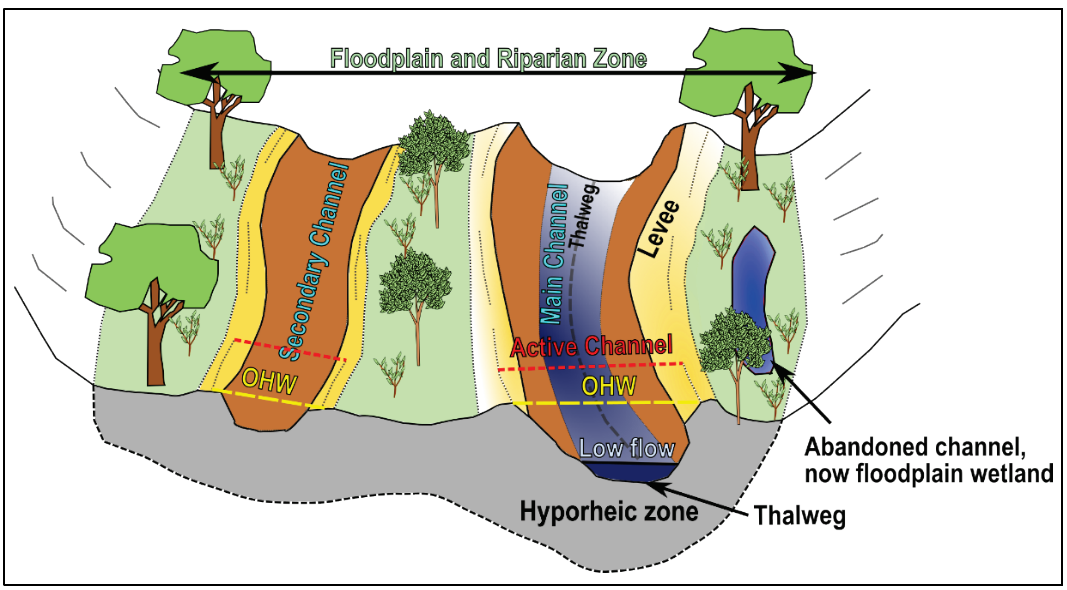


The OHWM is not a static line and can change over both time and space. Situations in which the OHWM may change over time, including changes in water or sediment deliveries and vegetation—and many of the disturbance factors that drive them—are discussed in Chapters 6 and 7. The spatial differences in the OHWM within a short segment of a channel are discussed throughout. Although often represented in schematics as a flat surface for ease of demonstrating the elevation of water flowing through a channel, water does not flow through a stream as a flat surface (Figure 2). When a water surface is measured, the elevation is averaged to represent a flat surface. Spatial variability in velocity and flow depth can cause the water stage to be higher in some locations and lower in others. As water flows around a channel bend during high flows, for example, it will be at a higher stage on the outside of the bend. Similarly, water heights may rise where roughness elements cause velocities to decrease. Furthermore, the elevation of the OHWM will adjust with the channel gradient. Therefore, the OHWM may occur at slightly different elevations in the lateral and longitudinal directions.

1.1.2 Review of the relationship between the OHWM and the active and bankfull channels

The OHWM is used to distinguish the regulatory boundaries of a stream as a feature that is distinct from the surrounding landscape or stream corridor (Figure 5). Before describing the many indicators used to identify the OHWM (Chapter 2), a common understanding of terms used to characterize a stream is needed. The definitions of physical features used throughout this manual are based on the scientific synthesis report published by the NTC-OHWM (Wohl et al. 2016). The *stream corridor* is defined as the portion of any landscape that has been created by river erosion through time and remains connected to the contemporary stream, at least during small, frequent floods. The stream corridor includes the active channel, the adjacent floodplain and riparian zone, secondary channels, the zone in which the active channel migrates, and the underlying hyporheic zone.

Figure 5. Block diagram showing the stream corridor with the location of active channels (*dotted red lines*) and the ordinary high-water (OHW) level. In this example, the main channel has a perennial low flow, and the secondary channel is nonperennial. Both the active channel and the OHW level are at the top of the natural levee (*yellow shading*). Above the levee, flow would no longer be contained within the channel and would spread across the floodplain, which does not show evidence of being inundated by frequent high flows. The floodplain and riparian zone make up the valley bottom in this diagram. (Image adapted from Wohl et al. 2016.)



1.1.2.1 OHWM and active channel

Active channel and *bankfull channel* are often used to describe the same physical characteristics that encompass the upper limit of frequently occurring fluvial processes within the channel boundaries. Active channel is a phrase that is used widely but inconsistently. Wohl et al. (2016) detailed the many definitions used in scientific literature to describe the active channel. Generally, the phrase is used (1) to denote the unvegetated portion of the channel (e.g., Johnson 1994) or (2) to describe the section of channel below which the banks slope steeply (e.g., Osterkamp 2008). These two interpretations of active channel can result in the identification of very different portions of the channel, particularly in systems in which vegetation changes seasonally or following a flood event. This document follows from Wohl et al. (2016, p.5), who stated that an active channel can be determined using three primary criteria: An active channel can be

- "any portion of a valley bottom [i.e., floodplain] within channels defined by erosional and depositional features created by [ongoing] river processes," with the exception of overbank sedimentation and "as opposed to upland processes such as sheet flow or debris flow (this criterion is particularly useful for rivers with multiple channels, such as braided rivers)" (Figure 5);
- "the upper elevation limit at which water is contained within a channel as opposed to spreading across the floodplain or valley bottom" (though, for deeply incised channels, the upper elevation of the enlarged channel may be above the active channel); and
- "portions of a channel generally without trunks of mature woody vegetation (the active channel can include newly germinated woody seedlings or various wetland ecological response species, including rooted aquatic macrophytes such as sedges or rushes. In very small channels, the roots of mature woody vegetation can cross the channel), where coarse sediment is mobilized and transported during annual flooding."

The active channel will commonly meet at least one of these criteria, but rarely will all three apply in any given river system. Figure 5 demonstrates that the active channel and elevation of the OHW can occur at the same stream stage; *stage*, here, is defined as the elevation of water surface usually above some datum level. The active channel is meant to define that portion of the floodplain that is covered by water intermittently over a period of a few years; this is similar to boundaries that are being identified to delineate the OHWM (Wohl et al. 2016), although the OHWM may be located on floodplains above the active channel (Figure 4). The active channel often distinguishes the channel from the floodplain. The floodplain begins at the top of the channel banks. Because of diversity in landscape processes and varying physical characteristics, many streams have flows that frequently overtop the active channel. For such streams, the OHWM occurs beyond the top of the banks and on the floodplain and, in some cases, at the floodplain–upland boundary (Dunne and Leopold 1978; Wohl et al. 2016). Wohl et al. (2016) discuss connections between the OHWM and the active channel in more detail. Overall, the OHWM and active channel are expected to approximately coincide in streams with limited variability in discharge through time, but they may not be the same in streams with greater variability in flows.

1.1.2.2 OHWM and bankfull channel

Bankfull channel is the scientific concept most associated with the regulatory definition of the OHWM. The morphologic definition of bankfull and OHWM are similar in that they are both broad descriptions of vertical elevation thresholds at which physical and vegetative transitions will occur. Table 1 summarizes similarities between the two concepts by comparing the regulatory definition of the OHWM to the scientific descriptions of bankfull.

Table 1. Comparison of definition of the OHWM to descriptions of bankfull.

OHWM definition from 33 CFR 328.3(c)(7)[1]	Bankfull descriptions with references
"A clear, natural line impressed on the bank, shelving"	The boundary between the active channel and floodplain commonly exists as a clear, natural line impressed on the bank of a river (Wolman and Leopold 1957).
"Changes in the character of soil"	The boundary between the active channel and surrounding floodplain creates hydraulic conditions what will cause a transition between river sediment and soils on an adjacent floodplain (Leopold and Skibitzke 1967).
"Destruction of terrestrial vegetation"	Terrestrial vegetation is commonly destroyed by the hydraulic forces associated with frequent flows below bankfull discharge (Leopold and Skibitzke 1967).
"The presence of litter and debris"	Litter and debris will likely be deposited and persist above bankfull discharge (Leopold and Skibitzke 1967).

[1] In a regulatory guidance letter (RGL 05-05), USACE (2005) explains, "There are no 'required' physical characteristics that must be present to make an OHWM determination." Any of these features may be missing or masked depending on the site conditions.

In many streams, the boundaries of bankfull channel, active channel, and the location of the OHWM will correspond or closely overlap. However, the OHWM may differ because of variations in landscape processes between regions or sites or because of channel-change dynamics caused by localized effects on the channel from human-built features (e.g., dams, bridges, and riprap) or natural disturbances (e.g., floods, fires, debris flows, landslides, and rockfalls).

1.1.2.3 Understanding similarities and differences among bankfull, dominant, and effective discharges

Bankfull is a scientific concept that is characterized in terms of channel geometry (i.e., morphology) by identifying the bankfull elevation or is defined in terms of flow (i.e., discharge) by identifying the discharge that fills the channel to the top of the banks (Williams 1978). Many scientific studies explore concepts connected to bankfull, but this has sometimes led to conflicting and inconsistent definitions. The definition of bankfull and how it is characterized depends on the specific stream processes being investigated by each of the scientific studies. A simple morphologic definition of *bankfull discharge* is the flow that fills a channel up to the top of the banks (Wolman and Leopold 1957). Banks may be defined by low, relatively subtle features compared to other more prominent morphological features, such as terraces. Wolman and Leopold's (1957) study focused on defining the elevation at which flow began to pour out onto the floodplain so that they could better understand the frequency of flood flows and floodplain formation. Other studies focused on channel geometry and the flows that are responsible for shaping the channel (Wolman and Miller 1960).

Wolman and Miller (1960) defined a *dominant discharge* as one that carries enough sediment over time to maintain the current channel geometry. They hypothesized that large floods, although effective in occasionally causing dramatic channel change, were too infrequent to control channel geometry over extended periods of time. Furthermore, frequent flows, such as base flows, are ineffective in terms of eroding or carrying sediment and, therefore, do not shape the channel. In certain perennial streams, the bankfull discharge is the flow that does the most work and, therefore, can be equated to the dominant discharge. A dominant discharge, or a discharge that does the most work, is a theoretical concept of a flow that, over time, would carry the most sediment (Wolman and Miller 1960).

Sometimes the term *effective discharge* is used as well. Effective discharge is an empirical concept that is based on using observed sediment and flow data and calculating the discharge that does the most work. The concepts of dominant and effective discharge are useful for characterizing flows because they help scientists understand which flows are responsible for shaping observed channel characteristics, such as the tops of channel banks. Therefore, these concepts are useful for understanding the types of flows that leave behind the persistent landscape characteristics (i.e., high-flow indicators) used to identify the OHWM.

Based on high variability in bankfull flow frequencies, the OHWM is not connected to a specific recurrence interval but is a result of a range of flows; this is similar to what is documented in the literature regarding bankfull channel morphology (Knighton 1998; Tal and Paola 2007; Vargas-Luna et al. 2019; Naito and Parker 2019). Any frequency of flow connected to the OHWM will vary greatly across different climatic and landscape settings. The frequency of the high-water stage associated with the OHWM may be a 1.01-year event (see discussion that follows) in one stream and a 10- to 15-year event, or more, in another (Curtis et al. 2011; Wohl et al. 2016; Hamill and David 2021). Flood-frequency curves are discussed in greater detail in Section 5.4, but the key to interpreting return periods is to remember that they are statistical probabilities that a flow of that size or larger will occur in any given year. Therefore, a 1.01-year event has a 99% chance of occurring in any given year, but that does not mean that a flow will only occur once that year. In general, large, infrequent flows will have a more enduring influence on channel form in streams in which moderate flows are infrequent or the bed and bank are resistant to erosion. Moderate-magnitude flows are relatively infrequent in arid regions and in small headwater catchments, so larger infrequent flows are more likely to leave a persistent mark in those environments. Over time, smaller flows rework changes that were made by a large flood flow (Baker 1977; Wohl et al. 2016). Erosion resistance may be encouraged by vegetation, bedrock, and coarse substrate along the channel boundaries. Recovery following extreme or high flows can vary with climatic and landscape setting (Wolman and Gerson 1978) and so can affect the longevity of high-water marks. For instance, drier regions have slower soil development and vegetation growth than more mesic regions. However, other processes, such as wind erosion, may more quickly mask high-water marks in regions that have sparse vegetation. The concepts of bankfull discharge and the OHWM are described in more detail in Section 4.3.

There are many stream systems in which the channel geometry is unlikely to be controlled by bankfull flows. For instance, streams in New England that have experienced continental glaciation sometimes flow through bedrock channels that were shaped by glaciers (Snyder et al. 2009, 2012; Wilkins and Snyder 2011). Bedrock streams are a channel type that is more likely shaped by extreme events, and therefore, the morphology may not be representative of current landscape processes. In these bedrock channels, the bankfull concept is not as useful for understanding channel-shaping flows. However, evidence of the OHW level can still occur and be used to understand what channel segments are frequently inundated in contemporary landscapes.

The concepts of bankfull and active channels tend to focus on how streams function on average, but they do not necessarily encompass every channel type in every region of the country. Many of the simplest definitions are based on characterizing meandering channels in the mid-Atlantic or Midwest regions. Streams are dynamic and diverse systems, so there will be special cases in which they are hard to characterize based on these simplified definitions. Because of the evident linkages between the OHWM and bankfull, all the scientific research behind bankfull can be useful in understanding and characterizing the OHWM.

1.2 Objective

The purpose of this manual, the first technical guide to describe differences in OHWM identification and delineation across the entire nation, is to guide the user through an assessment of field indicators that can be applied to any type of stream to identify the lateral and longitudinal location of the OHWM. Once high-water marks are identified, a line can be drawn to connect and delineate the location of the OHWM. The manual provides definitions and detailed descriptions of stream characteristics that are used as OHWM indicators. For sites with challenging OHWM indicators, the manual provides a process for identifying supporting evidence to delineate the OHWM. Therefore, methods and findings presented in this manual should be regarded as the most current information and supersede information in previously published technical reports supporting OHWM delineation (Lichvar and Wakeley 2004; Lichvar and McColley 2008; Mersel and Lichvar 2014; Gartner, Lichvar, et al. 2016; Gartner, Mersel, Lefebvre et al. 2016; Gartner, Mersel, and Lichvar 2016).

Topics that are not fully covered in this national manual will be covered in future regional manuals, with regions defined based on the boundaries illustrated in Figure 1. Regional manuals will be supplemental to the guidelines provided in this national manual and focus on providing additional examples to help users make more consistent and objective determinations within each region. Any forthcoming updates to the existing Arid West and Western Mountain regional manuals (Lichvar and Wakeley 2004; Lichvar and McColley 2008; Mersel and Lichvar 2014) will include additional information that is not covered by older manuals or this national manual.

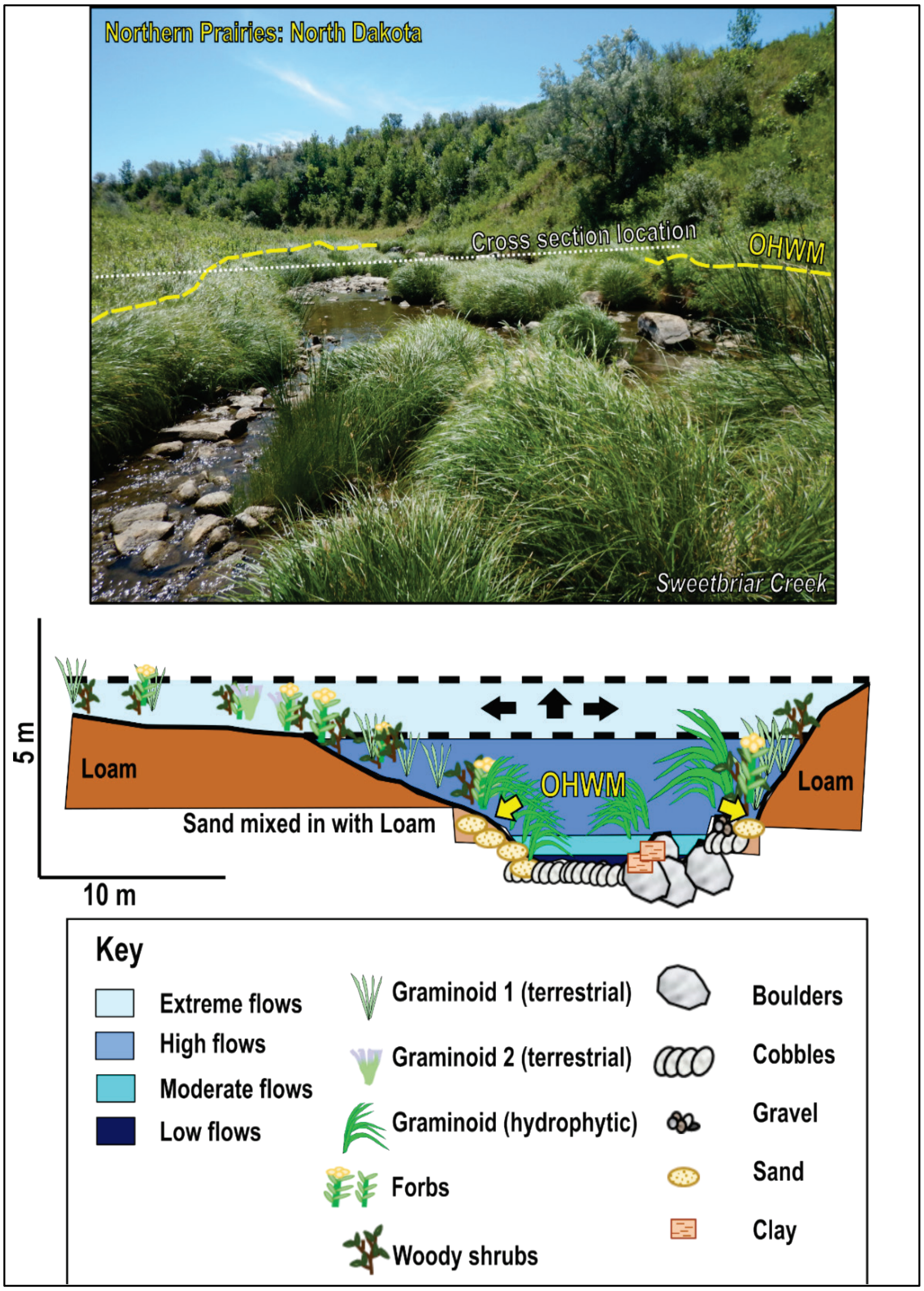
1.3 Approach

1.3.1 Approach for development of this manual through collection and analysis of field data

Throughout this manual, regional case studies are provided to aid the user in identifying the described stream characteristics in various geologic and climatic settings. Case studies include photographs taken in the field and surveyed cross sections. Twenty-eight of the surveyed sites were adjacent to USGS stream gaging stations. Detailed cross sections were surveyed using either a total station or real-time kinematic GPS receivers at these locations. High-flow indicators were surveyed as well. The bed grain size was measured using a Wolman pebble count, where 150–300 pebbles were counted at each site. The lower number was used at sites with a consistent grain size throughout. Stream channel slopes were measured in the field but were also extracted using remotely sensed data, such as lidar. All these data were used together to develop flow models in Hydrologic Engineering Center's River Analysis System (HEC-RAS) for each of these locations (Hamill and David 2021).

Flow data are combined with field survey data throughout this manual to clearly show users the flows that are connected to the observed physical characteristics identified as high-water marks (Figure 6). All cross sections are vertically exaggerated to help illustrate changes in the vertical dimension that may be more subtle in the field. *Vertical exaggeration* is simply when the vertical scale is larger than the horizontal scale (e.g., 1 m on the vertical scale is equal to 5 m on the horizontal scale).

Figure 6. A surveyed cross section in the Northern Prairies region showing flow data and other physical characteristics. Photographs throughout this manual include site information, such as region and state, in the upper corners and the stream name in the lower corners. This example shows where the weight-of-evidence (WoE) supports the identification of the OHWM on the cross section and how combining observed evidence of high-water marks along the bank can allow a delineation of the OHWM elevation in the photograph.



The flow boundaries are determined by hydrologic information from nearby USGS streamgage stations and flow models developed in HEC-RAS. The development of these models is discussed further in Hamill and

David (2021). Chapter 5 contains a more detailed discussion of the hydrologic data. Remote and other types of data, such as satellite imagery, topographic maps, geologic data, and lidar, were also collected and used to evaluate each site. Chapter 5 includes a discussion on using supplementary information, and Chapters 6 and 7 include more detailed case studies showing examples of using this information.

In addition to sites with detailed cross-sectional and flow data, the manual includes several case studies in which cross-sectional data were collected using a laser range finder or points were collected with a GPS and notes and photographs were taken regarding the surrounding physical characteristics. These cross sections are shown with flow levels corresponding to the day the site was surveyed. There are 120 sites spanning all study regions included in this manual. Twenty-eight of those sites were at streamgages and include detailed cross-sectional data. Twenty-five more include cross-sectional data collected in the field but were not located near a streamgage. Photographs, location data, and observations were collected at the rest of the sites. The photographs, descriptions, and examples from these sites are included throughout the manual.

The NTC-OHWM played a large role in the development of the manual. The NTC-OHWM met annually from 2013–2019, in different regions of the country, to identify and discuss problematic situations when identifying the OHWM. The annual meetings and quarterly conference calls also involved continued review, organization, and editing of the developing procedure and manual to assure they met end-user needs. Furthermore, members of the NTC-OHWM interviewed regulatory personnel from each region of the country to discuss problematic OHWM identification situations within those regions and to collect input on what information was needed in a national manual.

1.3.2 Development of approach for OHWM delineation

This manual provides a process for identifying the OHWM using stream characteristics observed in the field; it also provides information on how to use other lines of evidence to support field delineations. A data sheet and field procedure are included to guide users through the step-by-step process of identifying the OHWM (Box 1, Box 2, and Appendix B). Observed stream characteristics are considered indicators of streamflow and are divided into four categories of indicators in the data sheet: geomorphic, sediment, vegetation, and ancillary. Each indicator on the sheet is described in more detail in Chapter 2 of this manual, and examples and photographs from selected regional settings (Figure 1) are used as case studies.

Box 1. Data sheet (page 1) for recording the physical evidence used for OHWM identification. (Data sheet reproduced from USACE 2022, 1).

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U.S. Army Corps of Engineers (USACE)

RAPID ORDINARY HIGH WATER MARK (OHWM) FIELD IDENTIFICATION DATA SHEET

The proponent agency is Headquarters USACE CECW-CO-R.

From Approved -
OMB No. 0710-OHWM
Expires: xx-xx-xxxx

AGENCY DISCLOSURE NOTICE

The public reporting burden for this collection of information, 0710-OHWM, is estimated to average 30 **minutes** per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding the burden estimate or burden reduction suggestions to the Department of Defense, Washington Headquarters Services, at whs.mc-alex.esd.mbx.dd-dod-information-collections@mail.mil. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

Project ID #:	Site Name:	Date and Time:
Location (lat/long):	Investigator(s):	

Step 1 Site overview from remote and online resources
Check boxes for online resources used to evaluate site:

- ☐ gage data ☐ LiDAR ☐ geologic maps
- ☐ climatic data ☐ satellite imagery ☐ land use maps
- ☐ aerial photos ☐ topographic maps ☐ Other: ______

Describe land use and flow conditions from online resources.
Were there any recent extreme events (floods or drought)?

Step 2 Site conditions during field assessment. First look for changes in channel shape, depositional and erosional features, and changes in vegetation and sediment type, size, density, and distribution. Make note of natural or anthropogenic disturbances that would affect flow and channel form, such as bridges, riprap, landslides, rockfalls, etc.

Step 3 Check the boxes next to the indicators used to identify the location of the OHWM.
OHWM is at a transition point, therefore some indicators that are used to determine location may be just below and above the OHWM. From the drop-down menu next to each indicator, select the appropriate location of the indicator by selecting either just below `b', at `x', or just above `a' the OHWM.
Go to page 2 to describe overall rationale for location of OHWM, write any additional observations, and to attach a photo log.

Geomorphic indicators

- ☐ **Break in slope:**
  - ☐ *on the bank:*
  - ☐ *undercut bank:*
  - ☐ *valley bottom:*
  - ☐ Other: ______
- ☐ **Shelving:**
  - ☐ *shelf at top of bank:*
  - ☐ *natural levee:*
  - ☐ *man-made berms or levees:*
  - ☐ *other berms:* ______
- ☐ **Channel bar:**
  - ☐ *shelving (berms) on bar:*
  - ☐ *unvegetated:*
  - ☐ *vegetation transition (go to veg. indicators)*
  - ☐ *sediment transition (go to sed. indicators)*
  - ☐ *upper limit of deposition on bar:*
- ☐ **Instream bedforms and other bedload transport evidence:**
  - ☐ *deposition bedload indicators (e.g., imbricated clasts, gravel sheets, etc.)*
  - ☐ *bedforms (e.g.,pools riffles, steps, etc.):*
  - ☐ *erosional bedload indicators (e.g., obstacle marks, scour, smoothing, etc.)*
- ☐ **Secondary channels:**

Sediment indicators

- ☐ **Soil development:**
- ☐ **Changes in character of soil:**
- ☐ **Mudcracks:**
- ☐ **Changes in particle-sized distribution:**
  - ☐ *transition from* ______ to ______
  - ☐ *upper limit of sand-sized particles*
  - ☐ *silt deposits:*

Vegetation Indicators

- ☐ **Change in vegetation type and/or density:**
  Check the appropriate boxes and select the general vegetation change *(e.g., graminoids to woody shrubs).* ***Describe the vegetation transition looking from the middle of the channel, up the banks, and into the floodplain.***
  - ☐ *vegetation absent to:*
  - ☐ *moss to:*
  - ☐ *forbs to:*
  - ☐ *graminoids to:*
  - ☐ *woody shrubs to:*
  - ☐ *deciduous trees to:*
  - ☐ *coniferous trees to:*
- ☐ **Vegetation matted down and/or bent:**
- ☐ **Exposed roots below intact soil layer:**

Ancillary indicators

- ☐ **Wracking/presence of organic litter:**
- ☐ **Presence of large wood:**
- ☐ **Leaf litter disturbed or washed away:**
- ☐ **Water staining:**
- ☐ **Weathered clasts or bedrock:**

Other observed indicators? Describe:

ENG FORM 6250, AUG 2022 PREVIOUS EDITIONS ARE OBSOLETE. Page 1 of 4

Box 2. Data sheet (page 2) that contains spaces for the rationale for the OHWM determination, a photograph log, and further descriptions and observations. (Data sheet reproduced from USACE 2022, 2).

Print Form | Save As | E-mail

Project ID #: ____________________

Step 4 Is additional information needed to support this determination? ☐ Yes ☐ No If yes, describe and attach information to datasheet:

Step 5 Describe rationale for location of OHWM

Additional observations or notes

Attach a photo log of the site. Use the table below, or attach separately.

Photo log attached? ☐ Yes ☐ No If no, explain why not: ____________________

List photographs and include descriptions in the table below.

Number photographs in the order that they are taken. Attach photographs and include annotations of features.

Photo Number	Photograph description

ENG FORM 6250, AUG 2022 Page 2 of 4

Note that many of the indicators listed in Box 1 are similar to those in the guidance provided by the US Army Corps of Engineers (USACE 2005) in a regulatory guidance letter (RGL 05-05; Table 2). Recognizing that streams are highly complex systems, space is provided so that the user can include additional indicators that may be particular to certain regions or channel types. Similar to the guidance in USACE RGL 05-05, there are no specific physical characteristics that must be present to delineate the OHWM. Therefore, the WoE method is described in the section that follows to assist with organizing observations and coming to the most credible conclusion for the location of the OHWM.

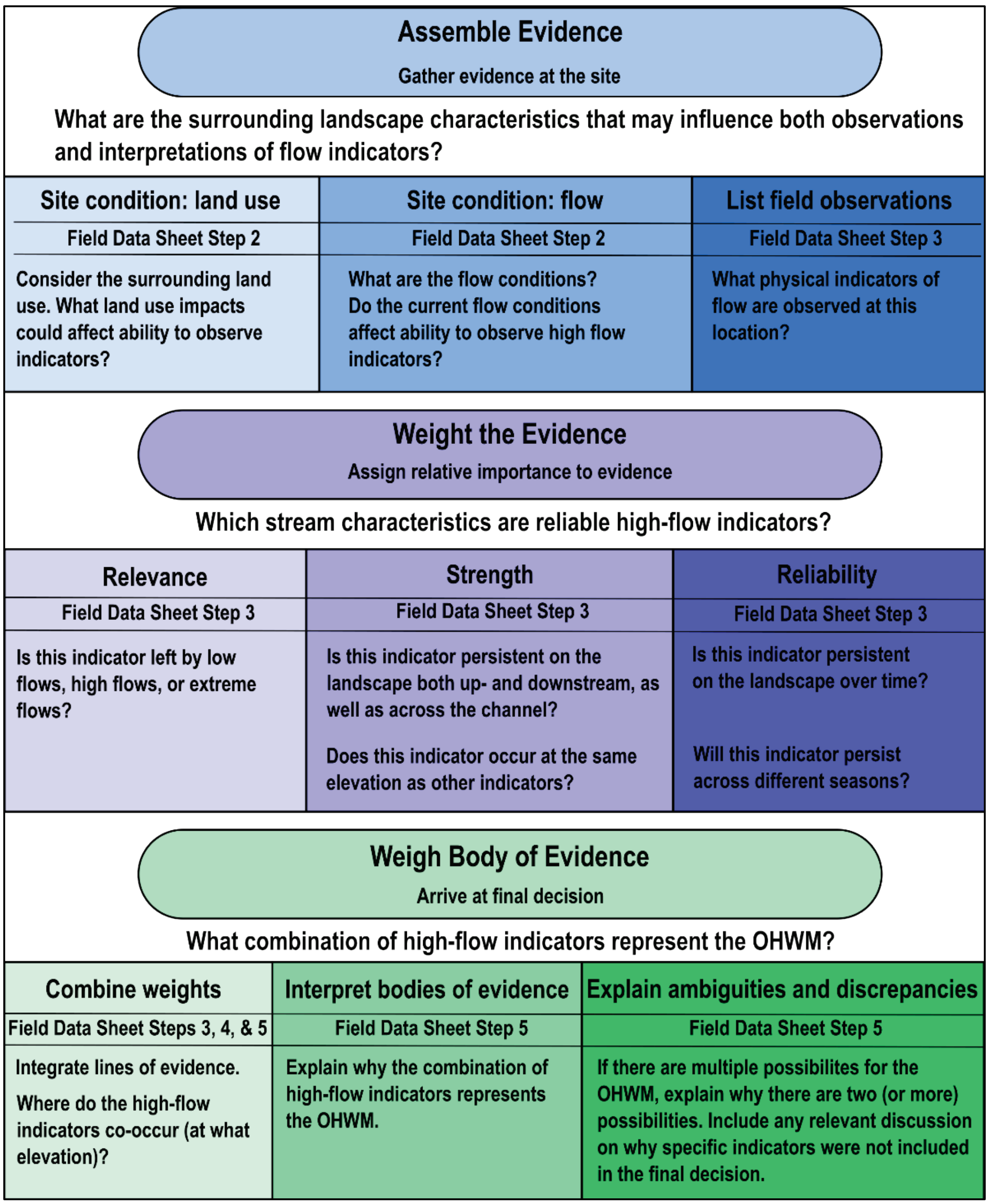
Table 2. Physical characteristics, listed in regulatory guidance letter (RGL) 05-05 (USACE 2005), used to identify the OHWM.

Physical Characteristics Used to Identify the OHWM	
Natural line impressed on the bank	Sediment sorting
Shelving	Leaf litter disturbed or washed away
Changes in the character of soil	Scour
Destruction of terrestrial vegetation	Deposition
Presence of litter and debris	Multiple observed flow events
Wracking	Water staining
Vegetation matted down, bent, or absent	Change in plant community

1.3.3 Identifying the OHWM using a scientific methodology called weight-of-evidence (WoE)

This manual relies on WoE, a well-established scientific methodology, for identifying the OHWM (Linkov et al. 2009; Suter 2016). The WoE approach, which is an inferential process to assemble, evaluate, and integrate different lines of evidence (Suter 2016), provides a way to determine the significance of observations and to combine those observations to arrive at scientifically supported conclusions (Linkov et al. 2009). The WoE approach is presented here to help users organize observations into lines of evidence and determine the relative significance of each of those lines. Many users may find they were already applying this scientific process but did not have it documented in a clear, step-by-step way. WoE is how well lines of evidence (e.g., physical marks left by high flows) are connected to a specific conclusion or alternative conclusion, such as the location of the OHWM or of an extreme flood event (Linkov et al. 2009). Many of the stream characteristics described in Box 1 and Table 2 are simply characteristics of streamflow. Therefore, a WoE approach integrates the lines of evidence occurring on the landscape into the most credible location for the OHWM (Figure 7). In some cases, those lines of evidence may point to a clear conclusion on the location of the OHWM in a few minutes; in other cases, the lines of evidence may take more time to interpret because of the complexity of the setting. This approach is outlined here to help users formalize methods they were already applying and to improve consistency in how those methods are applied in the decision-making process. The WoE approach is described for field investigation, but it can also be used when evaluating online resources. Applying this approach to online data will be described further in Chapter 5.

Figure 7. WoE approach, summarizing the process used for OHWM identification. Associated steps from the OHWM data sheet (Box 1) are noted below each WoE subcategory. The WoE method is described for the field portion of the process. A WoE approach can also be used for Step 1 (assembling remote and online resources), which will be described separately in Ch. 5.



To apply the WoE approach to identify the OHWM, the physical characteristics, or indicators, occurring on the landscape first need to be recognized and interpreted. Chapter 2 provides a detailed description of each of the indicators included on the data sheet. Chapter 3 gives a step-by-step example of how to use the data sheet (Box 1 and Box 2) and apply a WoE approach to identify the OHWM in the field in both a complex (Sections 3.2–3.7) and a simple (Section 3.8) setting. The OHWM is determined from the WoE of high-flow marks that persist on the landscape (Figure 7). Chapter 4 describes placing the site in a landscape context to assist with understanding the observations being made on the ground. Chapter 5 describes using other supporting evidence for an OHWM identification in complex situations. Last, Chapters 6 and Chapter 7 describe the effects of anthropogenic and natural disturbances on the physical characteristics of streams and approaches for identifying OHWM thus affected. Chapters 5, 6, and 7 include case studies that provide information on using satellite imagery, lidar, and streamgage data.

2 Field Identification of the OHWM Indicators

2.1 Key points

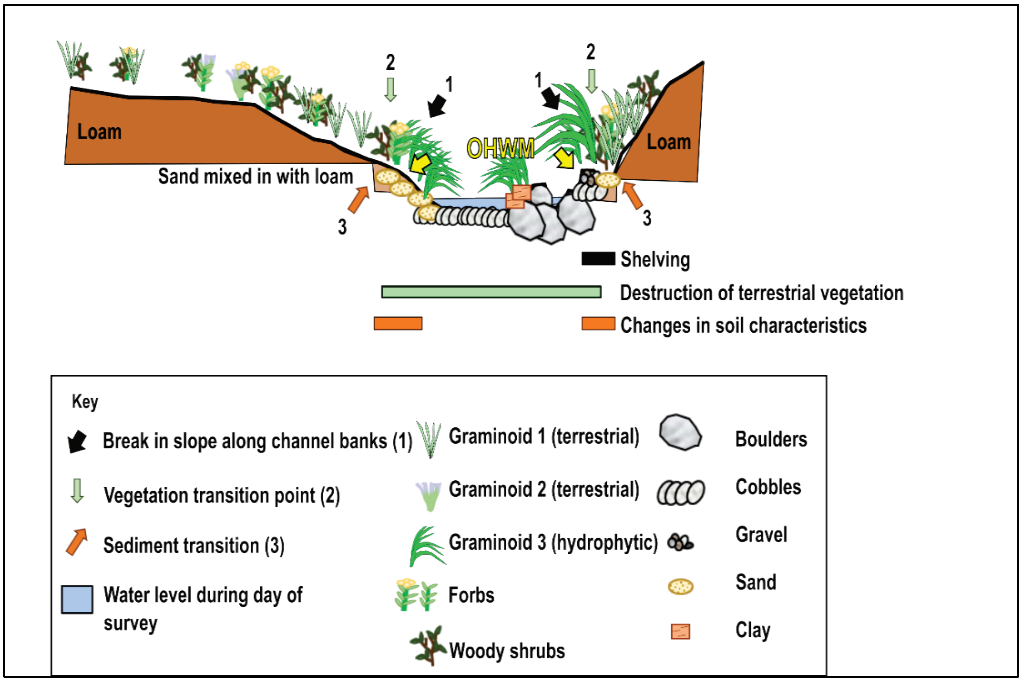
The OHWM is identified through physical characteristics that correspond to a break in bank slope, a transition in vegetation type and coverage, and changes in sediment characteristics (Wohl et al. 2016). First, it is important to understand the definition of each indicator and how the appearance of each can change based on channel type and regional differences in these characteristics (Figures 3 and 4). This chapter describes each indicator, listed in Step 3 of the data sheet (Box 1), that could be observed in a stream corridor and the underlying processes connected to the formation of those indicators (Figure 5). Wohl et al. (2016) provide a further description of landscape characteristics in a stream corridor.

2.2 Overview of identifying OHWM indicators

The definition of OHWM in 33 CFR 328.3(c)(7), which was a "line on the shore established by fluctuations of water," points to key characteristics for identifying its location in the field; these characteristics include (a) a clear, natural line impressed on the banks; (b) shelving; (c) changes in the character of soil; (d) destruction of terrestrial vegetation; (e) presence of litter and debris; and (f) other appropriate means of identification. However, no specific type of physical characteristic must be present to make an OHWM determination (USACE 2005). A break in slope, or *inflection point*, along the banks is the transition point that can be associated with shelving, or a clear, natural line impressed on the banks. The natural line observed on the shore can be from a number of stream characteristics, such as the break in slope (2.3.1.1), erosional bedload indicators and the deposition of sediment (2.3.1.4), weathered clasts or bedrock (2.3.1.4), changes in particle size distribution (2.3.2.3), the deposition of organic litter (2.3.4.1), water staining (2.3.4.4), and transitions in vegetation type and density (2.3.3). Therefore, the data sheet (Box 1) includes all of the stream characteristics that may be creating the natural line observed along the banks as a way to provide a more specific description of that observed natural line. Changes in the character of soil and the destruction of terrestrial vegetation can be more broadly described as changes in sediment and vegetation characteristics. The variety, age structure, and density of vegetation will vary based on climatic, geologic, and land-use controls. This is also true for sediment characteristics. First, the shift from residual soils to alluvial soils may be an important transition point. Second, understanding how soil types vary across regions and adjacent to streams can assist in identifying zones of more recent alluvial deposition and areas where residual soils have been forming over a longer period of time. The OHWM occurs at transition points between the stream features and the terrestrial features; therefore, the three initial characteristics to look for when assessing a stream reach are at these transition points, where there is generally (1) a break in slope, (2) changes in sediment characteristics, and (3) a transition in vegetation type and density (Figure 8). If these initial characteristics are unapparent, then other indicators can be used to locate the OHWM (Chapters 4 and 5).

The most credible OHW elevation may occur at the transition from more hydrophytic to terrestrial vegetation types, such as upland woody shrubs (Figure 8). The OHW elevation is the hypothetical elevation of the water surface at the location of the physical characteristics along the banks identified as the OHWM. The destruction of terrestrial vegetation, in the example in Figure 8, is evidenced by the lack of woody shrubs below a certain elevation, rather than the lack of all vegetation. There are two processes to consider when discussing the destruction of terrestrial vegetation. Figure 8 provides an example of a site where the terrestrial vegetation is likely controlled by physical processes that scour and erode the banks, which can prevent or destroy the establishment of the vegetation. Another possibility for explaining the presence or lack of vegetation is the hydrology. If no water is present at a site, there may be no vegetation. At some sites, the presence of specific vegetation may be related to a shallow groundwater table. Therefore, the presence and absence of vegetation should be considered with other site characteristics. Furthermore, the transition from the absence of woody shrubs to more frequent woody shrubs in the floodplain and hillslope is one example of where the OHWM may be found for this channel type, which occurs in the Northern Prairies region. In some regions, woody vegetation grows below the OHWM. These differences will be described in more detail in Section 2.3.

Figure 8. Schematic of a stream cross section, showing the final identification of the OHWM (*yellow arrows*) by weighing the body of evidence at the elevation where three key high-water marks overlap. The physical changes in stream characteristics include (1) location of the break in slope and shelving, (2) vegetation, and (3) sediment.



A clear, natural line impressed on the banks is the first part of the regulatory definition, 33 CFR 328.3(c)(7), used to identify the OHWM, but unfortunately, such a line can be inconsistently identified based on the timing of the site visit. Visiting streams during low flows often results in observations of characteristics that are a result of low to moderate flows, not ordinary high flows. Similarly, if a site is visited soon after an extreme event, the site may be completely altered, and any natural lines impressed on the bank may be obscured by erosion, deposition, or flood debris. If a site is visited during the growing season, the natural line left by high flows can be obscured by fast-growing herbaceous vegetation. In northern regions, snow and ice will sometimes obscure high-water marks during winter months; therefore, identification of the OHWM should not be done when snow or ice masks or covers physical characteristics. The natural line identified as correlating to the OHWM should be one that persists (or is recurrently maintained by ordinary high flows) despite the season of the visit.

2.3 Definitions of stream characteristics that are used to identify the OHWM

The physical characteristics corresponding to the location of the OHWM can be divided into four indicator categories: geomorphic, vegetation, sediment, and ancillary. *Geomorphic* refers to that part of the landscape shaped by stream processes and, therefore, shaped by a range of flows. Vegetation and sediment are described separately to increase understanding of how stream processes influence vegetation growth and sediment erosion and deposition. Ancillary indicators are a separate category because they are common fluvial characteristics, such as the deposition of large wood (LW), that do not necessarily fit into the three previous categories but can assist in determining the location of the OHWM in some circumstances. This division of characteristics differs slightly from what was used by Wohl et al. (2016); they grouped geomorphic, sediment, and ancillary indicators under geomorphic indicators. Many of these physical features are a result of hydrometeorological events that produce a range of flow magnitudes. Therefore, these hydrologic indicators, as also discussed by Wohl et al. (2016), are described in more detail in Chapter 5. Landscape controls are also discussed in Chapter 4, while the effects of land use on the OHWM are discussed in Chapter 6.

2.3.1 Geomorphic indicators

2.3.1.1 Locating the OHWM along breaks in slope on stream banks

Breaks in slope can occur at various elevations on a stream bank: at the top of the bank, at the top of levees, out in the floodplain (Section 2.3.1.2), and on channel bars (Section 2.3.1.3). Breaks in slope occur because of different physical and chemical processes working on the land surface that leave behind these changes in topography. A stream bank is distinguished from the bed of the channel by a break in slope and a change in lateral gradient, from the flatter bed to the steeper bank. The bank often extends to a higher stage of flow or to the point at which there is another transition in slope where water would begin to move laterally over the floodplain surface (Wolman and Leopold 1957; Florsheim et al. 2008). This section begins by describing the characteristics of a stream bank and other types of slope breaks; floodplain and channel bar features are described in Sections 2.3.1.2 and 2.3.1.3, respectively.

Breaks in slope on stream banks can be easy to characterize when there are sharp breaks over bare sediment, but when hidden under dense vegetation growth, slope breaks at the top and bottom of the bank can be difficult to distinguish (Figure 9). Bank sloughing and the removal of vegetation by streamflow are clear signs of fluvial action and erosion. The timing of the last high-flow event, as well as the season in which the stream is observed, can determine whether the banks are exposed or hidden under dense vegetation growth. The identification of active channel banks is complicated by the possibility that relict banks remain from former conditions. Those banks may be higher than the capacity of the currently active channel and may now be terraces largely abandoned by channel incision. Thus, bank-like features should be noted and described, but they do not necessarily represent the top of the active or bankfull channel.

Figure 9. Example of a heavily vegetated bank and a vertical cutbank.

The sediment exposed in channel banks is representative of the material through which the stream is cutting. The sediment may be alluvial deposits from floodplain development, exposed strata from past processes, or exposed bedrock. Sediment exposed on channel banks is often finer grained than the bed sediment because much of it is alluvial deposits from overbank flows, but this depends on regional landscape controls. Figure 10 shows a sequence of fine- and coarse-sediment alluvial deposition on the floodplain of the Powder River in Montana.

Figure 10. Exposure of overbank deposits along a vertical cutbank on the Powder River, Montana, in the Northern Prairies region of the country. A coarser layer shows the location of gravel transported onto the former floodplain during a high-flow event. The valley bottom marked on the photograph includes both the current and former floodplain (i.e., terraces). The extent of the valley bottom is most easily distinguished in the satellite imagery, whereas the extent of the current floodplain can be better mapped with a field survey. See Moody and Meade (2008) to view the extent of the mapped floodplain.

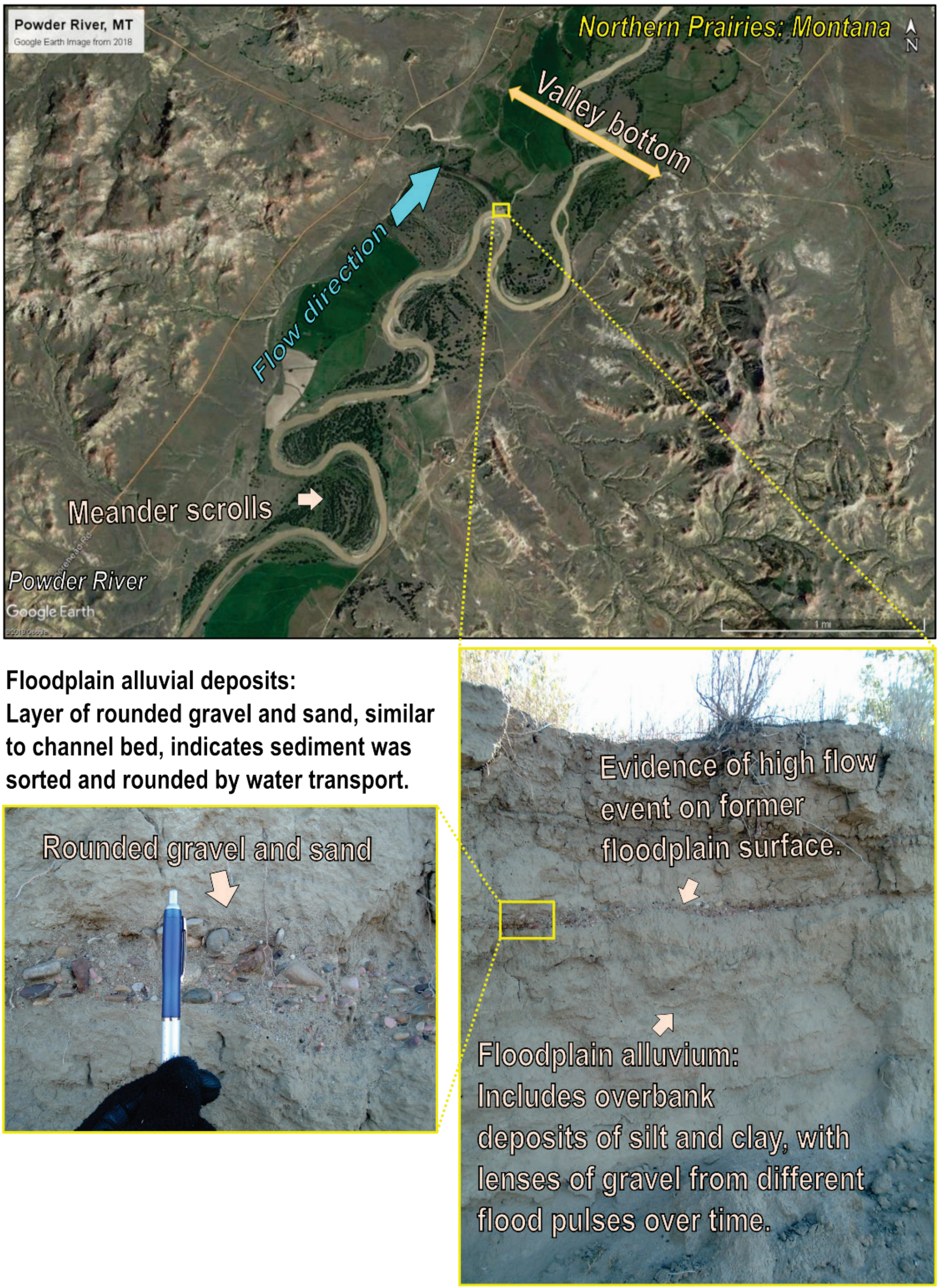
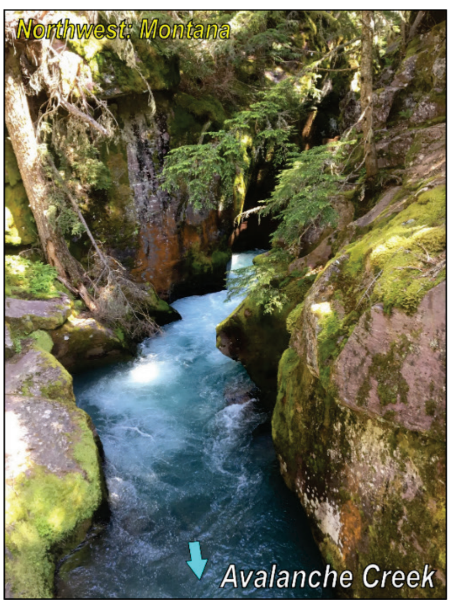


Figure 10 shows a classic example, mapped by Moody and Meade (2008), of a meandering channel flowing through a broad valley bottom composed of silt, sand, and gravel. The valley bottom described here includes both the current floodplain (i.e., a horizontally bedded alluvial landform adjacent to a channel that is built of sediment transported by the present flow regime) and river terraces, which are former floodplains (formed under prior flow regimes). Streams flow through a variety of material, depending on the geologic history of the landscape. As shown in Figure 11, Avalanche Creek flows through exposed bedrock, whereas the Weir 4 tributary to Hubbard Brook flows through old glacial till, which means that the processes that control bank formation and shape differ (Davis et al. 1985). For instance, the bedrock and large boulders are harder for these streams to erode and move, so the channel will tend to become deeper, rather than wider, during high-flow events. Therefore, the flow indicators that represent the OHWM would occur higher up the banks in these confined systems, rather than being in older, deeper layers.

Figure 11. Bedrock (*left*) and boulder-bed (*right*) channels that occur on glacially sculpted landscapes in Avalanche Creek (Glacier National Park, Montana) and Hubbard Brook Experimental Forest (New Hampshire).



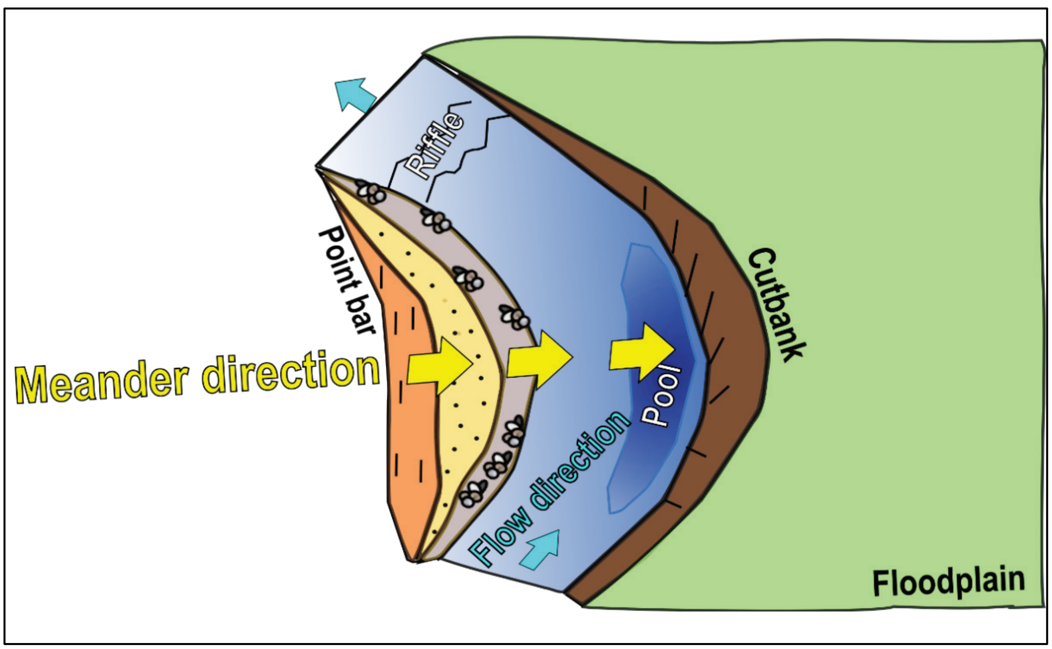
Bank erosion can be initiated by the natural processes of channel migration and channel widening (Leopold et al. 1964; Davis and Gregory 1994; González del Tánago and García de Jalón 2006; Florsheim et al. 2008). Erosion can also occur because of anthropogenic changes to the landscape or direct changes to the channel. Understanding the erosional and depositional processes at a site assists in identifying channel characteristics and, therefore, identifying characteristics connected to high flows in the channel. Vertical cutbanks and undercut banks are common stream characteristics that are part of natural channel systems and are important habitat for organisms. For instance, vertical banks in the Sacramento River in California are important bird habitat (Kondolf 2011). Undercut banks are important habitat for fish, aquatic insects, and other organisms (House and Boehne 1985; Rhodes and Hubert 1991; Myers and Resh 2000). High erosion rates can make it difficult for vegetation to establish, resulting in unvegetated vertical cutbanks (González del Tánago and García de Jalón 2006). Human activities can sometimes accelerate erosion rates in channels. Understanding the landscape context and stream characteristics that are likely to occur on that landscape can assist in identifying the OHWM in the field. The landscape context is described in more detail in Chapter 4. This section focuses on the variety of bank features that are observed around the country.

Cutbanks are common features in an actively migrating stream. Although sediment is exposed on most cutbanks, the OHWM indicators may be difficult to identify along a cutbank because the bank is actively eroding. Banks are eroded by (1) fluvial entrainment of material and (2) processes that weaken and weather bank material (Thorne 1982; Lindow et al. 2009). Fluvial entrainment erodes banks in two major ways: by moving material downstream and by scouring the toe of the bank and causing gravitational failure (i.e., slumping, sliding, or collapse) of the bank. The processes of weakening and weathering are related to climatic conditions and bank material properties. For instance, changes in soil moisture conditions during precipitation events can weaken bank material and result in slumping (Rinaldi et al. 2004). Alternately, seepage erosion and piping can cause progressive weakening of the bank material. Seepage erosion occurs where subsurface flow removes material as individual particles or in bulk and can appear as holes or cavities in the bank of a stream (Dietrich and Dunne 1993). Active erosion of a bank can be recognized through the following observations: (1) exposure of bank sediment, loose sediment, or lack of vegetation establishment; (2) high bank slope angle; (3) tension cracks and slumping of material; and (4) undercutting (Pfankuch 1975).

Figure 12 shows a general example of the meandering process, in which the stream erodes the outer part of the bend and deposits sediment on the inside portion of the bend. A break in slope and shelving occur at the break between the steep cutbank and floodplain on the outside of the bend.

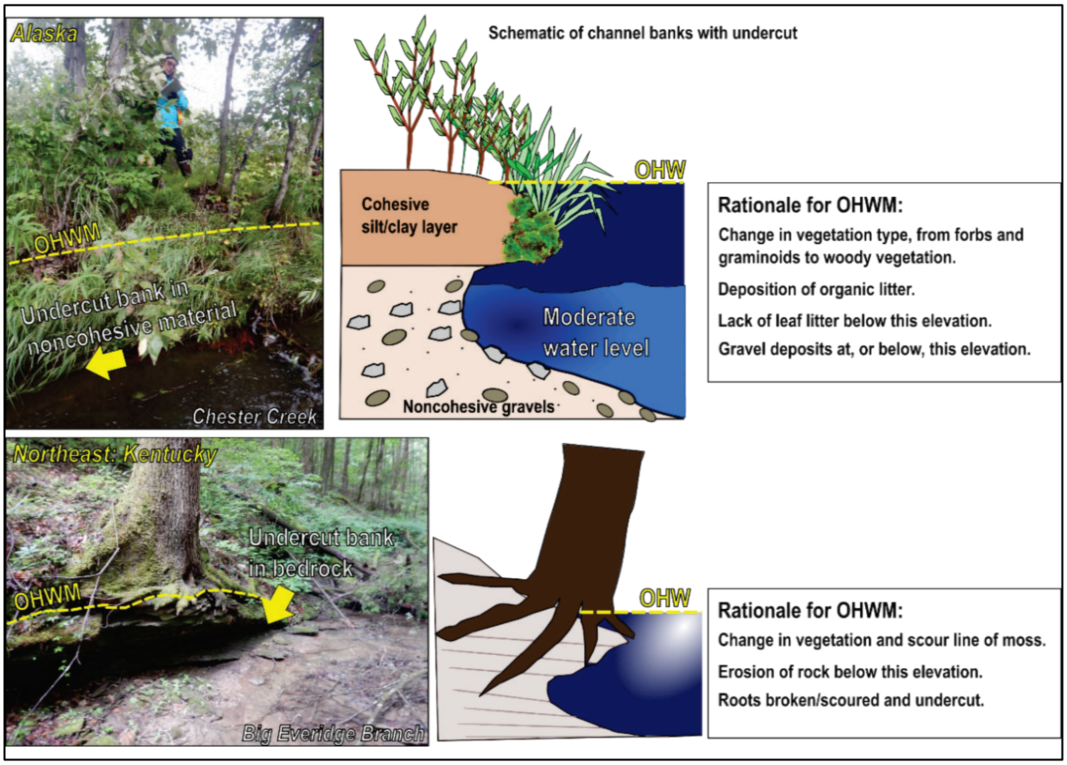
There are often multiple elevations of shelving along the point bar features, which will be discussed further in Section 2.3.1.3. The steeper the cutbank, the more active the erosional processes are likely to be on that bank. Over time, banks tend to slump and form gentler slopes. If a bank angle remains steep, then any material slumping off the bank is being actively removed by the stream. Other factors, such as the cohesiveness of banks from both the material properties and vegetation (roots), must also be considered (Thorne 1982). Silt- and clay-rich materials, for example, are cohesive and can cause banks to remain steep and vertical. The OHWM can be difficult to identify along steep cutbanks. The OHWM may sometimes be at the top of the cutbank but can also occur at a midpoint down the bank. If there is a point bar across from the cutbank, it may be easier to identify indicators along the point bar and interpolate the elevation across the channel. Remember that the water surface is rarely flat, particularly at high flows; therefore, the elevation of the OHWM can be slightly higher along the cutbank side, versus the point bar side, of the stream.

Figure 12. Generalized schematic of a cutbank on the outside of a meander bend and a point bar on the inside of a meander bend.



Undercut banks, sometimes referred to as *rooted cutbanks*, occur when the lower bank is eroded but the upper bank is held together by roots or cohesive sediment, creating a sheltering overhang (Figure 13; Harrelson et al. 1994; Finkenbine et al. 2000). High-flow features may take more time to identify with greater geomorphic and vegetative complexity, but similar attributes can still occur in these channel types. For instance, there is often a dense root mat beneath which the bank is undercut. These types of undercut banks may be stable features in the channel that provide important habitat and may often be submerged during intermediate to high flows (Overton et al. 1997; Kondolf 2011). Submerged undercut banks are formed by channel lateral migration and widening processes, in which the stream erodes the outer bank at the toe (i.e., bottom of the bank) and leaves behind the upper layer of soil held together by plant roots (Rhodes and Hubert 1991).

Figure 13. Examples of bank undercuts occurring in noncohesive material and in bedrock.

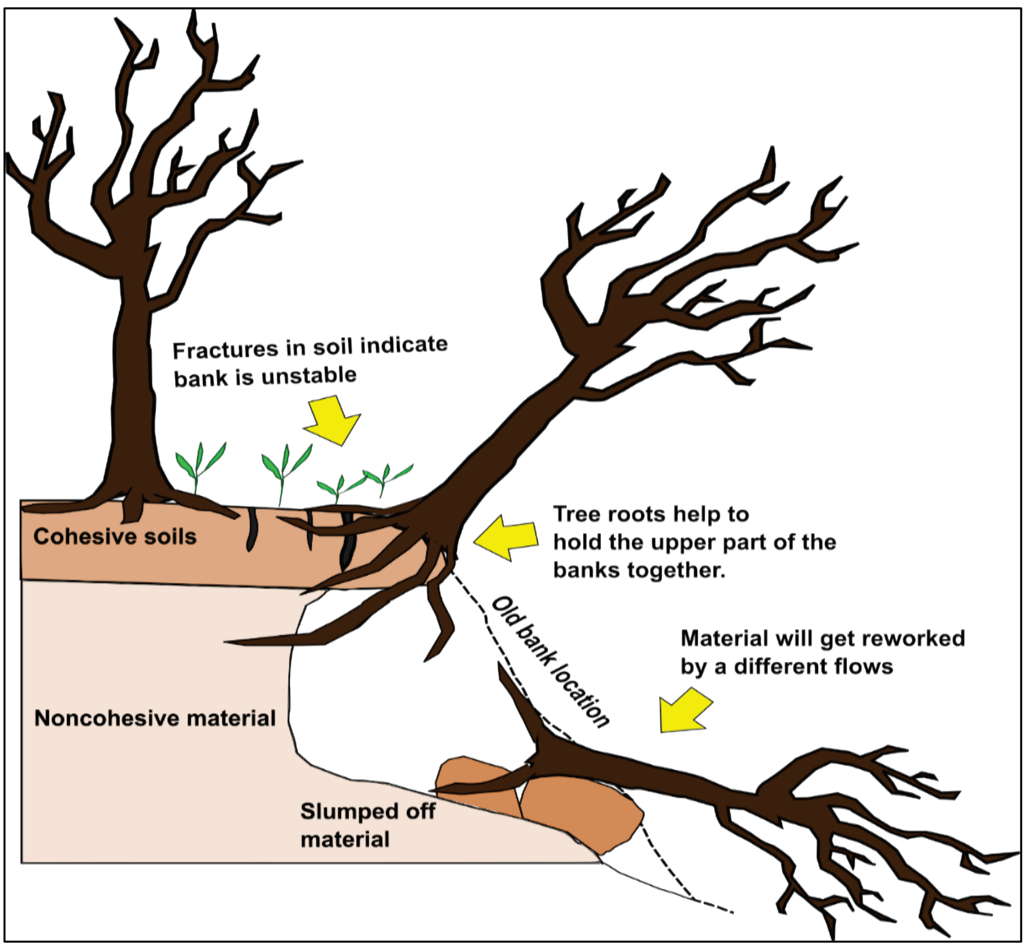


Undercutting can also be promoted by other mechanisms, such as LW in the channel, and by the weakening of bank material through piping and seepage erosion (Wilson et al. 2007; Cancienne et al. 2008; Lindow et al. 2009). LW can cause undercutting by directing flow toward the banks, increasing both geomorphic complexity and habitat diversity for both vegetation and biota (Davis and Gregory 1994; Malik and Matyja 2008; Beagle 2010; Kondolf 2011; Dugan and Rahel 2019). Biota can encourage development of macropores through burrowing (e.g., beavers and muskrats) and tree root decay (Meentemeyer et al. 1998; Menichino et al. 2015). Geomorphic complexity occurs where a variety of stream characteristics alter velocity, water depth, and bed sediment size and is often linked to corresponding habitat diversity (Wohl 2016; Castro and Thorne 2019). LW can increase complexity by altering the velocity of the water and the direction of flow and by providing habitat for stream biota (Wohl 2017). The formation of bank undercuts increases geomorphic complexity in a channel. It can also start a slow process of bank slumping and channel widening. For example, the undercut area of bank slumps into the channel, and the stream begins to incorporate that area into the main channel (Davis and Gregory 1994). Some undercut banks will collapse vertically, causing the turf from the former bank top to form a vegetated ramp that resists erosion and disguises the vertical cutbank created by the collapse. The tops of collapsed banks may appear to be high-water marks, but their elevations are generally independent of flow stage unless they have been sculpted by flows after failure.

The outward extent of the undercut can assist in determining the outward extent of the OHWM and may coincide with changes in vegetative characteristics, or other indicators listed on the data sheet, above the undercut. A survey rod, or pin-flag, inserted horizontally can help identify the length of the undercut, which can then be used to find the width of the stream near the elevation of the OHW flows (Harrelson et al. 1994). In this way, the undercut can identify where to look along and above the banks for the OHWM. This is part of the process of assembling lines of evidence at the site.

In both forested and grassland streams, undercut banks can be stable features that provide important habitat or unstable features that are part of the process of channel adjustment after a natural or anthropogenic disturbance in the watershed (Overton et al. 1997; Piégay et al. 1998). An unstable undercut bank generally shows signs of breakdown, slumping, tension cracking or fracturing, and vertical erosion (Figure 14; Bauer and Burton 1993; Overton et al. 1997). In forested channels, trees angling or falling into the channel can be a sign of bank instability. Trees can be undermined considerably by bank erosion before they fall into the channel (Keller and Swanson 1979; Davis and Gregory 1994). Root mats protect stream banks by retarding erosion (Smith 1976; Beeson and Doyle 1995). The ability of plant roots to protect banks from erosion depends on the type of vegetation, with different species of trees having differing amounts of effectiveness. A study in Australia showed that tree roots can protect a stream bank from erosion at a radius less than half of the tree canopy radius (Rutherford and Grove 2004). In herbaceous meadow systems, the dense root mats from these types of vegetation can increase bank cohesion and cause stable undercuts to form, allowing for essential fish habitat (Smith 1976; Myers and Resh 2002). The cohesiveness of grassland stream banks from riparian vegetation can be so high in comparison to forested streams that such channels may erode their beds and deepen rather than widen, indicating higher root density in these grassland streams (Trimble 1997; Hession et al. 2003). Bank undercutting beneath trees may be a result of channel incision below the mean root level. The surface populated by trees could be an abandoned terrace top, and a new floodplain with incipient bank tops may be developing at a lower level inset between the undercut trees, so look for evidence of channel-bed incision at these sites.

Figure 14. Cross section of unstable banks with fractures in the soil and trees falling into the channel.



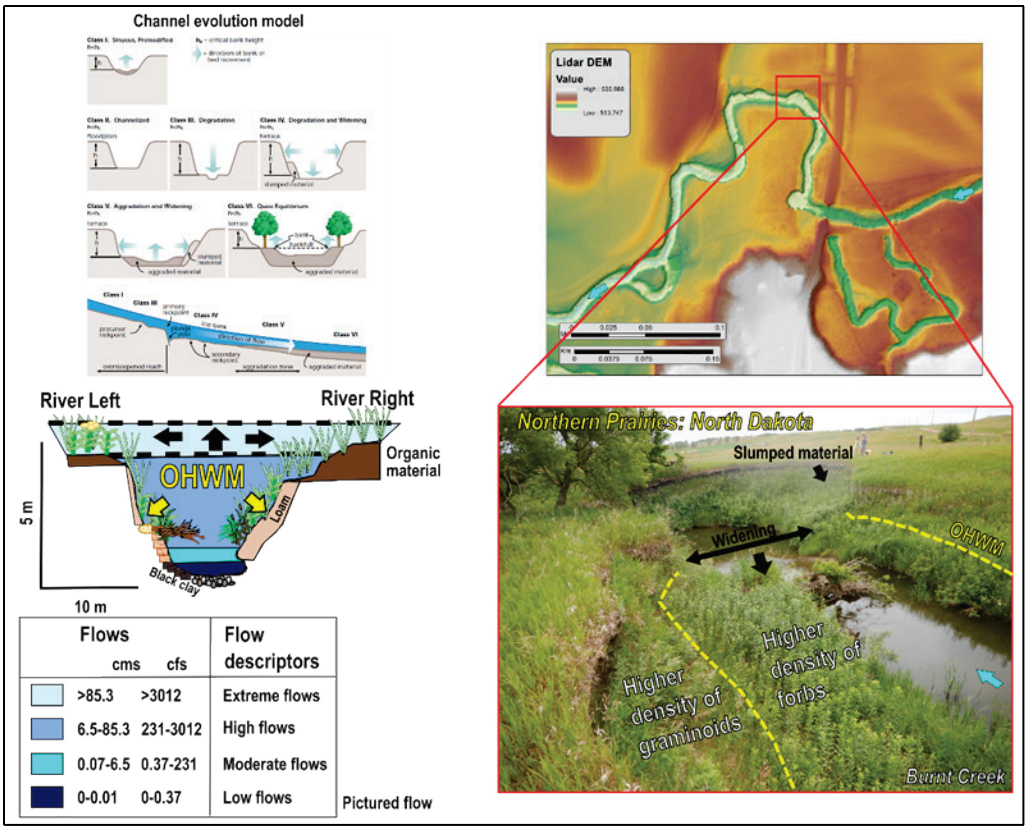
Land use in the watershed, as well as in-channel structures such as bridge piers and culverts, can alter movement of material and thus the extent and type of bank undercuts. Therefore, the stream characteristics used to identify the OHWM may differ depending on location in the watershed, adjacent land use, and distance from the nearest road–stream crossing where there may be a culvert or bridge. For instance, House and Boehne (1985) identified an area upstream of a culvert and logging activities that had LW, diverse channel morphology, and undercut banks. In the logged reach downstream of the culvert, however, the stream had been cleared of wood and had no undercut banks. LW can protect a stream bank by being buried in or positioned against it, but it can also cause instability by directing flow toward the banks (Keller and Swanson 1979).

Indications of channel enlargement from unstable banks include features such as undercut banks, exposed tree roots and tilting trees that face each other on opposite sides of the channel, trees within the channel, and erosion behind trees (Gregory et al. 1992). Figure 15 shows a bank that has slumped into the stream, bringing a tree with it, and has active erosion and deposition occurring around the slumped tree and exposed tree roots. Evidence for the area below the OHWM at this location along the banks includes (1) the change from exposed tree roots to the roots being in the soil, (2) the deposition of sand on top of vegetation and tree roots, and (3) the large wood deposit.

Figure 15. Tree slumping toward a stream on an unstable bank. The elevation at which roots are anchored into the ground, rather than the current elevation of the slumped tree, reveals the elevation of woody tree growth. The OHWM is shown as a *dashed line* and was determined from evidence on both the left and right banks.

The indicators used to identify the OHWM may depend on whether a bank is actively eroding, stable, or reforming. Channel evolution models (CEMs) describe the sequence of channel adjustments that occur in response to disturbances (Schumm et al. 1984; Simon and Hupp 1986; Watson et al. 1986; Thorne 1999; Van Dyke 2013). The stages a channel goes through when changes are made in the stream or watershed, in terms of incising, widening, and eventually reaching a new state of equilibrium, are described in detail by CEMs. Figure 16 shows the stages of incision and widening described in Federal Interagency Stream Restoration Working Group (FISRWG 1998) Simon and Rinaldi's (2006) CEM and how to interpret what is happening in a channel based on these stages.

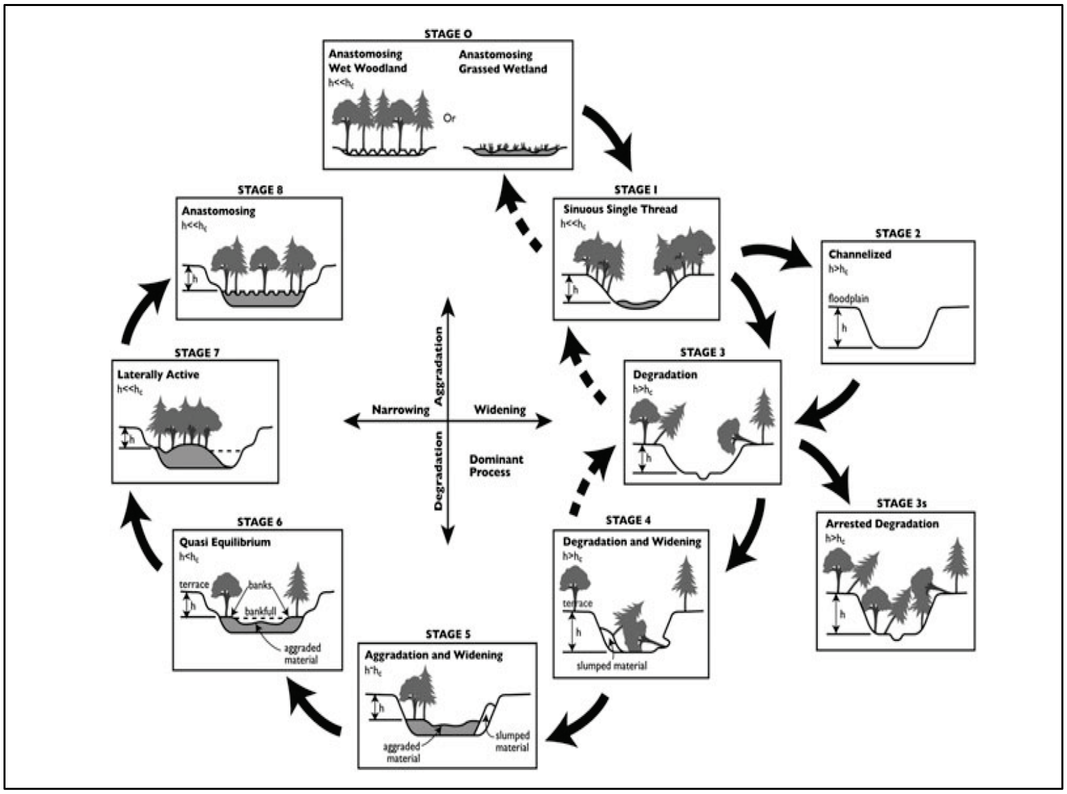
Figure 16. Example showing Burnt Creek, North Dakota, in Stage IV of Simon and Hupp's (1986) channel evolution model (CEM). (Image on *top left* adapted from USACE 1990.)



Understanding CEMs can be useful when identifying OHWM indicators associated with channels that are actively incising or experiencing subsequent bank erosion, rather than aggrading. An actively aggrading channel (i.e., one that is accumulating sediment; Section 2.3.1.3) is likely to have more channel bars than an actively incising channel (Stage III; Figure 16). Cluer and Thorne (2014) expanded on CEMs with their Stream Evolution

Model (SEM), incorporating channel adjustments to and from an anastomosing channel and an SWC (Figure 17).

Figure 17. Stream evolution model (SEM). Image reproduced from Cluer and Thorne (2014, 141), used with permission.



While the SEM and CEMs depict that undercutting occurs during channel widening phases, they do not describe channel types, such as many mountain streams, that have naturally occurring undercuts in a stable system. Nonetheless, these models describe the stream characteristics, and therefore the OHWM indicators, associated with channels actively adjusting to degradational or aggradational processes. Chapter 4 provides more details on how to identify degradational and aggradational systems and how that can assist with interpreting OHWM indicators.

Two examples of differing cutbanks formed during lateral migration are shown in Figure 18. Both channels are likely in a degradation and widening phase of the CEM. The first (Antelope Creek) is a channel in which sediment is accumulating and possibly forming a new bank, and the second (Jimmy Creek) is a channel that is actively eroding the cutbank. In Antelope Creek, the bank is armored by sediment that likely collapsed from the cutbank, accumulated, and was reworked by a range of flows in the channel, creating a gentler vegetated slope along the bottom half of the bank that slowed the lateral migration process. The collapsed portion of the bank may be armoring the cutbank. If the channel is still in the process of degradation and widening, this material will eventually be removed by channel erosion. In Jimmy Creek, conversely, the bank is being actively undercut. Roots from trees and woody shrubs are holding the upper part of the bank in place. The lack of sediment accumulating next to the bank indicates that flows with sufficiently high velocities move through this channel frequently enough to remove any sediment that erodes off the banks. Therefore, the process of undercutting and the erosion of the bank continue. Sediment is likely accumulating along the bank of Antelope Creek because the channel had not experienced a high-flow event, above a 1.01-year recurrence interval, for at least the three years prior to this survey. Following a WoE approach, the knowledge of wet and dry periods and timing since the last high-flow event helps in understanding the landscape context of these sites (Chapter 4). The relevance, strength, and reliability of the indicators along the cutbank can be weighed against the evidence up- and downstream and across the channel on the point bar. The evidence on the point bar may differ because it is a depositional environment, in which velocities of flows that submerge the bar decrease moving perpendicularly away from the channel centerline (Figure 12). Therefore, in the case of Antelope Creek, the point bar evidence on the opposite bank may be better for investigating the elevation of the OHWM than evidence along the collapsed bank.

A full cross section of Antelope Creek (Figure 19) depicts the multiple lines of evidence (i.e., WoE) used to locate the OHWM at the edge of a cottonwood tree that is growing on the point bar directly across from the bank. In this case, the OHWM corresponds with the tops of the collapsed bank, but this will not always be the case. The more reliable high-water marks are likely to be identified on the opposite bank from vertical cutbanks or collapsed bank features.

Figure 18. Cutbanks on a meander bend with accumulation of slumping material (*left*) and evidence of erosion through undercutting (*right*). Note that the location of the OHWM is delineated based primarily on evidence from the point bar across the channel and up- and downstream of the cutbanks, not from evidence shown along these cutbanks.

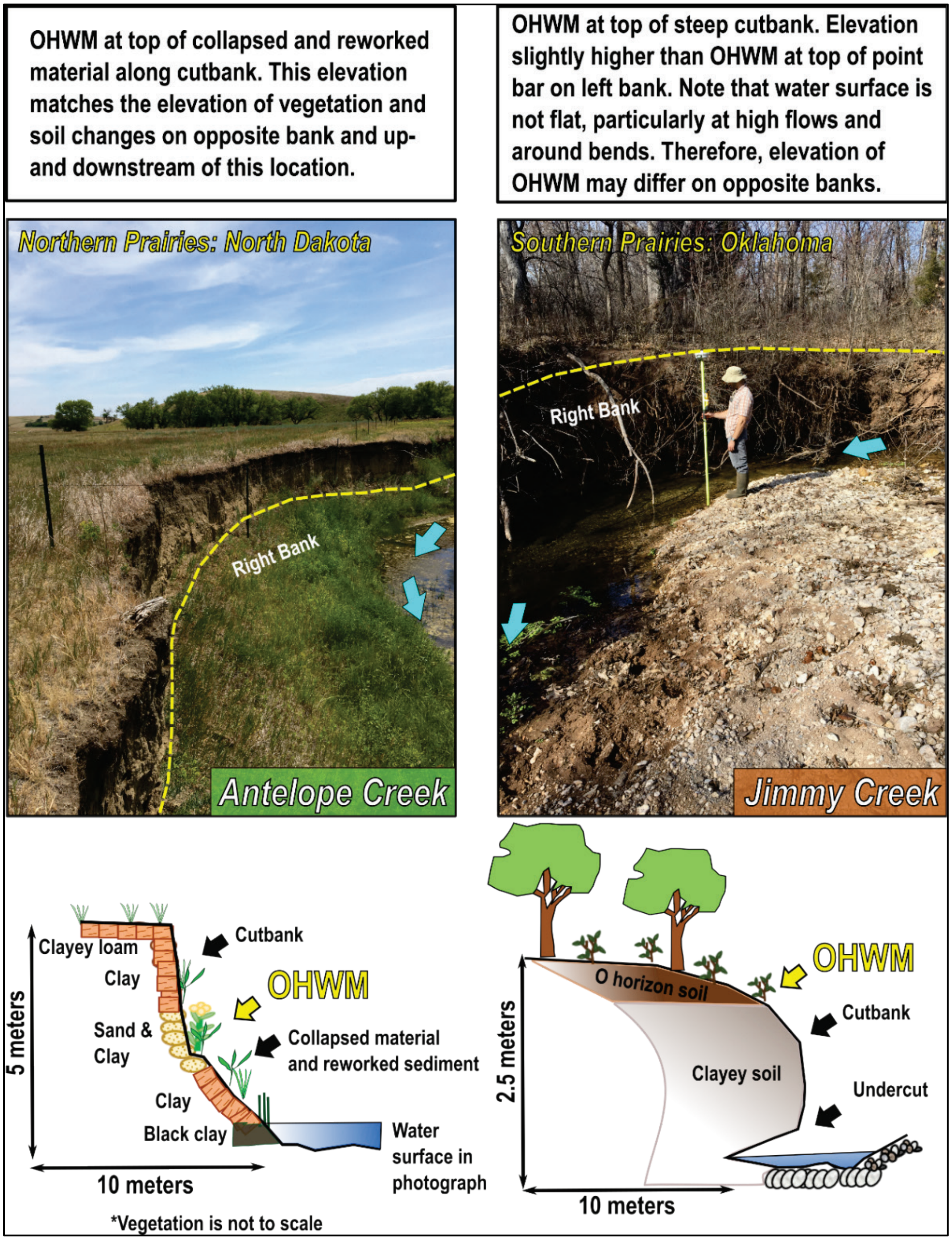
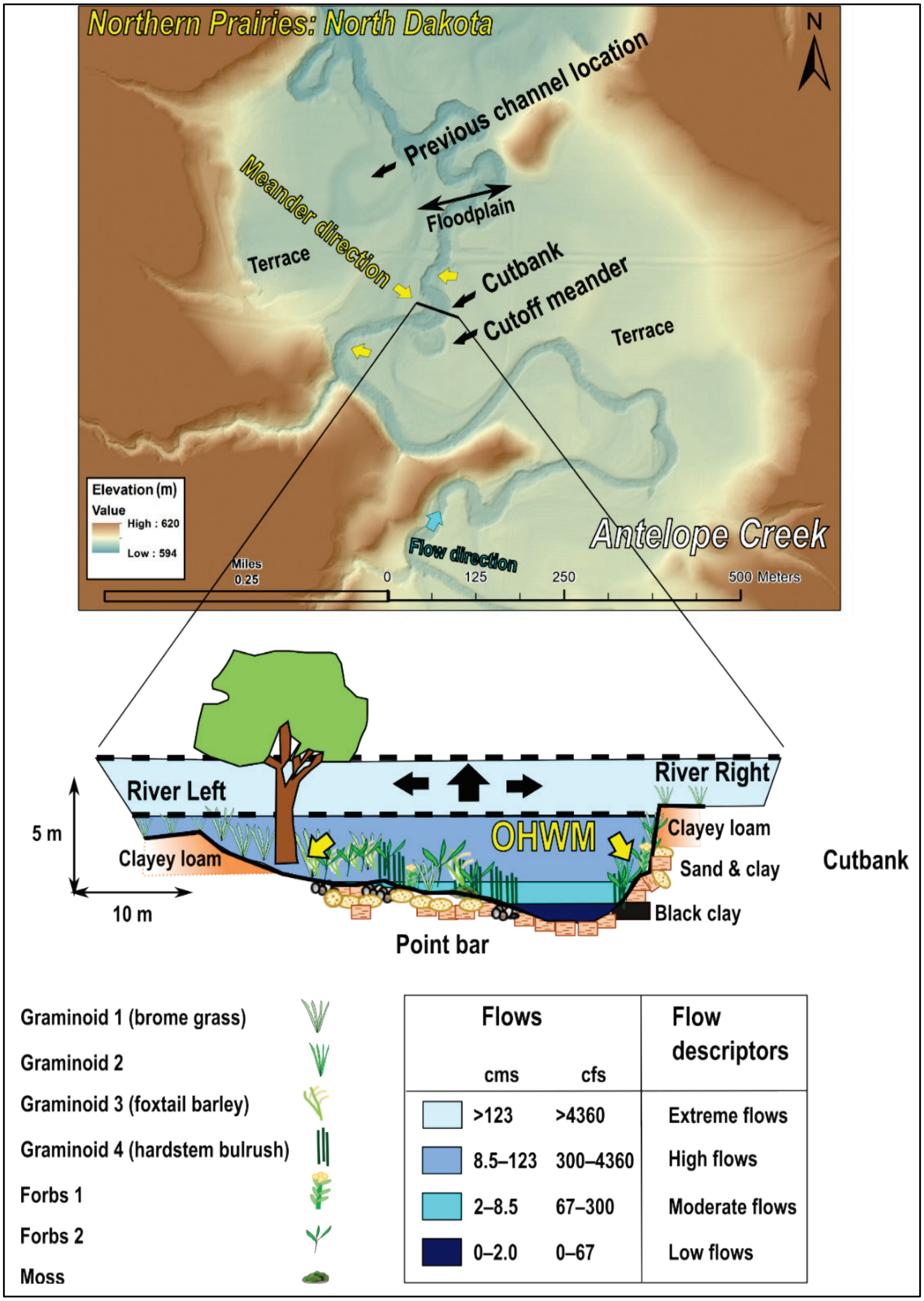


Figure 19. Plan view of a meandering channel with cutoff meanders and previous channel locations evident from hillshade and digital elevation models (DEMs) created from lidar data (*top*). The full cross section from Antelope Creek, with the point bar, flows, and location of the OHWM, is also shown (*bottom*). The change in vegetation, sediment, and slope break are all used to identify the location of the OHWM.



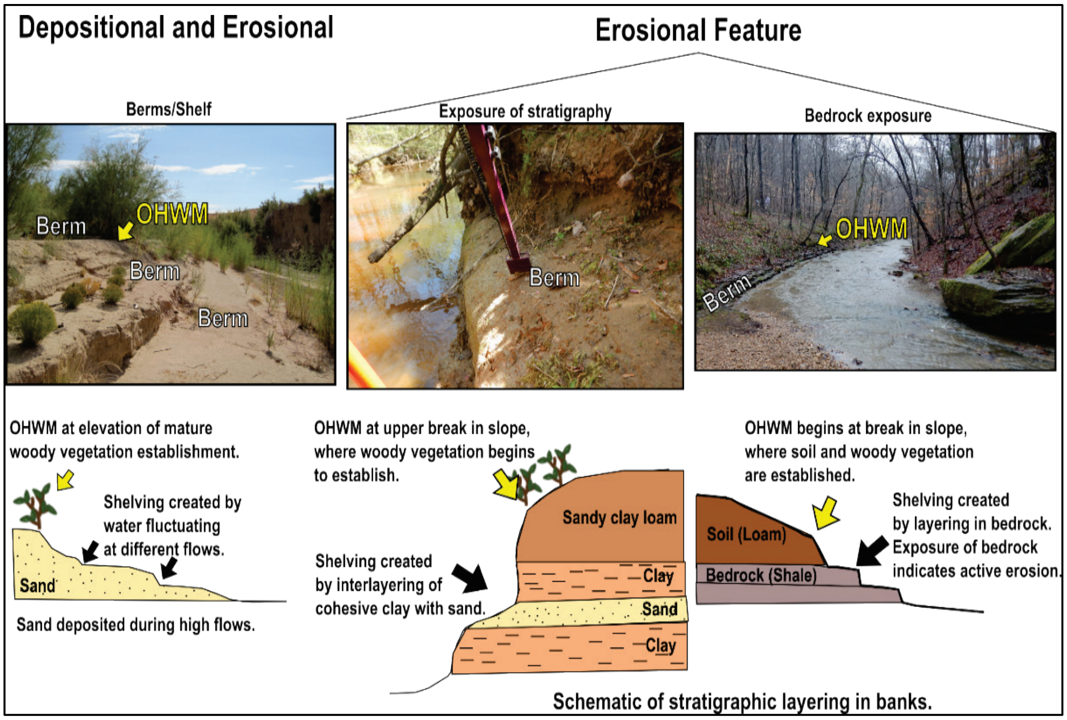
Flows (cms)	Flows (cfs)	Flow descriptors
>123	>4360	Extreme flows
8.5–123	300–4360	High flows
2–8.5	67–300	Moderate flows
0–2.0	0–67	Low flows

The landscape context of the site can be seen using a high-resolution (i.e., 1 m) DEM of Antelope Creek. The DEM shows the current location of the channel and where previous meanders were located in the floodplain. As meanders lengthen, they may become so long that the stream no longer has enough energy to flow around the meander bend and a meander cutoff occurs. Former meanders can become *oxbow lakes*, or secondary channels that may only be accessed during high flows, until sediment infills the less-used secondary channels over time. (These types of channels will be discussed further in Section 2.3.1.5). The latter process occurs as lower velocity flows move through these secondary channels, depositing sediment until eventually the channel is filled in and no longer accessed by the main stem of the stream. Lidar products, such as hillshades and DEMs, provide the larger landscape context of the fluvial environment. A hillshade is a well-known technique used to create a 3D representation of the surface from elevation data in geospatial software. High-resolution lidar data are available for much of the country; Section 5.2 discusses how to locate and use these data.

2.3.1.2 Locating the OHWM on shelving

Shelving (e.g., natural berms, natural levees, floodplains, valley flats, and terraces) results from depositional and erosional processes and can occur along the channel margins. Valley flats on terraces typically occur beyond the range of the OHWM, but they can be used to assemble lines of evidence on locations that are well above the OHWM. There are circumstances, such as SWCs (including multithread systems, swamps, and marshes) or aggrading channel systems, in which high flows inundate the valley flats on a regular basis. Shelving adjacent to the channel bed provides clear breaks in slope and should be observed (both above and below) for other evidence of the OHWM. A *natural berm* is a level space, shelf, or raised barrier separating two areas of the landscape. Whereas natural berms can occur anywhere on the landscape, the focus of this manual is on berms that are adjacent and oriented parallel to flow along channel banks and floodplains. Typically, a berm is located at the top of a channel bank or terrace in fluvial environments, but there may be multiple berms on a channel bar or inset along the channel bank (Figure 20). Berms can be particularly important lines of evidence for identifying the OHWM in channels that are removing recently deposited sediment or have incised downward and abandoned their former banks. The berms may provide evidence of a new channel bank being formed by the active channel.

Figure 20. Three examples of shelving in a channel from natural berm development (*left*), exposure of underlying stratigraphy (*middle*), and bedrock (*right*). The *middle* and *right* examples are structural features resulting from sediment or rock strength and are not reliable indicators of flow frequencies. The berms in the *left* example may represent recurring flows and should be considered along with other indicators in the WoE process.

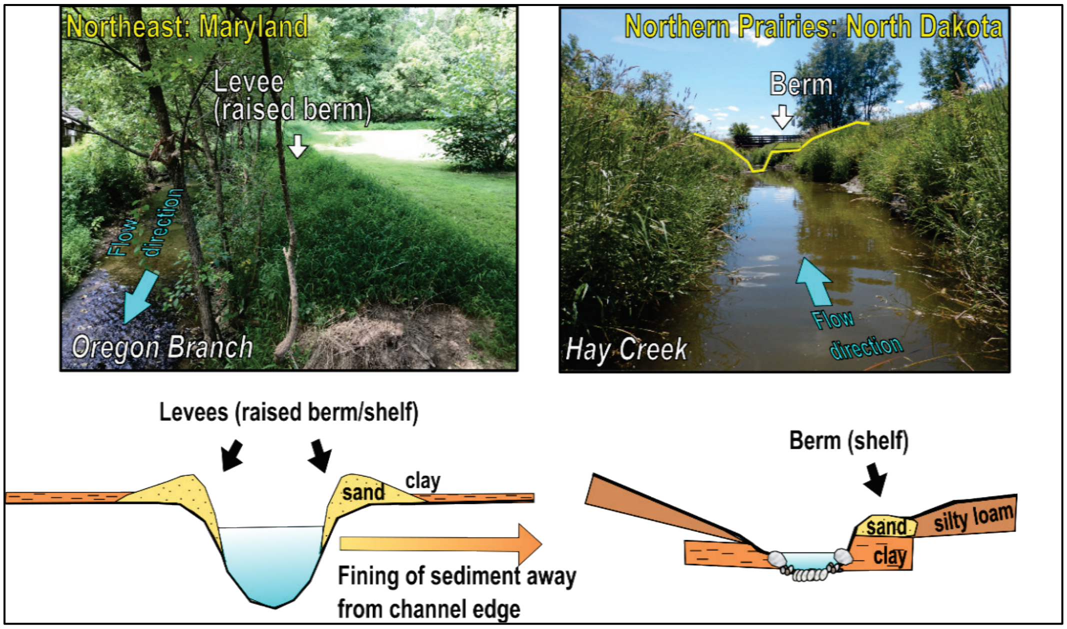


Multiple levels of berms may occur along channel margins because of fluctuations in low, moderate, and high flows or from progressive downward channel incision (Figure 20, left). These berms often create a natural line along the banks, particularly at transition points. If there is more than one berm, then berm elevations can be used with other high-flow indicators, such as vegetation age, structure, and density, as lines of evidence to locate the OHWM. Many channels have multiple types of shelving along the banks, particularly if there are significant geologic (structural) controls that are creating layering in the underlying stratigraphy or bedrock. As previously discussed, layering in the stratigraphy can also cause sapping erosion, which can contribute to the formation of undercuts and berms. Furthermore, erosional fluvial processes can reveal these underlying geologic controls. Because of the variety of processes working on the banks, shelving can sometimes be indicative of a variety of water stages and not just high flows connected to the OHWM. For instance, Figure 20 depicts berms in both erosional and depositional environments. In the erosional environments, the lower berms were likely formed because of removal of sediment at lower water stages and not necessarily because of high flows. Figure 20 also shows the interpreted location of the OHWM based on the cumulative site evidence and provides information on why the lower berms are not representative of the OHWM. In the three examples, the OHWM is identified at the upper break in slope, before the upper shelf, and at the transition to woody vegetation.

A *natural levee* is a raised berm that forms naturally from overbank deposits. Levees and berms can also be human-built features constructed out of sediment, concrete, or other materials. The terminology that follows is used in this manual to more easily distinguish different types of shelving adjacent to a stream. Natural levee is used to describe a raised berm on top of the bank, whereas *berm*, by itself, is used to describe a flat shelf, and *constructed berm* or *levee* is used to describe artificial features built along the margin of a watercourse to protect land from erosion or inundation or to confine streamflow to its channel. The data sheet (Box 1) provides an additional place to distinguish between whether there is a raised shelf (natural levee), flat shelf (berm), or a constructed berm or levee extending from the top of the bank out into the floodplain.

A natural levee is formed as water spreads out across the floodplain, perpendicularly away from the channel centerline; as water velocities drop, sediments and other materials are deposited. It is a natural break between the more frequent high-flow channel processes and floodplain processes. Identifying the presence and the top of a natural levee can assist in determining an upper limit to the elevation for the OHWM. Levee crests are often higher than both OHWM indicators and much of the floodplain. Generally, coarser material, such as sand, will be deposited near the channel edge during high flows, and finer material, such as clays and silts, will be deposited further away from the channel margin in the floodplain. This fining of the material away from the water's edge (Figure 21) is indicative of a reduction in velocity. As water flows away from the channel, velocities decrease, so the flows no longer have the energy to transport sand and, eventually, the clays and silts in suspension. Over time, a range of flows will either reach the top of the banks or overtop them. Flows that reach the top of banks occur more often than flows that overtop the banks and extend out into the floodplain. Therefore, sands often accumulate adjacent to the bank and eventually form a natural levee (i.e., a raised berm; Figure 21). Large (i.e., extreme) flood events may break through these levees or even remove portions of them.

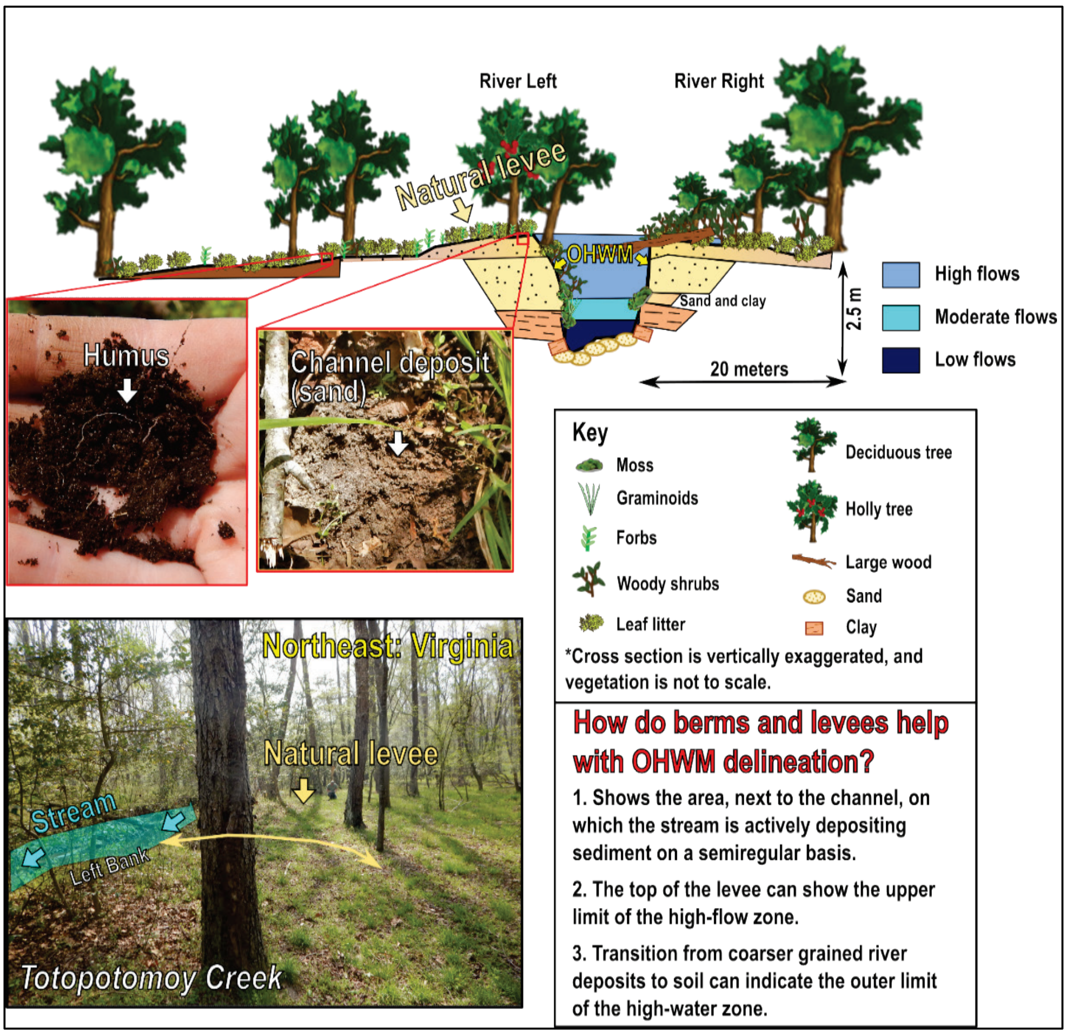
Figure 21. Natural levees in the form of a raised shelf/levee (*left*) and a flat shelf next to the channel (*right*). Material next to the channel is often coarser and fines away from the top of the bank. Note sand deposition in both the levee and berm, with finer sediment located in the floodplain.



The shape of berms and natural levees may be influenced by interactions with vegetation and flows. Flows and the transport of material affect their shape and the colonization of terrestrial plants and burrowing animals. Figure 21 provides an example of a levee with thick graminoids and herbaceous vegetation growing along the channel banks. Erosion is less likely for vegetated berms and levees than it is for berms with bare sediment. A vegetated berm is more likely to have a change in shape because of sediment deposition. Furthermore, a natural levee can sometimes be hard to distinguish by sight because vegetation density or type can obscure the feature or because it may be small and have a low grade of bank sloping toward the channel centerline.

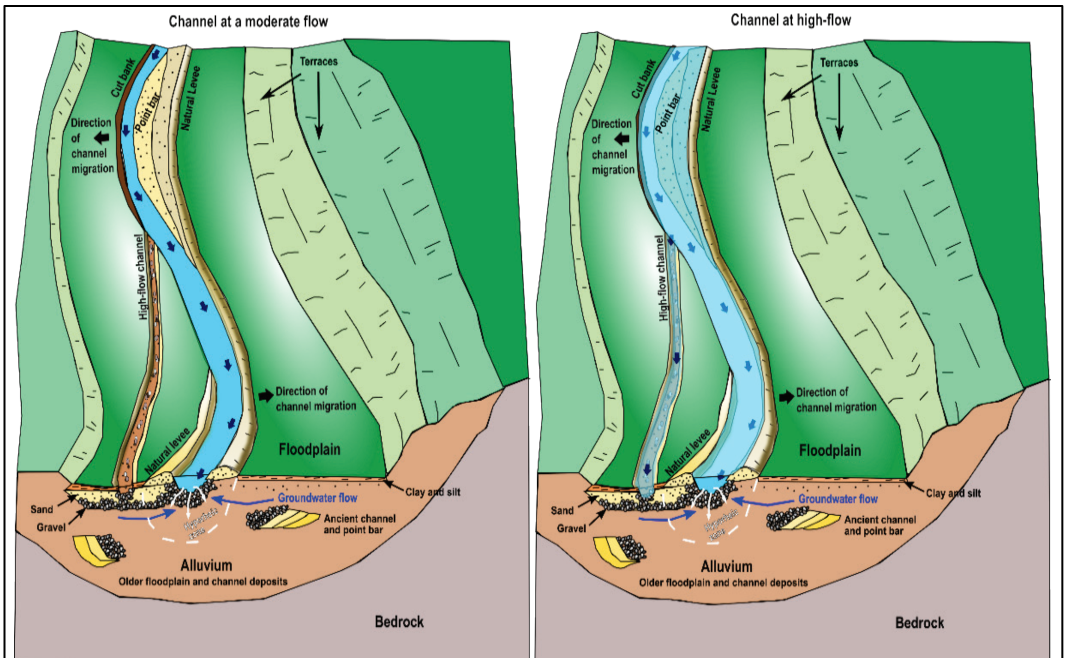
Large natural levees can also be difficult to observe due to a gradual change in elevation. In Figure 22, the broad natural levee in a stream in Virginia is more easily observed through a cross-sectional measurement of the channel. Note that, in the photograph, the trees growing on the levee obscure the feature. A faster assessment of the levee can be done by walking in a straight line away from the channel banks and looking for where the ground slopes down, away from the channel edge. At the same time, the changes in sediment texture can indicate where the channel is depositing coarse alluvial material versus where the soil surface is dominated by fines and organics. Identifying these transition points allows for determining a possible upper limit of the OHWM. Evidence can be accumulated along and below this transition point and interpreted to determine a location of the OHWM based on the WoE. Figure 22 shows a clear transition from sand deposited adjacent to the channel in a broad natural levee to a thick dark soil, or humus. The OHWM is not likely to extend into the region with the thick nonalluvial soil; therefore, the search for the OHWM should start at the top of the levee, looking up- and downstream and across the channel.

Figure 22. Cross section showing a broad natural levee. The stream is highlighted in *blue* in the photograph to show the location and direction of flow in the channel.



Another type of shelving can occur on stream terraces. Terraces are old or inactive floodplains. They form when streams incise down into their floodplain, leaving behind remnants of older floodplains (Figure 23). Shelving is one of the first indicators in the description of the OHWM, but unless a stream system is in a rapid period of aggradation, the shelf created by terraces would be above the OHWM. For high terraces, this difference can be substantial, whereas low terraces may be only slightly above the bankfull stage and therefore the OHWM. Some features of terraces, such as backswamps and high-flow side channels, may be included in the OHWM. The identification of high terraces can provide evidence of an elevation that is well above the OHWM. In the paragraphs that follow, the different types of terraces are described, and photographs are provided to assist the user in understanding how stream terraces form and what they would look like in the field (Figures 24 and 25).

Figure 23. Shelving in the form of stream terraces. The schematic shows a continuous segment of stream terraces, but terraces are often discontinuous features that are parallel to the stream. (Image modified from Brady and Weil 1999.)

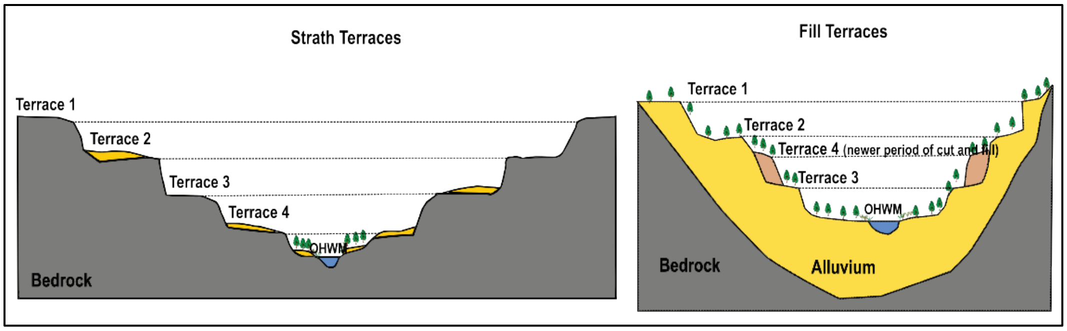


Point bar is exposed and high-flow channel is dry during moderate and low flows.

Point bar, high-flow channel, and part of the levee are inundated during ordinary high flow.

Stream terraces can form from erosional and depositional processes (Figure 24). An erosional terrace is referred to as a *strath terrace*. Such terraces form where a stream has enough energy not only to carry the sediment load moving through the channel, but also to erode the bedrock. Strath terraces can sometimes have a thin mantle of alluvium on top.

Figure 24. Example of strath versus fill terraces. Terraces are another form of shelving, but the terrace surface would be well above the OHWM.



A *fill terrace* is a depositional terrace (Figures 23 and 25, right) that forms in a system in which an alluvial stream cuts back down through its own sediment, abandoning its former floodplain.

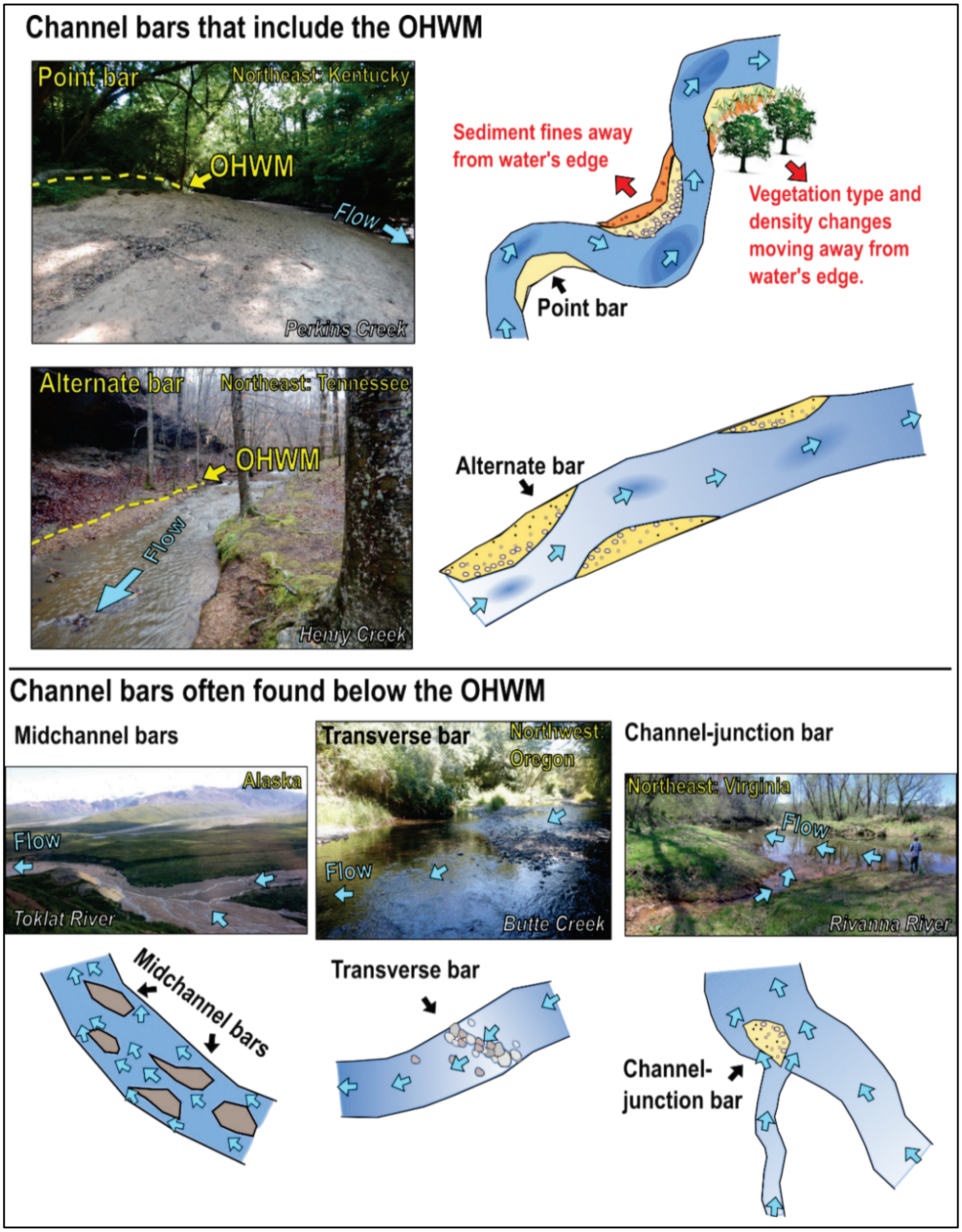
Terraces are sometimes easy to define in landscapes, particularly when they are dramatic features that are well above the current fluvial system. Figure 25 displays terraces above the Wulik River in Alaska and in Campbell Creek in Colorado. The South Fork of the Poudre River and Horse Creek examples in the same figure show a modern stream cutting laterally into the terrace surface. In each case, the terrace can be clearly demarcated from the current floodplain because of the drastic difference in elevation between the surfaces of the terrace and modern floodplain. Sometimes the difference in elevation between terraces and modern floodplains is more subtle. It is important to recognize terraces because they are not as frequently inundated as the active channel and, except in situations of extreme channel aggradation, do not usually occur at a lower elevation than the OHWM.

Figure 25. Shelving located at the top of cut and fill terraces in the Northwest and Alaska. In each case, the shelving that defines the terrace surface is well above the OHWM.

2.3.1.3 Locating the OHWM on channel bars

Channel bars are depositional features associated with channels (on the active bed and between the banks). Channel bars form when the size or amount of sediment in a channel is greater than the transport capacity of the stream. Alternatively, exposed bedrock within a channel indicates the stream has a higher transport capacity than sediment load and is thus able to move all incoming sediment and erode the bedrock. Although the erosion of bedrock can create features that are similar in shape to channel bars, the evidence for the OHWM differs in those erosional environments and will be discussed in Section 2.3.1.4. There are five common types of channel bars: point, alternate, midchannel, transverse, and channel-junction (Figure 26).

Figure 26. A photograph and schematic of each type of channel bar.



Channel bars that are connected to channel banks, such as point and alternate bars, are much more likely to contain the elevation of the OHWM than channel bars that are disconnected from banks, such as midchannel, transverse, and channel-junction bars (Wohl et al. 2016). Channel bars are evidence of fluvial action because they are created by the deposition of bedload. Therefore, the top of the active channel bar can provide evidence of the minimum water surface elevation for flows that are able to transport sediment, which are likely to be high flows. The evidence for the OHWM would, in some cases, be above that elevation along the banks of the channel when observing the height of midchannel, transverse, and channel-junction bars. The OHWM may then be at or above point and alternate bars, but it is not likely to fall below the upper elevation of those bars. Often, evidence at the top of these bars corresponds to sediment sorting and vegetation growth, or the lack thereof. Both *zonation* (i.e., the co-occurrence of the same species under specific ecological conditions or along a strong environmental gradient) of vegetation and changes in sediment characteristics can occur on all types of channel bars. Using a point bar as an example, Figure 26 shows the fining of sediment, from sand to clay, and changes in vegetation structure moving away from the water's edge or channel centerline if there is no water during the time the channel is observed. Channel bars become fluvial or channel islands if they become surrounded by channel and persist long enough for permanent vegetation to become established; different processes can lead to this transformation (Osterkamp 1998; Wintenberger et al. 2015). The OHWM is typically below the peak elevation of fluvial islands such that islands are not completely submerged during ordinary high flows.

The material that makes up channel bars depends on the type of material being transported by the stream. Figure 27 shows channel bars that are characterized by the size of the dominant sediment being transported by the river, such as boulders, cobbles, gravel, sand, silt, and clay. Channel bars are often a mix of sediment types.

Figure 27. Channel bars dominated by different sizes of sediment, such as boulders, cobbles, gravel, sand, silt, and clay. The size classes and symbols used throughout the manual are shown. Each photograph shows channel bars that are below the OHWM.

Often, the texture of surface sediment on a channel bar is coarser near the channel centerline and finer along the outer boundary of the channel. Velocities are faster near the deepest part of the channel, called the *thalweg*; therefore, smaller surface material is transported (i.e., winnowed) away, and larger material is left behind. The resulting vertical pattern within a streambed, with larger material dominating the surface layer and finer, more mixed-sized materials underneath, is sometimes described as *stream bed armoring*. Flow velocities decrease along the edges of the channel because of increased roughness from channel boundaries, and fine materials are deposited, or simply not transported, downstream. Figure 28 shows examples of sediment fining with distance away from the thalweg and toward the banks of the channel. *Fining* is a term used to describe the decrease in the dominant sediment grain size in a specific direction; for instance, a change from gravel to clay in the downstream direction would be described as fining in the downstream direction. Such fining can occur at both small and large scales along channels. Generally, a coarser size fraction (Figure 27) is left behind where velocities are faster, and a finer size fraction is deposited where velocities decrease. This type of sediment sorting, due to differences in velocity, indicates recent fluvial processes occurring on the channel bed, and the results can be observed whether water is present or absent in the channel. In stream channels that suddenly lose capacity for transporting sediment because of sharp changes in gradient or underlying geology, lateral patterns in substrate particle sizes may be less apparent as rapid deposition becomes the dominant process across the channel width (Laronne et al. 1994; Jones 2010). Therefore, understanding landscape context (Chapter 4) can be useful for understanding the fluvial processes occurring in the stream corridor and how they affect stream characteristics, such as sediment sorting, on channel bars.

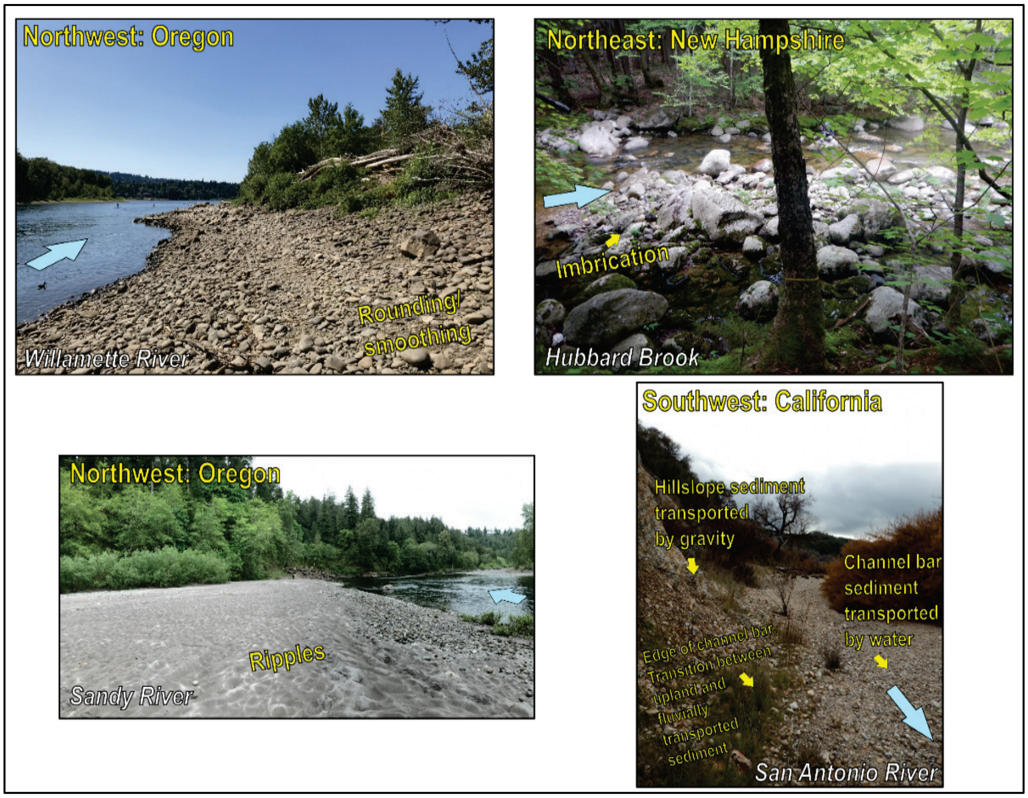
Figure 28. Sediment fining away from the stream centerline (direction of *orange arrows*) on gravel bars in two different regions of the country (Hawaii and the Northeast). The channel bars are highlighted in *yellow* in the upper photographs and shown from above in the bottom photographs for each stream.

Sediment on the channel bed and bars can also be characterized by the degree of rounding or smoothing and by the depositional pattern (e.g., imbrication or ripples) that are indicative of flow direction. *Imbrication* is when sediment, or another material in a stream, is pushed in one direction by the current so that they overlap (Figure 29).

Figure 29. Imbrication on the bed of a dry channel in Maryland.

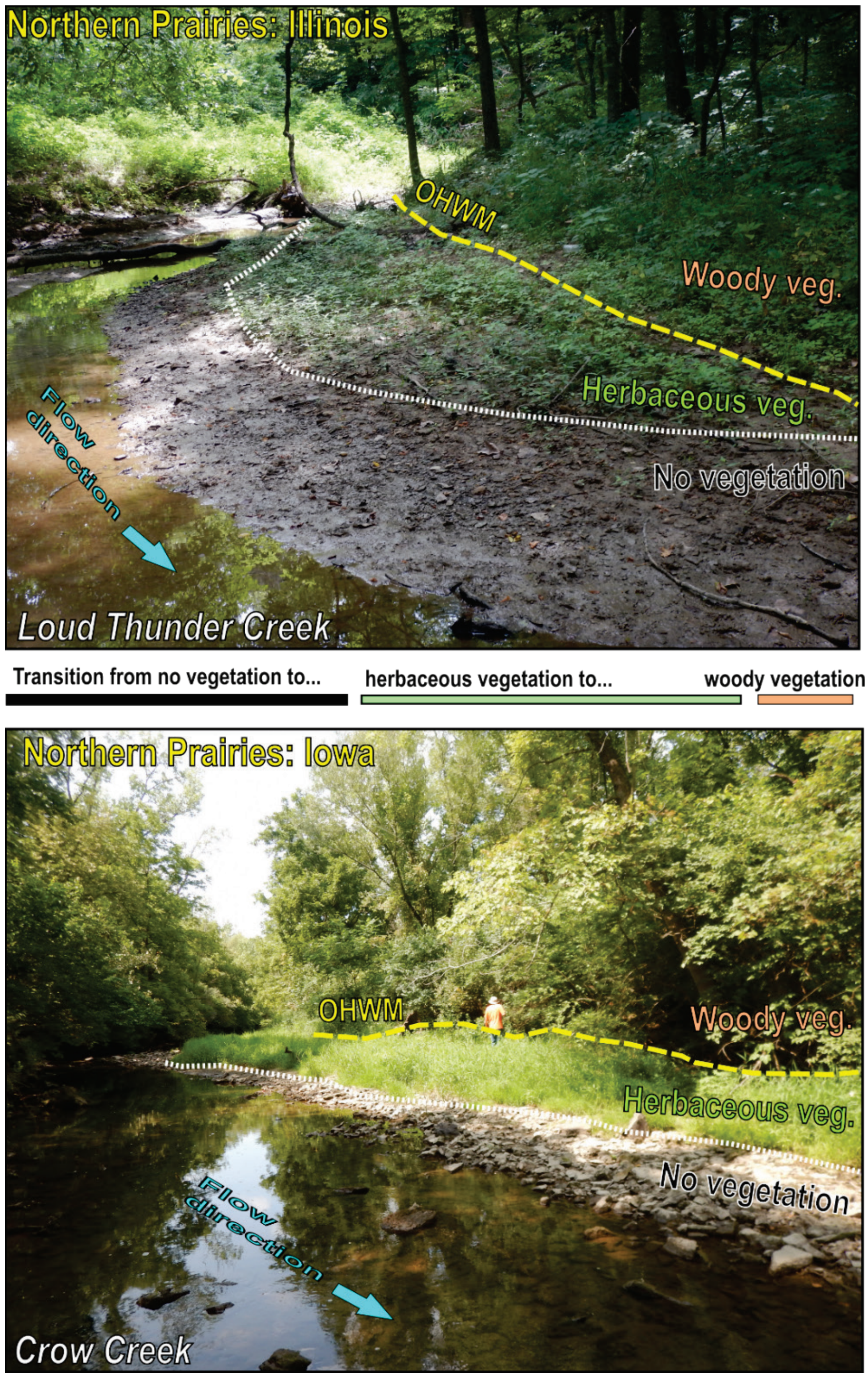
Therefore, sediment on channel beds and bars can be characterized by assembling evidence based on transitions related to sorting of sediment, rounding of material, and other indicators that provide evidence of flow direction. The evidence and significance of transition points are relative to what is happening in any given channel because each of these characteristics is related to landscape controls such as climate, vegetation, geology, and land use, which affect sediment loads and streamflow (Figure 30). A more detailed description of landscape controls is in Chapter 4. The other stream characteristics and high-flow indicators identified on channel bars are discussed in more detail in Sections 2.3.2 and 2.3.3. This section provides a few more examples to help users understand what observations can be made on channel bars in different regions of the country.

Figure 30. Rounding, imbrication, ripples, and transition from sediment source (colluvial) to alluvial sediment on channel bars in different regions of the country. Ripples are a bedform in the sediment that indicates the direction of water flow. The size, rounding, and distribution of sediment depends on the sediment source material, distance from the source, and streamflow.



Additional evidence to support the identification of the OHWM may be provided by the vegetation on channel bars. Vegetation on channel bars is particularly evident in some temperate regions during times of lower flows in the growing season. A general transition of vegetation, from exposed sediment, to forbs and graminoids, and eventually to woody shrubs and trees, is shown for two Northern Prairie streams in Figure 31. This gradual transition in vegetation is related to the frequency of flows. Vegetation change along channel boundaries, including vegetation tolerance to inundation, is discussed in more detail in Section 2.3.3. The key factor about bars when assessing the OHWM is that exposed sediment is an indication that flows frequently inundate that portion of the bar while transporting sediment, preventing vegetation from establishing. Therefore, unvegetated sediment is evidence of the bar being below the OHWM. Because many species of herbaceous vegetation can establish very quickly during periods of low flows, often in the spring and summer, this type of vegetation is generally not a good indicator of high flow in regions of the country where woody vegetation is common along stream banks. Many caveats are needed for this, depending on the species, age, and structure of riparian vegetation in a region and climate (Section 2.3.3). In many of the northern and mountainous regions of the country, the location of woody vegetation establishment is a persistent indicator that can help to identify the elevation of high flows in the channel.

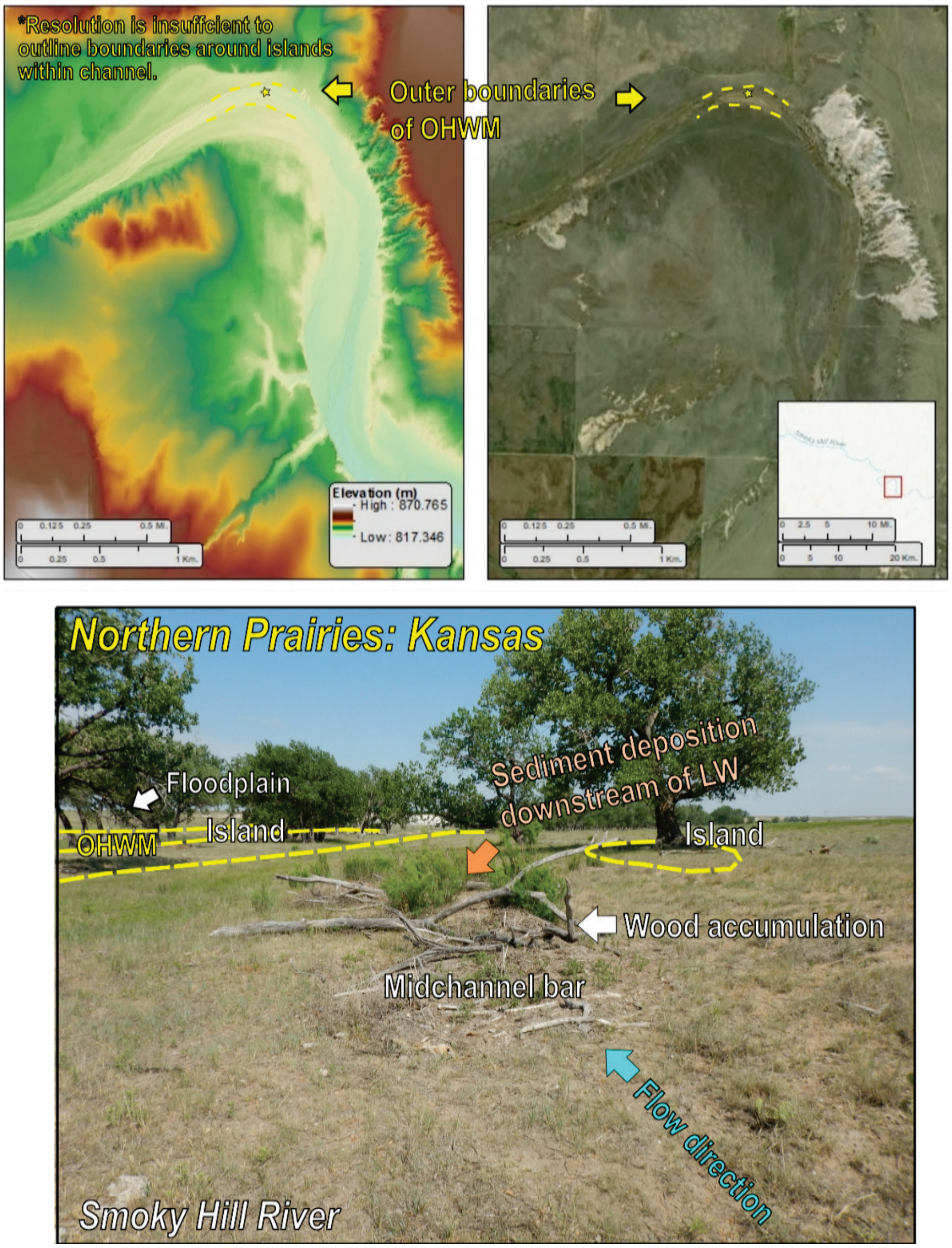
Figure 31. Vegetation transition on channel bars. In these two Northern Prairie streams, the OHWM is identified where the more persistent woody vegetation establishes.



LW, an ancillary OHWM indicator that will be discussed in Section 2.3.4, can assist with identifying and understanding flow levels on channel bars. LW is pieces of wood in the channel that are at minimum 1 m (3.281 ft) long and 10 cm (4 in.) in diameter (Wohl and Scott 2017). LW often creates flow feedback that results in the deposition of material and creation of bars by increasing roughness, which causes a decrease in velocity and, therefore, the deposition of sediment up- or downstream of the LW deposit (Figure 32).

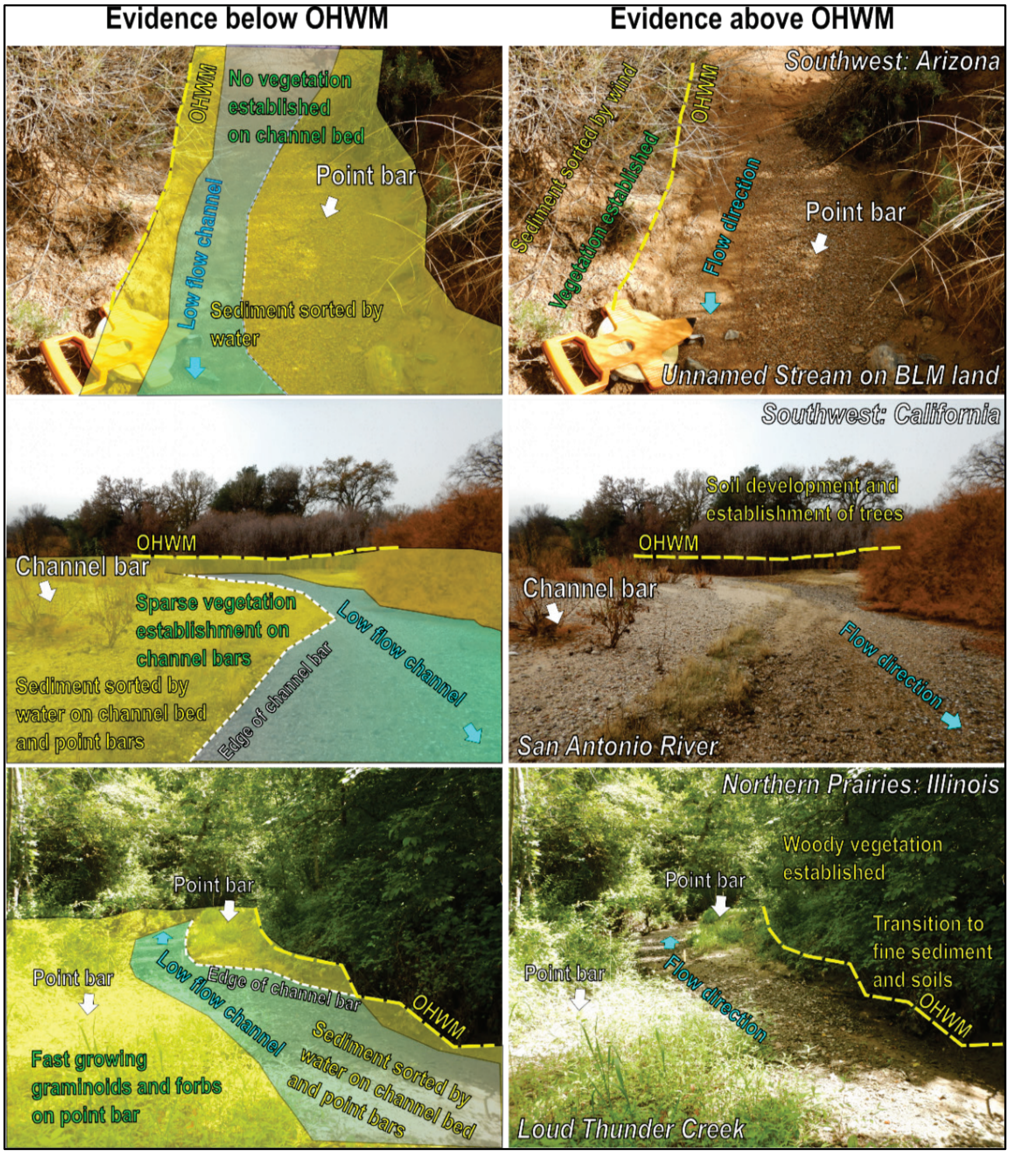
The development of channel bars through the deposition of sediment on top of and around the LW may indicate that such bars are below the OHWM. Furthermore, LW can create a damming effect on flow, causing deeper water upstream of LW jams and increasing the height of the OHWM. Figure 32 provides an example of an LW jam with sediment deposited downstream and herbaceous vegetation growing on the LW-created bar. In this example, there is evidence that the LW jam and mid-channel bar are below the elevation of the OHWM. The sediment deposition on top of the LW jam indicates that flows reached that water stage frequently enough to deposit ample sediment for the establishment of vegetation. LW and channel bed sediment are materials that were transported and deposited by flow. LW is discussed in more detail in Section 2.3.4.1.

Figure 32. Accumulation of large wood (LW) and midchannel bar development in a nonperennial stream. Directionality in LW accumulation and channel bar development indicate that these areas are below the OHWM. The DEM (*upper left*) and aerial photograph (*upper right*) indicate the location of the photograph near the outer boundaries of the OHWM.



Channel bar development and the physical evidence on channel bars can be useful for OHWM identification in both wet and dry channels. Figure 33 provides examples of flow indicators in dry channels that are both below and above the OHWM, allowing for delineation of the OHWM at the transition point. Channel bars can have very different dimensions depending on the size of the channel. For instance, the point bar in the Arizona stream in Figure 33 is relatively small (note tape for scale) in comparison to the bars at the other two sites. Careful examination of channel bars, including breaks in slope and vegetation and sediment characteristics, can assist in gathering evidence to locate the OHWM.

Figure 33. Evidence identified below (*left*) and above (*right*) the OHWM in dry channels with point bars in the Southwest and Northern Prairies regions.

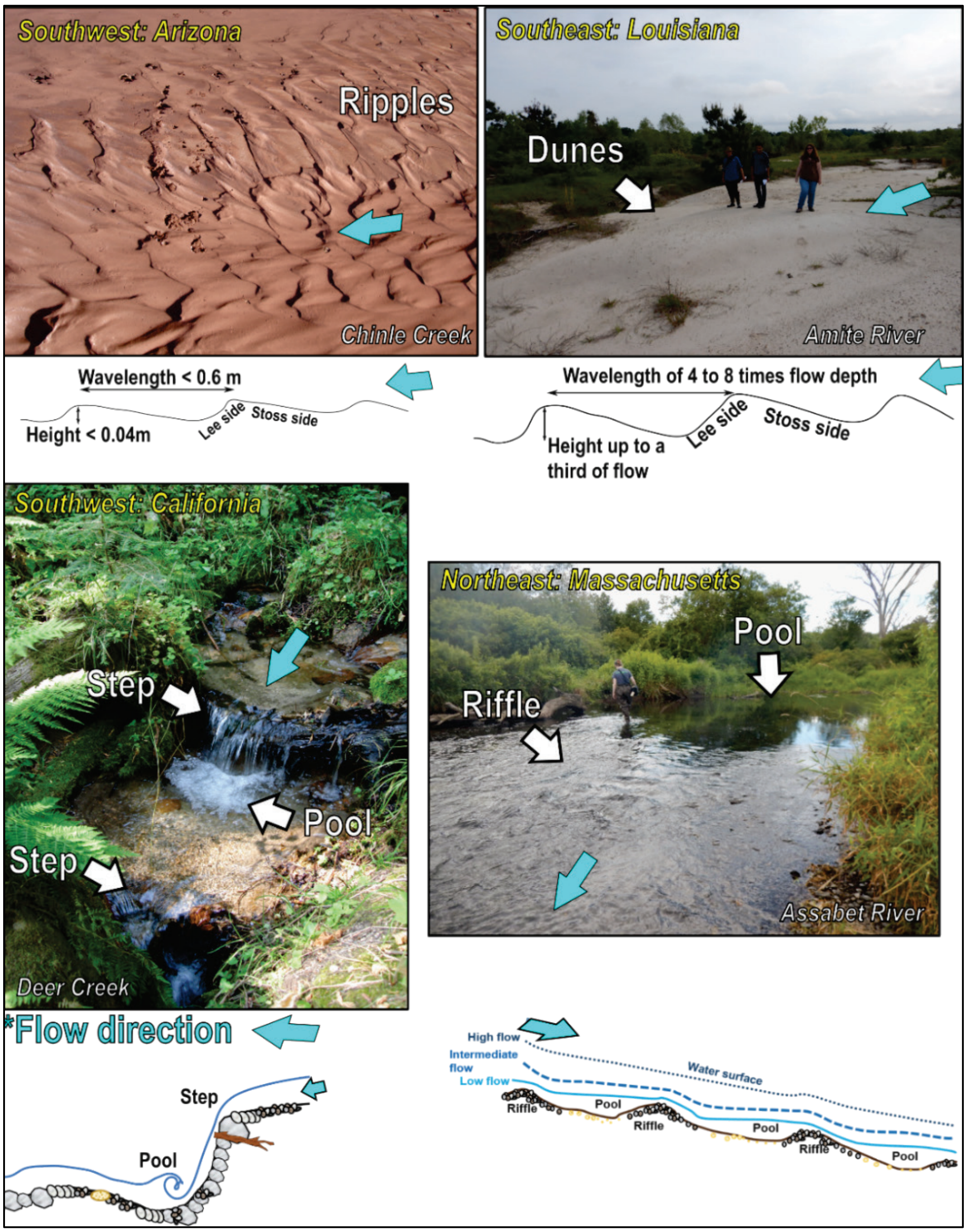


2.3.1.4 Instream bedforms, scour holes, scour lines, obstacle marks, and other evidence of bedload transport to support locating the OHWM

Bedload transport provides evidence of where flowing water has reached within the channel and on the floodplain, which can be a useful line of evidence when identifying the elevation that both high and extreme flows have reached on the floodplain. Flowing water sorts sediment because of differences in velocity along the bed and banks of the channel. Faster, deeper flows have a higher capacity for carrying sediment and, if supply is available, may carry a larger quantity (i.e., higher load) than slower, shallower flows. A high degree of sediment sorting into uniform size classes (e.g., cobble, gravel, and pebble) often indicates—if fine material was initially available—that finer materials were carried away, which represents higher flow energy. The relevance, strength, and reliability of this evidence depends on other lines of evidence (e.g., recent extreme events such as flooding) in combination with evidence of flow occurring in each part of the channel and surrounding area. Each indicator listed on the data sheet (Box 1) is described in more detail in the sections that follow to improve understanding of the relevance, strength, and reliability of these flow indicators (Figure 7).

Evidence of flowing water from bedload transport can be divided into erosional and depositional features. Instream bedforms, like channel bars (Section 2.3.1.3), provide evidence of bedload transport, mainly from deposition of sediment or sequences of erosion and deposition. Instream bedforms include ripples, dunes, and stepped-bed and pool-riffle morphology (Figure 34). When these bedforms occur on the bed of a stream channel, then they are obviously below the elevation of the OHWM. Bedforms may occur on bars, above what appears to be the top of a bank, or in a secondary channel and, therefore, provide evidence of areas below the OHWM. For instance, the dunes in Figure 34 were well above the current water surface elevation in the Amite River during the day of the field visit. The dunes occurred a few hundred meters away from the water’s edge on a large point bar. It was evident the dunes were shaped by flowing water because they were streamlined and had the characteristic dune asymmetry of steep slip-off faces on the downstream side. Therefore, these dunes are evidence that the stream is interacting with the landscape at this elevation. Bedforms can sometimes be left behind during extreme flood events high on the floodplain and above the OHWM. These would likely be most evident soon after a flood event and less evident over time. Therefore, other lines of evidence may be needed to determine if the dunes are above, at, or below the OHWM. Dunes can be formed by extreme flows, not just by high-flow events. Therefore, they provide one line of evidence, but their relevance, weight, and reliability are determined by other pieces of information for the site. Dunes and other bedforms can often be identified at low positions on the bed of a sand-bed channel, but they are only noted in the OHWM delineation process if their occurrence assists in identifying flow stages above the low-water line. Therefore, noting the context of the bedform site is important for understanding why the bedforms are being noted when determining the location of the OHWM.

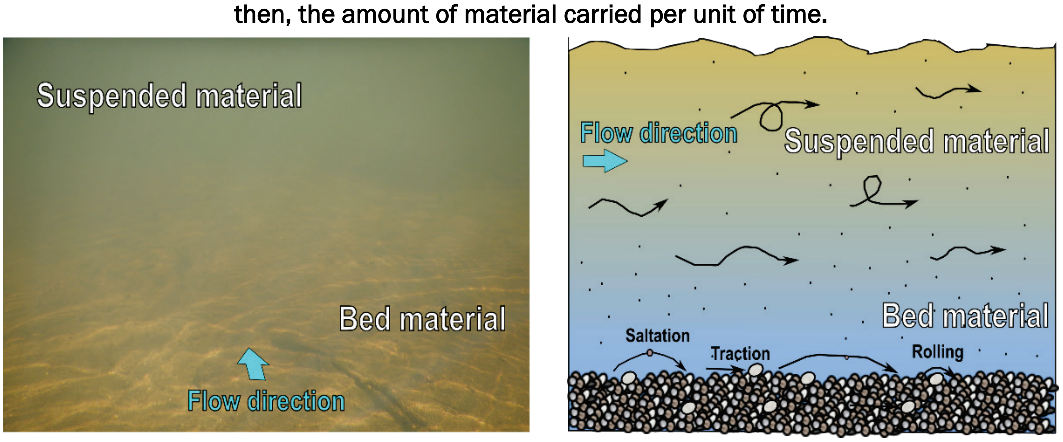
Figure 34. Common bedforms, such as ripples, dunes, step-pools, and pool-riffles. *Blue arrows* show flow direction in each photo. A schematic of each bedform is shown in profile view.



Occasionally, bedforms may either impinge on each other or be truncated by a subsequent flow. For instance, dunes on a point bar are evidence of differing processes occurring to first form the point bar and then form the dunes. This provides evidence of different flow stages. The presence of bedforms causes local disturbances to flow stages and generates dynamic changes to flow stages when built or breached. For instance, the breaching of bedforms, such as incision across channel bars, may cause local lowering of flow stages. If such changes in bedforms and the flow dynamics they generate can be recognized in the field, that may indicate a change in the present frequency of flows associated with evidence of flows at a site.

Sediment sorting from flowing water can create other distinct depositional features, such as imbricated clasts, gravel sheets, rippled sands, sand tongues, and flaser bedding. Again, sorted sediment may be observed on the channel bed, but it can also be observed along bars and on the floodplain. Streams carry sediment as bedload, suspended load, and dissolved load (Figure 35). The *bedload* is the sediment that moves along the channel bed by bouncing (i.e., saltation), rolling, and dragging (i.e., traction). *Suspended load* is the sediment that is carried in the water column by suspension. Generally, suspended loads tend to be silt and clay. The faster, deeper, and more turbulent the flow, the larger the sediment and greater the distance a stream can carry suspended material. Evidence of bedload or suspended load on the channel banks may be evidence of recent high flows or of locations high flows frequently access.

Figure 35. Picture and schematic showing bed material and suspended material (*left*) and the modes in which these materials are transported (*right*). The bedload and suspended load are, then, the amount of material carried per unit of time.



Sediment of all sizes, as well as bedrock, is broken apart, smoothed, and rounded by the movement of material along a channel bed. The smoothing of bedrock and development of potholes are stream characteristics that provide evidence of where flowing water with sufficient force and frequency shaped these features. Figure 36 shows that the OHWM can be delineated in a nonperennial channel at the transition between a smoothed and a rougher rock face. Therefore, a bedrock surface that is smoothed by fluvial processes is potentially below the OHWM. Again, this information should be combined with other lines of evidence and weighted to determine the most likely elevation of the OHWM.

Figure 36. Bedrock smoothed by flowing water provides evidence for the location of the OHWM. The red box (*left*) shows the location of the closeup photo of a pothole on the *right*. The OHWM at this site is identified where there is a difference between abrasion processes and lichens.

The rounding of sediment can also provide evidence of where water is flowing, but this evidence must be considered in the context of other landscape characteristics. For instance, if the sediment is from a nearby hillslope, rather than from further upstream, there would have been limited time for rounding to occur. This is often the case when the site is in a confined valley, particularly if it is near the top of a watershed (e.g., 1st-order streams; Strahler 1952).

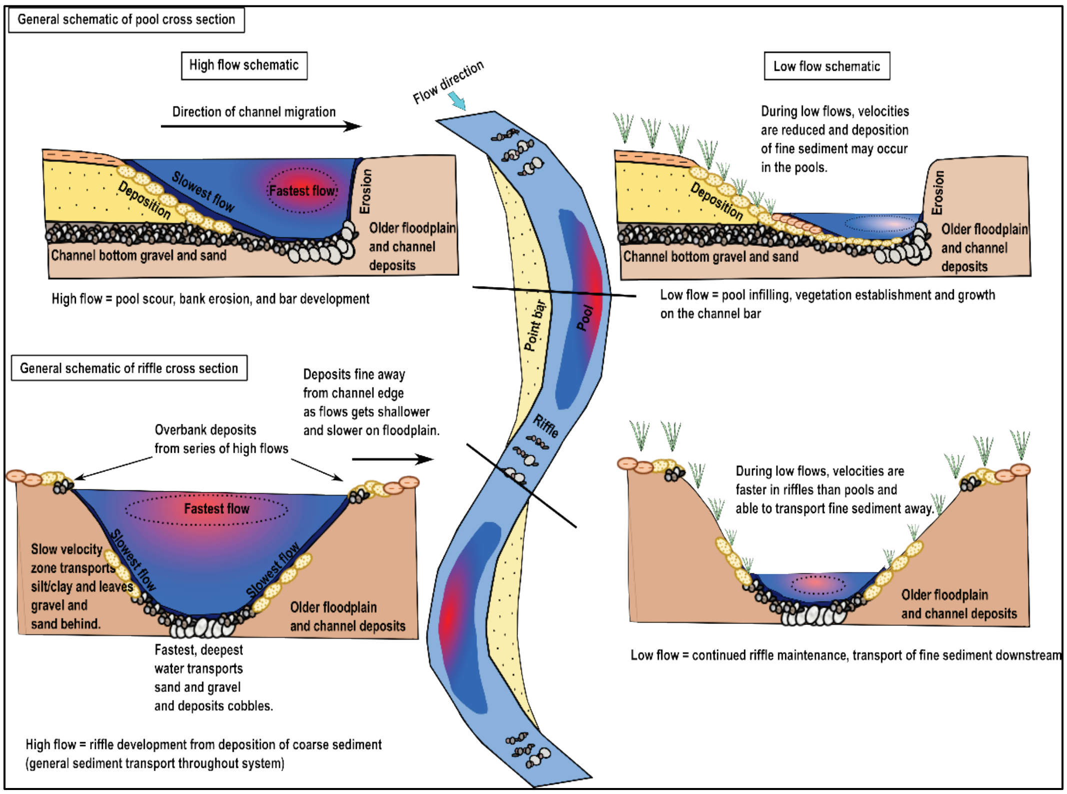
Sediment is rounded and smoothed as it is moved downstream. The closer the sediment is to its source, the more angular the sediment will appear (Figure 37). Therefore, the difference between smooth and rough rocks is relative to differences between the sediment in the channel and the surrounding landscape, which can be used to define the lower and upper boundaries of within-bank or overbank flows (Figure 38). Transitions between relatively smoother and rougher sediment can sometimes be identified as a potential location of the OHWM.

Figure 37. The degree of roundness or smoothness of sediment reflects how close the sediment in the channel is to its source. The angular sediment on the bed of the Tennessee stream (*left*) is next to the source material. The rounded, smooth sediment on the bed of the Oregon stream (*right*) comes from further up in the watershed.

Figure 38. Lighter and smoother boulders on channel bed versus surrounding hillslope. Relative difference between channel bed and surrounding landscape provides evidence for the OHWM.

Bedforms, such as pool-riffle sequences, occur because differential forces are applied to the channel bed. Where the water is fast and deep, sediment transport and erosion are likely to occur. Where the water is slow and shallow, deposition is more likely to occur. A pool-riffle sequence demonstrates this both in the downstream direction and through the cross sections. Figure 39 shows where the deepest and fastest flow results in the greatest sediment transport potential during high flows through both the pool and riffle. Pool scour, bank erosion, and channel bar development all occur during high flows. Aggradation of coarse sediment also occurs in riffles during high flows. During lower flows, pools may start to infill with fine sediment, while riffles are maintained (Knighton 1998). Deposition occurs along the point bars or channel edges, where the flow is slow and shallow, particularly as the storm flow wanes. If a channel begins to completely dry up, water will pond in the pools, depositing silts and clays during these low flow stages. Once the pool completely dries, mudcracks will form in the deposited material (Section 2.3.2.2).

Figure 39. General schematic of pool-riffle bedforms showing where the fastest, deepest flow leads to erosion in the pool bend and riffle.



Deposition of fine sediment over coarse sediment can also occur as flow recedes along the floodplain and the banks of a river (Figure 40). These depositional sequences can provide evidence of high flows followed by waning flows (Figure 41). There may, however, be differing explanations for a sequence of coarse to fine sediment. The floodplain in the pool-riffle example (Figure 39) shows where fine sediment is deposited when overbank flows reach that elevation and deposit silt and clay as velocities decrease on the floodplain. Figures 40 and 41 show examples of areas within the channel that are clearly below the OHWM. Clay was deposited on top of coarser sediment on channel bars along the outer channel boundary (Figure 40) and in the high-flow channel as flow receded from a higher to lower flow event. These streams had high suspended loads, so it was unsurprising that silt and clay deposits occurred below the OHWM.

Figure 40. Deposits of clay on top of sand on the channel bar in the Comite River indicate an area that was submerged during higher flows, deposited coarser sand, and then continued to be submerged as flow waned, depositing clay.

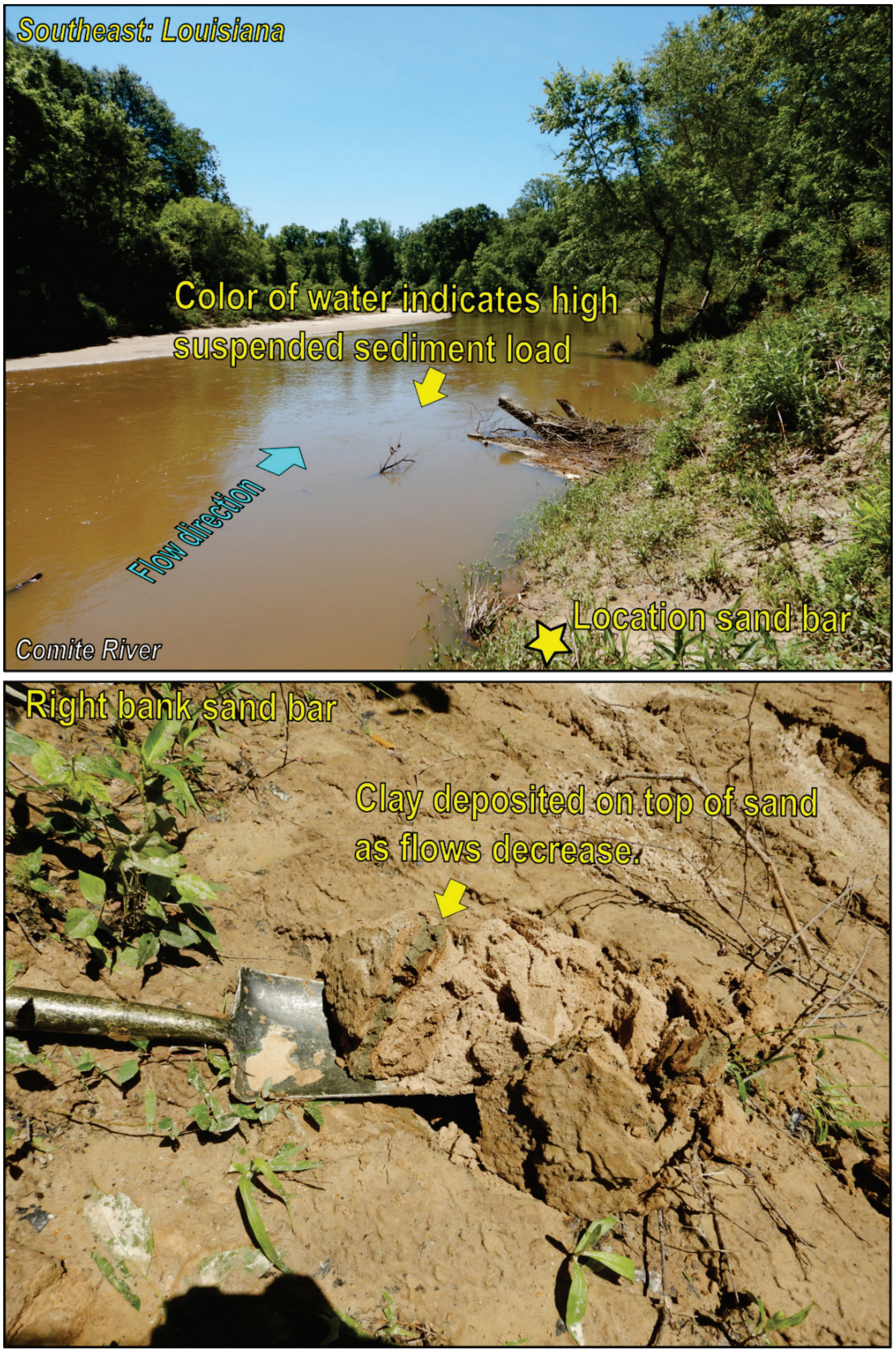
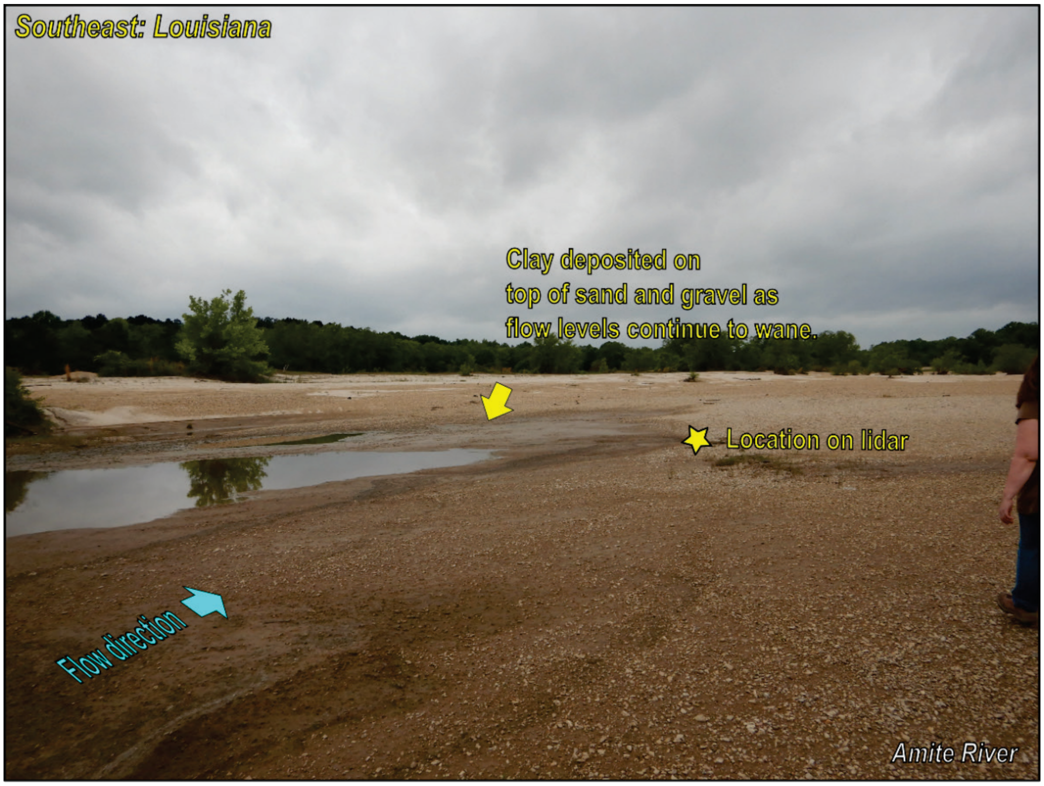
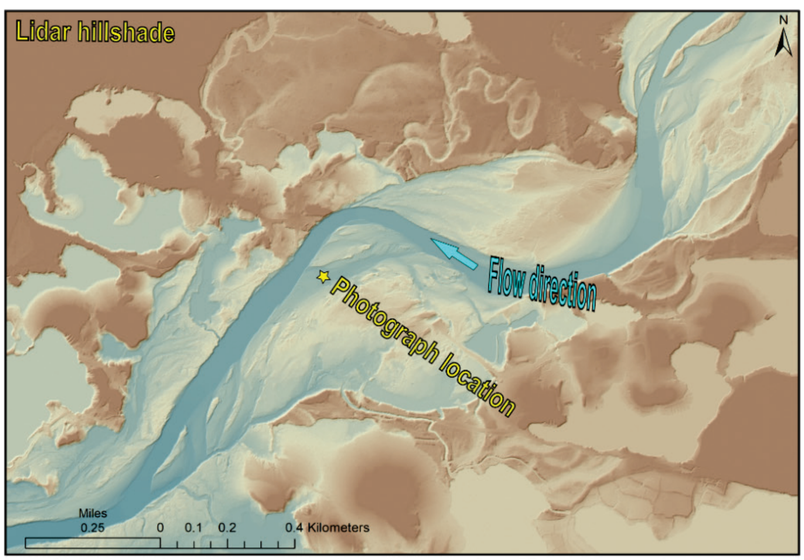


Figure 41. Flow decreasing in cutoff channel. Water pools as flow retracts, causing clay to be deposited on top of sand and gravel.





Erosional and depositional features around obstacles in the flow are called *obstacle marks*. Obstacle marks, scour holes, and scour lines provide evidence of river erosion and, depending on the magnitudes of recent flows, can occur on the channel bed and along point bars and floodplains (Wohl et al. 2016). The size and scope of an obstacle mark is relative to the size of the obstacle and the size of flows in the channel. Obstacle marks can occur around large boulders, bridge piers, or rooted, woody vegetation (Figure 42). Often, erosion occurs around the obstacle, and deposition of the eroded material occurs slightly further downstream. Figure 42 shows the pattern of coarser sediment being exposed; finer sediment is eroded away as water flows around the obstacle. The woody vegetation in the Amite River is an obstacle that has deposition of LW and sediment around it. Obstacle marks show flow direction in dry channels because of the teardrop shape created during the scouring process.

Figure 42. Obstacle marks on a point bar (Sandy River, *top left*), on the channel bed (Wild Burro Alluvial Fan, *top right*), and on a midchannel bar (Amite River, *bottom*).

Scour holes (Figure 43) form downstream of an obstruction because of vortices created by turbulent flow patterns that cause increased erosion (i.e., scour) downstream of an obstacle or step (Wohl et al. 2016). The scour process creates a hole that can eventually become a pool in the channel. As a stream dries, the water will pond in these areas.

Figure 43. Scour holes in two streams in Illinois. The scour hole in Devils Glen Park (*left*) formed downstream of a step or headcut in the channel. The scour hole in Loud Thunder Creek (*right*) formed because the LW created an obstruction and step.

The examples in Figures 42 and 43 are obstacle marks and scour holes identified below the OHWM. Again, there will be cases in which these stream characteristics may be observed above the OHWM after an extreme flood event. The context of obstacle marks or scour holes, in terms of recent extreme events and location, may determine whether they are significant for identification of the OHWM. Identifying other stream characteristics, such as channel bars, high-flow channels, levees, and terraces, can assist in determining if the stream characteristic is a useful OHWM indicator. This is where applying the WoE technique helps to determine the relevance, strength, and reliability of each of these indicators.

2.3.1.5 Identifying secondary channels that are below the OHWM

Secondary channels are channel branches that carry a small portion of the flow (Figures 44 and 45). These channels can be geomorphic indicators that assist in identifying the elevation of the OHWM. They may flow during any flow stage and can occur in any portion of the watershed. In this report, the term *secondary channels* encompasses side, high-flow, and abandoned channels. High-flow and abandoned channels are features in the stream floodplain that are accessed during high or extreme flows or that may have previously been active channels but were abandoned due to horizontal migration within the floodplain. It can be difficult to distinguish if a channel has been abandoned or is accessed only during high flow. Braided and anastomosing streams have several secondary channels. In large systems, these may be more easily identified using satellite imagery and lidar (Chapter 5). Therefore, at the outset, the secondary channels can be identified using remote data and field examination. Once the secondary channels are identified, it can be useful to investigate both how they were formed and potential land-use effects in a region. Understanding how secondary channels were formed and the degree to which they are maintained by being contemporaneously connected to the main channel informs whether the secondary channels are being actively maintained as high-flow channels or are abandoned channels.

Figure 44. A secondary channel with trees growing in the middle indicates that the stream is expanding in this direction. This may have been a secondary channel that is now enlarged or be a secondary channel that is accessed during high flow and may eventually become a main channel.

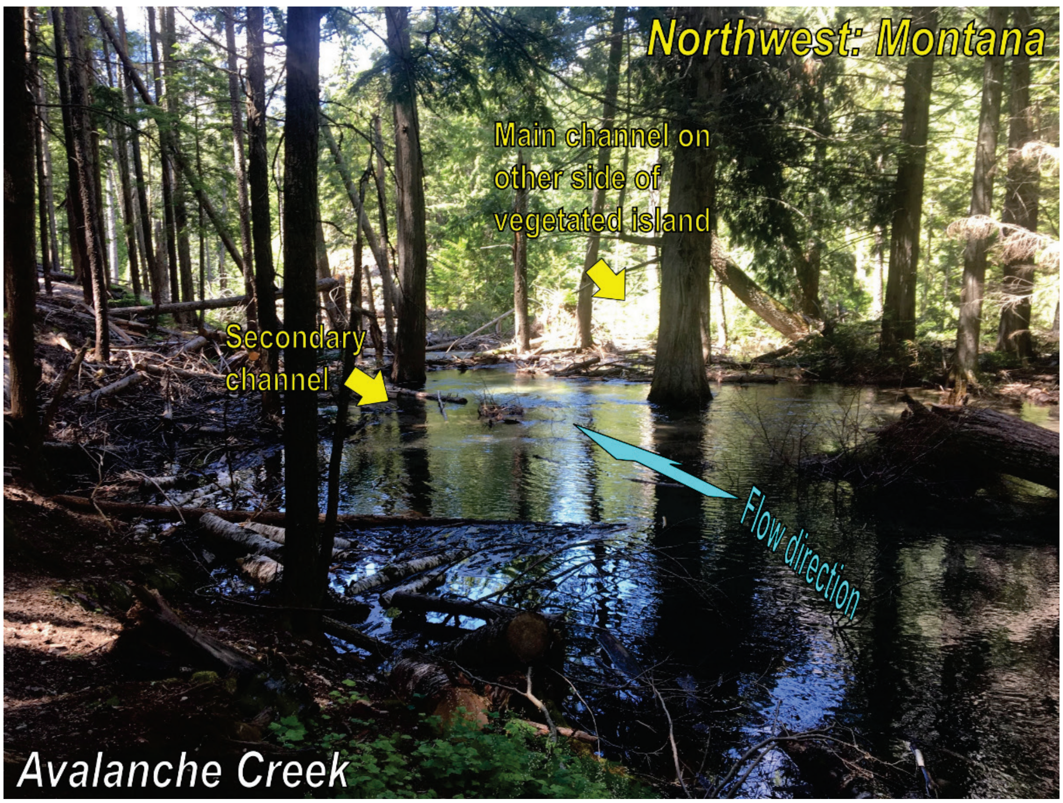
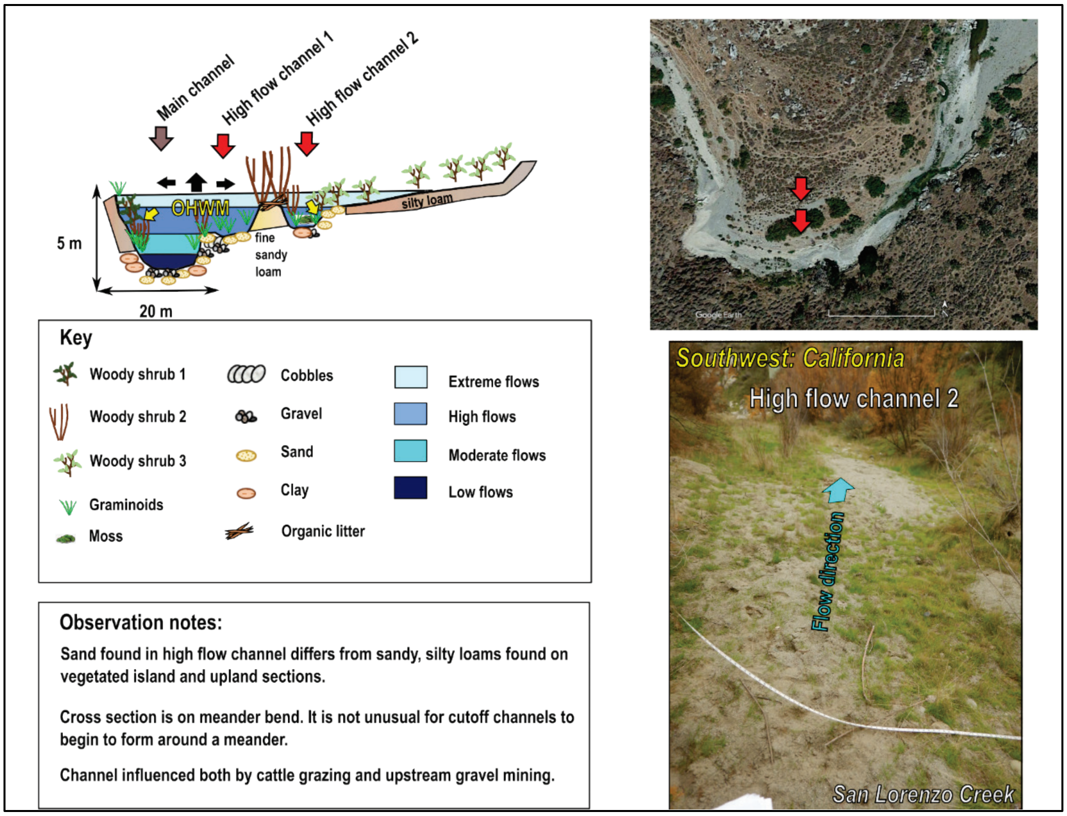
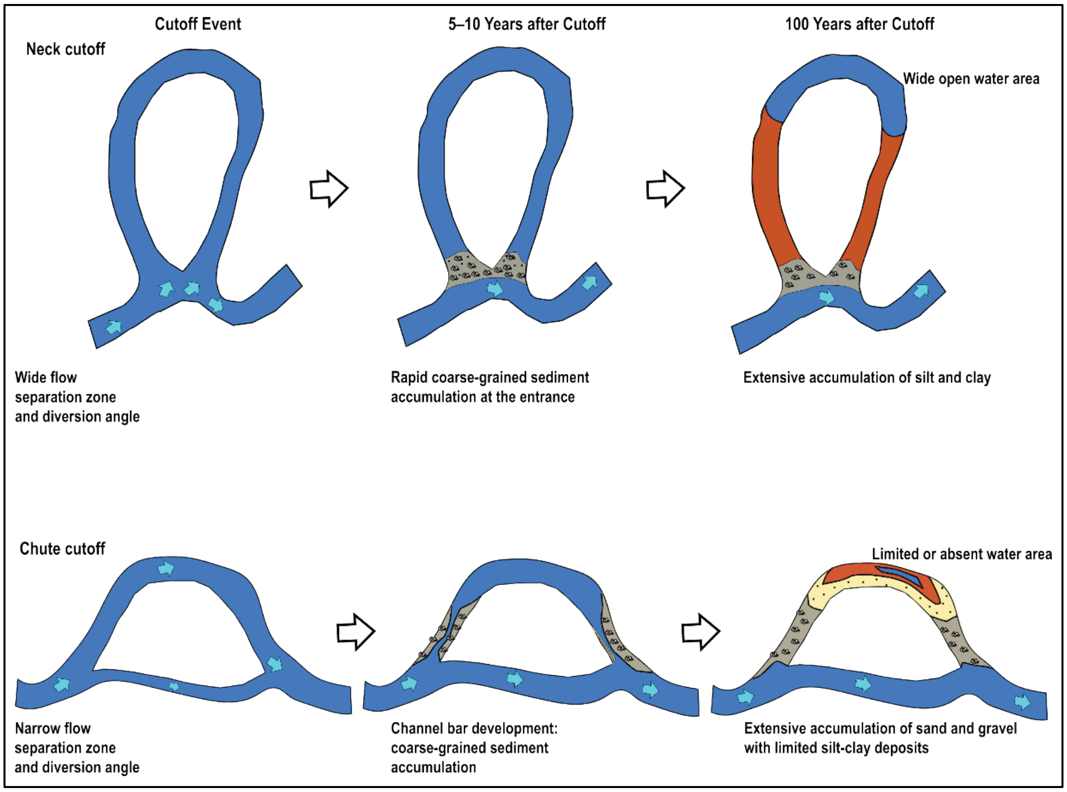


Figure 45. Secondary channels, identified as high-flow channels (*red arrows*), in a dry stream. Identifying the stage that the flow would have to reach to access these high-flow channels assists with identifying the elevation of the OHWM. Photograph on *lower right* shows high-flow channel 2, which corresponds to the upper arrow in the Google Earth image.



Abandoned channels can be created by the development of particularly sinuous meander bends, leading to neck cutoff (Hooke 1984). Neck cutoffs primarily occur because of lateral migration processes that do not require overbank flows, although the final cutoff may occur during high water. The cut off meander may be abandoned by frequent flows but continue to act as a channel during floods; that is, it may continue to be a high-flow channel after abandonment by the low-flow channel. Another type of cutoff resulting in an abandoned channel is a chute cutoff (Teisseyre 1977; Micheli and Larsen 2011; Dépret et al. 2017). Chute cutoffs occur where there is aggradation in the main channel, which can result in abandonment of the meander bend and the majority of water flowing through what was previously a secondary channel (Figure 46). Channel abandonment is not restricted to meandering streams but also occurs with braided, straight, or anastomosed channels. Abandoned channels can also be created by avulsions caused by LW jams or sedimentation and abandonment of a secondary channel of a braided stream (Kondolf 2011).

Figure 46. Examples of neck cutoff and chute cutoff (modified from Dépret et al. 2017).



Secondary channels, or side branches, can occur in any portion of a watershed. In narrow floodplains, channels are commonly single-thread channels or have secondary channels near the main channel. The presence of additional side branches is also affected by past land use. For instance, tie drives (i.e., floats of lumber) were commonly used in streams to transport materials for railroads, mines, and buildings. Where these occurred, stream geometries were simplified to make it easier to move the wood downstream. Remnant secondary channels can still be observed on these systems, but the stream may no longer access them. This practice also removed LW from channels and was associated with road construction next to streams, simplifying channel geometries and leaving only a main channel active (Blanton and Marcus 2009; Wohl 2019).

Secondary channels are a key geomorphic indicator of the OHWM. Once the secondary channels are identified, the WoE method can be applied to determine the relevance, strength, and reliability of this indicator for the specific site. Vegetation, sediment, and ancillary indicators can be combined to determine the relevance, strength, and reliability of the secondary channel as an indicator of the elevation of the OHWM.

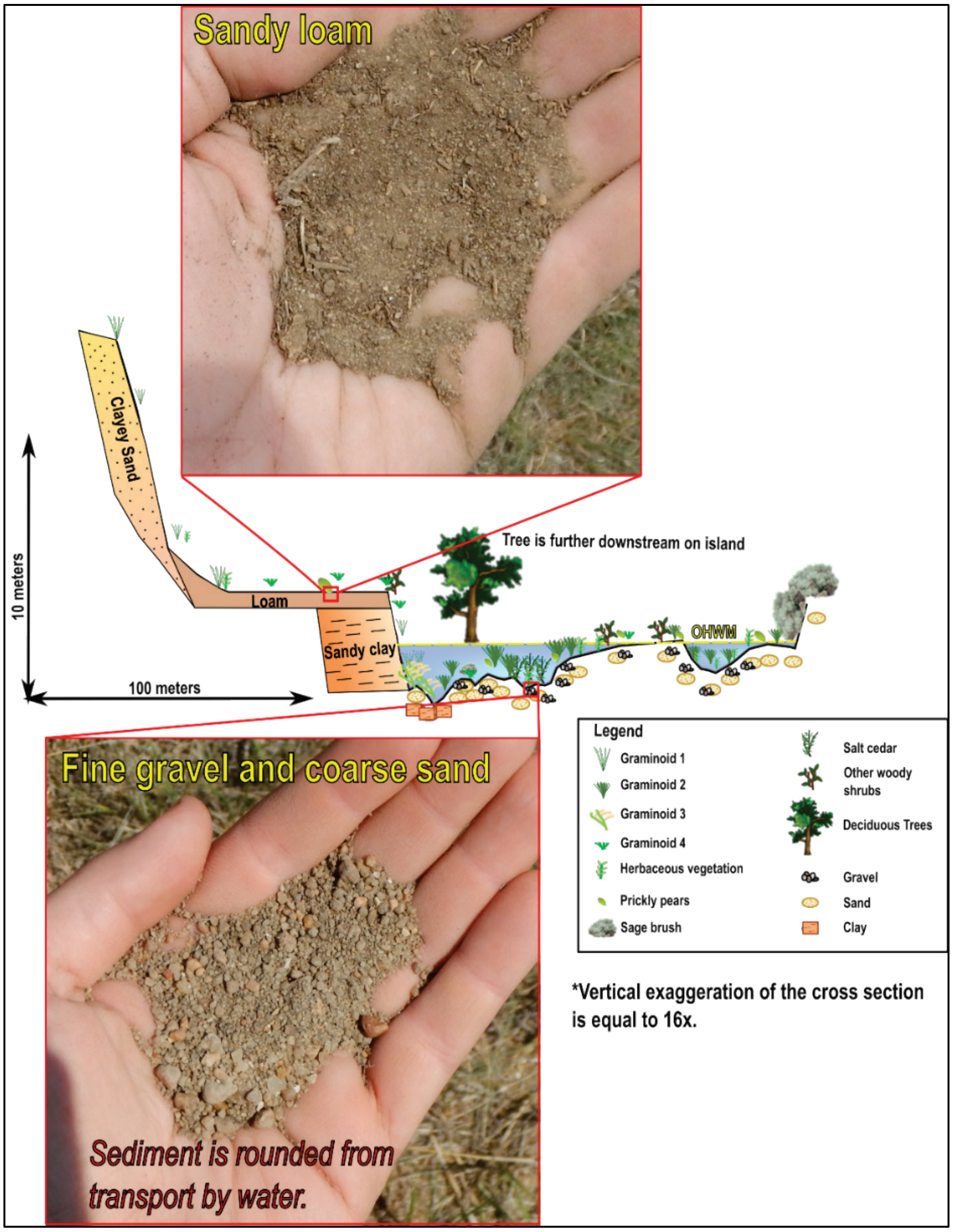
2.3.2 Sediment and soil indicators

2.3.2.1 Soil development and changes in the character of soil

Residual and alluvial soils are two general categories of soils identified adjacent to stream channels. Residual soils are dominated by decomposed rock—augmented by organic matter—left by weathering of the underlying rock over an extended period of time. Morphological and color features of the parent rock material may remain in residual soil profiles even though the parent rock is weathered and friable (i.e., easily crumbled; Le Pera et al. 2001). Residual soils tend to be older and often lie beyond the reach of erosive or depositional flows. In contrast, alluvial soils are developed by pedogenesis in stream sediment (Brady and Weil 1999). Alluvial soils occur on floodplains, terraces, alluvial fans, and deltas and represent pedogenesis on surfaces deposited by water at some time in the recent or distant geologic past. Their textures and lithologic characteristics reflect the source areas of sediment (Ogg et al. 2017). Floodplain alluvial soils may have primary sedimentary structures that can be preserved in deposits exposed in channel banks if soil formation has not obscured them. For example, they may be vertically stratified by the deposition of coarse sediment during floods followed by finer sediment later. They may have cross-bedded sands that are common in bars, dunes, and ripples (Reineck and Singh 1980). Alluvium may also show spatial patterns, such as coarse deposits near the edge of the stream bank and fine sediment further away from the channel, where water velocities slow down. Silts and clays are deposited when water slows, which may occur in depressions on floodplains or in pools of abandoned channels, because the fine material can no longer be carried in suspension (Brady and Weil 1999; Bridge 2003). In assembling evidence for the OHWM, clear differences often occur between alluvial and residual soils and in sediment grain sizes between channel and floodplain soils and sediment (Figure 47).

In the Smoky Hill River example (Figure 47), the floodplain material is a fine-grained sandy loam, whereas the bed material includes both coarse sand and pebbles. The Smoky Hill River was dry when surveyed; through careful observation, this revealed clear differences in sediment types between the channel and floodplain surface materials beneath the vegetation. In this case, the stream cuts laterally into the older floodplain material on its left bank, so it does not have a distinct sediment transition point on that side. On the right bank, however, the sediment transitions from sand and pebbles in the channel to sand at a flow stage in which flow velocities slow down on the floodplain and sediment grain sizes decrease. As described for floodplain sediment associated with natural levees in Section 2.3.1.2, this example shows how changes in sediment grain size may provide relevant indicators of OHWMs, especially if they can be tied to other evidence. The strength of the indicator in this example is corroborated by the fact that the grain-size transition occurs at the same elevation as transitions in vegetation species and a break in slope. Furthermore, a high-flow event at this elevation would inundate the midchannel bar, which still has a combination of sand and gravel deposited in it, but would be below the elevation of the island, which is downstream of this cross section but is shown with the elevation of the tree. This corroboration of various lines of evidence is a good example of how the WoE approach can be effective in locating the OHWM.

Figure 47. Change in sediment characteristics between floodplain and channel bed in the Northern Prairies region on the Smoky Hill River in Kansas.



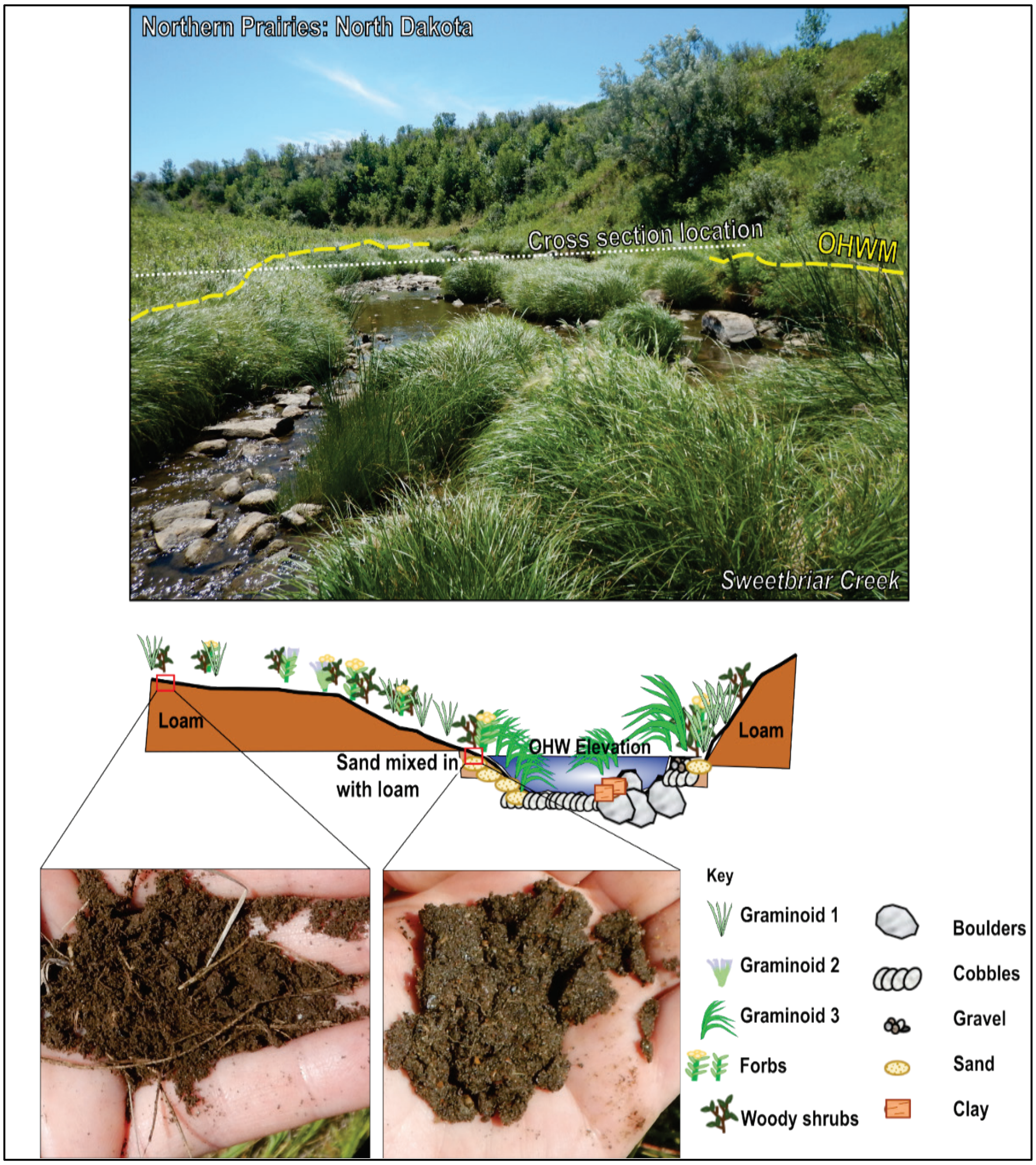
The relative development of soils (i.e., pedogenesis) on a surface may indicate the age of the surface. Well-developed soils tend to be on older, stable surfaces that have not been severely eroded or received large amounts of sediment (unless they are buried). They can have multiple soil horizons (Table 3) and other evidence of strong soil development. Not all soil horizons will be present in each soil, and young floodplain soils often have simple soil horizons consisting of an A/C profile; that is, an A horizon directly overlying a C horizon. Soil profiles with E and B horizons are generally older and indicate stable or recently exhumed surfaces on which weathering and soil development operated for long periods of time. Surfaces with old soils may be scoured by flows or buried by younger sediment, indicating more recent geomorphic activity. Soils are often exposed in eroding stream banks and can be examined.

Table 3. Description of possible soil horizons occurring in residual soils.

Soil Horizon	Description
O horizon	Layer of decomposing organic matter at or near the ground surface; also referred to as *humus* if fine or *peat* if coarse
A horizon	Mineral layer possibly darkened by decomposed organic matter mixed with the mineral grains
E horizon	Light-colored, low-density zone of mineral material from which clay, iron, aluminum, and so on have been removed (i.e., leached)
B horizon	Accumulation and concentration of materials from A horizon, including clays and Fe
C horizon	Underlying parent material largely unmodified except for carbonates and groundwater effects; the least-weathered part of the soil profile

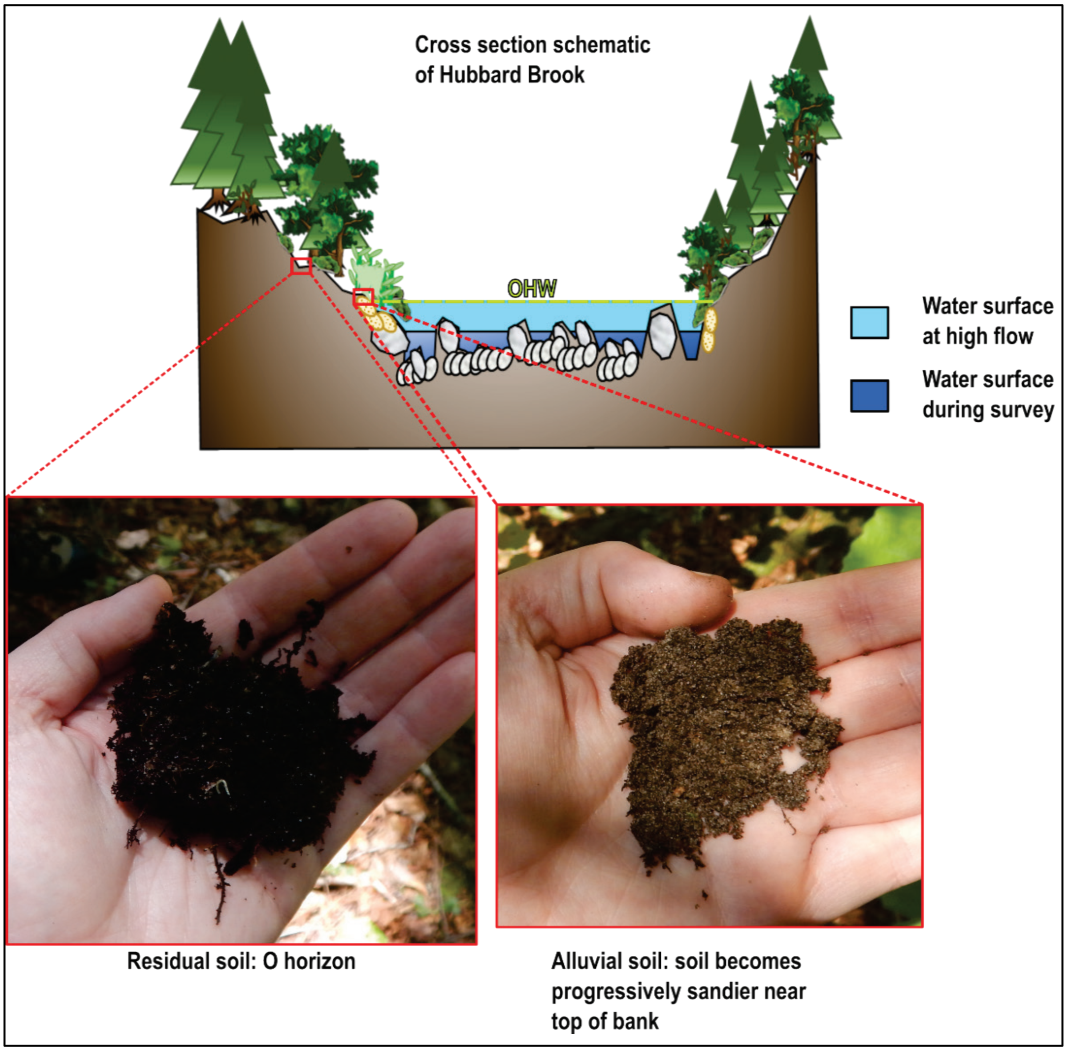
The degree of alluvial soil pedogenesis depends on the timing between flood events, climate, the activity of organisms and organic matter, local topography, the nature of parent materials, and the age of the surface (Jenny 1980). Although the degree of soil formation varies with several complex, nonlinear factors, time is a key factor. Moreover, at the scale of a local study site, differences in climate, parent material, and vegetation may be negligible, so topography and time take on further importance. Time is especially important in near-channel environments, where channel processes may frequently bury or erode soils (i.e., arrest or restart pedogenesis). The degree of pedogenesis observed, therefore, can indicate whether recent disturbances, such as sedimentation or erosion, have occurred on that surface. Time is a limiting factor for many soil features, but the A horizon of a soil tends to be one of the fastest features to develop. Floodplains are conducive to deposition, so it is not uncommon to find a series of stacked cumulic or multistory soils with two or more weakly developed A horizons. This represents short periods of soil development interrupted by floodplain sedimentation that buried the previous soil (Schaetzl and Thompson 2015). This is evidence of rapid floodplain sedimentation at some time in the past. Conversely, the lack of A horizons on floodplain and in-channel sites may represent scour or sedimentation by one or more flow events without sufficient time to generate an A horizon. In the case of either sedimentation or erosion, an elevational pattern of soils may exist that indicates the relative frequency of flooding. The hypothetical pattern is for increasing A-horizon development with distance and elevation from the active channel. Although alluvial soils may differ on floodplains and within channels in different parts of the country in response to the many factors of soil formation, subtle differences in pedogenesis at a site and the transition to coarser sediment in the area adjacent to the channel may indicate a pattern of differences in flow frequencies (Figure 48).

Figure 48. Changes from loamy soil to sand in the direction of the stream in the Northern Prairies region, on Sweetbriar Creek in North Dakota. The sandier soil is coarser, indicating a closer proximity to higher-energy flows.



The lateral transition from residual to alluvial soils toward a channel can provide evidence of flows in streams, which is relevant if the alluvial materials are recent. For example, in Figure 49, a mountain stream in the Northeast region shows the change from a thick, residual soil with an O horizon rich in organic carbon on the hillslope to sand with a weakly developed soil just above the banks in the area parallel to the channel.

Figure 49. Transition from a well-developed residual soil on the hillslope to alluvial soils adjacent to the channel boundary on a Northeast region stream.



It is common in North American streams of the Atlantic and southern Coastal Plain and the Mississippi Valley to have a buried soil exposed in stream banks (Figure 50). The A horizon of the buried soil may represent the floodplain surface prior to the arrival of European settlers, whereas the overlying sediment is relatively fine grained and has only weak pedogenesis. The rapid introduction of agricultural technology along with deforestation and plowing led to an episode of extreme erosion and floodplain sedimentation in many regions (Knox 1977; James 2019).

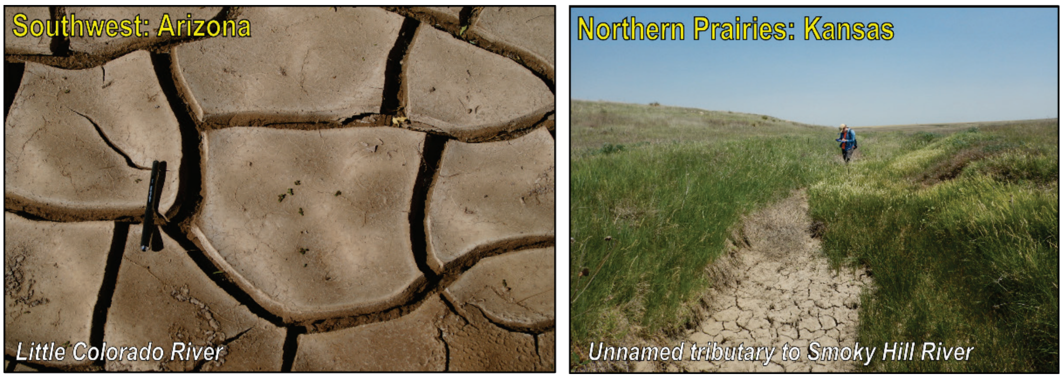
Figure 50. Sedimentary contact at top of dark soil buried by approximately 2 m (6 ft) of historical stratified tan sandy silt. The buried soil (at *hat level*) represents the floodplain surface prior to settlement by European American farmers. The light-colored sediment overlying the soil was deposited after the introduction of agriculture and deforestation of the watershed (Dearman and James 2019).

Chapter 5 provides resources for learning more about local soils in a region. Understanding the type of soils expected in an area prior to a site visit can help with interpreting the sediment and the transitions between residual soils and alluvial soils that are observed at the site.

2.3.2.2 Mudcracks

Mudcracks occur in areas where water pooled for a time, allowing for the deposition of fine-grained sediment, and then evaporated (Figure 51). Silt and clay are deposited during the waning stages of flow. Mudcracks often indicate where water pools in the channel and can help identify where pools have formed in a dry channel. Mudcracks typically occur below the OHWM, but they may occur in temporary floodplain wetlands above the OHWM.

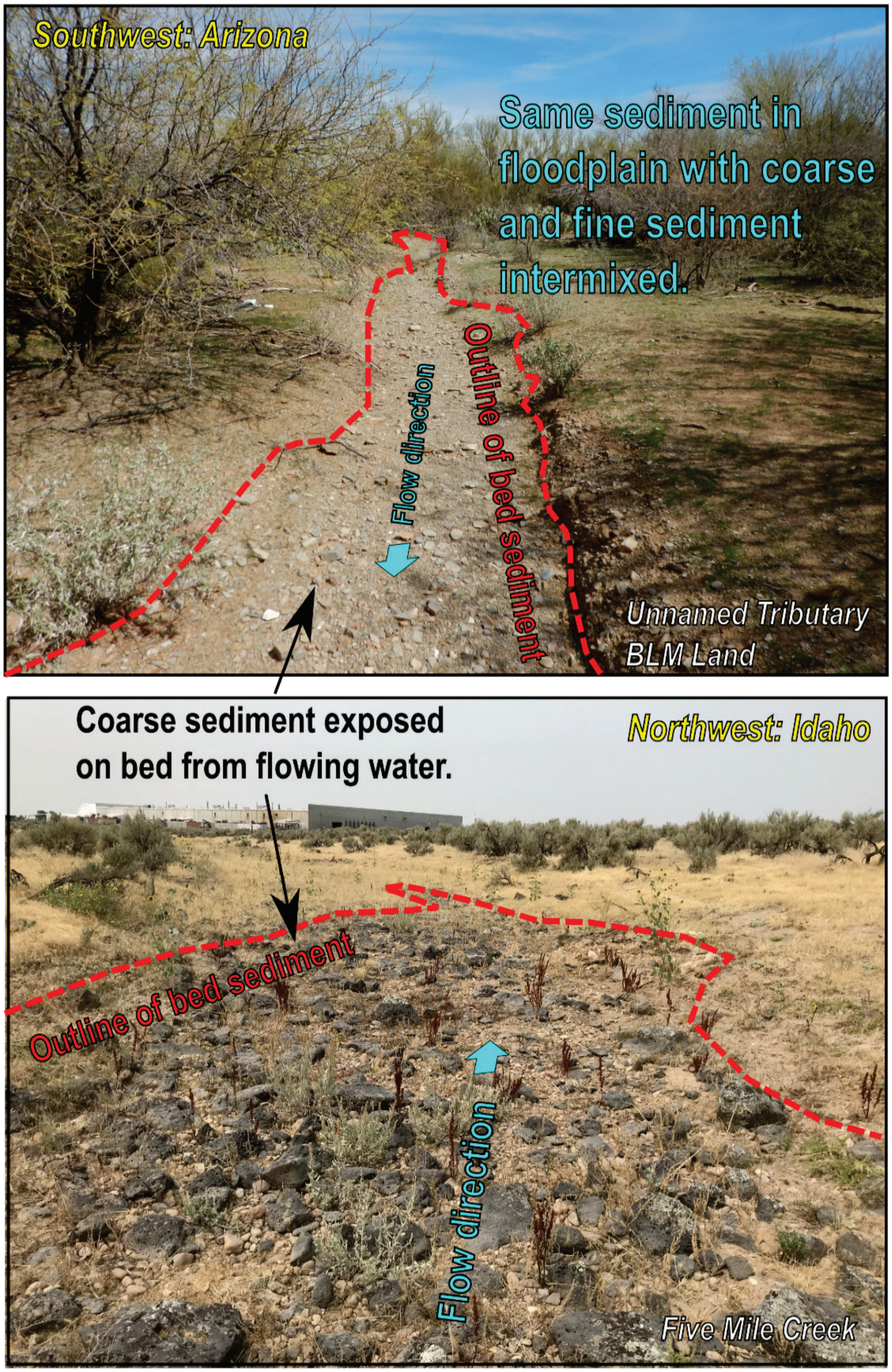
Figure 51. Mudcracks on a channel bed in the Southwest and Northern Prairies regions.



2.3.2.3 Changes in particle size distribution (sediment sorting)

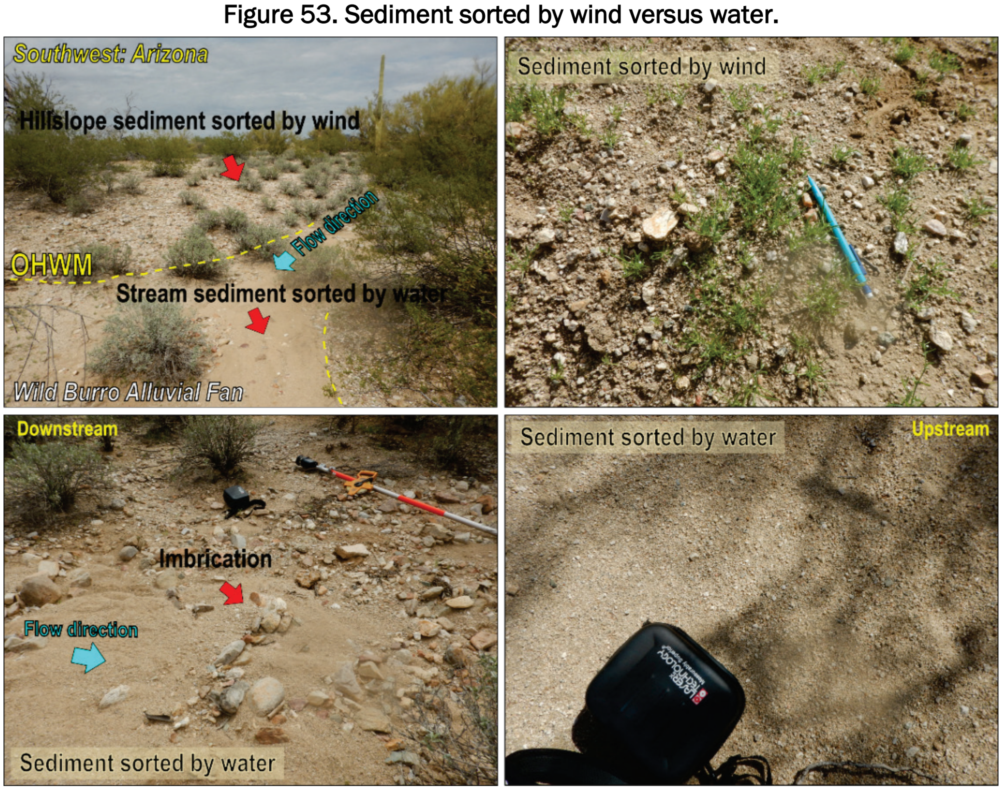
Sections 2.3.1.3 and 2.3.1.4 described evidence of sediment sorting and bedload transport. This section focuses on the identification of qualitative evidence of scour in the form of differences in sediment sorting and grain size between the channel and floodplain and the identification of the transition point between the two (Figure 52). Sometimes a major difference between the channel and floodplain is a lack of fine sediment and the exposure of the underlying coarse fraction because of the removal of the fine sediment fraction by higher velocity flows in the channel. Figure 52 outlines the bed sediment in dry channels in the Southwest and Northwest regions of the country. These boundaries serve as a first line of evidence when investigating the location of the OHWM. Once the transition in sediment characteristics is identified, then other vegetative, geomorphic, and ancillary indicators can be identified above and below that boundary to narrow down the location of the OHWM.

Figure 52. Coarse sediment is exposed on the bed of a channel in the Southwest (Arizona, *top*) and Northwest (Idaho, *bottom*) regions.



Sediment can be transported by different processes, such as gravity, wind, ice, and water. The relative differences between the channel and surrounding terrain can help narrow down the location of the OHWM in these arid environments. Hillslope sediment is transported downhill through mass wasting processes, such as landslides, rockfalls, and soil creep. Hillslope sediment can also be transported by wind, which can dominate the sorting of sediment in arid environments (Figure 53). Sediment that is predominantly moved by these processes is usually above the OHWM; therefore, it is useful to understand and be able to identify what is clearly above the OHWM. The movement of sediment by wind depends on wind speeds and the resistance of the surface substrate. Vegetation, climate, soil properties, and soil moisture content all influence how easily material can be transported by wind. Because of the lack of vegetation and the presence of noncohesive material, transportation of sediment by wind tends to dominate in sandy desert environments. Wind erosion (i.e., deflation) strips away the silts and clay and leaves a lag deposit of coarse material. Figure 53 illustrates differences in sorting by wind and water on a hillslope adjacent to a channel. The wind removed fine material and left larger clasts behind, so gravel protrudes above the finer material underneath. The sediment moved by water was sorted based on the channel gradient. Fines were deposited by water in this stream reach, but just downstream, coarser particles were imbricated in the direction of flow on a slightly steeper segment of channel. The coloration of the sediment is also different between the hillslope and the channel.

Figure 53. Sediment sorted by wind versus water.

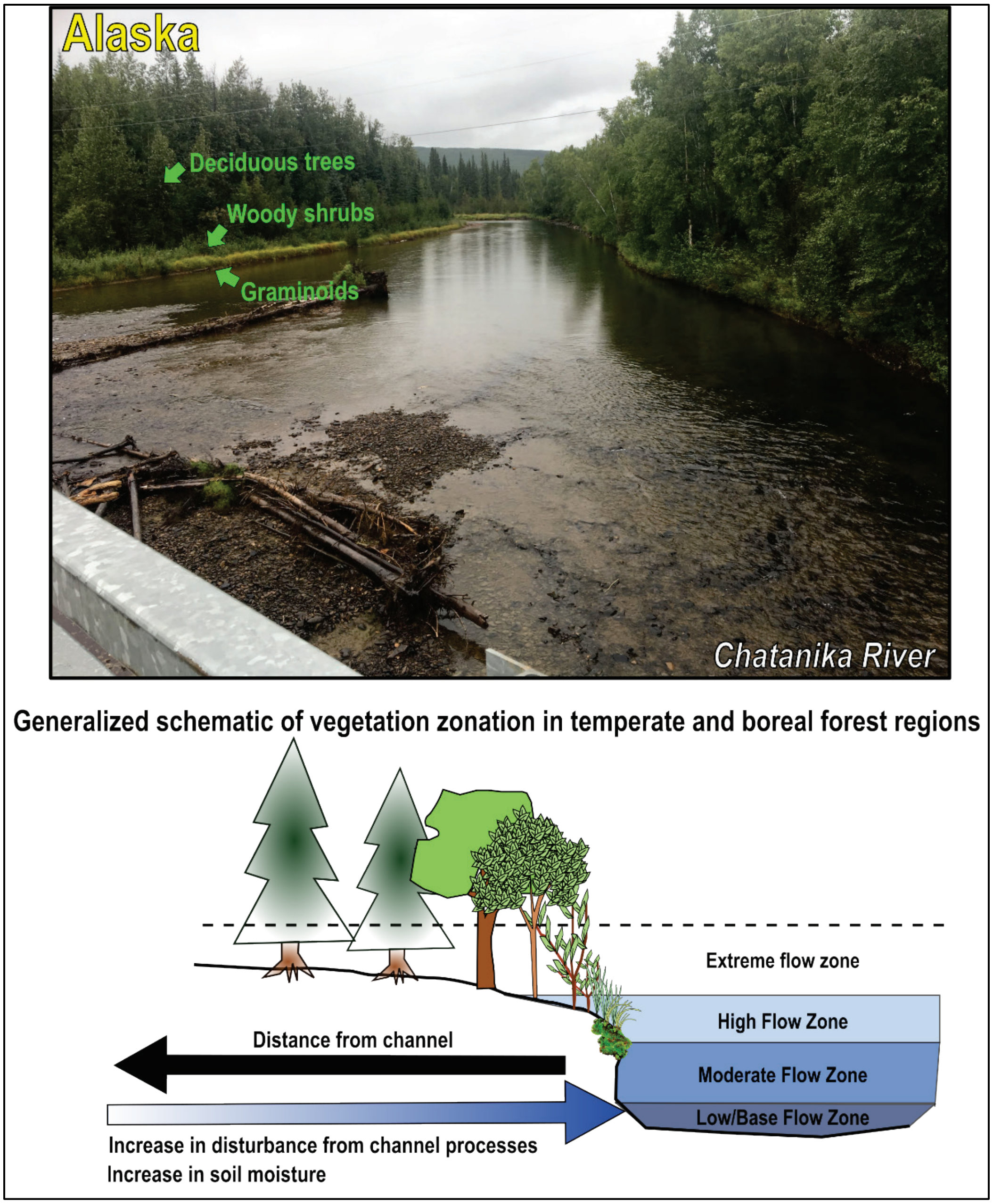


These examples emphasize differences in sediment characteristics between the channel, floodplain, and hillslope; these differences can also be observed in more temperate and humid environments. Changes in particle size distribution may sometimes be more obvious in dry channels and assist with an initial location to identify other indicators of the OHWM. In other areas, bank formation may be an initial line of evidence that can then be followed by looking for changes in particle size distribution along the tops of the banks and signs of residual versus alluvial soils.

2.3.3 Vegetation indicators

The community organization and dynamics of vegetation along river corridors are largely controlled by physical and biological factors, with the dominant physical factor being the disturbance created by fluvial (stream) processes. A *disturbance*, in ecological terms, is a discrete event that disrupts ecological structure and/or changes a physical environment (Pickett and White 1985). For instance, fires, floods, and landslides are examples of physical disturbances, whereas a disease is a biological disturbance. The bed and banks of channels have high disturbance frequency in comparison to the riparian zone and floodplain. Where the disturbance is frequent and/or intense, ruderal, or disturbance-tolerant, species will grow (Bornette et al. 2008). The establishment of specific species depends on a site's suitability for germination and conditions that allow a species to persist until reproductive age (Hupp et al. 2016). Disturbance from fluvial processes gradually decreases, moving perpendicularly away from the channel boundary (Figure 54). As disturbance decreases, the relative influence of biological interactions, such as competition and herbivory, on vegetation patterns increases, altering the community to more competitive, stable species (Bornette et al. 2008). Community structure in riparian areas can be related to flow frequency and, in many regions of the country, can assist in distinguishing the transition point at which the OHWM is identified. The OHWM does not require the destruction of terrestrial vegetation. Transitions in vegetation species, density, and age along stream boundaries all provide evidence for determining the location of the OHWM. The relevance, strength, and reliability of vegetation evidence depends on the regional differences in vegetation and landscape characteristics and history, such as recent and past land use and climatic extremes (i.e., droughts and flooding). When compiling evidence for the location of the OHWM based on vegetation indicators, it is essential that the user has a knowledge of regional vegetation.

Figure 54. Vegetation zonation in temperate and boreal forest regions. Vegetation transitions from hydrophytic to upland species as distance from the stream channel increases because there is less frequent disturbance by fluctuations of flows. Soil moisture, conversely, increases with proximity to the channel.



2.3.3.1 Vegetation zonation

Figure 54 illustrates vegetation zonation in a stream riparian area, defined as "lands adjacent to streams, rivers, lakes, and estuarine marine shorelines" (33 CFR 332.2). Riparian areas provide a variety of ecological functions and services and help improve or maintain local water quality. They are transitional areas between terrestrial and aquatic ecosystems, through which surface and subsurface hydrology connect riverine, lacustrine, estuarine, and marine waters with their adjacent wetlands, nonwetland waters, or uplands. Bank structure, along with transitions in vegetation moving from the bed up the banks and into the floodplain, helps with understanding which parts of the channels experience low, moderate, high, and extreme flows. These transitions can also occur on other channel features, such as channel bars and islands. Areas with completely exposed sediment are likely more frequently inundated than areas with vegetation cover, particularly in mesic regions. When an area is periodically inundated by flow, sediment transport may occur, making it difficult for vegetation to establish because sediment deposition often inhibits germination (Sluis and Tandarich 2004). Sediment deposition and the associated chemistry from flooding can also be important to the maintenance of some streamside plants (Beauchamp and Stromberg 2008). Most herbaceous plants (e.g., graminoids and forbs) are fast growing, relative to woody shrubs and trees. Therefore, the establishment of herbaceous plants may be related to seasonal changes in flow (i.e., low flows during summer months) and may not be an adequate indicator of the boundary line that is the OHWM. On the other hand, the presence of these plants might indicate there were sufficiently high flows to eliminate longer-lived woody vegetation.

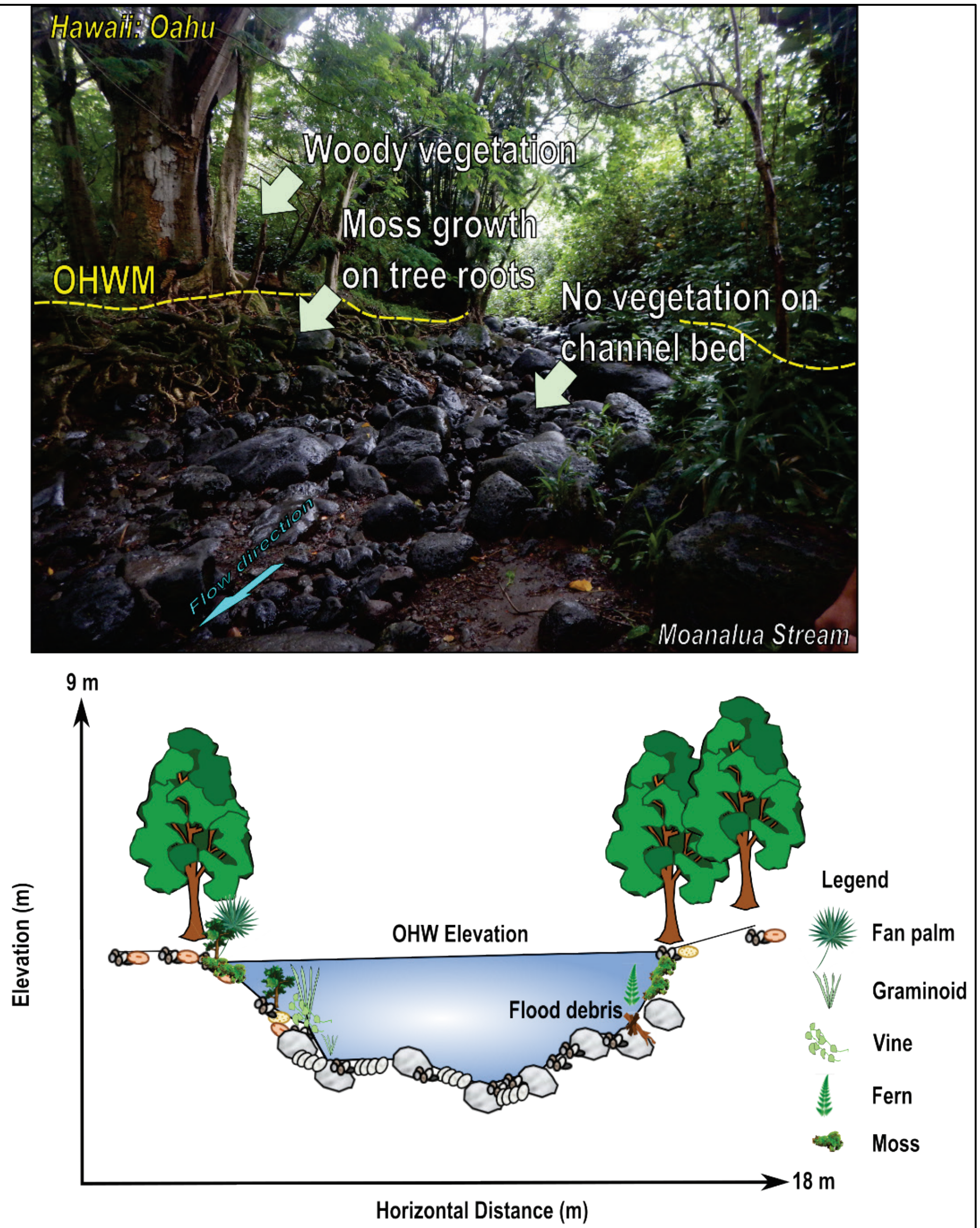
Many woody shrubs and trees (but not all, e.g., buttonbush and bald cypress) generally establish in areas in which their roots will not be constantly inundated by flows or have extended exposure to waterlogged conditions (Section 2.3.3.2; Blom and Voesenek 1996). Therefore, in many of the northern regions (Northeast, Northern Prairies, Northwest, and Alaska), changes in the distribution and abundance of woody vegetation can be a good indication of the elevation of the OHWM (Figure 55; Toner and Keddy 1997; Yarie et al. 1998; Nilsson 1999). The zonation of vegetation may be less distinct along streams bounded by steep hillslopes, as seen in coastal Oregon, and there are many exceptions to any generalized rules about zonation. Generally, there are many herbaceous plants that are adapted to periodic flooding and will predominate on banks immediately adjacent to streams, whereas woody shrubs and other species will persist on terraces and the bases of hillslopes (Pabst and Spies 1998).

Figure 55. Vegetation zones in Northern Prairie streams. Vegetation that flourishes in drier conditions is likely above the OHWM. Vegetation that is water tolerant or dependent (hydro- or hygrophilic), such as hydrophytes (obligate and facultative), grows below the OHWM in both these Northern Prairie streams.

Vegetation zonation also occurs along channels in subtropical regions (Figure 56). Pike and Scatena (2010) associated the elevations of the first occurrence of different riparian vegetation types with flow frequency at nine gages in northeastern Puerto Rico. Moss and short grasses began to colonize places that were inundated by flows on a weekly to monthly basis and by flows with magnitudes below the threshold needed to transport sediments. Larger grasses and other herbaceous vegetation colonized elevations that experienced flows near the sediment-moving threshold, and woody vegetation established at stages that coincided with brief flows that occurred several times a year. For eight of the nine sites (including montane and alluvial channels), the elevation at which woody vegetation first established coincided with a recurrence interval between 26 and 92 days.

No strong zonation pattern among only tree (>10 cm diameter at breast height) species was identified with distance from high gradient headwater streams in northeastern Puerto Rico (Heartsill Scalley et al. 2009). Total tree stem density increased with distance from the stream. The tree species composition became less variable with distance from the stream channel (Heartsill Scalley et al. 2009). Zonation of understory herbs was more pronounced in riparian areas of headwater streams in Amazonas, Brazil (Drucker et al. 2008). Zonation included a gradual change in herb species composition with distance from the stream and an abrupt, narrow band with a distinct group of species restricted to a few meters of the stream margin. The species composition pattern was not explained by canopy openness, but it was related to water-table depth and distance from the stream margin (i.e., surrogate for probability of flooding; Drucker et al. 2008).

Figure 56. Example of vegetation zonation occurring in a subtropical stream in Hawaii.

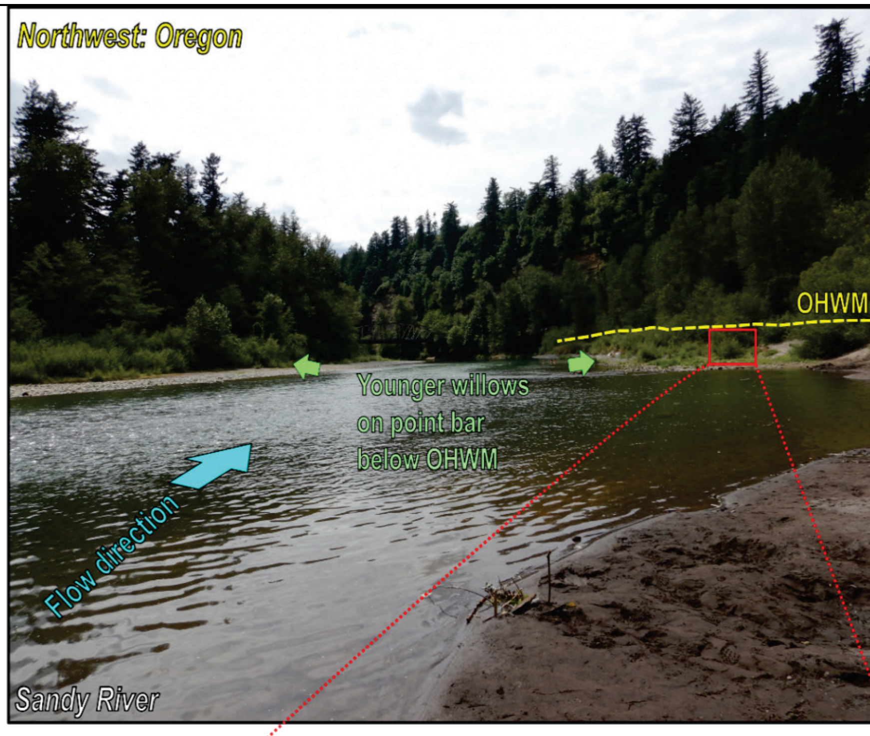


Rationale for OHWM: There is a clear break in slope. Sand, gravel, and boulders are present below this elevation. Vegetation transition to trees at the top of the banks. At a lower elevation the only seedlings of woody vegetation are found. Some sand deposition on the left bank just over the top of the bank. Organic litter found below this elevation.

2.3.3.2 Woody vegetation

The taxonomic and size-and-age distribution of woody vegetation that informs OHWM identification can vary depending on the region of the country. Generally, smaller plants are younger than larger plants, but one would have to age them to definitively determine this because plants can grow at varying rates depending on local conditions. Also, because some plants resprout after damage, what might appear to be a young tree could be regrowth from an older tree. As discussed in Section 2.3.3.1, the location of woody vegetation growth in relation to frequency of inundation is species dependent and, therefore, will vary between and within regions. For instance, Figure 57 shows small willows growing on the cobble bars in Oregon's Sandy River. Unlike parts of the Southeast region, where more woody species adapted to constant root inundation and made vegetation zonation along rivers less apparent, the zonation in the Northwest region is more distinctive, with most woody vegetation growing at elevations higher than the OHWM. Piecing together each line of evidence at Sandy River indicates that the smaller willows on the channel bar are inundated on a regular basis by high flows. Organic litter accumulated in the branches and around the bases of the willows on the bar indicates that these plants are inundated on a regular basis, most likely by high-flow events. Further up the bank slope, the density of organic litter decreases, and the willows are larger and more established. The larger willows also correspond to a break in slope; therefore, the WoE indicates that the OHWM is at this higher elevation. The exposed cobble on the channel bar provides additional evidence that these bars are inundated on a regular basis. Other channel reaches have sand deposition, and the lack of the finer sediment size in these cobble-dominated areas indicates sediment transport; therefore, fluvial sorting is occurring. The example from Oregon's Sandy River demonstrates how to assemble evidence, weight each line of evidence, and combine that information by weighing the body of evidence to decide on the location of the OHWM. The rest of this section provides general information about woody vegetation to assist with understanding if, or in what circumstances, woody vegetation transitions are likely to occur above or below the OHWM.

Figure 57. Vegetation zonation in the Sandy River near Portland, Oregon. Younger willows are growing on cobble bars.



Supporting evidence for OHWM identification:

1. Break in slope and shelving found above the smaller willows.

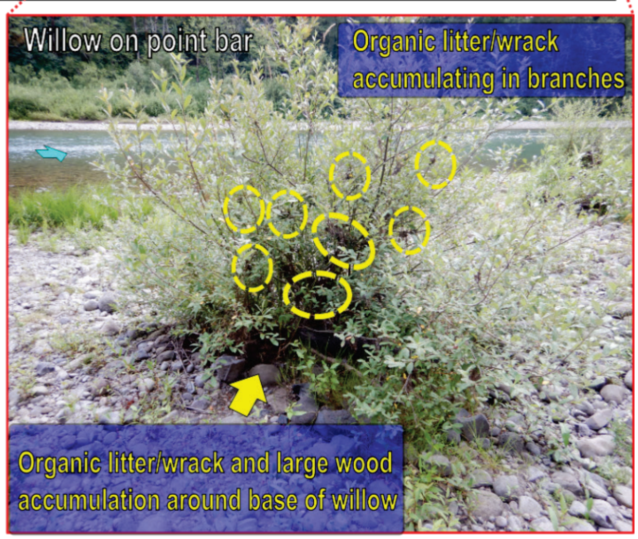
2. Willows are smaller and likely younger on the cobble bar.

3. Lower density of willows on the cobble bar.

4. Willows have organic litter/wrack accumulation throughout the branches and around the base. Much less evidence of organic litter and flood debris ascending the banks, away from the channel edge.

5. Change in sediment type and distribution from exposed cobbles to sand.

6. Elevation of OHWM matches location of evidence on the other bank.



Woody plants vary in their ability to physiologically tolerate inundation and subsurface saturation with anoxic conditions (Auble et al. 1994; Shafroth et al. 2000). For example, willow trees (Salix spp) tolerate root inundation to a greater extent than cottonwood trees (Populus spp; Amlin and Rood 2001). Adult riparian plants can typically survive longer periods of inundation than younger plants (Siebel and Blom 1998; Glenz et al. 2006). Adult boxelders (*Acer negundo*) can survive inundation over the entire growing season; saplings can survive 85–105 days, and first-year seedlings 25–60 days (Friedman and Auble 1999). Older woody plants tend to have larger rooting zones around them, so the entire root zone of older plants is less likely to be inundated than that of younger plants. The roots of younger plants are, for the most part, shallower than adult plants, so the roots of adult plants are likely to be in waterlogged sediment longer than younger plants. Some plants develop specialized tissues (e.g., aerenchyma) and structures (e.g., aerial roots) as they age, so they are less susceptible to waterlogging than young seedlings (Kozlowski 1984; Melick 1990). However, there are plants (especially hydrophytes) that have adaptations (e.g., life-cycle timing) that enable them to either avoid flooding periods or tolerate inundation (Blom and Voesenek 1996).

The deeper rooting of some woody plants, including older ones, enables them to tolerate dry periods when the water table is lower and resist uprooting to a greater extent than other, younger woody plants (Asaeda et al. 2010). However, the greater aboveground surface area of older, less flexible trees and shrubs greatly increases drag, making them more vulnerable to physical destruction by flooding than younger, more flexible saplings (Peterson and Claassen 2013; Stone et al. 2013). Root erosion and growth irregularities in woody vegetation, in the form of impact scars, adventitious sprouts, and eccentric rings, can be used as evidence of high flows (Stoffel et al. 2017). Following floods, propagules dispersed by wind (i.e., anemochory) and water (i.e., hydrochory) germinate in places where older plants have been eliminated. The establishment of young plants or vegetative fragments of older individuals at these frequently flooded river margins occurs because (1) conditions are suitable for colonization and germination (e.g., little competition and availability of light, water, and nutrients) and (2) they have not yet experienced disturbance to eliminate them. Often, recruitment of woody riparian vegetation requires flooding because floods open space at elevations that provide sufficient moisture for young trees to become established to survive subsequent lower magnitude floods (Scott et al. 1997).

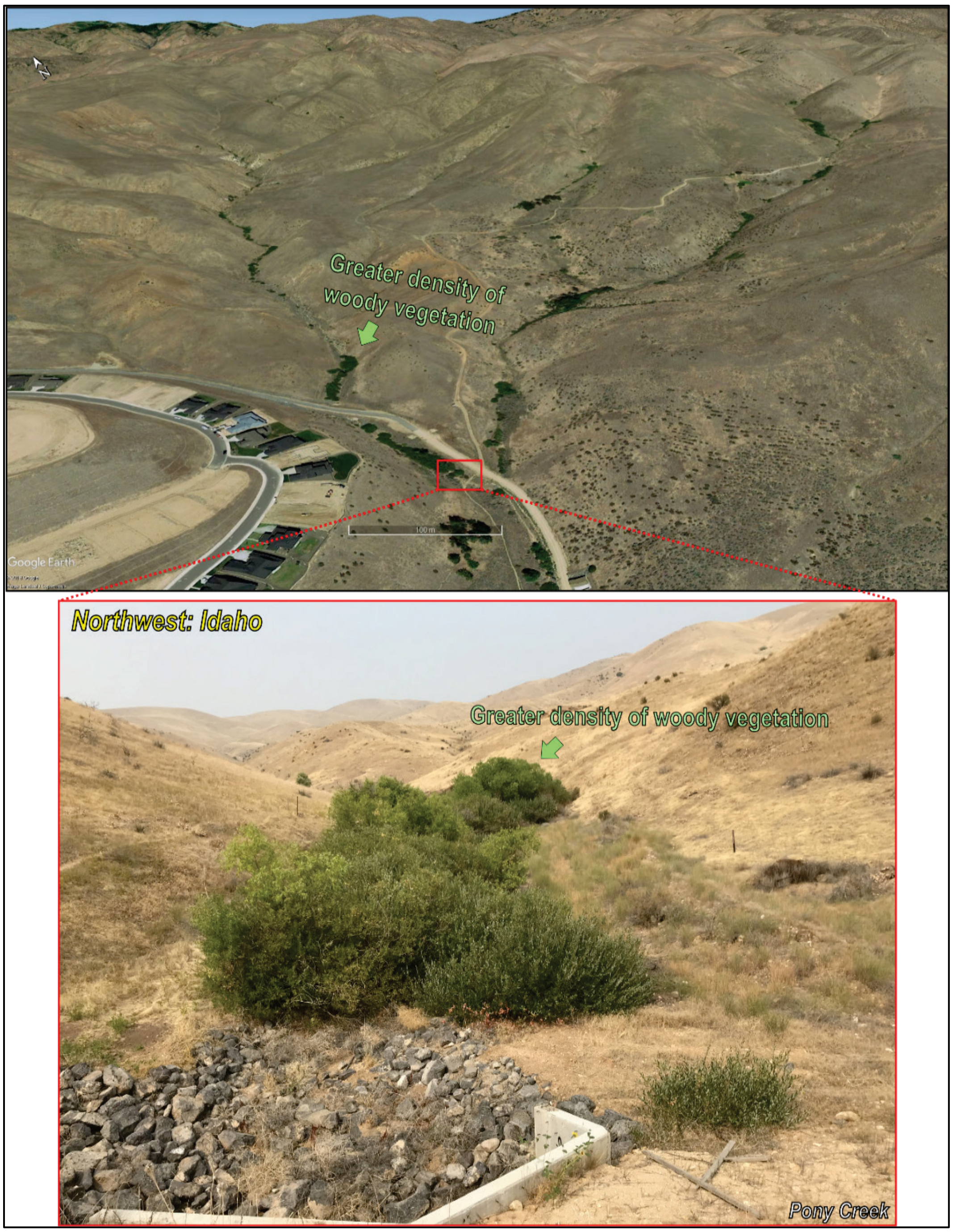
Woody vegetation in some regions of the country, such as the Southeast and particularly in river or swamp systems, may not provide a clear zonation line because some species of trees are more hydrophytic (Figure 58;

Smith 1996; Hupp 2000). In these areas, other lines of evidence are needed to support identifying the elevation of the OHWM. This is similar to how the lines of evidence were combined in Figure 57 to show that the willows are likely inundated by high flows.

Figure 58. Cypress trees growing in the Fish River in Alabama. Woody species that grow in the bed of streams can complicate the use of vegetation to identify the OHWM; other lines of evidence may be important. It is possible other transitions in vegetation could be used, but a more detailed vegetation survey at this site would be needed to find those transitional zones.

In arid environments, the presence of woody shrubs generally indicates the presence of either ponded or flowing water (Figure 59). The taxonomic composition and density change of woody vegetation upland of riparian areas will often be more noticeable than at the channel margin because of the steep moisture gradient. Most channels in arid regions do not have continuous flow, so the form of nonperennial channels can change dramatically between periodic small to intermediate flood events (i.e., >5 year recurrence; Lichvar et al. 2009). Lichvar et al. (2009) reported that flows that had less than a 5-year-recurrence interval were usually not geomorphically effective and, therefore, did not control channel form or the distribution of vegetation. Similar to other regions, riparian vegetation in arid regions is controlled by a multitude of environmental and physical factors, including inundation duration and frequency, floodwater depth, velocity and stream power, and depth to groundwater (Katz 2004). Each of these factors can vary based on lateral gradients away from the channel and can also be dependent on the landscape topography.

Figure 59. Overview of arid landscape in Northwest region of the country (*top*). Pony Creek, in Idaho (*bottom*), shows where the channel is located based on the higher density of vegetation in the valleys.



Other factors to consider are geology, landscape position, channel morphology, the size of the watershed, land use within the watershed, and recovery time since the last flood event (Lichvar et al. 2009). The distribution and density of riparian vegetation is particularly useful for showing where there is a stable boundary between the floodplain zones and surrounding terraces in arid environments (Lichvar et al. 2009). The OHWM in these areas has sometimes been identified outside the boundaries (or banks) of the low-flow channels and along the edges of the floodplain, or what Lichvar et al. (2009) described as an active floodplain. Subsequently, the active floodplain of multithreaded systems was considered analogous to the active channel for the Western Mountains region (Mersel and Lichvar 2014). A series of ERDC technical reports describe vegetation in arid systems in more detail (Lichvar and Wakeley 2004; Lichvar et al. 2006; Lichvar and McColley 2008; Lichvar et al. 2009; Curtis et al. 2011). However, some of the terminology used to describe stream channel characteristics may have been updated and may differ in this current national manual. Therefore, when referring to these reports, make sure to check the glossaries and figures to understand what channel characteristics are being described. Overall, variability in the density, type, and age of riparian vegetation can assist with identifying the OHWM in arid regions, but a WoE method should be used to combine information about vegetation with other lines of evidence to better delineate the OHWM.

2.3.3.3 Herbaceous vegetation: Forbs and graminoids

Herbaceous vegetation includes vascular plants without significant woody tissue (Figure 60). The two main groups of herbaceous vegetation are forbs and graminoids. Graminoids are grasses and grass-like plants, such as sedges and rushes, whereas forbs are broad-leaved flowering plants. Other groups of nonflowering vascular plants often considered forbs include ferns, horsetails, whisk ferns, and club mosses. Herbaceous vegetation can complete their life cycle within one growing season (i.e., annual) over two years (i.e., biennial) or over more than two years (i.e., perennial). Some plants can also complete more than one life cycle within a growing season (i.e., ephemeral). The lack of woody tissue for structural support means that herbaceous vegetation is typically of lower stature and aboveground biomass than woody shrubs and trees. The maximum rooting depth and lateral spread of roots are typically related to aboveground biomass, with short-lived herbs having the smallest and trees having the largest root systems. The differences in rooting depths between herbaceous plants and woody plants decrease with increasing precipitation, but herbaceous plants tend to have larger lateral root spread relative to canopy size in dry, rather than mesic, environments (Schenk and Jackson 2002).

The lack of woody tissue also makes herbaceous vegetation more likely to be bent or matted in the direction of flow by high water along streams. Although many herbaceous plants that grow along stream margins have flexible stems that are geometrically and structurally resistant to bending deformation, at sufficient velocity and depth, the stems will rupture and bend, but this will vary among species and time of the year (Duan et al. 2002; Das and Tanaka 2007). The transition from bent or matted vegetation to erect vegetation can be used as a line of evidence for the OHWM. However, because velocity and depth can be sufficient to bend vegetation below the OHWM elevation or, in extreme floods, above the OHWM, and because vegetation can recover after high flows recede, bent or matted vegetation may not be spatially stable over time (Koenig et al. 2016). The context of the transition needs to be carefully evaluated for other coinciding changes (e.g., vegetation species and elevation).

Figure 60. Herbaceous vegetation growing on streambeds and channel bars. Hatchet Creek (*left*) shows an emergent hydrophyte cover (i.e., water willows) that would occur well below the OHWM. Water willow (*Justicia americana*) is an emergent herbaceous hydrophyte that grows on submerged streambeds, shores, and gravel bars of streams. Water willow is adapted to propagate and persist in stream systems in which scouring floods are common. Threemile Creek (*right*) shows a distinct herbaceous vegetation band, with the OHWM occurring at the transition between herbaceous and woody vegetation.

The diversity of herbaceous vegetation tends to be higher than that of woody vegetation in riparian areas, but the percent of cover of herbaceous vegetation tends to be lower than that of woody (Zimmerman et al. 1999;

Goebel et al. 2003; Clinton et al. 2010). Across the diverse herbaceous assemblage are plants that range broadly in their tolerance for inundation and ability to persist despite scouring from high flows (Bagstad et al. 2005; Dwire et al. 2006). As seen among woody vegetation, taxonomic zonation among herbaceous plants is evident, but because of their life cycles (e.g., only belowground structures are perennial), cohort zonation is typically less evident than it is for woody plants (Dietz and Ullmann 1997). Because of their shorter life spans, shallower root systems, and shorter statures, herbaceous vegetation is typically more responsive to environmental changes over shorter periods than woody plants (e.g., Lyon and Sagers 1998; Lite et al. 2005).

Herbaceous vegetation growing at the land–water margin ranges from aquatic plants that are submerged and rooted (e.g., eelgrass), to floating and rooted (e.g., water lily), to free-floating (e.g., duckweed) and emergent (e.g., cattail and sedges), to terrestrial forbs (e.g., clover and goldenrod) and grasses (e.g., bluegrass and bromegrass). Herbaceous riparian plants adapted to wet environments that may grow completely submerged under water or in wet soil are called *hydrophytes* (Tiner 1991). *Helophyte* is a term to describe emergent hydrophytes or plants that normally have much of their aboveground tissue out of the water (Figure 60). Therefore, riverine helophytes are typically restricted to shallower habitats along banks but may not always have their roots in water. Most submerged and floating aquatic plants are restricted to the active channel that is inundated during base flow. Hydrophytes that almost always occur associated with the presence of water or wet soil are considered obligate, whereas those usually associated with the presence of water or wet soil but that may occur in upland areas are facultative wetland plants (Lichvar et al. 2012). Plants that can occur in water or wet soil or in other conditions are also referred to as facultative wetland plants but are classified as facultative. Plants that usually do not or almost never occur in water or wet soil are facultative upland plants and upland plants, respectively (Lichvar et al. 2012). Obligate hydrophytes, including emergent species, are typically restricted to areas below the OHWM, but they can occur more patchily in wet habitats on floodplains or hillslopes (Nelson et al. 2011; Rooney et al. 2013).

Moving from lower elevations at the land–water interface to higher elevations, there is typically a transition from predominantly obligate hydrophytic herbs at the stream edge, to mostly facultative wetland plants of herbaceous and woody species at midelevations, to mostly terrestrial upland species (i.e., facultative and upland plants) at higher elevations (Chapin et al. 2002; Hagen et al. 2006). For example, 13 of the 21 riparian herb species identified were correlated with elevation along the Chippewa River (in Wisconsin), including species characteristic of elevations below the mean annual flood level and those more characteristic of elevations flooded every six to eight years (Barnes 1978). However, the elevations in between were transitional and were not represented by characteristic herb species. In riparian corridors lacking woody vegetation, such as montane meadows and headwater prairie streams, zonation of herbaceous vegetation can be clearly observed (Figure 55; Dwire et al. 2006; Meehan and O'Brien 2020). Although there are forb and graminoid species in each of the described hydrophyte and upland plant classes, zonation between forbs and graminoids can occur with distance from the channel and be quickly recognized. Vegetation shifts can be particularly abrupt (e.g., obligate hydrophytes to upland plant species) where channels are incised (Turner et al. 2015). However, because of varying groundwater availability across valleys, some riparian corridors can support hydrophytic vegetation beyond a band of terrestrial species immediately adjacent to incised channels (Loheide and Gorelick 2007). The lateral zonation of herbaceous vegetation can be complex, reflecting abiotic (e.g., water requirements, flood tolerance, light availability, and soil texture) and biotic (e.g., competition and herbivory) factors, which often coincide and rapidly change over small lateral distances away from streams. While often a strong OHWM indicator, the interpretation of vegetation patterns requires contextualizing more factors than just flood magnitude and frequency.

2.3.3.4 Bryophytes and lichen

The presence of bryophytes (i.e., mosses, liverworts, and hornworts) can assist users in locating the OHWM. Because bryophytes are nonvascular plants lacking roots, they are relatively low statured and slow growing, and they have adaptations to acquire and retain water and anchor themselves firmly to substrates. Like vascular plants, bryophytes vary broadly in their environmental requirements, but because of their characteristics, they can thrive in habitats that most vascular plants cannot (e.g., bare rock and tree trunks). Some bryophytes are also more shade tolerant and resistant to scouring flows than aquatic vascular plants, so they may represent distinct zones or bands along the edges of streams (Stream Bryophyte Group 1999).

Bryophyte species differ in their tolerance for submergence and desiccation (Glime and Vitt 1984; Arscott et al. 2000). Vertical zonation among bryophyte species has been documented relative to stream water level (Craw 1976; Slack and Glime 1985) and resistance to scouring and shear force by floods (Kimmerer and Allen 1982; Steinman and Boston 1993). The life forms of bryophyte colonies have been shown to correspond with the frequency and magnitude of flooding (Gimingham and Birse 1957; Muotka and Virtanen 1995). Cushions (which are dome shaped, with shoots radiating from a central point) and turfs (with parallel, upright shoots) are more characteristic of terrestrial species that inhabit drier, higher-elevation environments that are infrequently inundated. Wefts (which have horizontal stems with loose intertwining shoots) and mats (which have horizontal stems with dense shoot arrangement) are more characteristic of semiaquatic and aquatic species typically inhabiting lower elevations that are more frequently inundated. Species forming long streamer mats that are long-lived and strongly attached to substrates by rhizomes on basal ends of dangling shoots are characteristic of aquatic species inhabiting streams with infrequent and low-intensity floods (Vitt and Glime 1984; Muotka and Virtanen 1995). Short-lived, low statured, and firmly attached turfs are characteristic of habitat experiencing high frequency and high intensity flooding. While scouring and shear stress may create bare areas by removing bryophyte cover, breaks in bryophyte cover may be indirectly related to flooding and subsequent deposition of substrates. Bryophyte cover increases with increasing substrate size and stability (Englund 1991; Duncan et al. 1999). Because a large number of mosses can survive in a variety of conditions (e.g., Gillrich and Bowman 2010), this type of vegetative indicator should be used in conjunction with other indicators (Figures 61 and 62).

Figure 61. Photos and diagrams illustrating major growth forms of mosses along moisture and flood-tolerance gradient (weft photo by Erika Mitchell).

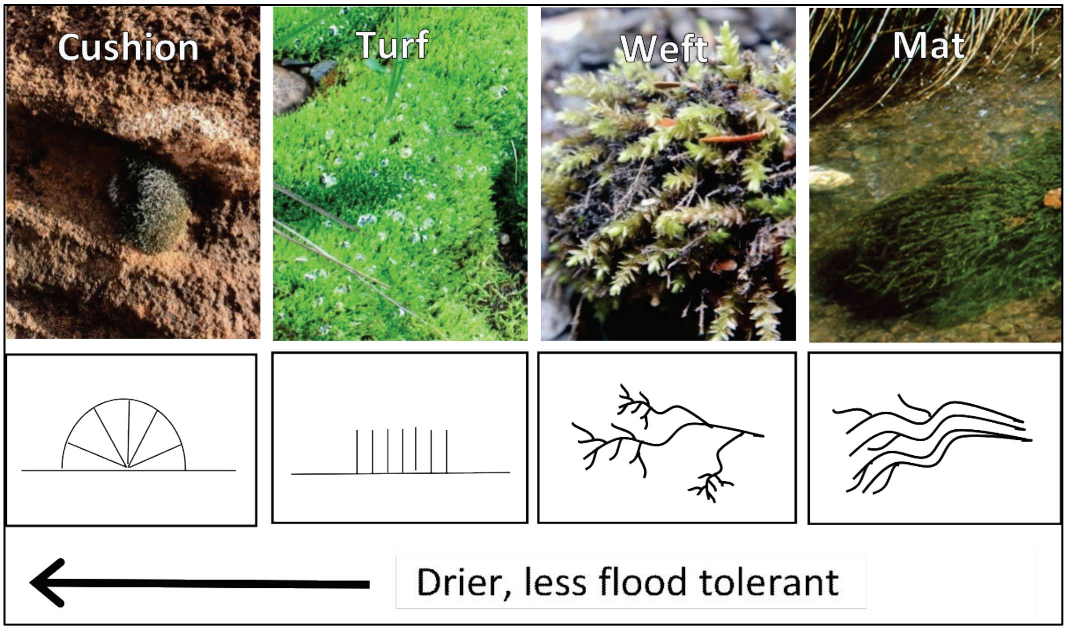
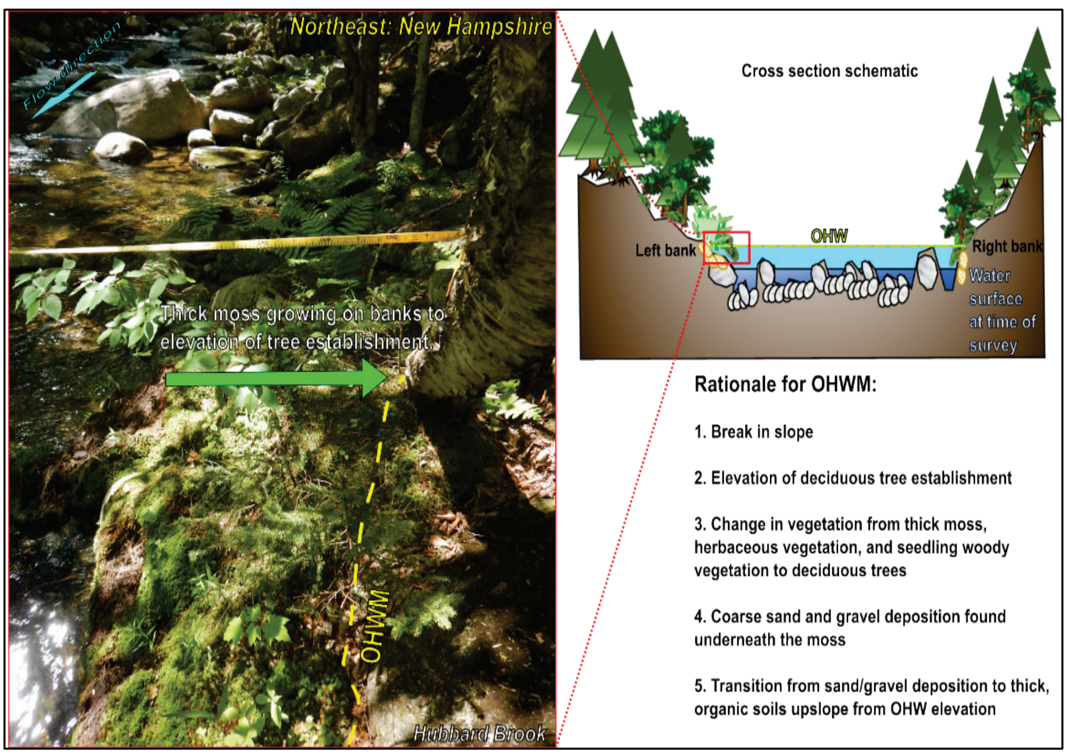


Figure 62. Example of thick moss growth on shelf above the break in slope.

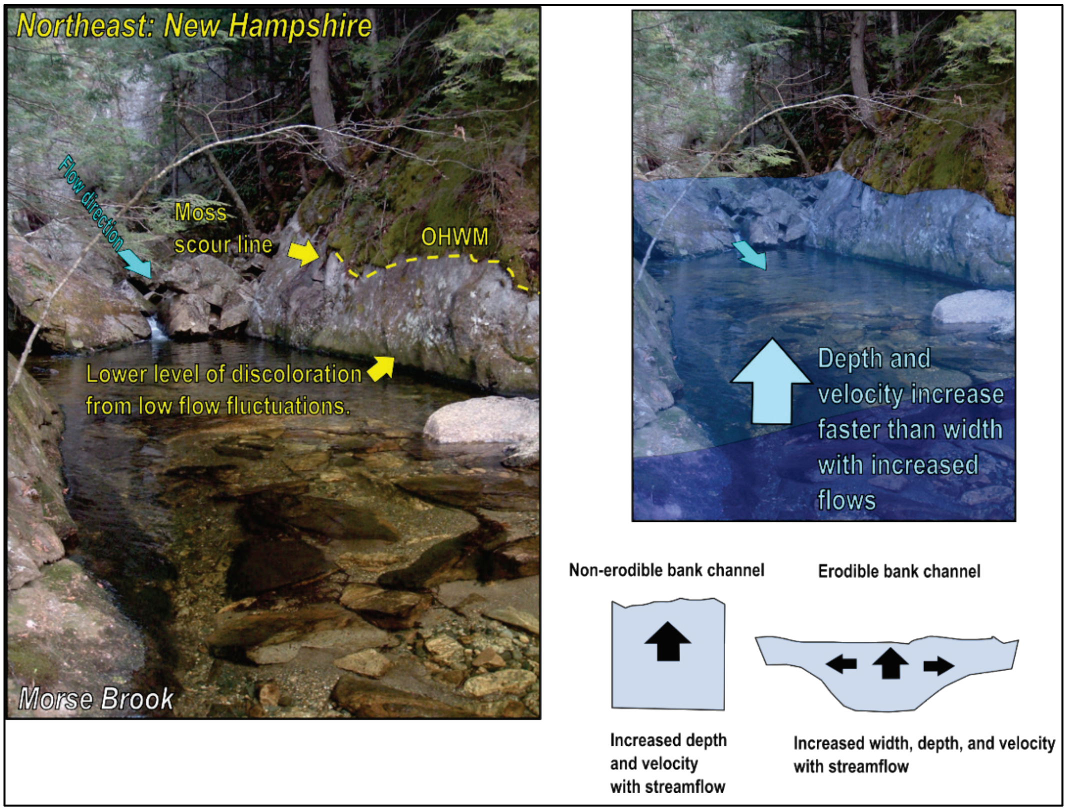


Moss that has been scoured away or is growing thin and patchy on rocks because of constant inundation or varying tolerance of inundation (Figure 63) can be used as a line of evidence in OHWM identification. Sometimes, distinct scour lines can occur along bedrock and be used as a line of evidence for the elevation of the OHWM (Figure 64).

Figure 63. Different types of moss and lichen growing on rocks and banks.

1. Thick moss growing on banks.
2. Thin moss growing on boulders.
3. No moss in this spot; it is likely there was a boulder here that fell into the channel.
4. Lichen and thin moss growing on boulder

Figure 64. Using moss scour lines in a channel with nonerodible banks. This is a bedrock channel, but the same effect can be seen in concrete-lined channels.



Lichens are composite organisms that result from algae or cyanobacteria (i.e., phycobiont) living with fungi (i.e., mycobiont) in a stable self-supporting association. Unlike vascular plants and bryophytes, lichens are not a taxonomic group; they are a lifestyle for fungi, much like parasitism can be a lifestyle for parasites and their hosts (Gilbert 2000). The association of lichens has been described as a foundational transition for biota moving from aquatic to terrestrial environments because both phycobiont and mycobiont ancestors are considered *poikilohydric*, or unable to maintain or regulate water content within cells and tissue (Lipnicki 2015). However, together as lichens, they can greatly expand their range of habitats, including living attached to rock (i.e., saxicolous), living bark (i.e., corticolous), dead wood (i.e., lignicolous), or bare soil (i.e., terricolous) across various biomes and microclimates (e.g., varying distances from water bodies; Figure 65). Lichens are also broadly recognized by the growth form of their vegetative body or thallus. There are three primary growth forms of lichens that are useful for field assessments. Crustose growth forms are tightly attached to substrates (i.e., they cannot be detached from the substrate without destroying the thallus) and may appear like spray paint on substrates. Crustose forms tend to occur in the most extreme habitats, and most aquatic and amphibious lichens are crustose lichens. Foliose growth forms are leaf-like in appearance, and though flat, they are only partially attached to the underlying substrate. Fruticose lichens are shrub- or bush-like and may appear erect or draped over the underlying substrate.

Figure 65. Lichen growth forms on different substrates: saxicolous crustose lichen (*left*); corticolous foliose lichen (*center*), and corticolous fruticose lichen (*right*).

Like bryophytes, lichens do not have roots and must acquire moisture through their tissue. However, unlike bryophytes, lichens lack waxy cuticles to conserve water but can rapidly absorb water as liquid or vapor. In addition, lichens are also well known for their desiccation tolerance and relatively slow growth compared to most vascular plants. Despite evolving from ancestrally aquatic organisms, most lichens cannot survive constant immersion (Figure 66; Thüs et al. 2014). While there are few truly aquatic lichens in freshwaters, many occur more abundantly along the margins of rivers and lakes (e.g., Gilbert and Giavarini 1997; Timoney and Marsh 2004) because of increased air humidity and lower air temperatures compared to more upland habitats.

Figure 66. Scour (or trim) line demonstrated by lichen in a dry stream. This was one line of evidence that the OHWM was at the elevation at which lichen is being scoured off the boulders in the channel.

Most lichens show a negative carbon balance (i.e., respiration > photosynthesis) during extended inundation because gas exchange capacity is lost (Farrar 1976). Inundation causes the thallus of most lichens to break down or to be invaded by nonsymbiotic fungi, but survival is prolonged with lower water temperatures (Marsh and Timoney 2005; Sammut and Erskine 2013). Aquatic and amphibious lichens have physiological and anatomical adaptations optimized for permanent or periodic submergence (Thüs et al. 2014; Coste et al. 2016). Water, therefore, creates a tenuous balance between lichen growth, and survival contributes to their strong zonation pattern. Zonation has been well studied in lichens. In addition to water availability, other physical and ecological factors, including shade, siltation, substrate stability, substrate chemistry (i.e., geology), ice and flood scour, and competition with other autotrophs, contribute to zonation patterns. Larger watercourses—those with more seasonally stable flows, in drier climates, and with stable banks (e.g., bedrock gorges)—form more distinct lichen zonation than smaller streams with flashy flows, in moist climates, or with unstable banks (Rosentreter 1984; Thüs et al. 2014).

Vertical zonation along streams has been described as having four overlapping zones: (1) submerged or low water, (2) fluvial mesic or normal flood, (3) fluvial xeric or high flood, and (4) fluvial terrestrial or extreme flood (Rosentreter 1984; Gilbert and Giavarini 1997). The submerged zone is inundated for most or all of the year and is dominated by truly aquatic lichen that are most often dark and crustose forms that are sensitive to desiccation. As many truly aquatic species are restricted to cool water and some amphibious taxa may extend their tolerance in cooler water, this layer is uncommon or absent in warmer climates and lowlands. The fluvial mesic zone is immediately above the annual base-flow level and so is inundated and splashed for much of the year. This zone is dominated by lighter colored, amphibious lichens and tends to have the highest diversity among freshwater lichens. The fluvial mesic zone lichens from sandstone streambeds in France were further classified into those inundated (or contacted by splash) for >9 months per year, 6–9 months per year, and 3–6 months per year (Coste 2010). The fluvial xeric zone is rarely submersed or splashed, so it is transitional between aquatic and terrestrial and is represented by weakly amphibious and truly terrestrial lichens. Therefore, the OHWM is likely to occur above the fluvial mesic and somewhere within the fluvial xeric zones. Last, the upper terrestrial zone is furthest from the water and so only has truly terrestrial lichens. Depending on the climate, the upper terrestrial zone may support more lichen species and lichens with faster growth than more terrestrially distant habitats because of higher humidity and lower air temperatures (Beschel 1973; Innes 1985).

Relatively level and distinct marks associated with transitional zones of lichen species composition or changes in lichen presence along shores of waterbodies are also called *trimlines* or *lichen lines* (Hale 1984; Timoney and Marsh 2004). These lines are indicative of high water levels such that they mark the level below which lichens intolerant of extended immersion (often foliose and fruticose forms) are absent or rare (Figures 66 and 67). Because of their slow rates of colonization and growth, stable, undisturbed shore substrates that are periodically inundated, scoured, or silted will lack lichen or be very small. Distinct lichen lines can form on bedrock and boulder shorelines (Rosentreter 1984; Timoney and Marsh 2004) and on trunks of flood-tolerant trees (Beckelhimer and Weaks 1984; Hale 1984); these lines are less distinct on less stable or more complex surfaces, like bank roots (Hachułka 2011). Because of differences in climate, species tolerance, water quality, substrates, shading, and siltation, the inundation duration needed to form a discernable lichen line varies greatly across studies (Table 4).

Figure 67. Lichen line apparent on culvert foundation (*left*), on left bedrock bank of gorge channel (*center*), and on boulder on bank (*right*).

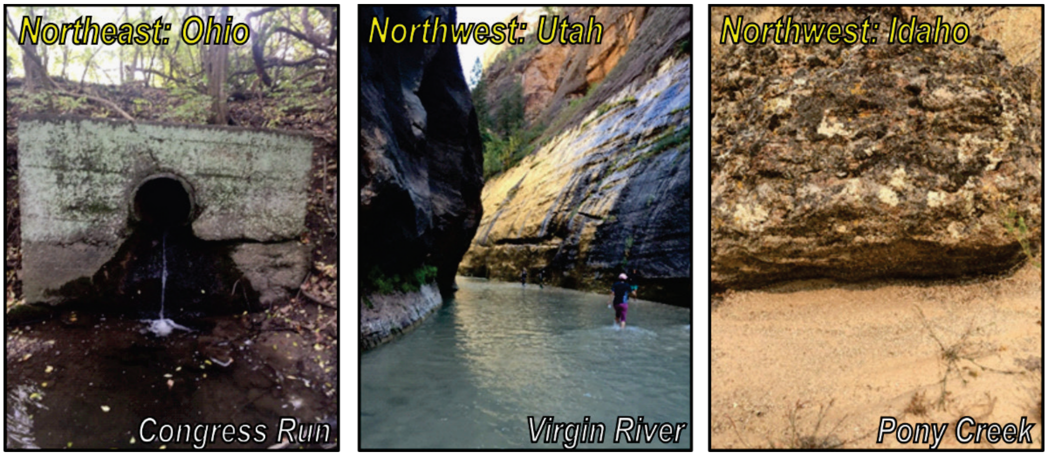


Table 4. Estimated durations necessary for trimline or lichen line formation across published studies.

Location	Substrate	Inundation Duration (wk)	Reference
Sweden lake	Rock	1–2	Santesson 1939
Germany rivers	Rock	1–3	Ried 1960
Florida river	Tree	~1	Hale 1984
West Virginia river	Tree	1–2	Beckelhimer and Weaks 1984
Alberta, Canada lake	Rock	12–24	Marsh and Timoney 2005
Australia river	Rock	9–14	Sammut and Erskine 2013

Lichenometry is the use of lichens to estimate the timing of events (Innes 1988). The premise behind the approach is that the time of lichen colonization on a surface can be inferred from the size of the lichens on the surface and that the largest lichen was the first to colonize the surface for a given species. In practice, this approach involves developing a size–age relationship for a lichen species based on measurements taken from nearby surfaces of known age (e.g., tombstones, bridges, and buildings). When colocated with gauging stations, lichenometry can be used to estimate the return interval and flow duration associated with flows aligning with lichen-line elevations or boulder-moving floods (Gregory 1976a, 1976b; Gob et al. 2003; Sammut and Erskine 2013). Where they have been determined, the lichen lines corresponded to stages for floods with return periods of one to two years on the annual maximum series (Gregory 1976b; Sammut and Erskine 2013). Therefore, lichen often occur above the

OHWM, but as previously discussed, there may be zonation in lichen and some species that occur below the OHWM.

2.3.4 Ancillary indicators

Ancillary indicators include organic litter, which includes wrack, LW deposition, leaf litter disturbed or washed away, and staining. These indicators are categorized as ancillary because they may not necessarily persist over time but can still be useful in identifying the OHWM. Koenig et al. (2016) and Feaster and Koenig (2017) described identifying and preserving high-water-mark data that included some of these indicators. Their focus was on preserving data from extreme events, but there is overlap with the indicators used to identify the OHWM. The high-water marks used to identify extreme events are particularly perishable because physical and chemical weathering and erosion have enough time to work on these marks and remove them between events. Ancillary indicators of the OHWM may occur in a greater density and in combination with other indicators. If there has been a recent extreme flow, then some of these ancillary indicators may have been removed during those events. Therefore, it is important to check nearby USGS streamgages before visiting a site to better understand flow levels prior to the visit. This section describes each of the ancillary indicators and provides information on how to interpret field observations.

2.3.4.1 Organic litter and wrack

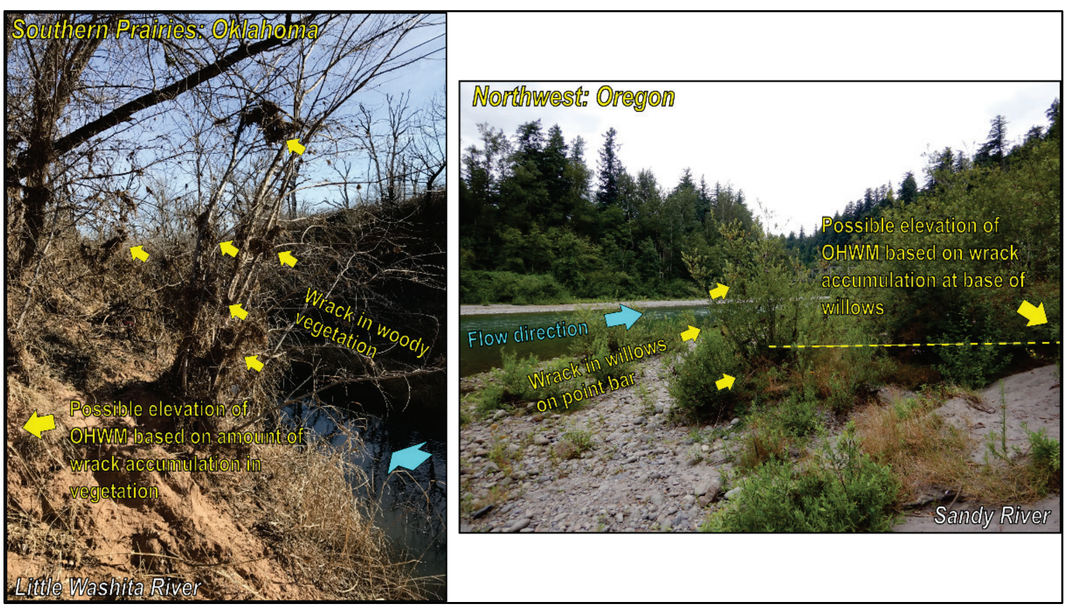
Organic litter is composed of leaves, needles, twigs, and other fine organic matter that is deposited on the channel margins during waning high flows (Wohl et al. 2016). Organic litter and the linear features they often indicate are sometimes referred to as *wrack*, *wrack lines*, and *flood debris*. This term also encompasses the inorganic material, such as Styrofoam, plastic, and other buoyant items that get dumped into streams, that can get caught up and deposited with the organic material (Shumilova et al. 2019). Organic litter can get caught around vegetation, LW, and other objects in the flow path, such as bridge piers (Figure 68). This deposition of organic litter often occurs during the waning stages of high flows.

Figure 68. Organic litter accumulation on channel beds, channel bars, riparian zones, and floodplains.

Organic litter often accumulates in the woody vegetation surrounding the channel. Plant foliage may be knocked down during high flows and rise again once the flows decrease. Therefore, the levels of wrack lines on these types of vegetation may be higher than the flows that deposited the material (Figure 69). Furthermore, organic litter can affect riparian vegetation by causing feedback that can either reduce or enhance riparian vegetation. For instance, large amounts of organic litter may damage riparian vegetation but may also contribute to the germination of certain plant species (Nilsson and Grelsson 1990; Xiong and Nilsson 1997).

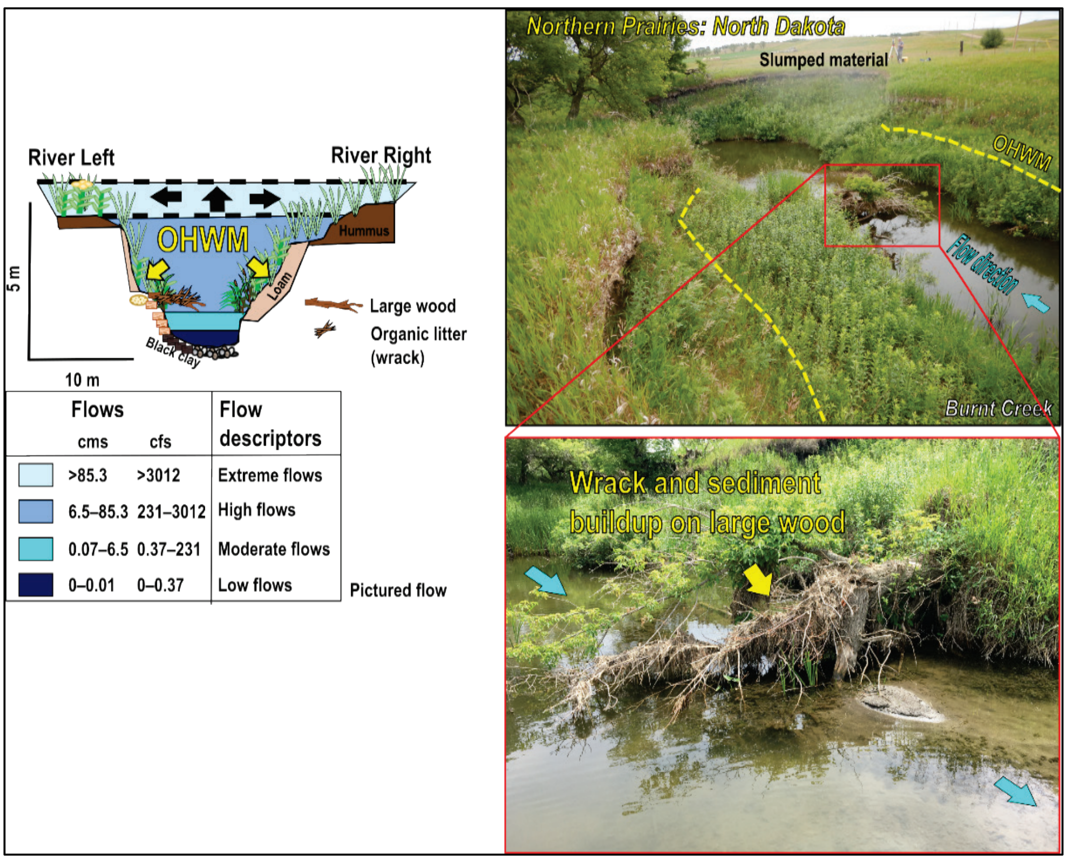
Figure 69 shows organic litter accumulations in woody shrubs along the channel banks in a stream in Oklahoma and on a point bar in a stream in Oregon. Another term that has been used for this type of accumulation in branches of trees is *litter hovel* (Loeser et al. 2006). Organic litter accumulation in these streams can be used to provide evidence of high flows. For instance, the stream in Oregon has a large amount of material accumulated around the base of the willow. Up the right bank, the vegetation does not have as high a density of wrack accumulation. The evidence here says that the willow on this point bar is, at minimum, inundated on a much more regular basis than the vegetation on the sandy berm next to the point bar. The accumulation of organic litter is at a higher elevation in the willows than the dotted yellow line drawn in the picture. The assumption is also that willows are knocked down with higher flows; therefore, the elevation of the organic litter in the upper branches of the willow is not as strong of a line of evidence of high flow as the organic litter accumulation around the base of the willows. The organic litter accumulation at the base of the willows can be used as a secondary line of evidence to point to where to look for other OHWM indicators along the channel banks. In this case, the yellow line is drawn to the top of a break in slope on the channel bar, which also corresponds to a change in the riparian vegetation characteristics.

Figure 69. Organic litter as wrack accumulation in woody vegetation.



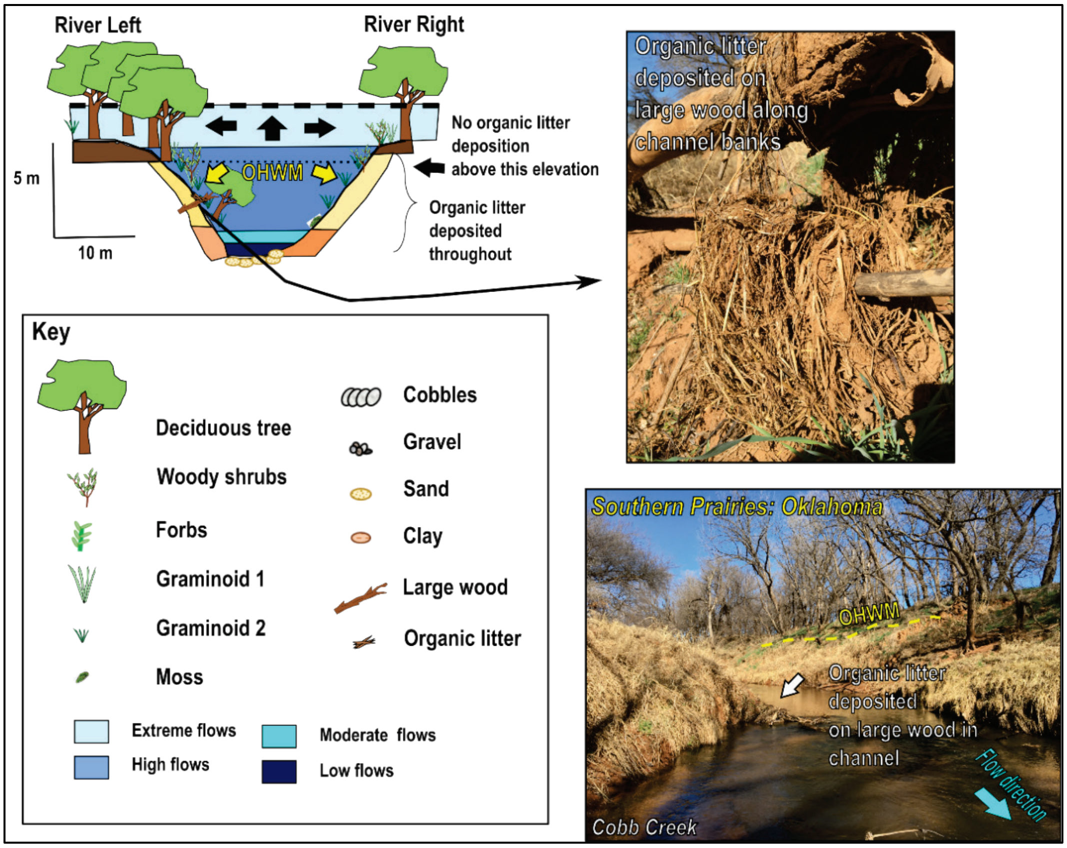
Organic litter accumulation can occur at every flow level, depending on the most recent flow events. If only low-flow events have occurred recently, there may be organic litter accumulation lower down. Higher or extreme flows can remove evidence of lower-flow accumulation. Therefore, the elevations at which, or below which, a higher density of organic litter is accumulating may provide supporting evidence for the OHWM (Figures 70 and 71). Another challenge of using organic litter as an indicator is that the deposited lines are slow to decompose, and the organic litter left after extreme flows may remain present for a long time and may be misinterpreted as an indicator of the OHWM. The persistence of these features depends on the timing since the most recent event and regional variability in climate. For instance, organic litter may persist over longer time scales in arid regions. Furthermore, organic litter has been shown to decompose faster on artificial shoreline structures (i.e., cribbing) than on natural sandy or rocky shorelines (Harris et al. 2014).

Figure 70. Organic litter as wrack built up on LW in Burnt Creek.



Flows cms	cfs	Flow descriptors
>85.3	>3012	Extreme flows
6.5–85.3	231–3012	High flows
0.07–6.5	0.37–231	Moderate flows
0–0.01	0–0.37	Low flows

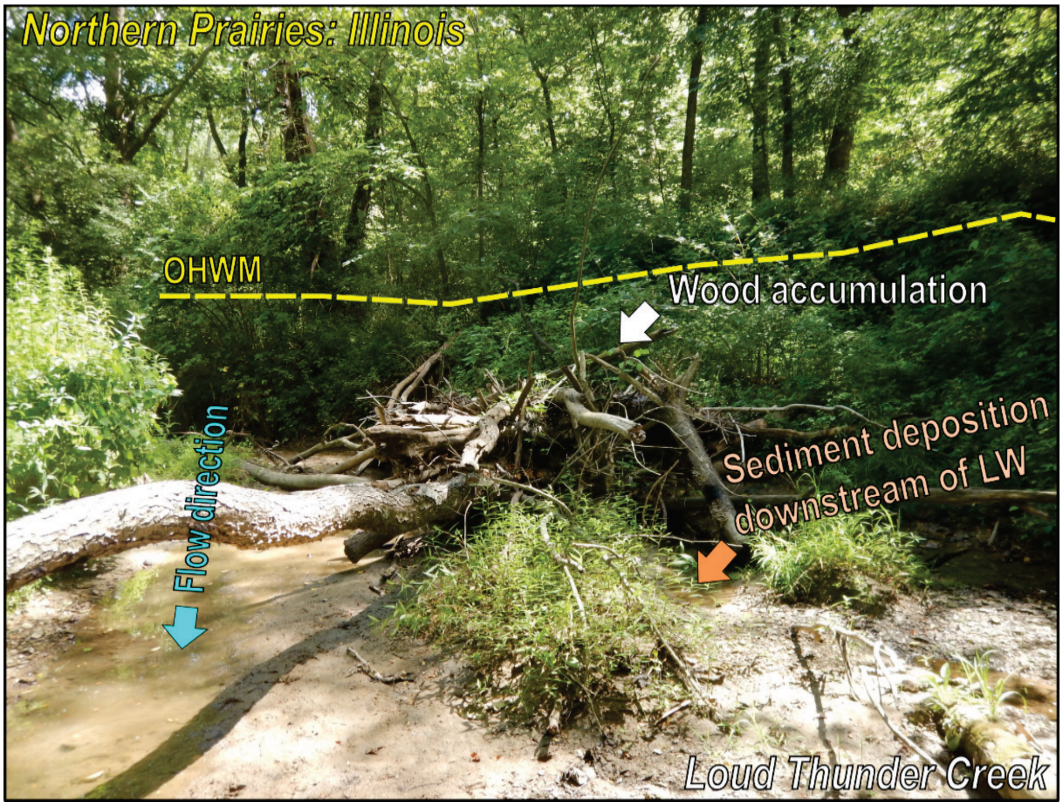
Figure 71. Organic litter as wrack accumulation throughout left and right banks during various high flows.



2.3.4.2 Presence of large wood (LW)

LW, sometimes referred to as *large woody debris*, falls into streams from the surrounding landscape and is transported through a channel system. LW can be evaluated in two ways in a stream channel: (1) the effect of LW on reducing flow velocities and increasing depth and (2) the elevation of LW deposition. First, LW increases roughness in a channel, which can cause velocity to slow and flow depth to increase (Gippel et al. 1996; Curran and Wohl 2003; Manners et al. 2007; David et al. 2010). Therefore, the OHWM may be at a higher depth than initially expected when investigating a channel reach that includes LW. Figure 72 shows where LW has developed similar channel bar features. In the stream, the LW is likely causing an increase in flow depth through that channel reach. In this example from Illinois, one line of evidence that the LW jam is below the OHWM is that there is bed sediment deposited on top of the wood, enabling vegetation growth to occur in those depositional zones. The deposition of sediment on top of the LW jam indicates that flows reached that water stage frequently enough to deposit enough sediment to allow vegetation to establish. The presence of LW is evidence of material that has been transported and deposited by flows. The fluvial processes that developed this midchannel bar are similar to those that led to the establishment of a midchannel bar in Figure 32.

Figure 72. LW that is likely creating a backwater effect, increasing roughness and channel depth and causing the development of a channel bar.



LW alters longitudinal, lateral, and cross-stream flow lines and can cause water to be deflected away from one bank, effectively armoring the bank, and toward another bank, causing erosion (Smith et al. 1993; Montgomery et al. 2003; Daniels and Rhoads 2004). LW also contributes to the development of features, such as pools, steps (Montgomery et al. 1995), channel bars (Lisle 1986; Abbe and Montgomery 1996), and side channels (Wohl 2011). The effect of wood on flow depends on a number of channel characteristics and on the characteristics of the wood itself, including the location of wood in the channel (Wilcox and Wohl 2006; David et al. 2011), whether the wood occurs as individual pieces or in a jam (Manga and Kirchner 2000; Manners et al. 2007; Manners and Doyle 2008), the shape of the wood, the depth of the water in relation to the diameter of the logs (Wallerstein et al. 2002), and the length of the pieces in relation to the bankfull width of the channel. The OHWM may be higher than expected when LW is present in the channel because it may slow water velocity and increase flow depth. Furthermore, LW may cause the diversion of flow into secondary channels, which should be investigated to determine if these secondary channels are at the elevation of the OHWM.

LW is transported and deposited by streams and, thus, can be an additional indicator of the OHWM, although LW should be used with caution as an indicator. The first step is to determine whether the LW was transported by the stream. Many wood pieces in the floodplain may be branches and logs that fell from the surrounding forest. The best way to determine transport is to find pieces of LW that give an indication of flow direction, either because they are oriented in the direction of flow or jammed around a tree or other object in the floodplain (Figure 73).

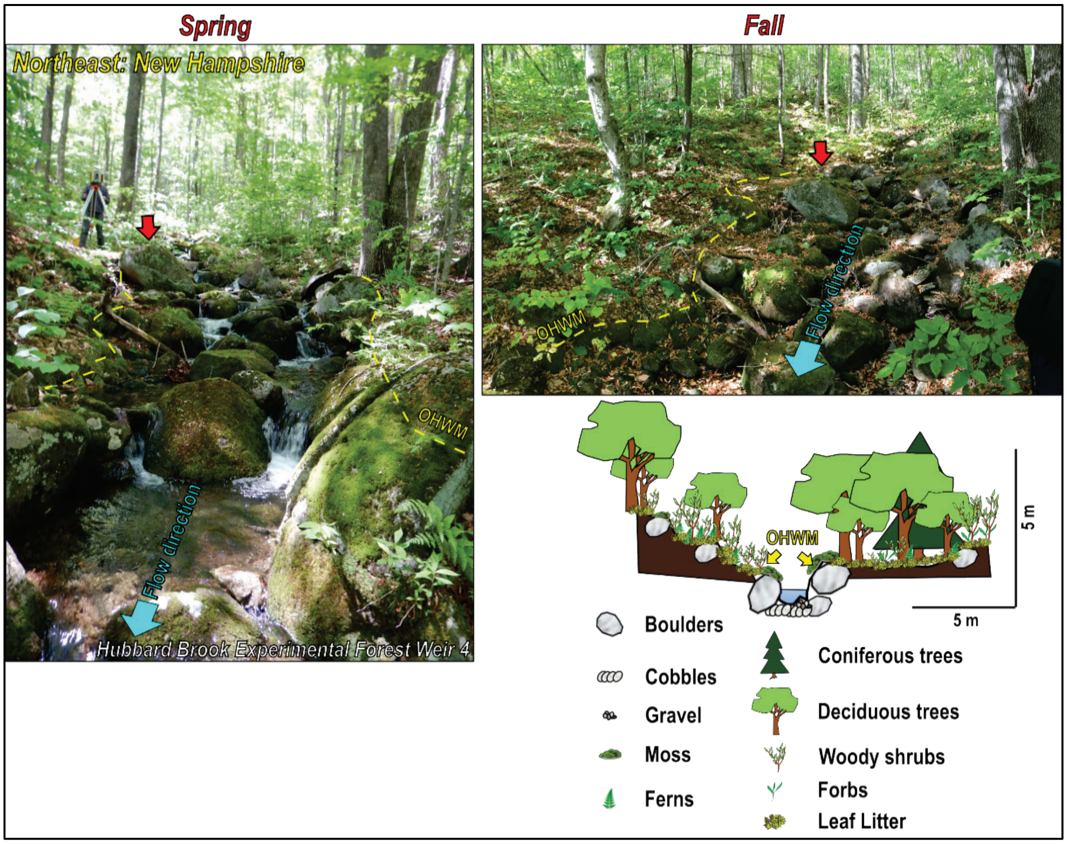
Figure 73 demonstrates three examples of LW deposition. Mud Creek, in Oklahoma, had a large amount of LW accumulation in the floodplain riparian zone, just above the channel. These pieces of LW were determined to be above the OHWM, but they indicated that the stream frequently accessed this area and, therefore, was not incised. The break in slope at the top of the bank and the change in vegetation characteristics were then used to determine the OHWM. The example from Rabbit Creek, in Idaho, shows LW deposition from an extreme event. The LW was trapped in the upper branches of a tree. There were indicators at a much lower elevation that assisted in determining that this deposit likely happened during a particularly large flood flow. The third example shows LW that was deposited around the base of a tree and was determined to be below the OHWM. Minebank Run, the third example in the figure, is an urban channel in Maryland that experiences flashy flows. The LW deposit was accompanied by sand deposits and secondary channel development, indicating that the stream was shifting and incorporating this area back into the main channel. These examples demonstrate that once the LW is determined to have been deposited by flowing water, the LW needs to be put in context of what is happening at the site and within the watershed. Other indicators should then be investigated above, below, or at that elevation. The placement of LW can then be considered with other lines of evidence when weighing the body of evidence.

Figure 73. LW deposited above the OHWM (*top left* and *right*) and below the OHWM (*bottom left*).

2.3.4.3 Leaf litter disturbed or washed away

The usefulness of leaf litter as an indicator depends on several factors, including the season of observation and flow frequency. For instance, leaf litter can cover streams in the fall, obscuring OHWM features. In some regions of the country, the timing of leaf fall can coincide with seasonal changes in flow, such as low flows in the stream during the fall season. Figure 74 provides an example of a small mountain stream in the Northeast region. The lack of flow in the channel during the fall months causes the leaf litter to remain intact, masking the evidence of sediment sorting and pool development. In the late spring, the presence of the channel is much more evident.

Figure 74. The same mountain stream in the spring and fall. The *red arrow* points to the same location on both images.



Leaf litter accumulation may vary along a cross section of stream (perpendicular to the flow). The transition between a thin cover of leaf litter and a thick decomposing deposit of leaf litter may help in determining the location of the OHWM. Leaf litter in channel reaches that experience longer duration and higher frequency of flow is more likely to be redistributed than that in areas infrequently inundated for shorter durations, and it will decompose faster (Hutchens and Wallace 2002; Langhans and Tockner 2006; M'Erimba et al. 2007; Riedl et al. 2013). Therefore, leaf litter could be expected to remain a thin layer or clumped distribution (i.e., leaf packs or debris dams) in areas frequently inundated by flow, relative to the surrounding riparian zone.

Breakdown in organic matter varies depending on the type of organic matter, the frequency of flow, the channel type, and climatic differences between regions. Organic matter will travel faster through high gradient systems and through riffles, versus accumulating in lower gradient pools (Hoover et al. 2010). Furthermore, the type of leaf litter, whether flexible or stiff (e.g., leaves versus needles), will determine how quickly it is able to be moved downstream.

Although leaf litter input into tropical streams may not be as concentrated in a single season as it is in temperate biomes dominated by deciduous trees, leaf litter input into a Brazilian rainforest stream was at its highest concentration when transitioning from the dry to rainy season (Gonçalves and Callisto 2013). Leaf litter needs to be seasonally contextualized in any region when considering its usefulness as an indicator of the OHWM.

2.3.4.4 Understanding staining when identifying the OHWM

Staining (sometimes referred to as *varnish*) is observed as a discoloration on the rock at the air–water interface and, therefore, often occurs at the elevations of frequent water stages, whether low or high flows. Staining may result from different processes, including (1) precipitation, or microbially mediated precipitation, of dissolved minerals onto rocks and other structures along the channel edges (Konhauser et al. 1994; Wohl et al. 2016); (2) microbially produced pigment (Wotton and Preston 2005); and (3) deposition of suspended material or washing of loose material along the water's edge (Koenig et al. 2016). Discoloration of the rock can also result from differences in physical and chemical weathering above and below the air–water interface. For instance, the bedrock surface could be smoothed from the mechanical process of sediment being carried by the streamflow, which may result in it being a different color than the rock at higher elevations (Figure 75).

Because staining can be left at a variety of water stages, as with other ancillary indicators, staining should only be used to support other primary lines of evidence of the location of the OHWM (Figure 76). Staining can occur because of the elevations of some of the most frequent flows, not just from a single flow. There can often be different levels of staining, depending on how frequently the bedrock, boulders, tree trunks, bridge or pier pilings, or other structures are partially inundated. Staining can vary depending on what dissolved constituents are in the flow, which can vary based on flow levels and land use. Staining resulting from microbially mediated precipitation depends on what dissolved constituents are in the flow (Konhauser et al. 1994). Furthermore, the surface tension at the air–water interface of water bodies accumulates materials from the air and water. Surface films typically have a complex mixture of hydrophobic compounds, low density particles, and unique microbial assemblages that can cause staining on the surrounding structures (Wotton and Preston 2005). Therefore, staining is rarely just one bright line; rather, it is usually a series of lines from different magnitudes of flows. Staining can provide confirmation that flows have risen on a frequent enough basis to stain rock, cement, or even trees. Stains can also be left by silt and clay that was suspended in turbid flood waters and deposited on structures. If there have not been subsequent high flows or strong rains, silt and clay staining will be seen as a continuous band down to the current water level. However, if there have been subsequent high flows, but not to the height of the previous flood that left the silt and clay deposits, the staining may appear as a narrow band.

Figure 75. Staining examples in different regions of the country. Precipitate on rock in San Lorenzo Creek (*top left*), discoloration of rock from differences in physical and chemical weathering on Na'ili'ili Haele Stream in Hawaii (*bottom left*), and fine sediment deposited on structures and bedrock in Willamette River in Oregon (*top right*) and an unnamed tributary in Hawaii (*bottom right*).

Figure 76. Staining can occur at multiple elevations from a range of flows. The numbers indicate the same location on the photograph and cross section.

Another reason lines may be observed along exposed bedrock and other exposed strata is differences in layering. Therefore, any interpretation of staining on bedrock and banks should be observed closely to determine that it is, in fact, a secondary coloration and not from underlying strata.

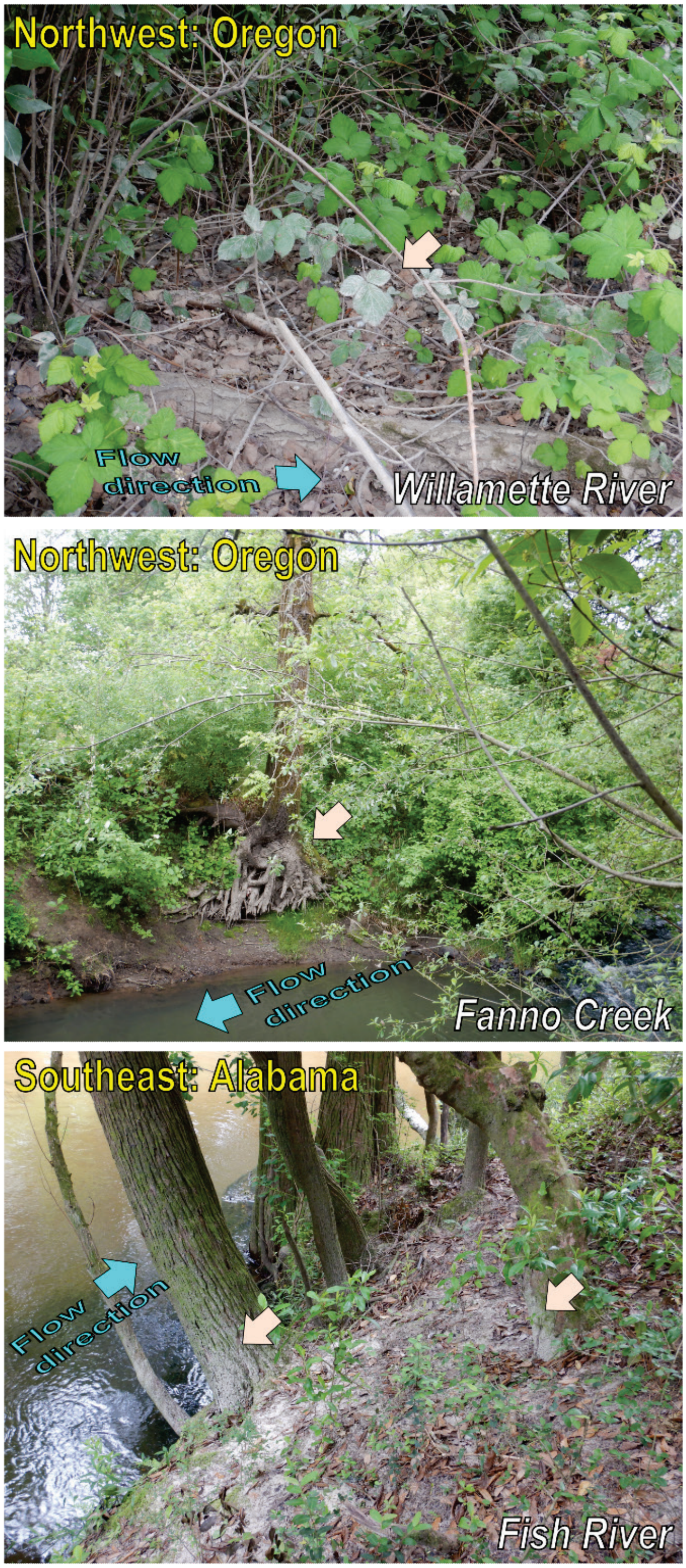
2.3.4.5 Sediment deposited on trees and other vegetation

In some cases, sediment deposition on vegetation may be observed at elevations that are associated with the edge of flood waters (Higgitt and Warburton 1999) or the OHWM. Note that plant foliage may be temporarily knocked down by flows, lowering leaves or other herbaceous vegetation (Figure 77). Therefore, stains or sediment on vegetation may not be precisely at the OHWM. In some cases, the elevation of sediment on vegetation may be higher or lower than the level of flow that caused it. This is because the vegetation could have been bent downward or upward by floodwaters when the sediment and other debris were deposited and then returned to vegetation posture after the water receded (Koenig et al. 2016).

Nonetheless, sediment deposited on vegetation may serve as a secondary line of evidence for determining the location of the OHWM (Figure 78). Sediment deposition can also affect other OHWM indicators. For instance, Lowe et al. (2010) reported that sediment deposition, relative to inundation alone, reduced survival of two riparian herbs. So fine sediment load and deposition may affect the spatial pattern of other OHWM indicators.

Figure 77. Example of vegetation knocked over by a recent high flow on the bed of the Ottauquechee River in Vermont. The elevation of the vegetation is well below the OHWM in this river.

Figure 78. Ancillary indicators include sediment deposition on vegetation. The *beige arrows* show where fine sediment has been deposited on leaves, tree roots, and the base of a tree.



2.4 Field indicator summary

This chapter of the manual described each indicator listed in Step 3 of the data sheet (Box 1) that would be observed in a stream corridor and the underlying processes connected to the formation of those indicators. The OHWM occurs at transition points between stream and terrestrial features; therefore, the three initial characteristics to look for when assessing a stream reach are at transition points where there is generally (1) a break in slope, (2) changes in sediment characteristics, and (3) a transition in vegetation type and density. The physical characteristics corresponding to the location of the OHWM can be divided into four general categories: geomorphic, vegetation, sediment, and ancillary indicators. Geomorphic refers to that part of the landscape shaped by stream processes and therefore shaped by a range of flows. Vegetation and sediment are described separately to assist in understanding how stream processes influence vegetation growth and sediment erosion and deposition. Ancillary indicators are a separate category because they are common fluvial characteristics, such as LW deposition, that do not necessarily fit into the three previous categories but, in some circumstances, can assist in determining the location of the OHWM. Overall, site-specific examinations of these categories of indicators will identify transition points in a stream reach, but the WoE method should be used to combine and evaluate observations of breaks in slope, changes in sediment characteristics, vegetation, and other lines of evidence to delineate the OHWM.

3 Procedure for Identifying the OHWM

3.1 Key points

A site located on the North Fork (NF) of the Rivanna River, a single-thread channel in Virginia, is used throughout this chapter as a case study illustrating the field delineation procedure for identifying the OHWM using the provided data sheets (Box 1 and Box 2) and the WoE approach (Figure 7). Cross sections, schematics, and pictures are included to help users visualize the site and understand how to apply a detailed analysis to a site. A cross-sectional survey is not required for identifying the OHWM, but it is included to help users understand the lines of evidence and how they relate to each other. The recommended field procedure and data sheet (Box 1 and Box 2) are included in Appendix B so they can be easily printed for use at field sites.

Section 3.8 includes case studies in which the OHWM can be easily identified without additional supporting information. In many cases, the high-flow indicators may line up at the same location, which means that observations can be quickly checked off the data sheet to determine the location of the OHWM.

3.2 Step 1: Site overview from remote and online resources

Prior to a field site visit, a desktop site overview using aerial imagery and data layers can provide context for identifying the potential location of the OHWM (Figures 79 and 80). Satellite imagery, airborne lidar, land use, and geologic maps can provide site landscape context prior to a field site visit. Chapter 5 discusses how to locate and interpret this imagery in more detail. The intent of Step 1 is to identify spatial and hydrologic information relevant to streamflow at the site, which can aid in understanding the relevance, strength, and reliability, or weighting, of specific lines of evidence. For example, streamgage and climatic data can provide insight on whether the site is drier or wetter than normal or has experienced a drought or recent flooding. An initial overview using satellite imagery and airborne lidar can assist in outlining the assessment area, determining reach lengths for OHWM delineation, and making initial identification of the location of the OHWM.

3.2.1 Step 1: Site overview of North Fork (NF) Rivanna River using remote data

At the NF Rivanna River site (Figure 79), roads, farmland, and recent construction can be observed adjacent to the site. Topographic features may be recognizable on high resolution (HR) topographic data (e.g., airborne lidar). The lidar hillshade in Figure 79 shows the extent of the floodplain, the overall width of the stream channel, and the location of tributaries and hillslopes. More than one data sheet may be needed, depending on the length of the OHWM survey. An initial remote evaluation of the site can assist in understanding where significant changes may happen and if additional data sheets may be needed. In this example, significant changes may be found up- and downstream of a bridge (Reaches 1 and 2) or downstream of tributaries (Reaches 3 and 4). The NF Rivanna River has a floodplain on the right side of the channel and a confining hillslope on the left side. A tributary flows from a reservoir into the downstream portion of the reach. The tributary can increase water and sediment inputs and alter the elevation of the OHWM. Channel bars, which are a geomorphic indicator (Section 2.3.1.3), are common at tributary junctions, particularly if there have not been any recent flood events in the main channel. An increase in sediment downstream of tributaries can cause aggradation, decreasing flow velocity and increasing water depths. Therefore, the OHWM may be at a higher stage downstream of the tributary than it is upstream. The example presented throughout the rest of this chapter will focus on the area around Reach 2.

Rood et al. (2019) used aerial photos and lidar to map changes in patterns of inundation that identify the growth of gravel bars and islands before and after a large flood on the Bow River near Calgary, in Canada. Such preliminary evaluation may provide important information to focus the field survey strategy and promote understanding of landscape controls on the fluvial system. Figure 80 shows historical imagery of the NF Rivanna River from Google Earth. The imagery shows that between 2003 and 2017, a midchannel bar shifted toward the right bank and merged with Point Bar A, creating a much larger point bar. An image from 2013 allows a view of the site without leaves on the trees, providing insight into the potential location of the OHWM along the point bars. Table 5 provides an initial analysis of the site using remote data and applying the WoE approach. Figure 81 shows additional resources that are available and can be used for a preliminary evaluation of a site.

Figure 79. Online resources can provide an overview of the site and insight into where there are changes to the system, either from anthropogenic or natural disturbances. *Top*. Google Earth image of the North Fork (NF) Rivanna River. *Bottom*: Lidar hillshade and DEM of the NF Rivanna River, annotated to show landscape characteristics. The numbers separate out reaches of the NF Rivanna based on the landscape characteristics. A longer survey may require additional data sheets.

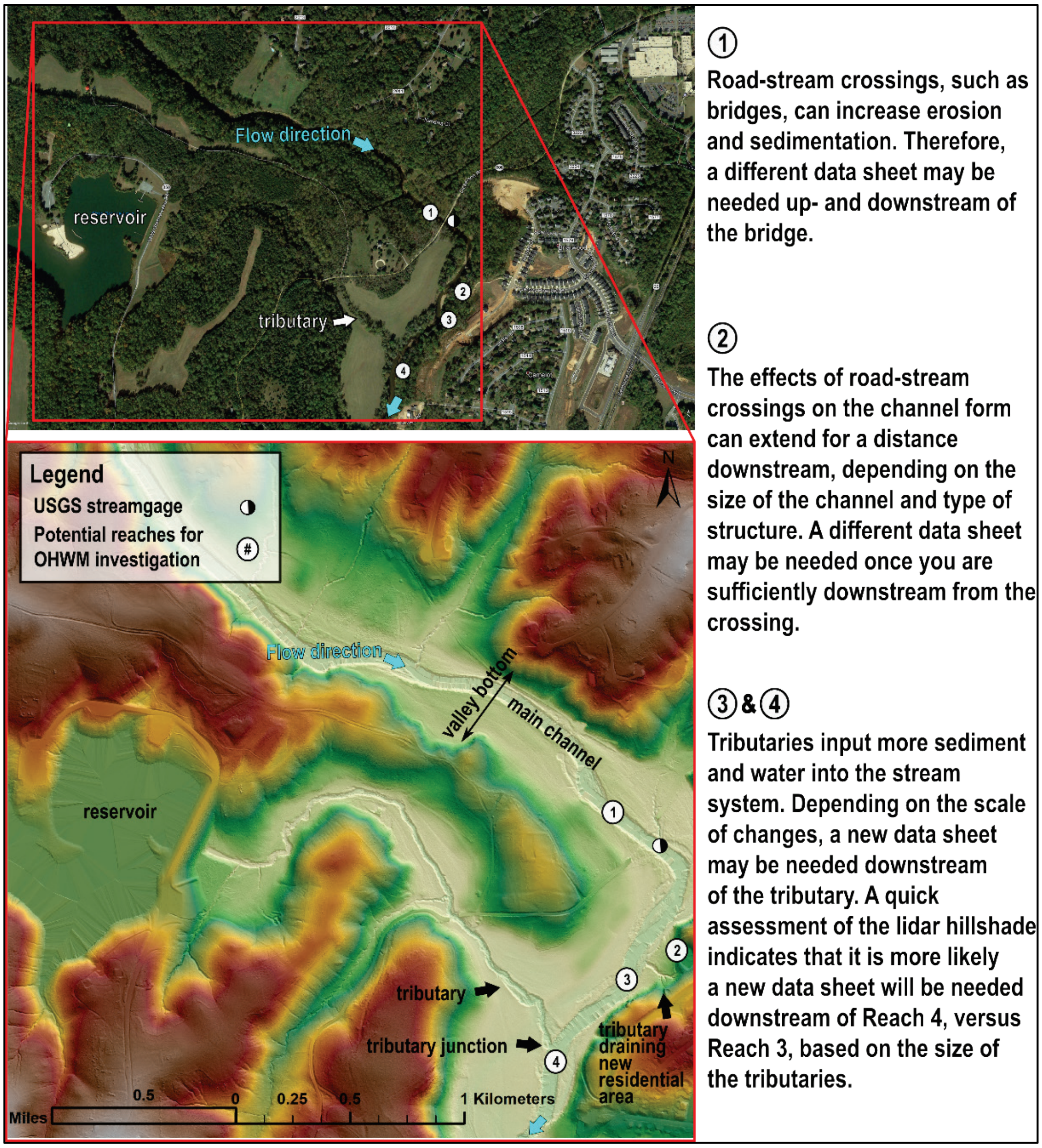


Figure 80. Several observations can be made of the NF Rivanna River using satellite imagery prior to the site visit. Google Earth allows easy viewing of historical imagery. The historical imagery of NF Rivanna River provides an overview of changes in flow and channel bars over time.

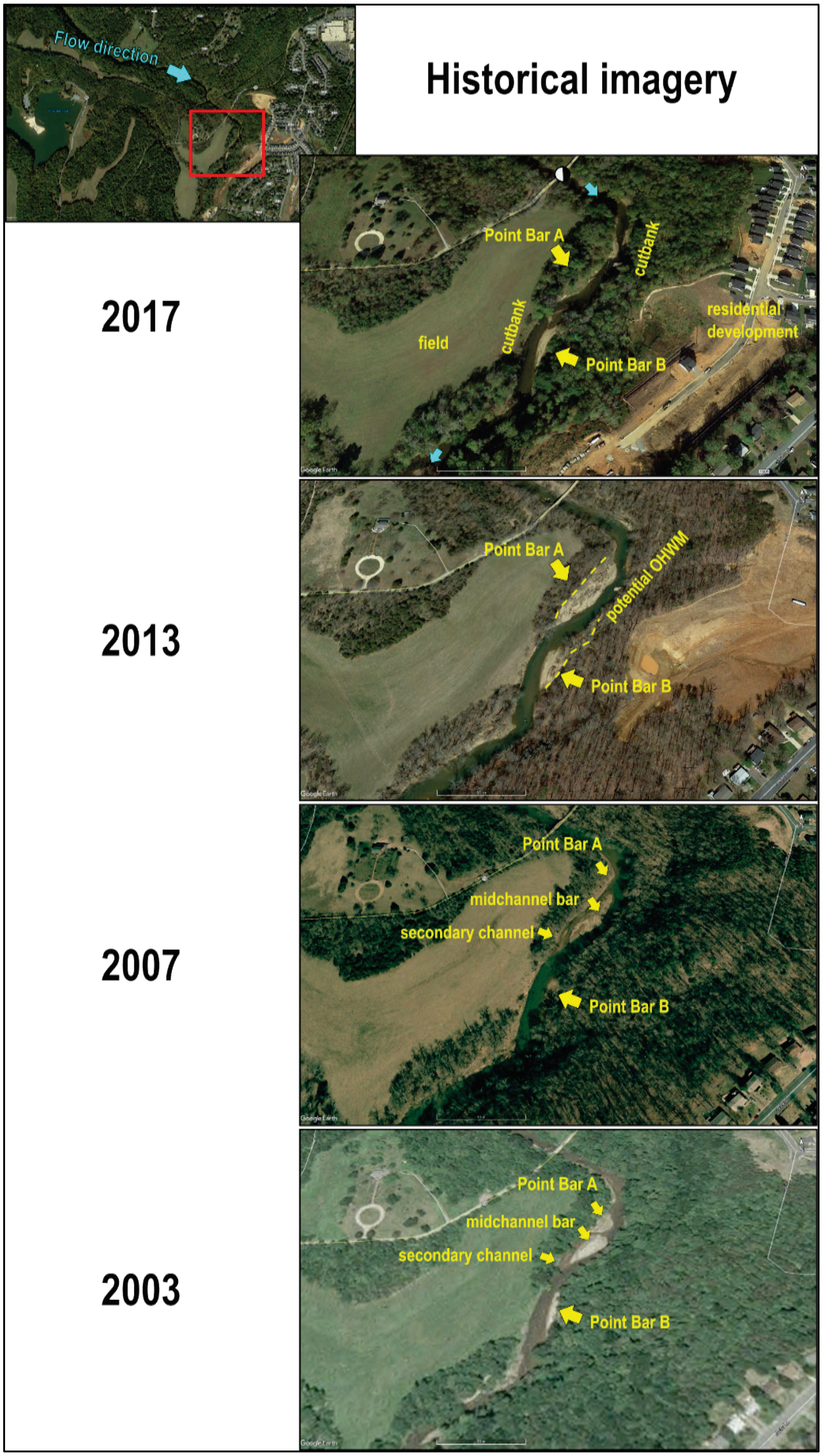
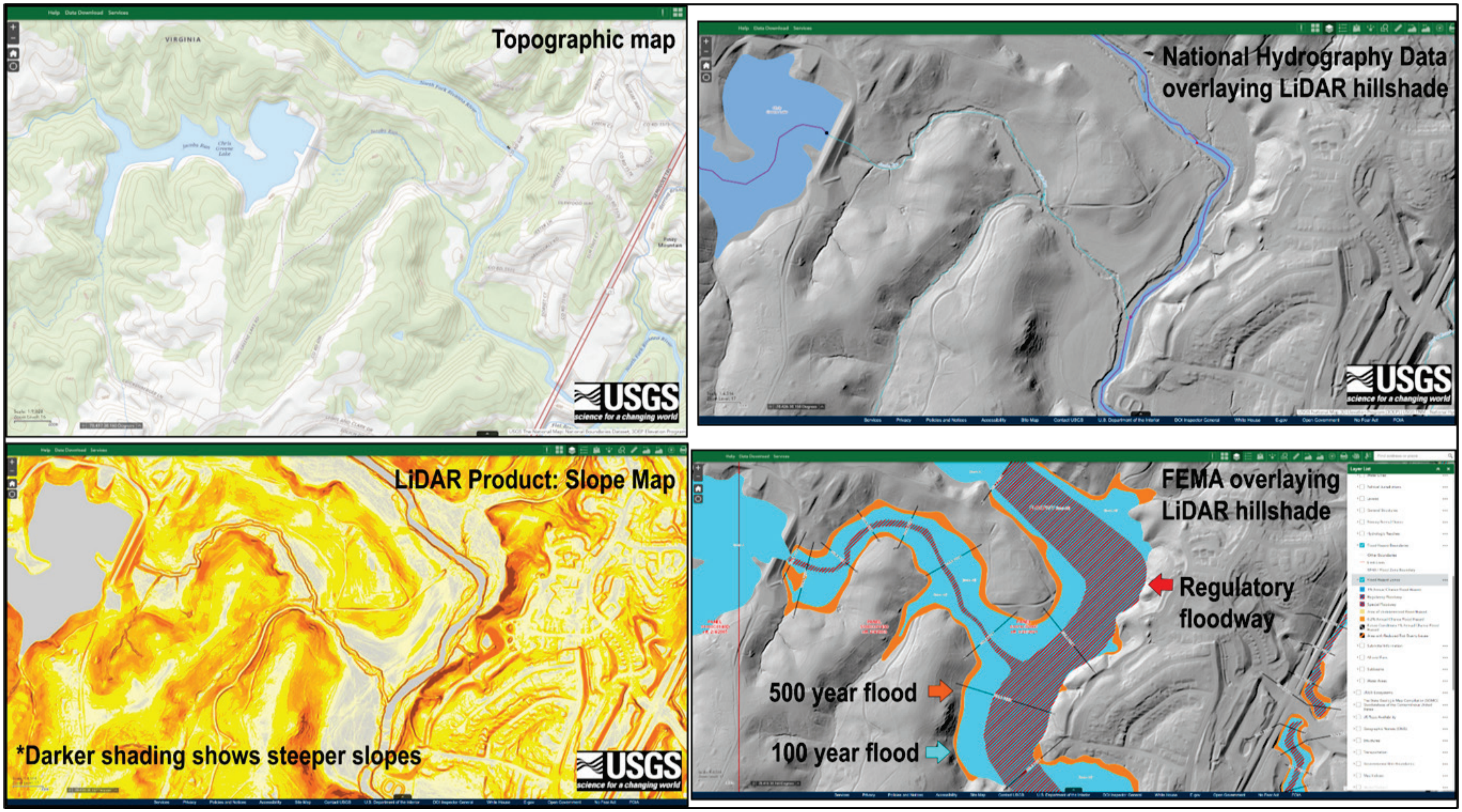


Table 5. Using WoE method to conduct initial remote assessment of the stream.

			Description of Weights			
Indicator Name	Indicator Type	Description	Relevance	Strength	Reliability	Initial conclusion based on remote data
Point Bar A	G	Point Bar A in 2017 developed from merging of a midchannel bar with a smaller point bar (2003–2013 imagery)	Channel bars form and adjust during high-flow events.	Lines of evidence on the point bar and between Point Bars A and B can be compared.	Evidence may be more reliable on upstream portion of point bar, where point bar has persisted over time.	The point bar has been transient over time. Evidence of the OHWM may be better observed at the upstream portion of the point bar.
Point Bar A vegetation	V	There is a distinct line on the point bar where woody vegetation has established.	In NE region, woody vegetation establishes above areas of frequent inundation.	Distinct line can be seen in images from 2013, when leaves were off the trees.	Woody vegetation present, no matter the season.	Despite changes in the point bar, the elevation of woody vegetation establishment may not have changed.
Point Bar B	G	A point bar that has remained in the same location between 2003 and 2013.	Same as Point Bar A.	Same as Point Bar A.	This point bar has been persistent over time.	Because Point Bar B has persisted in its current form over time, it may have additional lines of evidence for the OHWM.
Point Bar B vegetation	V	Same as Point Bar A.	Same as Point Bar A.	Same as Point Bar A.	Same as Point Bar A.	Woody vegetation line may be the same as the OHWM line.
Break in slope on lidar (Fig. 79)	G	The lidar shows a distinct break in slope between the channel and surrounding terrain.	The lidar provides a view of the site without vegetation. Channel form (banks and point bars) can be observed from above.	A clear, continuous break in slope can be seen up- and downstream.	Only lidar from one year is provided, but the break in slope corresponds to the location of the stream in the satellite imagery.	This may be an initial location to look for channel banks and the OHWM.

Figure 81. Other resources available through the USGS National Map Advanced viewer include topographic maps, lidar products such as hillshade and slope maps, and maps (such as FEMA maps) that can be imported. (Images reproduced from USGS n.d.c.)



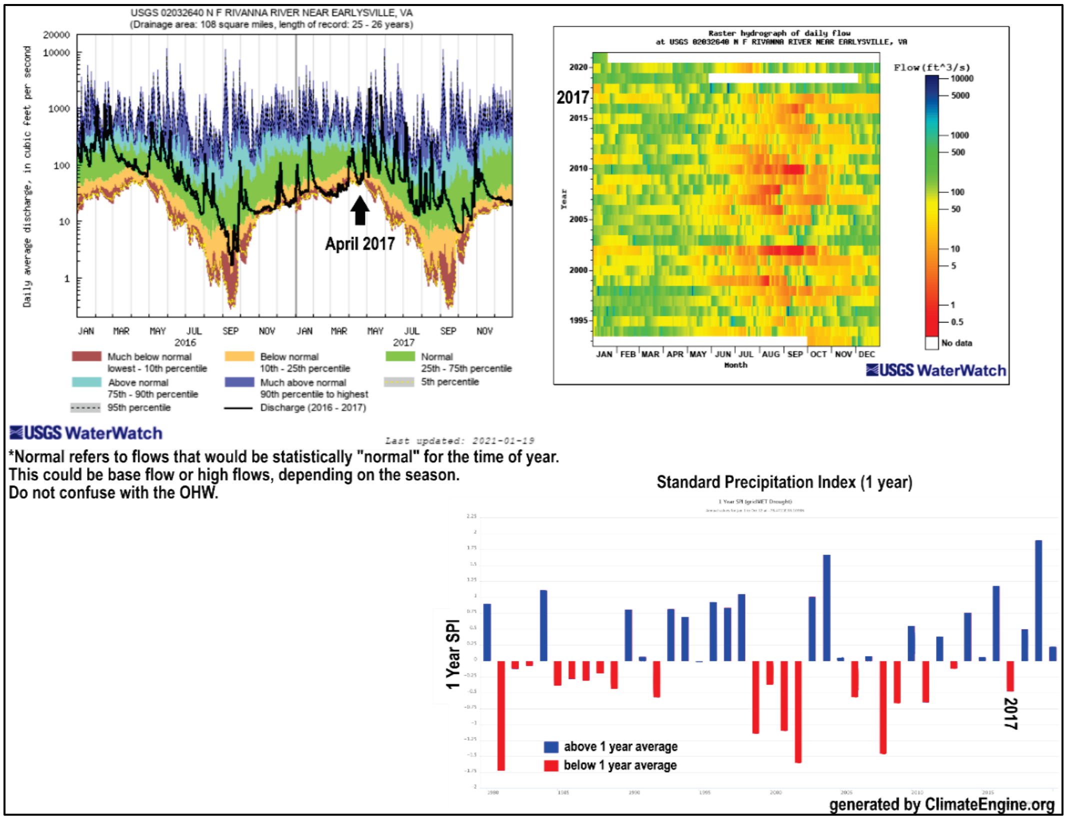
3.2.2 Step 1: Site overview of NF Rivanna River using other online resources

USGS streamgage data can provide information about recent flooding events or droughts as well as the temporal context for how representative streamflow conditions are during a site visit. It is important to know if a stream is at a relatively high or low stage during a visit or was at a relatively high stage prior to the visit. Recent flooding events can obscure OHWM indicators; therefore, it is important to determine if there were recent floods in the region.

Figure 82 provides summary information from the NF Rivanna River USGS streamgage (02032640) and an analysis of precipitation data using online tools. Section 5.4.1 describes how to extract and understand streamgage data, along with other remote data, in more detail. In this example, precipitation and streamflow were lower than average in 2017. The raster hydrograph of the site shows that the lowest flows occur during the summer months but that there is a lot of variability when low flows occur throughout the year. This means that this site may have an increase in fine sediment deposition along channel boundaries and on the channel bed, which can create a distinct low-flow line. These lines can be confused with high-flow indicators; therefore, it is useful to know that there were no recent high-flow events. Furthermore, in the absence of recent high-flow events, vegetation may be encroaching along the channel boundaries, which can further obscure high-flow indicators. Forbs and graminoids will begin to fill in the spaces adjacent to the low-flow channel. Also, staining from lower flows may be more evident than staining from high flows.

The NF Rivanna River was visited during a low-flow period in April 2017. Therefore, the elevation of the water surface during the visit was representative of low-flow conditions. Any geomorphic, vegetative, and sedimentary indicators that were close to that elevation were more representative of low-flow, rather than high-flow, conditions. When investigating a site during a field visit, this should be kept in mind so that observations are made and recorded beyond these low-flow lines.

Figure 82. Summaries of streamgage and climatic data can assist in understanding if flows have been lower or higher than normal prior to the site visit. Data for this site indicate low precipitation and lower-than-average flows prior to the site visit. Streamflows are shown in *black* against an analysis of flow duration in the graph on the *left*. A raster hydrograph provides a general overview of what time of year the flows are low versus high (*right*).



An overview of the site prior to a field visit provides a better understanding of where to look for OHWM indicators during the field visit and where landscape controls are likely to affect the location and identification of OHWM indicators. Resources for Step 1, as well as the benefits, limitations, and resolution of such data sets and sources, are discussed in Section 5.2. Following a site visit, these resources may also aid in interpreting observations made at the site. Online data can help to weight the relative importance of particular lines of evidence and support a final delineation when combining information and weighing the body of evidence.

3.2.3 Filling out the data sheet for Step 1.

A description of the data sources used and any interpretations from those sources should be recorded in Step 1 on the OHWM data sheet or the administrative record. Box 3 describes the field procedure for Step 1, the questions to consider when observing online resources, and an example of Step 1 of the data sheet filled out for the NF Rivanna River.

Box 3. Field procedure for Step 1 with the corresponding portion of the data sheet (adapted from USACE 2022).

Step 1 Site overview from remote and online resources **Complete Step 1 prior to site visit.**

Online Resources: Identify what information is available for the site. Check boxes on datasheet next to the resources used to assess this site.

- a. gage data
- b. aerial photos
- c. satellite imagery
- d. LiDAR
- e. topographic maps
- f. geologic maps
- g. land use maps
- h. climatic data (precipitation and temperature)

Landscape context: Use the online resources to put the site in the context of the surrounding landscape.

a. Note on the datasheet under Step 1:

- i. Overall land use and change if known
- ii. Recent extreme events if known: e.g., flood, drought, landslides, debris flows, wildfires

b. Consider the following to inform weighting of evidence observed during field visit.

- i. What physical characteristics are likely to be observed in specific environments?
- ii. Was there a recent flood or drought? Are you expecting to see recently formed or obscured indicators?
- iii. How will land use affect specific stream characteristics? How natural is the hydrologic regime? How stable has the landscape been over the last year, decade, century?

Step 1 of datasheet for NF Rivanna River Case Study

Step 1 Site overview from remote and online resources

Check boxes for online resources used to evaluate site:

☒ *gage data* ☒ *LiDAR* ☐ *geologic maps*
☒ *climatic data* ☒ *satellite imagery* ☐ *land use maps*
☐ *aerial photos* ☒ *topographic maps* ☐ *other:* ____________

Describe land use and flow conditions from online resources.
Were there any recent extreme events (floods or drought)?
No recent flood events. Last extreme event was in 2000. Analysis of precipitation and streamgage data indicates that streamflow and precipitation were lower than average in 2017 prior to site visit. Confining hillslope along left side of channel, with runoff from residential development.

3.3 Step 2: Site condition during field assessment

Once in the field, begin to assemble the evidence by looking up- and downstream and across the channel to obtain a better understanding of the broad trends and dominant characteristics that extend along the reach (Box 4).

Box 4. Field procedure for evaluating site condition during the field assessment. (Data sheet adapted from USACE 2022.)

Assemble Evidence

Step 2 **Site conditions during the field assessment (assemble evidence)**

a. Identify the assessment area.

b. Walk up and down the assessment area noting all the potential OHWM indicators.

c. Note broad trends in channel shape, vegetation, and sediment characteristics.
- i. Is this a single thread or multi-thread system? Is this a stream-wetland complex?
- ii. Are there any secondary and/or floodplain channels?
- iii. Are there obvious man-made alterations to the system?
- iv. Are there man-made (e.g., bridges, dams, culverts) or natural structures (e.g., bedrock outcrops, Large Wood jams) that will influence or control flow?

d. Look for signs of recurring fluvial action.
- i. Where does the flow converge on the landscape?
- ii. Are there signs of fluvial action (sediment sorting, bedforms, etc.) at the convergence zone?

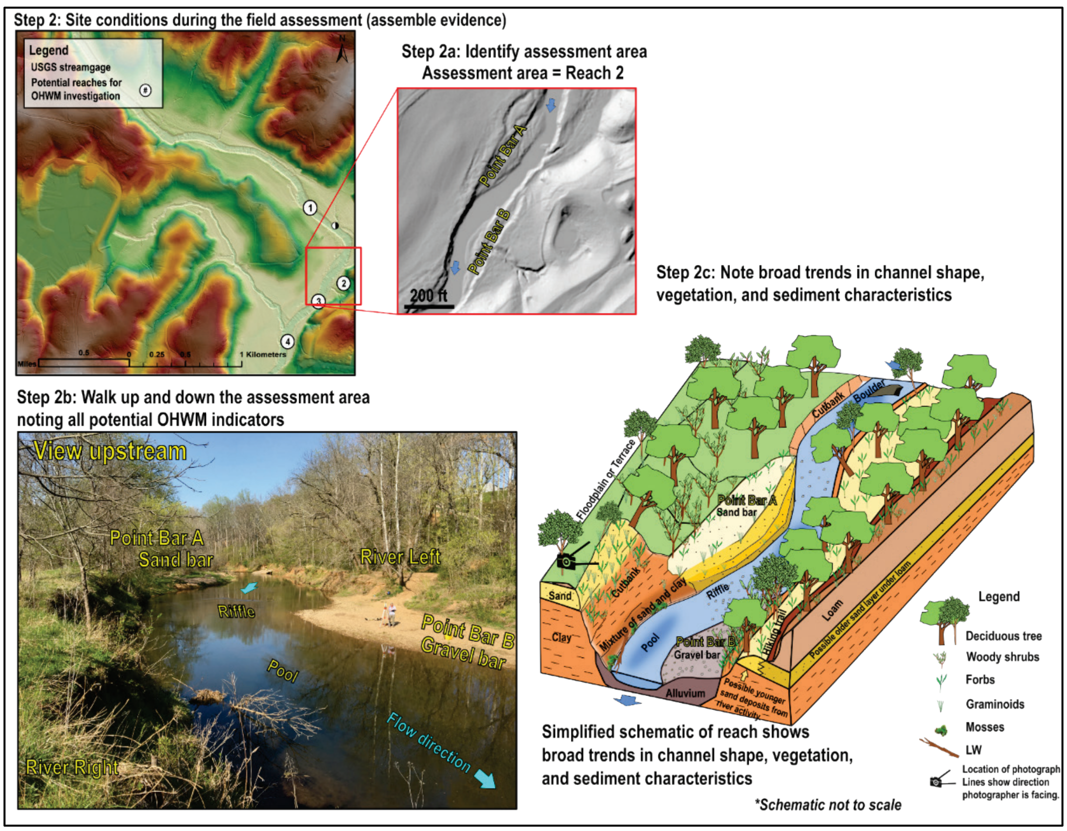
e. Look for indicators on both banks. If the opposite bank is not accessible, then look across the channel at the bank.

f. **In Step 2 of the datasheet** describe any adjacent land use or flow conditions that may influence interpretation of each line of evidence.
- i. What land use and flow conditions may be affecting your ability to observe indicators at the site?
- ii. What recent extreme events may have caused changes to the site and affected your ability to observe indicators?

3.3.1 Identify the assessment area

Step 2 of the field assessment begins by identifying the assessment area. The length of stream that is being assessed will likely be predefined by the permit applicant. The site overview from Step 1 can help to identify the length of channel that will need to be surveyed and whether one or more data sheets are needed (Figure 79). Figure 83 shows the area on the NF Rivanna River that will be used to demonstrate the delineation of the OHWM in the rest of this chapter.

Figure 83. Evaluating site condition and identifying the assessment area. (Image on *top right* adapted from USGS n.d.c.)



3.3.2 Initial observations of site condition

Once the assessment area is identified, continue assembling evidence by walking up- and downstream and noting broad changes in landscape form, vegetation, and sediment. While assembling different lines of evidence, consider the four categories of OHWM indicators (i.e., geomorphic, vegetation, sediment, and ancillary) and use the questions outlined in Box 3 to inform the systematic search for and documentation of observed characteristics. Field observations can be made of the point bars, breaks in slope at the top of and along the cutbanks, and transitions in vegetation along the banks and bars (Figure 84).

Figure 84. An upstream (*left*) and downstream (*right*) view of the NF Rivanna River showing locations of observed geomorphic, vegetative, and sedimentary indicators. The *bottom* photograph is a panoramic view to help provide an overview of the reach.

The assessment area on the NF Rivanna River has two point bars (Point Bars A and B), a confining hillslope on the river left, and a broad floodplain or terrace on the river right. Initial observations may not provide enough information to know whether the open valley on river right is a floodplain or a terrace. The bed morphology appears to be a pool-riffle. Vegetation is composed of deciduous trees, woody shrubs, forbs, and graminoids. There is sand deposited on the floodplain on river left, which may be part of the underlying strata or of more recent fluvial deposits. A quick, one-day survey of the site would not necessarily reveal the answer to that question. A generalized schematic of the site is included in Figure 83 to illustrate the broad trends that would be observed while walking up and down the assessment area.

Photographs show what was observed at a site and can provide a record of the lines of evidence used to support the OHWM delineation. Furthermore, if the site is visited more than once, photographs can be useful for documenting the degree to which conditions changed over time, including changes following extreme events such as floods or debris flows. Initially, photographs should be taken looking up- and downstream along the assessment area and of points of interest. Figure 84 shows an upstream, downstream, and panoramic view of the site with possible locations of geomorphic, vegetative, and sedimentary indicators that were observed while walking around the site. Several potential OHWM indicators, which will be discussed further in Step 3, are tagged in the photographs. Photographs should continue to be taken during each of the steps that follow. Photographs can be documented on page 2 of the data sheet (Box 2) or in a separate photo log. Associated descriptions and annotations can provide context for the observation documented in the photograph.

3.3.3 Filling out the data sheet for Step 2

An assessment of the site condition on the NF Rivanna River reveals that the alternating point bars are composed of different material. The upstream point bar (Point Bar A) is mainly sand, and the downstream point bar (Point Bar B) is mainly gravel. There is an old dirt road that is now a recreational trail on the floodplain on river left. There are steep embankments on both sides of the channel, which can be seen with the lidar hillshade and slope products in Step 1 (Figure 81). There is a small tributary entering the channel just downstream of the gravel point bar. The whole assessment area is downstream of a bridge, where there is a USGS streamgage and a sharp bend in the channel. It is likely that there are point bars downstream of this bend because of the reduction in streamflow velocity as water flows around the bend. The stream was at low flow during the site visit; therefore, all the photographs show the water surface at a low-flow stage. This information can be briefly summarized on the field form under Step 2 (Box 5).

Box 5. Questions to consider when making initial observations at a site. Step 2 in the data sheet (adapted from USACE 2022) is shown below the questions in the field procedure.

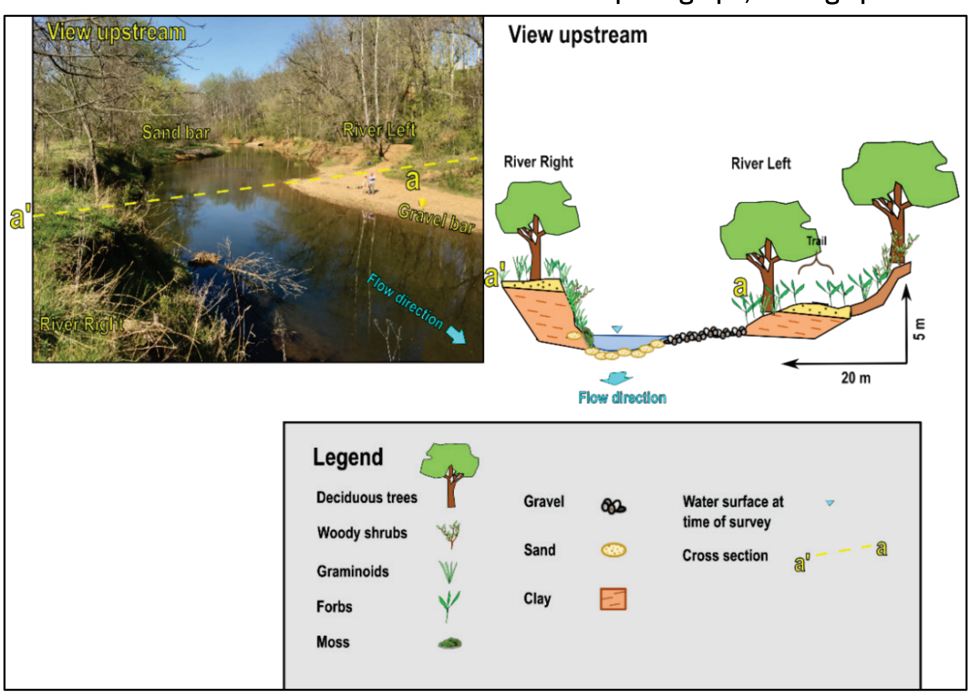
Step 2 Site condition during field assessment.
First look for changes in channel shape, depositional and erosional features, and changes in vegetation and sediment type, size, density, and distribution. Make note of natural, or man-made, disturbances that would affect flow and channel form, such as bridges, riprap, landslides, rockfalls etc.

Stream is at a low flow during the time of the site visit. There is a dirt trail that follows the left side of the channel, between the stream and steep hillslope. The right side has a steep eroding cutbank.
There is a small tributary draining off the hillslope and entering the channel downstream of the gravel point bar along the left bank. The assessment area is a few hundred meters downstream of a bridge and USGS streamgage.

3.4 Step 3: Check the boxes next to indicators used to identify the OHWM

Step 1 identified potential locations of the OHWM along the outer edge of the point bars, or at the top of steep banks along river right and left. Step 2 provided an initial assessment of the form and condition of the channel. Step 3 on the data sheet (Box 1) is split into two parts in the field procedure; these align with the WoE steps of assembling evidence, weighting evidence, and combining weights as part of weighing the body of evidence (Figure 7). Step 3a (Box 6) is where the evidence is initially assembled on the data sheet, first by listing all the possible evidence for locating the OHWM and sorting it into the appropriate categories on the data sheet. Step 3b (Box 8) describes the process of weighting the relevance, strength, and reliability of each line of evidence and then combining weights to support a final delineation. Throughout the rest of this chapter, a cross-sectional survey is used to provide an understanding of the major transition points along the channel boundaries perpendicular to streamflow. Figure 85 shows the location and shape of the cross section and the vegetative and sedimentary information. The cross-sectional survey provides a visual guide to support the decision-making process. A cross-sectional survey, while helpful, is not required to identify and delineate the OHWM. It is included here for demonstration purposes.

Figure 85. Cross section of the site with vegetation and sedimentary characteristics labeled. Cross section is oriented in the same direction as the photograph, looking upstream.



3.4.1 Step 3a: Assemble evidence by first listing each line of evidence

The initial list of evidence may include observations that are ultimately not helpful for identifying the OHWM; thus, a scratch data sheet may be helpful for checking all initial observations. Consider the questions listed in Box 6 when investigating a site and listing potential evidence of the OHWM. The context provided by Steps 1 and 2 is important when considering the evidence used to determine the location of the OHWM. For instance, gravel deposited and sorted by flowing water may not be of interest when located below the water's edge, but it may be important to note if it occurs above the top of the bank. Therefore, consider the context of each line of evidence when deciding which indicators to note in the data sheet.

Box 6. Questions to consider when listing evidence and putting the evidence in context of the site. (Data sheet adapted from USACE 2022).

Assemble Evidence

Step 3a List evidence

Assemble evidence by checking the boxes next to each line of evidence:

a. If needed, use a separate scratch datasheet to check boxes next to possible indicators, or check boxes of possible indicators in pencil and use pen for final decision.
b. If using fillable form, then follow the instructions for filling in the fillable form.

Context is important when assembling evidence. For instance, pool development may be an indicator of interest on the bed of a dry stream, but may not be a useful indicator to take note of in a flowing stream. On the other hand, if the pool is found in a secondary channel adjacent to the main channel, it could provide a line of evidence for a minimum elevation of high flows. Therefore, consider the site context when deciding which indicators provide evidence for identifying the OHWM. Explain reasoning in Step 5.

Questions to consider while making observations and listing evidence at a site:

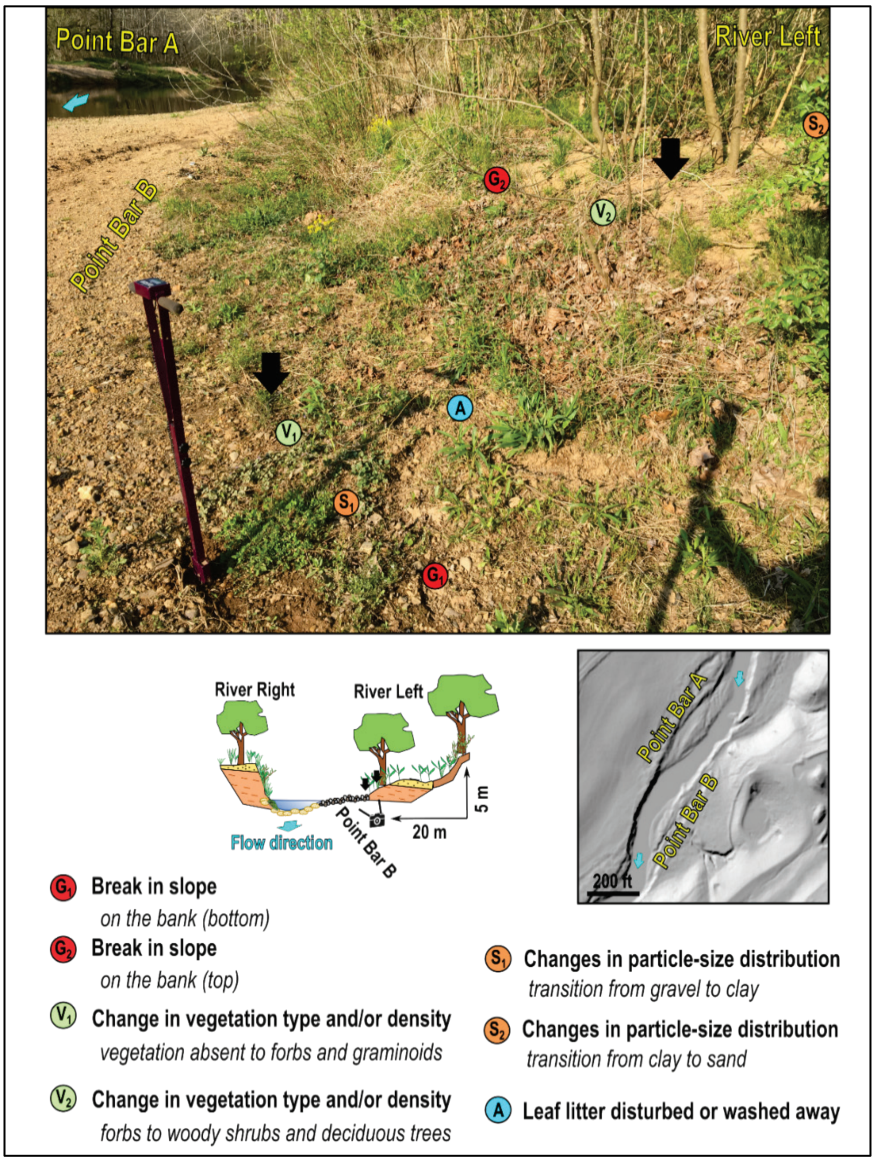
Geomorphic indicators	Sediment and soil indicators	Vegetation Indicators	Ancillary indicators
Where are the breaks in slope? Are there identifiable banks? Is there an easily identifiable top of bank? Are the banks actively eroding? Are the banks undercut? Are the banks armored? Is the channel confined by the surrounding hillslopes? Are there natural or man-made berms and levees? Are there fluvial terraces? Are there channel bars?	Where does evidence of soil formation appear? Are there mudcracks present? Is there evidence of sediment sorting by grain size?	Where are the significant transitions in vegetation species, density, and age? Is there vegetation growing on the channel bed? If no, how long does it take for the non-tolerant vegetation to establish relative to how often flows occur in the channel? Where are the significant transitions in vegetation? Is the vegetation tolerant of flowing water? Has any vegetation been flattened by flowing water?	Is there organic litter present? Is there any leaf litter disturbed or washed away? Is there large wood deposition? Is there evidence of water staining?

Are the following features of fluvial transport present?
Evidence of erosion: obstacle marks, scour, armoring
Bedforms; riffles, pools, steps, knickpoints/headcuts
Evidence of deposition: imbricated clasts, gravel sheets, etc.

In some cases, it may be helpful to explain why an indicator was NOT at the OHWM elevation, but found above or below. It can also be useful to note if specific indicators (e.g., vegetation) are NOT present. For instance, note if the site has no clear vegetation zonation.

Because there are potential OHWM indicators at multiple elevations at this site, include all potential indicators when listing evidence. Figure 86 shows a photograph looking upstream at the edge of Point Bar B. The geomorphic indicators include two breaks in slope, one at the edge of the point bar and another just above where woody vegetation has established. There is a transition in sediment from gravel to clay. The clay is likely part of the underlying stratigraphy, whereas the gravel was deposited more recently by the river. There is another transition in sediment further up the bank, where sand is deposited. The sand might be from more recent fluvial action, but it could also be stratigraphic layering. There are also two clear transitions in vegetation. At the edge of the gravel bar, there is a transition from no vegetation to forbs and graminoids. Further up the bank, there is a transition to woody shrubs and deciduous trees. The ancillary indicator at this site is some disturbed leaf litter. The leaf litter is not continuous through this channel reach but, rather, appears in patches. There is no leaf litter on the point bar.

Figure 86. Geomorphic, vegetative, sedimentary, and ancillary indicators at transition points on the edge of Point Bar B. The *black arrows* reference the same locations on the cross section and in the photograph. (Image on *bottom right* adapted from USGS n.d.c.)



There are similar transitions occurring up- and downstream of the cross section (Figures 87 and 88). The elevation of woody vegetation establishment can be seen in many of the photographs. Geomorphic indicators include more breaks in slope on the banks and shelving on Point Bar A. On river right, there is a steep embankment. There are some breaks in slope along the embankment and at its very top. There are also some areas of shelving lower down on the embankment and above the top break in slope. There is a shift in sediment characteristics, from a mix of sand, silt, and clay at the bottom of the embankment to layers of silt and clay and then sand moving toward the top. Patches of leaf litter appear on the left floodplain. There is shelving on the top of the cutbank and multiple breaks in slope along the left cutbank.

Additional evidence can be identified on the floodplain and at the downstream portion of the reach, where the tributary enters the channel (Figure 89).

Figure 87. Photographs looking up- and downstream at potential OHWM indicators along the eroding cutbanks on the NF Rivanna River site. (Image on *bottom left* adapted from USGS n.d.c.)

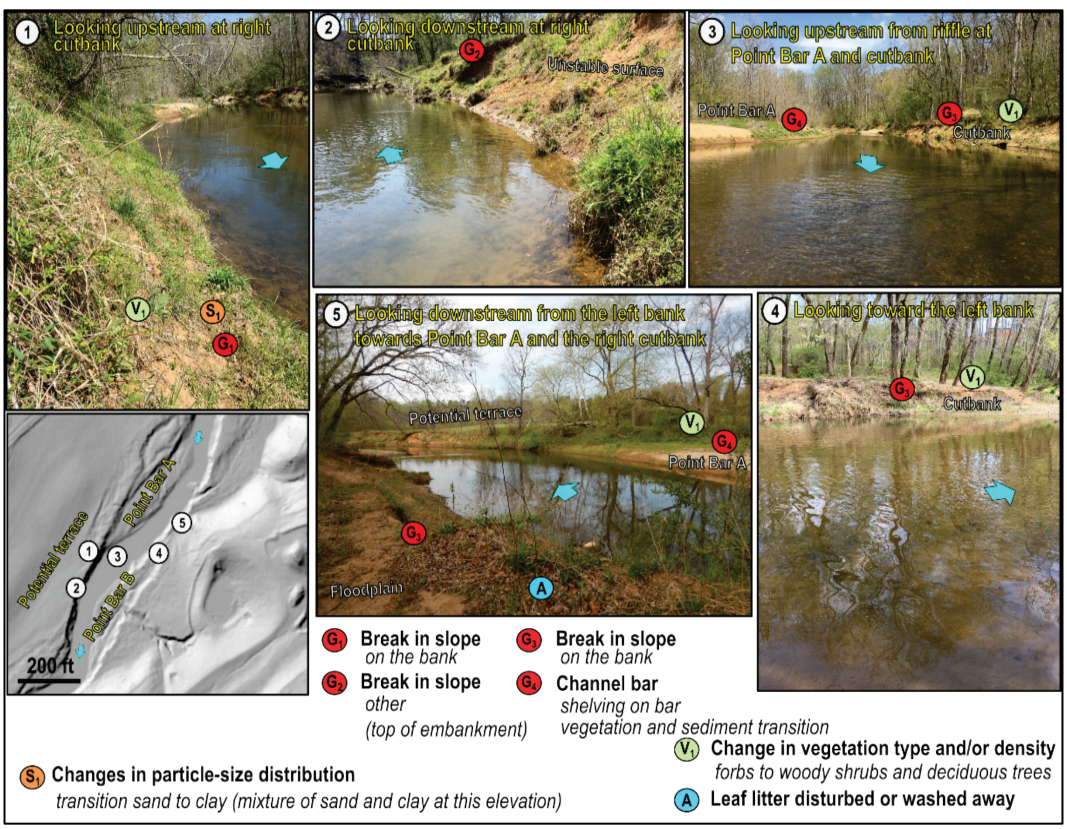


Figure 88. Photographs showing additional views of the geomorphic, sedimentary, and vegetative indicators on the channel bars and at the base of the right embankment on the NF Rivanna River site. (Image in *top center* adapted from USGS n.d.c.)

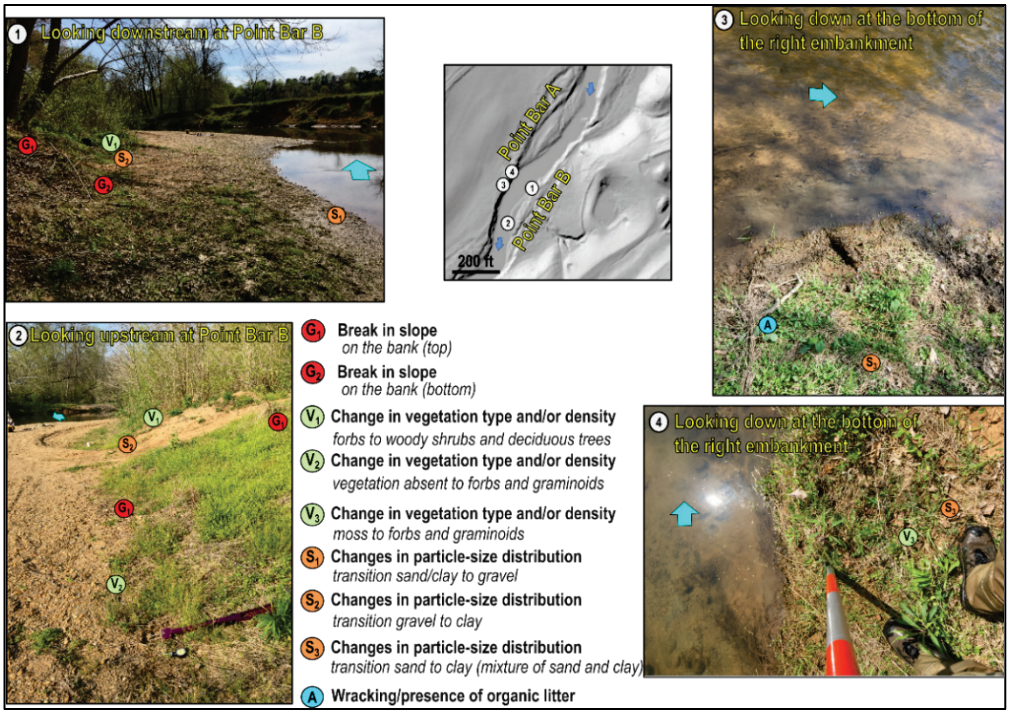
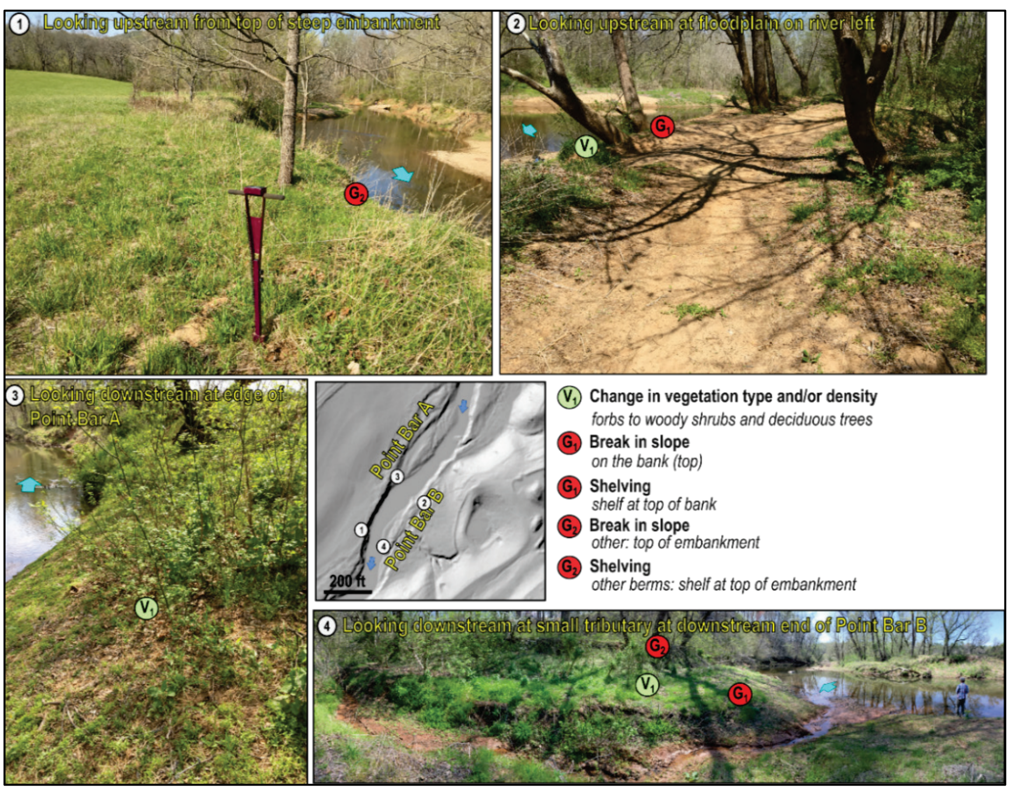


Figure 89. Indicators at the edge of the floodplain and potential fluvial terrace. (*Center* image adapted from USGS n.d.c.)



To document the lines of evidence in Step 3a, the practitioner should select each indicator observed at the sampling point by checking the box next to that indicator on the OHWM data sheet (Box 7).

Box 7. Step 3a of the data sheet (adapted from USACE 2022). Use to initially list evidence and then revise when weighting evidence. In this initial listing, it would likely be too soon to determine if the indicators are below, at, or above the OHWM.

Assemble Evidence

Step 3a List evidence:

Step 3 Check the boxes next to the indicators used to identify the location of the OHWM.
OHWM is at a transition point, therefore some indicators that are used to determine location may be just below and above the OHWM. From the drop-down menu next to each indicator, select the appropriate location of the indicator by selecting either just below `b', at `x', or just above `a' the OHWM.
Go to page 2 to describe overall rationale for location of OHWM, write any additional observations, and to attach a photo log.

Geomorphic indicators

- [x] **Break in slope:**
  - [x] *on the bank:*
  - [x] *undercut bank:*
  - [ ] *valley bottom:*
  - [ ] Other:
- [x] **Shelving:**
  - [ ] *shelf at top of bank:*
  - [ ] *natural levee:*
  - [ ] *man-made berms or levees:*
  - [x] *other berms:* at top of embankment
- [x] **Channel bar:**
  - [x] *shelving (berms) on bar:*
  - [x] *unvegetated:*
  - [x] *vegetation transition (go to veg. indicators)*
  - [x] *sediment transition (go to sed. indicators)*
  - [x] *upper limit of deposition on bar:*
- [x] **Instream bedforms and other bedload transport evidence:**
  - [x] *deposition bedload indicators (e.g., imbricated clasts, gravel sheets, etc.)*
  - [ ] *bedforms (e.g., pools, riffles, steps, etc.):*
  - [ ] *erosional bedload indicators (e.g., obstacle marks, scour, smoothing, etc.)*
- [ ] **Secondary channels:**

Sediment indicators

- [x] **Soil development:**
- [ ] **Changes in character of soil:**
- [ ] **Mudcracks:**
- [x] **Changes in particle-sized distribution:**
  - [x] *transition from* gravel to silt/clay
  - [x] *upper limit of sand-sized particles*
  - [ ] *silt deposits:*

Vegetation Indicators

- [x] **Change in vegetation type and/or density:**
  Check the appropriate boxes and select the general vegetation change *(e.g., graminoids to woody shrubs)*. ***Describe the vegetation transition looking from the middle of the channel, up the banks, and into the floodplain.***
  - [x] *vegetation absent to:* forbs
  - [x] *moss to:* forbs
  - [x] *forbs to:* woody shrubs
  - [x] *graminoids to:* woody shrubs
  - [ ] *woody shrubs to:*
  - [ ] *deciduous trees to:*
  - [ ] *coniferous trees to:*
- [ ] **Vegetation matted down and/or bent:**
- [x] **Exposed roots below intact soil layer:**

Ancillary indicators

- [x] **Wracking/presence of organic litter:**
- [ ] **Presence of large wood:**
- [x] **Leaf litter disturbed or washed away:**
- [ ] **Water staining:**
- [ ] **Weathered clasts or bedrock:**

Other observed indicators? Describe:
Sand, silt, clay are mixed together at the bottom of the right embankment.
At the same location there is a small shelf at the bottom of the right embankment.

ENG FORM 6250, AUG 2022 PREVIOUS EDITIONS ARE OBSOLETE. Page 1 of 4

3.4.2 Step 3b: Weight each line of evidence and then weigh the body of evidence

Once the lines of evidence are assembled (Box 7), each line of evidence is then weighted (Figure 7). Box 8 lists the questions to ask about each line of evidence to determine its relevance, strength, and reliability. These questions are also listed in the two-page field form in Appendix A, which can be printed out and brought to the field.

Box 8. Questions to ask when weighting each line of evidence and ultimately combining data to weigh the body of evidence. (Data sheet adapted from USACE 2022.)

Weight the Evidence

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

Weight each indicator by considering its importance based upon:

a. Relevance:

i. Is this indicator left by low, high, or extreme flows?

Tips on how to assess the indicator relative to type of flow:

Consider the elevation of the indicator relative to the channel bed.
What is the current flow level based on season or nearby gages?
Consider the elevation of the indicator relative to the current flow.
If the stream is currently at baseflow and indicator is adjacent to that, then it is likely a low flow indicator. The difference between high and extreme flow indicators can sometimes be difficult to determine.

ii. Did recent extreme events and/or land use affect this indicator?

1. Recent floods may have left many extreme flow indicators, or temporarily altered channel form. Other resources will likely be needed to support any OHWM identification at this site. Field evidence of the OHWM may have to wait for the site to recover from the recent flood.
2. Droughts may cause field evidence of OHWM to be obscured, because there has been an extended time since the last high flow event. There can be overgrowth of vegetation or deposition of material from surrounding landscape that can obscure indicators.
3. Both anthropogenic (e.g., dams, construction, mining activities, urbanization, agriculture, grazing) and natural (e.g., fires, floods, flows, beaver dams) disturbances can all alter how indicators are expected to appear at a site. Chapter 6 and Chapter 7 of the OHWM field manual provides specific case-studies that can help in interpreting evidence at these sites.

***Landscape context from Step 1 can help determine the relevance, strength, and reliability of the indicators observed in the field.**

***Information in Chapter 2 of the OHWM field manual provides information on specific indicators which can assist in putting these in context and determining relevance, strength, and reliability.**

b. Strength:

i. Is this indicator persistent across the landscape?

1. Look up and downstream and across the channel to see if you see the same indicator at multiple locations.
2. Does the indicator occur at the same elevation as other indicators?

c. Reliability:

i. Is this indicator persistent on the landscape over time? Will this indicator still persist across seasons?

1. 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.
2. Chapter 2, Chapter 6, and Chapter 7 of the OHWM field manual describes each indicator in detail and provides examples of areas where indicators are difficult to interpret.

Weigh Body of Evidence

d. Weigh body of evidence:

i. Combine weights: integrate the weighted line of evidence (relevance, strength, reliability) of each indicator.

ii. For each of the observed indicators, which are more heavily weighted? Where do high value indicators co-occur along the stream reach? Do they co-occur at a similar elevation along the banks relative to water surface (or channel bed if there is no water).

iii. On datasheet, select the indicators used to identify the OHWM. Information in Chapter 2 of the OHWM field manual provides descriptions of specific indicators which can assist in putting these in context and determining relevance, strength, and reliability.

e. Take photographs of indicators and attach a log using either page 2 of datasheet or another method of logging photos.

i. Annotate photos with descriptions of indicators.

Figure 90 demonstrates the transitions in geomorphic, vegetative, and sedimentary characteristics along the detailed cross section of the NF Rivanna River site. Through the initial assessment of site conditions (Figure 84), and by listing all possible evidence in the data sheet (Figures 86, 87, 88, and 89), multiple possible elevations of the OHWM are revealed. By characterizing the relevance, strength, and reliability (i.e., weights) of each line of evidence, the user can determine which of the possible elevations are most strongly supported by the evidence to be the OHWM. Table 6 outlines how to interpret the individual lines of evidence identified along the cross section in Figure 90.

First, to locate the elevation of the OHWM, look for stream features that are clearly above and below the OHWM to find the point at which change is occurring. (See Chapter 2 for assistance with interpreting each of these indicators when considering what is clearly above or below the OHWM.) For instance, first consider the lines of evidence that indicate areas that are above the OHWM. In the NF Rivanna River, deciduous trees are well-established on the floodplain elevation along the river left (Figure 89). This elevation is slightly lower than the shelving occurring at the top of the embankment on river right. Therefore, that valley on river right could be a terrace rather than a floodplain. A quick assessment of the site would not necessarily lead to a determination of whether it is a floodplain or terrace, but either way, the top of the embankment on river right is clearly above the OHWM. River left also includes a confining hillslope. There is soil development on the hillslope and vegetation (including trees) that is representative of terrestrial processes rather than riparian processes. Leaf litter is thicker on the slope, and there are no signs of fluvial depositional or erosional processes on the hillslope. There are some signs of rill and gully development from water moving downslope, rather than signs of water moving downstream. There are no signs of other ancillary or geomorphic indicators, such as organic litter deposition or other erosional or depositional characteristics, above these elevations. An examination of lidar along with the field survey shows that there are no secondary or floodplain channels further out in the valley on river right. Changes in vegetation and breaks in slope that are above those elevations are, then, not of interest when identifying the OHWM. Multiple pieces of evidence were used to provide support for this interpretation that these areas are well above the OHWM.

Figure 90. A cross section of the NF Rivanna River shows the multiple lines of evidence that can occur on the landscape. The cross section is oriented in the downstream direction, with the photograph.

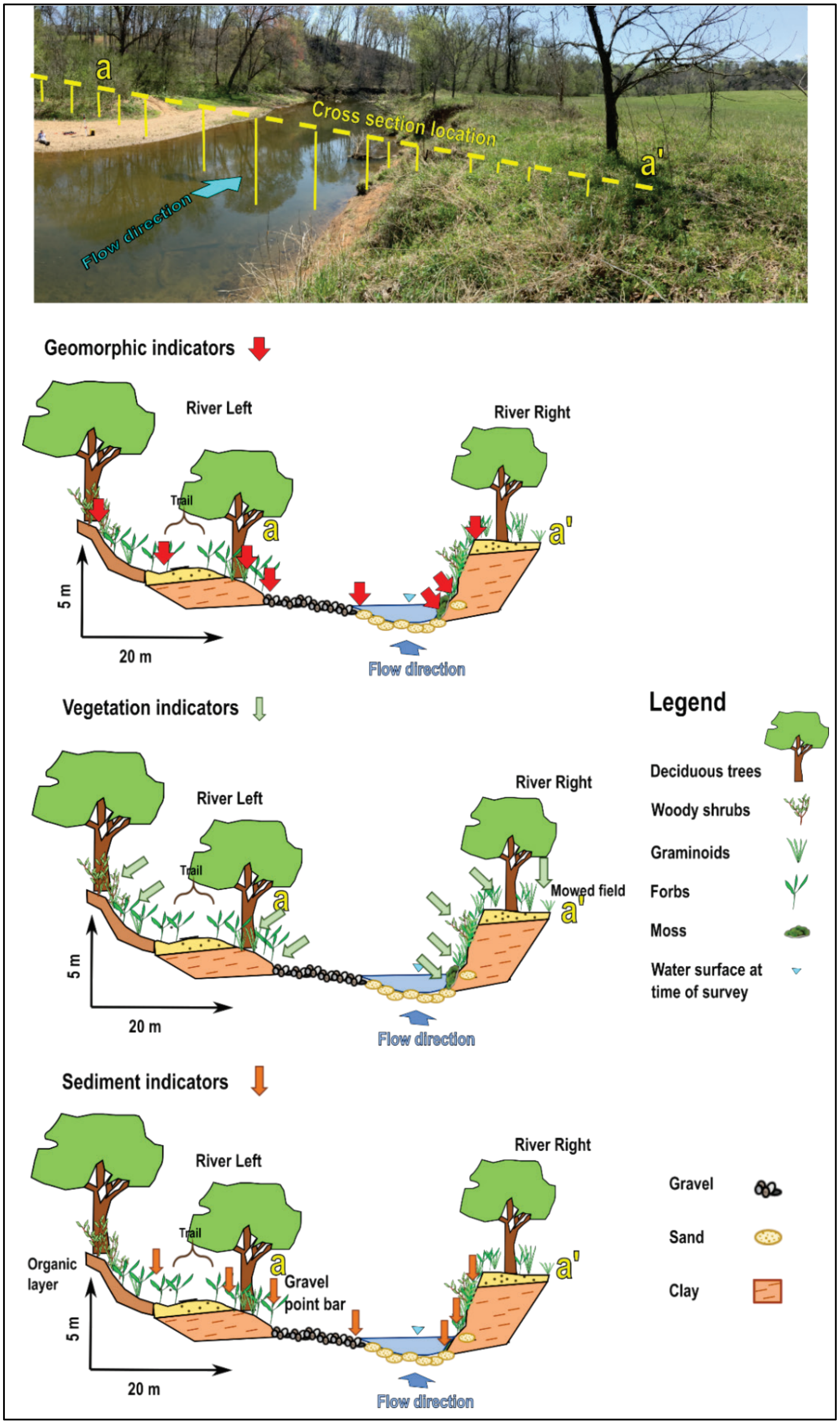


Table 6. Applying the WoE procedure to the lines of evidence identified along the cross section in Fig. 90.

			Description of Weights			
Indicator Name	Indicator Type	Description	Relevance	Strength	Reliability	Initial Conclusions
Break in slope: other (on the channel bar)	G	At the water's edge, there is a break in slope on the channel bar.	Evaluation of streamgage data showed the stream is currently at low flow.	This occurs at the same elevation as some other vegetative and sedimentary changes.	The point bar has persisted over time, but indicators at this elevation are likely related to low-flow fluctuations.	Indicators identified at this elevation are related to low-flow fluctuations and not high flows.
Break in slope: on the bank (river left)	G	A break in slope on the edge of the gravel point bar.	The break in slope appears to define the outer boundary of the gravel point bar.	This indicator persists on the point bar and corresponds to a break in slope on river right.	Remote data showed that this point bar has persisted over time. Therefore, indicators along the point bar may be fairly reliable.	The outside edge of the point bar is a good initial location to begin looking up- and downstream for other evidence of the OHWM.
Break in slope: on the bank (river left)	G	There is another break in slope along the clayey bank just above the edge of the gravel.	This break in slope corresponds to where woody vegetation is establishing.	A distinct line can be seen in images from 2013, when leaves were off the trees.	The presence of woody vegetation remains no matter the season.	Despite changes in the point bar, the elevation of woody vegetation establishment may not have changed.
Channel bar: upper limit of deposition on bar	G	There is an upper limit to deposition on the gravel point bar (Point Bar B).	The upper limit of deposition on the bar defines an area the higher flows frequently access.	This indicator persists on the point bar and corresponds to a break in slope on river right.	Remote data showed that this point bar has persisted over time. Therefore, indicators along the point bar may be fairly reliable.	The outside edge of the point bar is a good initial location to begin looking up- and downstream for other evidence of the OHWM.
Changes in particle size distribution (river left): gravel to silt/clay	S	There is a transition at which the deposition of gravel ends and clay begins. The clay is stratigraphic layering that includes silt.	Same as above	Same as above	Same as above	Same as above
Change in particle size distribution (river right): mixture of sand/silt/clay to mainly silt/clay	S	More sand is mixed in along a shelf at the base of the eroded embankment. Clay dominates above and below this shelf.	The shelf with a mixture of sediment indicates an area in which a new bank may be reforming at the base of the embankment. Sand is likely both from the bank and from upstream.	This indicator persists over a short length of channel. The shelving becomes more pronounced and includes more sand just upstream in the direction of the sand bar.	This indicator is less reliable because it is on an actively eroding bank.	Overall, this indicator may provide some support for other lines of evidence, but it would not be a strong or reliable indicator to use on its own.

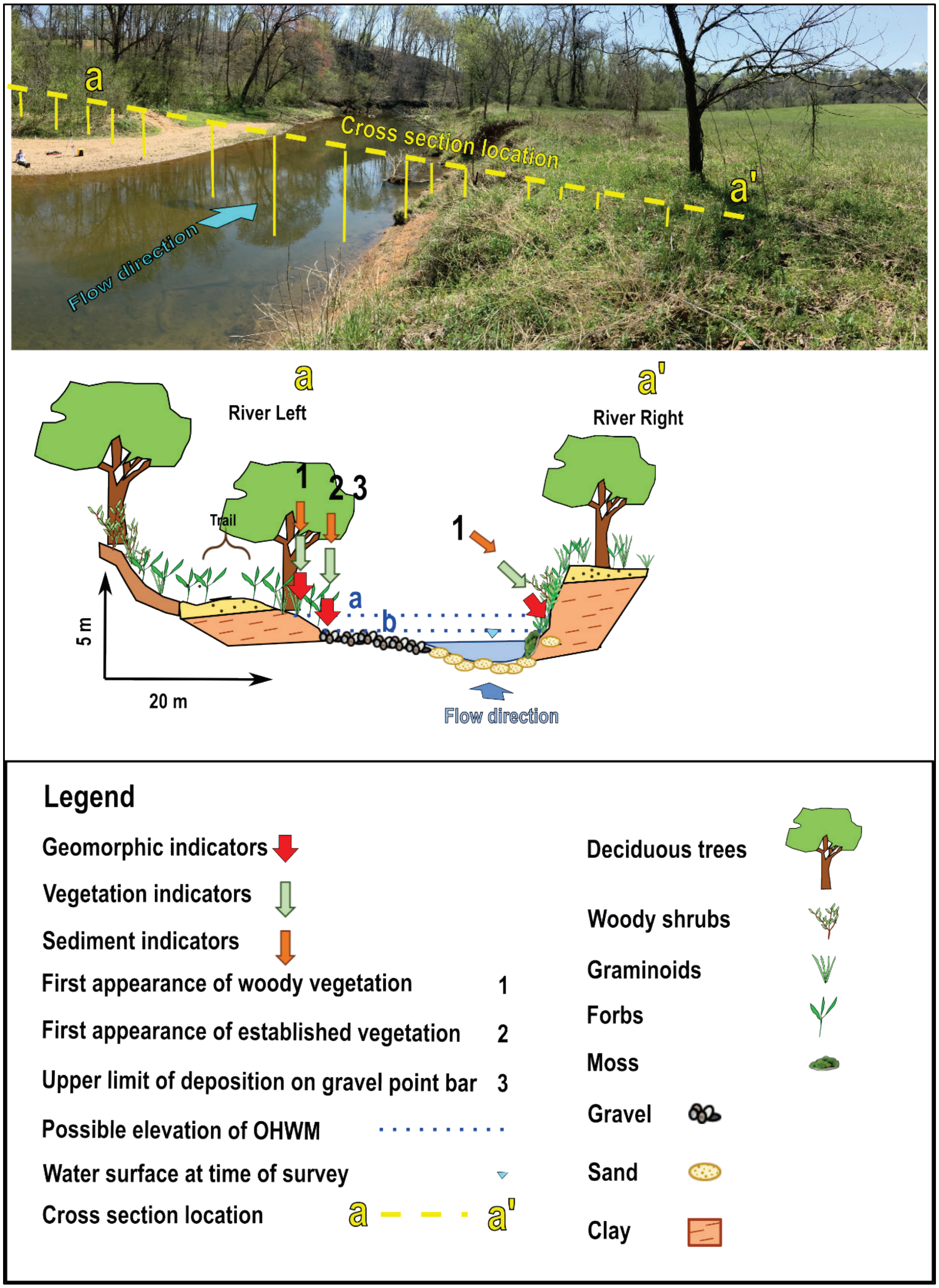
Table 6 (cont.). Applying the WoE procedure to the lines of evidence identified along the cross section in Fig. 90.

			Description of Weights			
Indicator Name	Indicator Type	Description	Relevance	Strength	Reliability	Initial Conclusions
Change in vegetation type and/or density: absent to forbs/graminoids	V	Above the edge of the gravel deposition, a higher density of forbs and graminoids are growing.	The change in vegetation occurs at the same location as the edge of gravel deposition on the point bar. The stream has not experienced any recent high flows, which would allow forbs and graminoids to establish.	Downstream, some forbs and graminoids have encroached further on the point bar.	It is unlikely this would persist over time. These would not be present during different seasons. Furthermore, high-flow events would likely remove them.	This change in vegetation type overlaps with the upper limit of gravel deposition, but it is not a line of evidence that is as strong or persistent as other lines of evidence.
Change in vegetation type and/or density: forbs/graminoids to woody shrubs and trees	V	On both banks, there is a consistent elevation of woody vegetation establishment.	Woody vegetation in this region tends not to establish where its roots will be frequently inundated during higher flow events.	Newer woody shrubs are establishing on the eroding cutbank at the same elevation as the trees and woody shrubs establishing above the gravel point bar.	Woody vegetation is still visible during different seasons. The remote data revealed this point bar has remained in place over time, meaning the elevation of woody vegetation establishment can be a reliable indicator.	The elevation at which the woody vegetation is establishing on river left is the most reliable because the point bar has not adjusted its shape and location over the past 14 years (2003–2017). The small woody shrubs establishing on the eroding right bank are less reliable, but they can help confirm that there is a consistent elevation at which woody vegetation is establishing.
Change in vegetation type and/or density: moss to forbs/graminoids	V	Moss growth occurring at the water's edge.	This indicator is likely related to low-flow fluctuations because it occurs at the current low-flow water stage.	There are some short stretches of moss growth along the eroding right embankment.	This is at too low an elevation relative to the current water level to be a high-flow indicator.	This indicator would be removed from the list because it is adjacent to the current low-flow stage and therefore related to low-flow fluctuations, not high-flow fluctuations.

After determining the upper bound for investigating OHWM indicators, the current water surface elevation can be used to provide a lower bound for identifying OHWM indicators. Climate tools and local streamgage data can assist in understanding if the stream is likely to be at a low or high flow during the site visit. Prior to visiting NF Rivanna River, the streamflow was determined to be lower than the mean annual average (Figure 82). The use of streamgage data to interpret the indicators observed at the water stage during the field visit will be discussed further in Step 4. This information can be combined with the evidence collected in the field to help determine the relevance of indicators adjacent to the current water surface. In this case, the indicators adjacent to the current surface are not relevant because they are low-flow, rather than high-flow, indicators. This provides a lower bound for investigating the OHWM.

The next part of Step 3b (Box 8) is identifying the elevation(s) at which OHWM indicators overlap and their connection to other indicators up- and downstream of the location being investigated (Figure 91). Overlapping indicators and the persistence of indicators on the landscape inform the strength and reliability of the indicators ultimately used to determine the OHWM. *Persistence of indicators* can refer to persistence spatially as well as temporally. Consider if the indicators would be present if the survey were conducted during different seasons. Specifically, consider seasonal changes in vegetation (Section 2.3.3). Also, consider if an indicator is an outlier or anomaly at the site. For instance, unstable banks can result in trees sliding down to an elevation lower than the elevation at which they are able to establish. Therefore, a single tree established at a lower elevation does not necessarily provide evidence of the location of the OHWM. (Figure 15 in Section 2.3.1.1 shows what to look for when this type of slumping occurs along the banks.) Figure 91 shows which indicators overlap in the NF Rivanna River cross section and eliminates the indicators that were determined to be well above and well below the OHWM (Table 6). Box 9 shows the updated data sheet after the evidence was weighted.

Figure 91. The location of overlapping, multiple lines of evidence for the OHWM are shown on this cross section, with the water surface from the day of the survey.



Box 9. The data sheet (adapted from USACE 2022) after weighting each line of evidence.

Weight the Evidence

Step 3b Weight each line of evidence:

Step 3 Check the boxes next to the indicators used to identify the location of the OHWM.
OHWM is at a transition point, therefore some indicators that are used to determine location may be just below and above the OHWM. From the drop-down menu next to each indicator, select the appropriate location of the indicator by selecting either just below `b', at `x', or just above `a' the OHWM.
Go to page 2 to describe overall rationale for location of OHWM, write any additional observations, and to attach a photo log.

Geomorphic indicators

- [x] **Break in slope:** x
  - [x] *on the bank:* x
  - [x] *undercut bank:* b
  - [ ] *valley bottom:*
  - [ ] Other: ______
- [x] **Shelving:**
  - [x] *shelf at top of bank:* a
  - [ ] *natural levee:*
  - [ ] *man-made berms or levees:*
  - [x] *other berms:* on embankment b
- [x] **Channel bar:** b
  - [x] *shelving (berms) on bar:* b
  - [x] *unvegetated:* b
  - [x] *vegetation transition (go to veg. indicators)*
  - [x] *sediment transition (go to sed. indicators)*
  - [x] *upper limit of deposition on bar:* b
- [ ] **Instream bedforms and other bedload transport evidence:**
  - [ ] *deposition bedload indicators (e.g., imbricated clasts, gravel sheets, etc.)*
  - [ ] *bedforms (e.g., pools, riffles, steps, etc.):*
  - [ ] *erosional bedload indicators (e.g., obstacle marks, scour, smoothing, etc.)*
- [ ] **Secondary channels:**

Sediment indicators

- [ ] **Soil development:**
- [ ] **Changes in character of soil:**
- [ ] **Mudcracks:**
- [x] **Changes in particle-sized distribution:** b
  - [x] *transition from* gravel to silt/clay
  - [ ] *upper limit of sand-sized particles*
  - [ ] *silt deposits:*

Vegetation Indicators

- [x] **Change in vegetation type and/or density:** x

  Check the appropriate boxes and select the general vegetation change *(e.g., graminoids to woody shrubs)*. ***Describe the vegetation transition looking from the middle of the channel, up the banks, and into the floodplain.***
  - [ ] *vegetation absent to:*
  - [ ] *moss to:*
  - [x] *forbs to:* woody shrubs
  - [x] *graminoids to:* woody shrubs
  - [ ] *woody shrubs to:*
  - [ ] *deciduous trees to:*
  - [ ] *coniferous trees to:*
- [ ] **Vegetation matted down and/or bent:**
- [x] **Exposed roots below intact soil layer:** b

Ancillary indicators

- [x] **Wracking/presence of organic litter:** b
- [ ] **Presence of large wood:**
- [x] **Leaf litter disturbed or washed away:** b
- [ ] **Water staining:**
- [ ] **Weathered clasts or bedrock:**

Other observed indicators? Describe:
Sand, silt, clay are mixed together at the bottom of the right embankment. At the same location there is a small shelf at the bottom of the right embankment. Both of these are at, or just below, the OHWM.

ENG FORM 6250, AUG 2022 PREVIOUS EDITIONS ARE OBSOLETE. Page 1 of 4

Once the locations of overlap are identified, the WoE approach involves weighing the body of evidence by combining weights (i.e., integrating lines of evidence), interpreting the evidence, and explaining any ambiguities or discrepancies (Box 8). Figure 91 shows two possible elevations of the OHWM (labeled *a* and *b* on the cross section). In this example, a cross section at one location is being used to discuss the WoE methodology. At any given assessment area, observations should be made along the length of the reach, not just at one cross section. In this example, making observations and gathering evidence up- and downstream of the provided cross section indicates that the high-flow indicators co-occur at the elevation marked *a*. Further upstream, the upper elevation of sand on the sand bar is close to the top of the cutbank on river left, which corresponds to the elevation marked *a* (Figures 86, 87, 88, and 89). Sometimes the connection between up- and downstream indicators can be quickly assessed visually. Survey equipment is not necessarily needed to make these connections, but it can help at difficult sites. If needed, a hand level or laser rangefinder can help determine what features occur at the same elevation. The elevation of the indicators should adjust with the gradient of the channel up- and downstream of the observation point.

3.5 Step 4: Are other resources needed to support OHWM identification?

Examining USGS streamgage data, seasonal fluctuations, and current trends in precipitation can provide information on flow levels prior to a site visit. Step 2 in the data sheet (Box 1 and Box 4) requires a description of the current flow conditions because the flow occurring when the observations are made can affect the way the evidence is weighted. If observations at a site are made during extreme-flow events, then it is unlikely high-flow indicators can be observed at that time. Or if an extreme event occurred recently, then these indicators would be more prominent than the high-flow indicators. If the flow is at low, or base flow, and has been for some time, then it is possible that some of the marks observed on the landscape resulted from more frequent lower flows and not ordinary high flows. Section 5.4.1 provides more detail on analyzing and understanding streamgage data.

In this example, a review of the hydrograph for the Water Year 2017 on the NF Rivanna River shows that the flow during the day of the survey was only slightly above the base flow (Figure 92). Therefore, indicators adjacent to the flow level during the site visit were determined to be below the OHWM. Figure 92 provides additional information from streamflow modeling in HEC-RAS on what proportion of the cross section is taken up during high-flow events. Modeling is not necessary but is used here to demonstrate that the OHWM indicators identified through a field survey occur within reasonable range of high-flow stages. Figure 93 shows photographs of the stream banks with a line indicating the approximate location of the OHWM.

Figure 92. Flow on the day of the survey compared to daily discharge during Water Year 2017 on the NF Rivanna River (USGS Gage 02032640).

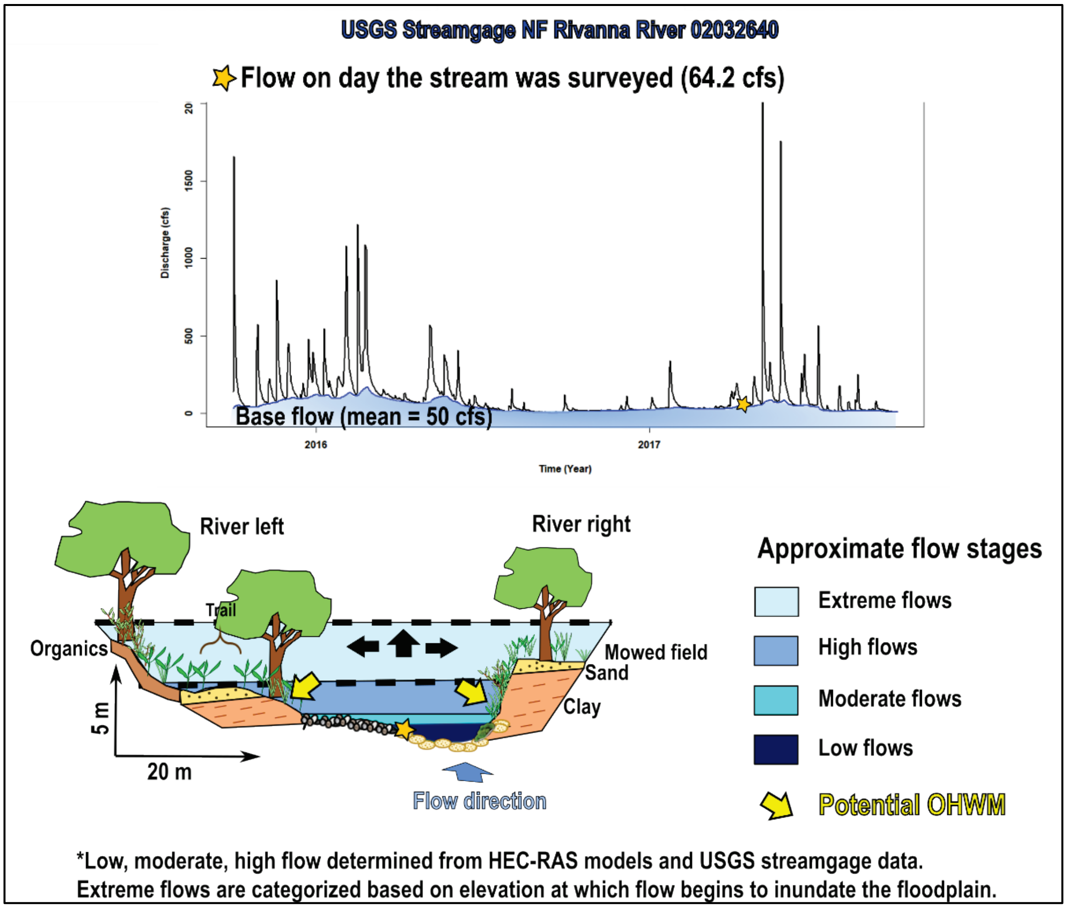
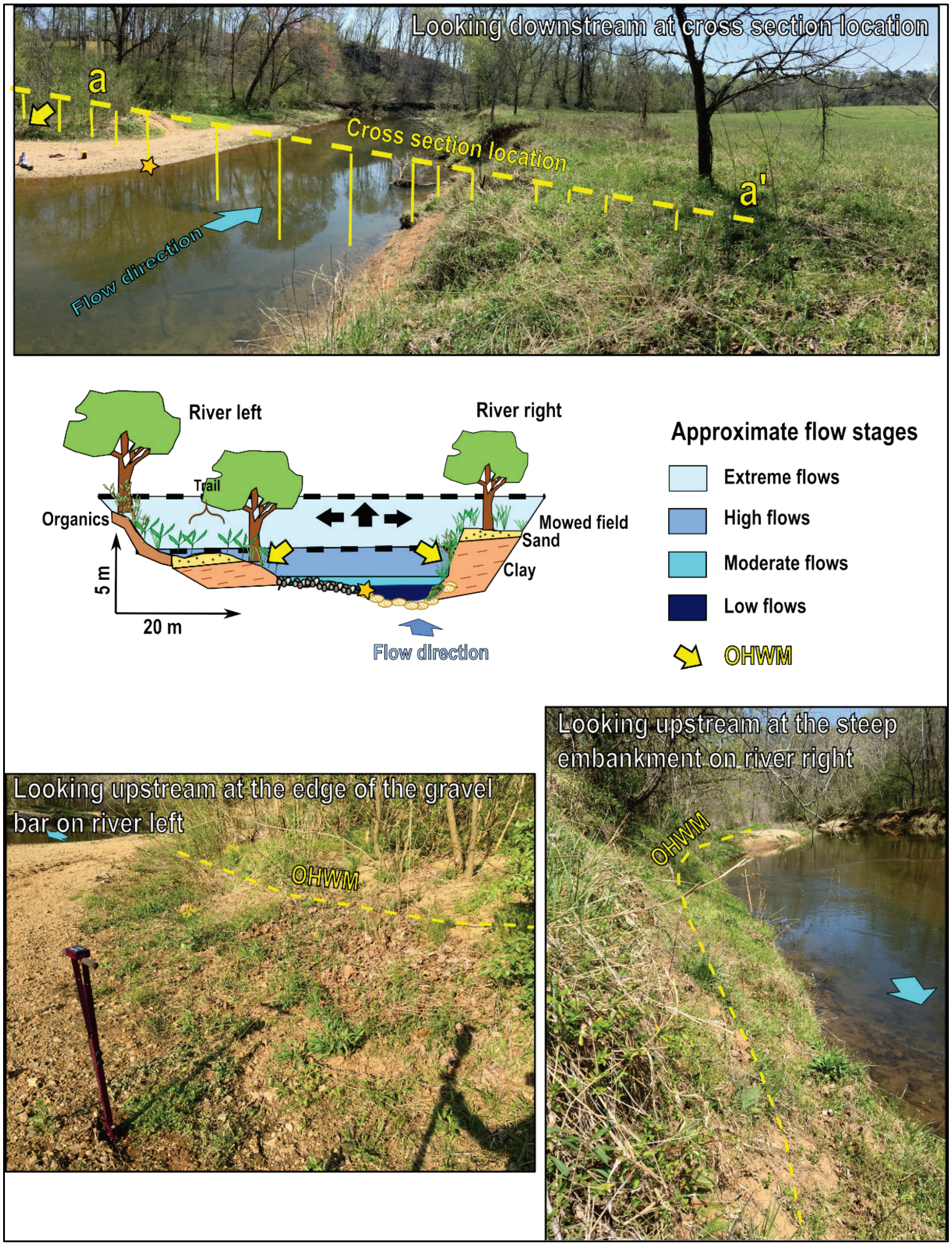


Figure 93. Photographs of river left and river right showing the approximate location of the OHWM along the banks.



Step 4 on the data sheet provides a place to note any additional information used to make interpretations when weighting evidence (Box 10). The information can also be used in Step 3 when applying the WoE methodology.

Box 10. Step 4 of the field procedure. (Data sheet adapted from USACE 2022.)

Step 4 Is additional information needed? Are other resources needed to support the lines of evidence observed in the field?

a. If additional resources are needed, then repeat steps 3a and 3b for the resources selected in Step 1 of assembling, weighting, and weighing evidence collected from online resources. Chapter 5 of the OHWM field manual provides information on using online resources.

b. Any data collected from online tools have strengths and weaknesses. Make sure these are clear when determining relevance, strength, and reliability of the remotely collected data. Clearly describe why other resources were needed to support the lines of evidence observed in the field, as well as the relevance, strength, and reliability of the supporting data and/or resources.

c. Attach any remote data and data analysis to the data sheet.

Step 4 Is additional information needed to support this determination? [X] Yes [ ] No If yes, describe and attach information to datasheet:

USGS streamgage data, satellite imagery, and lidar

3.6 Step 5: Describe rationale for location of the OHWM

After the WoE steps have been followed, the indicators' location(s), relative to the OHWM, can be marked in Step 3 of the data sheet, and the rationale can be described in Step 5 (Box 11). In this example, based on the weighed body of evidence, elevation *a*, from Figure 91, is the final OHWM delineation. Figure 94 provides some additional details, including a schematic showing the inundated features at the elevation of the identified OHWM. If needed, the elevation of the OHWM indicators can be used to delineate continuous lines for the OHWM along both banks. The rationale and cross section are described in Box 11 and Figure 94.

Box 11. Describe final rationale for location of the OHWM. (Data sheet adapted from USACE 2022.)

Step 5 Describe rationale for location of OHWM:

a. Why do the combination of indicators represent the OHWM?

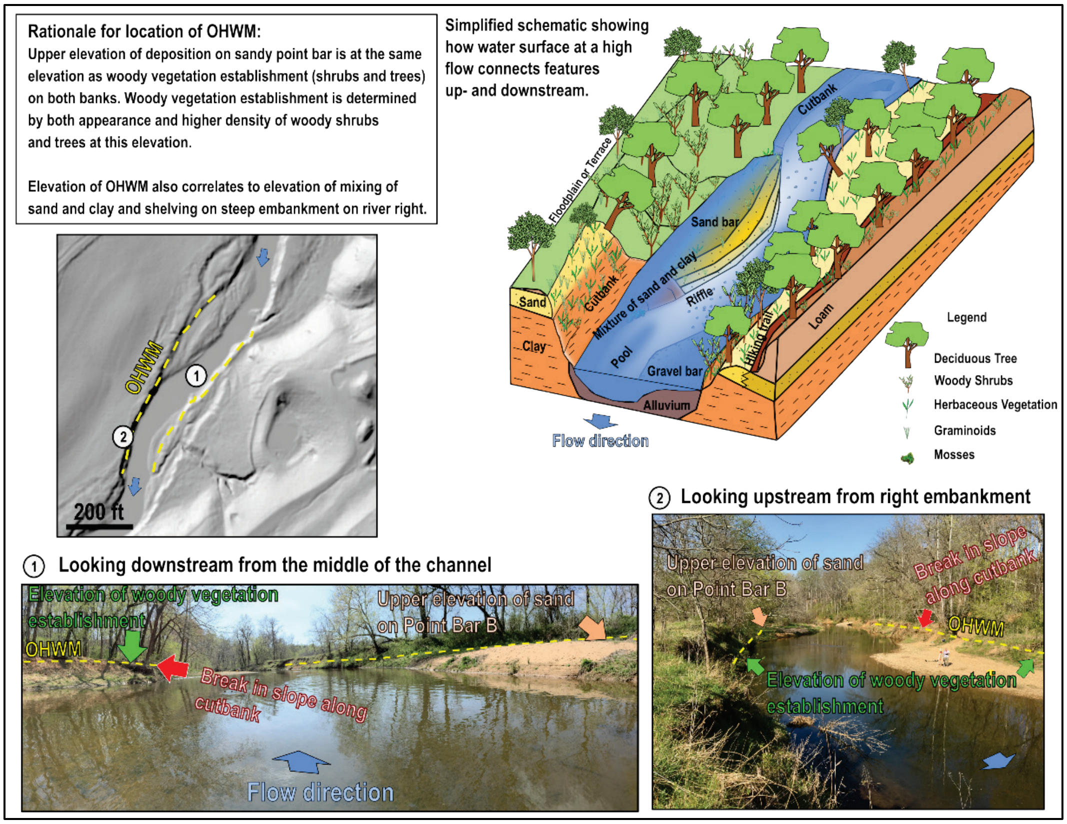
b. If there are multiple possibilites for the OHWM, explain why there are two (or more) possibilities. Include any relevant discussion on why specific indicators were not included in the final decision.

c. If needed, add additional site notes on page 2 of the data sheet under Step 5.

Step 5 Describe rationale for location of OHWM.

The OHWM is just above the upper limit of the gravel point bar deposit and is the upper limit of the sand point bar deposit. This corresponds to the elevation at which woody vegetation is established on both river left and river right. Leaf litter is thicker above, with just a few discontinuous patches below. On the steep eroding embankment across from the gravel bar, there is some shelving at the base at the same elevation that sediment is being reworked by the channel. There is a small amount of organic litter deposited here as well. The elevation where the sediment is being reworked is at or just below the elevation of the woody vegetation and the upper elevation of deposition on the sandy point bar. All of these indicators occur at a similar elevation, providing combined evidence of the location of the OHWM.

Figure 94. Rationale for field determination of the OHWM on the NF Rivanna River. The simplified schematic shows how a high-flow event would likely connect the observed indicators. The photographs show a line indicating the approximate location of the OHWM.



3.7 Final completed data sheet for case study at the NF Rivanna River in Virginia

A completed data sheet for the NF Rivanna River site is shown in Box 12. Box 13 shows annotated photos attached to page 2 of the data sheet, which is the photo log. For sites with many photos, it may be helpful to include a plan view map to orient the photos of the evidence relative to one another and the determined OHWM.

Box 12. Example of final data sheet for NF Rivanna River case study (adapted from USACE 2022, 1). Some of the indicators that were checked off when listing items (Box 6) were determined to not be useful observations for identifying the OHWM. For instance, instream bedforms were well below the OHWM and did not provide a useful line of evidence for delineating the OHWM.

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U.S. Army Corps of Engineers (USACE)

RAPID ORDINARY HIGH WATER MARK (OHWM) FIELD IDENTIFICATION DATA SHEET

The proponent agency is Headquarters USACE CECW-CO-R.

From Approved - OMB No. 0710-OHWM Expires: xx-xx-xxxx

AGENCY DISCLOSURE NOTICE

The public reporting burden for this collection of information, 0710-OHWM, is estimated to average 30 **minutes** per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding the burden estimate or burden reduction suggestions to the Department of Defense, Washington Headquarters Services, at whs.mc-alex.esd.mbx.dd-dod-information-collections@mail.mil. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

Project ID #: Example project | Site Name: NF of Rivanna River | Date and Time: 4/13/17 10:20 AM

Location (lat/long): 38.16097, -78.42494 | Investigator(s): G. David and B. Booker

Step 1 Site overview from remote and online resources
Check boxes for online resources used to evaluate site:

- [x] gage data
- [x] LiDAR
- [ ] geologic maps
- [x] climatic data
- [x] satellite imagery
- [ ] land use maps
- [ ] aerial photos
- [x] topographic maps
- [ ] Other:

Describe land use and flow conditions from online resources.
Were there any recent extreme events (floods or drought)?
No recent flood events. Last flood event >10 year was in 2000. Streamflow and precipitation are lower than average in 2017. Confining hillslope on left side of channel with runoff from residential developments.

Step 2 Site conditions during field assessment. First look for changes in channel shape, depositional and erosional features, and changes in vegetation and sediment type, size, density, and distribution. Make note of natural or anthropogenic disturbances that would affect flow and channel form, such as bridges, riprap, landslides, rockfalls, etc.
Stream is at low flow on day of site visit. There is a dirt trail that follows the left side of the channel between the stream and steep hillslope. The right side has a steep eroding cutbank. There is a small tributary that drains the hillslope and enters the channel downstream of site. A streamgage and bridge are a few hundred meters upstream. There are two point bars within the reach being assessed.

Step 3 Check the boxes next to the indicators used to identify the location of the OHWM.
OHWM is at a transition point, therefore some indicators that are used to determine location may be just below and above the OHWM. From the drop-down menu next to each indicator, select the appropriate location of the indicator by selecting either just below `b', at `x', or just above `a' the OHWM.
Go to page 2 to describe overall rationale for location of OHWM, write any additional observations, and to attach a photo log.

Geomorphic indicators

- [x] **Break in slope:** x
  - [x] *on the bank:* x
  - [x] *undercut bank:* b
  - [ ] *valley bottom:*
  - [ ] Other:
- [x] **Shelving:**
  - [x] *shelf at top of bank:* a
  - [ ] *natural levee:*
  - [ ] *man-made berms or levees:*
  - [x] *other berms:*
- [x] **Channel bar:** b
  - [x] *shelving (berms) on bar:* a
  - [x] *unvegetated:* b
  - [x] *vegetation transition (go to veg. indicators)*
  - [x] *sediment transition (go to sed. indicators)*
  - [ ] *upper limit of deposition on bar:* b
- [ ] **Instream bedforms and other bedload transport evidence:**
  - [ ] *deposition bedload indicators (e.g., imbricated clasts, gravel sheets, etc.)*
  - [ ] *bedforms (e.g., pools, riffles, steps, etc.):*
  - [ ] *erosional bedload indicators (e.g., obstacle marks, scour, smoothing, etc.)*
- [ ] **Secondary channels:**

Sediment indicators

- [ ] **Soil development:**
- [ ] **Changes in character of soil:**
- [ ] **Mudcracks:**
- [x] **Changes in particle-sized distribution:** b
  - [x] *transition from* gravel to silt/clay
  - [ ] *upper limit of sand-sized particles*
  - [ ] *silt deposits:*

Vegetation Indicators

- [x] **Change in vegetation type and/or density:** x
  Check the appropriate boxes and select the general vegetation change *(e.g., graminoids to woody shrubs)*. ***Describe the vegetation transition looking from the middle of the channel, up the banks, and into the floodplain.***
  - [ ] *vegetation absent to:*
  - [ ] *moss to:*
  - [ ] *forbs to:*
  - [x] *graminoids to:*
  - [ ] *woody shrubs to:*
  - [ ] *deciduous trees to:*
  - [ ] *coniferous trees to:*
- [ ] **Vegetation matted down and/or bent:**
- [x] **Exposed roots below intact soil layer:** b

Ancillary indicators

- [ ] **Wracking/presence of organic litter:**
- [ ] **Presence of large wood:**
- [x] **Leaf litter disturbed or washed away:** b
- [ ] **Water staining:**
- [ ] **Weathered clasts or bedrock:**

Other observed indicators? Describe:
Sand, silt, and clay are mixed together at the bottom of the right embankment. At the same location, there is a small shelf. Both of these are at or just below the OHWM.

Box 13. The rationale for the OHWM determination, photograph log, and further descriptions and observations for the NF Rivanna River data sheet (adapted from USACE 2022).

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Project ID #: Example project

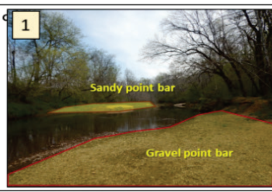
Step 4 Is additional information needed to support this determination? ☒ Yes ☐ No If yes, describe and attach information to datasheet:

USGS streamgage data, satellite imagery, and lidar

Step 5 Describe rationale for location of OHWM

The OHWM is just above the upper limit of the gravel point bar deposit and is the upper limit of the sand point bar deposit. This corresponds to the elevation at which woody vegetation is established on both river left and river right. Leaf litter is thicker above, with just a few discontinuous patches below. On the steep eroding embankment across from the gravel bar, there is some shelving at the base at the same elevation that sediment is being reworked by the channel. There is a small amount of organic litter deposited here as well. The elevation where the sediment is being reworked is at or just below the elevation of the woody vegetation and the upper elevation of deposition on the sandy point bar. All of these indicators occur at a similar elevation, providing combined evidence of the location of the OHWM.

Additional



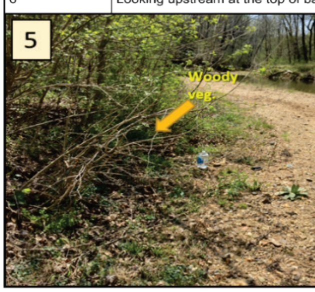
Attach a photo log of the site. Use the table below, or attach separately.

Photo log attached? ☒ Yes ☐ No If no, explain why not:

List photographs and include descriptions in the table below.

Number photographs in the order that they are taken. Attach photographs and include annotations of features.

Photo Number	Photograph description
1	Looking upstream at gravel and sandy point bars
2	Looking upstream at top of bank scarp and vegetation transition
3	Looking downstream at the steep cutbank
4	Looking upstream at point bar and steep cutbank
5	Looking downstream at upper limit of point bar and woody shrub growth
6	Looking upstream at the top of bank scarp and gravel point bar



ENG FORM 6250, AUG 2022 Page 2 of 4

3.8 Using the data sheet to identify the OHWM for simple case studies

In many situations, such as in small headwater channels near the upstream extent of river networks, the OHWM may be easily identified along the boundaries of a stream channel. The OHWM is often near the active channel margins of headwater streams that are bounded by steep valley slopes and lack well-developed floodplains. In simple cases, the physical characteristics that align with the location of the OHWM can be rapidly checked off on the data sheet. The process of applying the WoE technique

(Sections 1.3.3 and 3.4.2) remains the same, but in simple cases in which the location of the OHWM is readily apparent, the process is much faster. Box 14 and Box 15 illustrate a simple case study of a headwater channel in which the WoE strongly points to recognizable changes that represent the OHWM. Vegetation change is particularly conspicuous in the example, which is from a relatively humid region, but may not be as apparent in other situations. In many simple cases, various physical changes coincide within a few centimeters of one another on nearly vertical banks so there is little to no lateral difference in the OHWM delineation.

Box 14. First page of the OHWM data sheet for a simple case study in which the location of the OHWM is readily apparent because the WoE strongly points to one location. (Data sheet adapted from USACE 2022.)

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U.S. Army Corps of Engineers (USACE)
RAPID ORDINARY HIGH WATER MARK (OHWM) FIELD IDENTIFICATION DATA SHEET
The proponent agency is Headquarters USACE CECW-CO-R.

From Approved - OMB No. 0710-OHWM Expires: xx-xx-xxxx

AGENCY DISCLOSURE NOTICE

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Project ID #: Example project	Site Name: Unnamed Trib to Rossmoyne Creek	Date and Time: 5/20/20 13:57
Location (lat/long): 39.21953 -84.388984	Investigator(s): Ken Fritz	

Step 1 Site overview from remote and online resources
Check boxes for online resources used to evaluate site:

- [ ] gage data
- [ ] LiDAR
- [ ] geologic maps
- [x] climatic data
- [ ] satellite imagery
- [ ] land use maps
- [x] aerial photos
- [x] topographic maps
- [ ] Other:

Describe land use and flow conditions from online resources. Were there any recent extreme events (floods or drought)?
Located in Bechtold Park. Drains industrial stormwater detention pond. Light rain during visit. Rained 12 cm over past 48 hrs. but not extreme.

Step 2 Site conditions during field assessment. First look for changes in channel shape, depositional and erosional features, and changes in vegetation and sediment type, size, density, and distribution. Make note of natural or anthropogenic disturbances that would affect flow and channel form, such as bridges, riprap, landslides, rockfalls, etc.
Channel headcutting of the small tributary is evident. Stormwater detention pond beyond the park boundary contributes flow to the channel. Another pipe draining a different stormwater detention pond connects to the channel but downstream of the project reach.

Step 3 Check the boxes next to the indicators used to identify the location of the OHWM.
OHWM is at a transition point, therefore some indicators that are used to determine location may be just below and above the OHWM. From the drop-down menu next to each indicator, select the appropriate location of the indicator by selecting either just below `b', at `x', or just above `a' the OHWM.
Go to page 2 to describe overall rationale for location of OHWM, write any additional observations, and to attach a photo log.

Geomorphic indicators

- [x] **Break in slope:** x
  - [x] *on the bank:* x
  - [ ] *undercut bank:*
  - [ ] *valley bottom:*
  - [ ] Other:
- [ ] **Shelving:**
  - [ ] *shelf at top of bank:*
  - [ ] *natural levee:*
  - [ ] *man-made berms or levees:*
  - [ ] *other berms:*
- [ ] **Channel bar:**
  - [ ] *shelving (berms) on bar:*
  - [ ] *unvegetated:*
  - [ ] *vegetation transition (go to veg. indicators)*
  - [ ] *sediment transition (go to sed. indicators)*
  - [ ] *upper limit of deposition on bar:*
- [ ] **Instream bedforms and other bedload transport evidence:**
  - [ ] *deposition bedload indicators (e.g., imbricated clasts, gravel sheets, etc.)*
  - [ ] *bedforms (e.g., pools riffles, steps, etc.):*
  - [ ] *erosional bedload indicators (e.g., obstacle marks, scour, smoothing, etc.)*
- [ ] **Secondary channels:**

Sediment indicators

- [ ] **Soil development:**
- [ ] **Changes in character of soil:**
- [ ] **Mudcracks:**
- [x] **Changes in particle-sized distribution:** x
  - [x] *transition from* clay-silt to clay-grav
  - [ ] *upper limit of sand-sized particles*
  - [ ] *silt deposits:*

Vegetation Indicators

- [x] **Change in vegetation type and/or density:** x
  Check the appropriate boxes and select the general vegetation change *(e.g., graminoids to woody shrubs)*. ***Describe the vegetation transition looking from the middle of the channel, up the banks, and into the floodplain.***
  - [x] *vegetation absent to:* forbs
  - [ ] *moss to:*
  - [ ] *forbs to:*
  - [ ] *graminoids to:*
  - [ ] *woody shrubs to:*
  - [ ] *deciduous trees to:*
  - [ ] *coniferous trees to:*
- [ ] **Vegetation matted down and/or bent:**
- [x] **Exposed roots below intact soil layer:** x

Ancillary indicators

- [ ] **Wracking/presence of organic litter:**
- [ ] **Presence of large wood:**
- [ ] **Leaf litter disturbed or washed away:**
- [ ] **Water staining:**
- [ ] **Weathered clasts or bedrock:**

Other observed indicators? Describe:

ENG FORM 6250, AUG 2022 PREVIOUS EDITIONS ARE OBSOLETE. Page 1 of 4

Box 15. Second page of the OHWM data sheet (rationale for the OHWM determination and photograph log) for a simple case study. (Data sheet adapted from USACE 2022.)

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Project ID #: Example project

Step 4 Is additional information needed to support this determination? ☐ Yes ☒ No If yes, describe and attach information to datasheet:

Step 5 Describe rationale for location of OHWM

Break in slope at the top of bank is strongly vertical and spatially coincides with the change from no vegetation to dense forb (invasive lesser celandine) that covers entire forest understory, change from silt-clay soil to mostly clay with sparse gravel, and exposed roots from woody vegetation.

Additional observations or notes

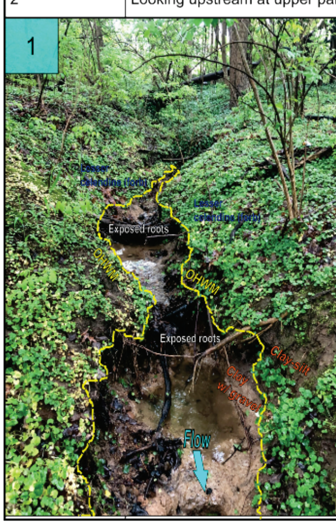
Attach a photo log of the site. Use the table below, or attach separately.

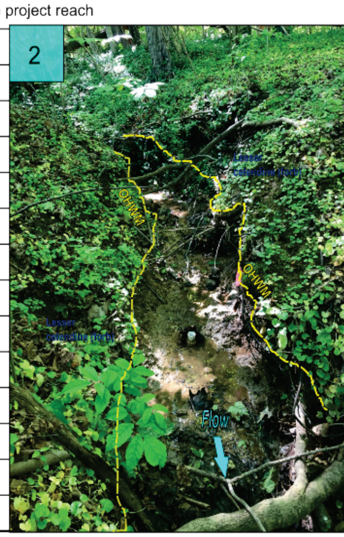
Photo log attached? ☒ Yes ☐ No If no, explain why not:

List photographs and include descriptions in the table below.

Number photographs in the order that they are taken. Attach photographs and include annotations of features.

Photo Number	**Photograph description**
1	Looking upstream at lower part of the project reach
2	Looking upstream at upper part of the project reach





4 Understanding the OHWM in the Context of the Surrounding Landscape

4.1 Key points

This chapter addresses how the physical surroundings of a site may influence the location of the OHWM, similarities between the indicators of the OHWM and bankfull channels, and supporting evidence that may be useful for the identification of the OHWM. Section 4.2 focuses on the physical context of sites and the resulting characteristics that may influence flows and the locations of OHWM evidence. Section 4.3 provides a comparison of OHWM and bankfull width and the connections with the surrounding landscape. Satellite imagery, lidar, and other spatial data can aid in recognizing significant controls on channel form at a stream. Anthropogenic controls on channel form include dams, culverts, bridges, and significant land use changes. Natural controls include underlying geologic characteristics, such as exposed bedrock, and steep topographic changes, such as valley slope and confinement. While natural or anthropogenic disturbances within the watershed may obscure or alter OHWM indicators, those disturbances are the focus of Chapters 5 and 6. Chapter 5 describes information available online for investigating a site and tips and resources on how to interpret the landscape controls. Chapters 6 and 7 provide specific examples of how to bring this information together at sites that have experienced either natural or human-induced disturbances.

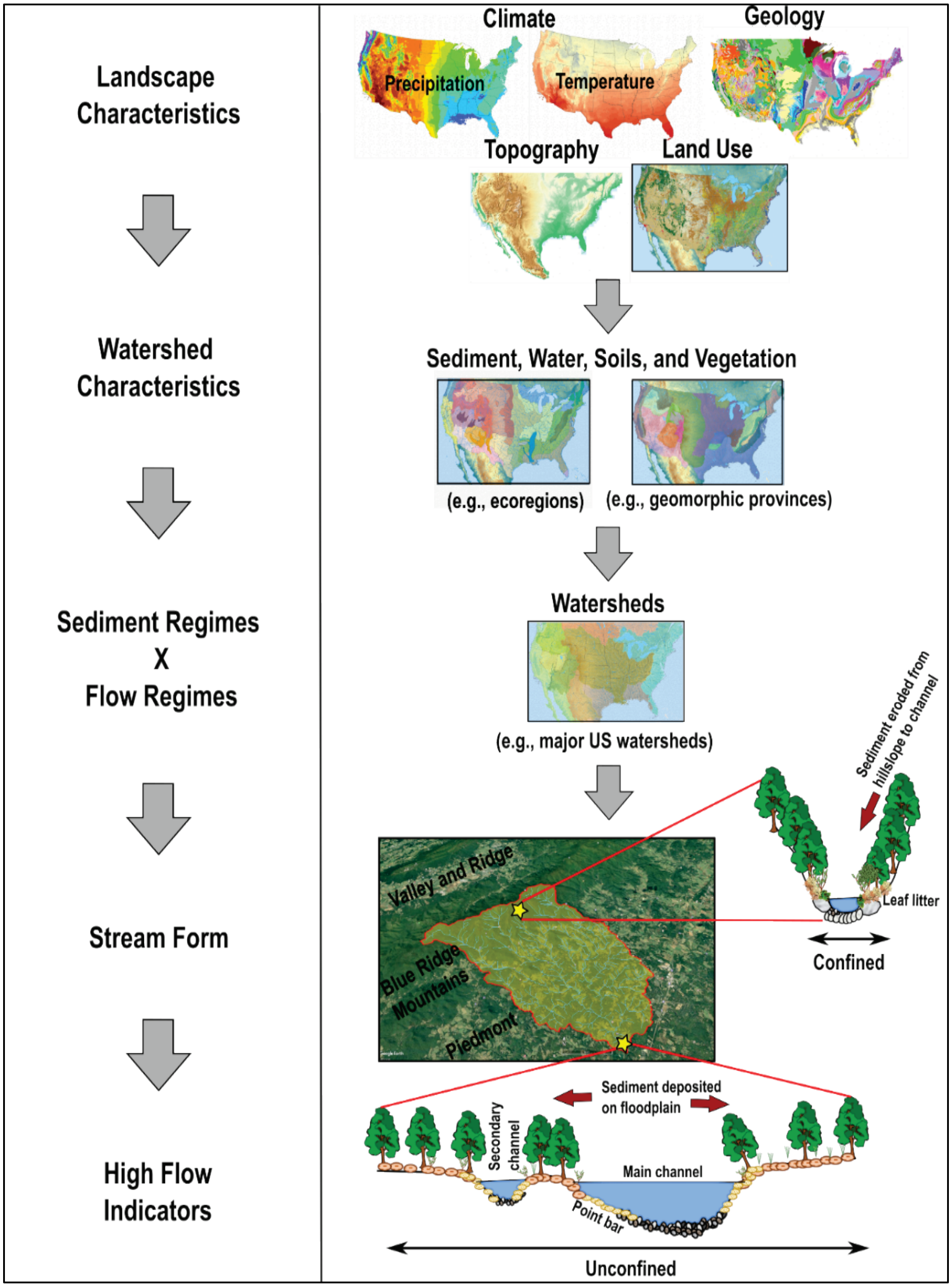
4.2 Landscape controls on OHWM features

It is important to understand landscape controls on stream characteristics when conducting an OHWM delineation because the relevance, strength, and reliability of specific OHWM indicators may vary based on the location of the site within the landscape. Streams adjust their planform, longitudinal profile, and cross sections based on the amount of water and sediment that moves through the channel over time (Leopold and Maddock 1953; Dunne and Leopold 1978; Thorne 1997). The amount of water and sediment that moves through a channel is controlled by landscape characteristics, including climate, topography, geology, and land use (Figure 95). Climate controls precipitation and temperature, which determine vegetation growth and processes such as evapotranspiration. This determines how much water is available to flow through the landscape

(Winter 2001). Climate and land use can also determine how much sediment is exposed and easily transported; therefore, climate and land use are both controls on the sediment regime. Topography and geology are underlying controls on gradient, sediment characteristics, and how quickly and through what pathways water will move through the landscape. Combined, these landscape characteristics determine watershed size (i.e., drainage basin area and, ultimately, the size of the stream cross section). The close relationship between bankfull width and OHWM, as discussed in Chapter 1, means that understanding expected cross section sizes can help point to where to look for OHWM indicators on the landscape.

The watershed or drainage area is a scale factor that is determined by how far downstream the site is positioned, which determines the amount of water that is being transported to a channel. Larger drainage areas usually result in periods with more water, and therefore, larger channels form to contain that water. In arid regions or in areas where there are large extra basin transfers, channels may not scale with the size of the drainage basin. Therefore, the strength and reliability of specific OHWM indicators may vary based on the location of a stream within a watershed and the surrounding landscape features (Figure 95). This section describes how users can incorporate knowledge of the surrounding landscape to interpret stream characteristics and delineate the OHWM.

Figure 95. Landscape characteristics control watershed characteristics, which determine sediment and flow regimes in a channel and, ultimately, channel form. Examples include a simplified schematic of a type of stream that occurs in the Blue Ridge Mountains valley and a type of stream in an unconfined piedmont valley of Virginia, both within the Rivanna River watershed in Virginia. The water surface is shown at the location of the OHWM for both cross sections.



4.2.1 Identifying the OHWM within different valley settings

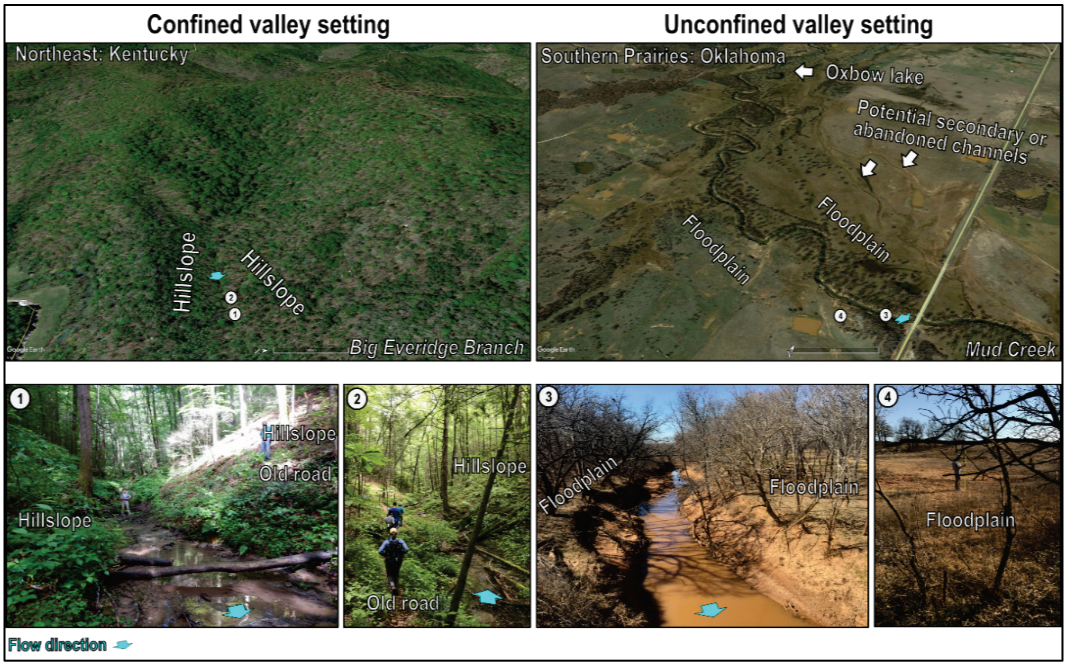
Valley setting refers to the area adjacent to a stream that was dominantly formed by the stream through contemporary processes (Nanson and Croke 1992). Valley confinement is related to the lateral confinement of a stream because of either natural landforms, such as hillslopes and fluvial terraces, or human-made structures, such as levees and bridge abutments (Fryirs et al. 2016). The more confined a stream channel is within a valley, the more likely the stream will deepen during high flows rather than spread out over a wider area. Therefore, a channel in a confined valley may have coarse bed sediment (e.g., boulders and cobbles) and a narrow riparian zone, whereas a channel in an unconfined valley allows more lateral movement and may have point bars and secondary channels across a broad floodplain. Indicators of the OHWM may be at higher elevations in very confined settings and spread out laterally in unconfined systems. Figure 95 provides cross sections from two channel types at different locations within the same watershed in Virginia. These cross sections give a generalized view of the locations of high-flow indicators for each channel type. For instance, the OHWM indicators of the headwater channel include a vegetation transition from moss and other herbaceous vegetation to woody shrubs. Leaf litter, thin near the channel and thicker on the hillslopes, could possibly be used as a supplementary indicator in this channel type. Further downstream in the watershed, the channel is in an unconfined valley and includes depositional features, such as a point bar and a secondary channel. In the downstream example, the presence of woody vegetation can also be used as an indicator of the OHWM; the presence of other indicators, such as moss and leaf litter, may not be as strong or reliable in this larger channel type, and therefore, they are not shown in the generalized cross section. Understanding the site in the context of landscape controls on channel form can assist in interpreting OHWM indicators at a site.

An initial overview of sites using topographic maps, lidar products, and satellite imagery can provide useful information on the level of confinement. For instance, one of the streams shown in Figure 96 is confined by hillslopes on either side and is further confined by an old road. Roads in such a narrow valley narrow the stream even further, causing increased depths at high flows and potentially increased erosion. The unconfined valley setting in the figure shows a stream that, at first glance, appears to be incised. Knowledge of observed flows from locals, along with flow modeling (Hamill and David 2021), indicated that this stream overtops its banks on a semiannual basis. Examination of historical satellite imagery also provided evidence, including oxbow lakes and potential secondary channels, that the channel is migrating laterally and accessing the flood-plain. This evidence should be examined further to determine if these are abandoned features.

Gaining an understanding of whether a channel is incised can provide some preliminary knowledge of where to look for the OHWM. Incised channels tend to be straighter and steeper. They can often end up being wider too, as stream banks slump and the material is moved out by the faster flow. Incised channels may have a greater length of actively unstable banks on which vegetation has a hard time establishing. The interaction between the stream and floodplain is greatly reduced or eliminated, causing dewatering of the floodplain and wetlands (Shields et al. 2010). Therefore, vegetation may transition to types that prefer drier conditions in the riparian zone and floodplain. There may be a lack of bedforms, particularly stable pools, or LW in these channels (Shields et al. 1994). In an incised channel, the OHWM may be further down the embankment. In this channel, it is at the top of the channel bank where the trees are established. Therefore, understanding the valley setting prior to visiting a site can assist in interpreting whether a channel is likely to get deeper or wider during high flows and if it has the ability to spread out further in the valley into secondary channel systems. Secondary channels can occur in any portion of a watershed, but a narrow floodplain will limit secondary channels to locations near the main channel or result in only one main channel. Removing LW from channels and constructing roads next to streams can result in simplified channel geometries, with only one main channel persisting over time (Blanton and Marcus 2009; Wohl 2019). If water spreads out between a main and secondary channel during high-flow events, then the OHWM indicators should be at an elevation that is high enough to allow the water to access that secondary channel.

Floodplain width and relative changes in floodplain width throughout a stream segment can be seen on topographic maps; lidar products, including shaded relief maps; and satellite imagery. Roads, railroads, and levees, which can also be observed using remote data, may cause channels to narrow (Blanton and Marcus 2009). An initial investigation of a site using remote data can indicate if the site is in a narrow valley, if secondary channels are present, or if there are other constraints on lateral movement of the channel, such as bedrock outcrops or anthropogenic structures.

Figure 96. A confined valley setting in Kentucky (*left*), and an unconfined valley setting in Oklahoma (*right*).

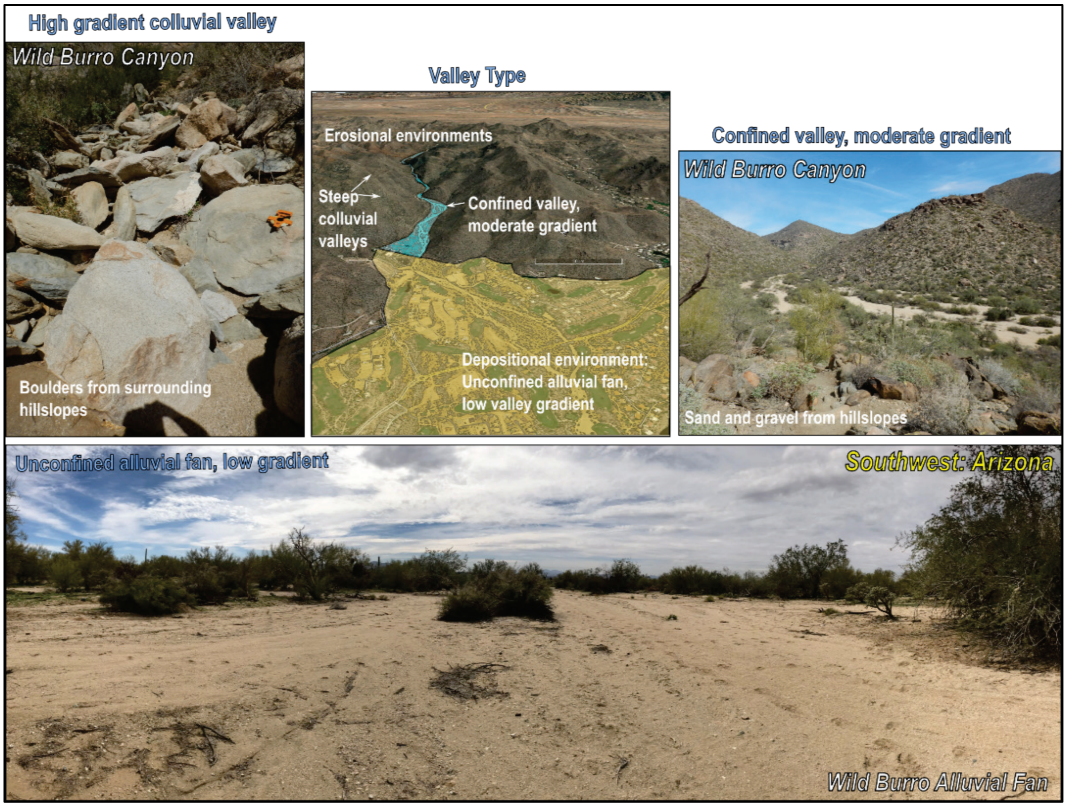


4.2.2 Depositional versus erosional environments

The following descriptions of erosional and depositional environments provide some general information about stream systems, but many factors can influence the width, depth, and velocity of high flows. Some common examples are presented to provide a general understanding of connections between landscape characteristics, erosion and deposition in a stream, and the OHWM. A key point is that the water does not flow downstream in a flat, uniform manner, so the height of the OHWM may vary through even a short channel reach. Understanding some general concepts about where flow velocities are likely to increase or decrease and where sediment is likely to be transported or deposited can provide information on where the width or depth of the stream is likely to increase or decrease. In some areas, the OHWM may expand wider than expected; in others, it may be at a higher elevation than initially expected.

Streams can transition through space from depositional to erosional environments, or vice versa. Landscape characteristics, such as valley confinement, breaks in valley slope, underlying geologic characteristics and history, vegetation characteristics, and land use (past and current), are all factors that govern local erosional versus depositional environments (Figure 97). Channel bars can be indicative of ongoing channel deposition, particularly if the bar is still being formed (Section 2.3.1.3). A channel that is flowing from a highly confined valley setting to an unconfined setting will often have heavy deposition and either an alluvial fan will form, on terrestrial landscapes (Figure 97), or a delta will form where the stream enters a larger body of water.

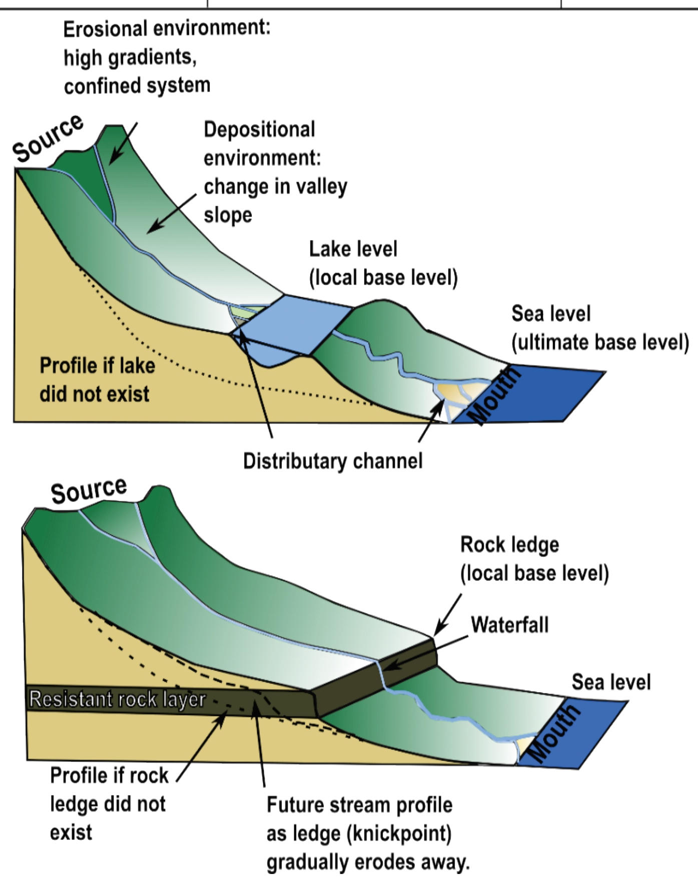
Figure 97. Examples of changes in channel types on an alluvial fan changing from a confined, coarse-grained colluvial channel above the fan apex (*upper left*), to a multithread channel midfan (*upper right*), to sandy distributary channels near the fan toe (*bottom*).



A stream's longitudinal profile facilitates understanding where erosion or deposition are likely to be active and where local base levels may exist (Figure 98). Base level is the lowest level to which a stream can flow. The ultimate base level is sea level, but there can be local base levels created by lakes, reservoirs, and even resistant bedrock layers. Areas in which a stream is approaching a lake, reservoir, sea level, or even a larger stream system are locations in which a stream can be actively depositing sediment. If the base level is rising in these downstream locations, then channels above that local or ultimate base level may be depositing and possibly raising their beds. If the base level is falling, then the channel upstream may be eroding down through its bed. In highly depositional areas, the OHWM may occur above the obvious top of the channel banks because the channel is actively raising its bed level through deposition. In highly erosional environments, where the stream is incising, the OHWM may be lower than the tops of the banks because the channel is downcutting. Understanding the context of these depositional and erosional landscapes prior to a site visit may point to places to look for OHWM indicators. Satellite imagery, topographic maps, and lidar can assist in identifying areas that may be creating local base levels.

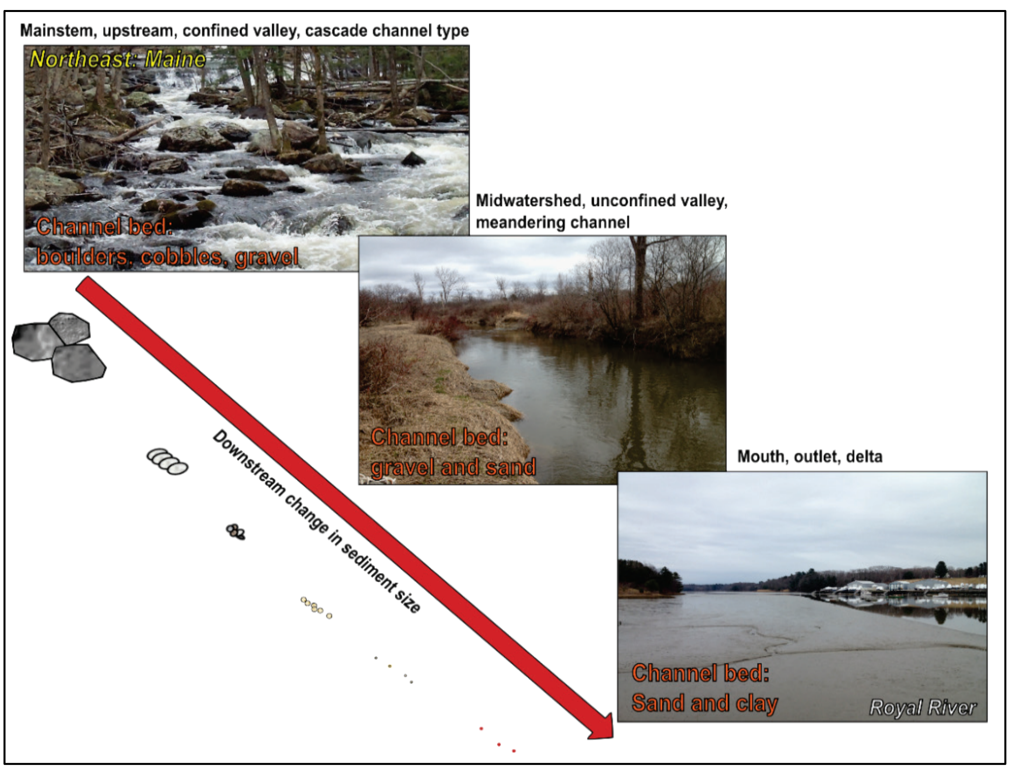
Figure 98. Local base levels versus ultimate base level. Example longitudinal profile. (Landscape figures adapted from Marshak 2009.)

	Source →		→ Mouth
Base level control	Upper part of stream cannot cut downward below local base level.	Transitional zone past the local base level.	Lower part of stream cannot cut downward below sea level.
Channel characteristics	Channel is narrow and confined. Vertical erosion may be greater than lateral erosion.	Channel is deeper and wider. Lateral erosion and deposition increase in importance in this zone.	Channel is at its widest and deepest, with deposition more important than erosion.
Problems with OHWM identification	Debris flows may complicate OHWM decisions.	Discontinuities in stream and OHWM may exist if channel is buried in depositional environment.	High water determined by mean high tide and not OHWM.



Generally, the size, rounding, and type of sediment are expected to change in the downstream direction in any stream system. These changes depend on the sediment source and regional location. A simplified view of changes in sediment size along the Royal River in Maine shows the landscape controls from the headwater to the mouth of the watershed (Figure 99). The boulders on the mainstem in the headwaters are much more jagged because they come from the surrounding hillslopes. Sand, silt, or clay particles are transported downstream in high gradient, confined, cascading systems. Any fine particles left behind are underneath or trapped at the base of the cobbles and boulders. The rounding of boulders from flowing water and the cascading bedform are related to the surrounding environment. Further downstream, the channel becomes an unconfined depositional environment in which sand and gravel are deposited and a pool-riffle channel morphology develops. The floodplain is likely made up of silt and clay in this stream segment. Again, relative differences in sediment size are seen in the main channel. The last (i.e., lower right) image in Figure 99 is of the river outlet into the Atlantic Ocean. Fine sediment is deposited as flow velocities are reduced, causing sand, silt, and clay to be deposited at the river mouth. This environment is now tidally controlled and defined by mean high tide, rather than the OHWM.

Figure 99. Simplified view of shift in grain size distribution from headwaters to mouth of the Royal River in Maine.

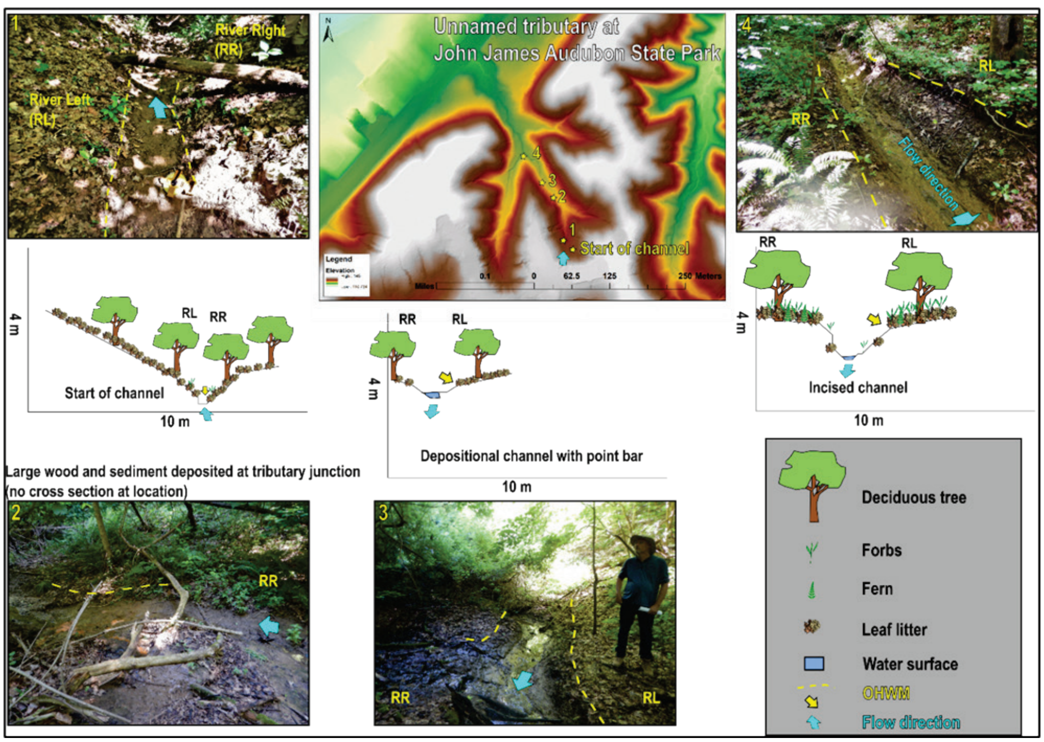


Although the Royal River is a good example of size decreasing in the downstream direction, a bedrock *knickpoint,* which is a sharp change in channel slope where the channel bed is resisting erosion, creates a waterfall between the midwatershed and mouth, which is characterized by large boulders and exposed bedrock. The knickpoint is not shown in Figure 99. Just upstream of the knickpoint, sand and clay dominate on the bed because the knickpoint creates a local base level. Just downstream of the knickpoint, the bed sediment coarsens to boulders and gravel again before fining to sand and clay at the outlet. These expected trends in river systems may be disrupted and alter the geomorphic trajectory of what is happening in the system.

Understanding landscape controls, such as valley confinement and changes in base level, informs how far up- and downstream to look when identifying relevant OHWM indicators. If there are natural or anthropogenic controls that may significantly alter stream features, then a new data sheet may be needed to identify the OHWM in the affected location. Figure 100 shows an example from Kentucky in which land use, specifically increased urban runoff during storm events caused by an expansion of the watershed downstream, caused a change from depositional to erosional processes. This may be due to an expanding watershed downstream that drains roads and parking lots, increasing runoff during storm events. Not only is there an increase in discharge with drainage area, but there is also an increase in storm runoff per unit area.

In this example (Figure 100), storm runoff after development carries less sediment than before development because the runoff is now flowing from a paved area instead of flowing over and through soil. Each segment of this stream system would need a new data sheet to evaluate the OHWM. The downstream segment (1) is an erosional segment in which the channel has straightened, narrowed, and incised into its bed. Flows from urban runoff may still be high enough to fill this channel to the top of the banks; therefore, the OHWM is placed where there is a transition from no vegetation to vegetation at the top of the banks. The midstream reaches (2 and 3) both show characteristics of depositional environments. The channel is meandering here, forming channel bars, and has widened. Therefore, the OHWM is placed at the top of the point bar, where vegetation has recently colonized. The leaf litter clearly transitions in this channel, from no leaf litter in the center to thick leaf litter around the boundaries. This channel was surveyed in spring, so there was an opportunity for high flows to move the leaf litter away from the center of the channel. The upstream segment (4) is where the channel is just forming. This is an erosional environment. The channel is narrow, shallow, and straight through this segment. The OHWM is just at the top of the small bank. In these examples, there is also a difference in sediment characteristics between the bed of the channel and the top of the banks. The bed includes silt and clay, and the area at the top of the banks has much more organic material accumulation. The main difference between the segments is that there are channel bars in the depositional segments and none in the erosional ones, which may change some of the identified indicators on the OHWM data sheet.

Figure 100. Transition between depositional and erosional environments in a small channel in Kentucky. (1) Channel is straight and shallow where it just begins to form (erosional). (2) LW has been deposited at the tributary junction, increasing deposition and widening of the channel (depositional). (3) Channel is meandering, and a point bar has formed (depositional). (4) Channel has narrowed and cut into its bed (erosional).



4.2.2.1 *Erosional environments*

Floodplain width is variable, and sites with narrow floodplains—either from natural geomorphic or anthropogenic constrictions—may have relatively higher ranges of flow velocities and stages than sites with wide floodplains. In constricted channel segments, increasing discharges cannot spread out horizontally, which forces flows to rise vertically to higher stages (Figure 64). Therefore, when comparing different stream systems in a narrow versus wide valley, flows may be deeper in the narrow valley system and spread out over multiple channels in the wide valley system. Faster and deeper flows in valley narrows result in increased channel erosion in these areas and may result in higher and steeper banks and increased undercutting. Therefore, the OHWM may occur at higher elevations in valley narrows than in other segments of the channel.

On the other hand, changes in channel width can have some complex relationships with water depth. As a stream approaches a constriction, such as a bridge, the high-flow water surface often backs up and then drops rapidly through the constriction. These zones of high velocities where depth decreases can also cause increased erosion. Scour of the banks and bed is often evident at, or just downstream of, these constrictions. Therefore, the elevation of the OHWM may drop through these types of channel constrictions, whether from bridge piers or bedrock. Channel depths usually return to the previous elevation once the flow has moved through the constricted area. Often, this occurs after some form of a hydraulic jump, which is the turbulent rise of flowing water in the form of a standing wave. These generalities are further complicated by changes in channel gradient and objects, such as boulders and LW, that create roughness in the channel. Increases in gradient can cause higher velocities and a decrease in depth, but roughness reduces flow velocities and causes the water surface to rise. Therefore, the water surface can change in complex patterns as the stream flows over these changes in landscape and stream characteristics. The OHWM may not always be a continuous line on the landscape, and understanding where water is likely to back up and become deeper, versus become shallow and move faster, can help to explain the relevance, strength, and reliability of OHWM indicators.

An area of increased erosion can often occur downstream of a headcut (i.e., at knickpoints). Knickpoints can migrate in response to shifts in the local base level and develop for a number of reasons, including (1) resistant lithology (Figure 98), (2) base level lowering, and (3) tectonic activity. Knickpoints do not necessarily form at a break in valley slope, but they can occur where there has been a change in valley characteristics. For instance, a valley formed by a glacier may leave behind valleys from tributary glaciers that are at a higher elevation than the main valley. These hanging valleys are a dramatic example of knickpoints where waterfalls flow over the valley walls. Therefore, the knickpoints have formed because of the geologic glacial history of the region. Other knickpoints may form simply because the stream is flowing over bedrock that is harder to erode than the material downstream.

Knickpoints can create a local base level (Figure 98) that is a transition between a depositional environment above and an erosional one below. Figure 98 shows a knickpoint created by a stream eroding through a resistant lithology and resulting in a local base level. A future stream profile is also shown because the stream will eventually erode back through the rock layer, and the profile may begin to flatten out. Not all knickpoints will flatten out in such a way over time. Knowledge of the presence and position of a knickpoint relative to a site provides insights into potential past or future channel incision and changes in the OHWM.

Headcuts, which are knickpoints that occur in headwater streams, are often examples of transitions from a highly depositional to erosional system. The term *headcut* is often used to refer to the sharp change in slope that occurs at a channel head, but it can refer to a feature further downstream that is migrating up toward the channel head (Figure 101). Channels are often actively incising below a headcut because they are moving toward a new base level. Headcuts can be initiated when there has been a change in base level. For example, sometimes headcuts can be initiated in tributary streams because the local base level of the main channel has changed because of alterations in flow regimes or physical alteration of the main channel.

Figure 101. Example of headcuts in four different regions of the country.

Northwest: Colorado

Landscape context: A forest fire in 2012 caused increased erosion, particularly through headcuts. A sequence of deep headcuts followed by areas of heavy deposition, which has buried the stream features, can be found all the way to the top of the drainage divide.

OHWM indicators:
1. presence of headcut
2. difference in vegetation below headcut
3. some sorting of bed sediment

Northern Prairies: Kansas

Landscape context: This watershed is surrounded by farmland and is managed by the Nature Conservancy as a working cattle ranch. Streams may be impacted by agricultural practices, groundwater pumping, and cattle grazing.

OHWM indicators:
1. presence of headcut
2. above headcut there is a sequence erosion and deposition with small headcuts and short segments of channel
3. change in vegetation on channel bed
4. mudcracks on channel bed

Hawaii: Big Island

Landscape context: This watershed is underlain by volcanic rock. The area has dirt roads and cattle grazing throughout.

OHWM indicators:
1. presence of headcut
2. change in vegetation on channel bed
3. exposure of bedrock just downstream of this picture

Northern Prairies: Iowa

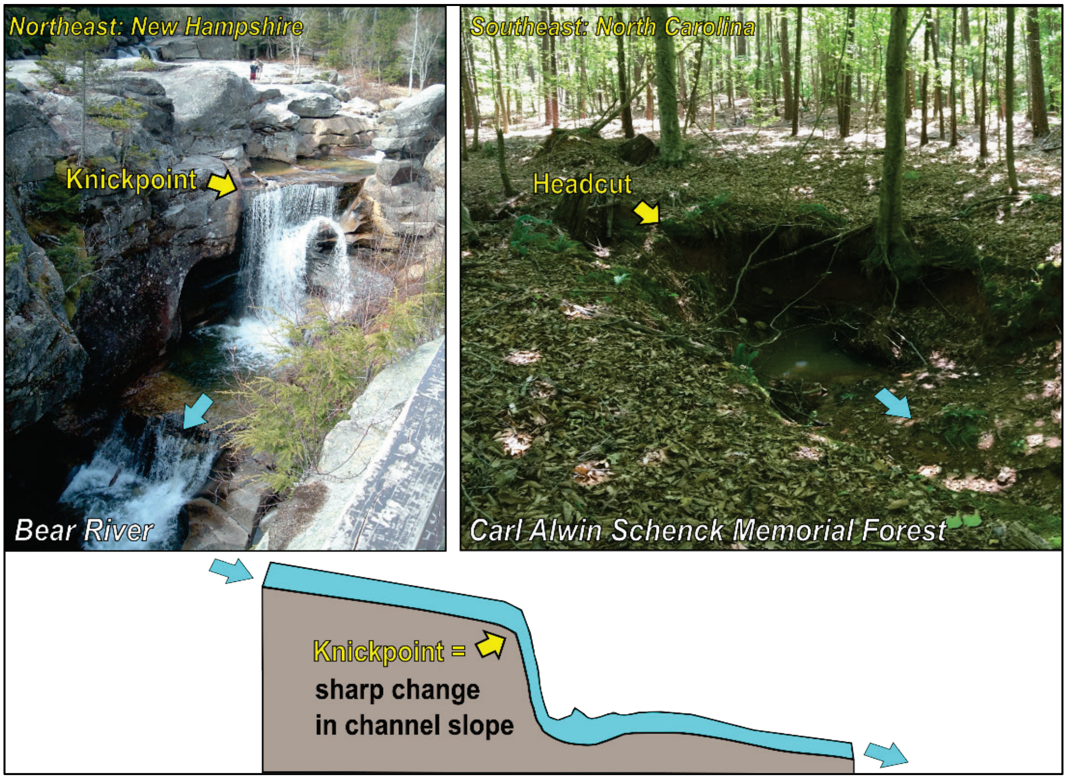
Landscape context: This watershed is in a park in an urban landscape. The stream drains a parking lot. Before the channel reaches a much larger tributary, the slope changes, sediment is deposited in a vegetated fan, and the channel goes subsurface.

OHWM indicators:
1. presence of headcut
2. removal of sediment and pool development downstream of headcut
3. no vegetation on channel bed
4. develpoment of channel banks

Figure 102 shows two very different types of local base levels created by historic changes to the landscape: a knickpoint and a headcut that is part of a sequence of headcuts near the top of the channel. The knickpoint in this New Hampshire stream was created by continental glaciation during the last ice age. A glacier plucked rocks off the bedrock and left behind a stepped pattern on the valley floor. Because these knickpoints are relic features of glacial history, evidence for the OHWM would not likely occur at the top of the rock ledge, but changes along the rock face would need to be examined. Indicators on the rock face that may be useful include staining, smoothing, and the growth of moss and lichen. As discussed in Chapter 3, it may be necessary to assemble evidence up- and downstream in OHWM situations involving knickpoints. The knickpoint creates a temporary base level in this watershed (Figure 98). Therefore, the channel immediately upstream of this point may have more sediment deposition and lateral erosion, and less bed erosion, so the OHWM locations may be wider across the channel. The channel downstream of the knickpoint may have characteristics connected to channel-bed incision with a narrower OHWM.

The headcut in Figure 102, from North Carolina, likely resulted from a land use history of logging. Logging can create increased runoff and therefore increased erosion, which may initiate headcuts along the slopes. Logging is just one of many different types of disturbances that can create headcuts and result in sequences of erosional and depositional features, as described in the sections that follow. Multiple headcuts were identified on this channel. In this example, the channel continues above the headcut. The stream goes through a sequence of heavy erosion at the headcuts, and coarse material is deposited just downstream of these features. Increased deposition downstream of some of the headcuts buried the channel, causing either shallow overland flow or subsurface flow over a short distance. In some cases, small alluvial deposits may form, and the channel may spread out into a multithread system over a short distance. Channel banks may be difficult to identify over these segments, but sediment sorting, changes in vegetation, and accumulation of organic litter may be present. Understanding this sequence of erosion and deposition aids in investigating the OHWM in such landscapes. Similar sequences caused by different land use and climatic histories were observed at differing scales across the country (Figure 101). Understanding landscape context can assist in identifying both why these sequences of erosion and deposition are occurring and when to look for indicators other than a break in slope for identifying the OHWM.

Figure 102. A knickpoint and a headcut developed through different processes in the Northeast and Southeast regions of the country. In the New Hampshire example (*left*), bedrock forms a resistant rock unit (in some cases, these can also be formed by glacial erratics). In the North Carolina example (*right*), the tree roots form a resistant layer to a small stream.



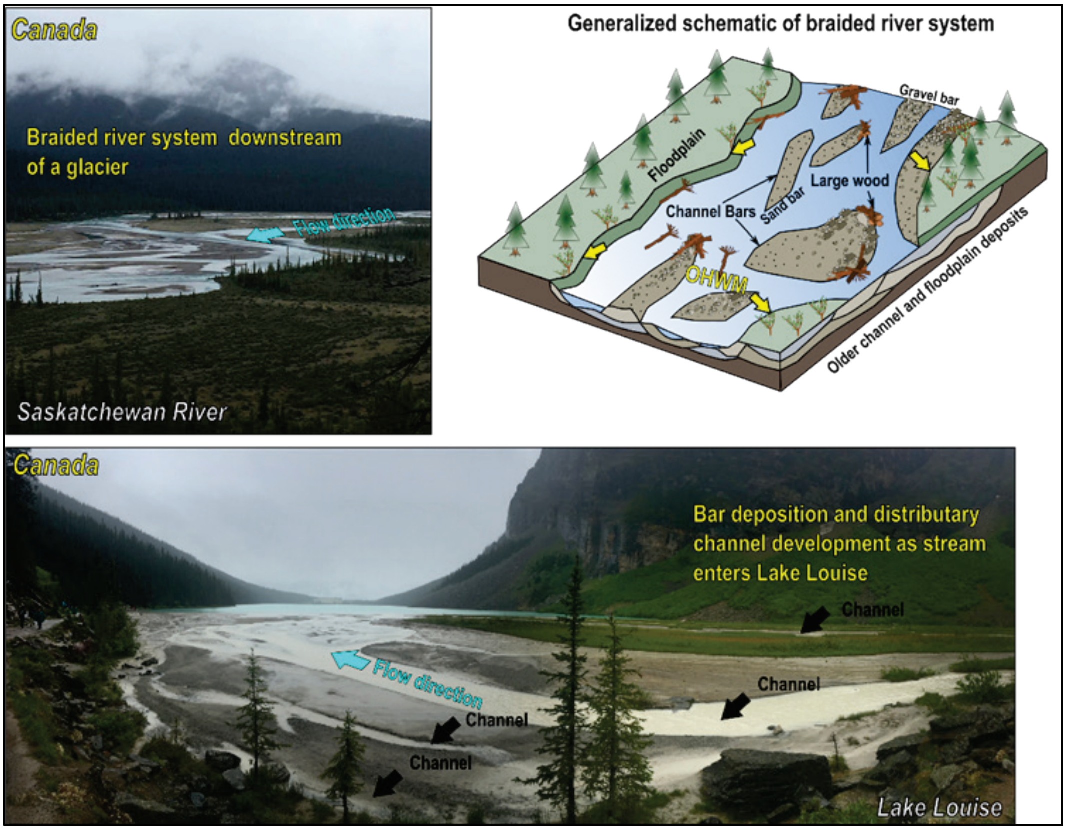
4.2.2.2 Depositional environments

Depositional zones often occur where a valley opens up downstream of a highly confined zone. Alluvial fans at the outlet of canyons are an example of such features (Figure 97). Streams in depositional environments tend to have more channel bars and islands and finer grained bed sediment (relative to upstream segments). Both alluvial fans and deltas are depositional environments with distributary channel systems. Multiple channels are expected at these sites, and it is likely the OHWM will be near the top or above many active channel bars, except for bars that are relics of downcutting channels. In these environments, streams are often approaching either a local base level or the ultimate base level, which is sea level. Another common depositional environment is found at tributary junctions (Figure 103). Particularly when smaller tributaries approach a larger main channel, the main channel acts as the local base level for the tributary stream. As discussed in Section 4.2.2.1, if the base level becomes lower in the main channel because of a change in flow regime, then the tributary confluence will revert to an erosional environment, often with a headcut migrating upstream.

Figure 103. Bar deposition where the small tributary, Trout Brook, enters a much larger channel system, the St. Croix River. Sand deposition can be seen in the satellite imagery (*top left*) and in the midchannel bars at the site (*top* and *bottom right*). The topographic maps show an area that is likely inundated during high flows in the St. Croix River. Staining on the trees and bridge (*top right*) also indicates that the area is inundated regularly by a much higher flow than is likely in Trout Brook.

Glacier-fed streams are highly depositional landscapes (Figure 104). Braided river systems are common in these channel types, resulting in a wide multithread system with multiple channel bars. The active channel bars often lack vegetation, or at least vegetation that needs a long time to colonize. The OHWM is usually found above, or at the very top of, the channel bars in these channel systems.

Figure 104. Depositional environments in the Saskatchewan River, downstream of a glacier and the unnamed tributary that is both downstream of a glacier and entering Lake Louise. The generalized schematic shows how the OHWM would encompass the entire width of the braided system.

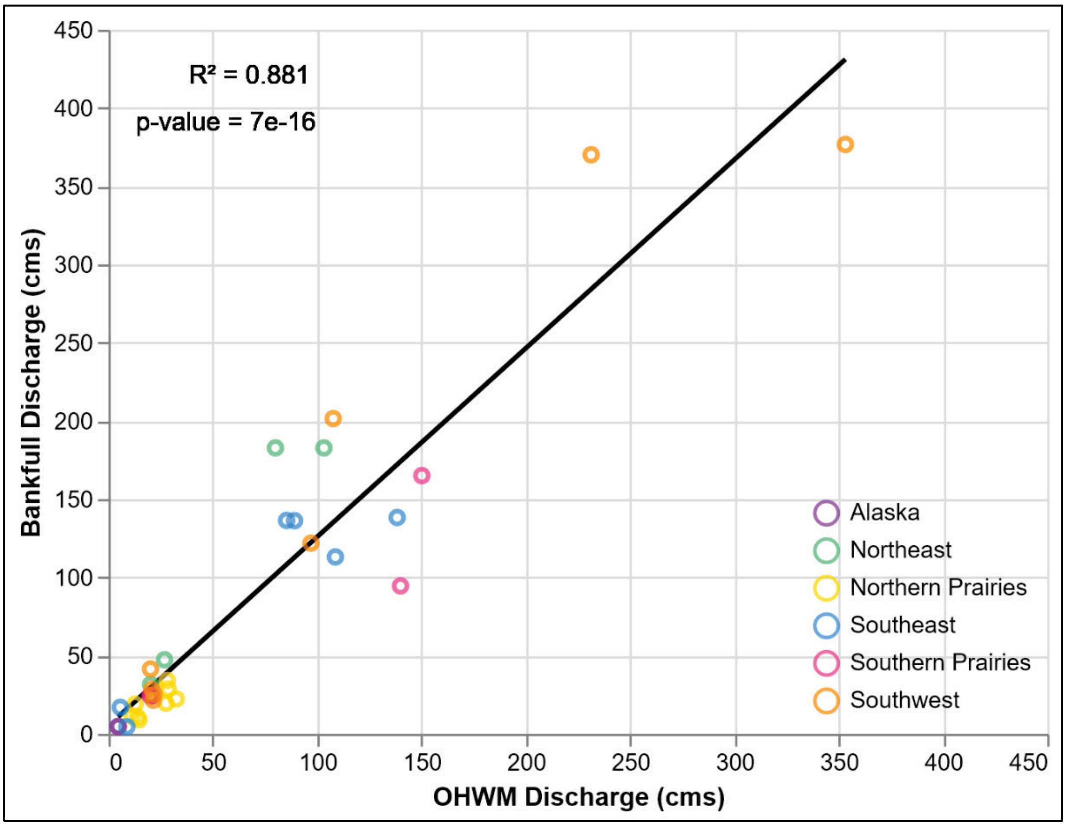


Generally, a change in valley characteristics, in terms of gradient (steep to flat) and width (narrow to wide), results in a reduction of flow energy in a stream system and, therefore, deposition of sediment. These processes can result in the development of channel bars and the channel splitting into multiple threads. Many other factors, such as changes in land use (e.g., logging, mining, and urbanization) or overall climatic changes (e.g., increases in precipitation over time and bigger storms), can cause a stream to begin to transport more upstream sediment and deposit more sediment downstream. The local geology and vegetation also control what types of sediment are available for transport and, ultimately, the type of channels that will form. Streams are dynamic systems and may fluctuate between erosional and depositional cycles throughout the stream system and through time. Streams reflect changes in landscape characteristics throughout the watershed, although the stream response lags behind changes in the watershed. If there are significant changes to landscape characteristics, there can be an associated change in channel features downstream. For example, in extreme cases of sediment deposition, channels can shift from single thread to braided. Therefore, different physical characteristics are useful as OHWM indicators, depending on where the stream is within the watershed and what has happened in the watershed in the recent past.

4.3 Comparison of bankfull width and discharge to OHWM

Variability in the magnitude, frequency, and duration of the streamflows that shape a channel are a result of differences in climate, geology, topography, vegetation, and land use, as discussed in the previous section. Channel bankfull width or bankfull discharge are often used to identify flows that are responsible for shaping the channel. Linkages in definitions between bankfull and the OHWM were introduced in Chapter 1 and are further discussed in Hamill and David (2021), with results of a hydrologic study comparing bankfull and OHWM discharges in streams throughout the United States. Hamill and David collected detailed cross-sectional data in streams throughout the country, and those same cross sections and case studies are used throughout this manual. The analyses in Hamill and David included a detailed analysis of streamflow data and the development of HEC-RAS flow models for 15 streams in six regions of the US. Two cross sections and the high-water marks up- and downstream of the cross-section locations were surveyed for each stream. These data were then used to estimate the flood frequency for flows at transition points along the cross section. The OHWM for each cross section was determined using the method presented in this manual. Individual cross sections were compared at each site to show the variability that can occur in field identification along a stream at one location. To make sure that a different method was used to identify bankfull, the OHWM elevation was compared to a geomorphic bankfull based on the breaks in slope along the channel banks. Field evidence was also used to determine the most likely location of bankfull, using the simplest definition of bankfull, which was where flow would first begin to submerge the floodplain (Williams 1978). At some locations, such as Burnt Creek and Antelope Creek in North Dakota, there were obvious inset floodplains below the top embankment that corresponded with bankfull. Therefore, the comparison between the OHWM and bankfull is a comparison using all the evidence described in Section 2.3 for identifying the OHWM versus focusing on channel form for identifying bankfull (Section 2.3.1.1). Hamill and David (2021) found that the OHWM is related to flows with return periods between 1.05 and 11.01 years using the annual maximum method to characterize flood frequency and between 0.5 to 9.08 years using a peaks-over-threshold method. Furthermore, they found a significant relationship between bankfull discharge and the OHWM using the method described to identify bankfull (Figure 105).

Figure 105. Discharge at OHWM versus bankfull levels, reproduced from Hamill and David (2021, 43). A linear regression line (*solid line*) demonstrates the close relationship between the geomorphic bankfull discharge and the OHWM discharge. Only sites with available streamgage data are included in this figure; therefore, there are no sites from Hawaii or the Northwest.

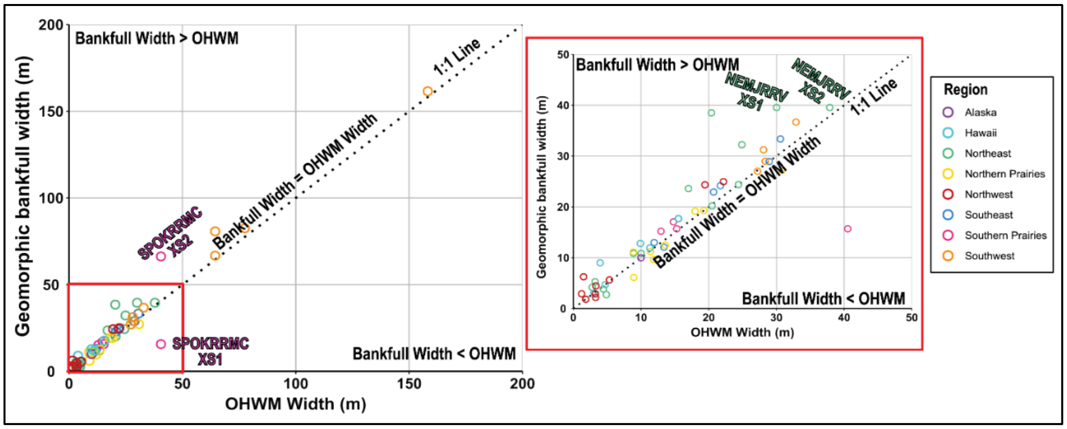


Hamill and David's (2021) findings are supported by many previous studies that found recurrence intervals of bankfull flows between 1.01 to 5 years in perennial rivers (Wolman and Leopold 1957; Wolman and Miller 1960; Leopold et al. 1964; Castro and Jackson 2001; Haucke and Clancy 2011) and 1.01 to 20 years in arid systems (Williams 1978). The problem with defining bankfull discharge is that the findings of 1.01 to 5 years are based on average trends found in alluvial perennial systems. Focusing on the recurrence interval is problematic because the frequency of a flow is not necessarily related to whether the flow has a geomorphic function, which would mean the flow is largely responsible for shaping the active channel. Even within the regions in which these trends were identified, a large variability in recurrence intervals among sites may occur. For instance, Williams (1978) investigated streamgage records in perennial channels in the western portion of the US and determined recurrence intervals for bankfull flows ranged between 1.01 and 32 years, but approximately 80% to 85% of bankfull flows had recurrence intervals between 1.01 and 5 years. The commonality of the 1.01–5-year-recurrence intervals resulted in bankfull discharge often being defined by the recurrence interval rather than by channel geometry (Dunne and Leopold 1978).

Arid systems are likely to have much greater variability in recurrence intervals for bankfull flows and, therefore, greater variability in the types of flows leaving physical indicators that can be identified as the OHWM. Furthermore, in arid systems with variable flow regimes, it is expected that high-magnitude, low-frequency floods are more likely to control channel form than low-magnitude, high-frequency floods (Graf 1988). Bankfull discharge, including field methods and regional distinctions (USFS 1995, 2003, 2005), has been studied carefully by hydrologists and geomorphologists for many years (Leopold et al. 1964; Williams 1978). Thus, the complexities, nuances, methods, and scientific explanations have been debated and carefully analyzed (Johnson and Heil 1996). The findings that the OHWM and geomorphic bankfull are closely related (Hamill and David 2021) mean that the same regional distinctions for bankfull can be used to support OHWM identification.

Although the OHWM and bankfull are closely related, there may be some variability between sites, or even between reaches at a site. Figure 106 provides a comparison of the calculated width from the field-delineated OHWM and bankfull widths. The OHWM width was equivalent to or below the geomorphic bankfull elevation at many of the surveyed sites. To maintain consistency between sites with highly variable cross sections, bankfull elevations were delineated for each cross section using channel morphology, with an emphasis placed on identifying inflection points along the banks using the stream cross sections; these were then compared to the elevation of the field-delineated OHWM. At sites that were highly incised, the break in slope at the newly developed top of bank was used to determine the bankfull location, which may have contributed to a bias to the bankfull discharge measurements representing mainly the transitions in channel form.

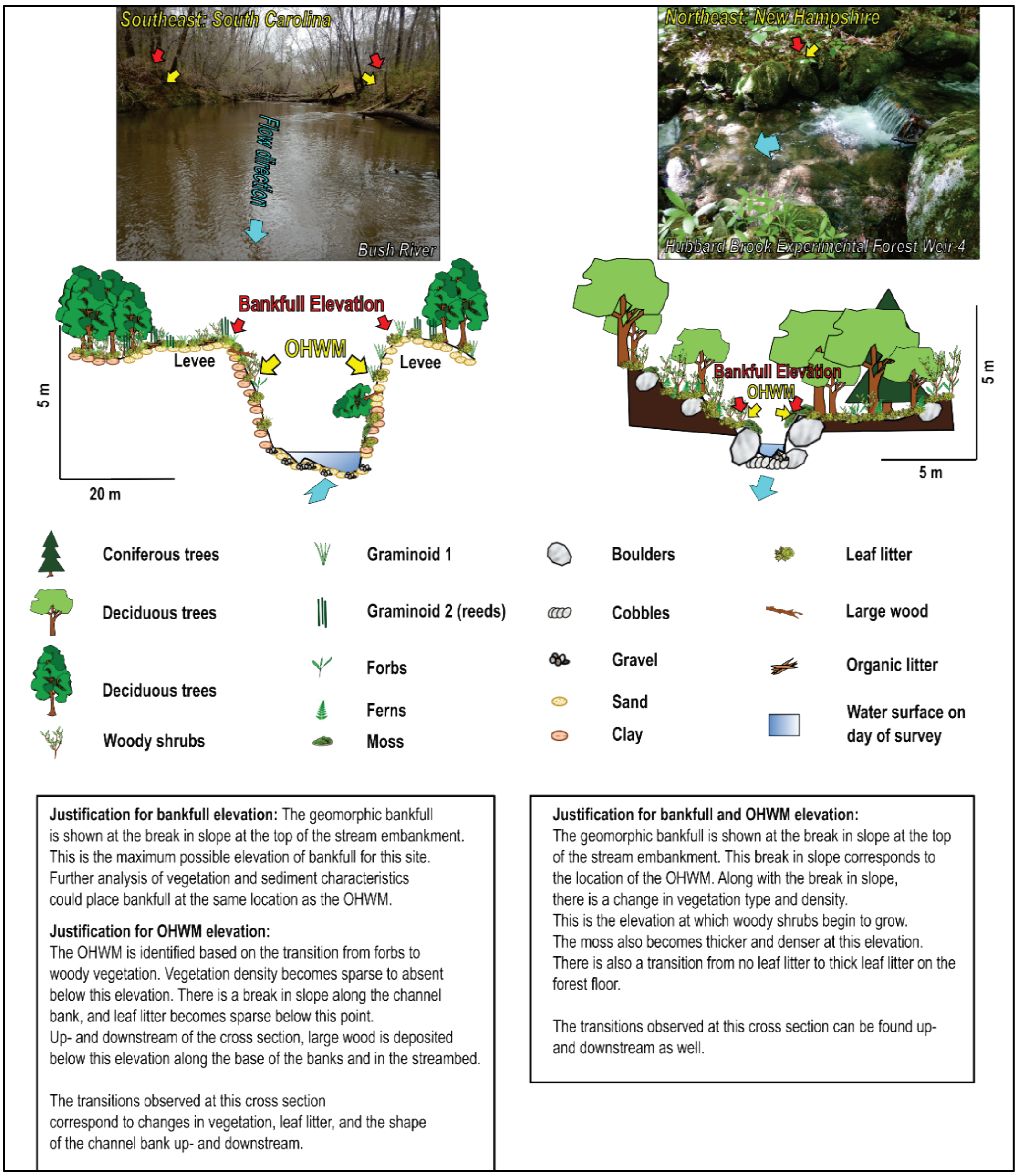
Figure 106. Comparison of bankfull width and width of stream at the OHWM elevation for each measured cross section in a variety of streams in different regions of the country (*left*). Inset panel (*right*) shows the width comparison for most sites. Calculations are for individual cross sections rather than reach averages. Labeled sites are included to highlight variability at a site (XS1 versus XS2). SPOKRRMC is Mud Creek in Oklahoma, and NEMJRRV is the Rivanna River in Virginia. A 1:1 line is shown, rather than a regression line, for better interpretation of whether bankfull width is greater or lesser than the OHWM width at most sites. More sites and regions are included here than in Fig. 105.



Many of the sites included in this study are USGS-gaged streams (Section 5.4). Streamgage sites generally have simplistic stream geometry (Juracek and Fitzpatrick 2009), which may partly explain why there are so few survey sites where the OHWM is wider than the bankfull width. More complex channel geometries, such as SWCs, may be sites where the OHWM is identified above the bankfull elevation or at least above the active channel boundary. These more complex channel geometries are not well represented in Figure 106 because of the limitation of using study sites near streamgages.

Figure 107 provides an example of a site at which the OHWM was determined to be below a levee (i.e., on the Bush River) and a site at which the OHWM and bankfull were clearly at the same location (i.e., Hubbard Brook tributary). A further analysis of soils at this site might indicate that the levee is actually a stream terrace. The Bush River maximum bankfull stage was set at the top of the prominent shelf, although this may be too high. Many streams in the southern piedmont of the Southeast region experienced substantial sedimentation in the early 20th century and have subsequently incised, leaving the aggraded historical floodplains as terraces. This possibility could not be tested adequately during the site visit due to high water from a storm the previous night; therefore, the high flat shelf is shown as a levee rather than a terrace. Flow modeling indicated that a flow would need to be, at minimum, a 10-year event to reach that elevation.

Figure 107. Comparison of bankfull and the OHWM in the Bush River (*left*) and Hubbard Brook tributary (*right*). The bankfull elevation shown for Bush River is the upper most possible bankfull discharge location. It is likely between the break in slope and the OHWM. The OHWM is slightly below the bankfull elevation on the Bush River, whereas the OHWM and bankfull are at the same elevation in Hubbard Brook.



Figures 105 and 106 describe the close association between the OHWM and the geomorphic bankfull, as well as the variability in cross-sectional dimensions like width and depth, that are often observed at a site. Reach averages are often used when investigating relationships between variables such as width, depth, and discharge. The at-a-site variability can be important for understanding how the OHWM may vary between cross sections and can help in identifying a line along the banks to represent the OHWM (Hamill and David 2021). Figure 106 highlights the variability between cross sections at individual streams in both OHWM width (NEMJRRV–NF Rivanna River) and bankfull width (SPOKRRMC–Mud Creek). It is useful to understand that variability in widths and elevation can occur at a site when identifying these characteristics in the field. Each of these sites had some changes in channel form between the two locations. The NF Rivanna River is discussed in detail in Chapter 3. The second Mud Creek cross section (XS2) is in a bedrock segment of the channel, rather than a sand and clay bed further downstream. Therefore, the controls on channel form are very different for XS2 and XS1. Using vegetation and sediment indicators assisted in converging on a similar width for the OHWM for the two cross sections.

If an average width were calculated for either Mud Creek or the Rivanna River, in the example in Figure 106, the relationship between the OHWM and bankfull width would improve, but throughout this manual, the individual cross sections are plotted and described to help with understanding the variability that occurs at a site. Reach averages are useful in developing regional relationships, understanding trends in how channels adjust cross sections with increasing discharge and sediment flow, and calculating parameters for modeling (Leopold and Maddock 1953). Users of this manual should recognize that the OHWM will not necessarily have a constant width, just as bankfull width can vary within a channel reach. Width, depth, and velocity depend on each other, meaning that a change in one will result in changes to the others. This was highlighted in Section 4.2.2.1, when discussing how channel narrowing can cause both a decrease in depth and rapid increase in velocity, which results in erosion. If a channel segment widens or narrows, then it is likely the depth and flow velocities have also adjusted. The difference in elevation between the OHWM and bankfull width or stage will be more dramatic at some sites than at others. Understanding that there is width variability at a site facilitates locating where the channel may be widening or narrowing and informs where to look for OHWM indicators. Once specific OHWM indicators along a bank are identified, a line can be drawn that connects those indicators and delineates the elevation of the OHWM (Chapter 3). Landscape controls, such as changes in valley confinement and bedrock outcropping and significant changes in geology and land use, can assist in understanding where significant adjustments are likely in the elevation of the OHWM along the channel. Online resources, described in Chapter 5, can help in understanding these landscape characteristics that may influence where channel adjustments are occurring.

5 Gathering Supporting Evidence for OHWM Identification

5.1 Key points

Supporting evidence can be evaluated prior to a field site visit, which may provide the landscape context (Chapter 4), or after investigating a site to better understand the field observations. Section 5.2 provides an overview of available online databases that may help with interpretation of the data and provide easy visualizations. Sections 5.3 to 5.6 review some of the most-used resources and describe their benefits and limitations as well as how to interpret the data. Section 5.7 provides a case study in which the use of remote data helped to understand the field evidence for identifying the OHWM.

5.2 Accessing supporting evidence for OHWM identification

There are several local, state, and national databases available online that can help evaluate the landscape and contextualize field observations. The websites and tools listed in Table 7 provide data and tools for summarizing watershed and stream characteristics at varying resolutions. Many tools are being developed or have been developed to assist with visualization and analysis of geospatial and remote data. Field observations can then verify or provide improved data at a site. RGL 05-05 (USACE 2005) states that USACE will "generally rely on physical evidence to ascertain the lateral limits of jurisdiction" (2) but "where the physical characteristics are inconclusive, misleading, unreliable, or otherwise not evident, districts may determine the OHWM by using other appropriate means that consider the characteristics of the surrounding areas, provided those other means are reliable" (3). Remotely collected data provide additional lines of evidence to support field observations and can inform the weighing of the relevance, strength, and reliability of each line of evidence.

Table 7. Overview of national databases that can provide landscape context and supporting evidence for identifying the OHWM.

Database	Website	Description	Benefits	Limitations
Antecedent Precipitation Tool (APT)	https://www.epa.gov/wotus/antecedent-precipitation-tool-apt	The APT was originally developed by USACE to automate the evaluation of precipitation normalcy and other climatic variables to complete wetland delineations (Gutenson and Deters 2022).	Uses a standardized methodology and provides other information, such as drought indices, that can help in determining whether a drought or other climatic conditions is normal.	The tool does not currently work as well in snowmelt-dominated or other systems in which rainfall is not the sole source of high flows.
Climate Engine	http://climateengine.com/	An online tool developed for on-demand processing of satellite and climate data. The tool was developed by a partnership of Desert Research Institute, University of Idaho, and Google (Huntington et al. 2017).	Combines geospatial data with statistical analysis to understand climate patterns.	Resolution of climate data. Climate data tend to encompass large areas and are not necessarily site specific.
Digital Globe	https://evwhs.digitalglobe.com	High resolution satellite imagery.	Some satellite imagery is of higher resolution than what is found on Google Earth. Detailed metadata are available for the imagery, and the site includes an easy-to-use interface.	Does not have as many years of historical imagery available as USGS Earth Explorer. Data are not publicly available.
EnviroAtlas	https://enviroatlas.epa.gov/enviroatlas/interactivemap/	Geospatial data available to view in one easy-to-use online interface that can provide landscape context for sites. Layers are available that integrate ecosystem services with water, land, chemical, and nonchemical stressor data and demographic data.	National data are available that summarize information by 12-digit Hydrologic Unit Codes (HUCs). Fine-scale data, at the meter scale, are available for 1,400 cities and towns.	Much of the national data are derived from data layers with resolution of 30 m. Any development of indicators in EnviroAtlas relies on the availability of national and local data sets.
Google Earth (or Google Earth Pro)	https://www.google.com/earth	A user-friendly format for observing current and past satellite and aerial photographic imagery.	Can provide a quick overview of site conditions and land use. Historical imagery can show changes in land use that may influence current channel conditions and OHWM indicators.	Dates on historical imagery may not be accurate, especially when zoomed out to small scales. If attempting to connect imagery with streamgage or other temporal data, zoom in to the site and check metadata using USGS Earth Explorer or other sites that include imagery metadata.

Table 7 (cont.). Overview of national databases that can provide landscape context and supporting evidence for identifying the OHWM.

Database	Website	Description	Benefits	Limitations
Model my Watershed by Stroud Water Research Center	https://modelmywatershed.org	Allows users to delineate a watershed and gather basic information about it, such as land use, stream network length, soil, climate, and water quality data. Does some basic modeling for urban and rural watersheds.	Provides an overview of a watershed, including information on when a stream is likely to have high or low flows within a year.	Summary data and models are based on National Hydrography Dataset (NHD) medium-resolution data (1:100,000 scale), a coarse scale of analysis for small streams.
National Resources Conservation Service (NRCS) Web Soil Survey	https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm	Soil data available from the National Cooperative Soil Survey.	Can give an understanding of soil properties over a broad area.	Differing methods were used to map soils over time. Soil data are updated as new methods are developed. Information from soil surveys can't replace site-specific details (USDA NRCS 2016).
OpenTopography	https://opentopography.org/	High resolution topographic data acquired using lidar and visualization tools. The data available on this site were from National Science Foundation funded projects.	Can download lidar data as point clouds (LAS or LAZ), as 2-D DEMs (GeoTIFF, IMG, Arc ASCII Grid) or as Google Earth files (KMZ). Visualization tools can explore lidar without downloading data and show stream features before site visits or observed features postvisit.	Can be difficult to navigate. Limited to National Science Foundation funded projects. Availability of tools varies based on location.
USDA: NRCS Geospatial Data Gateway	https://datagateway.nrcs.usda.gov/	A one-stop shop of data available for a location. Meant for downloading data to use in ArcGIS or other geospatial data processing software. Includes data on climate, elevation, geography, geology, government units, hydrography, hydrologic units, land use, land cover, ortho imagery, soils, topographic maps, and transportation.	Easy to find available remote data for a site.	Not meant for data visualization. The data will need to be processed using other software.

Table 7 (cont.). Overview of national databases that can provide landscape context and supporting evidence for identifying the OHWM.

Database	Website	Description	Benefits	Limitations
USGS National Water Dashboard	https://dashboard.waterdata.usgs.gov	Viewer that shows provisional real-time water data with weather-related data and other public resources.	An easy-to-use viewer with streamgage, lake, well, water quality, rain, atmospheric, and tidal data. These can be combined with weather conditions and hydrologic information.	Data are only for streamgage sites. It can give an overview of current and past conditions for nearby streams. It can also show if there is a nearby streamgage.
USGS StreamStats	https://streamstats.usgs.gov/ss/	Tools for analyzing streamgage data.	Delineates watersheds and gives summary data (e.g., drainage area and land use). Includes predicted flows with recurrence intervals.	Connecting flows with channel dimensions can take additional training and understanding of hydraulics.
USGS The National Map Advanced Viewer	https://viewer.nationalmap.gov/advanced-viewer/	Data visualization and download tool. Topographic maps, geographic names, structures, transportation, government unit boundaries, National Hydrography data, Watershed boundary data set, FWS Topo Wetlands, NLCD Land Cover data, Digital Elevation Products, and Hillshade are available (resolutions depend on whether lidar data are available in region).	Easy to view available spatial data sets, (e.g., lidar products such as slope and hillshade maps). Tools include distance, area, and location. Profiles can be drawn and elevations extracted from maps. Can add other data (e.g., FEMA flood data, geologic maps, and ecosystem data)	Only provides most recent satellite imagery.
USGS WaterWatch	https://waterwatch.usgs.gov/index.php	Compilation of streamgage data and visualizations showing if streams in a region are currently dry or at high or extreme flows. Stream toolkits for USGS streamgages can be accessed on the WaterWatch page.	Provides visualizations of streamgage data, allowing users to see if streams are wetter or drier than normal. The stream toolkit can evaluate local gages to understand current flow levels (e.g., if streams are currently at base or high flow).	Same as USGS National Water Dashboard.

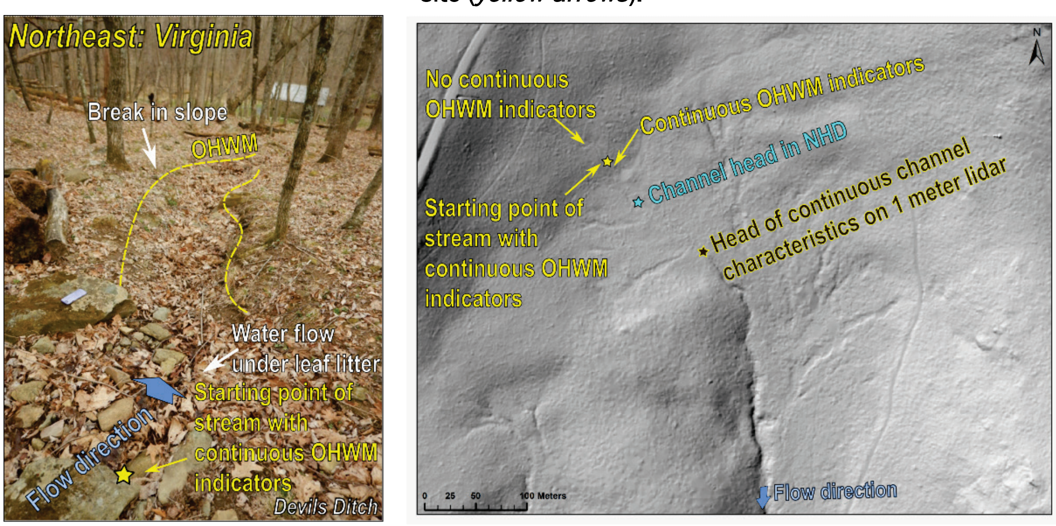
Resolution is one of the biggest limitations of remote tools. For instance, the zoom function in any tool can make it seem that the user is able to zoom in continuously on the landscape, but base map layers have set scales that limit the resolution and accuracy of their spatial data. For instance, topographic maps are generally at a scale of 1:24,000. The user may attempt to zoom in further, but that does not change the scale of the underlying base map layer. Some tools will remove the base map layer completely if the user zooms too far into the map. The summaries of stream characteristics provided by tools such as StreamStats or Model My Watershed, or any climate-related tool, all have limitations to them, starting with the resolution of the data in both spatial and temporal dimensions. These tools draw from a diverse set of publicly available data, often summarized for the user. This section of the manual describes the benefits and limitations of using these online resources and how these tools can be useful for providing supporting evidence or landscape context for OHWM delineations.

5.3 National Hydrography Data (NHD) resolution and usefulness for understanding the OHWM

The National Hydrography Dataset (NHD) and Watershed Boundary Dataset (WBD) are geospatial data sets maintained by the USGS that, respectively, map the nation's surface water network and hydrologic drainage areas. These data sets can provide an overview of the landscape prior to site visits, but the inherent limitations and errors in the data sets should be well-understood before using them for any application. For instance, much of the current high-resolution NHD is mapped from 1:24,000 scale maps. These maps tend to miss small headwater streams because the drainage network is being mapped using data that are at a scale too small to depict small channels (Figure 108). Small-scale maps show a larger geographic area with few details (i.e., lower resolution), whereas large-scale maps show a smaller geographic area with greater detail (i.e., higher resolution).

The NHD is constantly being updated and maintained through partnerships with states and counties; therefore, the quality of the maps depends on how much work has been done to ground truth and update the data set. Currently, the NHD High Resolution is being updated with the WBD data set and 3D Elevation Program data to create NHDPlus High Resolution (NHDPlus HR); the previous version, NHDPlus V2, will be referred to as NHD in this manual. Hafen et al. (2020) evaluated the NHD data sets and reported that stream classification and extent depicted on nonlidar NHD were influenced by meteorological conditions at the time aerial orthophotographs were acquired and field assessments were done. Furthermore, over the time that topographic maps were developed (1881 to 2000), the definition of a stream, specifically the definitions for perennial and nonperennial streams, changed, which resulted in differences in how streams were mapped (Hafen et al. 2020). Variability in channel-head locations, stream lengths, and stream order is partly because of the dynamic nature of stream systems, with headwater extent varying over both short and long time scales. For instance, headwater extents can change with a single precipitation event, resulting in temporary increases in stream length from concentrated overland flow (Godsey and Kirchner 2014). Streams can lengthen and channel-head locations can change over longer time scales after fires or logging in basins (Reid et al. 2010; Wohl 2013, 2018). Figure 108 shows the difference in identifying the channel head using lidar, NHD, and a field survey. Caruso and Haynes (2011) reported that NHD excluded many first-order streams, whether perennial or nonperennial. Many of these limitations will be improved with NHDPlus HR because lidar data will be used to update the data set. Rossi and David (2022) offer a detailed description of the use of online resources and field surveys to identify the upper extent of stream channels.

Figure 108. Comparison of where a channel head would be located on lidar (*brown star with yellow outline*), the National Hydrography Dataset (NHD; *blue star*), and a field survey of the site (*yellow arrows*).



The improvement in NHDPlus HR is shown by the increase in the number of mapped stream features, from 2.6 million in NHD to 30 million in NHDPlus HR (Moore et al. 2019). The quality and resolution of the updated NHD depends on the quality and resolution of the airborne lidar data in a region, which depends on topographic variance, vegetation canopy thickness, and technical aspects of data acquisition. The lidar data will be at a 1:24,000 scale or better. The identification of features, such as streams or rivers, artificial paths, canals or ditches, pipelines, and connectors, varies in quality and is being improved and updated but should be confirmed or corrected by field observations. The methods used to develop and update these data sets are available on the USGS NHD website* (Archuleta and Terziotti 2020). More information on lidar and DEMs resources are addressed in Section 5.5.

5.4 Stream hydrology, USGS streamgage data, and the OHWM

The OHWM results from a range of high flows that shape the stream channel, not necessarily from a single flow event. When streamflow data are available, they can be consulted to determine the type of flows that will be present in the channel during the initial survey. For instance, the streamgage information can show if the stream is at low or high flow, if there were recent high flows, and if the current flow is wetter or drier than normal for that time of year. USGS streamgage information can assist in interpreting bodies of evidence as part of the WoE procedure (Figure 7) by providing another line of evidence for the location of the OHWM. USGS streamgage data can also help explain ambiguities and discrepancies in high-flow indicators. This section describes where to find the streamgage data, how to understand the data, and how to integrate the information with other lines of evidence collected in the field. The information provided here expands on and updates previous ERDC technical reports that also provide information on evaluating and relating streamgage data to the OHWM (Curtis et al. 2011; Gartner, Lichvar, et al. 2016; Gartner, Mersel, and Lichvar 2016). A companion document describes the methods used to develop HEC-RAS models and to calculate flow frequencies for the included case studies (Hamill and David 2021).

5.4.1 Accessing and understanding USGS streamgage data

The USGS maintains more than 3,000 long-term (i.e., 30 years or more) streamgages across the nation. These data can be accessed online by searching for specific streamgages using the streamgage number or stream

*https://www.usgs.gov/core-science-systems/ngp/national-hydrography name, going to the USGS Water Resources website[*], or using USGS WaterWatch (Figure 109) or the newly available USGS National Water Dashboard[†]. Streamgage data are used for many applications that are connected to management of the nation's water resources. Analyses of streamgage data are available through StreamStats and other tools listed in Table 7. This section focuses on how the data are collected, and Section 5.4.2 discusses the analysis of the data. Box 16 contains questions to consider when investigating the USGS streamgage data. An explanation of how to understand streamgage data and answer these questions follows.

Box 16. Questions to consider when investigating USGS streamgage data prior to a site visit.

Description of flow during site visit:

Flow level during site visit: ______________________________

Note the presence or absence of flow, pooling, low flow, at flow banks, flow overtopping banks

Is there a nearby USGS gage? ☐ Yes ☐ No

If yes, what is the streamgage number? ______________________

Is the streamgage currently active? ☐ Yes ☐ No

If no, how long ago did it become inactive? Does it still represent current conditions?______________

Over what years has it been active? What is the total length of the record? ______________

Go to waterwatch.usgs.gov/index.php and check the Streamgage Dashboard (under Toolkit):

Investigate the streamflow compared to historical streamflow. The USGS colors the gage based on historical data to determine if the streamflow is dry, normal, or high for this time of year.

Explanation - Percentile classes						
●	●	●	●	●	●	●
Low	<10 Much below normal	10-24 Below normal	25-75 Normal	76-90 Above normal	>90 Much above normal	High

What is the threshold for high flows based on the flow duration curve? ______________________

Check the daily hydrograph.

Based on the gage data, was the flow at a low/base flow, moderate, high, or extreme flow during the site visit?

____

*OHWM should not be determined during extreme flow events.

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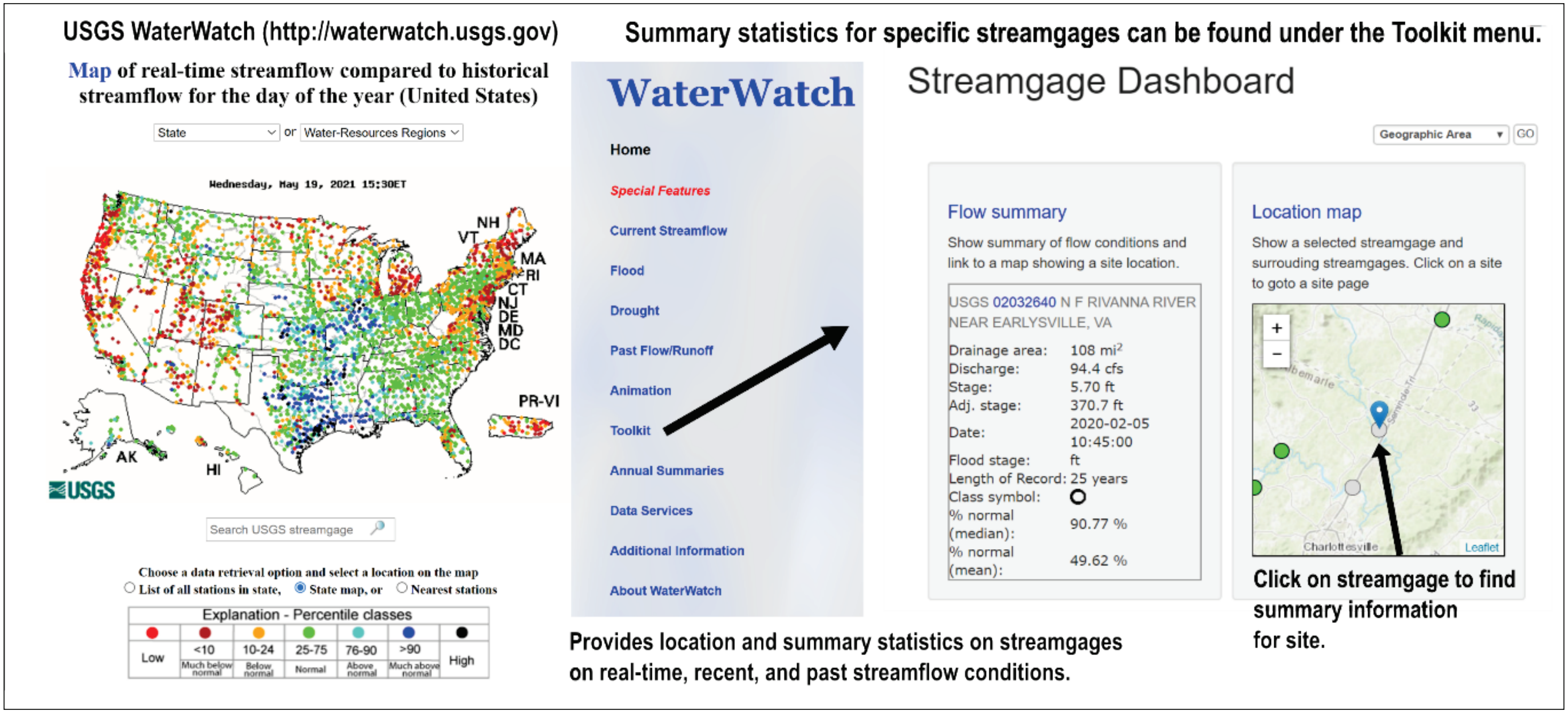
* https://www.usgs.gov/mission-areas/water-resources

† https://dashboard.waterdata.usgs.gov

Figure 109. Streamflow conditions can be accessed on the USGS WaterWatch website. The Streamgage Dashboard provides summary statistics for flow data. (Images reproduced from USGS n.d.g.)



Streamflow is collected through a network of dataloggers, maintained by the USGS and their partners, that record streamgage height, which is the height (or stage) of the water surface relative to an arbitrary datum (Sauer and Turnipseed 2010). The datum is usually set just below the lowest expected streamgage height so that negative discharges are not reported. Periodically, streamgage datums are reset because of situations such as excessive erosion of the channel bed. Field measurements are periodically made at the streamgage location to enable calculations of discharge for a variety of flows. A rating curve is then developed to connect streamgage height with discharge. Streamgages are maintained by resurveying sites and updating rating curves as necessary (Sauer 2002; Turnipseed and Sauer 2010). Many streamgages are placed on straight, incised, single-threaded channels to minimize channel bed changes (Juracek and Fitzpatrick 2009). Incised segments of channels are often used to minimize difficulties in estimating discharge for higher flows. Overbank flows, particularly large flood flows, are often modeled using indirect measures of these peak flows by gathering information on high-water marks following floods (i.e., extreme flows; Koenig et al. 2016; Feaster and Koenig 2017). The USGS maintains a national database* of high-water-mark information for flood events.

While streamgage data can assist in interpreting evidence for identifying the OHWM where they coincide, most places along river networks have no streamflow data. Data from nearby streamgages that are located up- or downstream of the reach in which OHWM identification is needed should reflect the ungaged hydrologic conditions if there are no significant differences in sources of flow (i.e., tributaries, groundwater, and outfalls), withdrawals (i.e., irrigation diversions), and storage (i.e., reservoirs). The channel form should also be comparable at the gaged reach and where the OHWM identification is needed. If there is no nearby streamgage on the same stream, one or more reference streamgages may be identified. Typically, reference streamgages are the nearest streamgages with comparable drainage areas, but the distance between a reference streamgage and the ungaged reach is not always the recommended criterion for selecting a reference streamgage (Archfield and Vogel 2010). A distance–relationship correlation can be used to select reference streamgages that are the most spatially correlated with an ungaged catchment, as has been done in different parts of the United States (e.g., Archfield et al. 2010; Linhart et al.

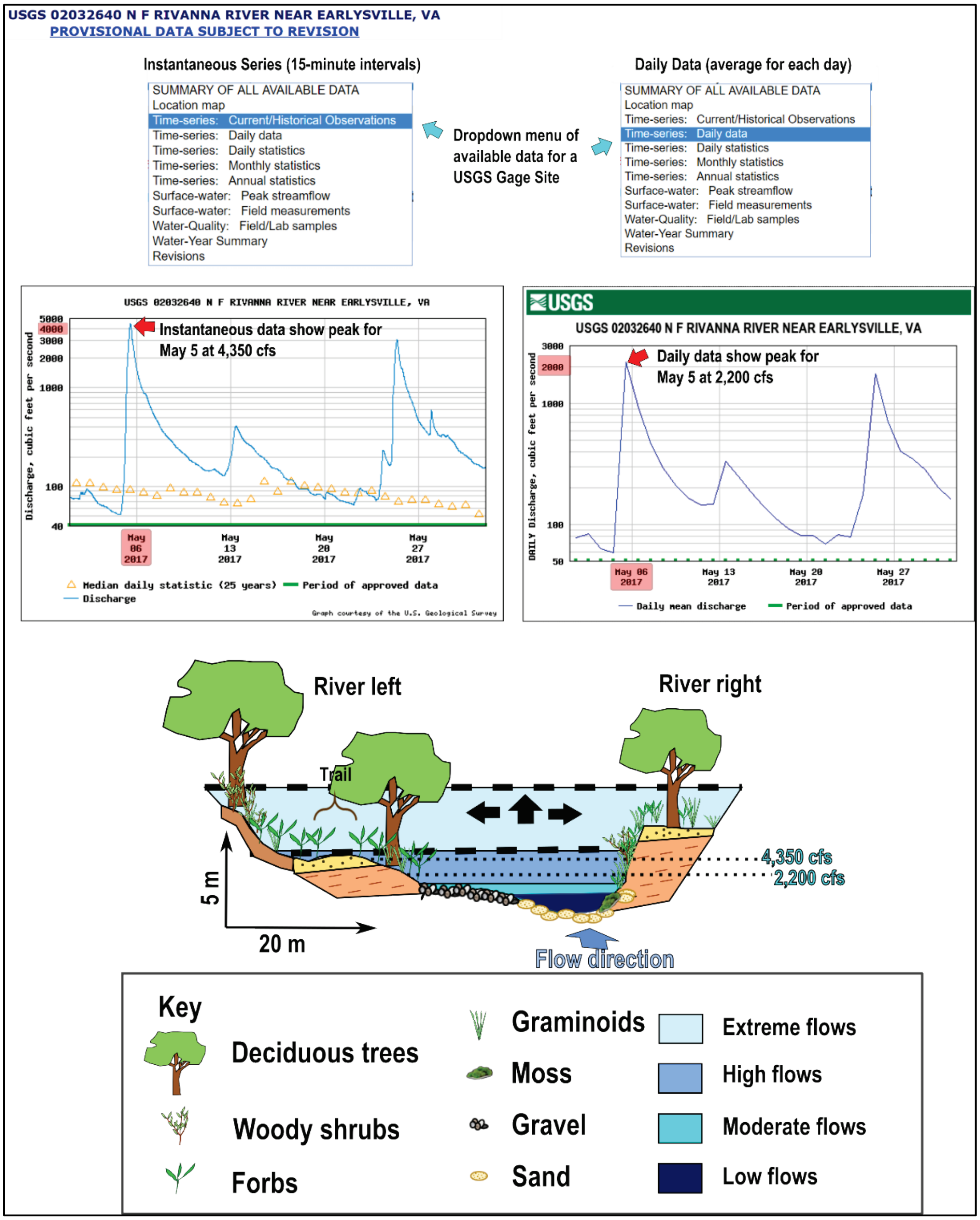
* http://water.usgs.gov/floods/FEV/

2012; Farmer et al. 2014; Stuckey et al. 2014). Streamflow statistics of ungaged reaches can be predicted using regional regression equations. Regional regression equations use widely available basin and climate characteristics, such as drainage area and mean annual precipitation, as predictors of streamflow statistics measured at a group of similarly situated streamgages (Fennessey and Vogel 1990; Ries 2007). Additional information on tools for ungaged locations is provided in Section 5.4.2.

Streamflow data collected at these sites can be summarized in a variety of ways. USGS streamgages collect streamflow data every 15 minutes. From these data, flow statistics, such as average daily, monthly, and annual flows, can be calculated. Peak flow data records, which are the highest recorded flows in any given year, can also be accessed on the USGS site. Average daily flows are calculated and used for flow analysis, such as the development of flow-duration curves (FDCs), or for other types of high-flow analysis using annual maximum series. The more years of data at a streamgage, the better the streamgage data represent the full range and probability of potential flows at a site. Overall, more years of data improve the sample size and, thus, the statistical representation for the site.

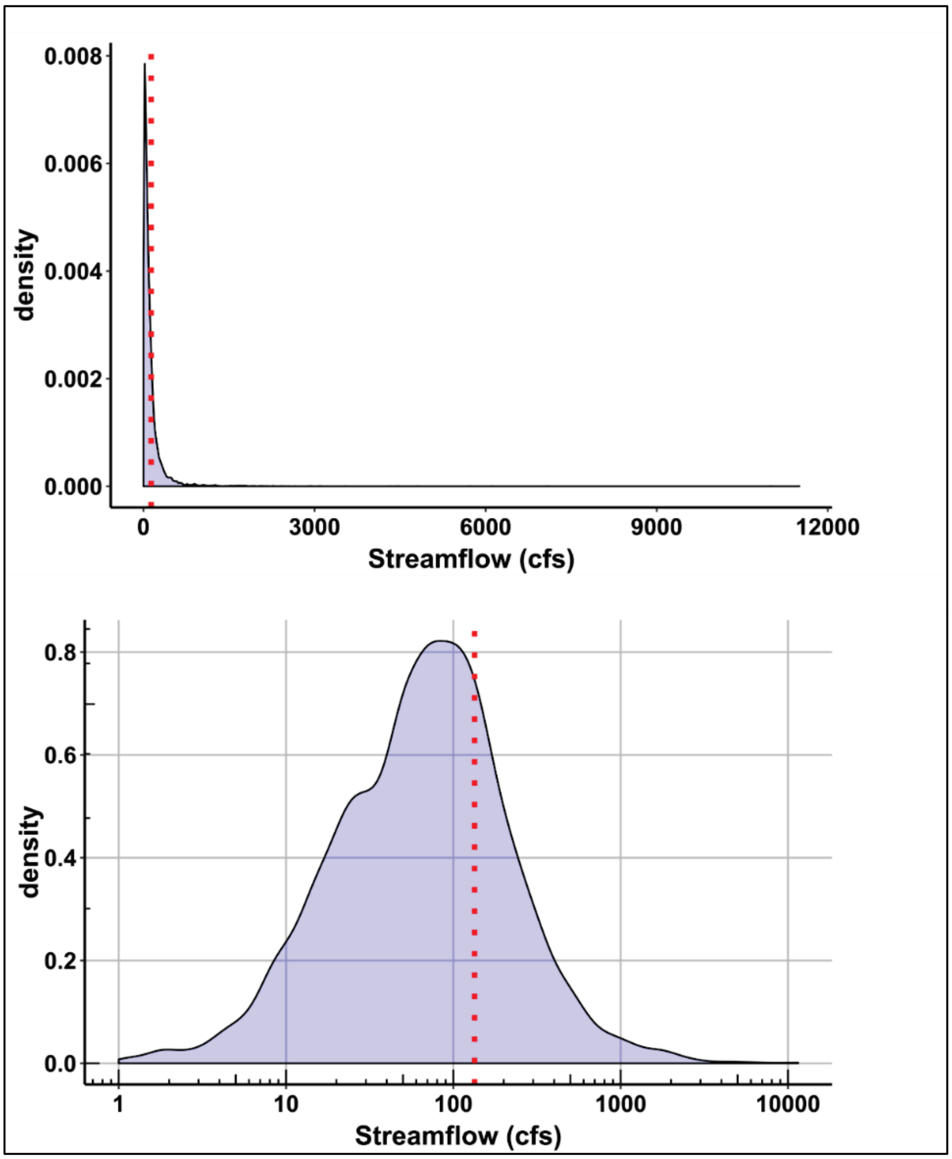
Because daily data are usually averaged over 96 fifteen-minute intervals each day, the daily flow values are lower than peak flows in the instantaneous record for the same site (Figure 110). Figure 110 provides one month of instantaneous data on the NF Rivanna River in Virginia and one month of average daily discharge. The peak flow that occurred on 5 May 2017 was logged at 4,350 cfs, but the mean daily data on that day was only 2,200 cfs. Therefore, when investigating the magnitude of flows in a channel, it is important to remember that daily data average flows over an entire day. This can make a significant difference when considering flows in particularly flashy streams, which will be demonstrated further in the section on urbanization (Section 6.6). The flows on 5 May on the NF Rivanna River demonstrate a day on which the peak flow would submerge the elevation of the OHWM (Chapter 3), but the daily data indicate that the flow remained below that level. This example is highlighted to demonstrate that average daily flows do not represent the full range of flows in a stream channel. However, daily data can be useful for many different types of analyses, including understanding relative differences in flows between days for a stream and between streams. Peak flow data are used to understand high and extreme flows because they represent the highest peak in a given year (Hamill and David 2021). For recognizing the OHWM, they are particularly relevant not only to understanding the frequency of high flows and recognizing when the last high or extreme flow occurred at a site, but also to get a sense of the water stage for those events.

Figure 110. Difference in values between instantaneous and averaged daily data. The approximate elevation of the water surface for instantaneous maximum (4,350 cfs) and daily maximum (2,200 cfs) flows on 5 May are shown on the NF Rivanna River cross section. (Images adapted from USGS n.d.d.)



Streamflow is inherently difficult to assess using basic statistical measures, such as mean (or average) and median, because of the inherent skewness of the data (Figure 111). The heavy skew toward high flows causes a bias in observations and understandings of flows. Figure 111 shows a probability density function of the data on a linear plot and on a logarithmic plot. Streamflow data are often presented on logarithmic plots to remove the heavy skew for better visualization, modeling, and hypothesis testing. Logarithmic plots may be used to meet normality assumptions in statistical analysis using streamflow.

Figure 111. Probability density functions showing the highly skewed nature of streamflow data (*top*). The *bottom* graph demonstrates that the use of a logarithmic scale for discharge allows better visualization of the data with a more symmetrical, pseudo-normal distribution. The *red dotted line* is the mean.

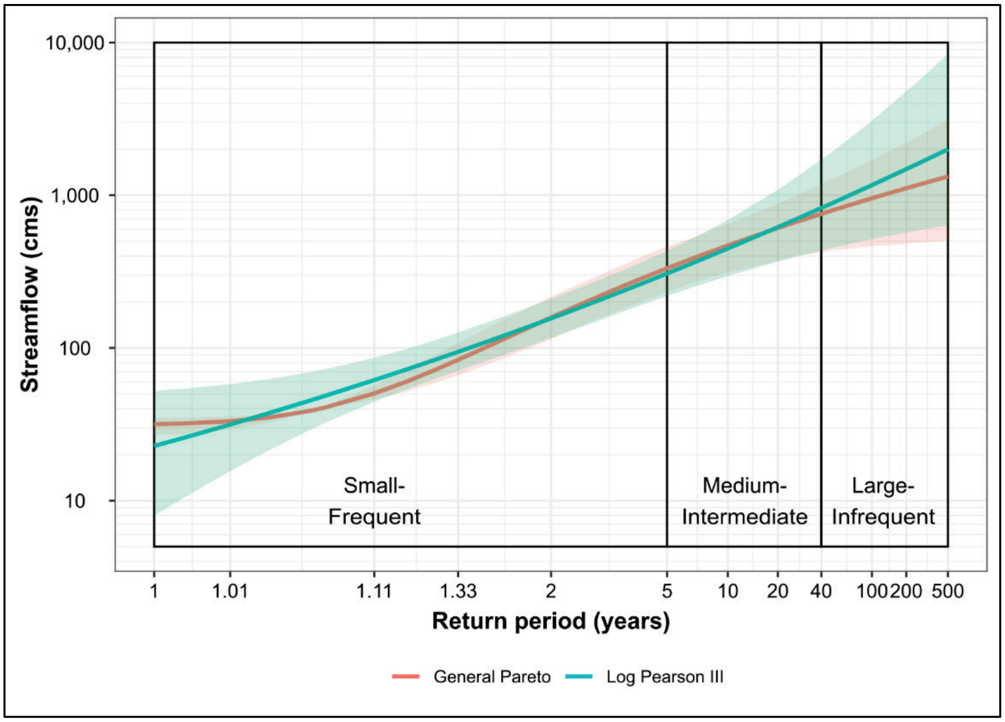


With such a heavy skew, the mean streamflow is not a useful measure of the flows relevant to channel processes (Vogel and Fennessey 1994). Mean annual streamflow provides information on the total volume of water moving through a channel over the course of a year, but it does not provide data on the types of streamflow (i.e., storm flows) that move sediment or create the indicators that are used to identify the OHWM. Throughout this manual, the mean annual flow has been used to provide the upper bound for the low flows associated with each of the presented cross sections. This is because the number of days with low flows far exceeds the number of days with high flows, and therefore, the mean is heavily skewed in the direction of the lower flows. Flood-frequency curves and FDCs are discussed in the two sections that follow to assist with understanding the types of flows that are considered high or extreme versus flows that are considered moderate or low. High flows are better represented in flood-frequency curves; therefore, the flow that encompasses the elevation of the OHWM would be represented by a flood-frequency curve. FDCs provide information about low and moderate flows and how to identify the lower bound of high flows. The discussion of flood-frequency curves and FDCs is meant to highlight the differences between these types of streamgage analyses and the data used to represent flows. The discussion of FDCs explains how random observations in time are biased toward low flows, whereas flood-frequency curves are representative of high and extreme flows. The discussion provides information on how to understand and characterize flow frequencies within a channel.

5.4.1.1 Understanding flood-frequency curves

Flood-frequency curves should be used to analyze high flows for identifying the OHWM. Flood-frequency curves are developed by analyzing peak flow data (e.g., the highest flow or flows in any given year). When analyzing flood-frequency curves, hydrologists may use an annual maximum series or a peaks-over-thresholds method. The differences between these methods are described in detail in Hamill and David (2021). The flows on a flood-frequency curve can be divided into small-frequent floods, medium-intermediate floods, and large-rare events, with high flows being in the small-frequent category and extreme flows, in this manual, lumping the medium-intermediate and large-rare categories. The divisions shown in Figure 112 are based on the return period and not necessarily the geomorphology at a site. Therefore, the actual cutoff between high and extreme flows may vary based on regional differences and localized channel characteristics.

Figure 112. Division of high to extreme flows on a flood-frequency curve. Also, an example of a general Pareto distribution, used to analyze data using a peaks-over-threshold method, versus a log Pearson distribution, used for annual maximum. (Image reproduced from Hamill and David 2021, 14.)

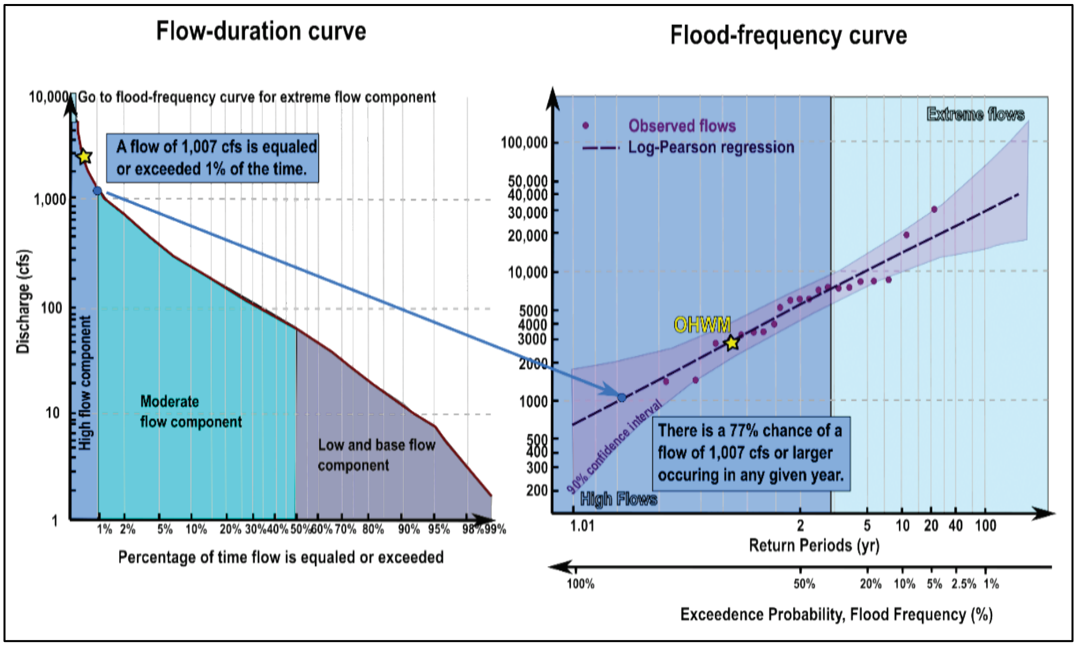


FDCs are not the same as flood-frequency curves (Figure 113). An FDC is not appropriate for analyzing high and extreme flows, which are lumped into one narrow category on the FDC. Since high-water marks generally reflect high flows and relatively small floods, a flood-frequency curve—if available—should be used for this range. Relevant to OHWM delineation, FDCs can be useful for identifying a lower bound for high flows in a stream and for understanding the influence of base flow versus storm flow in a channel (Winter 2007). Figure 113 shows the difference in interpretation of flow statistics when plotting the daily flow on the FDC and peak flow on a flood-frequency curve. Note that the discharge for the OHWM on the NF Rivanna River plots above the lower boundary of high flows that were identified on the FDC.

The FDC considers mean daily flows, whereas the flood-frequency curve considers only the highest flows in any given year. Therefore, the statistics and the interpretation of the statistics are different for FDCs and flood-frequency curves. A flood-frequency curve is an analysis of the peak-flow component of the gage record, not the daily component. The curve is usually developed by plotting the highest flow recorded in any given year. The peak flows are the highest flow in any given year and are from the instantaneous (i.e., 15-minute) series. Where instantaneous flow data are not available, the USGS uses other methods to develop a flood-frequency curve (England et al. 2019). Flood-frequency curves describe the probability of particular flood magnitudes occurring. Even though the flows on both curves can be referred to in terms of percentages, the percentages represent different time periods of the flow data.

Figure 113 demonstrates the differences between an FDC and a flood-frequency curve from the USGS streamgage (i.e., 02032640) on the NF Rivanna River. The percentages that are shown on a flood-frequency curve are not the same as those on an FDC. The boundary above which high flows occur on the NF Rivanna River was found to be 1,007 cfs. The FDC shows that a flow of 1,007 cfs is equaled or exceeded 1% of the time in the NF Rivanna River (i.e., flows that occur on average 3.65 days per year). Alternatively, a flow with greater than or equal to a 1.3-year return period on the flood-frequency curve has a 77% chance of a flow of that size, or larger, occurring in any given year. To separate the two types of curves, in this manual, the flood-frequency flows are referred to in terms of return periods in years (e.g., Q_{2yr}, Q_{5yr}), and the flow-duration flows are in terms of percentages (e.g., $Q_{1\%}$, $Q_{5\%}$). A flow that represents an ordinary high flow is likely to be better observed on the lower end of a flood-frequency curve but occur among the highest flows on an FDC (Hamill and David 2021).

Figure 113. Flow-duration curve (FDC, *left*) and flood-frequency curve (*right*) on the NF Rivanna River in Virginia (Ch. 3). The lower bound of high flow on the NF Rivanna River is at 1,007 cfs, which is shown both on the FDC and flood-frequency curve. The OHWM occurs above this flow (2,826 cfs), which is shown on the flood-frequency curve. The probabilities on these two curves are not the same. The 1% on the FDC are flows that occur, on average, 3.65 full days per year. The same flow is at 77% on a flood-frequency curve, which is a 1.3 recurrence interval and a flow that occurs, on average, less than once a year. Note that extreme flows combine both the intermediate- and large-flow categories in Fig. 112.



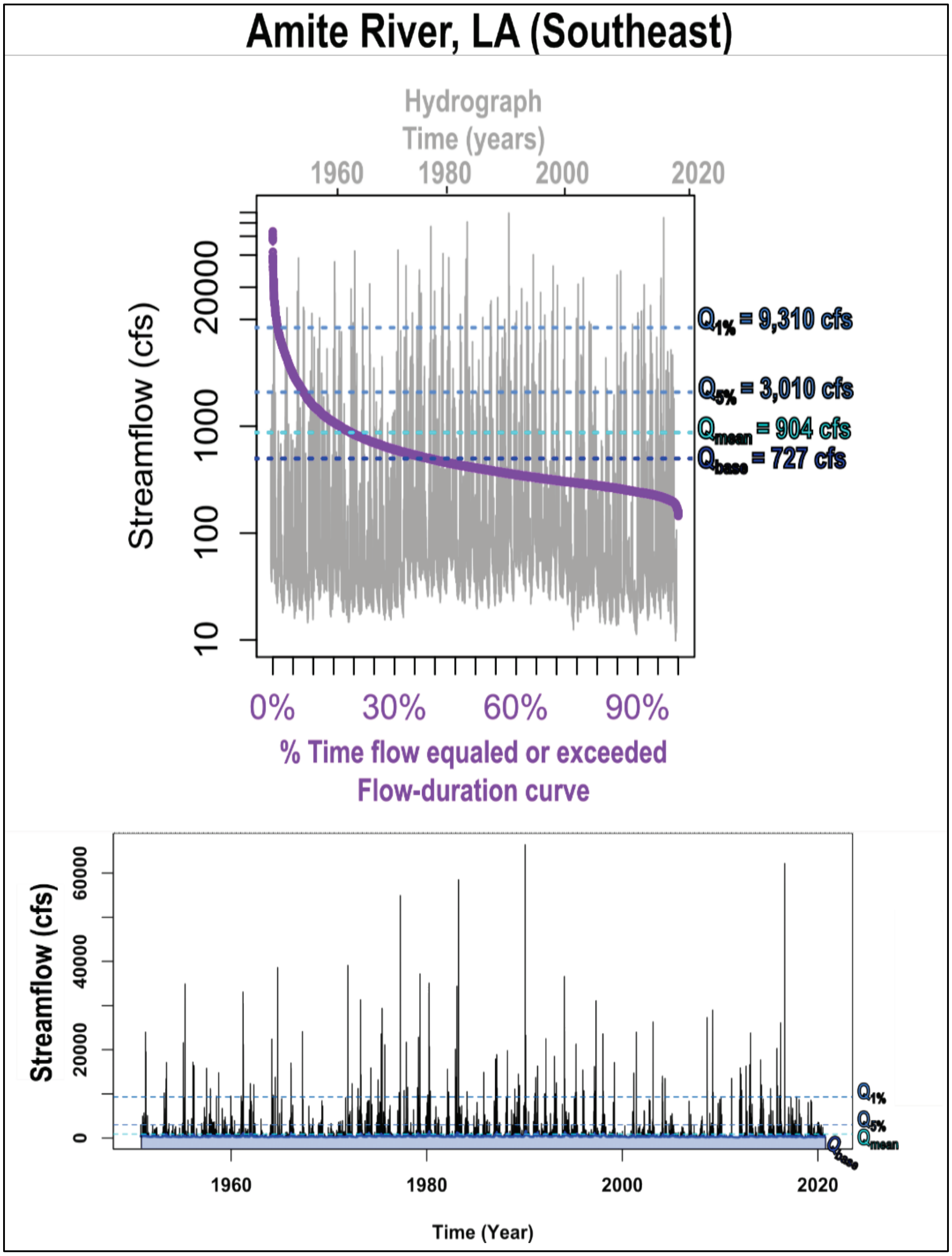
5.4.1.2 Understanding flow-duration curves (FDCs)

FDCs can often be used to interpret conditions before a field visit for OHWM identification, but they can also be used to put streamflows in context for a site. FDCs are a graphical representation of the relationship between the magnitude and frequency of daily, weekly, or monthly streamflow. FDCs, available through the USGS Streamgage Dashboard (WaterWatch toolkit), are an analysis of average daily discharges and arrange the daily flow values according to their frequency of occurrence (Figure 114). Therefore, the focus here is on describing how FDCs are developed from daily streamflow records. FDCs are a cumulative distribution of the daily flows and assist in understanding the influence of storm flows and base flows on a channel. FDCs represent the amount of time a flow is equaled or exceeded during a specified time period.

Figure 114 shows the hydrograph used to create the FDC. The hydrograph plots flows as they occur over time, whereas the FDC orders the flows in terms of size and how often those flows occurred. Being able to show when a channel is at a relatively low or base flow can assist with weighting specific lines of evidence. As in the NF Rivanna River case study shown in Chapter 3, an understanding of the current water level during the day of observation can provide context on the relevance, or lack thereof, for specific observations. Additionally, the FDC can be useful for understanding the lower bound of relatively high intra-annual flows that are occurring in any given channel. These lower bounds will likely be below the OHWM, but they provide an understanding of the size of flows needed to begin to leave persistent marks on the ground, which can be interpreted as indicators of the OHWM.

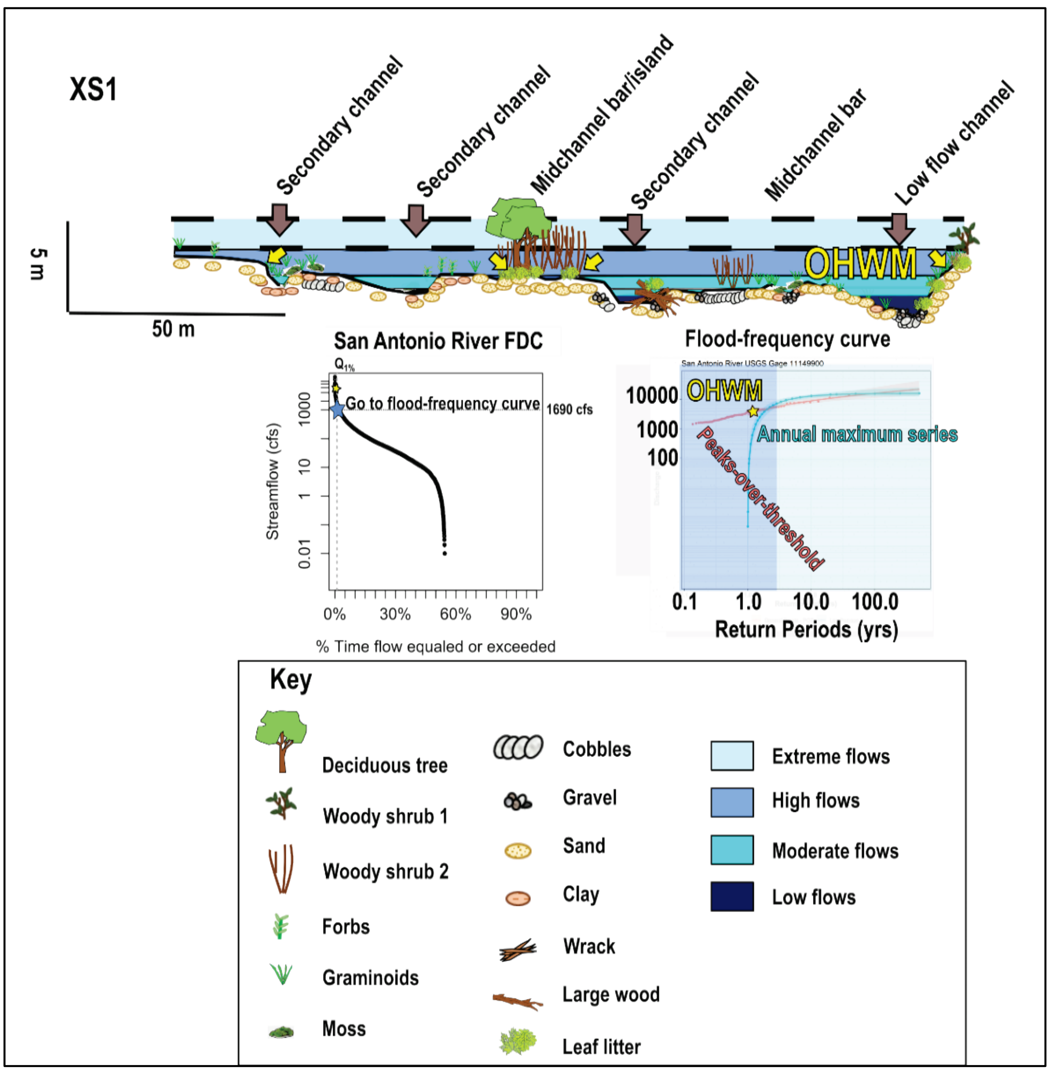
FDCs are often based on an analysis of all the mean daily data at a gage. Typically, most of these flows will be contained within the active channel. FDCs do not describe the number of days a specific flow will occur in a channel but, rather, the percentage of time the flow is above or below a certain level within a stream. For example, the flow in the Amite River is less than 727 cfs about 50% of the time in a given year, or, on average, less than this discharge about 182.5 days in a given year. The higher flow components of the FDC are equaled or exceeded only 1% of the time based on the daily gage data, so they are exceeded, on average, 3.65 days per year (i.e., 1% of 365 days). These 1% probability flows occur multiple times most years and are typically associated with flow stages below the OHWM. The inflection point of the curve (i.e., the point along the curve where the curvature changes dramatically) at the high-flow end—shown at about the 1% exceedance probability on Figure 113—can potentially be used as a break point for high flows. The bankfull flow stage, as well as the OHWM, should be found well above this point and will be better represented on a flood-frequency curve that includes instantaneous flows and not just mean daily flows. In other words, the channel-forming or bankfull discharge generally has an exceedance probability less than 1% on the FDC. As described in Section 4.3, OHWM and bankfull are closely related; similar to bankfull flows, the OHWM would be included on a flood-frequency curve with a recurrence interval well above 1.01 years on the annual maximum series. The OHWM flow would occur less than once per year.

Figure 114. FDC (*purple*) created from mean daily flows (*hydrograph grey*) on the Amite River in Louisiana (Southeast Region). The FDC shows that base flow (Q_{base}) is equaled or exceeded 50% of the time and that the mean annual flow (Q_{mean}) is equaled or exceeded 25% of the time. High flows occur above the 1% ($Q_{1\%}$ = 9,310 cfs) and, therefore, encompass flows greater than 9,310 cfs.



The 1% on the FDC (Figure 114) was used for the lower bound of high flows throughout this manual to provide consistency across sites, but there is likely some error and site-specific variability around that boundary. The FDC is used to find the lower bound of high flows so that, on each cross section, the high flows can be shown as a range. This acknowledges the dynamic nature of stream systems and that there may be a wider range of flows that are responsible for channel forms, which are connected to high-flow indicators (Ackers and Charlton 1970; Howard 1982; Pickup and Rieger 1979; Naito and Parker 2019), than in other systems. This is seen in stream systems that have high variability in precipitation events, such as an arid system like the San Antonio River (Figure 115).

Figure 115. The San Antonio River is a braided channel in an arid environment in the Southwest region (California). There is very little base flow and great variability in storm flow. The lower limit is shown for high flows on the FDC, with the OHWM shown on the flood-frequency curve. The OHWM at this site is 3,427 cfs. The extreme-flow category includes both intermediate- and large-flood flows. The line between high and extreme flows shown on the cross section is also shown on the flood-frequency curve but is not intended as a sharp boundary.



The shape of FDCs helps hydrologists and fluvial geomorphologists graphically illustrate how regional differences in climate, vegetation, topography, and other geologic factors influence flows (Figure 116). Steeper FDCs indicate that flows are variable over the period of record, whereas flatter FDCs represent more stable flows over the period of record (Winter 2007). Keeping in mind that FDCs represent daily mean rather than peak discharge, flat FDCs suggest that base flow is a strong contributor to flow so higher water levels are not very different from lower water levels. Steep FDCs suggest that storm flow can at times be a strong contributor to flow, so there could be a broad range of high-water levels that are well separated from low-water levels. Therefore, indicators of flow may occur over a broader area in streams with steeper FDCs than in streams with flatter FDCs. In Figure 114, the Amite River in Louisiana has a $Q_{1\%}$ that does not appear to fall at a significant inflection point on the curve, whereas the $Q_{5\%}$ does. This means that there is greater variability in storm flows, resulting in a wider variety of flows that may be shaping the channel. The average base flow and mean annual were calculated for this site and are shown on both the FDC and the hydrograph. The FDC shows that the Amite is a system with substantial base flow. The base flow is the flow in the stream from groundwater. The base flow at this site is so high and occurs so frequently that it is only equaled or exceeded 40% of the time. Sites, such as the Amite, can have stable base flow, but they will exhibit more variability at the storm-flow end of the FDC.

Analysis of FDCs is only helpful at sites with USGS streamgage data or when looking over regionally similar streams. Regional differences between FDCs are described in Figures 116 and 117 for all the case studies included in this manual, which span all eight regions of the country. The daily discharge is divided by the mean annual discharge to create a dimensionless discharge so that differences between sites are easier to observe. The comparison of curves shows which sites are drier and which sites have larger groundwater, or base flow, input. Understanding landscape controls, which are discussed in Chapter 4, helps with understanding what streams are regionally similar to each other and therefore would have similar FDCs. For instance, Chester Creek in Alaska has a very stable flow throughout the FDC. There is a large base-flow component, and the curve remains flat all the way to the $Q_{1\%}$. Chester Creek would be dominated by snowmelt at the high-flow end, which would create a much more stable curve throughout. The San Antonio River in California, however, is dry 45% of the time and has a very steep curve that is likely dominated by a combination of rainfall and snowmelt. Travertine Creek in Oklahoma is a spring fed channel, but it appears that there is some variability in discharge from the spring on the low-flow end of the curve. The regional curves shown in Figures 116 and 117 reveal that there is a greater similarity between streams in some regions of the country (Northeast and Southeast) and more variability between sites in other regions (Northern Prairies, Southwest, and Southern Prairies). This is a small sampling; therefore, these curves should always be considered in relation to surrounding landscape characteristics.

Figure 116. FDCs from one stream in each of the eight regions of the country.

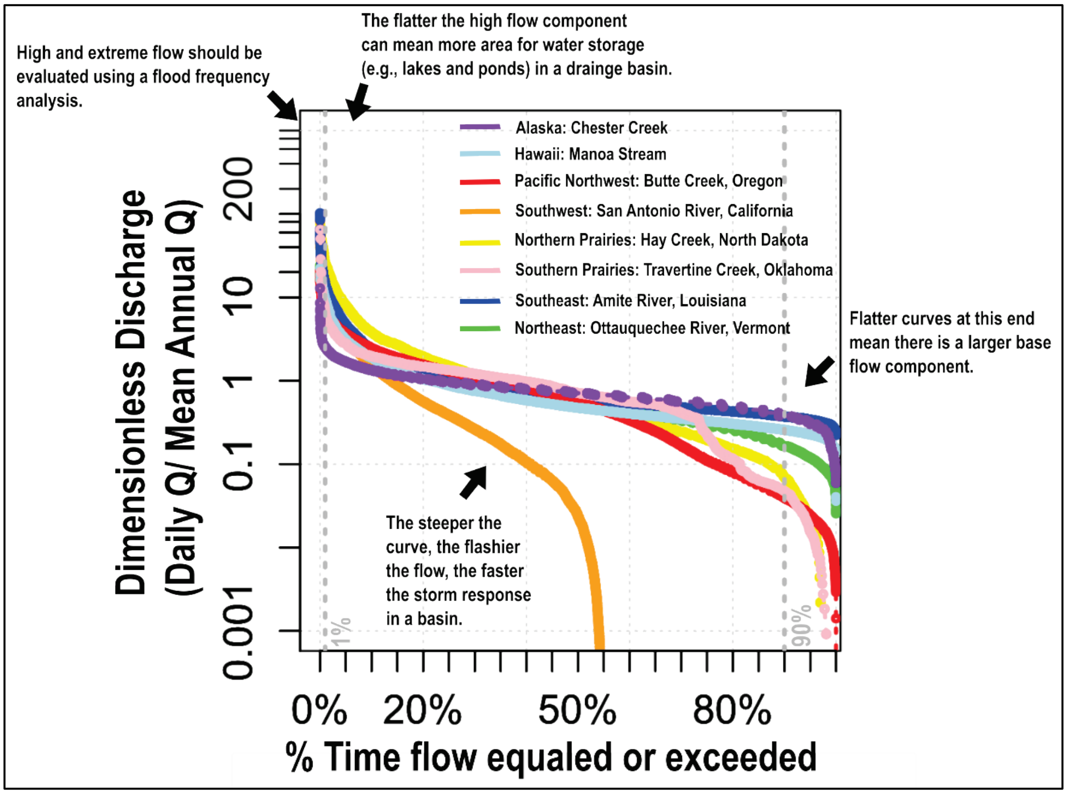
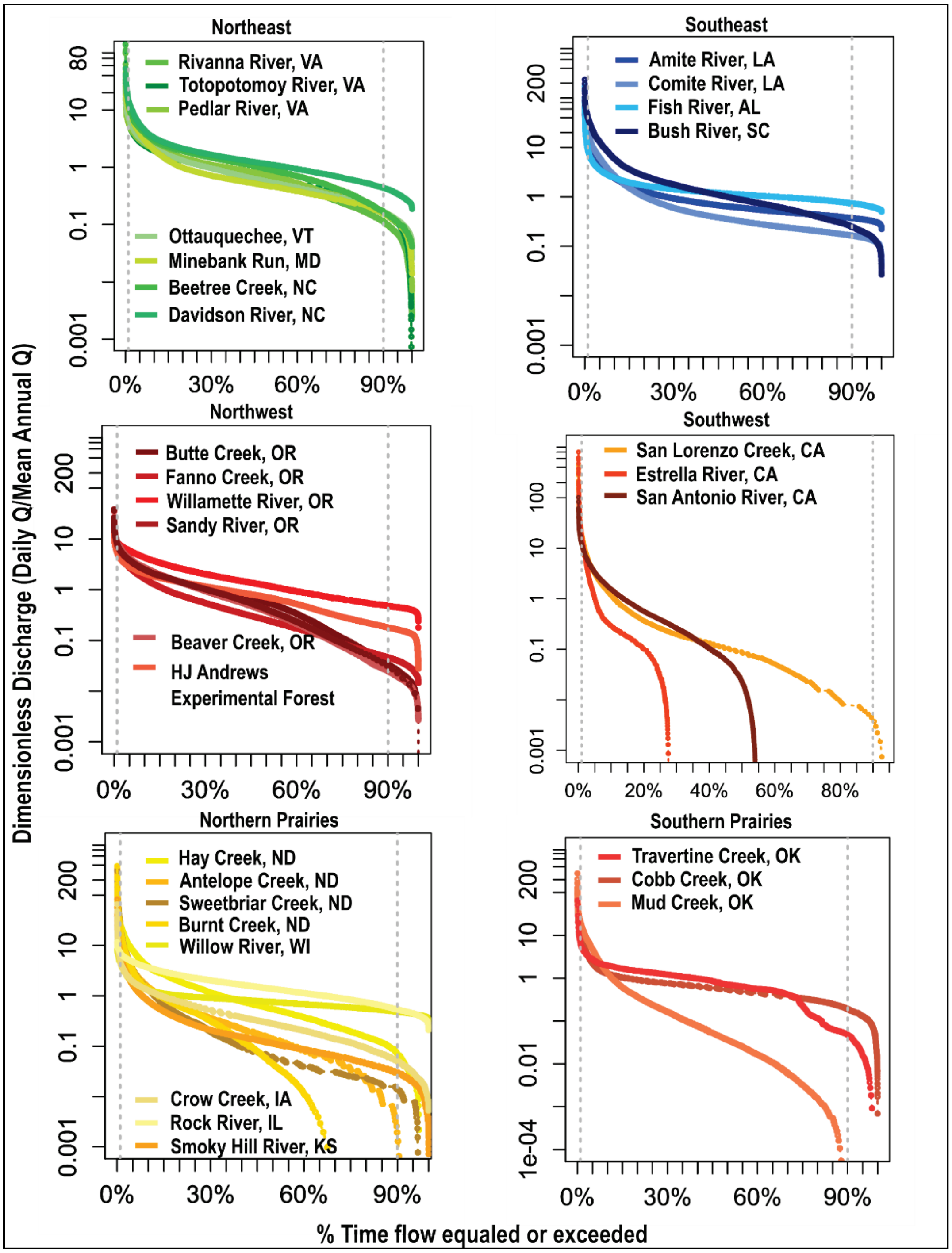


Figure 117. FDCs for streams in each region of the country.



5.4.1.3 Combining USGS streamgage information with observations at a site

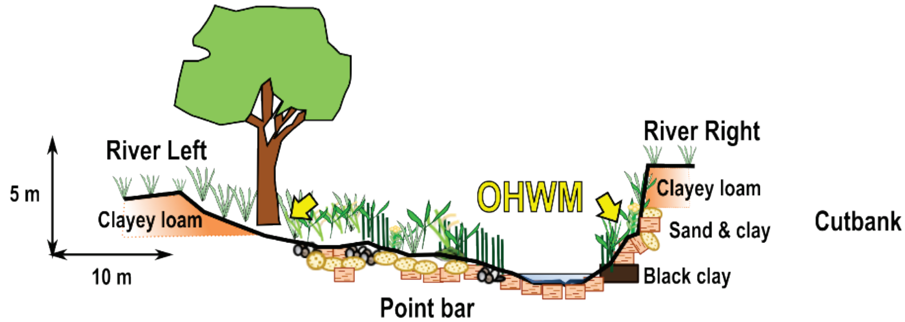
As noted, the online USGS streamgage information, including hydrographs and FDCs, can provide information on what types of flows occur at a site prior to the site visit. FDCs can be accessed under the Streamgage

Dashboard on the USGS WaterWatch website* or by going directly to the FDC builder†. Data downloaded and visualized with online software may look a little different from the FDCs and hydrographs shown in the preceding figures. For instance, Figure 118 shows how an FDC would appear on the USGS WaterWatch website. The FDCs in the figures are shown with the high-flow component included to help illustrate where the cutoff for the lower bound of high flows occurs on the flow spectrum. Figure 118 provides a USGS output hydrograph and FDC with annotations and a comparison to field data for Antelope Creek in North Dakota. The flow hydrograph for the Water Year 2017 and the FDC indicate that the stream was at low flow during the site visit. The curve is steeper with a small base-flow component in the channel, indicating a somewhat flashy system. There were no high flows during the 2017 water year, which resulted in fine sediment deposition throughout the channel bed and algae growth along the edges of the channel and on the channel bed. The lack of any high flows prior to the site visit may also mean that the high-flow indicators may be somewhat obscured by vegetation. The FDC shows that high flows are greater than 300 cfs, indicating that the elevation of the OHWM should be well above the current water surface. Figure 119 shows where the OHWM would fall on a flood-frequency curve, which is well above the lower limit of high flows identified on the FDC and well above the lower flows observed during the site visit. The USGS houses the peak flow data needed to develop flood-frequency curves, but the flood-frequency curves are not available online. Some flood-frequency curves may be available through USGS publications. These curves often need to be updated with the most recent data; therefore, it is best to develop these curves when needed. The methods used to develop the flood-frequency curve shown in Figure 119 are presented in Hamill and David (2021).

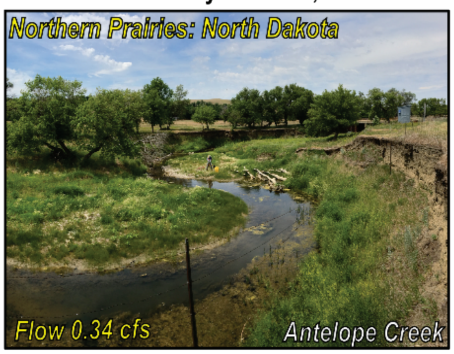
* https://waterwatch.usgs.gov/?id=wwsa

† https://waterwatch.usgs.gov/index.php?id=wwchart_fdc

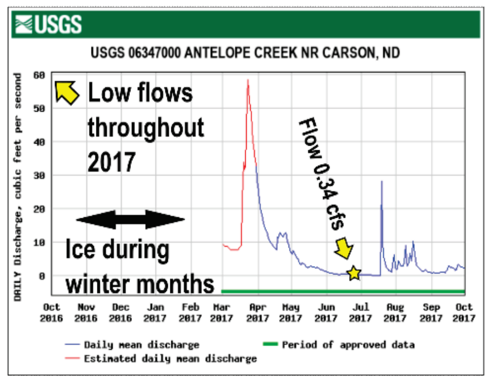
Figure 118. Case study showing how to evaluate and interpret USGS streamgage data on Antelope Creek. (Graphs adapted from USGS n.d.d.)



Date of survey: June 27, 2017



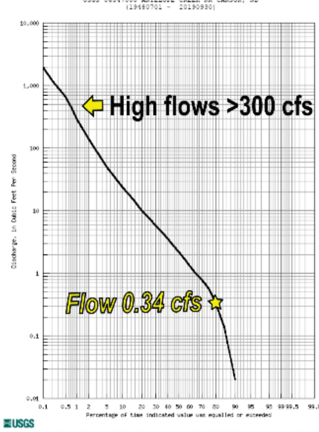
Average Daily Data from Water Year 2017



Length of gage record = 73 years
Daily data record: 1948–2021
Peak flow data record: 1943–2020

*Streamgage is currently active and has a long record.

Flow Duration Curve



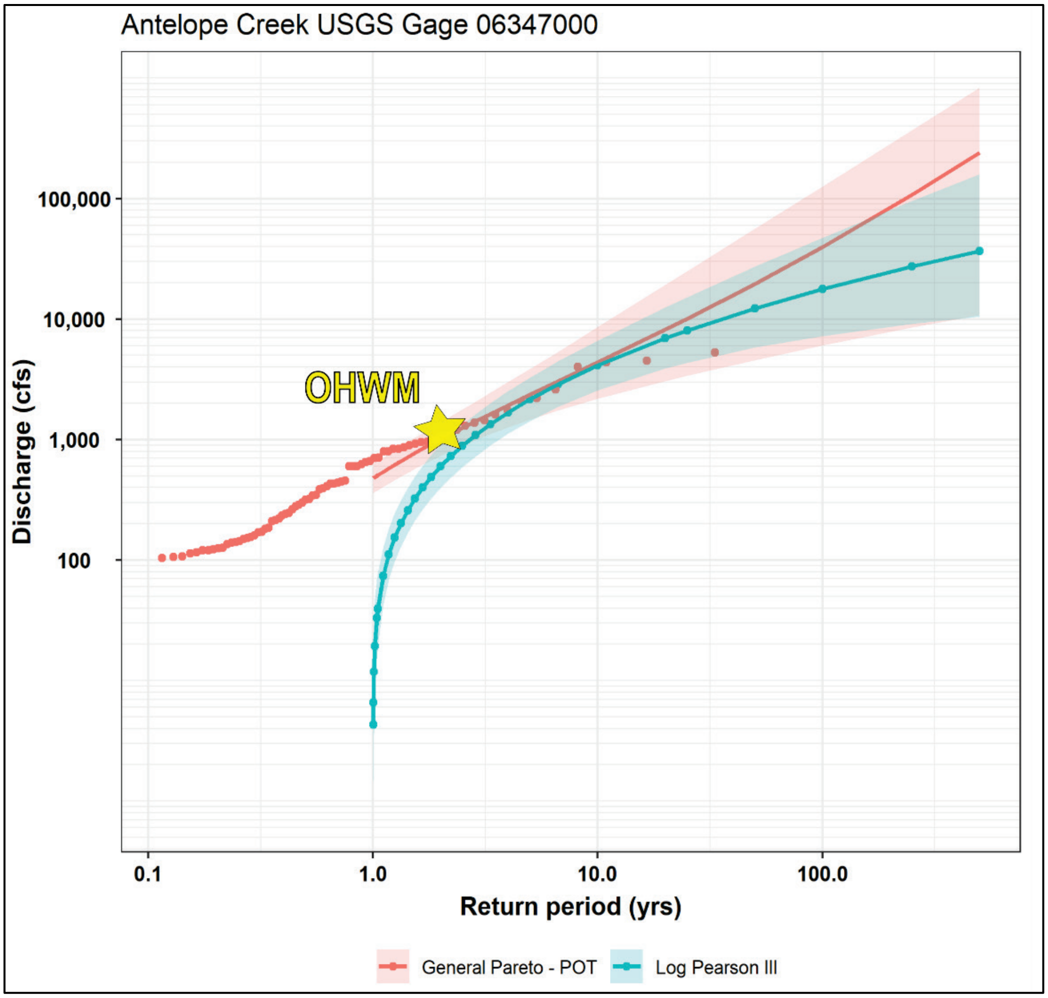
*The OHWM should be well above the current water level. The flow variability at this site may result in indicators being more spread out as well.

Interpretation of streamgage data:

*Flow duration curve is steep, indicating more variability in flows at this site. There is only a small regular base flow component, with flows that occur ~50% of the time being less than 2 cfs. The flow during the site visit was at low flow.

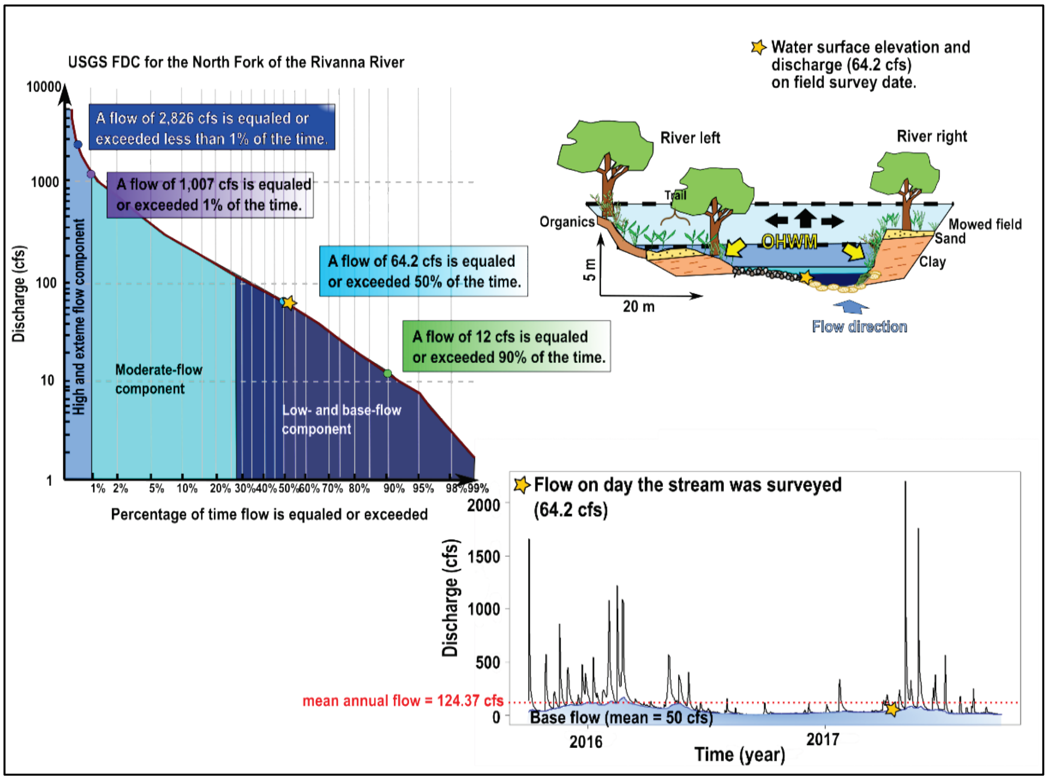
*High flows at this site would be greater than 300 cfs. The highest flow during 2017 was less than 60 cfs, which would still be in the moderate-flow category. Therefore, no high or extreme flows occurred in 2017. During winter months, the stream was likely iced over. The lack of high flow may explain the large amount of fine sediment deposition and algae growth on the channel bed.

Figure 119. The flood-frequency curve for Antelope Creek shows the discharge for the OHWM at this site. This flood-frequency curve was created using the methods described in Hamill and David (2021).



Cross sections presented throughout this manual demonstrate where low, moderate, and high flows would occur for each stream. Flow models were used to characterize water surface elevation at each of these flow levels (Hamill and David 2021). Figure 120 combines the information from an FDC with modeled streamflow information for the NF Rivanna River cross section discussed in Chapter 3. The boundaries between low, moderate, and high flows were interpreted using the FDC. The extreme-flow component is a boundary between in-channel flows and floodplain flows and lumps together both intermediate and large floods. These boundaries are shown as solid lines for demonstration purposes, but there would really be more of a gradient between each of these flow categories. Streamflow was at low flow during the site visit, which can be seen in both the FDC and hydrograph for the two surrounding water years (2016 and 2017). The FDC shows that, during the time of the survey, 64.2 cfs was equaled or exceeded 50% of the time. The mean base flow during the period of record was 50 cfs, and the mean annual flow was 124.37 cfs. Therefore, the flow during the field site visit was just above the base flow and not near high flow. This places the observations of flow indicators near the water surface during the day of the field survey into a broader context. Any indicators adjacent to the current water surface would then be related to low and moderate flows and not high flows.

Figure 120. FDC, stream hydrograph, and water surface elevation on day of survey versus OHWM elevation. The location of the OHWM on the flood-frequency curve is shown in Fig. 113. The extreme- and high-flow components are combined on the FDC.



5.4.1.4 *Understanding high flows and recognizing high-flow indicators using USGS streamgage data and flow models*

USGS streamgage data can be used to evaluate flows through analysis of hydrographs and FDCs and to build flow models for a site using programs like HEC-RAS. Flow models can be useful for characterizing the water surface elevation at high flows (Gartner, Lichvar, et al. 2016; Gartner, Mersel, and Lichvar 2016; Hamill and David 2021), but they should be used with good understanding of the underlying assumptions and uncertainty associated with the models. WoE was used to identify the OHWM elevation using physical indicators. The modeled discharge for the OHWM elevation is 2,826 cfs for the NF Rivanna River site (Hamill and David 2021). Although this is presented as an exact number, the flow model used to calculate the streamflow for this elevation has uncertainty inherent in the calculations. Calculations of discharge are based on accurately predicting velocity, which is based on estimating roughness in the channel. There is often error in the roughness estimates, which results in error in velocity calculations, water depth, and streamflow (David et al. 2010; Yochum et al. 2012; Rickenmann and Recking 2011). Therefore, the uncertainty in the NF Rivanna River flow model is represented by a 95% confidence interval, with Q_{ohwm} between 2,777.6 and 2,874.4. This flow is equaled or exceeded less than 1% of the time on an FDC and has a 1.2-year recurrence interval on a flood-frequency curve (Hamill and David 2021). A 1.2-year recurrence interval means that there is an 83% chance of getting a flow of that size or larger in any given year.

Because a range of high flows is responsible for the indicators used to identify the OHWM, no single recurrence interval or flow should be used nationwide to estimate the OHWM. As such, the figures used in this manual depict a range of high flows responsible for the expression of OHWM field indicators. Although high flows represent a small percentage of an FDC, that range of flows represents a larger percentage of a stream's cross section than low or moderate flows (Table 8). Low and moderate flows are important for stream function and ecosystem maintenance, but high flows are much more likely to be responsible for channel form. That is why the range of high flows is shown as a band in each of the case-study cross sections. The percentage of the total cross-sectional area that the high-flow band represents is much larger than the low- or moderate-flow bands. This illustrates why high flows are so important to shaping the channel. The small area made up by low flows in a stream cross section can be seen in Table 8. Generally, these flows make up a very small component of the total cross-sectional area, ranging from 0.9%–37.2%, which emphasizes that the high flows likely have a more significant influence on channel shape and the persistent stream features recognized as high-flow indicators. Nonetheless, because low flows occur during most of the year, as evidenced by the FDCs, low-flow indicators can be confused with high-flow indicators when the entire cross section is not fully considered while identifying the OHWM. The OHWM should occur within the zone along a stream cross section where high flows occur.

Table 8. Drainage area (D_A) and flow characteristics for streams used in case studies. Included are modeled OHWM flows (Q_{OHWM}) and bankfull flows (Q_{bkf}) and a comparison of total cross-sectional area ($Area_{TOT}$) versus the cross-sectional area for the mean annual flow ($Area_{MAF}$).

Region	Stream Name	D_A, km²	Cross Section	Q_{OHWM}, ft³/s	Q_{bkf}, ft³/s	$Area_{BKFL}$, ft²	$Area_{MAF}$, ft²	% Area contained by low flows ($Area_{MAF}$/$Area_{BKFL}$ *100)
Northeast	Rivanna River	279.1	XS1	2,826.2	6,452.7	768.2	52.7	6.9
			XS2	3,647.3	6,452.7	1,105.9	93.6	8.5
	Totopotomoy Creek	66.62	XS1	948.2	1,669.3	163.2	10.8	6.6
			XS2	712.6	1,114.2	159.7	25.8	16.2
Southeast	Beetree Creek	14.1	XS1	311.5	157.5	38.1	6.5	16.9
			XS2	199.5	595.8	115.1	6.5	5.6
	Davidson River	104.3	XS1	4,887.2	4,881.5	646.4	58.1	9.0
			XS2	3,840.8	3,990.6	511.6	68.9	13.5
	Bush River	303.3	XS1	3,150.1	4,809.9	756.3	50.6	6.7
			XS2	3,015.2	4,815.2	762.0	67.8	8.9
Southern Prairies	Cobb Creek	341.2	XS1	724.0	857.8	326.4	25.8	7.9
			XS2	730.7	857.8	373.9	29.1	7.8
			XS3	703.1	857.8	333.1	16.1	4.8
	Mud Creek	1488.5	XS1	4,944.1	3,338.3	1,556.6	94.7	6.1
			XS2	5,305.0	5,826.9	1,863.9	93.6	5.0
Northern Prairies	Antelope Creek	614.3	XS1	1,010.7	1,010.7	314.4	10.8	3.4
			XS2	1,147.0	786.1	86.4	16.1	18.7
	Burnt Creek	285.7	XS1	515.6	313.9	106.9	4.3	4.0
			XS2	488.0	381.4	135.9	3.2	2.4
	Hay Creek	82.4	XS1	392.3	392.3	90.4	4.3	4.8
			XS2	449.6	667.1	157.3	12.9	8.2
	Sweetwater Creek	407.4	XS1	994.1	1,204.2	103.4	4.3	4.2
			XS2	973.3	688.6	128.6	5.4	4.2
Southwest	Estrella River	3466.6	XS1	12,476.0	13,300.9	1,164.2	10.8	0.9
			XS2	8,171.5	13,068.9	1,249.2	14.0	1.1
	San Antonio River	558.1	XS1	3,427.6	4,302.7	582.4	68.9	11.8
			XS2	3,804.8	7,114.5	892.5	119.5	13.4
	San Lorenzo River	604.0	XS1	734.5	1,005.4	239.6	23.7	9.9
			XS2	773.4	897.0	342.1	54.9	16.0
			XS3	757.9	757.9	277.5	103.3	37.2
			XS4	711.6	1,461.7	216.7	16.1	7.5
Alaska	Chester Creek	2.3	XS1	165.3	165.3	62.4	19.4	31.0
			XS2	162.4	162.4	40.9	9.7	23.7

Table 8 further emphasizes the variability between cross sections at a site (i.e., XS1 versus XS2). As discussed in Section 4.3, two to four cross sections were surveyed at a site, and the OHWM and bankfull were determined based on field indicators. The variability in the calculated discharge between cross sections emphasizes the inherent variability identified because of the range of high flows responsible for the OHWM indicators, the fact that the water surface does not flow through the stream as a flat surface, and inherent errors in modeling flow. Calculating the discharge using flow models and cross section variability at each site is discussed further in Hamill and David (2021).

5.4.2 Accessing hydrologic information using StreamStats and understanding regional relationships

Regional relationships can predict expected channel dimensions for high flows, which in turn relate to expected channel dimensions for flows that reach the OHWM. Drainage area is closely correlated to channel size and discharge, meaning that channel dimensions can often be predicted through the development of regional relationships (Leopold and Maddock 1953; Leopold et al. 1964; Dunne and Leopold 1978). Furthermore, drainage area is easy to measure and has been closely correlated to bankfull discharge (Dunne and Leopold 1978). Many websites listed in Table 7, such as StreamStats and Model My Watershed, now draw watershed boundaries for the user. Watershed boundaries that are drawn with automated processes should always be checked before using any of the summary information, such as drainage area. Although average dimensions can be determined using these regional relationships, there is large variability both between regions and at a site. Generally, discharge will increase less rapidly than drainage area because (1) storms will cover limited areas, (2) there are differences in land use throughout a basin, and (3) water is stored in groundwater, lakes, ponds, and reservoirs. Nonetheless, it can be helpful to have an idea of the range of widths and depths to expect at a site for high flows so that an investigation for indicators occurs at appropriate locations adjacent to the channel. Therefore, regional regressions, information on where to find them, and precautions on their use are briefly described.

The relationship between drainage area and any frequency of flow can be represented with Equation (1):

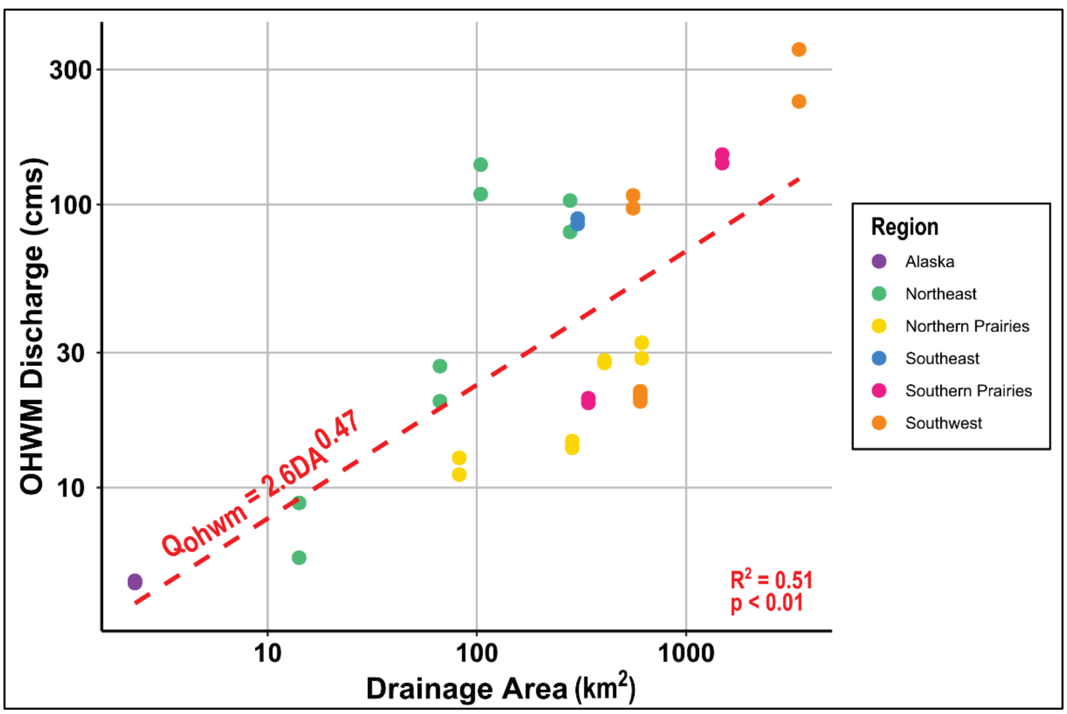
$$Q_F = bD_A^n, \tag{1}$$

where

Q_F = discharge from a flood of a given frequency,
D_A = drainage area,
B = coefficient that depends on climate and flood frequency, and
n = an exponent that has a value less than 1 (often between 0.7 and 0.8; Dunne and Leopold 1978).

Figure 121 shows that there is a relationship between the OHWM discharge and drainage area; this is similar to what is expected with bankfull discharge. The scatter in the plot is related to regional variations in climate, geology, topography, and vegetation throughout the United States. Many studies have shown improved relationships by developing regressions for specific regions rather than using a nationwide curve or some other large-scale division of regions (Bieger et al. 2015; Blackburn-Lynch et al. 2017). There are not enough case studies within the eight regions described in this manual to develop individual regressions, but other studies have already summarized regional curve development (Faustini et al. 2009; Bieger et al. 2015; Blackburn-Lynch et al. 2017).

Figure 121. OHWM discharge versus drainage area for case study sites plotted on a log-log plot.



Similar to the relationship between discharge and drainage area, width, depth, and velocity can be related to drainage area:

$$Q_{bkf} = aDA^{b}, \quad (2)$$

$$A_{bkf} = cDA^{d}, \quad (3)$$

$$W_{bkf} = gDA^{h}, \quad (4)$$

$$D_{bkf} = jDA^{k}, \quad (5)$$

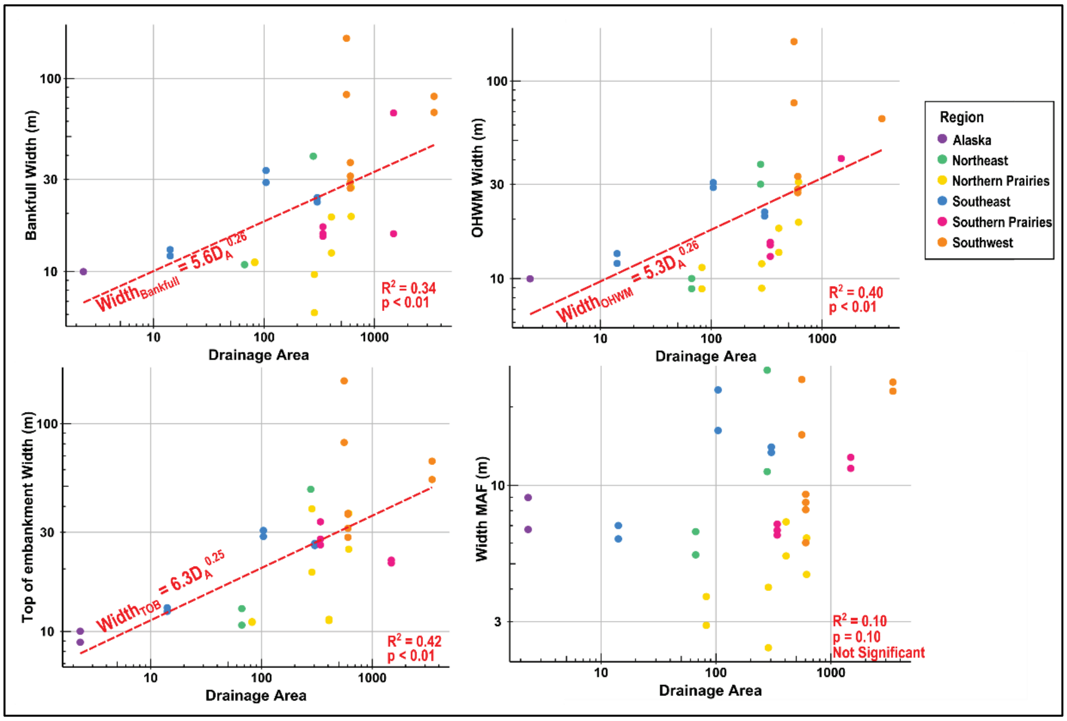
where

Q_{bkf} = bankfull discharge (cubic meters per second),
A_{bkf} = cross-sectional area (square meters),
W_{bkf} = bankfull width (meters), and
D_{bkf} = bankfull mean depth (meters).

The coefficients (a, c, g, and j) and the exponents (b, d, h, and k) are all empirically derived using regional data. This formulation of the curve assumes that drainage area is the dominant control on discharge. As discussed in Chapter 4, there are many other landscape controls that can influence discharge and ultimately channel dimensions, such as differences in climate, topography, soils, land cover, and other in-stream factors. Understanding how these landscape factors can alter the movement of both sediment and water can help explain the site variability in channel dimensions and any observed scatter in these curves. Generally, there is more scatter in regional curves developed using drainage area rather than bankfull discharge as the independent variable (Castro and Jackson 2001; Soar and Thorne 2001; Bieger et al. 2015), but as discussed, drainage area is an easier parameter to measure and use when discharge is not known or cannot be calculated. OHWM identification is often occurring where there are no streamgages or other information about discharge. Therefore, regional curves that relate bankfull channel dimensions to drainage area are the most useful for OHWM identification.

Figure 122 shows a significant relationship between bankfull width, OHWM width, and top of embankment width versus the drainage area. The wide scatter is because of cross sectional variability at each site as well as differences between regions. Nonetheless, three of the plots show the expected trend of an increase in channel width with drainage area. The fourth plot in Figure 122 shows that the width at the elevation of the mean annual flow is not related to drainage area. The lack of relationship reinforces that the mean annual flow does not have any significant control on channel morphology and should not be calculated or used as a proxy for flows related to the OHWM. No relationship between mean annual flow and drainage area means that it is not likely to leave the persistent physical and biological characteristics that are used to identify the OHWM.

Figure 122. Relationship of bankfull, top of embankment, and OHWM channel widths to drainage area. Data are plotted on a log-log scale. Variability in width at a site can be assessed because the points that are at the same drainage area are from the same reach of stream.



Despite the recognized usefulness of regional regressions, it is still difficult to find developed curves for different regions of the US that are provided in an easy-to-access format. Bieger et al. (2015) and Blackburn-Lynch et al. (2017) provided references and summary tables for regional relationships developed throughout the contiguous US. The USGS published studies on regional curves that can be accessed online. For instance, Cinotto (2003), Chaplin (2005), and Krstolic and Chaplin (2007) published studies on regional curves for Pennsylvania, Maryland, and Virginia.

Researchers have attempted to reduce variability in regional curves by stratifying data based on ecoregions (Castro and Jackson 2001; Faustini et al. 2009; Splinter et al. 2010), hydrologic regions (Blackburn-Lynch et al. 2017), water resource regions (Faustini et al. 2009), and physiographic regions (Castro and Jackson 2001; Johnson and Fecko 2008). Generally, improving the methods for stratifying regions reduces the scatter on regional curves (Faustini et al. 2009; Bieger et al. 2015; Blackburn-Lynch et al. 2017). For instance, regional curves are often developed for similar physiographic provinces, but issues may arise because of variability within the province from differences in climate, geology, and vegetation. Physiographic provinces divide the country based on common topography, rock types, structure, and geologic and geomorphic history (Fenneman and Johnson 1946). Blackburn-Lynch et al. (2017) developed better fitting regional curves by further dividing the country based on hydrologic landscape regions (see also Wolock et al. 2004). The regions are subdivided based on hydrologic characteristics that are related to land-surface form, geology, and climate for watersheds that are about 212 km^2 in size. Other factors, such as slope, geologic material, and density of riparian vegetation, can influence a stream's morphology (Rosgen 1994; Schumm 1977; Hession et al. 2003; Anderson et al. 2004; Wohl and David 2008). Schumm (1977) demonstrated that streams with higher amounts of silt and clay in the streambed and banks tend to be narrower and deeper. Faustini et al. (2009) reported that there were differences in regional curves for streams with predominantly fine material (i.e., silt and sand) versus coarse bed material (i.e., gravel, cobble, and boulder). However, despite expectations that bedrock channels would not scale similarly to alluvial channels with drainage area, Wohl and David (2008) reported the opposite to be true. Bedrock channel widths scaled with drainage area and discharge in a way that was similar to alluvial channels ($w \approx D_A^{0.3}$). They hypothesized that bedload transport may be a fundamental control on width in these channels, which was not included in their analysis. This emphasizes the natural variability and complex controls that influence stream channel morphology.

Similar to studies on geologic materials, differences in channel widths can occur because of differences in riparian vegetation, such as forested versus grassland regions (Hession et al. 2003; Anderson et al. 2004), and degree of urbanization (Doll et al. 2002). Overall, improved stratification improves fits to the curves, but sites influenced by reservoirs, irrigation, grazing, and urbanization tend to have poorer fits and need further study (Faustini et al. 2009; Blackburn-Lynch et al. 2017). Furthermore, regional models developed for semiarid to arid environments have not performed as well as those developed in the eastern portion of the US, which is characterized by humid and subhumid environments (Blackburn-Lynch et al. 2017). Therefore, there may be value in further stratifying based on vegetation, land use, and other geologic factors. If regressions need detailed, site-specific information, those can be less useful when trying to develop curves that cover a larger area and for the user who may not have access to those data.

Other researchers have improved regionalization by using multiple linear regressions to include other independent variables that further explain the natural variability in a population that is not explained by drainage area (Hey and Thorne 1986; Julien and Wargadalam 1995; Faustini et al. 2009). The USGS sometimes uses this method when developing regional relationships that are incorporated into programs such as USGS StreamStats (Table 7). StreamStats uses regional relationships using streamgage data to predict flood frequencies on nongaged streams. The analysis done by StreamStats can help to put flows in context, but it does not provide information on channel geometry. The StreamStats Watershed and Streamflow Report, which can be accessed on the USGS StreamStats website*, provides a summary that includes a link to a published document with the regional equations used to calculate flows in that watershed (Figure 123). These reports can be useful for investigating how a region was stratified (i.e., what independent variables were significant in controlling streamflow).

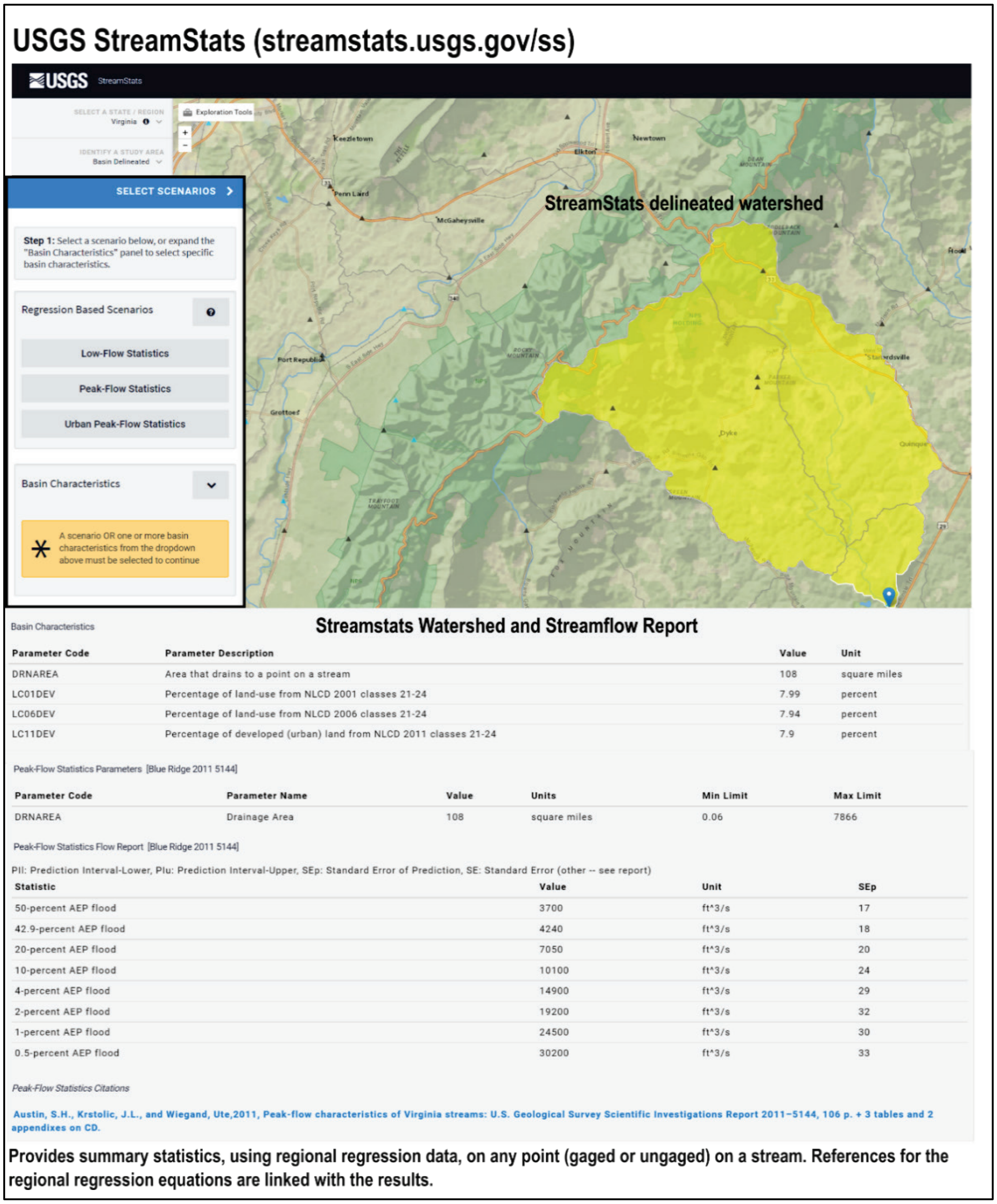
The StreamStats website provides information on drainage area and land use, which can be used with developed regional relationships (Figure 123). Any calculation of width based on drainage area and regional regressions is still only an estimate of an average width. Estimating these widths may help in understanding the relative scale of the system and put the site in context, especially where vegetation has encroached and made it difficult to see the channel boundaries or if the site has been heavily altered by human-made or natural disturbances. However, estimating an average width does not provide the site-specific width, which can vary dramatically. Therefore, StreamStats can assist in understanding the size of high flows in a channel and can provide information on some landscape characteristics within a watershed. Other means, such as a regional curve, would then

* https://streamstats.usgs.gov/ss/

need to be used to understand how this information relates to channel dimensions. This is information that can be gathered prior to a field site visit to better understand the size and scope of a stream or may be used as additional evidence for the field delineated OHWM. Every site will have natural variability in channel widths; therefore, the estimated widths from regional curves should only be used as a general guide for the size and scope of the channel and not as a definitive number. Understanding more about landscape controls on channel morphology can help when interpreting site-specific information.

A last limitation of regional regressions is that they are developed for specific regions and specific ranges of drainage areas. The regressions should, therefore, only be applied to streams that fit within those bounds. The placement of USGS streamflow gages along river networks is biased toward large streams and rivers, with small (i.e., first and second order) streams having <3% of the streamgages in the conterminous United States despite representing 95% of the streams (Poff et al. 2006). Because the regional regression curves are based on streamgage data sets, many smaller streams are not well represented by regional curves. StreamStats often provides a warning if there is a problem with calculations for a site (Ries et al. 2017).

Figure 123. StreamStats provides streamflow hydrologic statistics on gaged and ungaged watersheds. Drainage area and both peak-flow and low-flow statistics can be accessed for each site. Some regions also provide urban peak-flow statistics. (Image adapted from USGS n.d.d.)

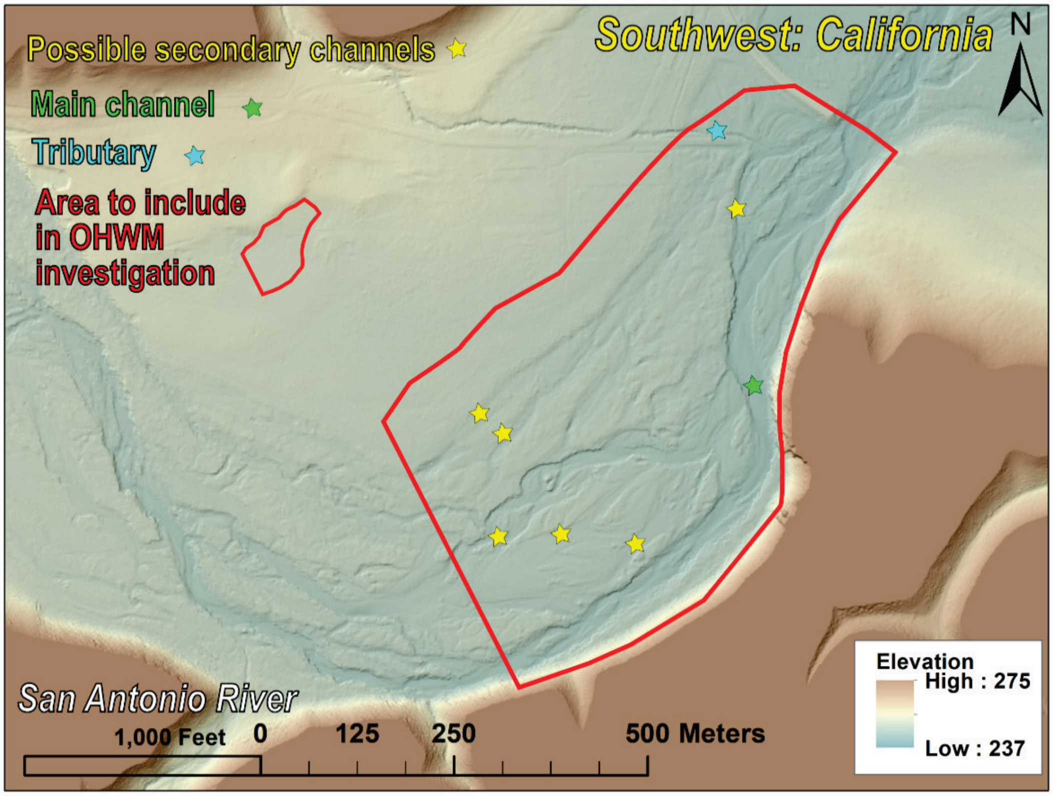


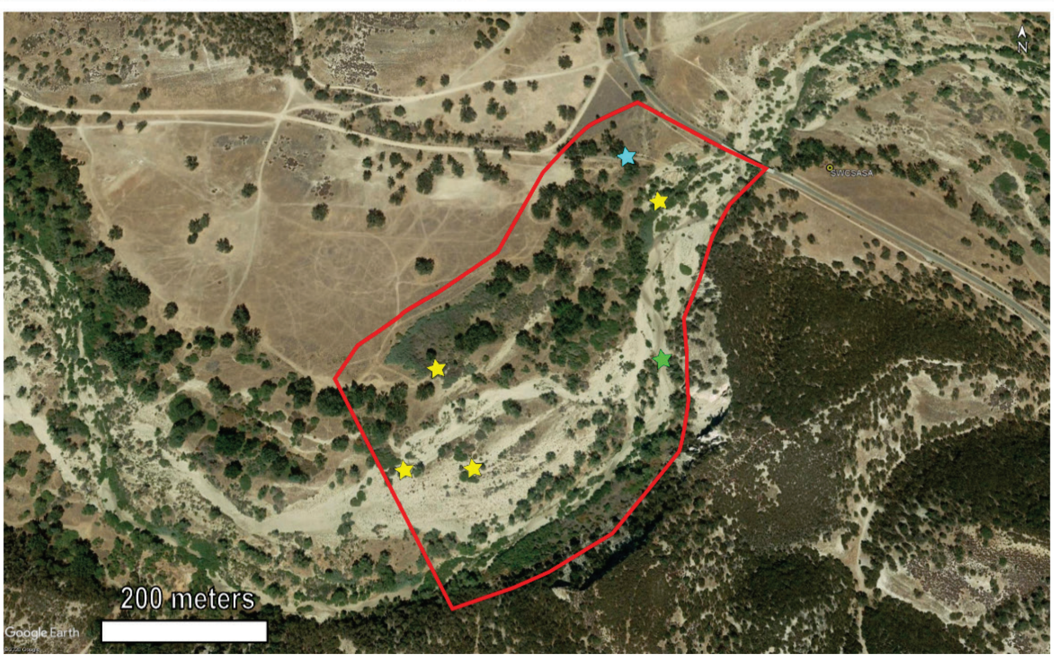
5.5 Airborne lidar topographic data and digital elevation models (DEMs)

Lidar is a form of high-resolution topographic mapping that is becoming increasingly available and can be helpful for initial reconnaissance of field sites (Gillrich and Lichvar 2014). A hardcopy of a shaded relief map from lidar bare-earth data for a site is a valuable addition to a field kit for reconnaissance. These maps provide high-resolution images that can show the location and connectivity of terraces, channel berms and bars, secondary channels, and other geomorphic features (Figure 124). In addition, lidar penetrates vegetation canopy and provides a bare-earth map of forested areas or shrublands that is rarely available from other sources. In the field, a lidar image provides a base map that can be annotated to show locations of features. In large stream systems, features both within and outside of the stream channel can be difficult to view from the ground. Lidar provides a bird's-eye view that can allow the user to see a large feature in its entirety and smaller features within a larger context. This can help with OHWM delineations by allowing a user to either confirm features observed on the ground or identify locations to investigate for possible indicators before the site visit. For instance, Figure 124 provides an example using a lidar product (hillshade) and satellite imagery to investigate a multichannel, or braided, river system prior to a site visit. The lidar hillshade provides a clear image without vegetation and shows the possible locations of secondary channels, the main channel, and tributaries. The lidar hillshade and satellite imagery provide landscape context and allow a priori analysis of the potential location of the OHWM. Both the lidar and satellite imagery indicate that a field investigation of this site should include assessing OHWM indicators across all the possible secondary channels.

Airborne lidar (as opposed to terrestrial lidar, which is ground based and local in scale) is collected by fixed- or rotary-wing aircraft over relatively large swaths that may cover small watersheds or entire counties. Two advantages to airborne lidar are (1) broad coverage at a relatively large scale and (2) penetration of vegetation that produces bare-earth imagery. The data are typically available in large point-cloud files (e.g., LAS files) that can be processed to optimize bare-earth penetration. Alternatively, with a minimal amount of experience with geographic information systems (GIS), preprocessed gridded DEMs can be manipulated to produce local shaded-relief maps, contours, and other topographic data that are ideal for reconnaissance (Gillrich and Lichvar 2014). A DEM is a bare-earth raster grid referenced to a vertical datum. Many of the websites listed in Table 7 include these preprocessed lidar products. A precaution is that airborne lidar data are generally not available for many time periods, and sites may have changed over time. Therefore, the date of the lidar data collection should be considered when examining any lidar products.

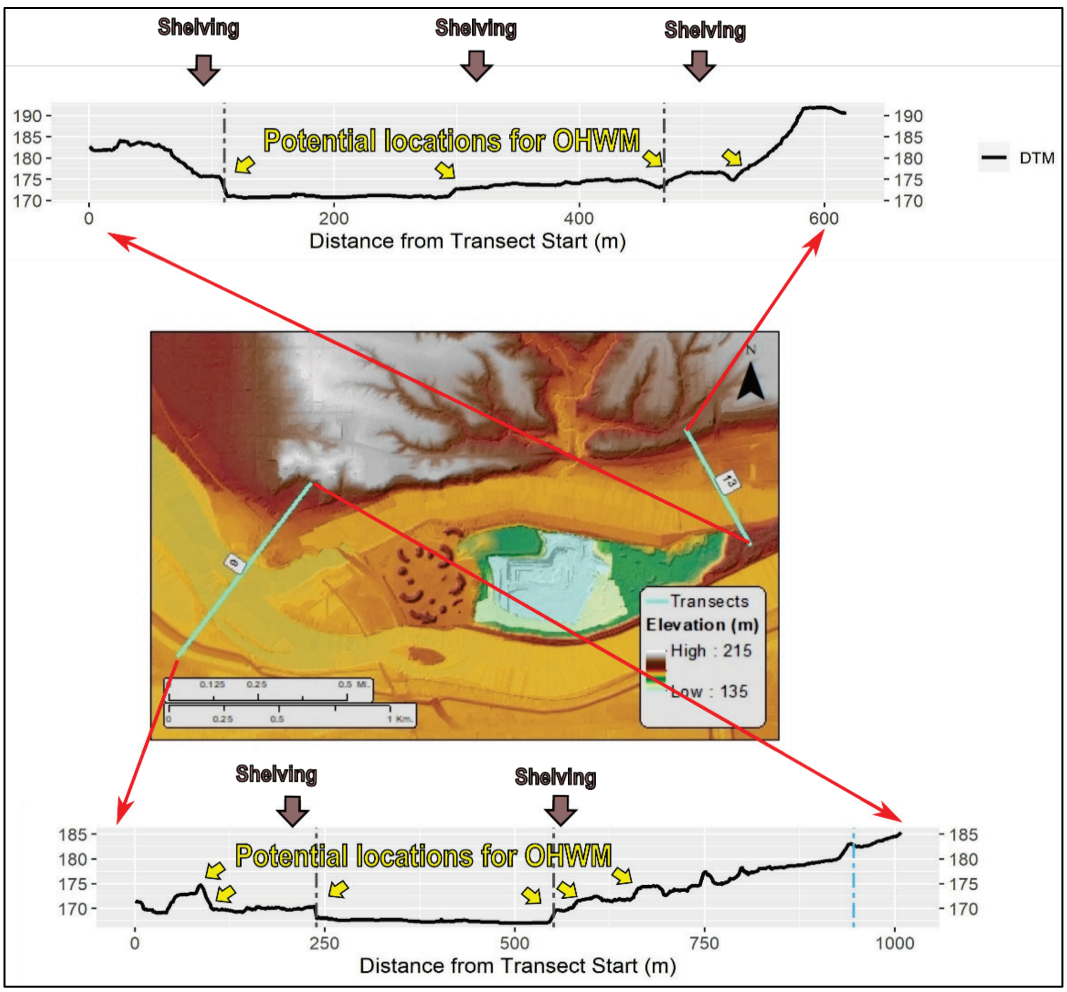
Figure 124. Using lidar (*top*) and satellite imagery (*bottom*) to get an overview of the site prior to a visit. This site includes a braided channel with several possible secondary and floodplain channels in the San Antonio River, California.





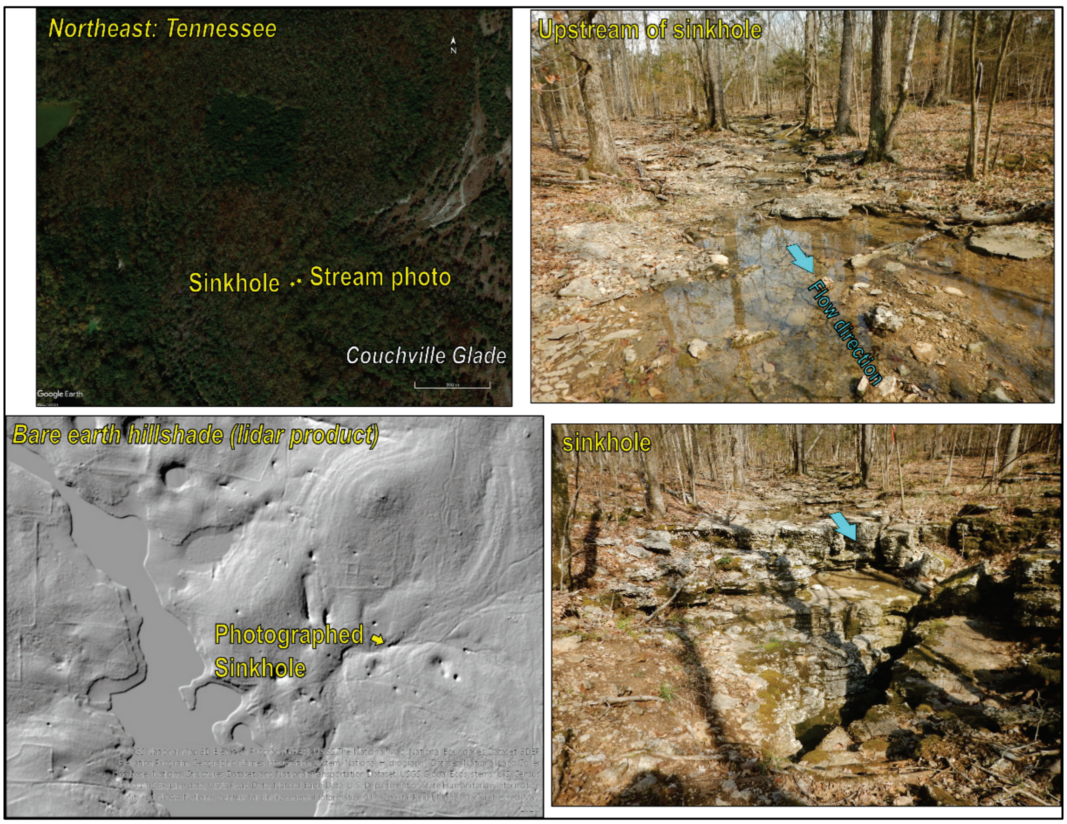
For users with GIS processing skills, shaded relief maps (i.e., hillshade maps) may be enhanced by sky-model shading that uses multiple light sources (Kennelly and Stuart 2014) or other methods. A hillshade, derived from the DEM, can be a valuable layer to extract for viewing channel and floodplain features and making interpretations either prior to or after a field visit (Gillrich and Lichvar 2014). In addition, aerial or satellite images can be draped over the DEM using a GIS to combine visual information from the imagery with topographic changes from the DEM (Bannerjee and Mitra 2004). Changes in topography, in terms of channel and floodplain morphology, can be further investigated by extracting cross sections using the lidar data. Figure 125 provides an example of using lidar products such as hillshade, DEM, and cross sections derived from the bare-earth DEM to look for the potential locations of the OHWM on a large river system. These cross sections were extracted from the lidar using ArcGIS.

Figure 125. Lidar hillshade overlain by digital terrain model (DTM) in the Northeast region, on the Rock River in Illinois. A digitally derived cross section shows shelving and breaks in slope on the surrounding landscape.



Publicly accessible, preprocessed, bare-earth lidar DEMs for areas in the US, from such sources as the National Elevation Dataset (part of the National Map; Table 7), are increasingly available. Many websites now have tools available for visualizing lidar products and extracting more information (Table 7 and Figure 126). For instance, in karst regions, lidar can assist in finding sinkholes underneath dense tree canopy.

Figure 126. A bare earth hillshade map, created from lidar data, shows the sinkholes present below thick tree coverage in this karst area. (*Bottom left* image adapted from USGS n.d.c.)



The scale of spatial data and imagery is an important consideration that may limit the ability to detect subtle OHWM features that are visible in the field. High-resolution imagery with submeter pixels may be available at a cost, but coarser, inexpensive imagery may become pixelated when zoomed in to local sites. Airborne lidar DEM data are typically available at scales ranging from 1 m (2.2 ft) to 4 m (13 ft) grid cell sizes. Shaded relief maps from these data will likely print well at a scale suitable for showing the geomorphic context of sites, but the ability to zoom in on details, such as individual stream banks, will be limited by the grid cell size. Stream banks and prominent terraces for most river channels at unvegetated sites are visible at scales up to 4 m. For smaller streams—especially under thick vegetation canopy—detection of more subtle geomorphic features, such as berms and shelves, may be inconsistent or missing entirely (Figure 108).

From a practical perspective, it is generally beneficial to collect lidar DEM data and aerial or satellite imagery at the highest possible resolution to maximize the capability to zoom in and generate large-scale maps. Although files will be larger and processing slower, the data can be resampled to a lower density for various purposes. For example, a DEM with 1 m cells will have 16 times more pixels than 4 m data for the same area and 100 times more cells than 10 m data. The 1 m data can be converted to larger pixels with smaller files and processing times, but the reverse cannot be done without introducing modeling artifacts.

Airborne lidar point-cloud data in LAS file format can be used to generate bare-earth DEMs at a selected grid cell size that establishes the resolution of DEMs. The optimal cell size is the smallest that can be produced from the data, which will be limited by the mean point spacing of the bare earth point cloud (Figure 127). In some regions of the country, lidar data are not yet available and, therefore, DEMs were developed from contour maps and may be at a coarser (e.g., 10 m or 30 m) resolution. The ability of these DEMs to provide supporting evidence for OHWM identification depends on the size of the stream being evaluated. Figure 128 shows a case study of Totopotomoy Creek, which is approximately 10 m wide at the top of its banks. Individual DEM grid cells represent an average elevation, so in steep terrain, such as narrow channels with high banks or terraces, a 10 m DEM may have cells with elevations that are too high at the low point at which the channel is located. This can obscure channels and prevent channel network processing from mapping the channel topology correctly (Tarboton et al. 1991). In general, the lidar data consistently underestimated the actual channel depth as measured by a field survey for the case studies used throughout this manual. This may be explained by cell elevation averaging, the impenetrability of water by lidar, and postprocessing of the lidar. Additionally, the underestimates by 1, 3, and 5 m data suggest that cell averaging is not the explanation for these resolutions. A similarly consistent underestimate of depths by airborne lidar was noted in numerous dry gullies in forested watersheds of South Carolina and was attributed to lidar post processing, which often filters out points that indicate steep slopes as a means for removing buildings from the bare-earth model (James et al. 2007).

Figure 127. Comparison of a high (1 m) and coarse (10 m) resolution elevation created from a lidar point cloud. The field survey cross section is shown on the aerial imagery (*left*) and as filled in circles on the DEMs (*right*). The extracted, equally spaced cross section is shown on the DEMs as open circles.

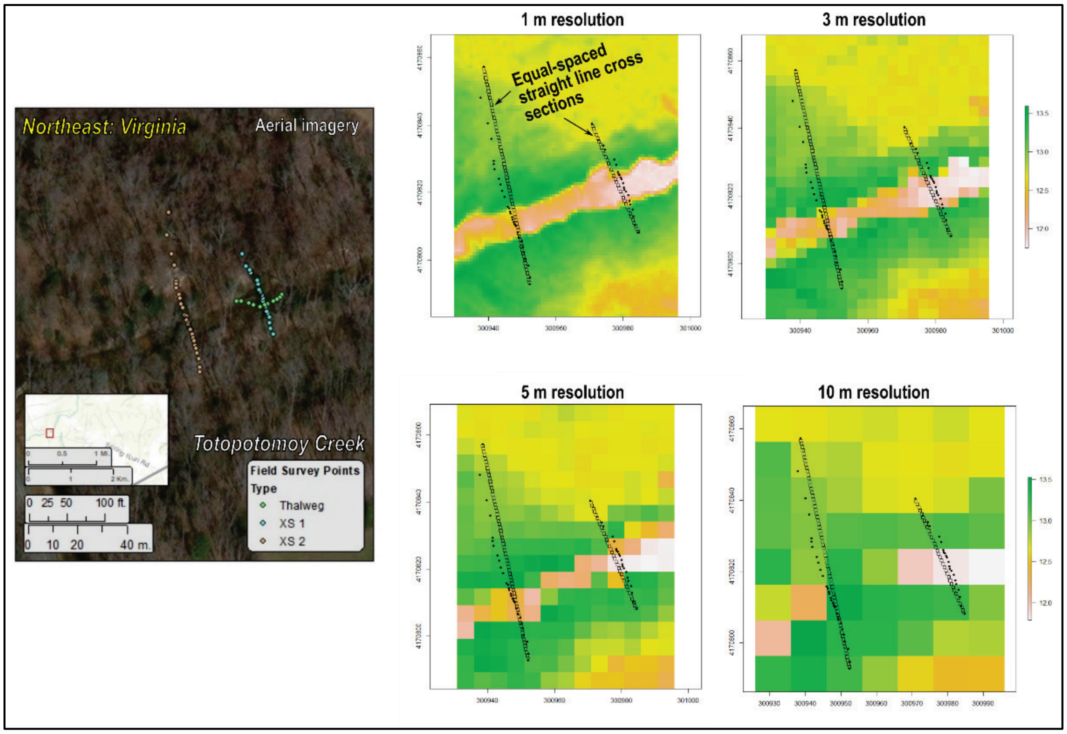
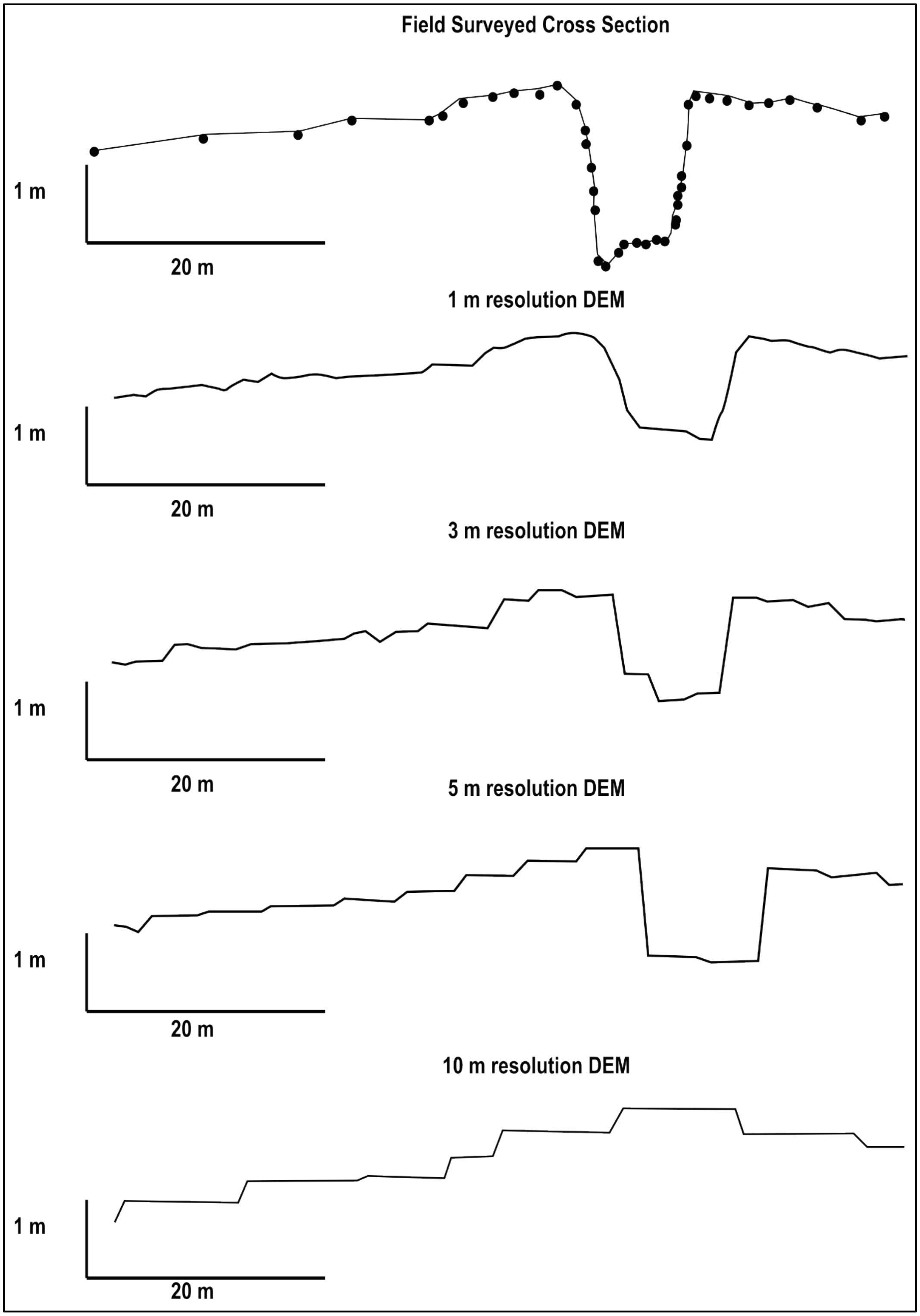
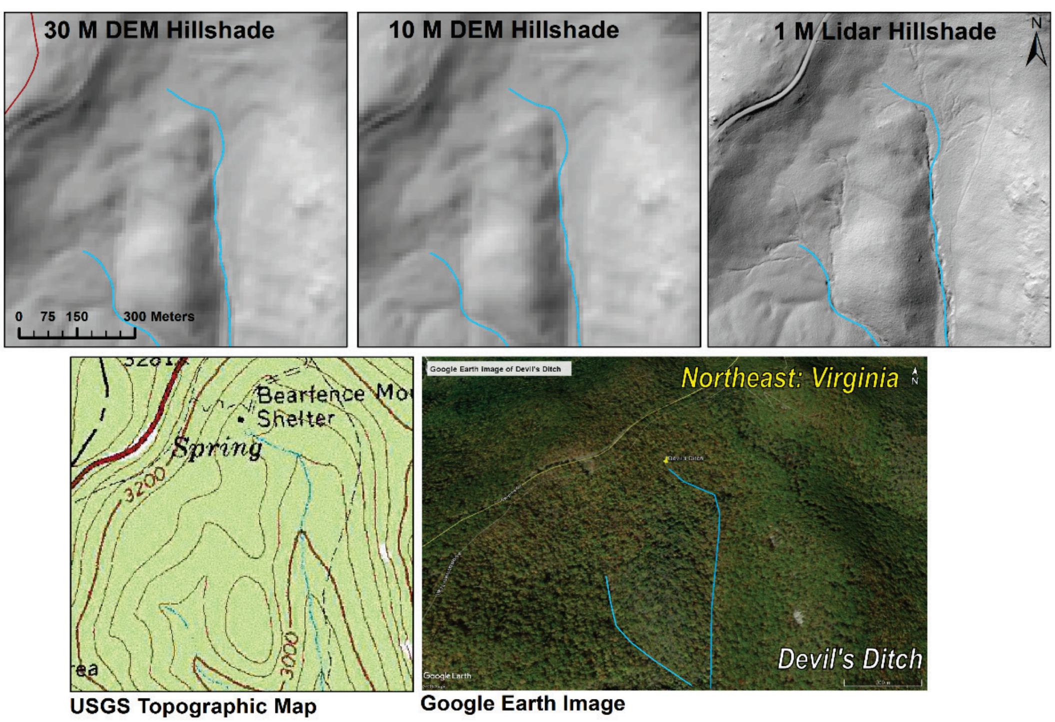


Figure 128. Difference in resolution of data when looking at a cross section measured from a field survey versus a 1 m, 3 m, 5 m, and 10 m resolution DEM. Field surveyed cross section (*top*) is cross section 2 (XS 2) on the aerial image in Fig. 127. Totopotomoy Creek is 10 m wide at the top of the bank; therefore, remote data with a 10 m resolution can miss the channel completely.



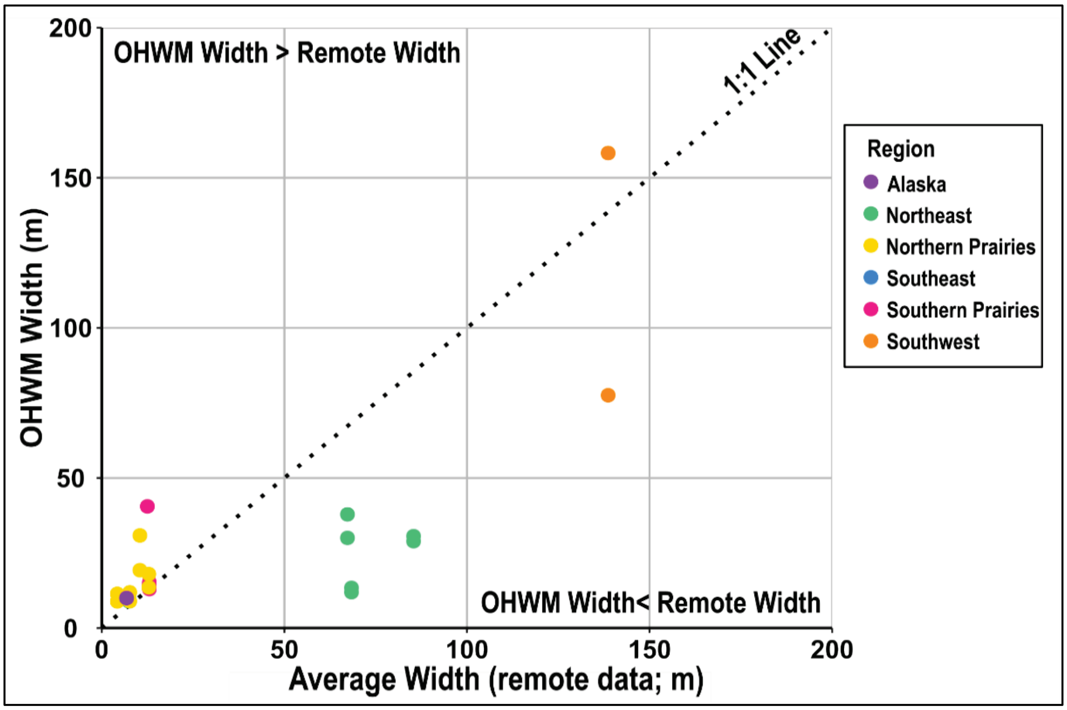
If suitable imagery is available, it can be combined with other spatial data to generate hybrid products. For instance, lidar hillshade products, or coarse-resolution DEMs, can be easily observed with other data sources on websites such as the USGS National Map (Table 7). The USGS National Map provides metadata that allow the user to see if the resolution of the hillshade layer is from a 30 m DEM or from 1 m airborne lidar data. Figure 129 demonstrates the difference in resolution and the ability to observe landscape characteristics using the online resources. The landscape appears blurred when looking at a hillshade derived from a 30 m DEM and much sharper with the 1 m. Overlaid on top of the hillshade maps is the stream network from the NHD data set. The NHD stream network follows the network mapped on the USGS topographic map. The high-resolution lidar provides a detailed view of the landscape relief such that locations of the main channel and, typically, more tributaries can be better inferred. Still, the smaller the stream channel dimensions, the less likely it is that the stream will appear even on a 1 m resolution map. The upper extent of the channel that is mapped on the topographic map and with the NHD is difficult to make out on the lidar hillshade.

Figure 129. Example of resolution differences on lidar hillshade maps and a stream network mapped from NHD map. (*Top* images adapted from USGS n.d.c.)



Remote data such as lidar can also be used to extract channel widths. The remotely extracted lidar widths may be quite different from field survey measurements, which are usually more reliable (Figure 130). Many studies have, with varying levels of success, used remote data to extract stream channel dimensions (Marcus and Fonstad 2008; Hall et al. 2009; McKean et al. 2009; Alber and Piégay 2011; Andreadis et al. 2013; Biron et al. 2013; Poppenga et al. 2013; Sofia et al. 2015; Demarchi et al. 2017; Yamazaki et al. 2019). It can be more difficult to extract channel widths from sites with heavy vegetation coverage. Also, sites with gradual changes in slope along the channel cross sections are particularly difficult to identify remotely. Streams with more distinct tops of banks with a sharp break in slope are more likely to have remote widths extracted that represent the actual channel width.

Figure 130. Comparison of remotely calculated channel widths using lidar versus field-derived OHWM widths.



If needed, airborne lidar can also be used to document changes at a site over time. Airborne lidar data are not available for many time periods, and the temporal resolution of imagery is limited, so change detection between multiple lidar images is not usually possible at present. This will likely change as more data become available in the future. A simple form of change detection for lidar data is to subtract one DEM from another to construct a DEM of difference that shows locations of erosion or deposition that occurred between the acquisition of the two images (Wheaton et al. 2009; James et al. 2012). This information can be useful if the site has changed dramatically over a short period of time.

5.6 Satellite imagery, USGS Earth Explorer, Google Earth, and Small Uncrewed Aerial Vehicles (sUAV)

Earth resources satellites are continuously generating high quality imagery of the Earth that shows regional relationships. Google Earth (Table 7), which provides recent and historical imagery back two or three decades, is one way to quickly access a combination of satellite and aerial imagery for OHWM sites. These images can be used to determine the present land use, roads, urbanization, levees, dams, and vegetation cover in the watershed upstream. Google Earth's historical imagery may also permit detection of changes over time at the site or in the watershed. Advances in optical sub-aqueous remote sensing present opportunities to map in-stream habitats at high submeter resolutions (Marcus and Fonstad 2008). At densely vegetated sites, however, aerial photographs and satellite images may only show the vegetation canopy, and much may be lost in shadows. Satellite imagery also tends to have limited spatial resolutions, which make ground features hard to discern. Thus, these images are best for developing the broad spatial and temporal context of the site rather than for showing subtle local features relevant to the OHWM.

An additional limitation of Google Earth is that the dates on the imagery are sometimes incorrect. When attempting to synchronize the imagery with information, such as streamflow or precipitation, it is important to verify the dates on the imagery in Google Earth (Figure 131). Google Earth provides the image source in the copyright information at the bottom of the image. Multiple images of different dates may be mosaicked (i.e., stitched) together in the display image, however, so the date for the area of concern may differ from the date displayed. The closer to the ground the viewer zooms in, the smaller the area covered and the more likely the view and the date are from a single image. Therefore, the accuracy of the source and date of the image tend to increase as a user zooms into the landscape (i.e., the onscreen information is more likely to be correct for large-scale images). Changes in dates between portions of a mosaicked Google Earth image are easily observed by moving around the image.

Some recent satellite imagery may be available from private companies, but older imagery tends to be from government data. USGS Earth Explorer provides a way to search for an image and verify its metadata, such as the date (Figure 132). Digital Globe (Table 7) is another resource for checking imagery and dates.

Figure 131. How to look up metadata for satellite imagery and verify dates using USGS Earth Explorer. (Image on *right* adapted from USGS n.d.a.)

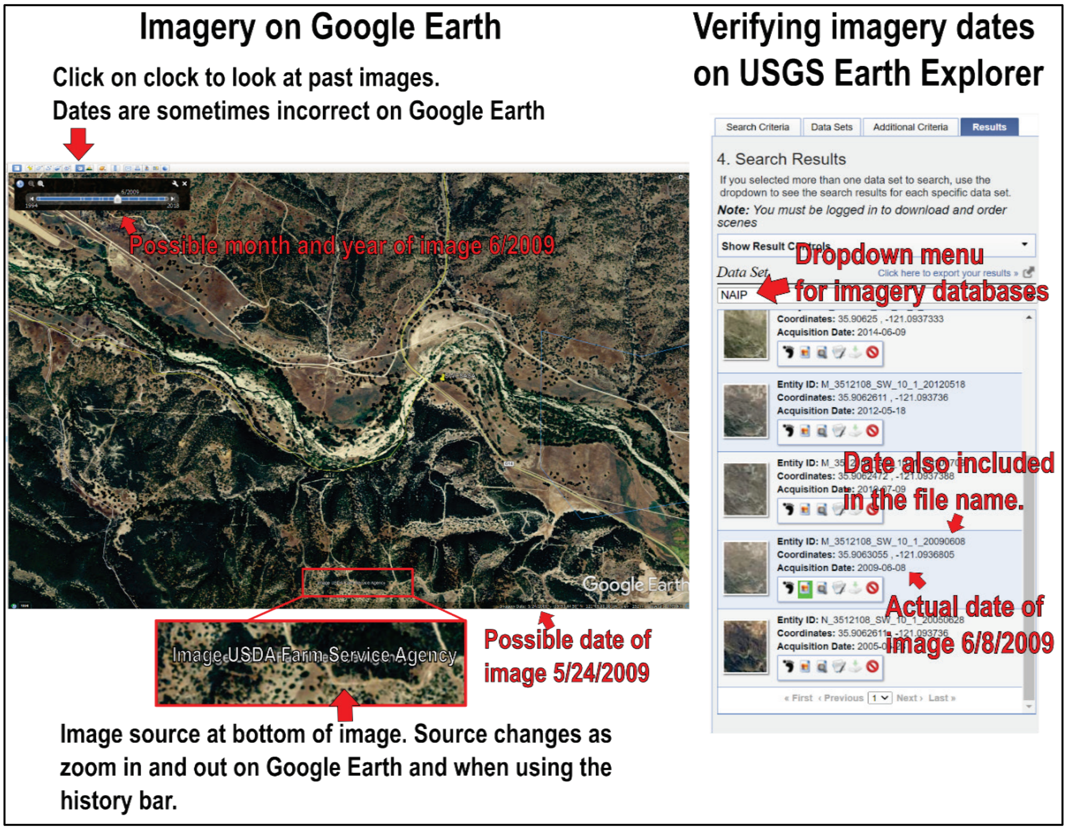
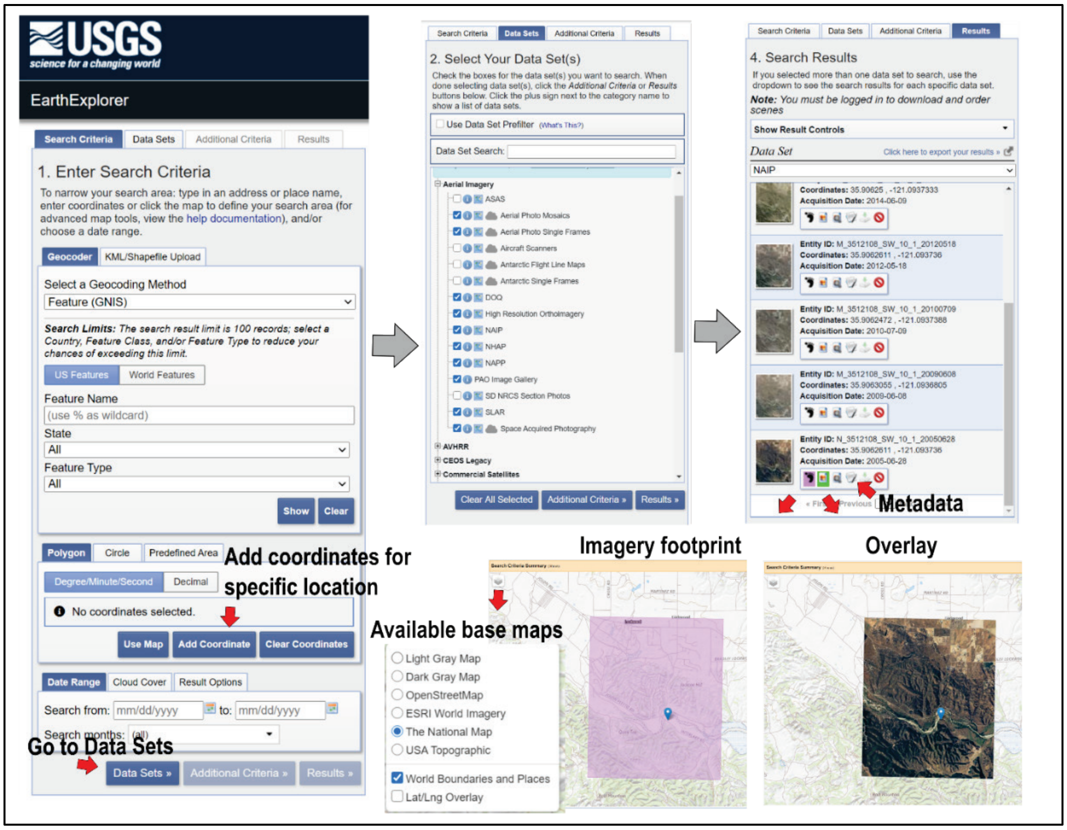


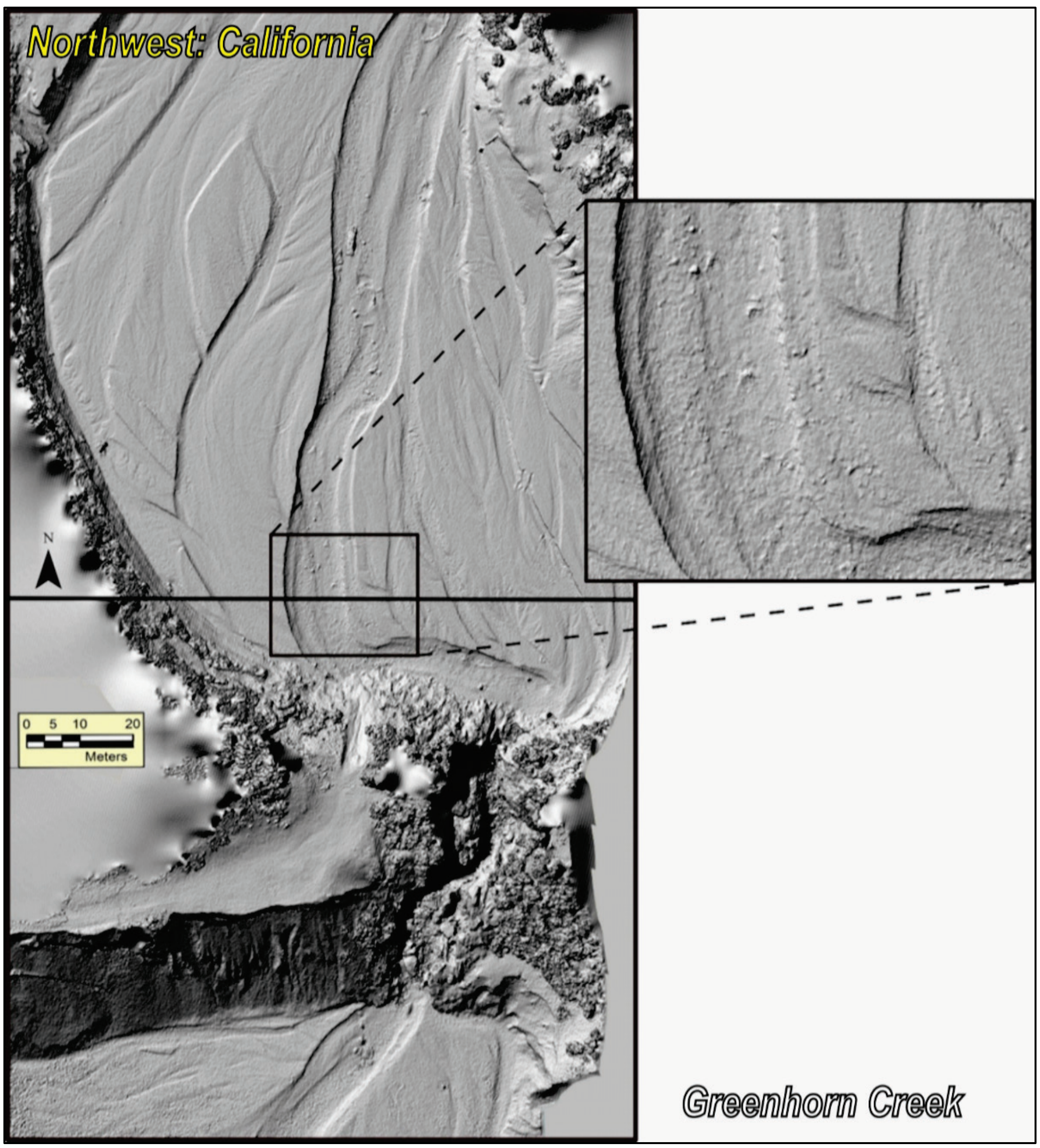
Figure 132. Searching for imagery on USGS Earth Explorer. (Images adapted from USGS n.d.a.)



Small uncrewed aerial vehicles (sUAV), or drones, can be used to acquire photographs of field sites that may be used to generate additional spatial data, such as topographic maps at very high resolutions (Karamuz et al. 2020). Although considerable expertise and field surveys are needed to generate imagery suitable for precise georeferenced maps, topographic maps, or change detection from repeated flights (Tamminga et al. 2015), reconnaissance flights can cheaply and easily generate high-resolution images (i.e., a few centimeters/pixel) that can be valuable in the field. Note that operating an sUAV for professional use is regulated by the FAA; aircrafts must be registered, and pilots certified. If it is not feasible to operate an sUAV yourself, experienced sUAV operators can be contracted.

Aircraft commonly used as sUAVs may be fixed wing or rotary and range from relatively large (i.e., approximately 2 m) wingspans or rotary diameters down to small, relatively inexpensive aircraft that can be carried in a backpack. Aircraft with an integrated camera and GPS system are recommended so that each image is stamped with a location that can be used by postprocessing software to mosaic the images. While postprocessing may not be necessary if the primary objective is simply to obtain single photographs, mosaics and topographic maps can be produced using structure-from-motion (SfM) software (Fonstad et al. 2013). Figure 133 contains two images collected with a Phantom 4 rotary sUAV. Most sUAV imagery is collected as photographs, so vegetation can be a substantial limitation to this technology, especially if SfM is to be used to generate topographic maps.

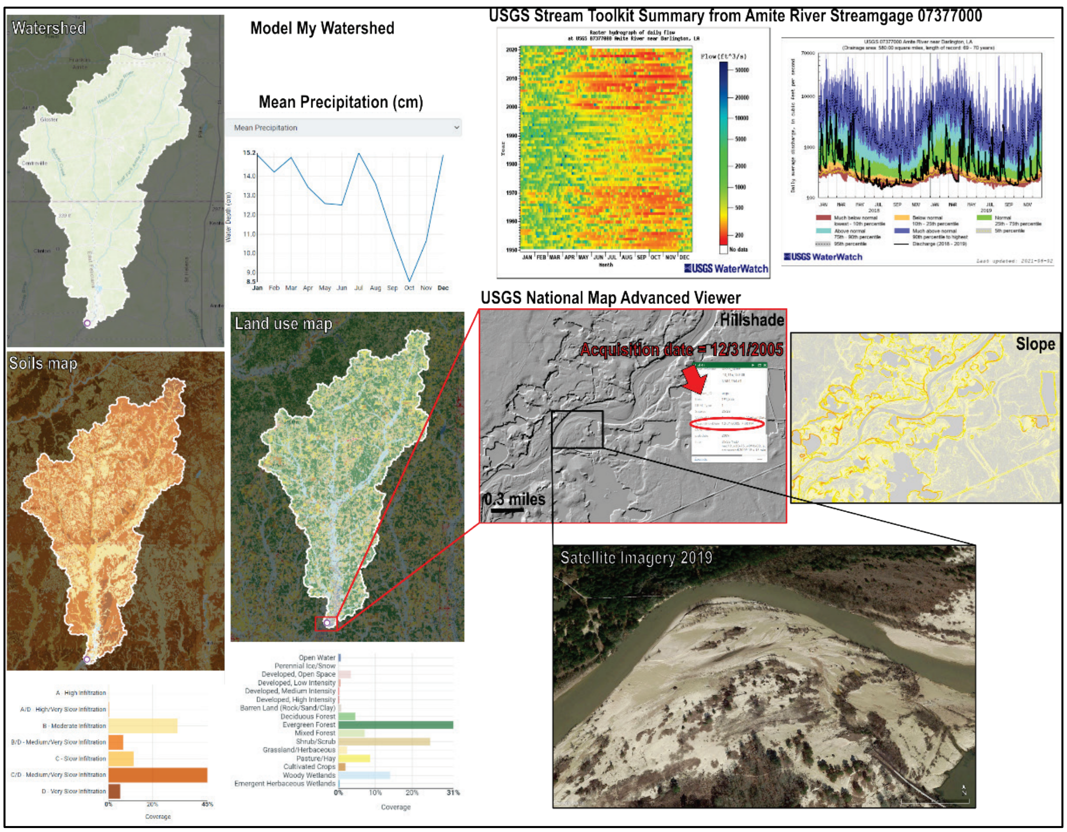
Figure 133. Images, captured by small uncrewed aerial vehicle (sUAV), of the gravel-bed channel cut into a floodplain with braid bars, which is now a broad low terrace. At the bottom of the image downstream, the channel passes through a bedrock constriction and drops 10 m through a cataract to a lower-level channel. Features within the gorge cannot be seen due to shadows. The inset shows the potential high resolution of the imagery that can distinguish individual cobbles and gravel clasts.



5.7 Case study: Identifying the OHWM on the Amite River in Louisiana, using lidar, satellite imagery, and USGS streamgage data

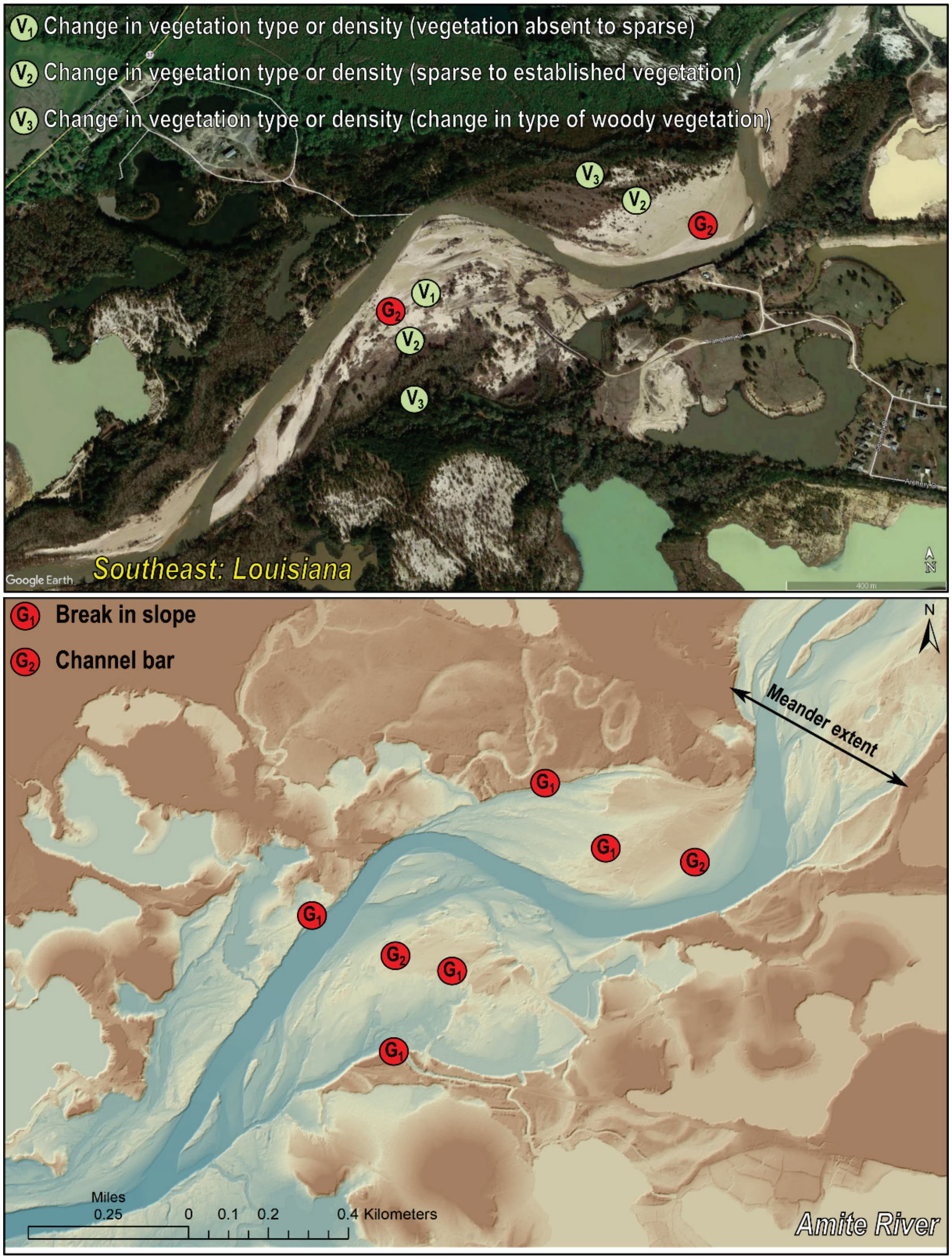
Online resources can support field identification of the OHWM, particularly in a stream with multiple elevations of high-flow indicators. The Amite River is in the Southeast region of the US and flows through both Mississippi and Louisiana. The watershed is 1,990 km² (768 mi²) at the study site (Figure 134).

Figure 134. Overview data about the Amite River from online resources listed in Table 7. Model My Watershed (*left*) delineates the drainage basin and provides information on soils, land use, and climate. USGS Stream Toolkit (*top right*) identifies when the Amite River experienced relatively wet and dry periods. The USGS National Map (*middle right*) provides easy access to lidar products. Google Earth (*bottom right*) provides easy access to satellite imagery.



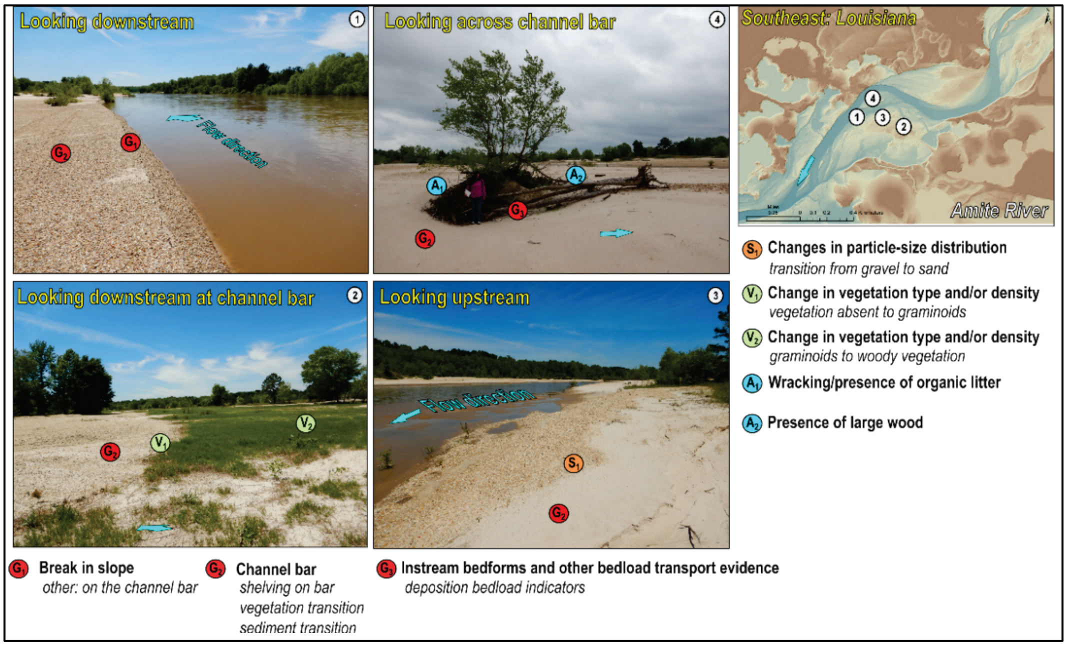
Satellite imagery and gage data provide information on the size and frequency of higher flows, particularly in larger systems that can be easily observed with satellite imagery. The Amite River has a substantial year-round base flow (mean = 371 cfs) and experiences a rapid rise in stage during storm events. An examination of the lidar hillshade and satellite imagery shows areas where the river has meandered and left substantial bar deposits (Figure 135). The area is pockmarked by artificial holes created by gravel mining. Both the remote and field examinations of the site show evidence of a possible OHWM at multiple elevations. Applying the WoE technique can be very useful at a site such as this.

Figure 135. Satellite imagery (*top*) showing locations where vegetation density and type are changing. Channel bars and breaks in slope can be seen both in the satellite imagery and lidar hillshade (*bottom*).



A field examination of the Amite River reveals changes in sediment size, vegetation, and instream bedforms, such as dunes, in the sandy substrate (Figure 136). There are also ancillary indicators, such as the presence of organic litter and LW.

Figure 136. Overview of field examination of the Amite River. Location of photographs is shown on the lidar hillshade map (*right*). Geomorphic (*G*), sediment (*S*), vegetative (*V*), and ancillary (*A*) indicators were identified at the site.



The change in particle-size distribution from gravel to sand occurs at a lower elevation than the transitions in vegetation and the instream bedforms and LW deposits. The relevance of each indicator can be difficult to determine without further information. Because this is a large river system, there is satellite imagery and USGS streamgage data available for this site (Figure 137). Historical imagery can be easy to access, either through Google Earth or USGS Earth Explorer. Caution should be taken when using Google Earth imagery because the dates shown on Google Earth may not be correct; therefore, dates should always be checked against the metadata available on the USGS website (Section 5.6). Once the date has been verified, the images can be combined with USGS streamgage data to classify the land areas inundated by low and high flows (Figures 137 and 138).

A high-flow event on the Amite River in 2006 was captured by satellite imagery (Figure 137). The actual imagery date, which was verified using USGS Earth Explorer (USGS n.d.a), coincided with the peak flow event of

8,340 cfs recorded at the USGS streamgage. The other dates associated with the mosaicked Google Earth image corresponded with near base flow in the streamgage record and so were deemed incorrect. The flow on 28 October 2006 was the highest flow that occurred in both the 2006 and 2007 water years.

Figure 137. Google Earth satellite imagery can be synchronized with USGS streamgage data to understand the size of flows in streams, but caution should be used when synchronizing data sets.

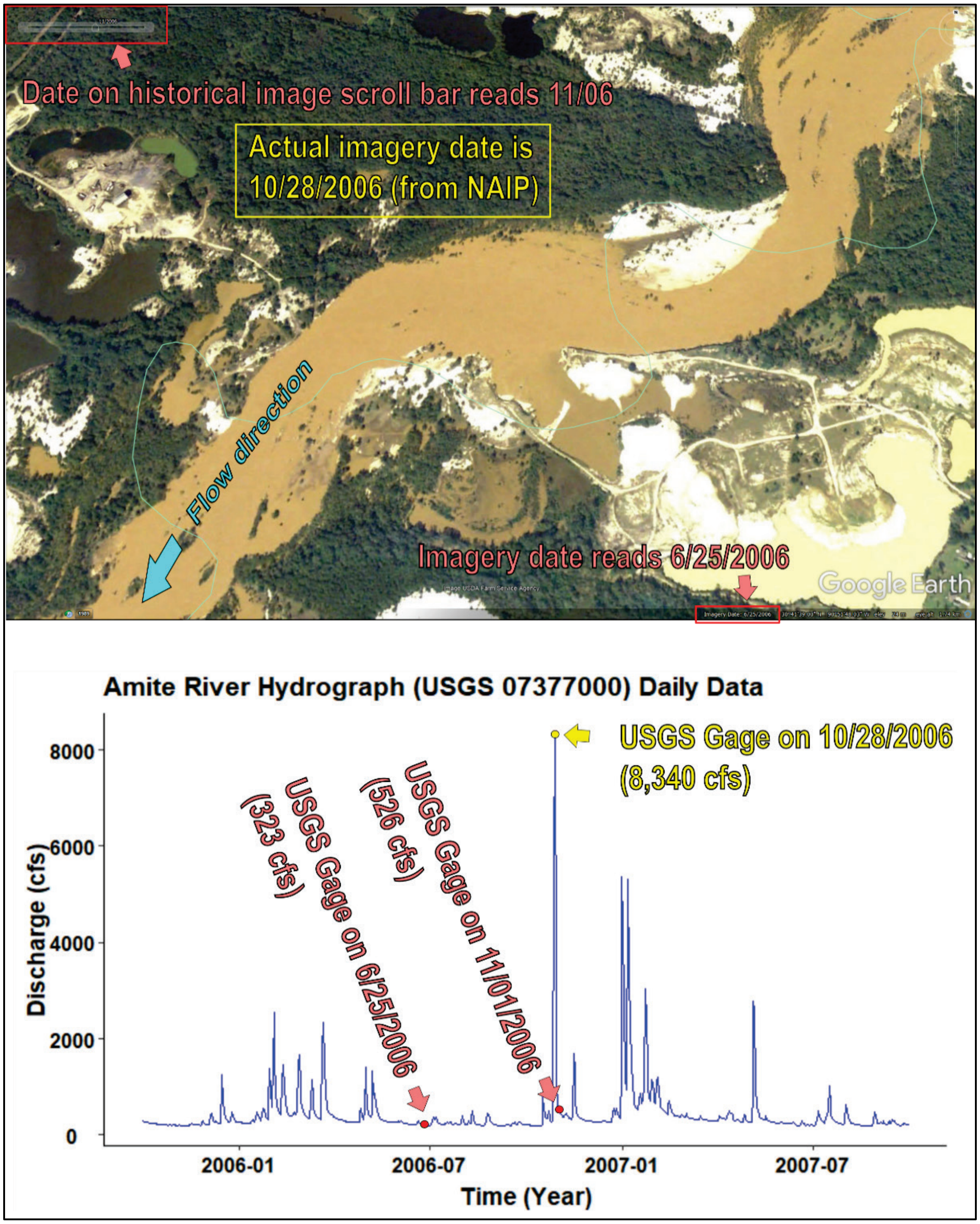
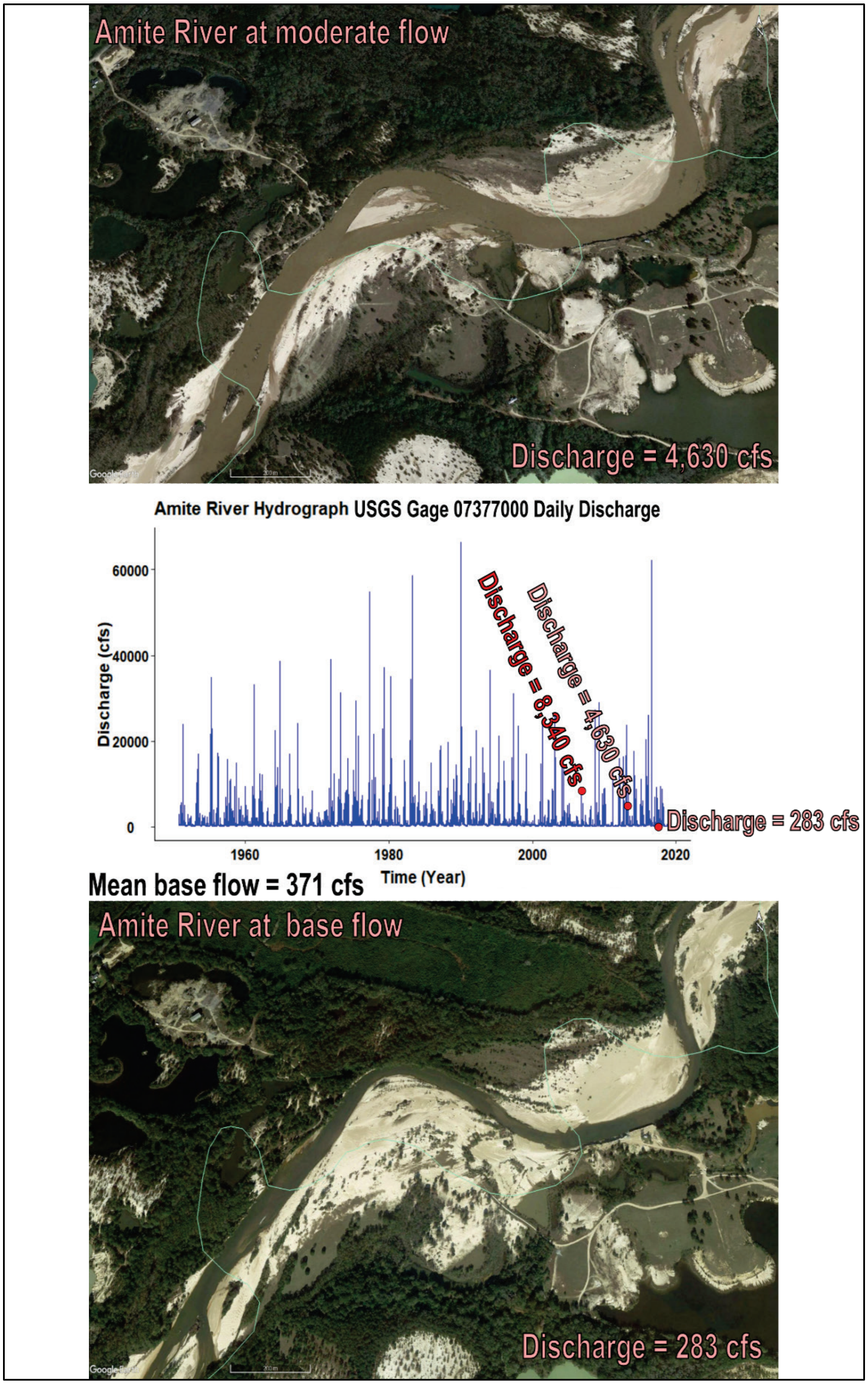
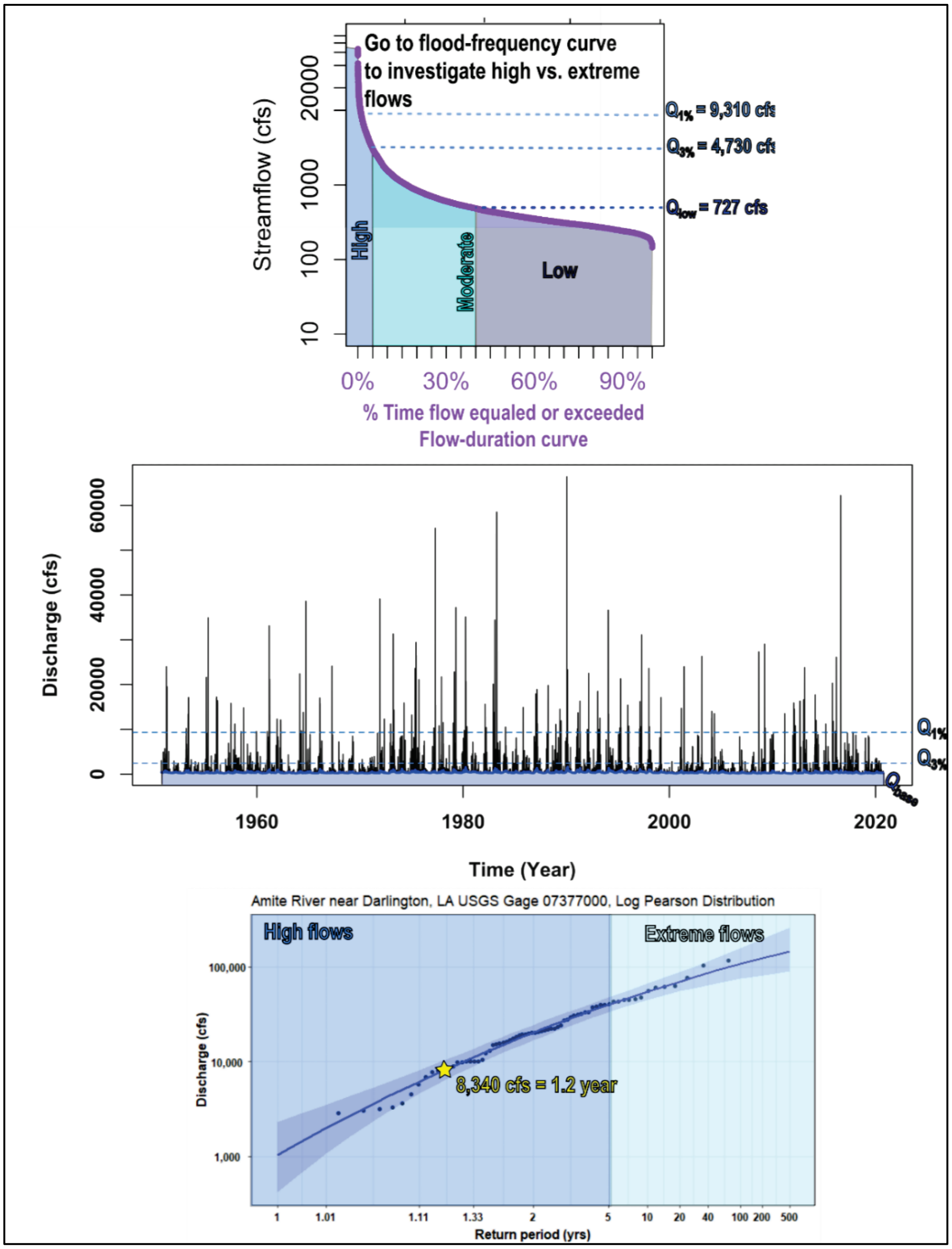


Figure 138. Google Earth images showing the Amite River at moderate and base flows. The high-flow event is shown on the hydrograph in *darker red* for comparison. Daily mean flows from these images and Fig. 135 are identified on the USGS streamgage hydrograph for the period of record (1950–2020).



If only two years of gage data were examined, this event would appear to be an extreme event. Examination of the full hydrograph between 1950 and 2020, however, shows that a flow of 8,340 cfs is not a particularly extreme event on the Amite River (Figure 138). Further evaluation of the USGS streamgage data demonstrates where a flow falls among the entire range of flows in the Amite River over the period of record (Figure 139). An analysis of the USGS streamgage data shows that high flows are greater than 4,730 cfs. The inflection point on the FDC is interpreted as the break point for high flows at this site. If the $Q_{1\%}$ were used, then high flows would be greater than 9,310 cfs, which is already a flow of 1.3 years on the flood-frequency curve. Figure 138 shows the area of land inundated from a flow that was just below a high-flow event and the area of land inundated during base flow. The 2006 high-flow event has a recurrence interval of 1.2 years. The land inundated during the 2006 event appears to correspond to many of the locations of flow indicators noted on the satellite imagery (Figure 135) and the field examination of the site (Figure 136).

Figure 139. The FDC (*top*) developed from Amite River USGS streamgage 07377000 shows at what range high, moderate, and low flows occur. The hydrograph (*middle*) shows the low (or base) flows over the period of record and the two possible break points for high flows. The flood-frequency curve (*bottom*) shows the location of the 2006 high-flow event.



Combining the satellite imagery and USGS streamgage data allows the indicators noted in Figure 136 to be interpreted as either low-, moderate-, or high-flow indicators. Therefore, the additional data provide support when determining the relevance, strength, and reliability of each of the flow indicators. The extent of flows during a moderate-flow event indicates that the transition from gravel to sand may be from these more moderate flows. Figure 137 shows that the midchannel bar is inundated during high-flow events, providing additional support for the observation of in-stream bedforms, such as dunes, forming at this elevation. One of these dunes and some organic litter and LW are shown in Figure 140. The area just downstream of picture 2 in Figure 140 is likely a backwater during high flows. Therefore, this area will still be inundated, but the high-flow indicators may include deposition of finer deposits.

Figure 140. Combining streamgage data with satellite imagery to assist with interpreting field observations.

The Amite River case study provides an example of how to combine information from satellite imagery and USGS streamgage to interpret the observations made at a field site.

5.8 Summary

Many resources can be gathered to support OHWM identification prior to WoE Step 1 and following the collection of field indicators (WoE Step 4). These resources include climate, geography, soil, topography, hydrography, and hydrology databases. This chapter identified key online national resources, what they represent, and how they can be used to support OHWM identification. The NHD and WBD are geodata sets that can provide an overview of the surface water network and hydrologic drainage area. Hydrology data from USGS streamgages can be particularly useful for understanding the magnitudes of flows that have occurred and can be integrated with other lines of evidence collected in the field. Flood-frequency curves and FDCs are tools that use streamflow data to place hydrologic data in historical and landscape context. Flood-frequency curves are used to portray the relationship between magnitudes of floods and their frequency of occurrence. Although not based on physical marks observed in the field, flood-frequency curves may be helpful for broadly distinguishing small-frequent, medium-intermediate, and large-rare floods and supporting the physical evidence. FDCs describe the percentage of time that flows of different magnitude are equaled or exceeded.

Generally, high flows represent a very small percentage of time, whereas lower flows represent a high percentage of time at a site. Identifying the inflection point on FDCs is a way to identify the boundary between intermediate and high flows and the associated elevational bands for which to begin surveys for the OHWM in the field. FDCs reflect the variation in landscape controls on hydrology, such as water storage, storm flow response, and groundwater contributions to base flow, observed across OHWM regions. Resource data can inform modeled discharge associated with field-identified OHWM elevations to infer streamflow exceedance levels and flood probabilities for further evaluation of OHWM identifications. Because streamgages are not near most sites, streamflow or channel measurements can be predicted using regional relationships with easily obtainable measures, such as drainage area. Remote sensing data sets can help with OHWM identification by allowing users to either confirm features observed in the field or to indicate locations before the site visit. Some data sets, such as lidar, can remove vegetation that may mask some features, and other satellite data sets that have been collected repeatedly may also provide information on changes over time at a site. Different case study locations that used multiple resources to support OHWM identification were used as examples in this chapter.

6 Effects of Human-Induced Alterations on OHWM Indicators and Appearance

6.1 Key points

Geomorphic disturbances are relatively discrete events that disrupt the form of geomorphic systems and alter geomorphic processes (Phillips and Van Dyke 2016). Geomorphic disturbances involve erosion or sedimentation. Disturbances can be natural or a result of human actions that affect watershed runoff processes, sediment yields, and channel form. Disturbances alter the resistance of the landscape to both flow and erosion (Knighton 1998). Disturbances are important within fluvial systems because they influence floodplain and riparian processes and longitudinal and lateral connectivity (Wohl et al. 2019). Ultimately, a certain level of disturbance has been recognized as important for increasing both geomorphic complexity and biodiversity in fluvial systems (Connell 1978; Wohl 2016).

Geomorphic complexity is defined as spatial heterogeneity within a fluvial system (Wohl 2016). This heterogeneity is what complicates identifying the OHWM in different regions of the country as well as in basins with differing levels of human-induced and natural disturbances. Geomorphic complexity is connected to the resistance and resilience of a system to any type of disturbance. A resistant system experiences little change, and a resilient system can quickly recover and return to predisturbance form and processes. Often, human-induced alterations to a system reduce geomorphic complexity, which can cause systems to be less resistant to disturbances. The identification and delineation of the OHWM occurs in systems that are at different timings of recovery from either human-induced or natural disturbances. This can make interpretation of indicators difficult because the system is in a state of flux. Therefore, this chapter describes common types of human-induced alterations to fluvial systems and provides case studies for each. Chapter 7 focuses on systems that have higher levels of geomorphic complexity and common natural disturbances to these systems.

The most common forms of human-induced alterations to a system are from flow regulation, road–stream crossings, mining, agriculture, logging, grazing, and urbanization. Flow regulation comes in the forms of both dams and water diversions (Section 6.2). Road–stream crossings can be bridges, culverts, or fords. Section 6.3 focuses on identifying OHWM indicators around culverts because they are not only a common type of crossing, but the way they alter channel form also has a large influence on flow up- and downstream. Mining effects can be from a variety of types of mining, including watershed changes from mountain-top removal or direct channel changes from mining tailings or in-stream gravel mining (Section 6.4). Agriculture is discussed in terms of historical effects that may be observed today and current changes to a system (Section 6.5). Grazing can directly alter channel form where animals are allowed to access the stream (Section 6.5.1). The effects of urbanization can be similar to or overlap with some of these other human-induced changes (e.g., flow regulation), but the combination of effects in urban environments can create a unique system that causes its own difficulties in understanding the varying lines of evidence that help to identify the OHWM (Section 6.6).

6.2 Flow regulation

Dams and diversions alter the movement of water and sediment through streams. Wohl et al. (2016) described the five common human-built dams in streams, including run-of-river, water storage, flood control, hydroelectric, and milldams, and how they affect the flux of water and sediment. Diversions include both flow extraction and flow augmentation. Most river systems in the US (i.e., approximately 98%) are affected by dams at some level (Graf 2001).

Flow management of regulated streams often means that flow is controlled for water storage and hydroelectric operations. Because water level is controlled by the dam operators, high-flow indicators reflect anthropogenic fluctuations in flow. A dam can also raise water levels upstream of the reservoir from a backwater effect and affect indicators up- and downstream of dams.

Dam removals are becoming increasingly common; disused dams are aging in river systems and being removed to improve stream functions and processes. Dam removal can create many changes in a stream system. Identification of the OHWM will vary based on whether the surveyor is upstream, downstream, or viewing a channel in a prior reservoir.

6.2.1 Effects of dams on OHWM indicators

Dams create a temporary base level in a drainage network. As a stream approaches a reservoir, the reduction in gradient (i.e., the flattening out of the stream profile) causes increased deposition of sediment and development of secondary channels. Therefore, channel bars and secondary channels may be common features upstream of a dam above the reservoir. The reservoir itself can also have increased sediment deposition, which also results in the formation of bars in the reservoir.

Dams trap sediment and prevent downstream transport of sediment and organic material and bidirectional movement by aquatic biota. Channels downstream of dams are sediment starved, which can cause reduced floodplain sedimentation (Renshaw et al. 2014) and accelerated channel erosion. Unstable banks and undercut banks are common features that may be a result of channel widening and bed incision associated with upstream dams. Incision of the mainstem bed may also lead to headcuts proceeding up the tributaries (Section 4.2.2.1).

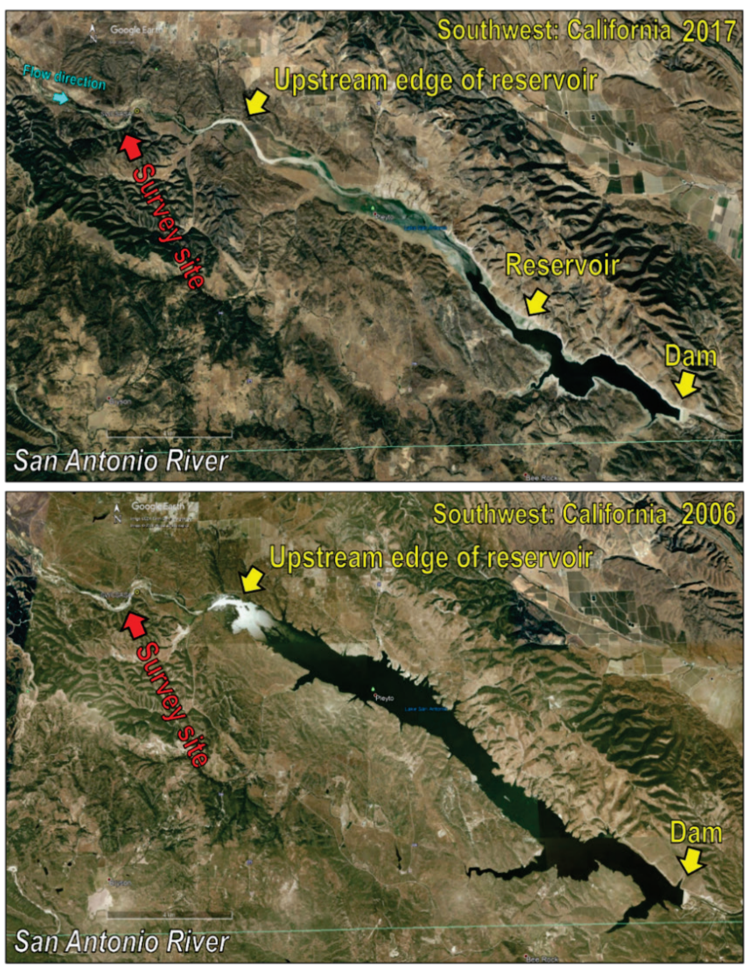
Channels that experience large reductions in peak flows downstream of a dam may experience narrowing, rather than widening, because of the channel's reduced capability to move sediment. If tributaries downstream of the dam are still providing significant sediment inputs, then the mainstem channel can narrow and aggrade in cases where it has reduced stream power.

Riparian vegetation communities are often altered by the regulated flows downstream of a dam, but they also often change upstream of dam sites. The controlled fluctuation of flow, reduction in peak flows, and changes in magnitude and timing of flows can alter the vegetative characteristics in the riparian zone both up- and downstream of a dam (Johnson 1998). For instance, reduction of peak flows can cause encroachment of upland species into the riparian zone and hydrophytes into the active channel. The reduction in peak flows below a dam may result in a lowering of the OHWM elevation, which could be reflected in the vegetation indicators. The maintenance of the reservoir level above the reservoir pool could cause the OHWM to occur at a higher elevation than had previously existed.

6.2.2 Identifying the OHWM upstream of a dam: San Antonio River case study

The San Antonio River is a braided stream in Lockwood, California, upstream of the San Antonio Dam (201 ft in height), which was built in 1952. The river has a 562 km² (217 mi²) drainage area and has had a USGS streamgage (USGS Gage 11149900) since 1966 (USGS n.d.g). The watershed is within Los Padres National Forest and is mainly undeveloped. Site investigation should begin with an understanding of the landscape controls (Figure 141). An initial review of the satellite imagery in Google Earth, both past and present, shows the overall extent of the reservoir. Absent the 2006 imagery, the size of the reservoir could be inferred by the wider valley and lack of woody vegetation in the area that is dry in the 2017 imagery.

Figure 141. Google Earth satellite imagery of San Antonio River in 2017 (*top*) and 2006 (*bottom*). The images show the reservoir pool area in a drier year (2017) and during a much wetter year (2006).



Prior to a site visit, the fluctuations between wet and dry years and current conditions can be investigated using the tools listed in Table 7. Figure 142 shows a graph created on the Climate Engine website* to evaluate drought conditions. Climate Engine allows for exploration of a variety of parameters, including precipitation, temperature, and various drought indices. The Palmer Z index is most often used to understand drought conditions over short time scales. Figure 142 shows predicted drought periods and streamflow data over a longer time period. The USGS provides overviews of streamgage data in the Stream Toolkit on the WaterWatch section of their website (USGS n.d.g; Table 7). The raster hydrograph is a useful visualization tool that can show over what seasons high flows and low flows are occurring in a stream. The bottom portion of Figure 142 shows an overview of daily streamflow data, not peak flow data, with month on the x-axis and year on the y-axis. A quick analysis of the figure shows that low flows occur over summer and fall, and higher flows occur in the winter and spring. The raster hydrograph also shows if there are extended periods of low flow. If the red bar is wider in any given year, it indicates an extended period of low flow compared to other years. The site survey was conducted in December of 2016, which had a longer period of low flow, compared to other years, prior to the site visit. The drought index also indicated that there were extended periods of drought prior to the site visit.

Information about flow conditions prior to and during site visits can help provide insight on the OHWM indicators observed at the site. Without any recent high flows, vegetation may have had time to establish. Alternatively, drought conditions may have inhibited some vegetation growth. Sediment on channel bars may not have been transported recently, and there may have been an increase in fine sediment deposition on the channel bed. This can be from low transport capacity in the stream or from wind blowing fine sediment onto portions of the channel bed that are no longer covered by flow. During wet periods, high flows are likely to inundate and transport sediment on the channel bars. During dry periods, the lack of sediment movement provides opportunities for the vegetation to encroach.

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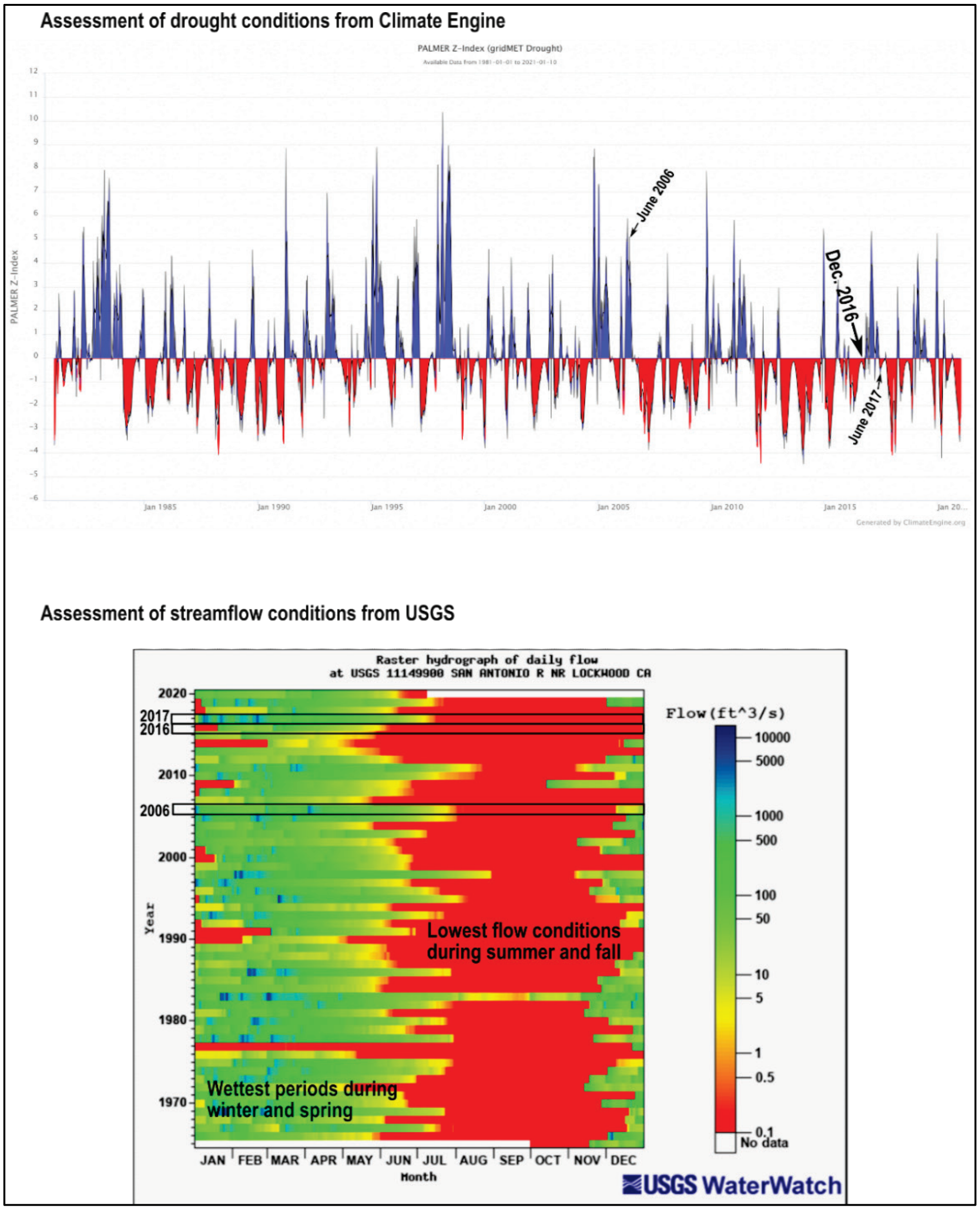
*www.climateengine.com

Figure 142. Assessing drought and streamflow conditions on the San Antonio River using tools from Climate Engine and USGS (Table 7). *Blue* indicates wet years, and *red* indicates dry years. The month and year correspond to the satellite imagery in Fig. 141. The channel was surveyed in December of 2016.



A close-up of the survey site using Google Earth imagery provides additional insight prior to a field visit (Figure 143). The San Antonio River is a braided channel with a hillslope confining the direction of migration on the right bank. Therefore, high flows will spread out on the left bank floodplain. There is a bridge just downstream of the surveyed site that creates another point at which the flow may be confined through the structure. The main stem of the channel appears to have shifted between 2006 and

2017. Shifting channels are common in braided systems. The old location of the main stem has more vegetation establishment by 2017. The change in the temporary base level, created by the reservoir, can influence stream characteristics upstream of the reservoir (Figure 141). For instance, the reservoir rises during wet periods, creating a backwater effect that may cause more sediment deposition and bar development upstream. When the water levels in the reservoir pool are lower, the channel may begin to cut down into its bed. This could be part of the reason the main channel shifted during this time period.

Figure 143. Overview of San Antonio River survey site using Google Earth satellite imagery from 2017 (*top*) and 2006 (*bottom*).

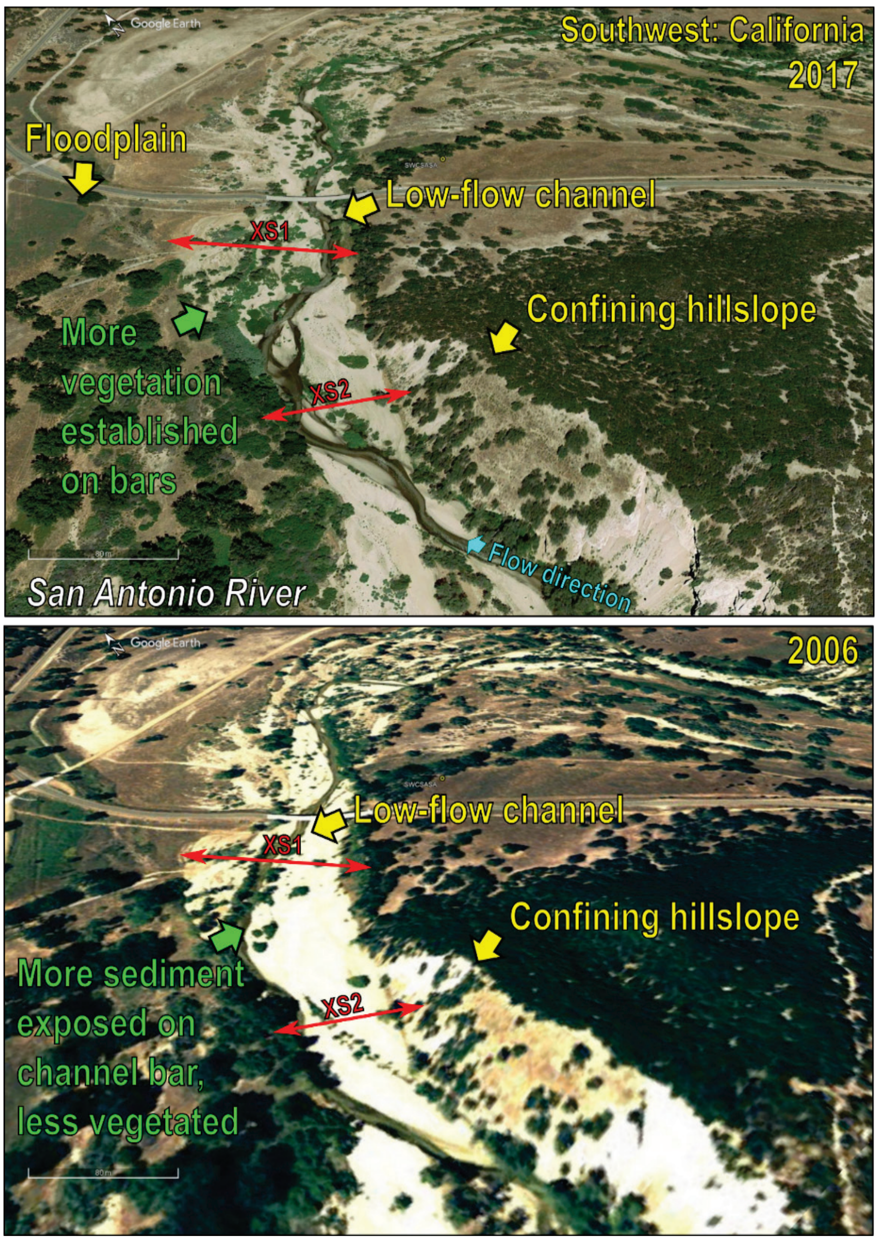
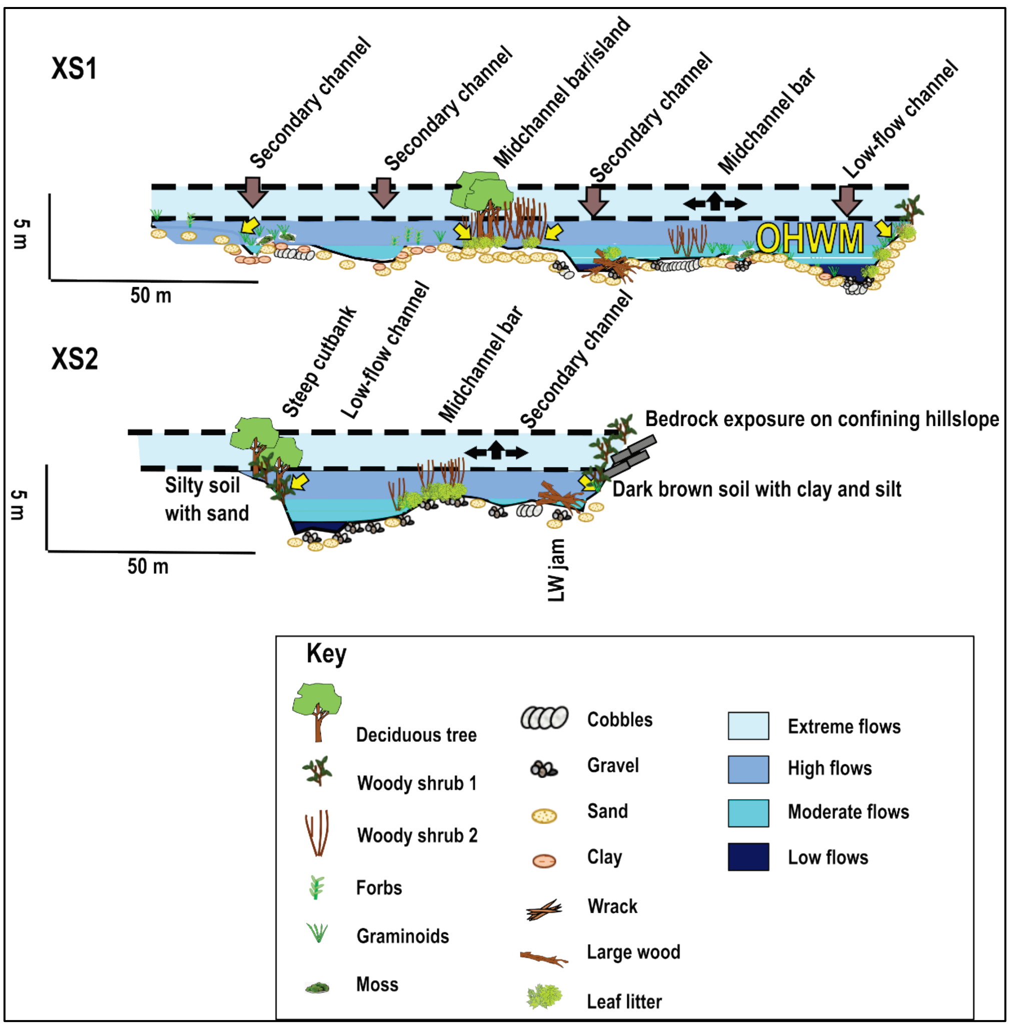


Figure 144 shows the details of Cross Sections 1 and 2, which are shown on the satellite imagery in Figure 143. During the field examination of the site, it was clear that there was a low flow main channel and several secondary channels. The sediment in the main stem was stained a darker color than the sediment in the rest of the site. The location of the main stem is easy to observe in these cross sections because of the lower elevation of the channel bed. Only moderate and high flows reach many of the secondary channels in both cross sections. There is likely more variability in the flows and how they move through the secondary channels, particularly in a braided system, than is shown by the flat line across the two cross sections. Water does not flow as a flat surface, and flow models all have some error associated with the modeled water surface. A flat water surface is used for ease of interpretation, but there should be blurred lines on either side of those flat surfaces.

Figure 144. Cross sections across the San Antonio River show the wide variability at a site between the upstream (XS2) and downstream (XS1) locations.



Box 17 to Box 20 contain an example of how to fill out the data sheet and photograph log for the San Antonio River. The satellite imagery provided an initial understanding of site conditions up- and downstream of the reach and an initial estimation of the channel width. The field observations were combined to provide multiple lines of evidence for the location of the OHWM. The OHWM was identified at the break in slope and at a vegetation transition point along the channel banks of both the main and secondary channels. The OHWM inundates some of the woody shrubs growing along the point bars, but it remains below the deciduous trees that were growing on the left bank or midchannel island. The elevation of deciduous trees provided an upper elevation for the potential OHWM. There is also a transition from coarser sediment deposits to finer sediment in some of the locations. Scour and pool development on the bars, particularly near the second cross section, clarified that these areas were still being influenced by flow on a semiregular basis. The staining of material in the low-flow channel can be combined with the understanding that the recent conditions at the site have tended toward drought conditions without many high flows. A review of the USGS streamflow raster hydrograph (Figure 142) shows very few years on record in which flows entered the dark blue range prior to the 2016 site visit. This means that there may not have been a recent flow that could transport the cobbles, identified on the bed of the main channel, which could result in darker staining from the more frequent low flows.

Box 17. Data sheet (adapted from USACE 2022) for San Antonio River case study, page 1.

Print Form | Save As | E-mail

U.S. Army Corps of Engineers (USACE)
RAPID ORDINARY HIGH WATER MARK (OHWM) FIELD IDENTIFICATION DATA SHEET
The proponent agency is Headquarters USACE CECW-CO-R.

From Approved - OMB No. 0710-OHWM Expires: xx-xx-xxxx

AGENCY DISCLOSURE NOTICE

The public reporting burden for this collection of information, 0710-OHWM, is estimated to average 30 **minutes** per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding the burden estimate or burden reduction suggestions to the Department of Defense, Washington Headquarters Services, at whs.mc-alex.esd.mbx.dd-dod-information-collections@mail.mil. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

Project ID #: Case study | Site Name: San Antonio River, CA | Date and Time: 12/8 to 12/9/2016

Location (lat/long): 35° 53' 48", -121° 05' 14" | Investigator(s): G. David and M. Mersel

Step 1 Site overview from remote and online resources
Check boxes for online resources used to evaluate site:

- [x] gage data
- [x] LiDAR
- [ ] geologic maps
- [x] climatic data
- [x] satellite imagery
- [ ] land use maps
- [ ] aerial photos
- [x] topographic maps
- [ ] Other:

Describe land use and flow conditions from online resources.
Were there any recent extreme events (floods or drought)?
No recent flood events but experiencing drought. The stream is on Fort Hunger Ligget property and upstream of a dam.

Step 2 Site conditions during field assessment. First look for changes in channel shape, depositional and erosional features, and changes in vegetation and sediment type, size, density, and distribution. Make note of natural or anthropogenic disturbances that would affect flow and channel form, such as bridges, riprap, landslides, rockfalls, etc.

No flow in the channel at the time of the survey. The stream is braided with an apparent low-flow channel and multiple secondary channels. Woody shrubs are growing on the channel bars. The stream is confined on its right bank by a hillslope. There is an open floodplain on river left.

Step 3 Check the boxes next to the indicators used to identify the location of the OHWM.
OHWM is at a transition point, therefore some indicators that are used to determine location may be just below and above the OHWM. From the drop-down menu next to each indicator, select the appropriate location of the indicator by selecting either just below `b', at `x', or just above `a' the OHWM.
Go to page 2 to describe overall rationale for location of OHWM, write any additional observations, and to attach a photo log.

Geomorphic indicators

- [x] **Break in slope:** x
  - [ ] *on the bank:*
  - [ ] *undercut bank:*
  - [ ] *valley bottom:*
  - [ ] Other:
- [x] **Shelving:**
  - [x] *shelf at top of bank:* x
  - [ ] *natural levee:*
  - [ ] *man-made berms or levees:*
  - [ ] *other berms:*
- [x] **Channel bar:** b
  - [x] *shelving (berms) on bar:* b
  - [ ] *unvegetated:*
  - [x] *vegetation transition (go to veg. indicators)*
  - [x] *sediment transition (go to sed. indicators)*
  - [ ] *upper limit of deposition on bar:*
- [x] **Instream bedforms and other bedload transport evidence:** b
  - [ ] *deposition bedload indicators (e.g., imbricated clasts, gravel sheets, etc.)*
  - [ ] *bedforms (e.g., pools riffles, steps, etc.):*
  - [x] *erosional bedload indicators (e.g., obstacle marks, scour, smoothing, etc.)* b
- [x] **Secondary channels:** b

Sediment indicators

- [x] **Soil development:** a
- [ ] **Changes in character of soil:**
- [ ] **Mudcracks:**
- [x] **Changes in particle-sized distribution:** x
  - [ ] *transition from* ______ to ______
  - [ ] *upper limit of sand-sized particles*
  - [x] *silt deposits:*

Vegetation Indicators

- [x] **Change in vegetation type and/or density:** x
  Check the appropriate boxes and select the general vegetation change *(e.g., graminoids to woody shrubs).* ***Describe the vegetation transition looking from the middle of the channel, up the banks, and into the floodplain.***
  - [ ] *vegetation absent to:*
  - [ ] *moss to:*
  - [ ] *forbs to:*
  - [x] *graminoids to:* deciduous trees
  - [x] *woody shrubs to:* deciduous trees
  - [ ] *deciduous trees to:*
  - [ ] *coniferous trees to:*
- [ ] **Vegetation matted down and/or bent:**
- [ ] **Exposed roots below intact soil layer:**

Ancillary indicators

- [x] **Wracking/presence of organic litter:** b
- [x] **Presence of large wood:** b
- [x] **Leaf litter disturbed or washed away:** b
- [ ] **Water staining:**
- [ ] **Weathered clasts or bedrock:**

Other observed indicators? Describe:

Box 18. Data for San Antonio River case study, page 2. (Data sheet adapted from USACE 2022.)

Print Form | Save As | E-mail

Project ID #: Case study

Step 4 Is additional information needed to support this determination? ☒ Yes ☐ No If yes, describe and attach information to datasheet:

Satellite imagery and USGS streamgage data

Step 5 Describe rationale for location of OHWM

The OHWM location is at the slope breaks on the outer edge of the braided system. These slope breaks are at an elevation where the channel bars would be inundated and above the large wood jams and scour holes and obstacle marks that are present in the secondary channels. Many of the slope breaks correspond to the elevation of deciduous tree growth. See additional observations for more information.

Additional observations or notes

In XS1, there is a small island with more established deciduous tree and woody shrub growth. Although a range of high flows likely inundate this island, it is interpreted that the elevation of the OHWM would be just at the elevation of the tree bases, based on the presence of this vegetation and the clay/silt deposits observed at this elevation. Satellite imagery provides a useful large-scale view of the site. The channel is over 200 meters wide in some sections, which makes it difficult to see the whole from the ground. The change in vegetation and presence of multiple threads is easier to observe with the satellite imagery. Also, past imagery shows the low-flow channel has moved over time. USGS gage data provides information on flow levels during the time of the survey. The channel was surveyed at the driest time of year and also had not experienced any substantial high flows in the past few years prior to the survey. This means more vegetation may have established on bars and banks during this time.

Attach a photo log of the site. Use the table below, or attach separately.

Photo log attached? ☒ Yes ☐ No If no, explain why not:

List photographs and include descriptions in the table below.

Number photographs in the order that they are taken. Attach photographs and include annotations of features.

Photo Number	Photograph description
1	Looking downstream at the low-flow channel toward XS1.
2	Looking downstream at the midchannel bar in XS1.
3	Looking upstream at vegetation changes on right bank of XS1.
4	Looking upstream at change in sediment size from sand to silt/clay in high-flow channel along left side of XS1.
5	Looking downstream at large wood and wrack accumulating around vegetation in high-flow channel.
6	Looking downstream at scour and obstacle marks from flow in high-flow channel.
7	Looking upstream at a high-flow channel in XS2.
8	Looking downstream at a high-flow channel in XS2. Scour holes present in channel under objects, such as tree roots.
9	Looking upstream at the steep cutbank on left bank of XS2.
10	Looking downstream at the low-flow channel downstream of XS2.

Box 19. Annotated photographs to attach to the data sheet for the San Antonio River case study. The *blue arrow* indicates flow direction. The OHWM that was identified based on the WoE is shown in the photographs that contain it.

Box 20. Photo log of San Antonio River case study. *Blue arrows* show the flow direction.

6.2.3 Effects of dam removals on OHWM indicators

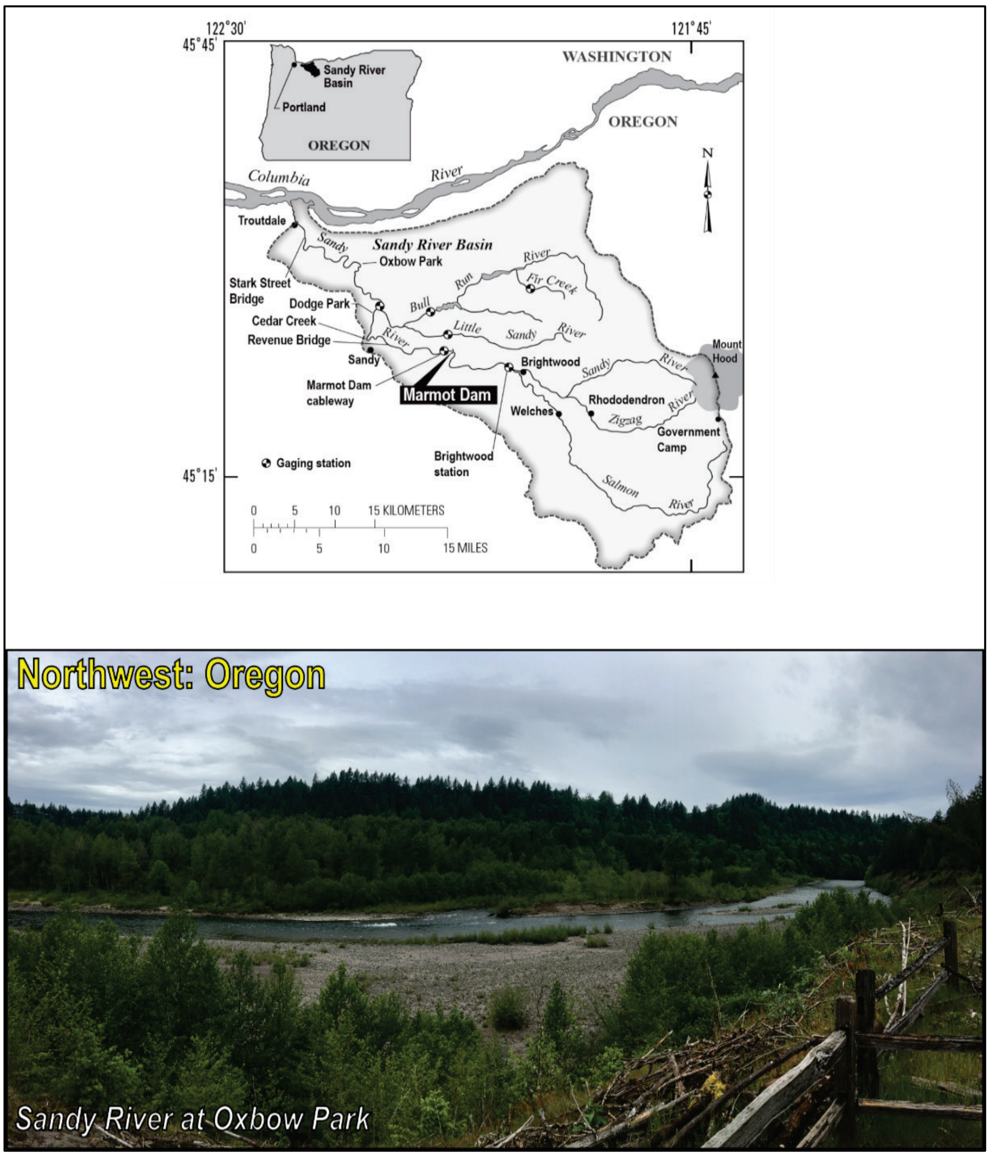
Dam removal is becoming increasingly common throughout the country. Dams are removed for a variety of reasons, including aging infrastructure that can no longer be maintained, no longer serving the purpose for which they were originally built, and to restore ecologic and geomorphic functions to stream channels. Once a dam is removed, the stream will reemerge in the space of the old reservoir. The OHWM indicators in a prior reservoir can change quickly after a dam removal (Figure 145). For instance, in reservoirs that have accumulated a large amount of sediment, knickpoints will migrate upstream after dam removal, causing both incision and widening of the channel. Channel formation in the reservoir depends on whether the reservoir accumulated sediment over time. In Figure 145, the two sites from Massachusetts are both on Mill River. The Hopewell Dam site had accumulated contaminated sediment, and so the sediment was removed during the dam removal process. The new floodplain and channel were then engineered. At the Whittenton dam removal site on the Mill River and the Montsweag dam removal site in Maine, both channels were able to reestablish their former pathways. Therefore, identifying breaks in slope along the tops of banks as indicators of the OHWM may be clearer than at the Hopewell dam site. The Little Falls Reservoir was experiencing a temporary drawdown at the time of the site survey. The Willow River formed a new path within the reservoir sediment during this drawdown. Even during this temporary drawdown, there were identifiable breaks in slope that indicated the top of banks and the likely location of the OHWM.

In Figure 145, variations in vegetative indicators in a former reservoir can also be seen. The removal of topsoil at the Hopewell Dam site meant that vegetation had a difficult time establishing, making it hard to identify vegetation zonation related to fluctuations in water level. Conversely, the site upstream on the Mill River is flowing through its previous channel. Sediment did not accumulate in this reservoir. Vegetation has reestablished much more quickly, and vegetation zonation is likely to be present.

Figure 145. Streams reforming within former reservoirs or during lake drawdown. The channel at the Hopewell Dam removal site was artificial. At the other sites, the channel formed in the former reservoir, in some cases finding the former channel pathway.

Where dams have been removed, sediment transport and deposition will likely dominate downstream of the site, whereas sediment erosion will be the dominant characteristic upstream (Figure 146; Major et al. 2012). These case studies provide examples of how to put a site in context of the surrounding landscape to better understand the variability in the OHWM indicators. Dam removal affects the reformed channel in the reservoir as well as conditions up- and downstream of the site. The expected changes include increased deposition for a time downstream and increased erosion upstream. Some reservoirs do not have significant amounts of sediment behind the dam so the stream will simply reestablish its old channel bed. In each case, the OHWM will reemerge as the landscape adjusts to the new flow regime and sediment loads. The time that it takes to identify an OHWM after a dam removal depends on the landscape characteristics and climate.

Figure 146. Location of the Marmot Dam, which was removed in 2007 (map reproduced from Major et al. 2012, public domain). The photograph is an extensive point bar on the Sandy River at Oxbow Park, about 30 km downstream of the removal site.



6.3 Culverts

Road–stream crossings, including culverts, alter the flow of water, sediment, and other material through a stream system. Culverts can affect streams similarly to dams, depending on the culvert's size in relation to the size of the channel. Although some culverts can be oversized to accommodate road size and associated drainage ditches, many culverts are undersized in relation to streamflow and can create a backwater effect, which can cause deposition of sediment upstream (Figure 147) and erosion downstream (Figure 148) of the culvert. Upstream of the culvert, deposition of material on the channel bed may cause flows to reach a higher elevation and the OHWM to occur over the tops of the banks (Figure 147).

Figure 147. Undersized culverts cause a reduction in velocity and sediment deposition upstream of the culvert.

The lack of sediment moving through these undersized culverts results in a greater capacity for sediment movement downstream. Therefore, an increase in erosion downstream of these sites is common (Figure 148). Channel incision, and particularly pool development, often occurs just downstream of the culvert. Channel widening can also occur. This means that for a short distance downstream of a culvert, the OHWM may be at a lower elevation than the observed location of the OHWM elsewhere in the channel.

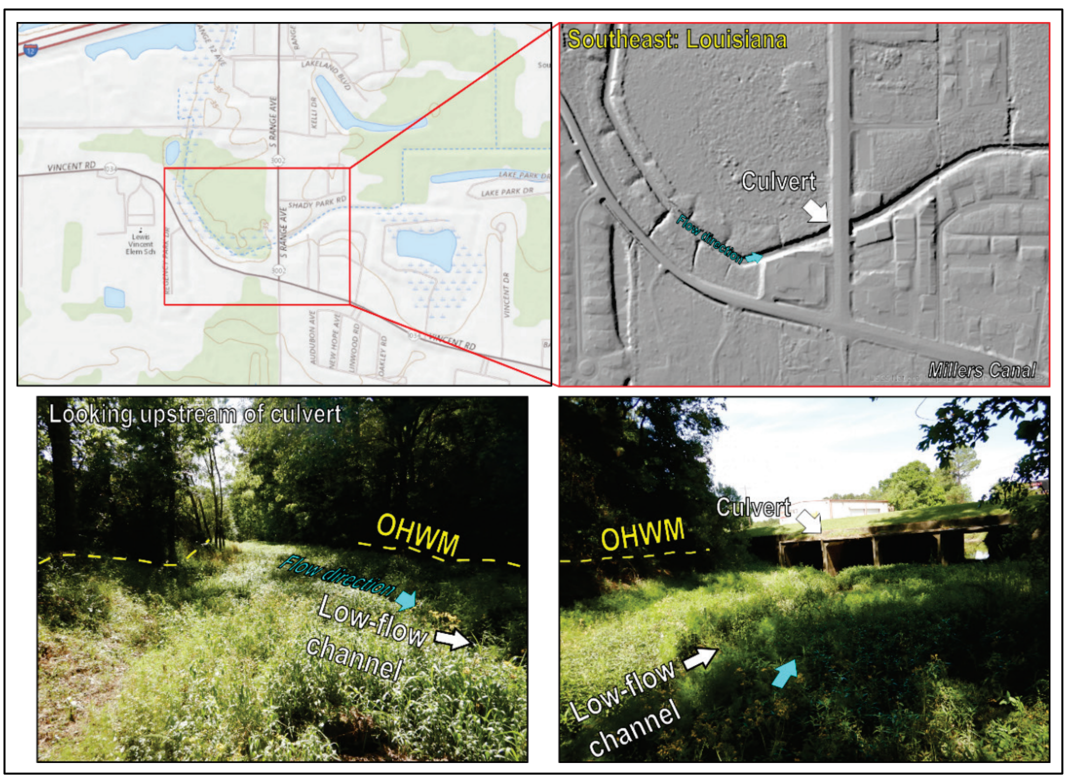
Figure 148. Erosion downstream of culverts caused by sediment deposition upstream. Channel incision and widening of the channel are common features downstream of the culvert.

Culverts that are extremely undersized will have evidence of erosion around the structure. Figure 149 shows two culverts, one that is exposed by fluvial action and another that is being bypassed. The sediment on top of the culvert in the unnamed tributary to Minebank Run has been removed because, at high flows, water is flowing on top of the culvert instead of only through it. This is likely because the culvert is too small for the storm flows coming down this tributary and so water flows over the top. The culvert that is being bypassed in Oregon Branch likely has a similar problem. The culvert is too small for the flows, so the higher flows divert around the culvert after the water piles up behind it. Water depth upstream of a culvert is likely increased because of the damming effect of the culverts. Therefore, the OHWM may be at a higher elevation than would be initially expected in these channels. Generally, with undersized culverts, the OHWM may be over the top of the banks upstream of the culvert, whereas downstream it may be below the top of the banks.

Figure 149. When culverts are severely undersized, the stream may bypass the structure completely. Evidence of erosion overtop (*left*) and around the sides (*right*) of the structure indicate that the culvert is not containing the high flows.

The size of culverts can sometimes provide evidence of the expected size of flows through a stream system (Figure 150). In Figure 150, the urban canal in Louisiana has a small, low-flow channel. It is difficult to see the low-flow channel because of the overgrowth of herbaceous vegetation. There is a wider channel with evidence of the OHWM from a change in vegetation type and a break in slope that is at a higher elevation than the low-flow channel. This larger channel can be seen in the lidar hillshade map. Each of these observations provides a line of evidence to help support using the break in slope along the tree line to delineate the OHWM. The culvert size may provide some additional evidence on the flow magnitudes expected in a channel. In this case, the culverts are much larger than the low-flow channel that was documented during the day of the field visit. This provides at least some support that flows commonly fill the width of the floodplain. As already noted, there are many cases in which culverts are undersized for the streamflow. The extent of the influence of culverts on a stream system depends on the surrounding land use in the watershed and the stream and valley gradient.

Figure 150. Culvert size can provide evidence of the magnitude of high flows in small channels. (*Top* images modified from USGS n.d.c.)

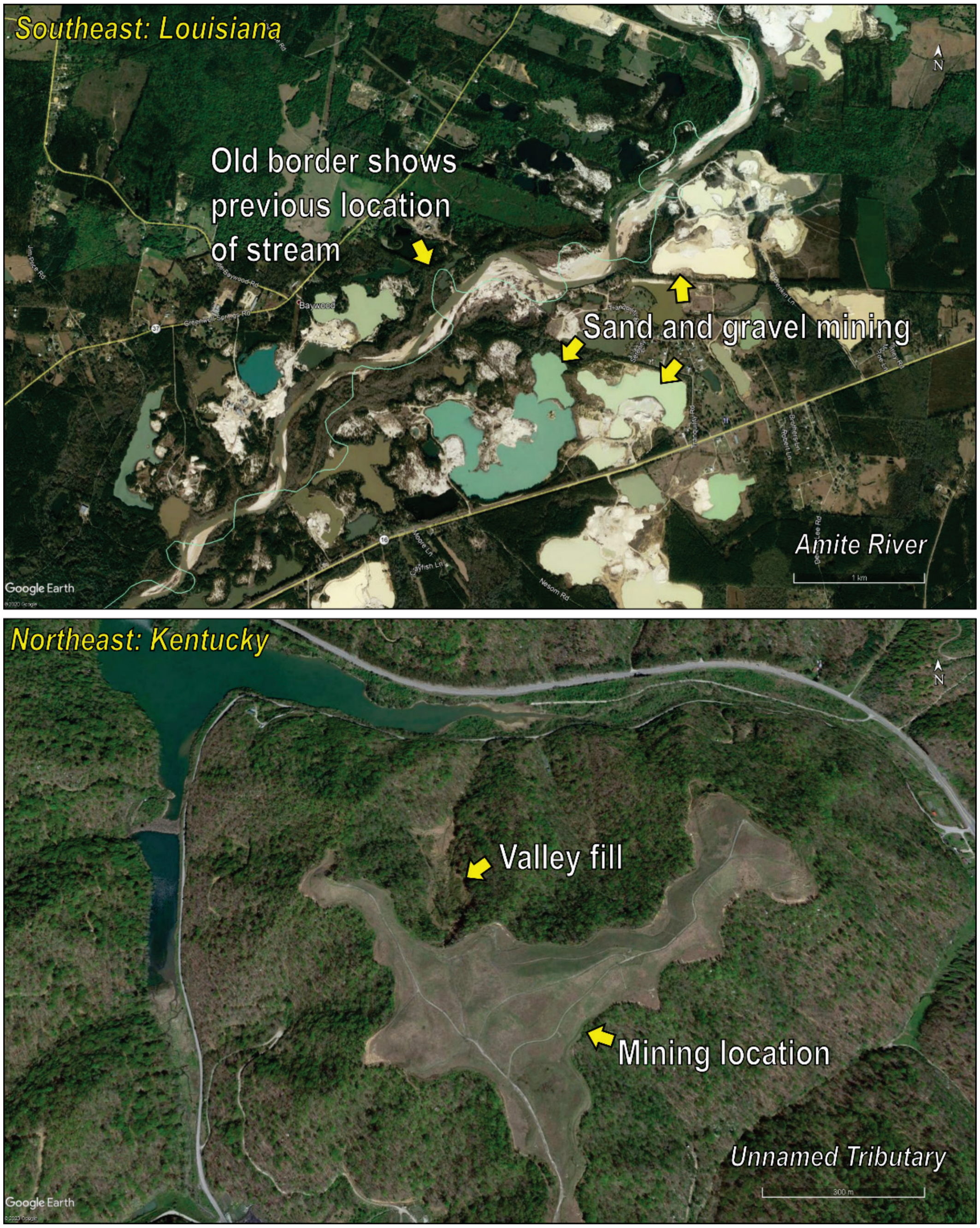


6.4 Mining

Various types of mining can affect the OHWM in different ways. Mining takes many different forms, with highly variable potential hydrologic, geomorphic, sedimentological, and geochemical outcomes. These effects vary with the scale of the mining, the materials mined, the location of the mines relative to the channel, and the type of mining. Forms of mining range from open pits, to deep tunnels, to solution mining, in which fluids are injected and retracted. Potential effects of mining are not confined to the mine itself but also include indirect or off-site affects, such as road building, logging, dust, and water transfers.

Two key types of mining that directly cause stream channel responses are (1) mines that produce tailings that are delivered to channels as high sediment loads and (2) in-channel mining of sand and gravel. In some cases, both types of mining may be present (Figure 151). Mining may also be associated with subsidence and sinkholes that affect drainage patterns or flow gradients. Depending on the age of mining activities, the effects of mining may be relatively clear. New roads, deforestation, the operation of heavy machinery in streams and on floodplains, open pits, the production of large amounts of sediment, tailings dumps, cones, fans, and discoloration of water by acid mine drainage are all signatures of mining (Mossa and James 2013) and can often be seen on aerial imagery.

Figure 151. Google Earth can be used to look for land use effects, such as mining around or in the stream. For instance, the *top* image shows sand and gravel mining surrounding a Louisiana river, and the *bottom* image shows strip mining in the headwaters of Kentucky streams.



6.4.1 Mine tailings

Mining may produce large volumes of sediment in the form of tailings that can cause persistent adjustments to channel geomorphology downstream (Dethier et al. 2018). Once introduced, these sediments may be stored and released repeatedly and conveyed downstream over long periods of time. A typical pattern is for channels to fill with sediment and aggrade during periods of rapid sediment production and then to incise after mining ceases. In extreme cases of aggradation, channel incision may continue for many years and can establish a geomorphic trajectory. The recognition of such ongoing geomorphic adjustments of channels can be essential to accurate interpretations of OHWM features.

An extreme example of channel sedimentation was caused by more than a billion cubic meters (>1.3 billion cubic yards) of hydraulic mining sediment produced in the northwest Sierra Nevada of California during the 19th century (Gilbert 1917). Hydraulic mining in California in the second half of the 19th century resulted in massive sediment deposits that raised channel beds tens of meters in some places. Subsequent erosion left high terraces with modern channel beds flowing on thick layers of mining sediment. In the mountains, the fine gravel tailings buried coarser cobbles of the premining channels. Much of this sediment remains active in modern channels, such as Greenhorn Creek (Figure 152). The sequence of channel aggradation during a period of high sediment deliveries followed by degradation when sediment loads decrease is common to many streams affected by human activities, including mining, agriculture, logging, and road building. Deposits of human-induced sediment—often referred to as *legacy sediment* (James 2013)—are described in Section 6.5.

Figure 152. *Top*: A terrace of mining sediment approximately 15 m (50 ft) high on Greenhorn Creek at Arkansas Ravine. *Bottom*: View upstream on Greenhorn Creek of high historical terraces near Buckeye Ford. The low-flow channel at *left* has been altered from a coarse-bedded mountain stream to a meandering pattern on fine gravel.

Indications of augmented sediment supplies during channel aggradation include abundant channel bars, evidence of accelerated lateral channel migration (e.g., active cutbanks), and large, fresh sedimentary deposits on floodplains. Relatively fine sediment deposited over the banks may bury young floodplain soils that may be seen in cutbank exposures. Recent sedimentation may also be seen in the form of marshy areas near the channel and at tributary junctions, fresh berms and shelves within the channel, and fresh fine-grained caps on coarse-grained bars and channel margins. Pools in former pool and riffle sequences may be filled, resulting in longitudinal profiles that lack variability at the local scale. Meandering single-thread channels may be converted to braided multithread channels. After tailings cease to be produced and channels incise, tailings deposited on floodplains may be abandoned and remain as one or more terraces, which may continue to contribute reworked tailings for long periods of time. Terraces composed of mining sediment are often higher upstream, toward the source of the sediment.

6.4.2 Sand and gravel mining

Aggregate mining often removes large volumes of sediment from within channels or from floodplains near channels. Instream mining or mining on floodplains within the range of flood flows can have a variety of direct and indirect effects on rivers and streams by removing bed material and creating sinks that trap sediment and reduce bedload transport downstream (Kondolf 1994, 1997; Rinaldi et al. 2005; Surian and Cisotto 2007). Mining within the channel is often done by dredging, which generally has a greater effect on channel morphology, sediment transport, and flow stages than mining on floodplains because it lowers the equilibrium profile of the channel bed (Kondolf 1994). Channel avulsions into floodplain pits can, however, cause responses similar to those from in-channel mining (Scott 1973).

Dredging can disrupt channel geomorphology and alter flow stages. Mining of point bars straightens and steepens channels (Meador and Layher 1998). The potential effects of instream mining on the OHWM are highly variable, but the dynamics of ongoing change should be considered when interpreting sites near such activities. Dredging is not only a type of mining but is also associated with channelization projects designed to improve navigation or reduce local flood risks.

Channel gradients gradually decrease below pits and steepen above instream pits, which encourages erosion upstream. Decreased gradients below mine pits may encourage deposition, but the capture of sediment by the pit tends to reduce sediment loads and result in sediment recruitment and incision downstream, which may cause a downstream migration of the pit. Gradient changes may propagate upstream into tributaries and downstream of the mining zone. Evidence of channel incision includes undermined bridge pilings, exposed pipeline crossings, abandonment of floodplains as terraces, and bed-material coarsening as fine sediment is selectively removed.

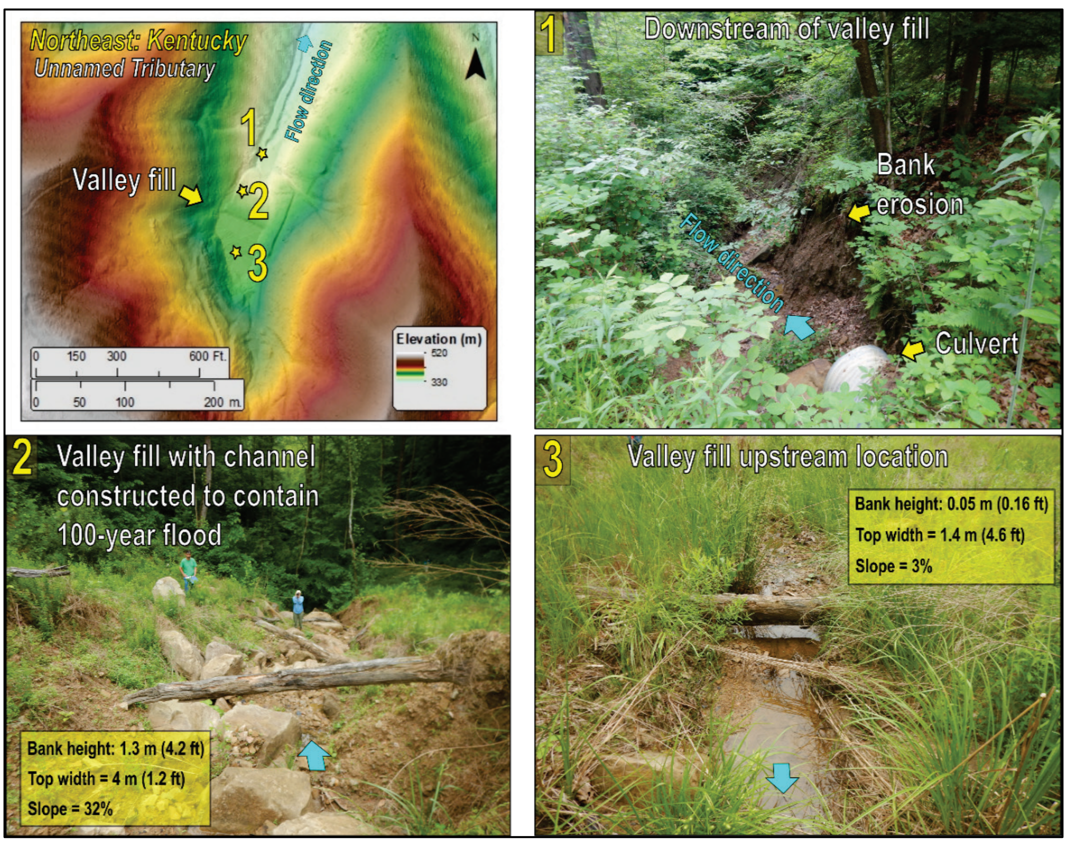
Morphological changes to channels and flow stages may be highly dynamic for decades both near and downstream of mining sites. Downstream channel incision and upstream knickpoint migration may result in pit enlargement. In extreme cases, incision below a pit may be measured in meters, extend several kilometers above and below the pit, and result in channel morphogenesis from a braided to a single-thread channel, as happened on the Russian River near Healdsburg in California (Kondolf 1994). A geospatial study of geomorphic responses to riverbed mining from 1946 to 2000 in a Spanish ephemeral stream, based on historical aerial photographs and lidar, documented 3.5–4 m of channel incision accompanied by changes to channels and bars (Calle et al. 2017).

6.4.3 Valley fill from mining: Kentucky case study

Kentucky provides examples of valley fills from mines that completely filled the former stream channel and recontoured the landscape with an entirely new ground surface. In such cases, the new channel generally will be constructed on the valley fill or where the valley fill abuts the remaining natural hillside, but it may not be the appropriate size for the range of flows occurring in the stream. At sites with recent valley fill, it is useful to first understand what was constructed. Everything has potentially been manipulated at these sites, and therefore, the streams are starting from human-induced initial conditions that will take decades or centuries to stabilize. Valley fill has various levels of size and compaction and may absorb water like an aquifer or shed water through surface and near-surface runoff. In some cases, channels may not carry water on valley fill except during extreme precipitation or snow-melt events. On the other hand, the area at the base of the fill can have semistable flows because the fill acts like an aquifer. Whenever approaching a valley fill site, it may be useful to investigate a few items before the site visit. First, is the site at the top of the fill or on the edge with the natural hillside? Second, does it have a water source from above the fill? Third, was the channel lined (e.g., by fabric or clay), and fourth, what is the age of the fill?

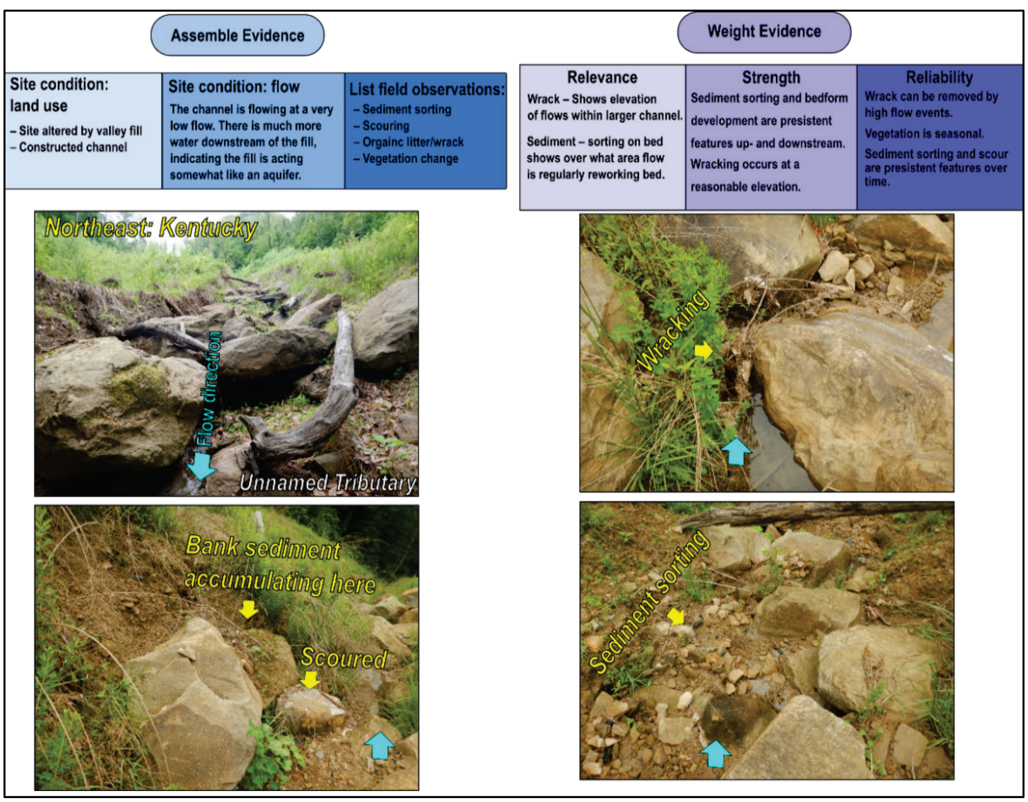
The first step in applying the WoE method is to get a site overview and identify the assessment area. Figure 153 shows images and lidar hillshade for the Kentucky valley fill site shown on the satellite image in Figure 151. The lidar hillshade and photographs show (1) where the channel incised downstream of the valley fill, (2) where an overly large channel was constructed on the valley fill (assessment area), and (3) where the channel is reforming on top of the fill material. The channel was constructed to contain a 100-year flood on a steep (i.e., approximately 32%) slope. The steep grade of the channel, the high velocity of the flows through the channel, and piping as water moves through the subsurface likely all contributed to the slumping of the large boulders off the banks and into the center of the channel. It can be difficult to estimate the location of the OHWM in a channel that was constructed to contain extreme flows. The WoE technique described in this manual can assist in gathering and combining multiple lines of evidence to identify a reasonable location for the OHWM. The area being assessed in this case is the constructed channel (Figure 153, Reach 2).

Figure 153. Channels constructed in a valley fill downstream of a strip-mining location in Kentucky. Reach 1 (*top right*) shows a channel just downstream of the valley fill that has incised. Reach 2 (*bottom left*) shows the constructed 100-year channel in the valley fill. Reach 3 (*bottom right*) shows a self-formed channel above the constructed channel.



The next step in applying the WoE technique to these sites is to assemble evidence (Figure 154). Satellite imagery and lidar are available online and are shown in Figures 151 and 153. The next part of assembling evidence is understanding the landscape context. There are three very different channel segments in the valley shown in Figure 153. The furthest downstream segment, Reach 1, is the channel below the valley fill, which still has a forested riparian zone. The channel has incised heavily due to changes upstream. The middle segment (i.e., Reach 2) is the channel constructed to contain a 100-year flood event, which is at a very high gradient. Boulders have been placed on the bed and banks to help maintain channel stability, but these were obviously placed without consideration of hydraulics. The high gradient is creating a high-velocity zone that is causing increased erosion and channel incision. Boulders that were meant to keep the banks stable have all slumped away from the banks and are now in the channel. The boulders remaining on the banks provide evidence of the original intent of boulder placement. The most upstream segment (i.e., Reach 3) appears to have been left to carve its own path through the valley fill. The gradient of this channel segment is much lower. Herbaceous vegetation, organic litter deposition, and secondary channels indicate that the flow is not contained only within this small channel but, rather, extends out into the floodplain.

Figure 154. Following the WoE approach in Reach 2 (from Fig. 153) by identifying high-water indicators at a valley fill site in Kentucky.



The next step is to weight evidence by determining its relevance, strength, and reliability. Organic litter accumulation indicates the elevations to which high flows are reaching along the bank slope in the larger channel segment (i.e., Reach 2) shown in Figure 154. Unfortunately, wracking is not a completely reliable line of evidence because it can be removed by larger flows. Nonetheless, wracking can provide support for other lines of evidence. Reach 2, the larger, constructed channel, has obvious sediment sorting on the bed and over the top of the boulders. Sediment has been scoured away from the top of one boulder and appears to have accumulated from previous bank failures at the top of a slightly higher boulder (Figure 154). Sorting and scour can be persistent over space and time. Finding the upper elevation at which this occurs can help with determining the OHWM within this channel segment. Little to no vegetation was growing within the channel. The vegetation at the very top of the steep cutbanks provides an upper elevation for the OHWM. The changes in vegetation can be a strong indicator spatially but may not be reliable over time. Vegetation cover is likely to appear very different in the fall and winter. Natural vegetation establishment on reclaimed mines is also limited by compacted soils, and the vegetation is often dominated by hydroseeded, fast growing graminoids and forbs. In contrast, the banks and width of the channel are much smaller in the most upstream segment (i.e., Reach 3), but there is evidence of overbank flow that spread out onto the adjacent floodplain (Figure 155).

Figure 155. Vegetation species and flattening of vegetation provide evidence of flow spreading across the floodplain at the upstream reach (i.e., Reach 3 from Fig. 153).

After weighting individual lines of evidence, the final step is to weigh the body of evidence and arrive at a final decision (Box 21). High flows likely spread out in the upper reach (i.e., Reach 3), and much of the water may end up flowing through the subsurface rather than flowing overland because of the loose substrate in the valley fill. The presence of wracking, the upper limit of sand deposition on the boulders, and the sorting of sediment on the channel bed indicate that Reach 2 has experienced enough high-flow events to begin to modify the channel form. The wracking, upper limit of sand-sized particles, and establishment of some vegetation occur at a similar elevation and, therefore, are interpreted to be at the elevation of the OHWM in Reach 2. Information at Reaches 1 and 3 was used to help interpret the data at Reach 2. If the OHWM were to be determined at each of the three reaches, a separate data sheet would need to be completed for each.

Box 21. Data sheet (adapted from USACE 2022) for valley fill site.

Print Form | Save As | E-mail

U.S. Army Corps of Engineers (USACE)
RAPID ORDINARY HIGH WATER MARK (OHWM) FIELD IDENTIFICATION DATA SHEET
The proponent agency is Headquarters USACE CECW-CO-R.

From Approved - OMB No. 0710-OHWM Expires: xx-xx-xxxx

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Project ID #: Valley fill case study | Site Name: Unnamed tributary to Defeated Creek KY | Date and Time: 5/23/2018

Location (lat/long): 37.21696944, -82.96969167 | Investigator(s): G. David, M. Tarasiewicz, & T. Williams

Step 1 Site overview from remote and online resources
Check boxes for online resources used to evaluate site:

- [ ] gage data
- [x] LiDAR
- [ ] geologic maps
- [ ] climatic data
- [x] satellite imagery
- [ ] land use maps
- [ ] aerial photos
- [ ] topographic maps
- [ ] Other:

Describe land use and flow conditions from online resources.
Were there any recent extreme events (floods or drought)?
Valley fill site with distinct transitions in gradient. Reach is just below a mining location.

Step 2 Site conditions during field assessment. First look for changes in channel shape, depositional and erosional features, and changes in vegetation and sediment type, size, density, and distribution. Make note of natural or anthropogenic disturbances that would affect flow and channel form, such as bridges, riprap, landslides, rockfalls, etc.

Valley fill site with a channel constructed to contain a 100-year flood. There is a culvert below the valley fill, and the channel is incised below the culvert. Trees have been removed in the area of the valley fill. The vegetation on the valley fill are forbs and graminoids. Stream was likely at base flow during visit.

Step 3 Check the boxes next to the indicators used to identify the location of the OHWM.
OHWM is at a transition point, therefore some indicators that are used to determine location may be just below and above the OHWM. From the drop-down menu next to each indicator, select the appropriate location of the indicator by selecting either just below `b', at `x', or just above `a' the OHWM.
Go to page 2 to describe overall rationale for location of OHWM, write any additional observations, and to attach a photo log.

Geomorphic indicators

- [ ] **Break in slope:**
  - [ ] *on the bank:*
  - [ ] *undercut bank:*
  - [ ] *valley bottom:*
  - [ ] Other:
- [ ] **Shelving:**
  - [ ] *shelf at top of bank:*
  - [ ] *natural levee:*
  - [ ] *man-made berms or levees:*
  - [ ] *other berms:*
- [ ] **Channel bar:**
  - [ ] *shelving (berms) on bar:*
  - [ ] *unvegetated:*
  - [ ] *vegetation transition (go to veg. indicators)*
  - [ ] *sediment transition (go to sed. indicators)*
  - [ ] *upper limit of deposition on bar:*
- [x] **Instream bedforms and other bedload transport evidence:** b
  - [x] *deposition bedload indicators (e.g., imbricated clasts, gravel sheets, etc.)* b
  - [ ] *bedforms (e.g., pools riffles, steps, etc.):*
  - [x] *erosional bedload indicators (e.g., obstacle marks, scour, smoothing, etc.)* b
- [x] **Secondary channels:** b

Sediment indicators

- [ ] **Soil development:**
- [ ] **Changes in character of soil:**
- [ ] **Mudcracks:**
- [x] **Changes in particle-sized distribution:** x
  - [ ] *transition from* ______ to ______
  - [x] *upper limit of sand-sized particles*
  - [ ] *silt deposits:*

Vegetation Indicators

- [x] **Change in vegetation type and/or density:** x

  Check the appropriate boxes and select the general vegetation change *(e.g., graminoids to woody shrubs)*. ***Describe the vegetation transition looking from the middle of the channel, up the banks, and into the floodplain.***
  - [x] *vegetation absent to:* forbs
  - [ ] *moss to:*
  - [x] *forbs to:* graminoids
  - [ ] *graminoids to:*
  - [ ] *woody shrubs to:*
  - [ ] *deciduous trees to:*
  - [ ] *coniferous trees to:*
- [ ] **Vegetation matted down and/or bent:**
- [ ] **Exposed roots below intact soil layer:**

Ancillary indicators

- [x] **Wracking/presence of organic litter:** x
- [ ] **Presence of large wood:**
- [ ] **Leaf litter disturbed or washed away:**
- [ ] **Water staining:**
- [ ] **Weathered clasts or bedrock:**

Other observed indicators? Describe:

The elevation at which the sediment (eroded from the channel banks) is being scoured away corresponds to the elevation where there is organic litter/wracking. The flow is confined in this channel, but the cross-sectional area that would be inundated would be similar as up- and downstream segments.

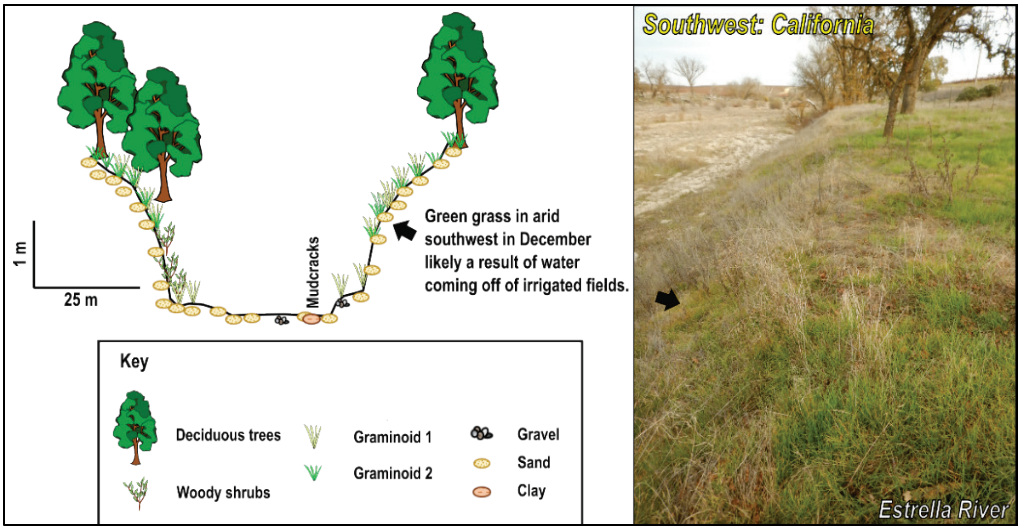
ENG FORM 6250, AUG 2022 PREVIOUS EDITIONS ARE OBSOLETE. Page 1 of 4

6.5 Agriculture and livestock

Agriculture can have several effects on streams because changes in land cover cause changes in runoff patterns and sediment yields (Wohl et al. 2016). Agriculture is commonly connected to increases in sediment production because of vegetation removal and plowing, but increased runoff can also result from vegetation removal, ploughing, irrigation, and reduction in floodplain wetlands. To reduce erosion, small streams draining farm fields are also frequently manipulated by broadening and shaping their beds and banks into grassed waterways. When modified into a grassed waterway, the natural bed, banks, and OHWM features can be masked for a period of time. However, given enough time, these physical features often naturally return without maintenance or additional manipulation. Riparian vegetation may be altered by direct removal, an increase in nutrients from adjacent fields, and runoff from adjacent fields. Streams in agricultural areas are often straightened (i.e., channelized), causing channel incision and bank erosion. In contrast to increased runoff, dewatering of channels can occur because of increases in groundwater pumping or direct extractions of water for irrigation. Dewatering can affect the movement of sediment and organic material through the channel and riparian vegetation growth characteristics. Agriculture also includes livestock grazing, which can further alter channel dimensions by compaction, sedimentation, and vegetation removal, which can all mask evidence of the OHWM.

Heavy irrigation next to channels can alter the vegetation along the channel riparian zone. As an example, the Estrella River is in an arid environment of California in the Southwest region, but although the grass on the channel bed was dry and dead, the grassy banks were green during a site visit (Figure 156). The river is surrounded by farmland; therefore, the greener vegetation in the riparian zone may be from fertilizer and an increase in water from the irrigated land. Therefore, the surrounding land use is important when considering how vegetation changes may be related to the OHWM in the channel. In this example, some of the vegetation transitions may be more closely related to surrounding water use rather than to streamflow.

Figure 156. Green grass on riparian zone and along banks is likely a result of irrigation from adjacent farmland.



Some channel systems have thick layers of historical sediment that was generated by human land-use changes upstream (Happ et al. 1940; Knox 1972; Jacobson and Coleman 1986; Donovan et al. 2015). These legacy sediments include material not only from agricultural erosion but also from mining, logging, and other disruptive land uses (James 2013; Wohl 2019). In extreme cases, legacy sediment may form thick deposits into which the channel incises, so the modern channel is confined laterally by high, historical terraces (Figure 157). Channel confinement tends to result in deepened flows that scour the bed. They may be widening due to treefall and bank caving and may have high sediment loads from bank erosion and floodplain gullying. Floodplain burial by legacy sediment has been well-documented in the Midwest, Mississippi Valley, and Southeastern and Atlantic piedmont regions (James 2019). Although not well documented, such historical burial may also have occurred in other regions of North America.

Evidence of past severe erosion and floodplain sedimentation includes buried soils in stream banks, hillside gullies, and terraces that may show up on airborne lidar imagery (Figure 158). Historical documentation, such as county histories, maps, and plat maps, may also indicate a history of erosion and land abandonment in the region. Understanding the historical land-use context can help to put the landscape and current conditions in context. Furthermore, changes in sediment that are related to legacy conditions should not be confused with how the current channel system is functioning.

Figure 157. Presettlement soil buried by approximately 1.4 m (4.6 ft) of legacy sediment at Chicken Creek, in Fairfield County, South Carolina. *Arrows* show the top of the buried soil, which was at the surface in the 19th century, prior to land clearance for agriculture. After deposition of the overlying sediment, the channel at this site scoured to bedrock, left the former floodplain as a terrace, and is currently widening and forming a new floodplain at a lower level within the incised area, near where the OHWM is located.

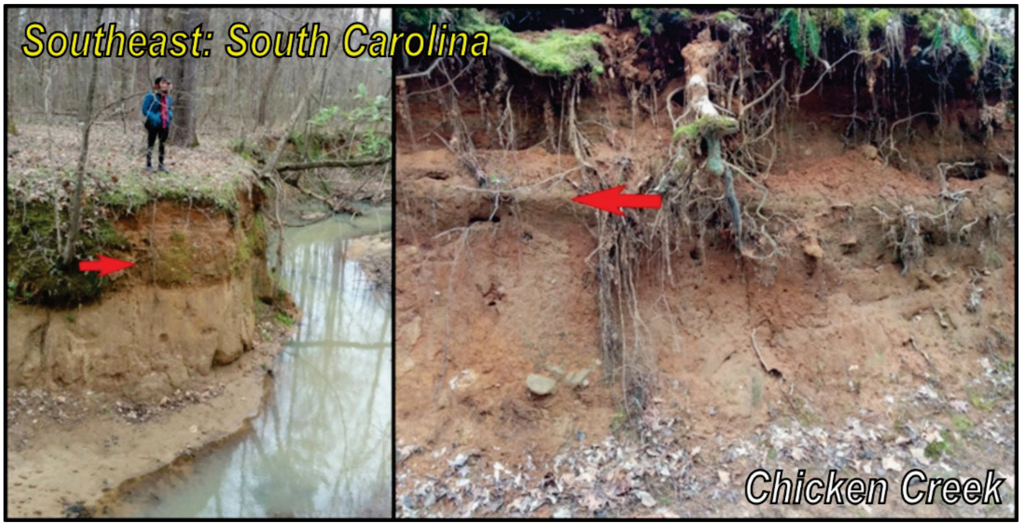
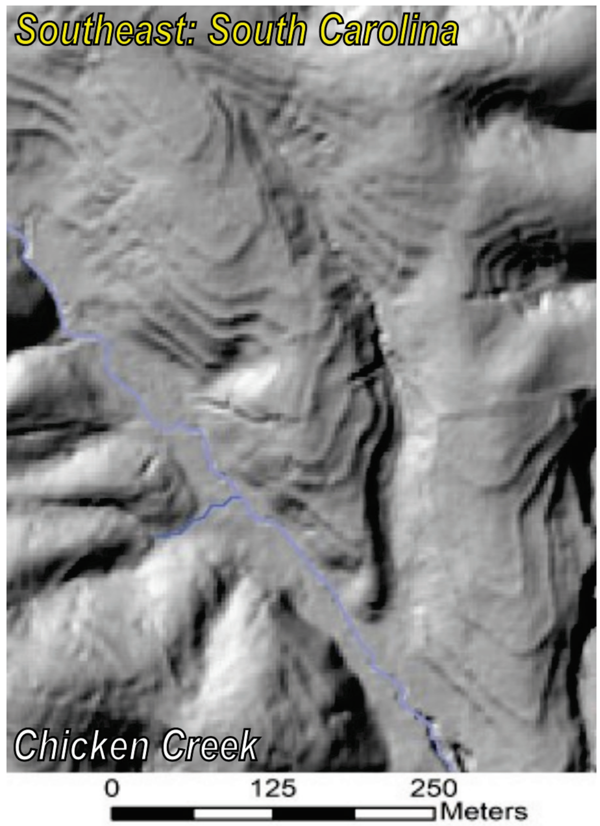


Figure 158. Hillshade lidar image of Chicken Creek watershed, in South Carolina, showing arcuate terraces from late 19th or early 20th century soil conservation efforts. These lands were abandoned by the mid-20th century and reverted to forest. Such landscapes indicate severe erosion problems at the time the terraces were constructed and potential floodplain burial by legacy sediment downstream. This area is near, but slightly downstream of, the site shown in Fig. 157.



6.5.1 Livestock (grazing)

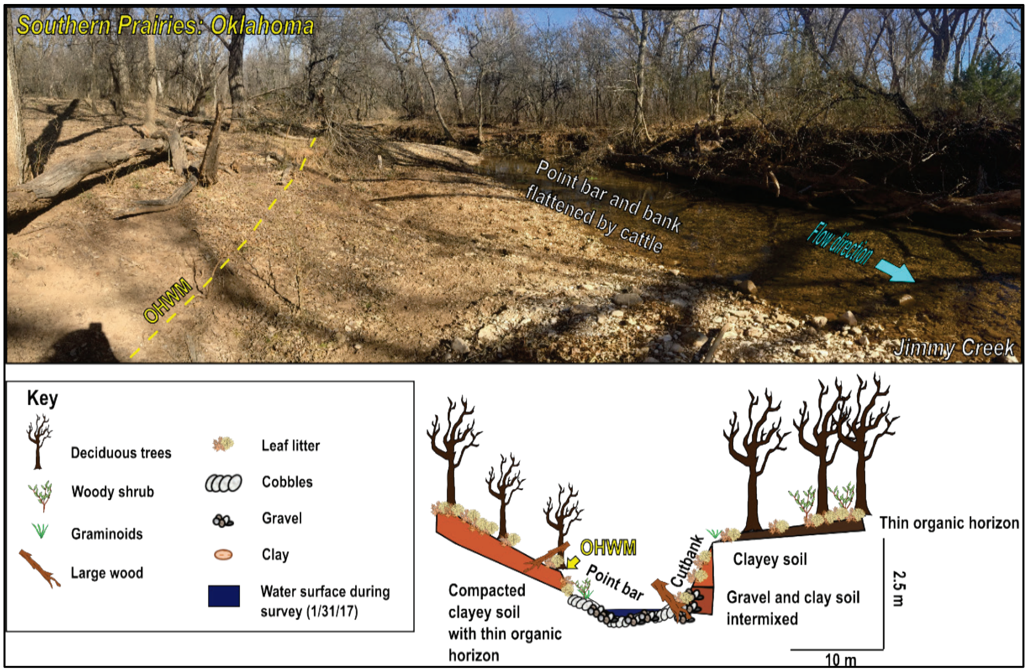
Hydrologic and geomorphic changes can be exerted by both natural and domesticated grazing animals. Long-term effects of grazing on soil compaction, suppression of woody vegetation, and forest regeneration may increase water and sediment deliveries to channels (Evans 1998; Meyles et al. 2006). At the local-site scale, cattle can eat riparian vegetation, altering OHWM indicators along the banks, and cattle trampling may leave terracettes on steep slopes (Weihs and Shroder 2011), including on inclined channel embankments, that may be mistaken for fluvial features or OHWMs caused by the stream. Grazing may be associated with channel cross-section morphology. Cattle trample and pack down soils in the banks, often causing them to erode to a lower bank slope (Trimble 1994;

Trimble and Mendel 1995). For instance, intense grazing pressure in Wickiup Creek, a small Eastern Oregon stream, was associated with a lack of vegetation on banks and greater channel widths that began to recover after grazing pressures were relaxed (Nagle and Clifton 2003).

6.5.2 Cattle grazing: Jimmy Creek, Oklahoma case study

The local effects of grazing on channel cross-section morphology are exemplified by Jimmy Creek, a small stream channel in Oklahoma. At the study site, heavily grazed banks were mostly clear of low vegetation, packed down, and eroded, creating lower bank gradients (Figure 159). The impact of grazing was intensified by the presence of a point bar, which apparently attracted cattle as a watering site and concentrated trampling along access routes. Although much of the evidence of the OHWM was obliterated by trampling and the grazing of vegetation, subtle changes in vegetation and sediment remained that allowed for identification of the OHWM. The OHWM was determined from the presence of deciduous trees, which were established at a specific elevation above the channel; the presence of LW and organic litter on the floodplain and around the base of the trees; and a break in slope just above the point bar. The transitions in sediment were determined to be below the OHWM. Despite the flattening by the cattle, there was a clear break in slope that corresponded to these other lines of evidence. The elevation of the break in slope along the cutbank appeared to be higher than the elevation of the identified OHWM along the other bank. Above the cutbank, a clayey soil was developing on the floodplain, indicating that this elevation was above the OHWM. LW was deposited near the bank, which was likely submerged during high flows. It is likely that the LW increased depths along the bank, causing some backwater, and allowed the water surface to reach a higher elevation along the cutbank than it did across the channel along the point bar. The cutbank included a transition from gravel intermixed with clay to mainly clay. That transition likely occurred just below the OHWM and corresponds with the elevation of the OHWM found just above the point bar.

Figure 159. The shape of banks and point bar flattened by cattle walking along the channel.



6.6 Urbanization

The hydrology of urbanized channels may be highly dynamic, so frequencies of various flow stages may change through time as the percentage of impervious surfaces increases in the watershed. These dynamics are driven by urbanization that changes the watershed, including new subdivisions with pavement and storm sewers, water and sediment generation from construction projects, and the construction of storm detention structures to capture sediment and retard storm flows. These upstream changes generate responses downstream that can result in OHWMs that shift through time. Urbanization greatly increases the variability of storm flows and sediment deliveries and often results in relatively high-flow stages at much greater frequencies than in nonurban watersheds of a similar size (Bosch et al. 2003; O'Driscoll et al. 2010; Walsh et al. 2005). For example, substantial increases in peak storm flows due to urbanization in South Carolina were quantified by rainfall runoff and statistical modeling (Bohman 1992). This was corroborated by measured increases in storm flows with precipitation in a highly urbanized catchment in Columbia, South Carolina, that were an order of magnitude greater than in a similar sized but unurbanized forested catchment outside the city (Hung et al. 2018). The dynamics of urban hydrology often follow a sequence that begins with an increase in storm flow and sediment production that results in higher flow stages downstream (Wolman 1967; Chin and Gregory 2001).

Later, sediment production from new construction declines, but increased runoff from pavement and a more rapid arrival of water from storm sewers continue. Thus, after a period of adjustments to urbanization, channels receive less sediment from upland sources, remove the earlier sediment, and enlarge to accommodate the larger flows. This, in turn, may result in flow stages changing to new levels in enlarged channels.

6.6.1 Identifying OHWM indicators around hard engineered structures

Hard engineering (e.g., riprap, revetment, channelization, and bridge abutments) is commonly observed in urban streams. These features may obscure evidence of the OHWM and make determinations more difficult, although some methods that apply to flashy, bouldery mountain streams may apply. Evidence of fluvial erosional and depositional processes can still occur around the engineered objects in the form of vegetation, sediment, and morphological features (Figure 160). Moreover, flow constrictions at bridge crossings, other obstructions, or roughness elements may cause backwater that can govern stages of high flows upstream and result in substantial differences in the OHWM above and below these features.

Figure 160. Concrete lined urban channels. There is staining on the concrete wall in the photograph on the *left*. Channel incision and undercutting of the concrete are evident along the bed in both photographs. There is also erosion above the concrete along the bank on the photograph on the *right*.

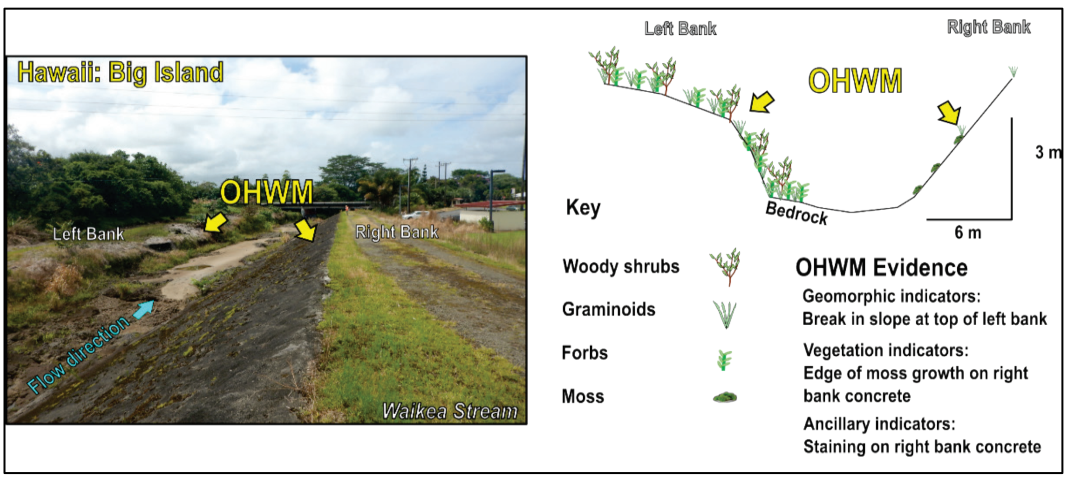
Erosional patterns around culverts and concrete-lined channels may reflect structures that are under- or oversized for the channel. Therefore, evidence of the OHWM needs to be based on observations of all the indicators discussed throughout this document. For instance, Figure 161 shows the potential location of the OHWM at the break in slope on the channel bank. The channel is likely incising just below the culvert, but this effect may only extend a short distance downstream. Therefore, the break in slope provides only one possible location. Following the WoE technique, more information should be gathered up- and downstream to provide more than one line of evidence for supporting the identification.

Figure 161. Channel incision and heavy erosion downstream of a culvert (*left*). The OHWM should be investigated further downstream. Channel widening and scour around a concrete-lined channel (*right*) downstream of urban runoff. In both cases, the streams appear to be sediment starved; therefore, the systems are dominated by erosion with little sedimentation.

In the photographs on the right side of Figure 161, the concrete-lined channel is sediment starved and shows one location (on top) where the channel is undersized and attempting to widen and one (on the bottom) where it is incising. The erosion of vegetation, exposure of roots, and deposition of sand provide multiple lines of evidence that the OHWM is above the edge of the concrete. Just downstream at this site, the channel has begun to incise down to concrete fragments due to increased velocities of high flows caused by the smooth, straight channel just upstream of this location. The OHWM is likely at the break in slope where the vegetation starts and is listed as the potential OHWM in Figure 161 because more evidence should be gathered from the other bank and up- and downstream before making a final decision. Both sites appear to be actively eroding, and therefore, it is useful to check recent local streamgage data to be certain that the erosion is not just from a recent flood event (see Chapter 5).

Although the anthropogenic structures located in urbanized environments have lines of evidence and OHWM indicators that are similar to those discussed throughout this manual, the indicators may present differently than expected in a channel without these constructed features (Figure 162).

Figure 162. Compiling lines of evidence for determining the OHWM in a concrete lined urban channel in Hawaii.

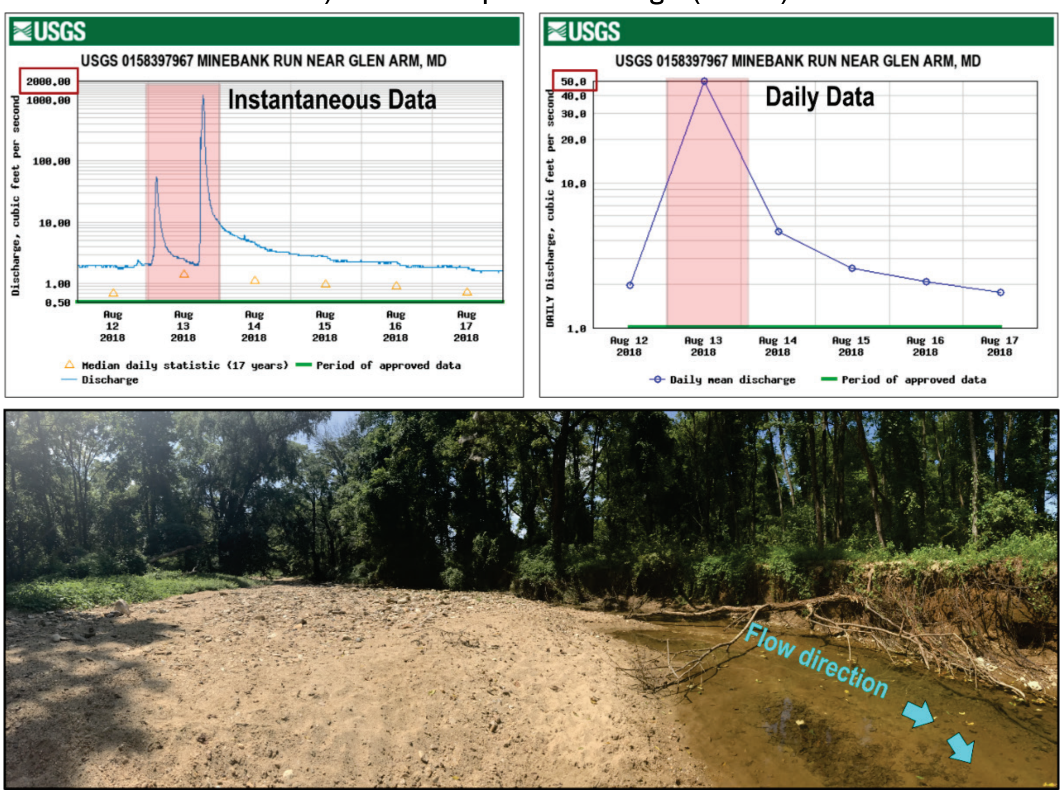


Land-use data can help determine the level of impact in a watershed prior to a site visit. The *percent impervious area* is commonly used as a metric of the degree of hydrologic change caused by urbanization. The National Land Cover Database can be used as a source of data on the percent impervious area (Chapter 5). The impact of high-flow variance and possibly obscured field evidence should be recognized when applying the methods for OHWM identification in urban streams.

6.6.2 Flashy flows in an urban stream: Minebank Run, Maryland, case study

Minebank Run, a small (5.5 km^2) catchment in Maryland, demonstrates evidence of changes in water and sediment discharges in an urban stream. The geomorphic dynamics of this system are evidenced by a recently eroded vertical cutbank opposite freshly deposited sand on a point bar, representing changes from recent flooding (Figure 163). In this case, the flooding responsible for the erosion and deposition occurred as two brief, intense flow events, both with a rapid rise and recession that can be seen in flood hydrographs derived from 15-minute instantaneous streamflow data. The two peaks are obscured and shown as a single peak when daily flow data are used.

Figure 163. Differences between instantaneous discharge and daily discharge in a flashy urban channel, Minebank Run, near Baltimore, Maryland (*top*; images adapted from USGS n.d.d). Point bar deposit on river right (*bottom*).



The high sediment loads in the Minebank Run system are also demonstrated by overbank sediment deposits in the area (Figure 164). Such unvegetated and undisturbed sandy deposits on floodplains in humid and subhumid regions often represent recent deposits. In these environments, such deposits tend to be rapidly obscured by plant growth, accumulation of leaves and other organic material, and bioturbation. However, such fresh-appearing deposits may be more persistent in arid environments, where biological processes tend to be slower.

Figure 164. Field indicators of high flow and channel adjustments in Minebank Run, an urban stream in Maryland. Wrack accumulation around the base of the trees on a vegetated channel bar (*top*), and sand deposition and scour around the base of a tree (*bottom*).

6.7 Summary

Disturbances can be natural or a result of human actions that affect watershed runoff processes, sediment yields, and channel form. Disturbances are important within fluvial systems because they influence floodplain and riparian processes and longitudinal and lateral connectivity (Wohl et al. 2019). The identification and delineation of the OHWM occurs in systems that are at different stages of recovery from either human-induced or natural disturbances. This can make the interpretation of OHWM indicators difficult because the system is in a state of flux. The most common forms of human-induced alterations to a system are from flow regulation, road–stream crossings, mining, agriculture, logging, grazing, and urbanization. Flow regulation comes in the forms of both dams and water diversions (Section 6.2). Road–stream crossings can be bridges, culverts, or fords. Identifying OHWM indicators around culverts was discussed in Section 6.3 because they are not only a common type of crossing, but they also have a large influence on flow up- and downstream because of the way they alter channel form. Mining effects can be from a variety of types of mining, including watershed changes from mountain-top removal or direct channel changes from mining tailings or in-stream gravel mining (Section 6.4). Agriculture and livestock were discussed in terms of historical effects that may be observed today and current changes to a system (Section 6.5). Livestock, through grazing, can directly alter channel form where animals are allowed to access the stream. The effects from urbanization can be similar to or overlap some of these other human-induced changes (e.g., flow regulation), but the combination of effects in urban environments can create a unique system that causes difficulties in understanding the varying lines of evidence that help to identify the OHWM (Section 6.6).

7 Complex Channels and Natural Disturbances

7.1 Key points

The geomorphic complexity of fluvial corridors increases with spatial heterogeneity. Streams that are braided or anastomosing, streams with high LW loads, and SWCs can be particularly complex systems. Natural disturbances can increase complexity depending on the type, magnitude, extent, and timing of these disturbances. Natural disturbances are events that affect the runoff processes, sediment yield, and channel form. These complex systems can have different OHWM indicators than in the commonly observed pool-riffle meandering channels. Therefore, SWCs and beaver-meadow complexes, which are a type of stream–wetland system, are discussed in detail in this chapter. The provided examples also address the effects of fires, debris flows, and flooding, which are natural or anthropogenic disturbances that often result in complex geomorphic responses.

7.2 Stream–wetland complexes (SWCs)

Many channel and valley characteristics that are considered indicators of OHWMs may be different or even absent in SWCs. SWCs are hydrologically integrated: the stream and wetland exchange flow continuously via hyporheic paths where soils are permeable. SWCs are unique in how integrated the stream system is with the wetland, but there are other cases in which a nearby wetland feature is connected to the stream and below the OHWM. For instance, a chute cutoff can have these hydrologic connections and may remain below the OHWM until sediment fills in the cutoff. In SWCs, relatively little precipitation is necessary for flows to reach flood stage (i.e., overtopping the banks), so flooding is frequent (e.g., several times, or even several dozen times, per year), although the duration of each event may be short (i.e., less than 24 hours). Frequent inundation of the floodplain, dense wetland vegetation, and gently sloping valley topography all have notable effects on the transitions in lateral slope, vegetation, and sediment that are considered the most reliable OHWM indicators in other settings.

7.2.1 Applying the WoE approach to SWCs

In SWCs, a WoE approach can assist in interpreting the OHWM indicators and determining which set of indicators have more weight. SWCs often have two potential locations for the OHWM: (1) at the channel boundaries or (2) on the wetland floodplain. Indicators at the channel boundaries are often the most obvious in SWCs. Applying the WoE approach to these systems will often reveal evidence of low to moderate flows at the channel boundaries and high flows on the wetland floodplain. Therefore, the more likely location of the OHWM will often be the wetland floodplain. This is especially true for SWCs in tributaries that are on wide, unconfined floodplains or those that are periodically submerged by flooding or backwater from larger rivers. In tributaries that are periodically submerged by flooding or backwater from larger rivers, the floodplain wetland indicators are likely to be obscured, modified, or otherwise unidentifiable. It is likely that the OHWM will then still be associated with the mainstem channel and, therefore, be identified at a much higher elevation than the tributary's channel boundary. The extent of the tributary length affected by the mainstem channel will depend on relative channel sizes and the topographic setting. The longitudinal distances affected up tributaries will typically extend beyond the OHWM along the mainstem river between the tributaries. Only the immediate reach near the confluence with the main channel will be affected in steep tributaries, whereas longer stretches of channel will be affected in low-gradient tributaries.

OHWM indicators may also be obscured at different times of the year, especially when vegetation grows into the channel during low-flow periods or grows tall and dense in the wetland floodplain. Furthermore, because of the nature of these systems, groundwater may be close to the surface and influence vegetation growth. Figure 165 shows an SWC in Alabama. The organic litter accumulated around the base of the trees at an elevation higher than that of the bank was a line of evidence that flow reached above the channel bank boundary. Some of this litter will pile up higher than the water reaches, but even the elevation at the base of the organic litter was higher than the banks. Therefore, extending that elevation put the OHWM further out into the wetland floodplain. The valley slope and lateral gradient across the wetland floodplain to the channel(s) were very low. There were some indications of scour and possible secondary channel flow in this floodplain. Vegetation growth is likely controlled by both streamflow and groundwater at this site; therefore, further out in the floodplain, the vegetation signatures were more difficult to interpret. There was some deposition of organic litter in the floodplain, and vegetation was bent over in the direction of the flow. The changes were much more subtle than those shown in the generalized schematic in Figure 166. The WoE approach, particularly with someone knowledgeable about local vegetation, can be applied to identify the OHWM.

Figure 165. Case study of an SWC of an unnamed tributary to Dyas Creek in the Southeast region (Alabama).

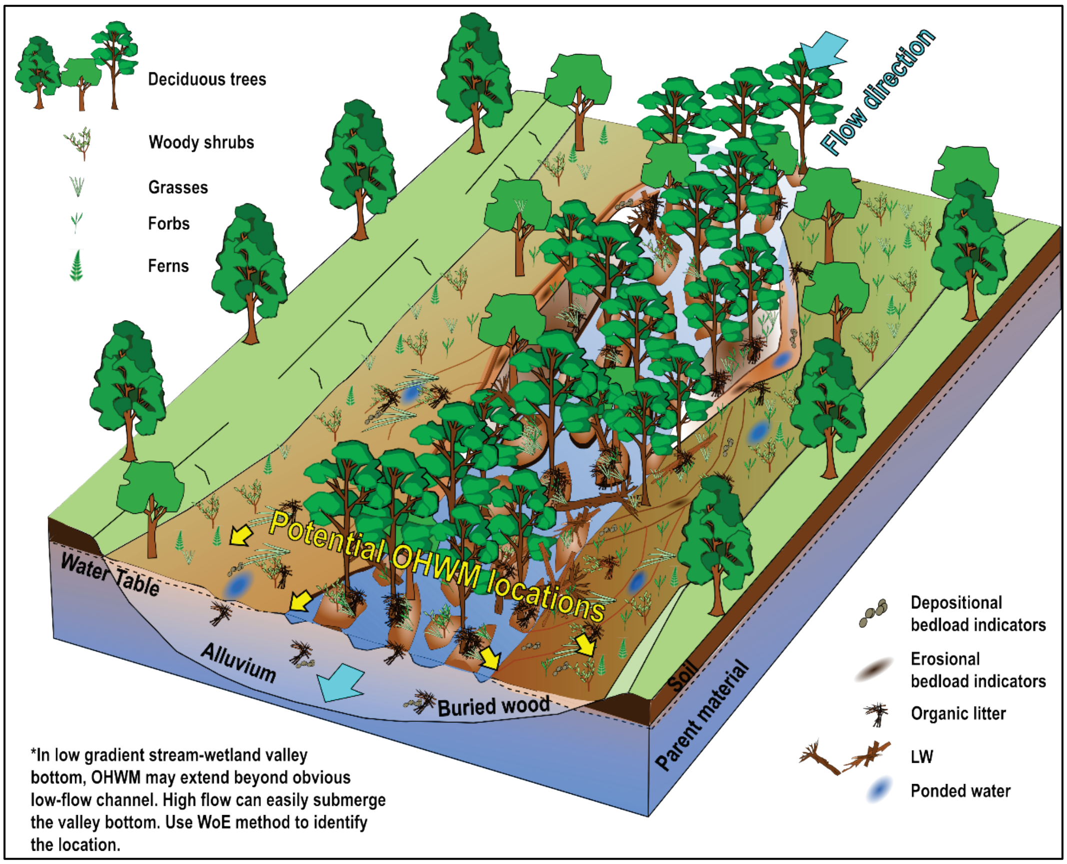
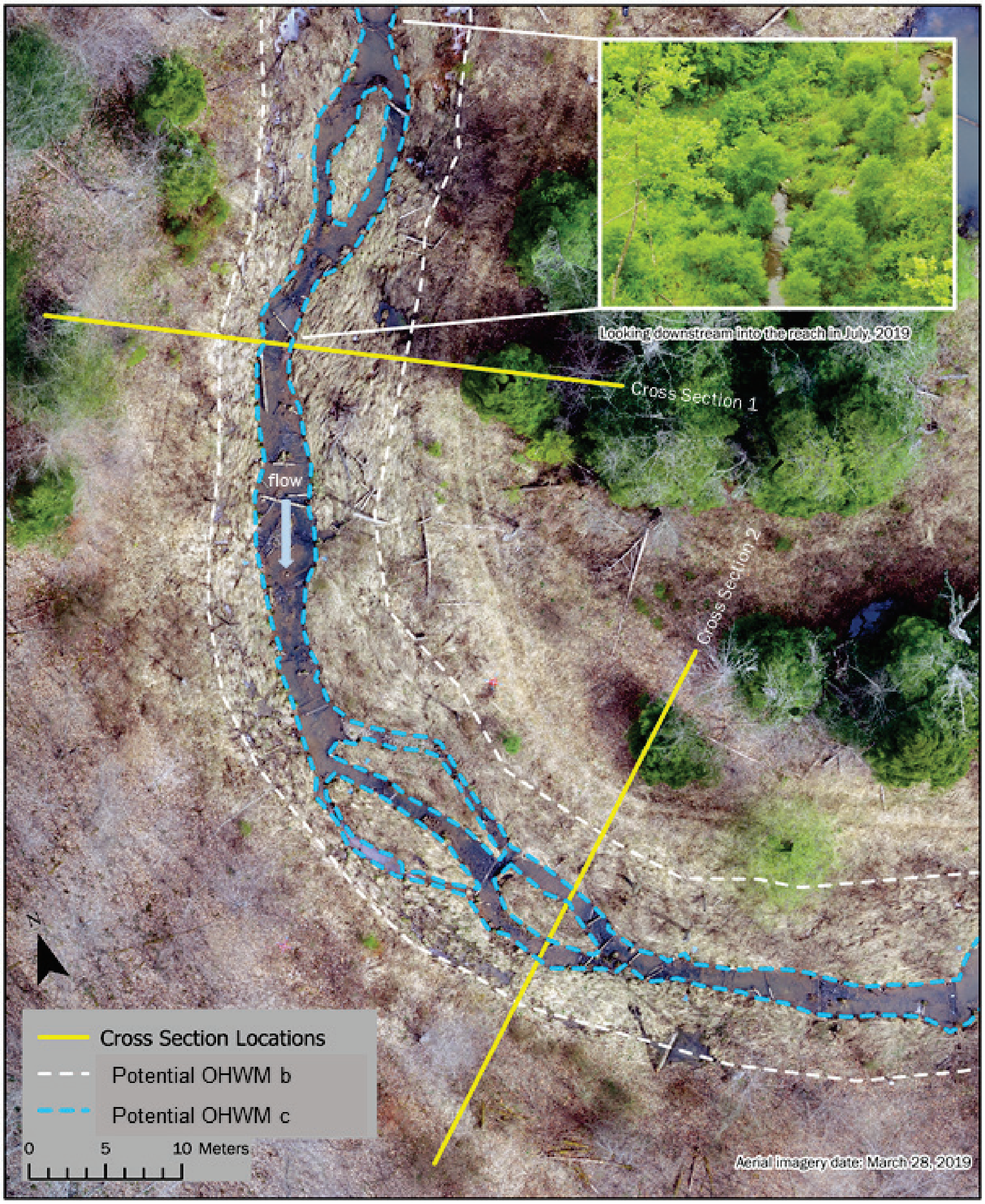


Figure 166. Photographs of an SWC showing how indicators are obscured by vegetation at the site.

7.2.2 SWC case study

Slabcamp Creek is an SWC in the Northeast region of the country. Figure 167 shows the location of the field site and—based on geomorphic, vegetative, and sedimentary characteristics—two potential locations of the OHWM.

Figure 167. Plan view of Slabcamp Creek marked with the locations of the example cross sections (see Figs. 168 and 169) and two potential OHWM locations. WoE will be used to determine which is the most likely location of the OHWM.



The process for identifying the OHWM is shown by examining two cross sections and identifying significant changes in slope, vegetation, and sediment type (Figures 168 and 169). The evidence is first assembled and examined at the site.

Figure 168. Cross Section 1 of Slabcamp Creek. *Arrows* show the significant transitions in geomorphic, vegetation, and sediment indicators.

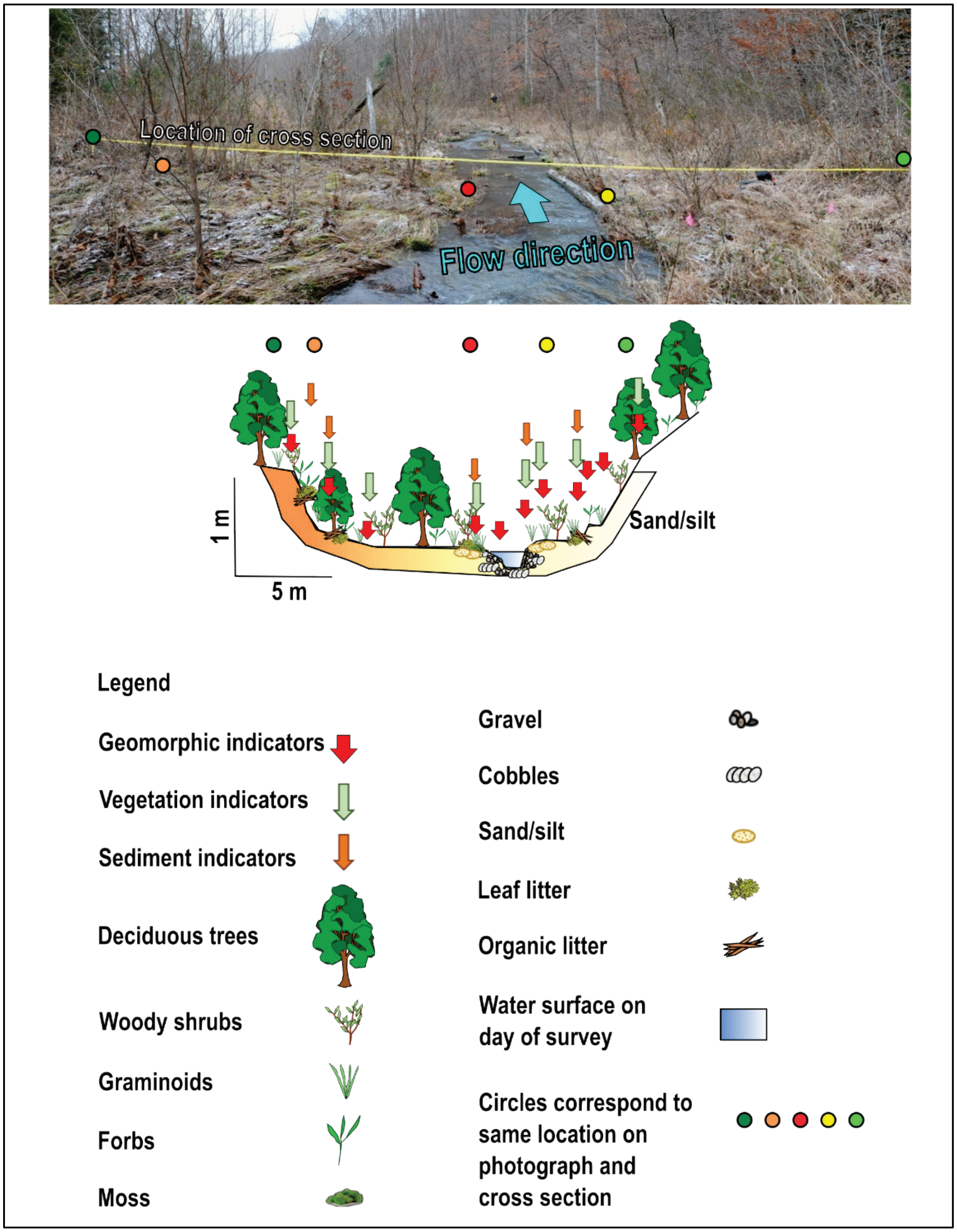
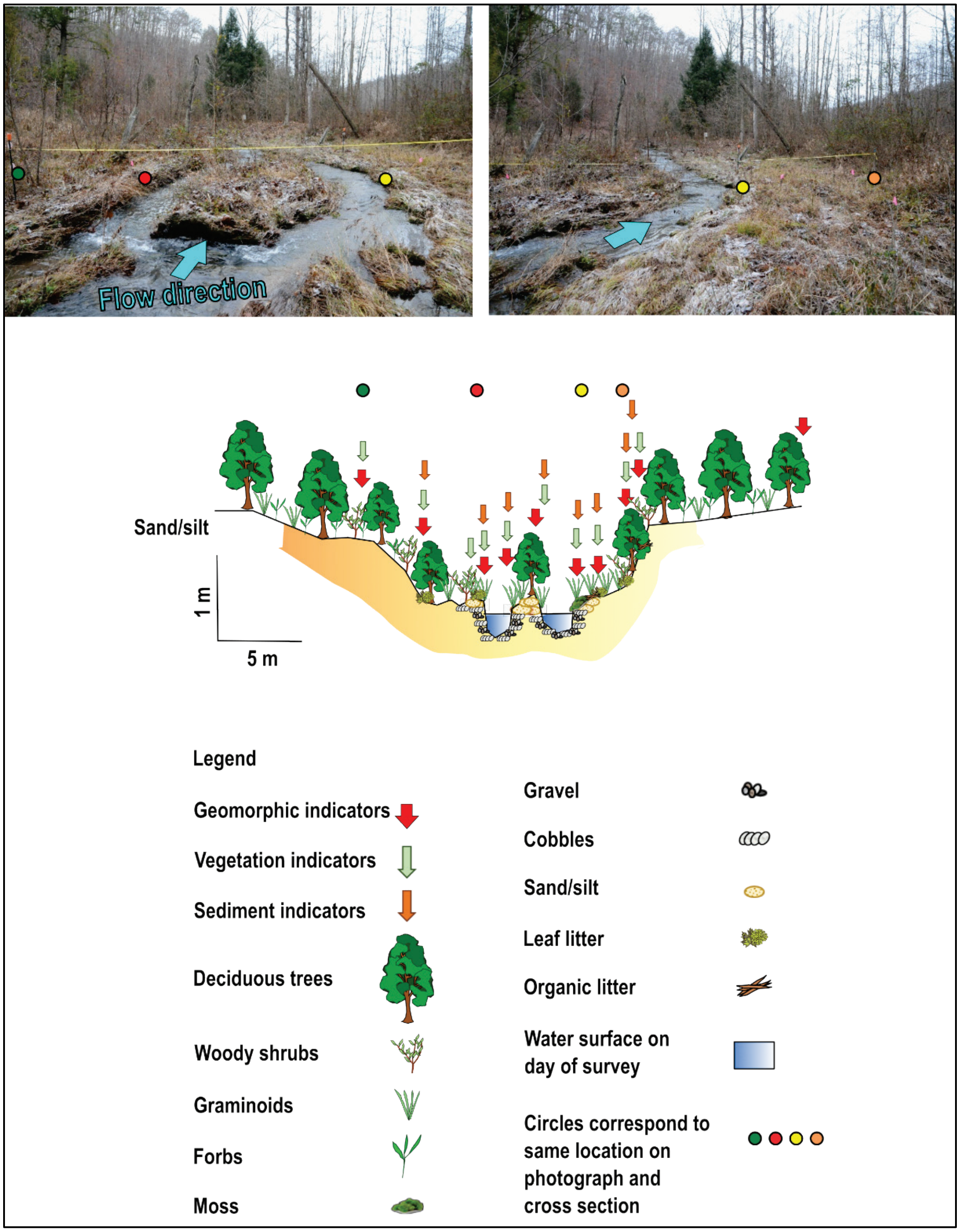
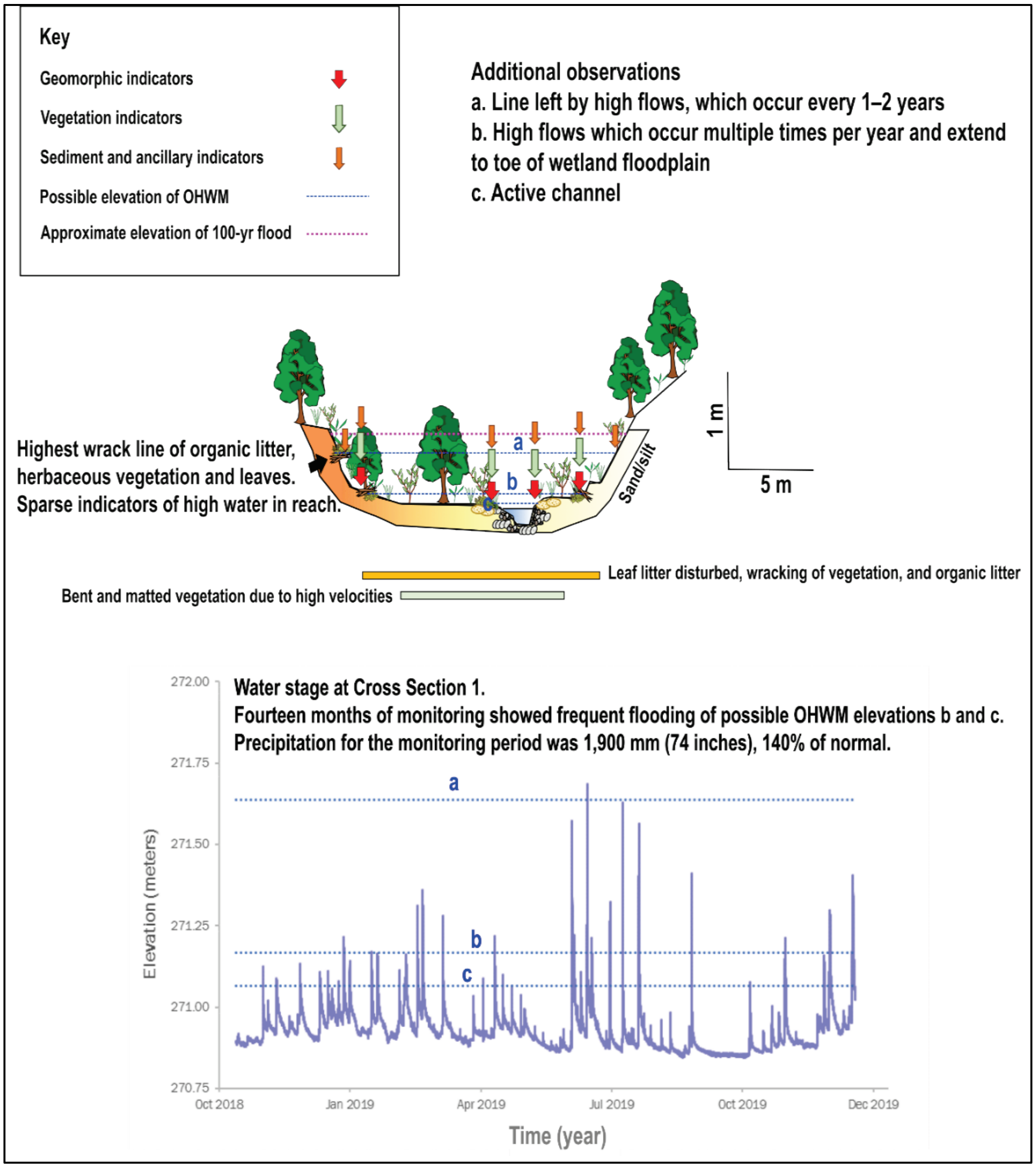


Figure 169. Cross Section 2 of Slabcamp Creek. *Arrows* show where the significant transitions in geomorphic, vegetation, and sediment indicators occur.



Both cross sections show significant changes at multiple points. Figure 170 shows where the lines of evidence overlap on Cross Section 1 and combines this information with streamgage data.

Figure 170. The overlap of multiple OHWM indicators shown for Cross Section 1.

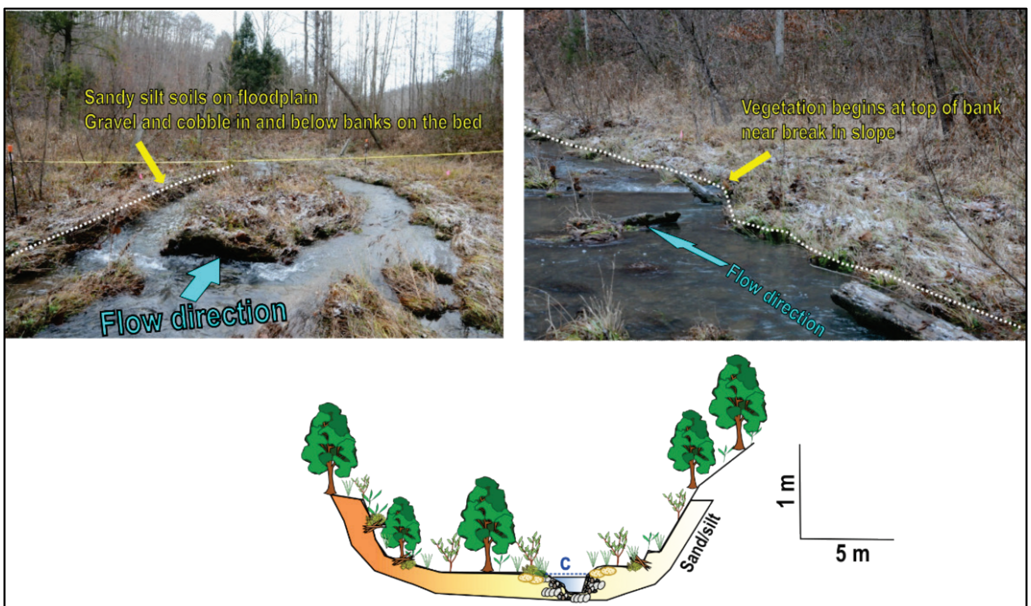


An examination of the overlap of the lines of evidence at these two cross sections, along with the hydrograph, leads to two possible elevations of the OHWM, elevations B and C. Elevation A appears to be connected more to extreme events than to high-flow events and so is not evaluated further. Elevation B is at the wetland–floodplain boundary, and elevation C is at the channel boundary. After reviewing the indicators and weighing the relevance, strength, and reliability of the indicators at each location, the WoE approach supports identifying the OHWM at elevation B (Section 1.3.3). The rationale is discussed in more detail on the pages that follow.

7.2.2.1 High water mark indicators at channel boundary in SWCs

Indicators at the channel boundary are established and maintained by sustained high base flow and episodic movement of the channel boundary during floods. Frequent flooding is facilitated by very low banks, suggesting that indicators found at the banks are not indicators of high water but of relatively low flows. These low banks may appear to be discontinuous in periods of the year when flow is very low or absent and vegetation grows into the channel or across riffles and other high points in the bed. During or immediately after the wet season, when sustained high base flow and episodic movement of the channel bed during floods has cleared vegetation from the channel, these small breaks in slope will be easier to identify (Figure 171). Base flow may be very slow, especially in low-gradient areas, but if blocked or dammed, the flow would form a new path around or over the barrier and through the vegetation. Avulsions and anastomosing channels are common in SWCs, and an OHWM associated with the channel boundary is likely to move as the channels change. Off-channel habitat may fall outside the OHWM.

Figure 171. Possible rationale for determining the OHWM is at the channel boundary.



Rationale for potential location of OHWM at elevation c:

Elevation of vegetation establishment. Break in bank slope corresponds to the transition from stream banks that are a mix of fine (silt, sand) and coarse (gravel, cobble) sediment to floodplain soils that are dominated by fine sediment.

Streambanks have the appearance of being actively reworked by ordinary high water, which leaves sparse indicators of erosion in the form of scour lines and obstacle marks.

Vegetation is likely to be absent or sparse within the channel boundary following periods of sustained high base flow or after episodic movement of the channel bed during floods. Dense wetland plants on the floodplain create a living bank line for the base-flow channel, which may be slightly lower than or at the channel boundary. During dry seasons, wetland vegetation is likely to encroach into or across some portions of the channel, making the channel harder to identify. The impermanent nature of indicators at the channel boundary, both within and across years, points to low reliability for identifying the OHWM.

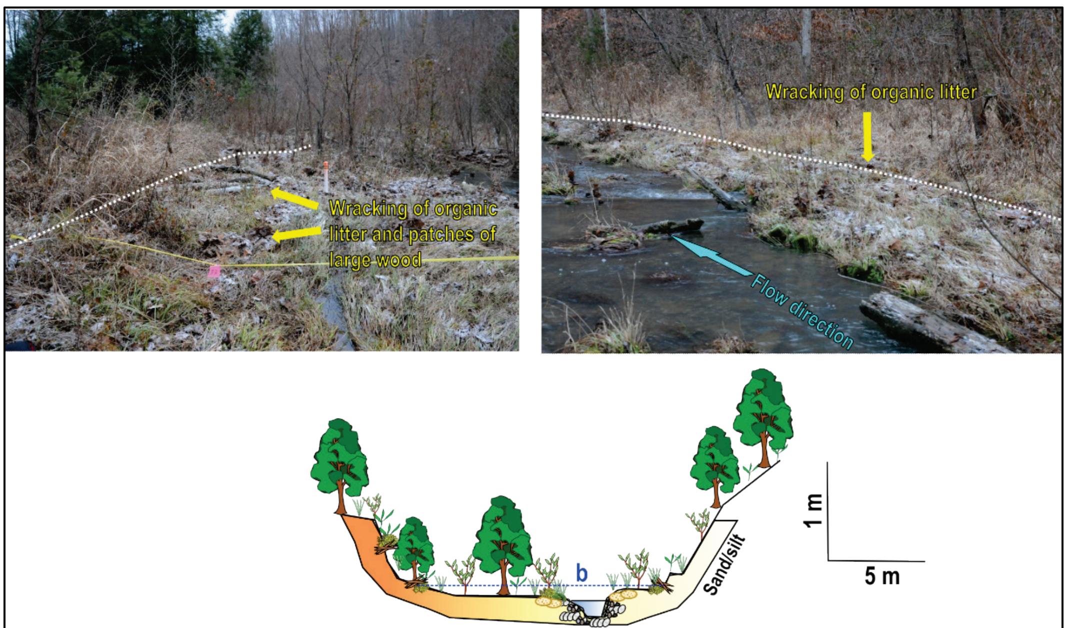
SWCs are retentive, depositional systems in which indicators of erosion are frequently sparse or absent in the channel and the floodplain, and deposition may be patchy. Sediment transitions, therefore, may be less reliable than vegetation transitions as indicators of the OWHM. However, water table depth may also be responsible for vegetation zonation as species vary in the ability of their root systems to cope with saturated soils (Section 2.3.3; Orellana et al. 2012). Fine sediment may accumulate at and above the active channel boundary in areas where low flood velocities occur in dense wetland plants, which can be efficient at trapping sand and silt carried by floodwaters. When the supply of fine sediment from upstream is moderate or low, however, fine sediment deposits may be sparse and unreliable as an OHWM indicator. Similarly, patches of sediment at and above the channel boundary may include high organic content accumulated from the periodic mortality of wetland plants, dead roots, and coarse and fine particulate organic carbon that was dropped, blown, or washed onto the floodplain.

Looking across the indicators at the channel boundary, there is strong and reliable evidence that the channel boundary is not above the OHWM. However, there is also strong and reliable evidence that water regularly overtops the banks and spreads throughout the SWC, so the OHWM is beyond the channel boundary.

7.2.2.2 High water mark indicators at edge of SWC floodplain

Indicators on the floodplain are established and maintained by small floods that leave marks on vegetation and areas of disturbed and accumulated organics and sediments (Figure 172). Slope breaks in the floodplain may be subtle and obscured by dense vegetation. Given the low shear stresses produced by floods, slope breaks are also unlikely to be a product of high flows. In relatively wide floodplain wetlands, the elevations of ordinary and extreme floods may differ vertically by only tens of centimeters, with no observable break in slope between them. Because of the low gradient, the lateral distance can be proportionally much greater, from tens to hundreds of meters. If the OHWM occurs beyond the active channel in SWCs in wide, flat valleys or plains, slope breaks are unlikely to be an easily observable or strong, reliable indicator. Slope breaks may be a strong and reliable indicator of the OHWM in SWCs that encompass the entire valley bottom, such as in the case study, but care must be taken to ensure that additional indicators support the relevance of the location for the OHWM.

Figure 172. Rationale for field determination of the OHWM at the wetland–floodplain boundary for Slabcamp Creek.



Rationale for location of OHWM:

At time of visit, this elevation had wracking of organic litter trapped in vegetation and patches where large wood was deposited. At the surveyed cross section, bent or matted vegetation due to high velocities was observed below b. However, at many locations along the reach, the bent and matted vegetation was found at the same elevation as the indicators located at b.

Most indicators of the OHWM were at or below b, therefore b was chosen as the location of the OHWM.

The transition from wetland to upland species is likely to coincide with a transition from floodplain to terrace or valley side slope, rather than a boundary associated with any particular flood elevation or frequency—so it may be strong, but it may or may not be relevant. The hydrological integration of the stream and wetland sustains a high water table near the surface, promoting the growth of hydrophytic vegetation across the floodplain. Because of the controlling influence of the water table in promoting hydrophytic vegetation, hydrophytic species are likely to occur below, at, and above the OHWM, especially if the OHW elevation is on the wetland floodplain in broad, low-gradient valleys or plains. A more reliable indicator of ordinary out-of-bank flows in SWCs is matted and bent vegetation, which may occur at or below the OHWM (Section 2.3.3.3). Vegetation may also show growth irregularities due to physical damage from frequent flood waters and transported sediment and debris (Section 2.3.3.2).

The nature of SWCs, as depositional systems, can result in geomorphic indicators related to erosion and deposition and sediment indicators being sparse or absent. Therefore, the more reliable indicators of OHWM may be the vegetation transitions and ancillary indicators (e.g., organic litter, LW, and leaf litter). Patches of sediment deposition may be located behind flow obstructions, including large woody debris, trees, or shrubs, but these may be too sparse to form a consistent line. Sediment deposits may be colocated with deposits of organic matter within the floodplain wetland or as wrack lines at the boundary of the OHWM. Sediment erosion due to frequent flooding may occur at or below the OHWM. Sediment erosion in SWCs may be limited to small, discontinuous patches that are near the channel or the interior of floodplain wetlands, where velocities are the highest. The scouring of fine sediments by flood waters may expose roots and rhizomes or larger sediment clasts in the floodplain soil that are resistant to erosion. The highest observed elevation of sediment erosion can provide an indicator of an elevation of high water but is unlikely to provide a strong or consistent line throughout the SWC.

Hydraulically rough floodplain wetlands are effective at catching organic debris transported during flood flows. These deposits can include a mixture of small and large woody debris, herbaceous stems, leaves, and sediment. These may occur at the boundary of frequent flood flows, as wrack lines at the OHWM, and upstream of obstructions.

Across the indicators found at the SWC boundary, reliable and relevant indicators supported that location B was regularly reached by high water and that high water went past location B only during extreme and infrequent events. Location B also provided a strong boundary at the case study site because it lined up with the boundary of the valley bottom and SWC; therefore, location B was identified as the OHWM. In SWCs on floodplains or in broad wide valleys, the detection of the OHWM boundary may need to rely primarily on vegetation matting and ancillary indicators within the floodplain. Box 22 to Box 24 provide an example data sheet for the SWC case study site visited in December.

Box 22. Page 1 of field identification of the OHWM at an SWC. (Data sheet adapted from USACE 2022.)

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U.S. Army Corps of Engineers (USACE)
RAPID ORDINARY HIGH WATER MARK (OHWM) FIELD IDENTIFICATION DATA SHEET
The proponent agency is Headquarters USACE CECW-CO-R.

From Approved - OMB No. 0710-OHWM Expires: xx-xx-xxxx

AGENCY DISCLOSURE NOTICE

The public reporting burden for this collection of information, 0710-OHWM, is estimated to average 30 **minutes** per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding the burden estimate or burden reduction suggestions to the Department of Defense, Washington Headquarters Services, at whs.mc-alex.esd.mbx.dd-dod-information-collections@mail.mil. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

Project ID #: SWC Example | Site Name: Slabcamp Creek, KY | Date and Time: 12/18/2019 12:00

Location (lat/long): 38.124467, -83.354183 | Investigator(s): J. Robinson, W. Veseley, & A. Parola

Step 1 Site overview from remote and online resources
Check boxes for online resources used to evaluate site:

- [ ] gage data
- [x] LiDAR
- [ ] geologic maps
- [ ] climatic data
- [x] satellite imagery
- [ ] land use maps
- [ ] aerial photos
- [ ] topographic maps
- [ ] Other: ______

Describe land use and flow conditions from online resources.
Were there any recent extreme events (floods or drought)?
Site is an 8-year-old restoration of a degraded stream to a stream-wetland complex. Aerial imagery of reach taken in March 2019 was used to identify representative cross sections for conducting OHWM analysis.

Step 2 Site conditions during field assessment. First look for changes in channel shape, depositional and erosional features, and changes in vegetation and sediment type, size, density, and distribution. Make note of natural or anthropogenic disturbances that would affect flow and channel form, such as bridges, riprap, landslides, rockfalls, etc.

Stream is on a receding limb of flood at time of visit. Floods from summer 2019 to winter 2019 left evidence of high water in the vegetation, organics, and small areas of fine sediment deposition in floodplain wetland.

Step 3 Check the boxes next to the indicators used to identify the location of the OHWM.
OHWM is at a transition point, therefore some indicators that are used to determine location may be just below and above the OHWM. From the drop-down menu next to each indicator, select the appropriate location of the indicator by selecting either just below `b', at `x', or just above `a' the OHWM.
Go to page 2 to describe overall rationale for location of OHWM, write any additional observations, and to attach a photo log.

Geomorphic indicators

- [x] **Break in slope:** x
  - [ ] *on the bank:*
  - [ ] *undercut bank:*
  - [x] *valley bottom:* x
  - [ ] Other: ______
- [ ] **Shelving:**
  - [ ] *shelf at top of bank:*
  - [ ] *natural levee:*
  - [ ] *man-made berms or levees:*
  - [ ] *other berms:* ______
- [x] **Channel bar:** b
  - [ ] *shelving (berms) on bar:*
  - [ ] *unvegetated:*
  - [x] *vegetation transition (go to veg. indicators)*
  - [ ] *sediment transition (go to sed. indicators)*
  - [ ] *upper limit of deposition on bar:*
- [ ] **Instream bedforms and other bedload transport evidence:**
  - [ ] *deposition bedload indicators (e.g., imbricated clasts, gravel sheets, etc.)*
  - [ ] *bedforms (e.g., pools riffles, steps, etc.):*
- [ ] *erosional bedload indicators (e.g., obstacle marks, scour, smoothing, etc.)*
- [ ] **Secondary channels:**

Sediment indicators

- [ ] **Soil development:**
- [ ] **Changes in character of soil:**
- [ ] **Mudcracks:**
- [ ] **Changes in particle-sized distribution:**
  - [ ] *transition from* ______ to ______
  - [ ] *upper limit of sand-sized particles*
  - [ ] *silt deposits:*

Vegetation Indicators

- [ ] **Change in vegetation type and/or density:**
  Check the appropriate boxes and select the general vegetation change *(e.g., graminoids to woody shrubs).* ***Describe the vegetation transition looking from the middle of the channel, up the banks, and into the floodplain.***
  - [ ] *vegetation absent to:*
  - [ ] *moss to:*
  - [ ] *forbs to:*
  - [ ] *graminoids to:*
  - [ ] *woody shrubs to:*
  - [ ] *deciduous trees to:*
  - [ ] *coniferous trees to:*
- [x] **Vegetation matted down and/or bent:** b
- [ ] **Exposed roots below intact soil layer:**

Ancillary indicators

- [x] **Wracking/presence of organic litter:** x
- [x] **Presence of large wood:** x
- [x] **Leaf litter disturbed or washed away:** x
- [ ] **Water staining:**
- [ ] **Weathered clasts or bedrock:**

Other observed indicators? Describe:

ENG FORM 6250, AUG 2022 PREVIOUS EDITIONS ARE OBSOLETE. Page 1 of 4

Box 23. Page 2 of field identification of the OHWM at an SWC. (Data sheet adapted from USACE 2022.)

Print Form | Save As | E-mail

Project ID #: SWC Example

Step 4 Is additional information needed to support this determination? ☐ Yes ☒ No If yes, describe and attach information to datasheet:

Step 5 Describe rationale for location of OHWM

At the time of visit, this elevation had wracking of organic litter trapped in vegetation and patches where large wood was deposited. At the surveyed cross section, bent or matted vegetation due to high velocities was observed (elevation b). However, at many other locations along the reach, the bent and matted vegetation was found at the same elevation as the indicators located at elevation b. Most indicators of the OHWM were at or below elevation b; therefore elevation b was chosen as the location of the OHWM.

Additional observations or notes

Three possible OHWM elevations (a, b, & c) were identified based on the physical characteristics observed during the survey. Elevation a was the highest elevation and was associated with only a wrackline of woody debris, herbaceous vegetation, and leaves. Physical characteristics observed associated with elevation b were disturbed leaf litter, bent and matted vegetation, and wracking of vegetation and woody debris. Most suble changes at elevation b were break in slope and change in sediment. Elevation c had a distinct break in slope at the active channel margins, and sediment changes were present but patchy. Vegetation change occurred at elevation c where open channel transitioned to dense border of wetland plants. Photos taken in July 2019 were used to characterize vegetation development on the floodplain because most vegetation was dormant in December 2019.

Attach a photo log of the site. Use the table below, or attach separately.

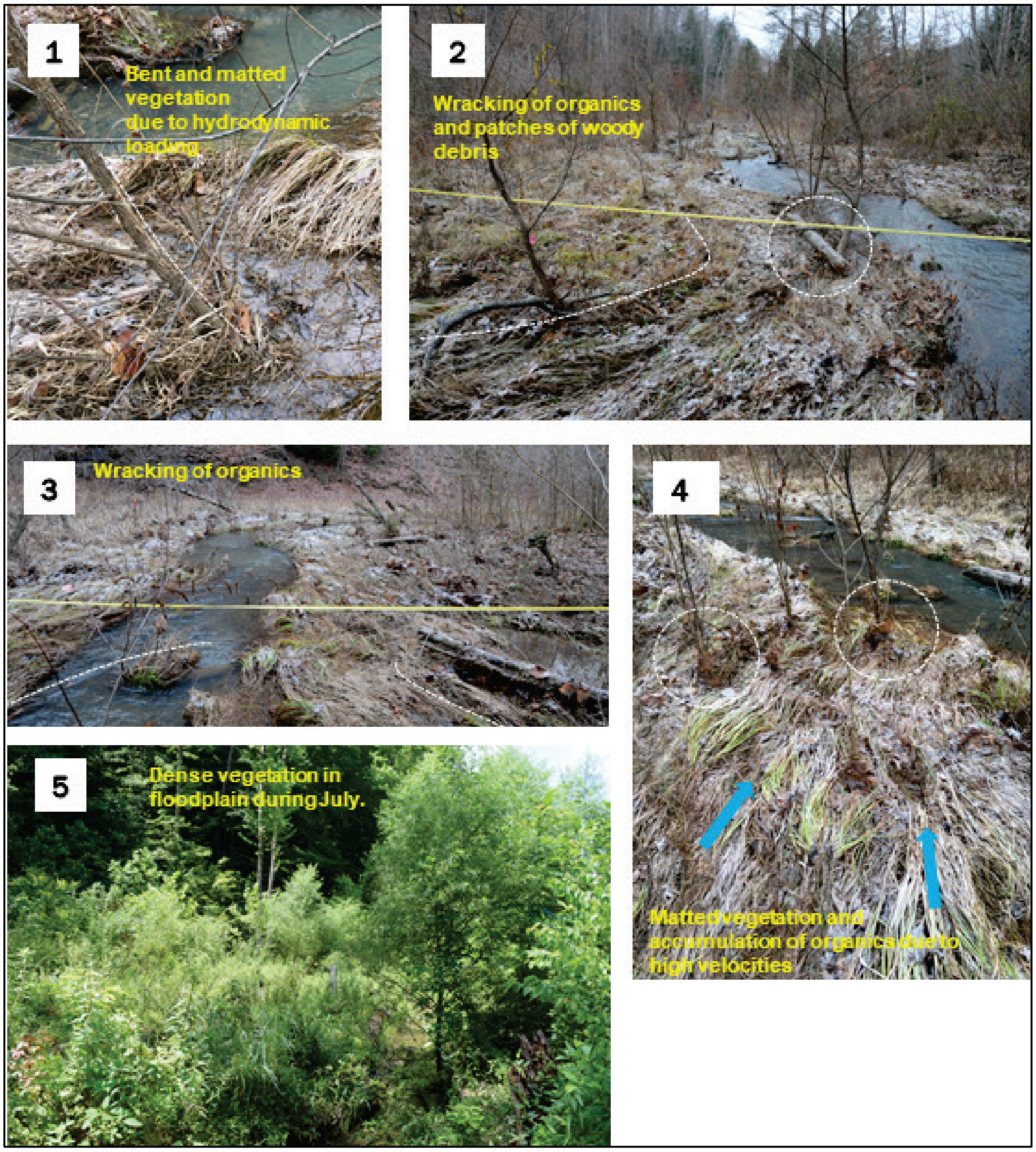
Photo log attached? ☒ Yes ☐ No If no, explain why not:

List photographs and include descriptions in the table below.

Number photographs in the order that they are taken. Attach photographs and include annotations of features.

Photo Number	Photograph description
1	Looking across the channel at area of recent high velocity flow
2	Looking downstream at visible wrack lines and deposits of organics
3	Looking downstream at wrack lines and matted vegetation
4	Looking downstream—close-up view of matted vegetation and organics.
5	Looking upstream during a previous visit at dense vegetation on floodplain

Box 24. Photolog for SWC.



7.3 Beaver-meadow complexes

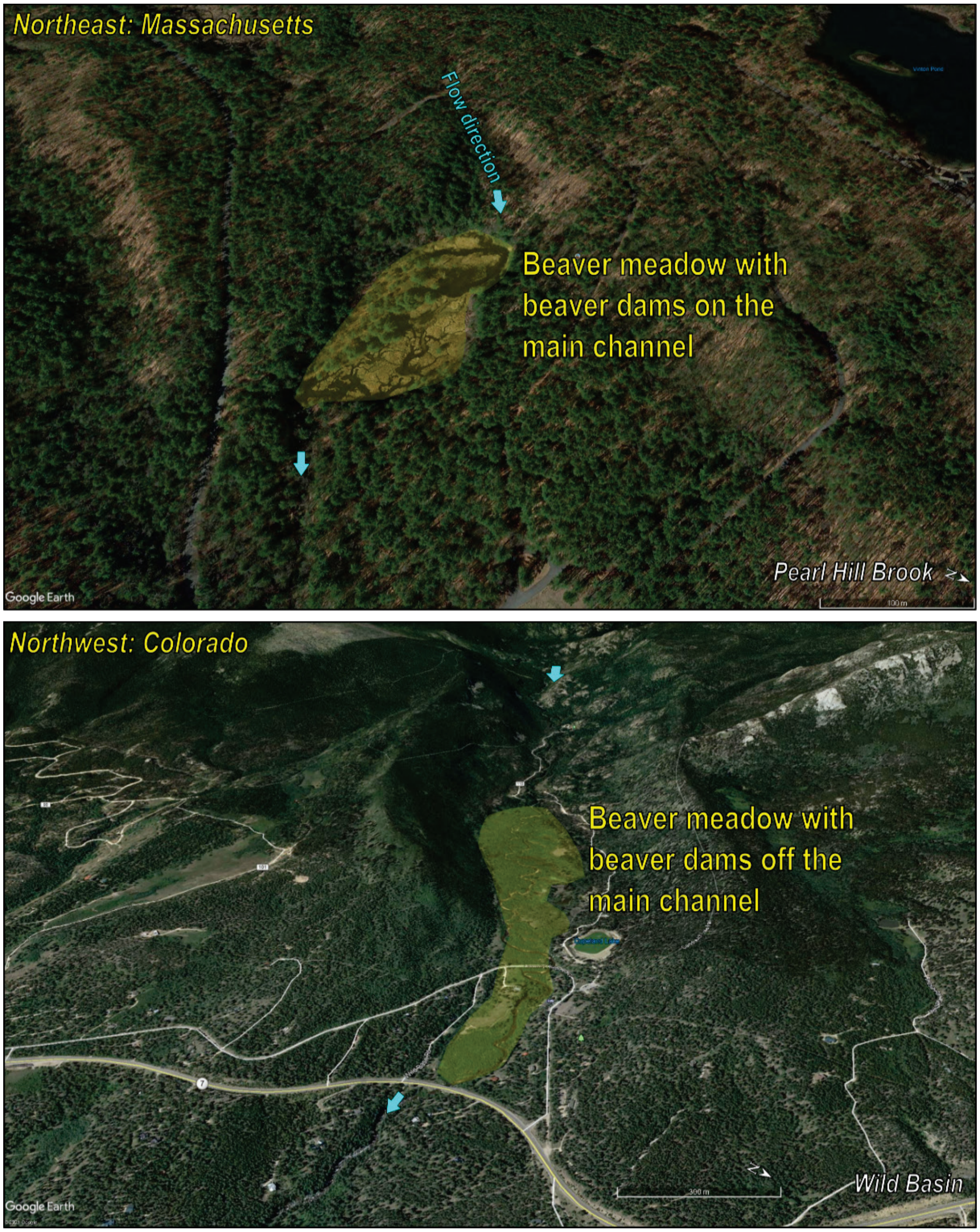
Beaver dams create multithread channel systems (Pollock et al. 2007; Burchsted et al. 2010; Polvi and Wohl 2013). A beaver dam can simply create a backwater ponded area in a narrow valley floor. Where the valley floor is sufficiently wide, however, one or more beaver dams can give rise to an extensive, spatially heterogeneous set of features known collectively as a *beaver meadow* (Polvi and Wohl 2013). A beaver meadow commonly includes multiple active dams and abandoned, intact, or partly breached dams that may be overgrown with vegetation. These dams do not necessarily cross the main channel, nor are they necessarily perpendicular to the main flow direction. Secondary channels associated with beaver canals (Grudzinski et al. 2020) or with channel avulsion and migration form an anastomosing channel planform (John and Klein 2004). Figure 173 shows a site with multiple beaver dams causing deposition, development of channel bars and anastomosing channels, and an alteration in vegetation and sediment characteristics.

The WoE technique can be particularly useful at sites where there is a potential OHWM at the edge of the inset channel and another potential OHWM at the edge of the floodplain. A thorough investigation of this site includes looking for additional secondary channels, indicating that the flow spreads out further than what is indicated at the main channel boundary, and an investigation of the vegetation. Beavers directly and indirectly influence the distribution and abundance of vegetation. Beavers are herbivores and use vegetation to build dams. Through their dam and canal building, beavers alter the local hydrology, which affects the distribution and variety of vegetation growing in beaver meadows. Among trees, beavers preferentially use willow, aspen, alder, and maple over conifers (Busher 1996; Haarberg and Rosell 2006), and they are known to selectively forage on some hydrophytes and shrubs (Bergman et al. 2018). The proximity of preferred vegetation to the shoreline is a strong factor of habitat selection for beavers (Gerwing et al. 2013). Proximity determines the energy beavers must expend moving building materials and is related to their risk from predators (Jenkins 1980; Salandre et al. 2017). Within the limits of the surrounding landscape, beavers can adjust their proximity to vegetation by impounding water through the construction of dams and canals. Beavers alter the elevation of both groundwater and surface water, which alters vegetation characteristics. Therefore, evidence of bedload transport (under geomorphic indicators), changes in particle-size distribution (under sediment indicators), and distribution of organic litter and LW (under ancillary indicators) may be significant at these sites for providing further evidence that flows often inundate the floodplain. The beaver meadow attenuates downstream fluxes of water, solutes, sediment, and particulate organic matter (Wegener et al. 2017); provides abundant and diverse habitat (e.g., Willby et al. 2018); and supports high biodiversity (e.g., Bartel et al. 2010). Fundamentally, a beaver meadow reduces longitudinal connectivity within the river corridor (e.g., Burchsted et al. 2010) but enhances lateral (e.g., Westbrook et al. 2006) and vertical (Lautz et al. 2006) connectivity.

Figure 173. Looking downstream at multiple beaver dams on Beaver Brook in New Hampshire. OHWM indicators can occur at the edge of the low-flow channel and at the edge of the floodplain, which likely corresponds to the high-flow channel.

Beavers can also dam tributary channels and hillside seeps and springs, creating ponded water at elevations well above the primary floodplain. Ponds of differing ages and stages of infilling are present across the floodplain. When investigating these meadows, it can help to recognize if the beaver dam is at the elevation of the primary channel or if it is damming another source of water, such as a tributary or hillside seep, and therefore would not be inundated during high flows. Figure 174 provides satellite imagery of two sites, one with multiple active and abandoned beaver dams on the main channel (in Massachusetts) and one with the same but off the main channel (in Colorado). Because beaver meadows often result in the removal of trees, they can be easy to identify with satellite imagery. Evidence for the OHWM at both of these sites will be explored in more detail in Sections 7.3.1 and 7.3.2.

Figure 174. Beaver meadows in Massachusetts (*top*) and Colorado (*bottom*). The Massachusetts site has multiple beaver dams on the main channel. The Colorado site has multiple beaver dams and beaver ponds off the main channel.



7.3.1 Massachusetts case study

Pearl Hill Brook in the Northeast region provides an example of a beaver meadow site with beaver dams within the main channel. Figure 175 shows the transitions in the channel type at three locations along this stream. Location 1, the upstream location, is a confined, high gradient, step-pool channel. The stream is in a confined valley and, therefore, is directly connected to the hillslopes and lacks a wide floodplain. Location 2 is the beaver meadow, where the channel widens and becomes anastomosing. There are multiple dams within this segment of the channel. Location 3 is the farthest downstream, where the valley narrows again and the channel becomes much more confined. Transitions in vegetation and sediment provide evidence for the location of the OHWM in the upstream and downstream reaches.

Figure 175. Transition of stream from a steep, confined step-pool channel, to a beaver meadow, to a confined pool-riffle channel.

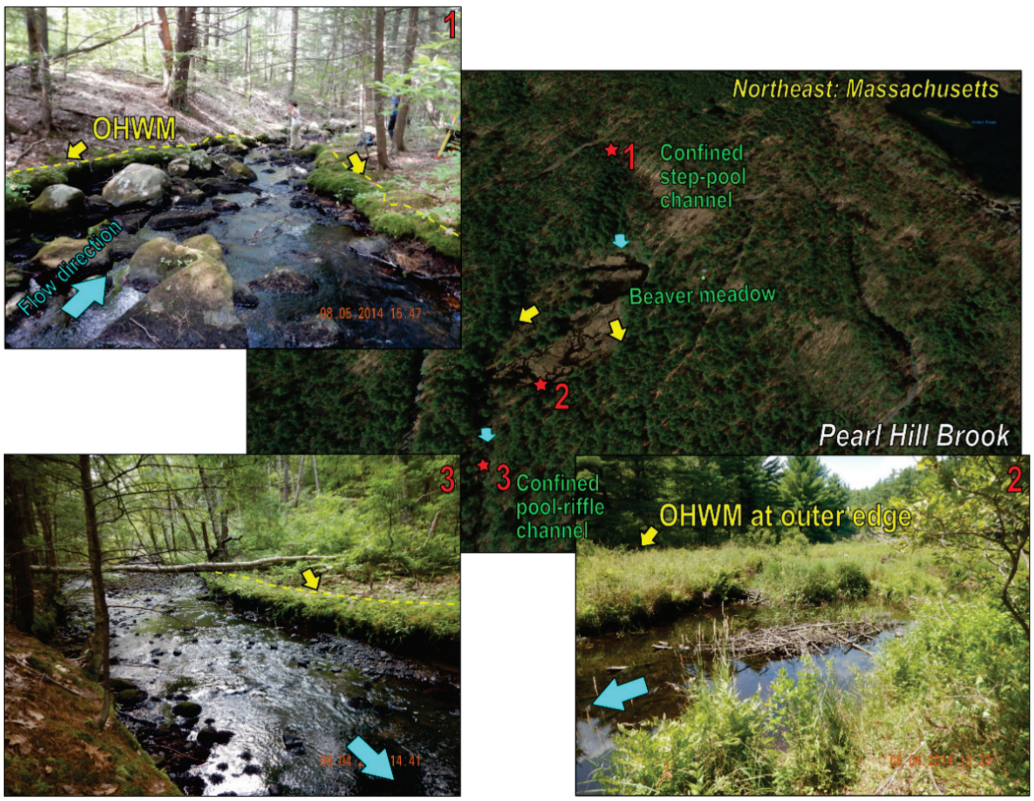


Figure 176 provides a generalized schematic of the characteristics occurring in the beaver-meadow complex in Figure 173. This schematic is for demonstration purposes and may not reflect exactly what was identified at the site. The multiple beaver dams increase lateral changes on the channel, causing water to pond, velocities to decrease, and sediment to deposit in multiple channel bars. The vegetation on these bars and the lack of tree growth indicate that these areas are inundated frequently. There are multiple breaks in slope and shelving that need to be investigated as part of applying the WoE method. There is an inset channel and an outer channel, meaning that there are breaks in slope on the bank and on the floodplain.

There is also a break in slope before the top of the terrace. This would be listed under other types of breaks in slope and other berms on the data sheet.

Geomorphic indicators, such as channel bars, instream bedforms, and other bedload evidence, can assist with the investigation of this site. The schematic depicts erosional and depositional bedload indicators occurring throughout the floodplain. This indicates that inundation may happen frequently enough to maintain these indicators. The channel bars near the center of the channel provide evidence of frequent inundation because of the type of vegetation growing on the bars. The bars along the edges may provide better information on transitions in vegetation and sediment; therefore, those bars are a better location to look for evidence of the OHWM. The evidence is considered relevant because it is fluvial deposition or erosion occurring on the channel bars. Therefore, it is most likely these characteristics were formed during high-flow events. If more than one location is identified with these lines of evidence, then it is persistent across the landscape. In this example, these lines of evidence are persistent. However, these pieces of evidence may be less reliable. If an extreme event occurred, the evidence could get obscured by new depositional and erosional material that was deposited during those extreme events. Alternatively, if a drought persisted over a long period of time, the evidence may be obscured by deposition of material from the surrounding hillslopes.

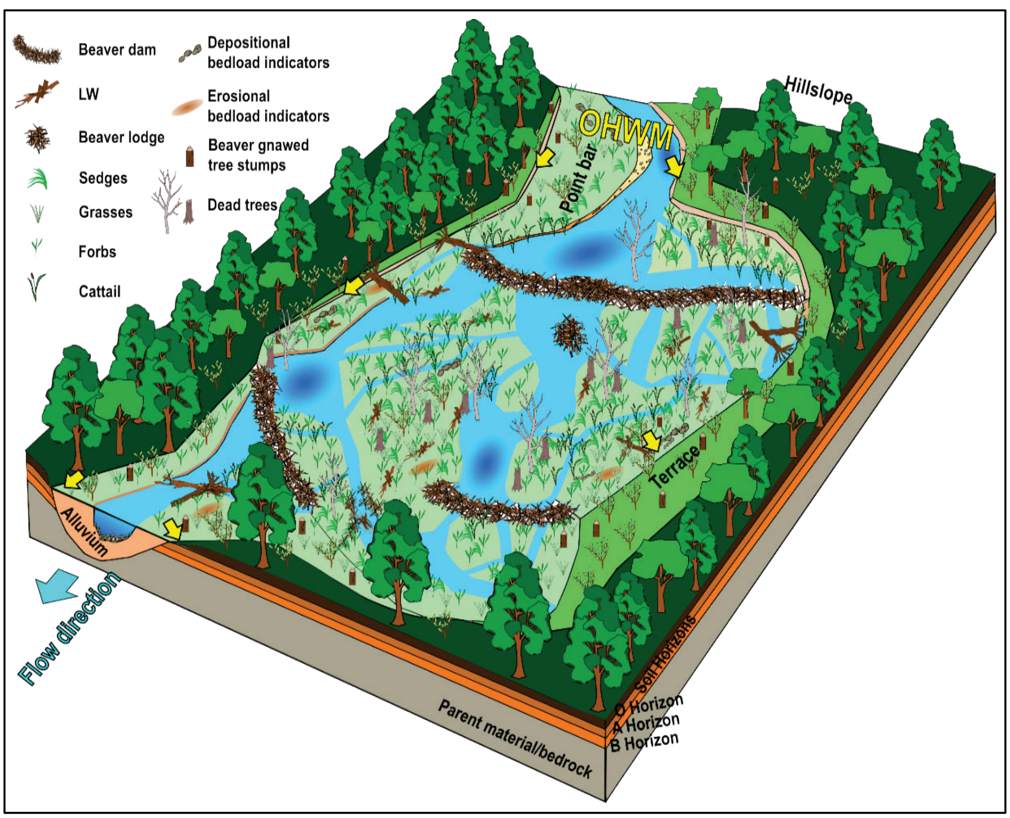
The slightly higher shelving next to the edge of the valley is interpreted to be a stream terrace. The evidence for this includes the shelving and the transition in vegetation species and density. Trees are not growing in this area because the beavers are still actively removing trees. The many stumps show where the beavers have been active. In this simplified schematic, there is no additional evidence that indicates that flows reach the level of the stream terrace. For example, there is no organic litter or LW deposition and no bedload transport evidence.

Some of the LW represented in this schematic does not necessarily assist with OHWM identification. LW is useful when it has obviously been moved and deposited by the streamflow. The LW with root wads represent trees that have fallen from the surrounding hillslope or terrace and have not been transported downstream. Throughout the channel bars, there are pieces of wood that have been deposited by flowing water and are streamlined in the direction of streamflow. The relevance, strength, and reliability of the LW indicators is similar to the other geomorphic indicators already discussed.

Vegetation provides the most dramatic transitions at this site. Much of the vegetation is hydrophytic in nature, and there may be a sharp transition between the floodplain and the terrace. The vegetation transitions are highly relevant and strong indicators. The reliability of the vegetation indicators is strong here as well. Some of the vegetation may not be present during colder seasons, but the lack of trees will continue to be evident through the seasons.

In this schematic, the OHWM would be delineated at the edge of the floodplain. The combined weights from all the lines of evidence indicate that the floodplain is frequently inundated, and therefore, the OHWM reaches that elevation. There is no additional evidence on the terrace to indicate that the OHWM would be at this elevation; therefore, the OHWM is shown to occur at a lower elevation than the terrace.

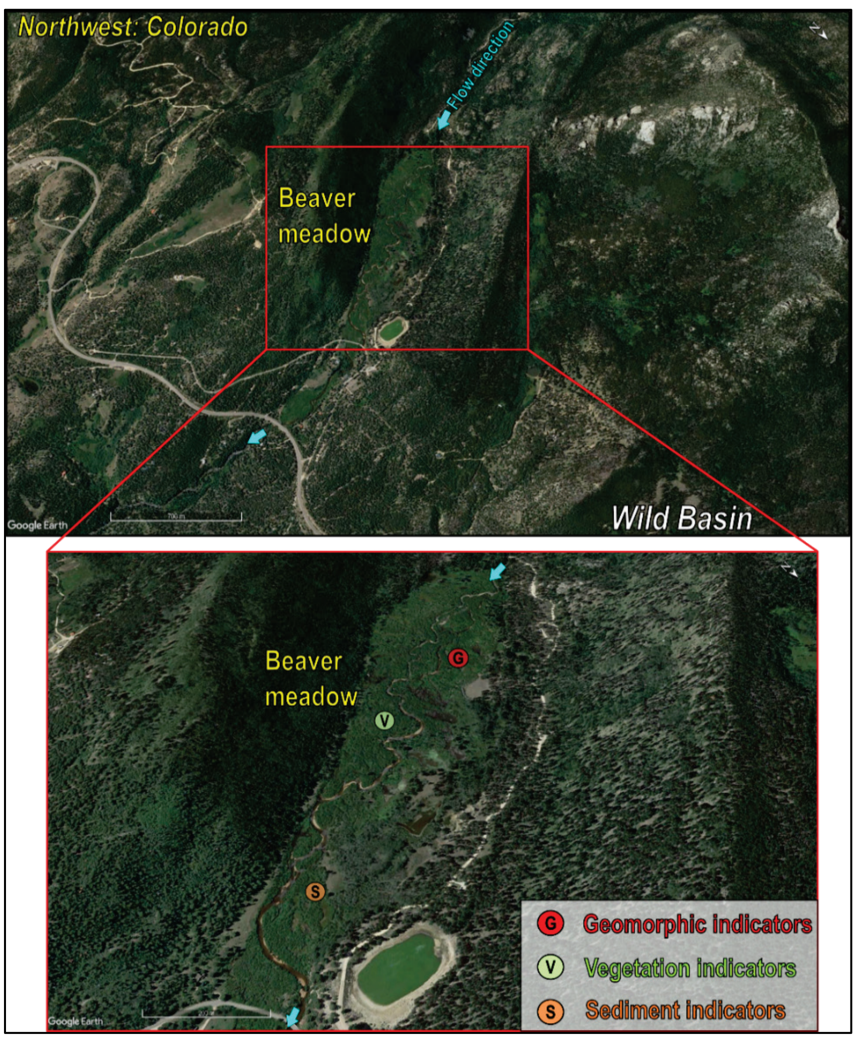
Figure 176. Generalized schematic of a beaver-meadow complex in a Northeast region stream (in Massachusetts).



7.3.2 Colorado case study

Beaver ponds can sometimes be located off the main channel but still be connected to the stream below the OHWM. A site like this occurs in Wild Basin, at the eastern boundary of Rocky Mountain National Park. This example provides an analysis of the site using online resources. Figure 177 shows satellite imagery, obtained from Google Earth, of the beaver-meadow complex. The satellite imagery reveals geomorphic, vegetative, and sediment indicators that should be investigated when conducting the field investigation. The geomorphic indicators include point bars and anastomosing channels. The vegetation is clearly different in the floodplain and the surrounding hillslopes. There are locations with exposed sediment that may help in the analysis of the site.

Figure 177. Satellite imagery from Google Earth of a beaver-meadow complex in Wild Basin, Colorado. Possible geomorphic, vegetation, and sediment indicators are labeled on the bottom image.



A topographic map and two lidar products for this site can be easily viewed in the National Map Advanced Viewer (USGS n.d.c; Figure 178). Each of the maps in Figure 178 shows that the stream is in a confined valley, becomes unconfined, and then is confined again. The topographic map indicates that the entire area where the beaver meadow is located is a wetland. Both the hillshade and slope map show the reworking of the floodplain by a multithread channel system. The anastomosing system is more easily viewed using the hillshade map. The slope map shows where there are steeper boundaries along the valley edge. Each of these maps can be used to determine where the potential OHWM is located to assist with a field investigation.

A further analysis of the satellite imagery shows the many interconnections between the primary and secondary channels, or beaver ponds (Figure 179). There is an area in the southern part of the satellite imagery that appears to be at a higher elevation than the rest of the beaver meadow. It is possible that the beaver dam at this site is damming water from the surrounding hillslope and not from the main channel. A field investigation would help determine the channel morphology present at this site.

Figure 178. Topographic map and lidar hillshade and slope products from the National Map Advanced Viewer of a beaver-meadow complex in Wild Basin in Colorado. The lidar slope map uses *darker colors* to represent steeper slopes and *lighter colors* for low slopes. (Images reproduced from USGS n.d.c.)

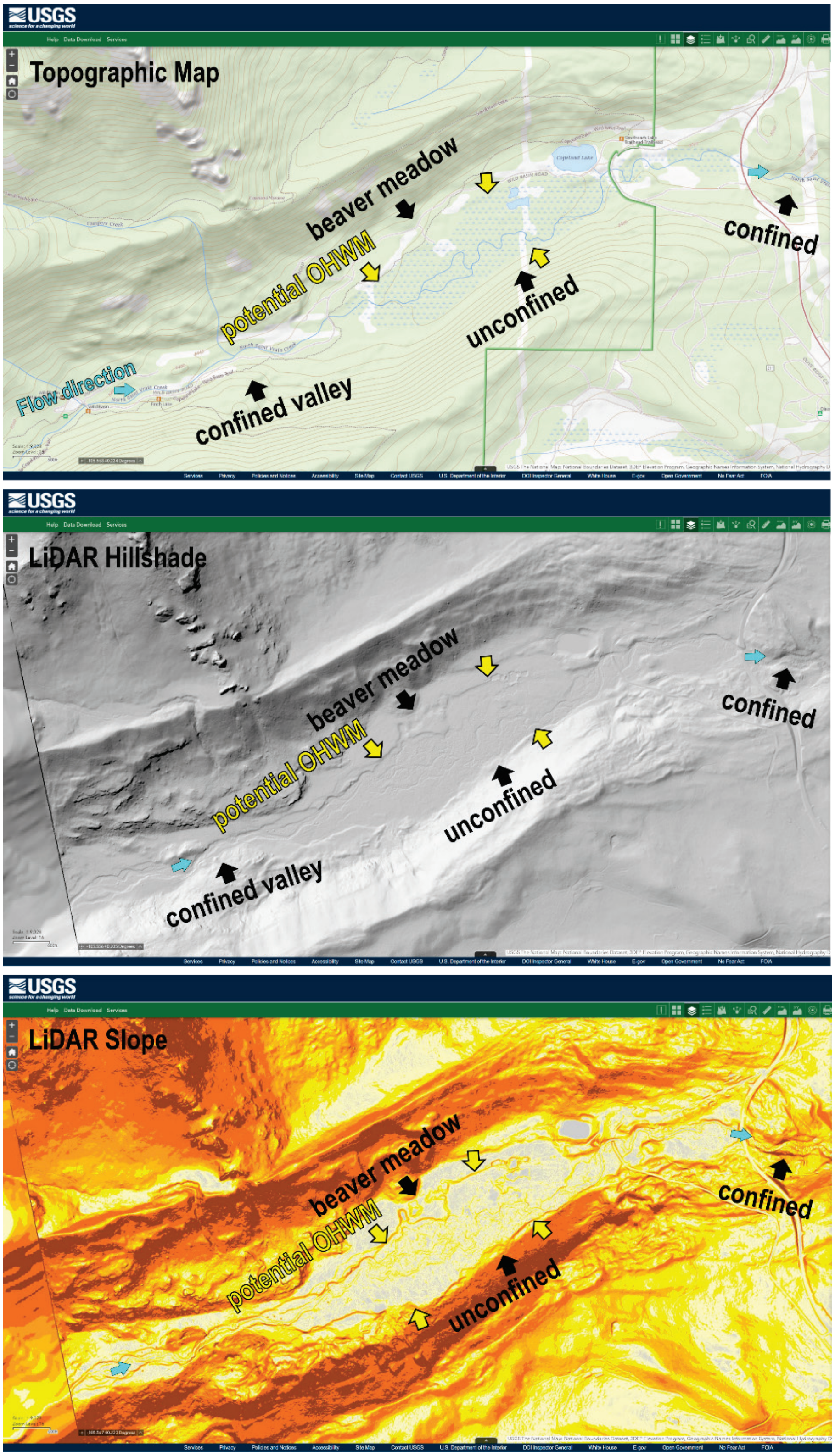


Figure 179. Satellite imagery obtained from Google Earth of the beaver-meadow complex. *Arrows* show where the main channel is connected to the secondary channels and beaver ponds. An area that may be at a higher elevation than the main channel is outlined in *yellow*.

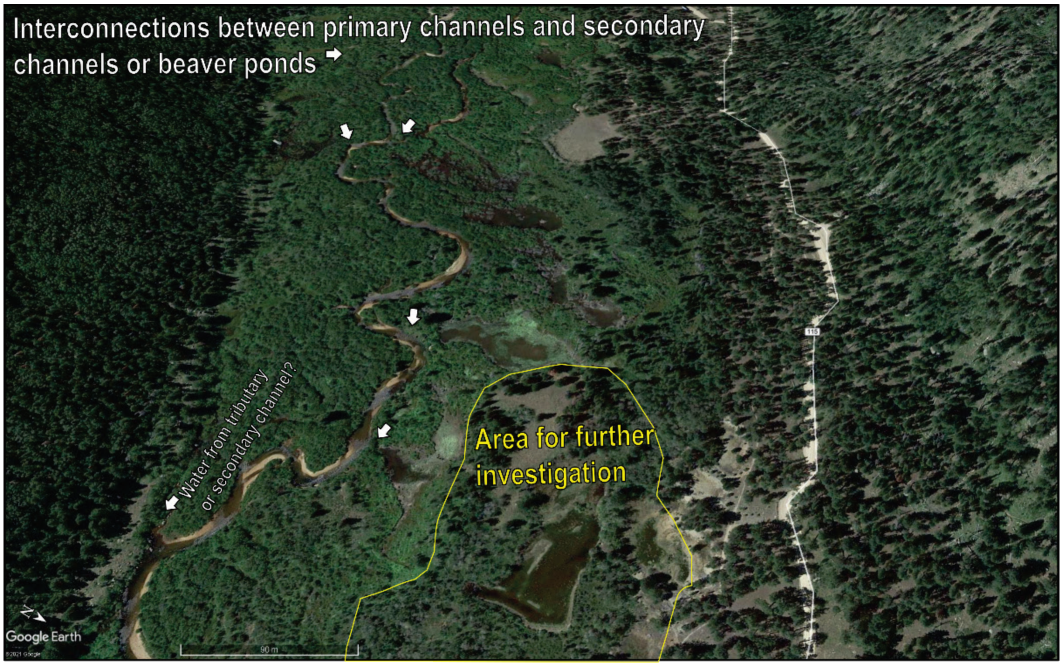
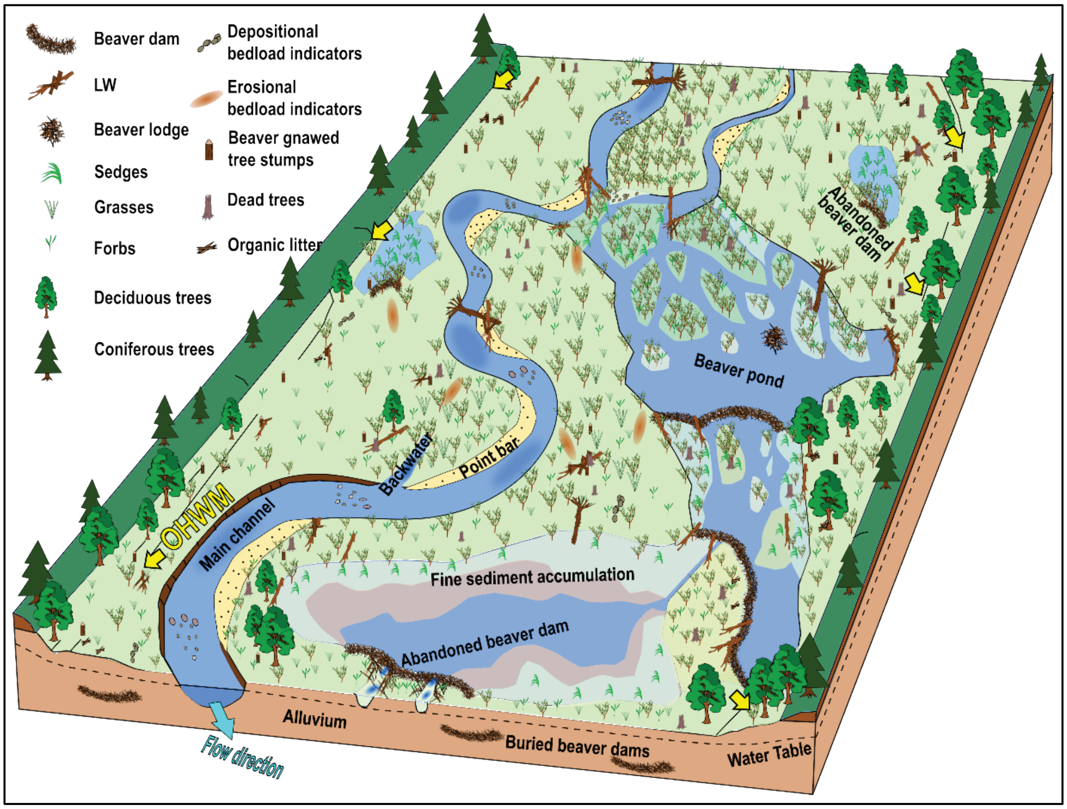


Figure 180 shows a simplified schematic of the beaver-meadow complex. Again, this schematic is not an exact replication. It is simplified to show the interconnection of the main channel with the secondary channels and beaver ponds and the possible OHWM indicators that may occur in the floodplain. The first geomorphic indicators to look for in a field investigation are the breaks in slope and areas of shelving. Figure 178 shows where to look for these in the field. There are breaks in slope along the channel banks and at the edge of the valley. Geomorphic indicators, such as depositional and erosional bedload indicators, may occur throughout the meadow. There is an obvious difference in vegetation between the floodplain and the hillslopes in the satellite imagery. It is possible that a field investigation will reveal other distinctive vegetation transitions that can be used to identify the OHWM. Deposition of LW may occur as well. In a beaver-meadow complex, LW may not be as reliable an indicator because so much of it may have been left behind by the beavers. LW should only be used as an OHWM indicator if it was obviously deposited by streamflow. Clear evidence of such deposition would be if the LW was oriented in the direction of flow. The satellite image shows evident, exposed point bars along the main and secondary channels. There may be evidence of sediment transitions along the bar, but this evidence may be found along the floodplain as well. Again, because of the obvious interconnection and movement of water between the main channel and secondary systems, the OHWM is interpreted to inundate the entire floodplain. The lidar hillshade and slope products further support that these areas are interconnected and that there is a more obvious break in slope at the outer edge of the valley. A field investigation would be needed to confirm these observations and look for OHWM indicators throughout the floodplain.

Figure 180. Beaver-meadow complex with beaver dams off channel. This schematic represents a site in the northwestern portion of Rocky Mountain National Park, in Colorado.



7.4 Natural disturbances

Natural disturbances include fires, debris flows, extreme floods, hurricanes, tornadoes, and beetle infestation of a forest. These events can cause stream systems to change dramatically over a short period of time. If possible, it is not recommended to delineate the OHWM too soon after a natural disturbance because of how quickly the system will change immediately afterward. These events often remove any indicators of the OHWM, but as a system readjusts over time, indicators will stabilize and reflect high flows. Again, the WoE technique can assist with assessing the most likely location of the OHWM at sites that are experiencing rapid change.

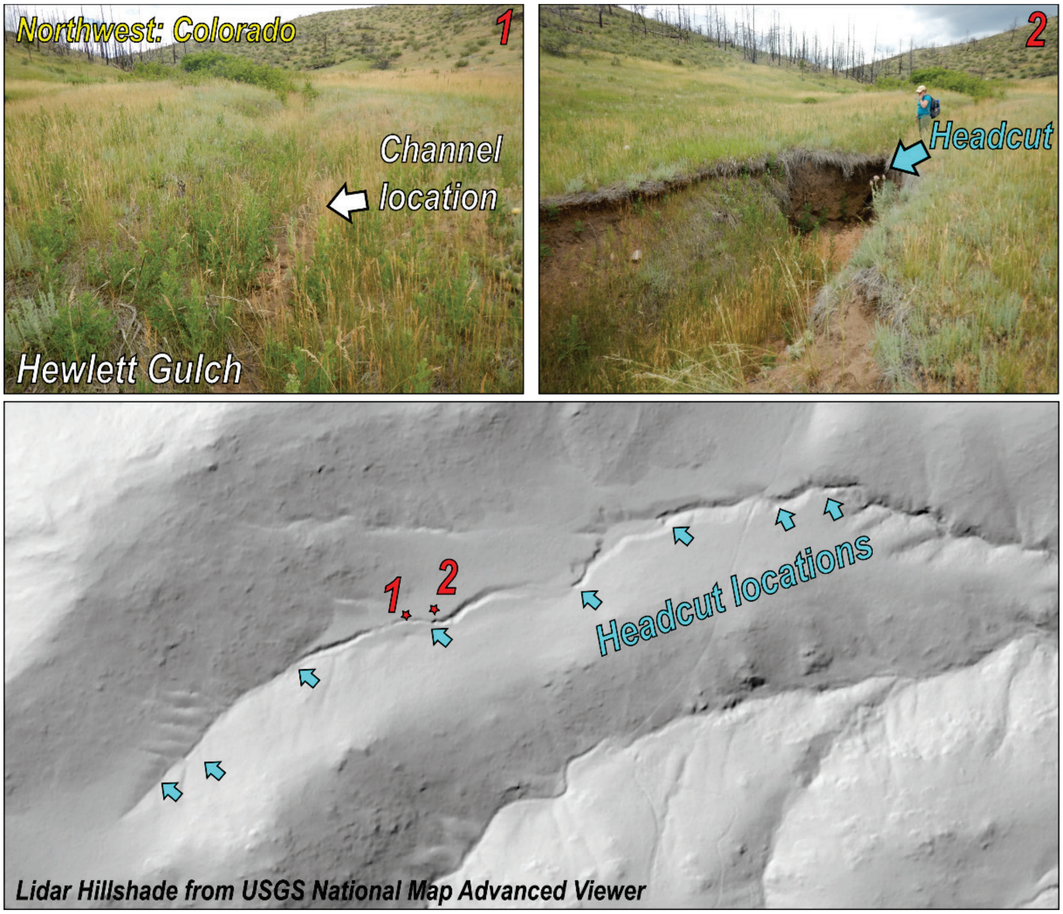
7.4.1 Fires and debris flows

Fires and debris flows often occur in sequence. After a wildfire, the removal of a large amount of vegetation on steep hillslopes can cause debris flows to increase (Cooke 1984; Moody et al. 2013). A stream may then adjust rapidly after a debris flow. Figure 181 shows a site in Colorado that experienced wildfires in 2012, followed by debris flows. A year later, in 2013, the sediment from the debris flows had been removed by the stream.

Figure 181. Two locations on Skin Gulch in Colorado after wildfires in 2012 (*top*) and a year later in 2013 (*bottom*). The *white arrows* indicate the same location on the pictures in 2012 and 2013. The *yellow arrows* show potential locations of the OHWM.

Headcuts can also migrate after fires because of the reduction in vegetation and increase in overland flow (Wohl 2013). Lidar provides a means of investigating the likeliest location for the start of the channel and can be combined with satellite imagery and field sampling. Headcuts are highly erosive zones; therefore, the channel can often go subsurface below a headcut because of the excess sedimentation (Figure 182). Once the start of a stream channel is located, the WoE method can be applied to investigate the location of the OHWM.

Figure 182. Using lidar hillshade to see the extent of channels. (Bottom image adapted from USGS n.d.c.)



7.4.2 Natural disturbances: Extreme flood flows

Floods can cause deposits of organic litter and LW that should not be impulsively considered the OHWM (Figure 183). Before examining any site, the recent flood record should be checked for extreme flood events so that the indicators can be put in context of the recent flow history. The LW jams in the floodplain in Figure 183 are more likely the result of an extreme-flow, rather than a high-flow, event. Therefore, these jams should not be used as evidence of the OHWM.

Figure 183. LW on floodplain in stream in New Mexico (Southwest region).

Extreme events can also alter the shape of a channel and remove evidence of the previous banks and channel form. Recovery time is required for a channel to return to its preflood dimensions. The recovery time is usually shorter (i.e., measured in years) in more temperate regions, where there are frequent flows at all stages of the flow regime, and longer (i.e., years to decades) in arid regions where flows occur relatively infrequently. If an investigation of the OHWM occurs too soon after a flood, the site may not contain enough evidence to identify the location of the OHWM; too few high flows may have occurred to reshape the landscape and leave behind the indicators of interest. If the OHWM needs to be delineated soon after an extreme flood event, then streamgage records and regional curves can be used to determine the preflood size of the channel. Satellite imagery can also be used to determine how dramatically the channel was altered by the extreme flood event. Therefore, the resources included in Chapter 5 are the most useful for understanding what has happened at these sites and determining the most likely location of a new OHWM.

8 Summary

The OHWM defines the jurisdictional limits for both streams and lakes, but the focus of this manual is presenting a method for delineating the OHWM in streams. The OHWM defines the lateral extent of nontidal aquatic features in the absence of adjacent wetlands in the United States. The federal regulatory definition of the OHWM, 33 CFR 328.3(c)(7), states, “The term ordinary high water mark means that line on the shore established by the fluctuations of water and indicated by physical characteristics such as [a] clear, natural line impressed on the bank, shelving, changes in the character of soil, destruction of terrestrial vegetation, the presence of litter and debris, or other appropriate means that consider the characteristics of the surrounding areas.” The stream characteristics described by the federal regulatory definition include geomorphic, vegetative, sedimentary, and ancillary indicators. This is the first manual to present a methodology to improve nationwide consistency in the identification and delineation of the OHWM since it was first defined in the Rivers and Harbors Act of 1899. This manual includes a new data sheet and outlines a commonly used WoE methodology to provide a credible method of hierarchically organizing and evaluating observations made at a stream site. The common indicators (i.e., geomorphic, vegetation, sediment, and ancillary) of the OHWM are described in detail, as are regional differences in those indicators for the eight regions described in this manual (Northeast, Southeast and Caribbean, Northern Prairies, Southern Prairies, Northwest, Southwest, Alaska, and Hawaii). The manual demonstrates that in many landscape settings, the OHWM may be located near the bankfull elevation.

The manual describes challenges in identifying the OHWM at sites that have been disturbed by human-induced or natural changes. The WoE method is demonstrated throughout the manual to illustrate how a credible conclusion can be drawn from the collected data. While this manual emphasizes identifying the OHWM using field observations, remotely available data can also be used within the WoE approach to help structure field inquiries and facilitate the interpretation of field evidence using principles of fluvial science. Therefore, detailed information is provided on how to collect and interpret remote data to support the field delineation of the OHWM.

This manual is a reference tool. The manual presents a two-page data sheet for assembling evidence and leads the user through the process of weighting the evidence and drawing a credible conclusion for the location of the OHWM. The data sheet and field procedure are in Appendix B. Chapter 1 provides background information and information on how the manual is set up and how the data from around the country were collected. Chapter 2 provides detailed information for each of the indicators listed on the data sheet. Chapter 3 demonstrates how to assess a site using the WoE method and how to complete the data sheet. Chapter 4 provides detailed information on how to put a site in context of the surrounding landscape to better understand how and why indicators may look different in locations around the country or even within a watershed. Chapter 5 lists where to find online resources and describes how to use and interpret stream-gage data, satellite imagery, and lidar. Chapters 6 and 7 provide detailed information regarding complex situations in which there have been anthropogenic or natural disturbances. Furthermore, Chapter 7 provides examples of more complex natural stream systems, including beaver-meadow complexes and SWCs. The manual is organized to instruct the user on how to locate the information needed to better understand a site and how to interpret and use other information to support an OHWM delineation for streams throughout the country.

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Appendix A: Glossary

Active channel: a portion of the floodplain that can be distinguished based on the three primary criteria of (i) channels defined by erosional and depositional forms created by river processes, (ii) the upper elevation limit at which water is contained within a channel, and (iii) portions of a channel without mature woody vegetation

Aggradation: continued deposition and accumulation of material

Alluvium: sediment deposited by water flowing within a channel

Alternate bars: accumulation of bed material positioned successively on opposite sides of the channel in a straight reach of the stream

Anastomosing channel segment: multiple secondary channels that branch and rejoin downstream, with vegetated, relatively stable areas above the elevation of the channel banks separating individual secondary channels

Avulsion: a rapid change in course or flow diversion from one channel into another due to blockage by sediment or debris

Bank: the side of an active channel, typically associated with a steeper side gradient than the adjacent channel bed or floodplain

Bankfull channel: the portion of the channel below the top of the banks, with the top of banks defined by a break in slope between relatively high-angle banks and relatively flat overbank portions of the floodplain

Bankfull discharge: the flow that fills the channel to the top of the riverbanks

Bank slumping (or sloughing): the mass movement of material down a bank by vertical collapse; material will slide or rotate away, leaving sediment deposited at the base with a concave scar or scarp left on the bank

Bar: in-channel sediment, typically coarse sand to cobble, that is deposited during the recession limb of high flows and is largely exposed during low flows; upper surface of bars of perennial streams is typically equivalent to the stage of ~40% flow duration (Osterkamp 2008)

Base level: the lowest point to which a river will erode; sea level is the ultimate base level, but local base levels can occur where a river enters a lake or another, larger river

Bed: the base of the active channel, distinguished as having a lower average side gradient than the adjacent banks

Bedform: a deposit on the riverbed that is formed by fluvial processes and typically repeated downstream (e.g., pool, riffle, point bar, alternate bar, ripple, or dune)

Bed material: sediment in transport that occurs in appreciable quantities in the streambed; typically includes bedload that travels in contact

Berm: a level space, shelf, or raised barrier separating two areas

Braided-channel segment: multiple secondary channels that branch and rejoin downstream, typically with unvegetated sections of floodplain (channel bars) between secondary channels; individual secondary channels can move laterally during a single flood

Channel: a natural or constructed passageway or depression of perceptible linear extent that conveys water and associated material downgradient

Channel avulsion: formation of a new channel that is commonly parallel or subparallel to the existing channel(s)

Channel form: description of channel geometry from planimetric, profile, and cross-sectional perspectives

Channel head: the upstream boundary of concentrated water flow and sediment transport on a distinct bed and between definable banks that are longitudinally continuous downstream

Channelized stream: a stream that has been modified by humans by straightening, deepening, and widening of the existing channel (Schumm et al. 1984)

Channel maintenance flow: components of a river's flow regime necessary to maintain specific physical characteristics, such as sediment transport or channel cross-sectional area

Channel migration zone: the width of the floodplain across which main and secondary channels can migrate and have migrated under the contemporary flow regime

Channel stability: the ability of a channel to resist changes in cross-sectional geometry, planform, or gradient during a specified time interval; a stable channel experiences relatively little net erosion or deposition during a large flood

Channel substrate: the sediment or bedrock in which a river channel is formed (i.e., the material that composes the bed and banks)

Clast: A mineral grain of any size, although typically used for gravel size or larger (≥2 mm; Wohl 2018).

Colluvium: sediment deposited by processes other than water flowing within a channel (e.g., rockfall, debris flow, landslide, or sheetwash)

Contributing area: the portion of a drainage area contributing runoff to a river segment during any particular precipitation event

Contributing basin: synonymous with *contributing area*

Cutbank: an outside bank of a stream that is continually undergoing erosion; these banks remain steep because of the continual stream processes eroding the banks

Debris flow: a slurry of water and sediment that is typically contained within a channel but has much higher sediment concentration and viscosity than river flow

Degradation: continued removal/erosion of material.

Dominant discharge: a hypothetical single flow magnitude that, if sustained, will maintain consistent channel geometry; this has been quantified as the flow that (i) transports the greatest proportion of suspended sediment when averaged over some time interval that is typically greater than a year, (ii) transports the greatest proportion of bedload or total sediment when averaged over some time interval greater than a year, or (iii) is most responsible for shaping channel geometry; but these criteria are not necessarily met by a single flow

Drainage area: the surface area that drains to a particular reference point on a river

Drainage basin: synonymous with *drainage area*

Dune: an alluvial bedform that forms in sand-bed channels and is similar in shape to ripples but much larger in size; dunes also tend to be more variable in shape than ripples, and their height can be up to a third of flow-depth (Knighton 1998)

Effective discharge: the discharge that transports the largest amount of sediment over time; in other words, effective discharge is synonymous with the first and second definitions of *dominant discharge*

Environmental flow: an entire annual hydrograph, or specific portions of an annual hydrograph (e.g., peak flow), interpreted to maintain specific aspects of a river; typically, environmental flow recommendations specify magnitude, frequency, timing, duration, and rate of change in flow

Ephemeral river: flows only during and soon after precipitation inputs; an ephemeral river has no groundwater inputs or base flow

Facultative plant: occurs in wetlands and nonwetlands that can be in hydric, mesic, or xeric habitats; occurrence in different habitats indicates response to other environmental variables (e.g., shade, soil pH, elevation) besides only hydrology (Lichvar et al. 2012)

Facultative upland plant: usually occurs in nonwetlands but may occur in wetlands; predominately occurs at drier or more mesic sites in geomorphic settings that rarely have saturated soils or are seasonally flooded (Lichvar et al. 2012)

Facultative wetland plant: usually occurs in wetlands but may occur in nonwetlands; predominately occur with hydric soils, often in geomorphic settings in which water saturates the soils or floods the surface at least seasonally (Lichvar et al. 2012)

Flood: high to extreme flows that fill a channel near to capacity and often go overbank. Flood flows tend to occur in response to storm events and rise and fall quickly. In certain climatic regions, flood flows may occur seasonally in response to snowmelt or rain on snow events. These flows tend to do the most geomorphic work in a stream.

Floodplain: a relatively flat sedimentary surface adjacent to the active channel that is built by river processes and inundated frequently

Flow-duration curve: a plot that equates discharge magnitude to the percentage of time that the discharge is equaled or exceeded at a particular geographic point along a river

Flow regulation: dams and diversions that change the characteristics of water and sediment fluxes within a river

Headcut: a location 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 can be where the channel starts, but they can also be at a location further downstream and progressively move upstream through the process of channel erosion; a type of knickpoint; the term is most often used on smaller channel systems, such as 1st- and 2nd-order channels

Hydraulic geometry: a set of statistical relationships that exist between discharge and other variables related to open-channel flow, such as width, depth, and velocity

Hydrograph: a plot of river discharge through time, typically either during a flood or over a longer time interval, such as a year

Hyporheic zone: the portion of unconfined, near-stream aquifers in which river water is present; this zone is a flow-through subsurface region in which flow paths originate and terminate at the river

Imbrication: alignment of clasts with the long axis of each clast parallel to the primary flow direction (edge of clasts sometimes overlap when one end of the long axis dips downward in the upstream direction; Wohl 2018)

Incised channel: a stream channel that has narrowed and deepened and become disconnected from its floodplain

Knickpoint: a location in a river where there is a sharp change in channel slope, such as at a waterfall or lake, resulting from differential erosion above and below the point

Levee or man-made berm/levee: an artificial or natural embankment built along the margin of a watercourse to protect land from inundation or to confine streamflow to its channel

Main channel: used to distinguish the larger (in terms of discharge) channel from secondary channels where the river or stream is multithreaded (i.e., braided or anastomosing)

Mainstem: used to distinguish the larger (in terms of discharge) of two intersecting channels of a river network

Mean annual flow: average volume of flow for an individual year in a multiyear period of interest

Meander scrolls: depressions and rises on the convex side of bends formed as the channel migrated laterally down valley and toward the concave bank

Obligate wetland plant: almost always occur in wetlands; with few exceptions, it grows in standing water or seasonally saturated soil (≥14 consecutive days) near the surface; includes submerged, floating, floating-leaved, and emergent growth forms (Lichvar et al. 2012)

Ordinary high water elevation: the hypothetical elevation of the water surface at the location of the physical characteristics along the banks, identified as the OHWM.

Ordinary high water mark: defined by federal regulations as the line on the shore established by the fluctuations of water and indicated by physical characteristics such as a clear, natural line impressed on the bank, shelving, changes in the character of soil, destruction of terrestrial vegetation, the presence of litter and debris, or other appropriate means that consider the characteristics of the surrounding areas

Perennial stream: surface water flowing continuously year-round

Piping: preferential subsurface flow that occurs above the water table in the unsaturated zone

Recovery time: the amount of time needed for a river to return to its preflood configuration

Resilience: the tendency of a channel to return to its preflood configuration following a large flood; a resilient channel returns to its preflood configuration relatively quickly

Rill: A small erosional feature that can be destroyed by tillage or natural processes such as frost action (Schumm et al. 1984; Kirkby and Bracken 2009); rills are a result of overland flow and often appear as parallel features on sides of slopes, particularly roadcuts; rill erosion is an intermediate process between sheet erosion and gully erosion (Casalí et al. 2006)

Riparian zone: adjacent to rivers, lands that are transitional between terrestrial and aquatic ecosystems through which surface and subsurface hydrology connects river waters with their adjacent wetlands, nonwetland waters, or uplands

Ripple: an alluvial bedform that forms in sand-bed channels; the profile is triangular in shape, with a gentle upstream slope (stoss), sharp crest, and steep downstream face (lee); generally, these bedforms are less than 0.6 m in wavelength and 0.04 m in height (Knighton 1998)

River corridor: the portion of any landscape that has been created by river erosion and deposition through time and that remains connected to the contemporary river at least during ordinary floods

Rooted cutbank: where the lower section of bank is eroded, but the upper section is stabilized by roots (Finkenbine et al. 2000)

Sapping: preferential subsurface flow that occurs below the water table in the saturated zone

Scarp: a very steep bank or slope; often used to describe near vertical slope

Scour hole: the removal of sediment from the bed of a river, or from around objects, by fast-flowing water when sediment transport capacity exceeds sediment supply

Secondary channel: a subsidiary channel that branches from the main channel and trends parallel or subparallel to the main channel before rejoining it downstream

Seepage erosion: flow through a permeable medium that involves the entrainment of materials as individual particles or in bulk (Dietrich and Dunne 1993; Knighton 1998)

Shelving: benches and breaks in slope along the channel margins (Mersel and Lichvar 2014)

Sinuosity: the ratio of stream length to valley length

Stream head: the upstream-most point in a stream in which perennial flow occurs

Stream order: a numerical value assigned to a river segment based on the number and size of upstream tributaries; in the most commonly used stream-order system, a first-order river has no tributaries, a second-order river is present downstream from the junction of two first-order rivers, and two rivers of equal magnitude must join to form the next stream order

Stream–wetland complex (SWC): hydrologically integrated channels where the stream and wetland exchange flow continuously via hyporheic paths where soils are permeable

Terrace: a valley-contained surface usually as a long, narrow, nearly flat or gently inclined landform bounded by steeper descending and ascending slopes; always topographically elevated relative to the floodplain and is inundated by floods of higher magnitude than mean annual flood; formed either by depositional (fill terrace) or erosional (strath terrace) processes (Osterkamp 2008)

Thalweg: a line defined by the downstream succession of points of deepest flow within a river channel

Tributary: a stream or river that flows into a higher-order stream or river

Trimline: boundary or transition zone marked by distinct difference in presence or composition of flora (e.g., lichens) due to either scouring or intolerance to immersion and/or sedimentation

Upland plant: almost never occurs in wetlands, standing water, or saturated soils occupying mesic to xeric nonwetland habitats; typical growth forms include herbaceous, shrubs, woody vines, and trees (Lichvar et al. 2012)

Uplands: any portion of a drainage basin outside the river corridor

Weight-of-evidence (WoE): an inferential process to assemble, evaluate, and integrate different lines of evidence (Suter 2016) that provides a way for determining the significance of observations and combining those observations to arrive at scientifically supported conclusions (Linkov et al. 2009)

Wrack(ing): vegetative debris and other materials deposited at the margins of high flows that commonly form linear features or piles on upstream sides of inundated objects (Mersel and Lichvar 2014); also referred to as *organic litter*

Appendix B: Field Procedure and Data Sheets

Figure B-1. Field procedure and data sheets. Reproduced from USACE 2022 (1–4).

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U.S. Army Corps of Engineers (USACE)

RAPID ORDINARY HIGH WATER MARK (OHWM) FIELD IDENTIFICATION DATA SHEET

The proponent agency is Headquarters USACE CECW-CO-R.

From Approved - OMB No. 0710-0025 Expires: 01-31-2025

AGENCY DISCLOSURE NOTICE

The public reporting burden for this collection of information, 0710-OHWM, is estimated to average 30 **minutes** per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding the burden estimate or burden reduction suggestions to the Department of Defense, Washington Headquarters Services, at whs.mc-alex.esd.mbx.dd-dod-information-collections@mail.mil. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

Project ID #: | Site Name: | Date and Time:

Location (lat/long): | Investigator(s):

Step 1 Site overview from remote and online resources

Check boxes for online resources used to evaluate site:

- gage data
- LiDAR
- geologic maps
- climatic data
- satellite imagery
- land use maps
- aerial photos
- topographic maps
- Other:

Describe land use and flow conditions from online resources.
Were there any recent extreme events (floods or drought)?

Step 2 Site conditions during field assessment. First look for changes in channel shape, depositional and erosional features, and changes in vegetation and sediment type, size, density, and distribution. Make note of natural or man-made disturbances that would affect flow and channel form, such as bridges, riprap, landslides, rockfalls etc.

Step 3 Check the boxes next to the indicators used to identify the location of the OHWM.

OHWM is at a transition point, therefore some indicators that are used to determine location may be just below and above the OHWM. From the drop-down menu next to each indicator, select the appropriate location of the indicator by selecting either just below `b', at `x', or just above `a' the OHWM.

OHWM. Go to page 2 to describe overall rationale for location of OHWM, write any additional observations, and to attach a photo log.

Geomorphic indicators

- **Break in slope:**
  - *on the bank:*
  - *undercut bank:*
  - *valley bottom:*
  - Other:
- **Shelving:**
  - *shelf at top of bank:*
  - *natural levee:*
  - *man-made berms or levees:*
  - *other berms:*
- **Channel bar:**
  - *shelving (berms) on bar:*
  - *unvegetated:*
  - *vegetation transition (go to veg. indicators)*
  - *sediment transition (go to sed. indicators)*
  - *upper limit of deposition on bar:*
- **Instream bedforms and other bedload transport evidence:**
  - *deposition bedload indicators (e.g., imbricated clasts, gravel sheets, etc.)*
  - *bedforms (e.g., pools, riffles, steps, etc.):*
- *erosional bedload indicators (e.g., obstacle marks, scour, smoothing, etc.)*
- **Secondary channels:**

Sediment indicators

- **Soil development:**
- **Changes in character of soil:**
- **Mudcracks:**
- **Changes in particle-sized distribution:**
  - *transition from* to
  - *upper limit of sand-sized particles*
  - *silt deposits:*

Vegetation Indicators

- **Change in vegetation type and/or density:**

  Check the appropriate boxes and select the general vegetation change (*e.g., graminoids to woody shrubs*). ***Describe the vegetation transition looking from the middle of the channel, up the banks, and into the floodplain.***

  - *vegetation absent to:*
  - *moss to:*
  - *forbs to:*
  - *graminoids to:*
  - *woody shrubs to:*
  - *deciduous trees to:*
  - *coniferous trees to:*
- **Vegetation matted down and/or bent:**
- **Exposed roots below intact soil layer:**

Ancillary indicators

- **Wracking/presence of organic litter:**
- **Presence of large wood:**
- **Leaf litter disturbed or washed away:**
- **Water staining:**
- **Weathered clasts or bedrock:**

Other observed indicators? Describe:

Figure B-1 (cont.). Field procedure and data sheets. Reproduced from USACE 2022 (1–4).

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Project ID #: ____________

Step 4 Is additional information needed to support this determination? ☐ Yes ☐ No If yes, describe and attach information to datasheet:

Step 5 Describe rationale for location of OHWM

Additional observations or notes

Attach a photo log of the site. Use the table below, or attach separately.

Photo log attached? ☐ Yes ☐ No If no, explain why not:

List photographs and include descriptions in the table below.

Number photographs in the order that they are taken. Attach photographs and include annotations of features.

Photo Number	Photograph description

Figure B-1 (cont.). Field procedure and data sheets. Reproduced from USACE 2022 (1–4).

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OHWM Field Identification Datasheet Instructions and Field Procedure

Step 1 Site overview from remote and online resources **Complete Step 1 prior to site visit.**

Online Resources: Identify what information is available for the site. Check boxes on datasheet next to the resources used to assess this site.

a. gage data
b. aerial photos
c. satellite imagery
d. LiDAR
e. topographic maps
f. geologic maps
g. land use maps
h. climatic data (precipitation and temperature)

Landscape context: Use the online resources to put the site in the context of the surrounding landscape.

a. **Note on the datasheet under Step 1:**
  i. Overall land use and change if known
  ii. Recent extreme events if known (e.g., flood, drought, landslides, debris flows, wildfires)
b. Consider the following to inform weighting of evidence observed during field visit.
  i. What physical characteristics are likely to be observed in specific environments?
  ii. Was there a recent flood or drought? Are you expecting to see recently formed or obscured indicators?
  iii. How will land use affect specific stream characteristics? How natural is the hydrologic regime? How stable has the landscape been over the last year, decade, century?

Step 2 Site conditions during the field assessment (assemble evidence)

a. Identify the assessment area.
b. Walk up and down the assessment area noting all the potential OHWM indicators.
c. Note broad trends in channel shape, vegetation, and sediment characteristics.
  i. Is this a single thread or multi-thread system? Is this a stream-wetland complex?
  ii. Are there any secondary and/or floodplain channels?
  iii. Are there obvious man-made alterations to the system?
  iv. Are there man-made (e.g., bridges, dams, culverts) or natural structures (e.g., bedrock outcrops, Large Wood jams) that will influence or control flow?
d. Look for signs of recurring fluvial action.
  i. Where does the flow converge on the landscape?
  ii. Are there signs of fluvial action (sediment sorting, bedforms, etc.) at the convergence zone?
e. Look for indicators on both banks. If the opposite bank is not accessible, then look across the channel at the bank.
f. **In Step 2 of the datasheet** describe any adjacent land use or flow conditions that may influence interpretation of each line of evidence.
  i. What land use and flow conditions may be affecting your ability to observe indicators at the site?
  ii. What recent extreme events may have caused changes to the site and affected your ability to observe indicators?

Step 3a List evidence

Assemble evidence by checking the boxes next to each line of evidence:

a. If needed, use a separate scratch datasheet to check boxes next to possible indicators, or check boxes of possible indicators in pencil and use pen for final decision.
b. If using fillable form, then follow the instructions for filling in the fillable form.

Context is important when assembling evidence. For instance, pool development may be an indicator of interest on the bed of a dry stream, but may not be a useful indicator to take note of in a flowing stream. On the other hand, if the pool is found in a secondary channel adjacent to the main channel, it could provide a line of evidence for a minimum elevation of high flows. Therefore, consider the site context when deciding which indicators provide evidence for identifying the OHWM. Explain reasoning in Step 5.

Questions to consider while making observations and listing evidence at a site:

Geomorphic indicators	Sediment and soil indicators	Vegetation Indicators	Ancillary indicators
Where are the breaks in slope? Are there identifiable banks? Is there an easily identifiable top of bank? Are the banks actively eroding? Are the banks undercut? Are the banks armored? Is the channel confined by the surrounding hillslopes? Are there natural or man-made berms and levees? Are there fluvial terraces? Are there channel bars?	Where does evidence of soil formation appear? Are there mudcracks present? Is there evidence of sediment sorting by grain size?	Where are the significant transitions in vegetation species, density, and age? Is there vegetation growing on the channel bed? If no, how long does it take for the non-tolerant vegetation to establish relative to how often flows occur in the channel? Where are the significant transitions in vegetation? Is the vegetation tolerant of flowing water? Has any vegetation been flattened by flowing water?	Is there organic litter present? Is there any leaf litter disturbed or washed away? Is there large wood deposition? Is there evidence of water staining?

Are the following features of fluvial transport present?
Evidence of erosion: obstacle marks, scour, armoring
Bedforms; riffles, pools, steps, knickpoints/headcuts
Evidence of deposition: imbricated clasts, gravel sheets, etc.

In some cases, it may be helpful to explain why an indicator was NOT at the OHWM elevation, but found above or below. It can also be useful to note if specific indicators (e.g., vegetation) are NOT present. For instance, note if the site has no clear vegetation zonation.

ENG FORM 6250, AUG 2022 Page 3 of 4

Figure B-1 (cont.). Field procedure and data sheets. Reproduced from USACE 2022 (1–4).

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OHWM Field Identification Datasheet Instructions and Field Procedure

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

Weight each indicator by considering its importance based upon:

a. Relevance:

i. Is this indicator left by low, high, or extreme flows?

Tips on how to assess the indicator relative to type of flow:

Consider the elevation of the indicator relative to the channel bed.
What is the current flow level based on season or nearby gages?
Consider the elevation of the indicator relative to the current flow.
If the stream is currently at baseflow and indicator is adjacent to that, then it is likely a low flow indicator. The difference between high and extreme flow indicators can sometimes be difficult to determine.

***Landscape context from Step 1 can help determine the relevance, strength, and reliability of the indicators observed in the field.**

***Information in Chapter 2 of the OHWM field manual provides information on specific indicators which can assist in putting these in context and determining relevance, strength, and reliability.**

ii. Did recent extreme events and/or land use affect this indicator?

1. Recent floods may have left many extreme flow indicators, or temporarily altered channel form. Other resources will likely be needed to support any OHWM identification at this site. Field evidence of the OHWM may have to wait for the site to recover from the recent flood.
2. Droughts may cause field evidence of OHWM to be obscured, because there has been an extended time since the last high flow event. There can be overgrowth of vegetation or deposition of material from surrounding landscape that can obscure indicators.
3. Both man-made (e.g., dams, construction, mining activities, urbanization, agriculture, grazing) and natural (e.g., fires, floods, debris flows, beaver dams) disturbances can all alter how indicators are expected to appear at a site. Chapter 6 and Chapter 7 of the OHWM field manual provides specific case-studies that can help in interpreting evidence at these sites.

b. Strength:

i. Is this indicator persistent across the landscape?

1. Look up and downstream and across the channel to see if you see the same indicator at multiple locations.
2. Does the indicator occur at the same elevation as other indicators?

c. Reliability:

i. Is this indicator persistent on the landscape over time? Will this indicator still persist across seasons?

1. 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.
2. Chapter 2, Chapter 6, and Chapter 7 of the OHWM field manual describes each indicator in detail and provides examples of areas where indicators are difficult to interpret.

d. Weigh body of evidence:

i. Combine weights: integrate the weighted line of evidence (relevance, strength, reliability) of each indicator.
ii. For each of the observed indicators, which are more heavily weighted? Where do high value indicators co-occur along the stream reach? Do they co-occur at a similar elevation along the banks relative to water surface (or channel bed if there is no water).
iii. On datasheet, select the indicators used to identify the OHWM. Information in Chapter 2 of the OHWM field manual provides descriptions of specific indicators which can assist in putting these in context and determining relevance, strength, and relieability.

e. Take photographs of indicators and attach a log using either page 2 of datasheet or another method of logging photos.

i. Annotate photos with descriptions of indicators.

Step 4 Is additional information needed? Are other resources needed to support the lines of evidence observed in the field?

a. If additional resources are needed, then repeat steps 3a and 3b for the resources selected in Step 1 of assembling, weighting, and weighing evidence collected from online resources. Chapter 5 of the OHWM field manual provides information on using online resources.
b. Any data collected from online tools have strengths and weaknesses. Make sure these are clear when determining relevance, strength, and reliability of the remotely collected data. Clearly describe why other resources were needed to support the lines of evidence observed in the field, as well as the relevance, strength, and reliability of the supporting data and/or resources.
c. Attach any remote data and data analysis to the datasheet.

Step 5 Describe rationale for location of OHWM:

a. Why do the combination of indicators represent the OHWM?
b. If there are multiple possibilites for the OHWM, explain why there are two (or more) possibilities. Include any relevant discussion on why specific indicators were not included in the final decision.
c. If needed, add additional site notes on page 2 of the datasheet under Step 5.

ENG FORM 6250, AUG 2022 Page 4 of 4

Appendix C: List of State GIS Databases

Table C-1. List of state GIS databases.

State	GIS Data Source Host
Alabama	Geological Survey of Alabama
	US Forest Service
Alaska	Alaska Department of Natural Resources
Arizona	AZGEO Clearinghouse–Arizona Geographic Information Council initiative, hosted by Arizona State Land Department
Arkansas	Arkansas Department of Transportation
California	California Spatial Information Library
Colorado	Colorado Department of Local Affairs
Connecticut	University of Connecticut Library—Map and Geographic Information Center
Delaware	Delaware Office of State Planning Coordination
Florida	State of Florida Geodata
Georgia	Georgia GIS Clearinghouse
Hawaii	Hawaii State Office of Planning
Idaho	Idaho Geospatial Office
Illinois	University of Illinois Springfield—Geographic Information Systems Laboratory
	USGS Upper Midwest Environmental Services Center—Illinois GIS data
	University of Illinois at Urbana-Champaign—Illinois Geospatial Information Clearinghouse
Indiana	State of Indiana—IndianaMap
	University of Indiana—Indiana Spatial Data Portal
Iowa	State of Iowa—Iowa Geodata
Kansas	State of Kansas—Kansas Data Access and Support Center
Kentucky	Commonwealth of Kentucky—Kentucky Geonet
	Kentucky Geological Survey—Geospatial Data Library
Louisiana	Louisiana Department of Transportation and Development—GIS Data
	LSU Atlas GIS
Maine	Maine Office of GIS—Data Catalog
Maryland	State of Maryland—GIS Data Catalog
	Maryland Department of Transportation—GIS Open Data Portal
Massachusetts	Massachusetts Bureau of Geographic Information—MassGIS
Michigan	State of Michigan—GIS Open Data
Minnesota	Minnesota IT Services—Geospatial Information Office
	Minnesota Geospatial Commons
Mississippi	State of Mississippi—Mississippi Geospatial Clearinghouse
Missouri	University of Missouri—Spatial Data Information Service Open Data Site
Montana	State of Montana—Geographic Information Clearinghouse

Table C-1 (cont.). List of state GIS databases.

State	GIS Data Source Host
Nebraska	State of Nebraska Geographic Information Office—NebraskaMap
Nevada	University of Nevada at Reno Virtual Clearinghouse for Nevada Geographic Information
	Nevada Division of State Lands—GIS Mapping Data
New Hampshire	New Hampshire GRANIT GIS Clearinghouse
New Jersey	New Jersey Department of GIS
	New Jersey Geographic Information Network
New Mexico	New Mexico State Land Office—GIS Data Download
	University of New Mexico Resource Geographic Information System
New York	State of New York GIS Data
North Carolina	NC OneMap
North Dakota	North Dakota GIS HUB Data Portal
	North Dakota Department of Geographic Information Systems
Ohio	Ohio Geographically Referenced Information Program
Oklahoma	Oklahoma Geographic Information Systems Council
	University of Oklahoma Center for Spatial Analysis
Oregon	State of Oregon Geospatial Data Clearinghouse
Pennsylvania	Pennsylvania State University—Pennsylvania Geospatial Data Clearinghouse
Rhode Island	Rhode Island Geographic Information System
South Carolina	South Carolina Department of Health and Environment Control—GIS Data Clearinghouse
South Dakota	South Dakota Department of Natural Resources—Digital Base Data
Tennessee	Tennessee GIS Clearinghouse
Texas	Texas General Land Office—GIS Maps and Data
Utah	Utah Automated Geographic Reference Center
Vermont	Vermont Center for Geographic Information
Virginia	Virginia Information Technologies Agency—GIS Clearinghouse
Washington	Washington Office of the Chief Information Officer—Washington Geospatial Open Data Portal
West Virginia	West Virginia GIS Technical Center—GIS Data/Services
Wisconsin	Geodata@Wisconsin
Wyoming	Wyoming State Geological Survey—GIS Data

Abbreviations

A_{bkf}	Cross-sectional area for bankfull
APT	Antecedent Precipitation Tool
$Area_{MAE}$	Cross-sectional area for mean annual flow
$Area_{TOT}$	Total cross-sectional area
CEM	Channel evolution model
CRREL	Cold Regions Research and Engineering Laboratory
D_A	Drainage area
D_{bkf}	Bankfull mean depth
DEM	Digital Elevation Model
DTM	Digital Terrain Model
ERDC	Engineer Research and Development Center
FDC	Flow-duration curve
GIS	Geographic Information System
HEC-RAS	Hydrologic Engineering Center's River Analysis System
HUC	Hydrologic Unit Code
LW	Large wood
NF	North Fork
NHD	National Hydrography Dataset
NHDPlus HR	National Hydrography Dataset Plus High Resolution

NRCS	Natural Resources Conservation Service
NTC	National Technical Committee
OHW	Ordinary high water
OHWM	Ordinary High Water Mark
Q%	Flow duration flow
Q_{base}	Base flow
Q_{bkf}	Modeled bankfull flows
Q_F	Flood return period
Q_{mean}	Mean annual flow
Q_{ohwm}	Modeled OHWM flows
RGL	Regulatory Guidance Letter
SEM	Stream Evolution Model
SfM	Structure-from-motion
sUAV	Small uncrewed aerial vehicles
SWC	Stream–wetland complex
USACE	United States Army Corps of Engineers
USFS	United States Forest Service
WBD	Watershed Boundary Dataset
W_{bkf}	Bankfull width
WoE	Weight-of-Evidence

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14. ABSTRACT
The ordinary high water mark (OHWM) defines the lateral extent of nontidal aquatic features in the absence of adjacent wetlands in the United States. The federal regulatory definition of the OHWM, 33 CFR 328.3(c)(7), states the OHWM is "that line on the shore established by the fluctuations of water and indicated by physical characteristics such as [a] clear, natural line impressed on the bank, shelving, changes in the character of soil, destruction of terrestrial vegetation, the presence of litter and debris, or other appropriate means that consider the characteristics of the surrounding areas." This is the first manual to present a methodology for nationwide identification and delineation of the OHWM. A two-page data sheet and field procedure outline a weight-of-evidence (WoE) methodology to organize and evaluate observations at stream sites. This manual presents a consistent, science-based method for delineating the OHWM in streams. It also describes regional differences and challenges in identifying the OHWM at sites disturbed by human-induced or natural changes and illustrates how to use remote data to structure field inquiries and interpret field evidence using the principles of fluvial science. The manual demonstrates that, in many landscape settings, the OHWM may be located near the bankfull elevation.

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