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Remote Sensing Tools to Support Ordinary High Water Mark Delineation

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PURPOSE: This document is a technical note (TN) that describes existing and recently developed tools to support ordinary high water mark (OHWM) identification and delineation. It also presents a case study to demonstrate how utilizing the tools provide supporting lines of evidence in OHWM delineations.

BACKGROUND: The OHWM defines the lateral extent of Clean Water Act jurisdiction for nontidal aquatic resources such as streams, rivers, and lakes in the United States. In current federal regulations found at 33 CFR 328.3(c)(7), the OHWM is defined as "that line on the shore established by the fluctuations of water and indicated by physical characteristics such as a clear, natural line impressed on the bank, shelving, changes in the character of soil, destruction of terrestrial vegetation, the presence of litter and debris, or other appropriate means that consider the characteristics of the surrounding areas (USACE 2005)." These physical characteristics, which serve as flow indicators for the location of the OHWM, are further described in Regulatory Guidance Letter (RGL) No. 05-05 (USACE 2005) (Table 1).

Table 1. Physical characteristics of the ordinary high water mark (OHWM) provided in Regulatory Guidance Letter (RGL) No. 05-05 (USACE 2005).

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

Led by the US Army Corps of Engineers (USACE), the National Technical Committee for OHWM developed a national manual and technical guide to support field identification and delineation of the OHWM (David et al. 2022). This manual describes physical indicators that can assist with identification of lateral and longitudinal extent of the OHWM, which are based on the physical characteristics of the OHWM found in both the definition of OHWM and RGL No. 05-05. David et al. (2022) also provide examples of remotely sensed data, including Light Detection and Ranging (lidar) imagery, that can be used (1) to identify potential locations of the OHWM for a more efficient and targeted field investigation or (2) as additional lines of evidence to support field OHWM determinations.

As described in Haring et al. (2019), Haring and Biedenharn (2021), and Haring (2021), lidar-derived cross sections are vital in the remote analysis of physical indicators identifying bankfull and OHWM morphology, such as breaks in slope, floodplain-berms, and channel bars. Existing tools available through ESRI's ArcGIS Pro, and recently developed tools like Fluvial Geomorph (FG) are capable of using lidar data and products to derive elevation profiles from lidar data and products, which can aid in identifying and delineating the OHWM through the identification and interpretation of breaks in slopes and shelving observed in those elevation profiles. The interpretation of what these geomorphic characteristics represent in relation to the OHWM can be understood by referencing the OHWM national manual (David et al. 2022). This TN provides four options for using these tools to assist in OHWM determinations:

- Google Earth Pro
- ArcGIS PRO
- FG, Level 1 Analysis
- an abbreviated FG analysis approach

While lidar products can provide advantages relative to the kinds of topographic data that have historically been utilized to support OHWM determinations, the variability in the temporal and spatial resolution of individual lidar data sets can have an adverse effect on the ultimate utility of using lidar data sets to complete an OHWM determination (Gillrich and Lichvar 2014; Haring 2019). Data availability and the level of effort required (Table 2) for the remote analysis also influence the utility of both lidar data and the tools described in this document. The analysis utilized may also be commensurate with the scope of analysis needed for the project requiring the OHWM determination.

Table 2. Anticipated time required to complete each analysis described in this document.

Analysis Method	Time to Complete Analysis (hours)
Google Earth Pro	¼ (15 min[1])
ArcGIS Pro	1
FG, Level 1	4–8
FG, abbreviated	2–4

The remote sensing analysis described in this TN is not intended to replace field procedures for OHWM determinations but may be used to develop supporting lines of evidence using these tools to identify and delineate OHWM.

Methods for OHWM Determinations. For this report, Antelope Creek, North Dakota, was chosen to illustrate the processes for identifying OHWMs using Google Earth Pro, ArcGIS PRO and FG. Antelope Creek is a tributary to the Missouri River in North Dakota and is also used as a case study in Hamill and David (2021) and in David et al. (2022). For the FG analysis, the field-surveyed cross-section locations (x,y,z) were compared to the existing 2014 lidar. Figure 1

[1]For a full list of the spelled-out forms of the units of measure and unit conversions used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed, (Washington, DC: US Government Publishing Office 2016) 248-52 and 345-7, respectively. *https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf*.

illustrates the OHWM delineation for the Antelope Creek site from field work completed during field site data collection in 2017 (Hamill and David 2021; from David et al. 2022).

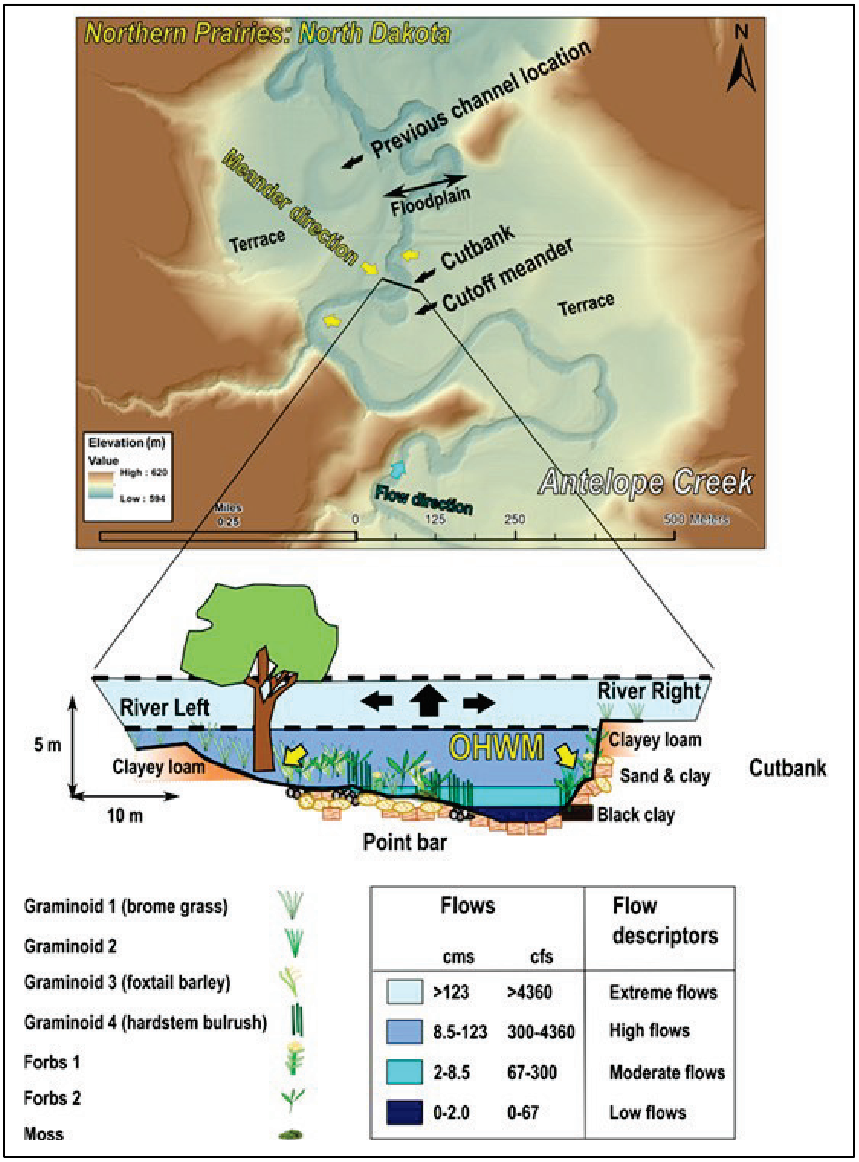

Figure 1. Antelope Creek, North Dakota; field delineation of ordinary high water mark (OHWM) (from David et al. 2022).

For this report, a typical geomorphic study reach was completed using a channel length of 1 mi upstream and downstream of the cross-section site to define the study area. The site is located at latitude 46°32'43", longitude: -101°38'42", at the 60th Street SW bridge crossing Antelope Creek in Grant County, North Dakota. Priority was placed on identification of physical channel characteristics (Figure 2) such as breaks in slope and shelving by deriving channel cross sections to identify geomorphic indicators, which may be useful as OHWM indicators or bankfull/channel forming discharge markers (Lawlor 2004; Hamill and David 2021; David et al. 2022). Once the study reach was defined, the four options were applied to determine their utility in defining OHWM at the Antelope Creek site.

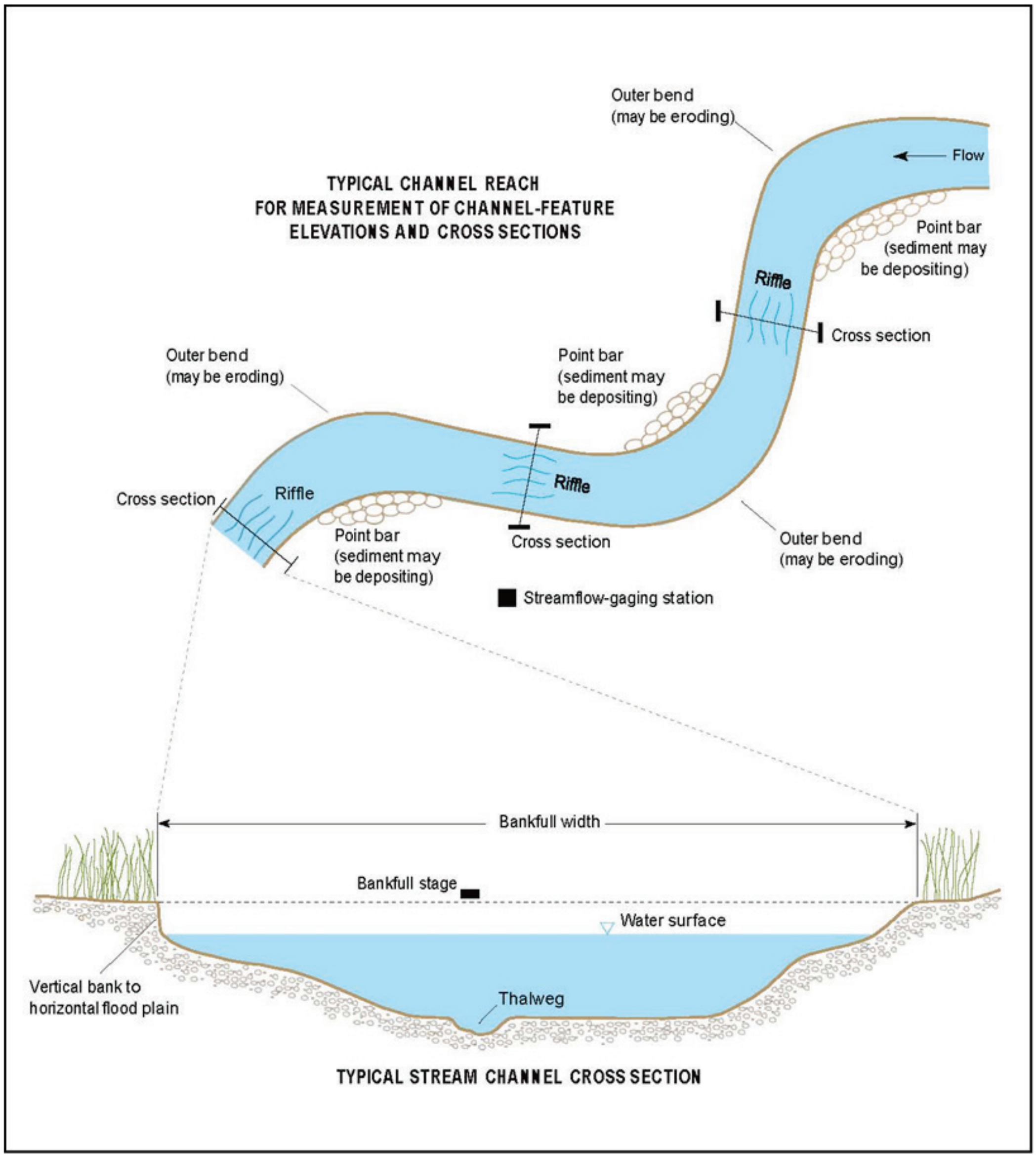

Figure 2. Typical stream reach and cross-section locations for channel features with bankfull stage identified (from Lawlor 2004).

Google Earth Pro is user-friendly, free software that allows for visualization, assessment, overlay and creation of geospatial data. Although not a true geographic information system (GIS) platform, it provides importing and exporting of georeferenced terrain data and thus allows for analysis of that data over aerial images. Data can be tied to specific *x*, *y*, and *z* coordinates for use in more GIS-friendly platforms such as ArcGIS Pro. ArcGIS Pro is a standard toolset that is a cloud-based mapping and analysis solution (ArcGIS, n.d.). Globally, it is used to create maps, analyze data, and to share and collaborate physical landscape terrain data. FG toolbox uses elements of ArcGIS PRO, additional coding scripts (Python and R-code) and high-resolution terrain data approach designed to measure channel, slope, floodplain, valley, and watershed metrics necessary for watershed or reach level assessments (Figure 3).

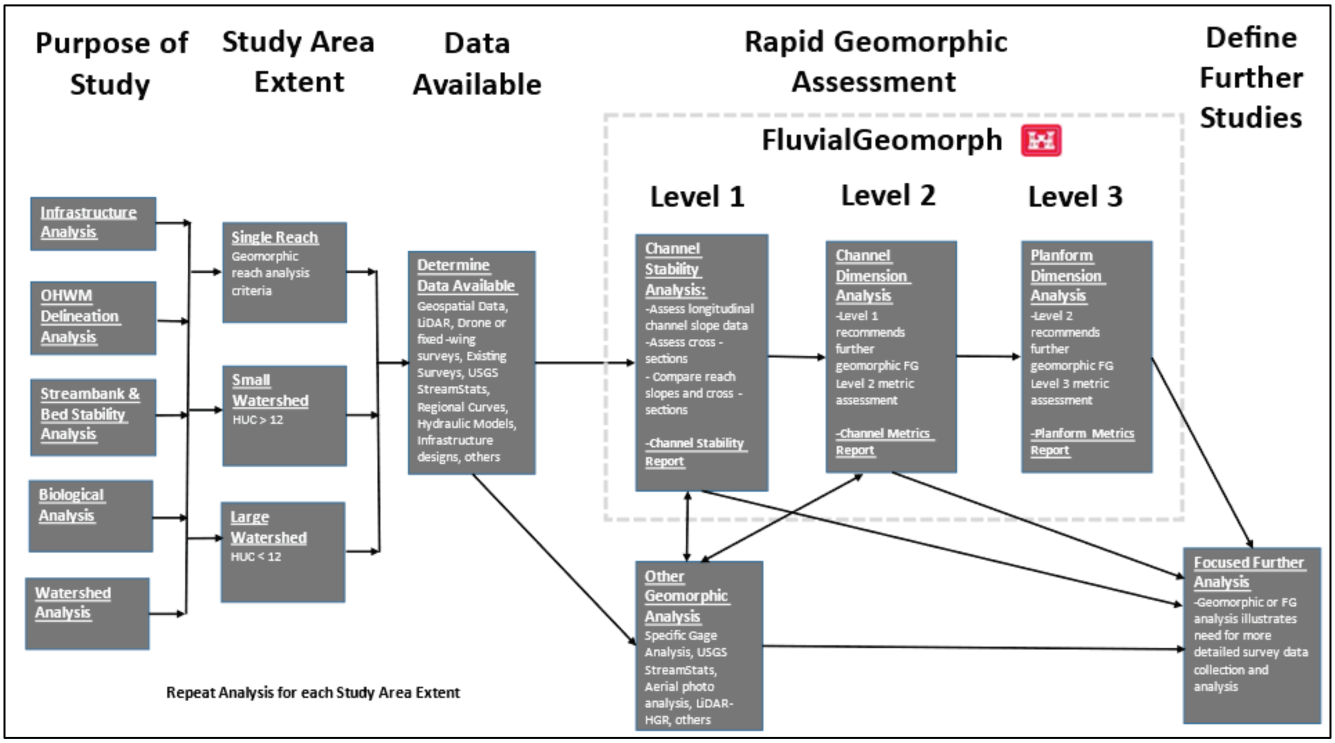

Figure 3. FluvialGeomorph (FG) rapid geomorphic assessment approach (from Haring et al. 2020).

Additional considerations for remote data analysis for OHWM determinations are listed and described below.

Data Availability. When using remotely sensed terrain data for OHWM determinations, accuracy in identifying the physical characteristics of the OHWM is generally dependent upon the resolution of the data. Haring (2019) and Haring (2021) describe the issues with interpreting high-resolution terrain data (lidar) and the difficulties with existing resolution in off-the-shelf data. Resolution and extent of existing terrain data affects both the time required to produce a usable analysis approach as well as the usefulness in any OHWM determinations resulting from the analysis approach. If Digital Elevation Models (DEM) are readily available with sufficient resolution (recommended minimum of 1 m resolution), then there will be improved success in identifying OHWM. In addition, plotting field-surveyed cross sections with existing DEMs is an important analysis technique and has been added to FG so that geomorphic changes both spatially and temporally can be assessed.

Geomorphic Channel Analysis. There is a plethora of methods for determining appropriate locations to measure and collect channel morphological features associated with bankfull, OHWM, floodplain and terrace connections (Leopold et al. 1964; Dunne and Leopold 1978; Rosgen 1996; Knighton 1998; Lawlor 2004; Haring 2019). An approach for determining where to initiate the exploration of bankfull and OHWM signatures are summarized below from Haring et al.[2]

[2] Haring, C. H., and M. W. Dougherty. In preparation. *Geomorphic Metrics Used in FluvialGeomorph*. ERDC/CHL Coastal and Hydraulics Engineering Technical Note. Vicksburg, MS: US Army Engineer Research and Development Center.

Standard fluvial geomorphic procedures for identifying and collecting channel morphology (bankfull and OHWM) include the following:

- Assessment of the two basic geomorphic units of measurement: the channel forming discharge (bankfull stage) and the channel reach length (Harrelson et al. 1994) are key components for fluvial geomorphic channel analysis.
- Harrelson et al. (1994) recommends measuring bankfull conditions at cross sections located in stable reaches between channel bends where the riffle cross-over locations (also often referred to as crossings) are located (Figure 1). Riffle cross-over locations are areas where the channel typically has the best geomorphic signature for capturing the bankfull stage and incipient floodplain connection typically located at the point of inflection (Rosgen 1996).
- The bankfull stage varies widely depending on the extent of the geographic region and potential differences in literature sources. For example, Williams (1978) found that the bankfull discharge for the rivers studied had a range of 1 to 30 yr recurrence interval. Hamill and David (2021) found that the OHWM elevation generally ranged from the 1 to 11 yr recurrence interval, which aligns with the findings from Wohl et al. (2016). Dunne and Leopold (1978), Rosgen (1996), and Haring (2019) found that the bankfull discharge ranged from 1 to 2 yr for the rivers in their studies. The USACE (USACE 1994) manual on channel stability recommends using a 2 yr recurrence interval for channel-forming discharge and engineering analysis. There are known differences in the local and regional conditions in which the data analyzed from study comparisons need to be considered when determining OHWM and bankfull discharge. The main point of this discussion is to acknowledge there is much variability and uncertainty regionally and in literature in determining the bankfull discharge (OHWM). Regional hydraulic geometry curves, local geomorphic surveys, and US Geological Survey (USGS) gage station analysis can be used to further assess and define bankfull geomorphic channel conditions.

Level of Effort. The analysis utilized may also be commensurate with the scope of analysis needed for the project requiring the OHWM determination. The greater the level of detail needed, the more the processing time will likely be required. For example, large mitigation projects may need detailed elevations, review, and monitoring.

Google Earth Pro. The most rapid method to view a cross section is to use the Elevation Profile Tool within Google Earth Pro. The Terrain Layer should be turned on. The best approach is to use an existing KMZ file containing the cross section. In this case study, that is accomplished by using a KMZ of cross section 121 from the Antelope Creek field survey. To open the cross-sectional profile, the user should click Edit and Show Elevation Profile. The cross section will display on the lower half of the Google Earth display (Figure 4). Google Earth Pro can also be used to sketch a Path along the study area. Using this method, the cross-sectional profile can be viewed in the Show Elevation Profile graph. The resolution will generally be based on the 10 m or 30 m National Elevation Dataset. Additional directions for Google Earth Pro's Elevation Profile tool are available at *https://support.google.com/earth/answer/148134?hl=en*.

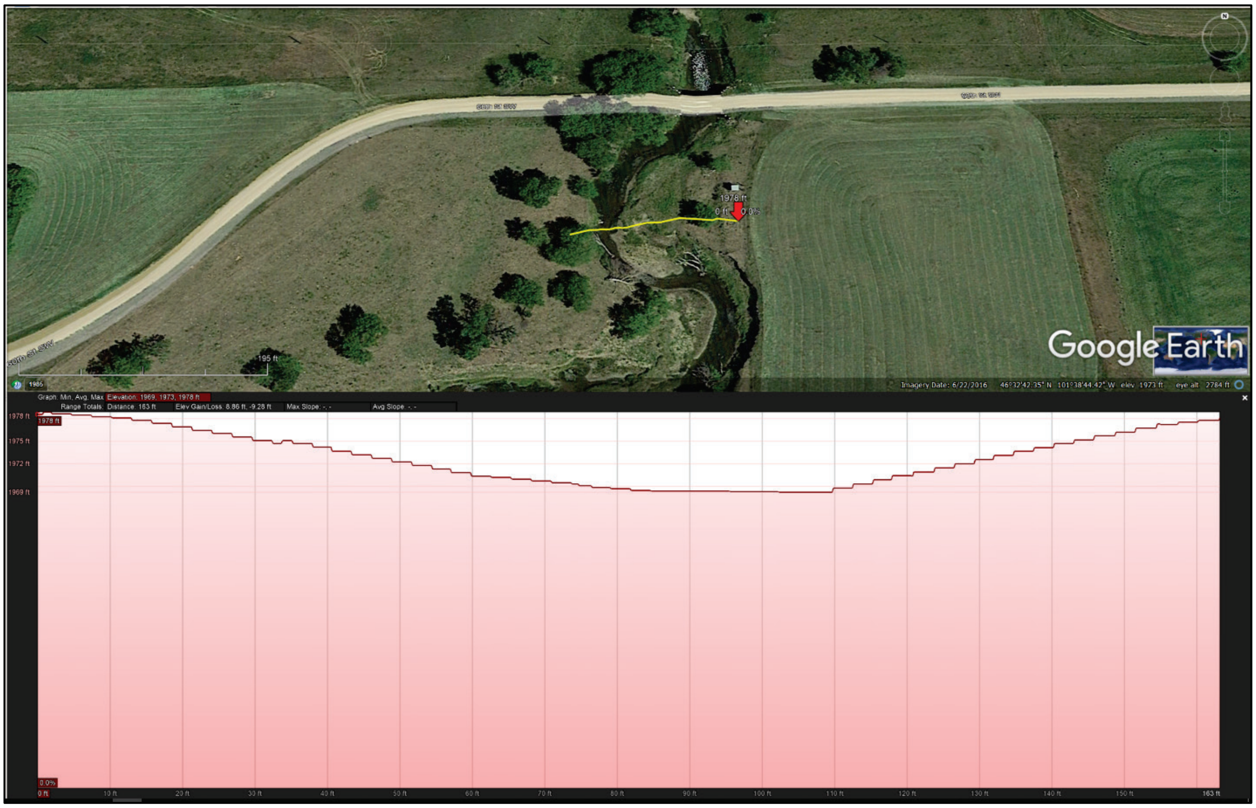

Figure 4. Antelope Creek; cross section 121 (Google Earth Pro; 10 m resolution).

Interpretation of Google Earth Pro Elevation. Identification of an OHWM with the 10 m resolution terrain data provided from Google Earth Pro analysis may not be appropriate as the use of low-resolution terrain data does not allow for sufficient identification of geomorphic signatures. Using the case study as an example, the consistent stair-step nature of the terrain (Figure 4) is produced by the low-resolution data that do not provide sufficient geomorphic signals that represent the physical characteristics of the OHWM. Higher resolution data are needed to provide more effective approach to OHWM determination.

ArcGIS PRO: The ArcGIS PRO method described here utilizes the Elevation Profile tool and existing off-the-shelf 1 m and 10 m resolution DEMs that are developed from various high-resolution terrain data. Step-by-step directions are provided with the 1 m resolution DEM in the following section. Additional information regarding the Elevation Profile tool can be found at the following tutorials:

https://youtu.be/FP6PfF3aiaM

https://pro.arcgis.com/en/pro-app/latest/help/mapping/exploratory-analysis/interactive-elevation-profile-basics.htm.

1. Open ArcGIS Pro version 2.7 or later. A 3D Analyst license is required. Start without a template.
2. Right-click the cross section or location point to Add to a new Local Scene.

3. In Catalog, from a connected folder, add a 1 m DEM for the study area. Additionally, in Portal under the Living Atlas, the Terrain layer may be added to the map. The Terrain layer included only 10 m resolution elevation data along Antelope Creek, so it was not used for this exercise.
4. Choose the Analysis tab on the top ribbon. Then choose the Exploratory 3D Analysis dropdown. Select the Elevation Profile tool.
5. The Elevation Profile tool allows Interactive Placement to draw a cross section across the terrain or From a Layer if the cross section is added to the Scene.
6. Via the Interactive Placement Method (IPM), sketch a line across the cross section and double-click to complete the line. The Elevation profile graph appears at the bottom of the Scene, along with the key elevation statistics (Figure 5). Use the Export Image button at the top right of the graph to export a .PNG of the graph. Slide the cursor along the graph to highlight the elevation at key locations.

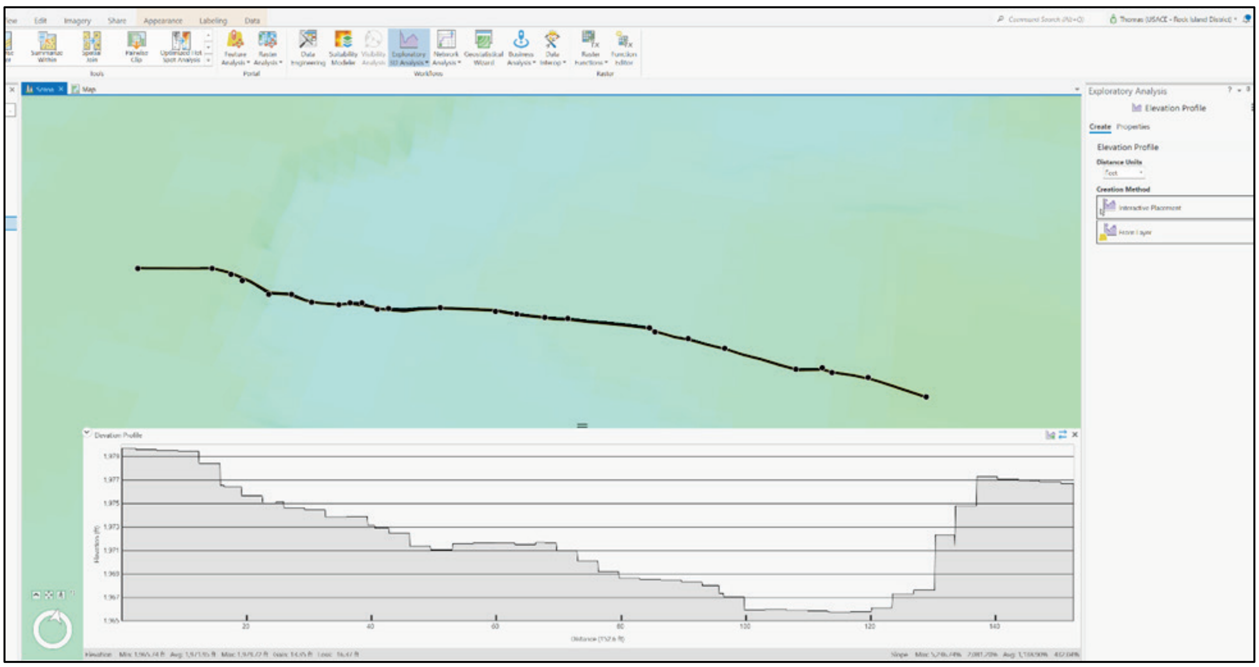

Figure 5. Antelope Creek; cross section 121 (ArcGIS Pro Interactive Placement Method [IPM]; 1 m existing DEM).

7. Using the from Layer Method (LM), select a cross section and choose Apply. A Profile Graph will appear at the bottom of the Scene (Figure 6). Export the Profile Graph, then select the next cross section.

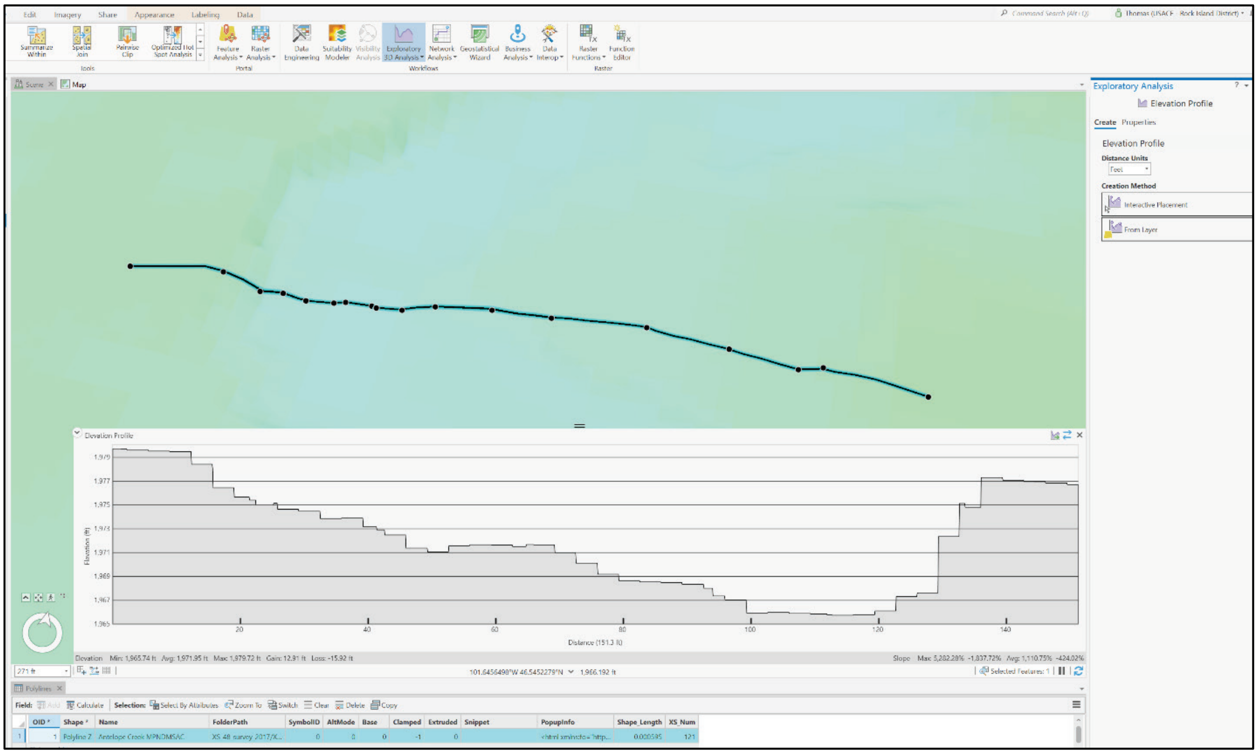

Figure 6. Antelope Creek cross section 121 (ArcGIS Pro Layer Method [LM]; 1 m existing DEM).

Local DEMs may also be loaded into ArcGIS Pro to extract Elevation Profile graphs. In Catalog, right-click on the DEM and Add to Global Scene. Multiple cross sections can be profiled by choosing the Analysis tab and then choosing the dropdown menu on the Exploratory 3D Analysis tool. Choose the Elevation Profile, and it will include the From Layer option. Add the cross sections to the Contents and select it in the From Layer drop down. The cross section to be profiled must be selected in the Attribute Table or on the Map.

Interpretation of ArcGIS PRO Cross Sections (1 m resolution). Identification of the OHWM and interpretation of data with low resolution is difficult (Figure 4). In contrast to the 30 m data that were used to generate Figure 4, the resolution of the Antelope Creek DEM used in the ArcGIS Pro analysis is 1 m. Although this output from the 1 m data (Figures 5 and 6) still contains a lot of stair-stepped, blocky elevation changes from hydro-flattening, the geomorphic signals that represent the physical characteristics of the OHWM are more evident and pronounced.

From cross section 121, remote geomorphic channel indicators of the potential OHWM are marked by breaks in slope and/or berm formation as indicated by red circles and various dashed lines (Figure 7). Visible breaks in slope are noted by dashed lines in Figure 7 at approximate elevation ranges (NAVD88) 1967 ft (green), 1969–70 ft (orange), 1972–73 ft (blue), 1975 ft (purple), and 1977 (red). Based on previous findings of Hamill and David (2021), the field delineated OHWM of this site was found at an elevation of approximately 1972 ft.

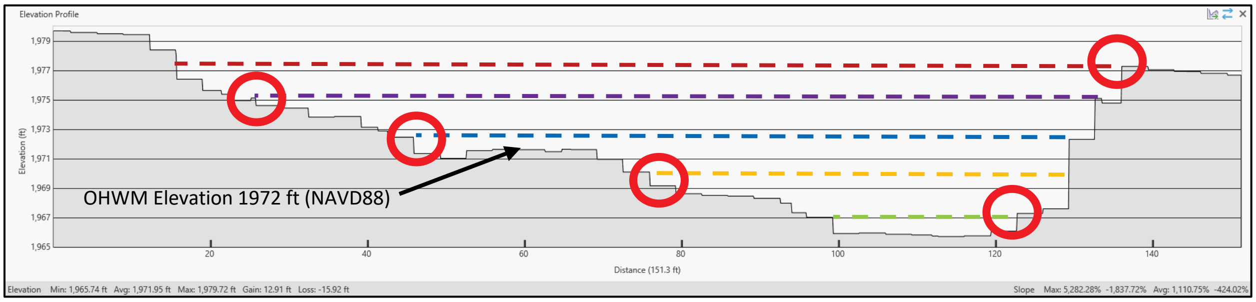

Figure 7. Antelope Creek cross section 121 (ArcGIS; 1 m existing Digital Elevation Model [DEM]) with colored lines illustrating potential OHWM locations (ArcGIS Pro LM; 1 m existing DEM). Red circles show the break in slope and the line shows the hypothetical water surface related to break in slope.

Using the weight-of-evidence technique described in David et al. (2022), the visual interpretation of this ArcGIS Pro-derived cross section could be used as a supporting line of evidence in the OHWM determination for this specific site. The identification of geomorphic indicators for OHWM determination using ArcGIS Pro is suitable for this site based on high-resolution DEM's (1 m); however, depending on the level of detail required more detailed analysis may be appropriate. The ArcGIS Pro OHWM analysis took approximately 1 hr. The time of analysis as well as the resolution of data has increased from the Google Earth Pro approach to the ArcGIS Pro approach, and those factors will increase more with the greater resolution FG (Table 1). The next section of this report provides higher resolution increment for OHWM determination using FG.

FG, LEVEL I ANALYSIS: FG toolbox uses elements of ArcGIS PRO but also uses additional coding scripts and high-resolution terrain data approach designed to measure geomorphic metrics necessary for watershed or reach level assessments (Figure 3). This toolbox has been expanded for this report to specifically identify physical characteristics to support OHWM determinations. FG Level I analysis provides information describing channel slope (energy slope analysis) and allows for cross-sectional examination of temporal, spatial, and existing conditions analysis. An FG Level II analysis can assess bankfull channel indicators (typically OHWM indicators) and can also identify the geomorphic metric at the reach scale, which may be useful for OHWM determinations (Hamill and David 2021). Additional reference information, as well as a user guide, is available at *https://www.usermanual.fluvialgeomorph.org/create-terrain.html*.

An example of OHWM and application of FG Level I-Channel Stability Analysis (CSA) includes the identification of physical channel processes (channel slope) identified on the longitudinal profile (Figures 8–9). In numerous instances, channels with steep energy slope profiles indicate potential issues occurring downstream as Figure 9 (purple circle) illustrating a large drop in channel elevation at approximate station 3,500. This may be a channel knickpoint location that is indicative of a degrading channel. Typically, what is found is upstream of the knickpoint the channel has access to a floodplain during frequent events, say the 1 to 2 yr channel discharge with easily identifiable OHWM locations. Downstream of the knickpoint, the channel has widened and deepened, and identification of the OHWM is difficult to determine. Identification of these locations provides insight into analysis of existing lidar data (CSA cross-sectional analysis) and the need for potential field investigations. With FG, there can be a comparison of cross sections upstream and downstream of the location to determine channel width and depth changes that are typically associated with channel degradation (Haring and Biedenharn 2021). If a stream restoration practitioner or Regulatory Project Manager was reviewing design plans and identifying OHWMs in the area and looking at bank protection upstream of this degrading channel location, then bed stabilization should be further considered to provide channel stability as the bank protection will fail in most if not all cases due to channel bed lowering. Stabilization and restoration projects downstream of the location should also consider excessive sediment delivery and its effects on any projects in the downstream direction. FG could then be used to inform targeted field reconnaissance to determine if the oversteepened nick-zone is actively migrating and if so, effectively stabilize the bed degradation issue prior to any work upstream or downstream.

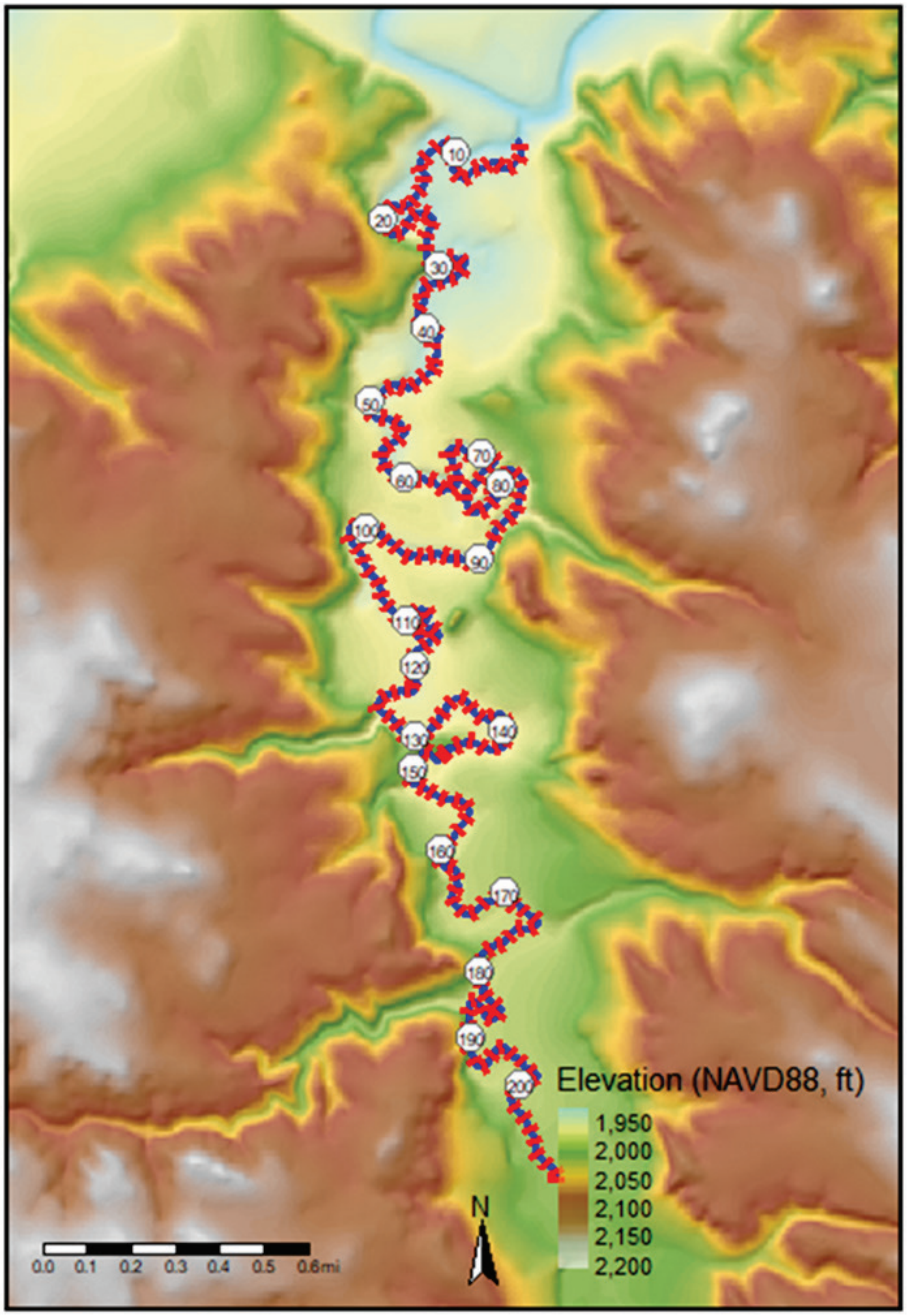

Figure 8. Antelope Creek study-site map with cross-section locations depicted by red bar and cross-section number by circle.

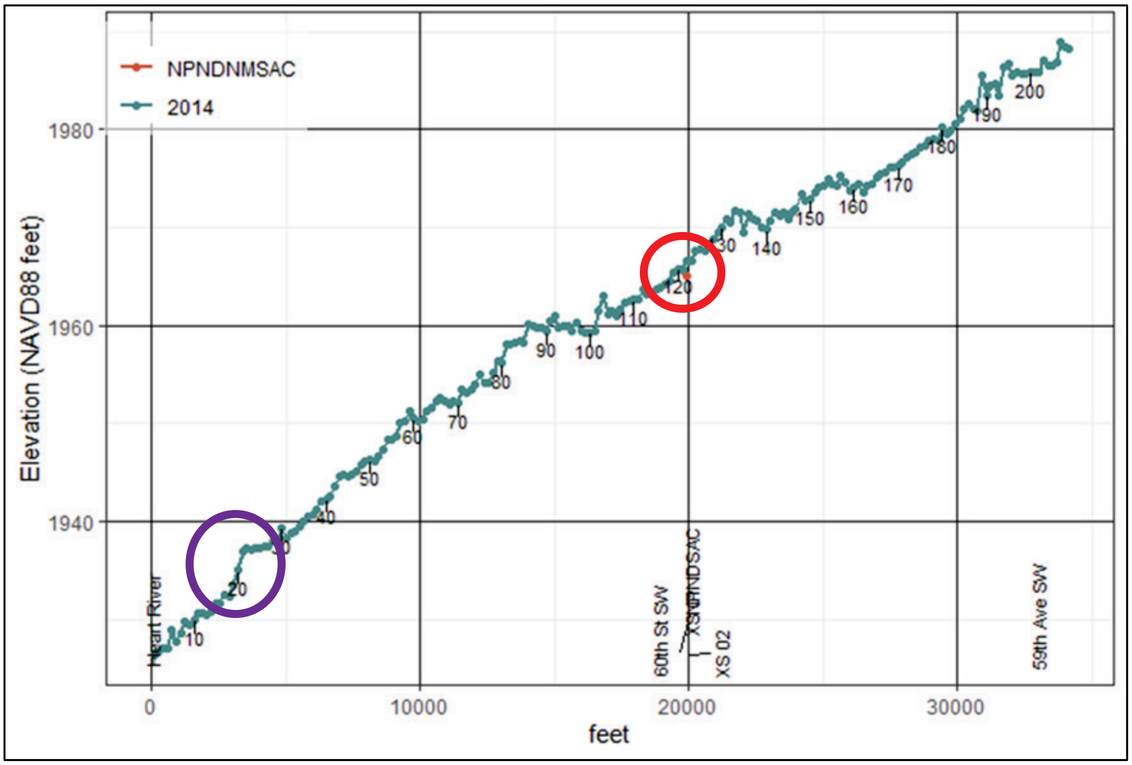

Figure 9. Antelope Creek; FG profile (1 m existing DEM) with location of field survey (*red dot*) and red circle identifying the reach. Purple circle indicates possible *headcut* or oversteepened energy slope.

Additional FG analysis considerations with a specific focus on this Antelope Creek case study are listed and described below.

Data Availability. Data needed for an FG analysis include high-resolution terrain data (lidar or DEMs with 1 m resolution or greater), which is generally available from the USGS National Map, state repositories, and/or local governments. The lidar survey for the site used in this example was flown during 2014. The classified lidar point cloud data were not available for this site; however, lidar-derived, bare-earth, 1 m resolution DEMs were provided through the North Dakota Geological Survey GIS clearinghouse website (North Dakota Geological Survey 2023) These premade DEMs contain no evidence of cosmetic hydro-flattening within the channel that would restrict fluvial geomorphology analysis. The analyst followed the instructions in the FG User Manual, Create Terrain chapter, to prepare the elevation data for further processing (FluvialGeomorph User Manual 2023).

Level of Effort. The identification of suitable elevation datasets, data processing, calculating cross-section dimensions, and report development for this case study took parts of two calendar days and approximately 2 to 4 hr. Commonly, the process will take 6 to 8 hr to find and retrieve suitable off-the-shelf terrain data. Verification of elevation data is relatively important based on study needs. The quality of existing terrain data is variable, so more time may be required to verify key metadata. Metadata includes date, coordinate system, points per meter, accuracy (root mean square error), and type of equipment used for collection of elevation data. Date of collection can be important for interpreting channel morphology. For example, high, low water, or ice conditions, leaf-on (not typical anymore) or leaf-off, have effects on how terrain data can be analyzed (Haring 2019).

For the Antelope Creek site, the USGS National Map was used to search for available lidar point cloud elevation data. No lidar data were available at the Antelope Creek site, so the North Dakota state site was searched, and a 1 m DEM was located. The DEM was downloaded and checked for hydro-flattening. Once the boundary 1 mi above and below the site along Antelope Creek was clipped, the processing started. Processing time could be decreased if the 1 mi upstream and downstream are reduced. It is highly recommended, based on general geomorphic survey practice outlined in Harrelson et al. (1994) and Haring (2019), that investigation of a stream reach should include a length of 1 mi upstream and downstream. However, that may not be always appropriate or necessary for OHWM determinations based on time constraints.

Once terrain data are developed, the FG toolset is used to create a flowline for the longitudinal extent of the Antelope Creek as well as one or more cross-section locations along the longitudinal extent of Antelope Creek. The FG Level 1 Report displays the longitudinal profile and cross sections for the study area, as well as local slope and sinuosity values.

FLUVIALGEOMORPH, LEVEL I ANALYSIS, ABBREVIATED: The key to quicker processing times is finding a premade DEM that is not hydro-flattened in your area of interest. A 1 m resolution DEM is a typical product included in a lidar collection. Once a DEM tile is downloaded from the USGS National Map, check the elevations along the channel bed to make sure it is not hydro-flattened. Hydro-flattening will show up as a stairstep of elevations along the stream instead of the actual elevations (Haring 2019; Haring 2021). The DEM should also be checked to see if the elevation is in meters or feet. If the elevation needs to be converted from meters to feet, use the ArcGIS Pro Times tool to multiply the DEM times 3.28084 to convert the elevation to feet. Create a boundary polygon by buffering 1 mi around the point of interest along the creek, then use the polygon to clip the DEM. Using the 1 m premade DEM and limiting the project scope to 1 mi above and below the point of interest allows for faster processing of the site. Starting at 1200 with a premade 1 m DEM created from a 2014 lidar collect, a Level 1 Report with 85 cross sections 1 mi above and below the point of interest on Antelope Creek was completed by 1400. A smaller area or fewer cross sections can shorten the processing time. If a stream has been changing rapidly and it is useful to understand the amount and direction of changes over time when evaluating the OHWM, the FG Level 1 analysis can help with change comparison. If available, processing elevation data from another year allows for this change comparison along the stream but will require more time to process.

FG-ANTELOPE CREEK CASE STUDY: This section provides an example of FG applications that can be used to support OHWM delineations. The location of this case study was also utilized as a case study in David et al. (2022) and Hamill and David (2021). As part of those case studies, field surveys of Antelope Creek were taken at cross-section locations 121 on 27 June 2017 (Figure 10). The FG analysis was completed 1 mi upstream and downstream of cross section 121.

Following the instructions in the FG User Manual, Level 1 CSA extracts channel dimensions from the lidar survey. The FG tools were used to derive the stream flowline and regularly spaced cross sections to cover the study area channel. Channel dimensions were derived from the 2014 lidar survey DEM for the study area cross sections. The Level 1 Report displays overview maps, longitudinal profile graphs, cross-section metrics, and individual cross-section profiles for the study area.

Profile plots provide a method to assess energy slopes within a given reach. In FG, upstream and downstream slopes are plotted to determine if there are relative changes, which may show changes in channel types or general stream characteristics and conditions. In addition, there may be a lack of geomorphic floodplain indicators at the site location, so investigating upstream and downstream may be required to determine OHWM in certain situations. However, practitioners may often need to complete only the FG analysis for a smaller reach. The slope for Antelope Creek study area is plotted in Figure 9. Interpretation of the data as it relates to OHWM identification is described for each cross section in the rest of the section.

Channel profiles provide energy slope relationships upstream, downstream, and at the current locations and can be used to interpret channel stability and potential degradation/aggradation sites. The profile for this case is based on lidar terrain data, so the profile is likely the water surface profile not necessarily channel bottom. There are many factors that influence the accuracy of the lidar data. More detailed information on drivers of lidar accuracy and coverage can be found in Haring et al. (2019) and Haring (2021). The profile shows the location of field surveyed cross-section locations 121 (Figure 9, red circle).

The cross-section plots produced by FG can be used to visually interpret geomorphic indicators of the potential OHWM (e.g., break in slope, shelving) prior to or following a site inspection and may serve as supporting lines of evidence for OHWM delineations. The OHWM national manual has more information on how to apply the weight-of-evidence method when using remote data. If multiple years of data are available, FG can also be used to interpret temporal changes to the channel geometry. The Antelope Creek field surveyed cross section 121 is illustrated in Figure 10. FG matched the *x* and *y* coordinates from the field-surveyed cross section to derive the same cross-section alignment using lidar data (Figure 10) and extrapolated *z* elevations from the existing 2014 lidar-derived DEM. There are obvious differences in the comparisons of the two cross sections in Figure 11; however, they are similar.

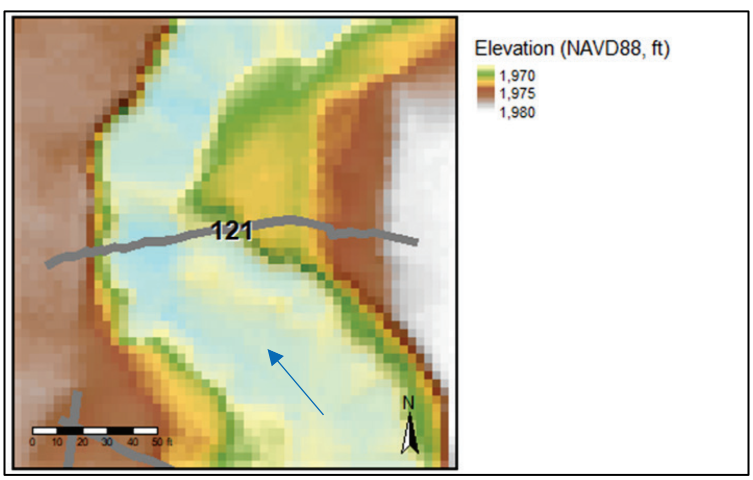

Figure 10. Cross section 121; plan-view map illustrating field-surveyed cross-section location.

From cross section 121 (Figure 11, blue line), geomorphic channel indicators of the potential OHWM are marked by breaks in slope or berm formation as indicated by red circles and various dashed lines. Visible breaks in slope are noted by dashed lines in Figure 11 at approximate elevations (NAVD88) 1967 ft (green), 1972 ft (orange), 1974.9 ft (blue), and 1976.5 ft (purple). Based on previous findings of Hamill and David (2021), the field-delineated OHWM was found at an elevation of approximately 1972 ft. Using the weight of evidence technique described in David et al. (2022), the visual interpretation of this FG-derived cross section could be used a supporting line of evidence in identifying and delineating the OHWM for this specific site.

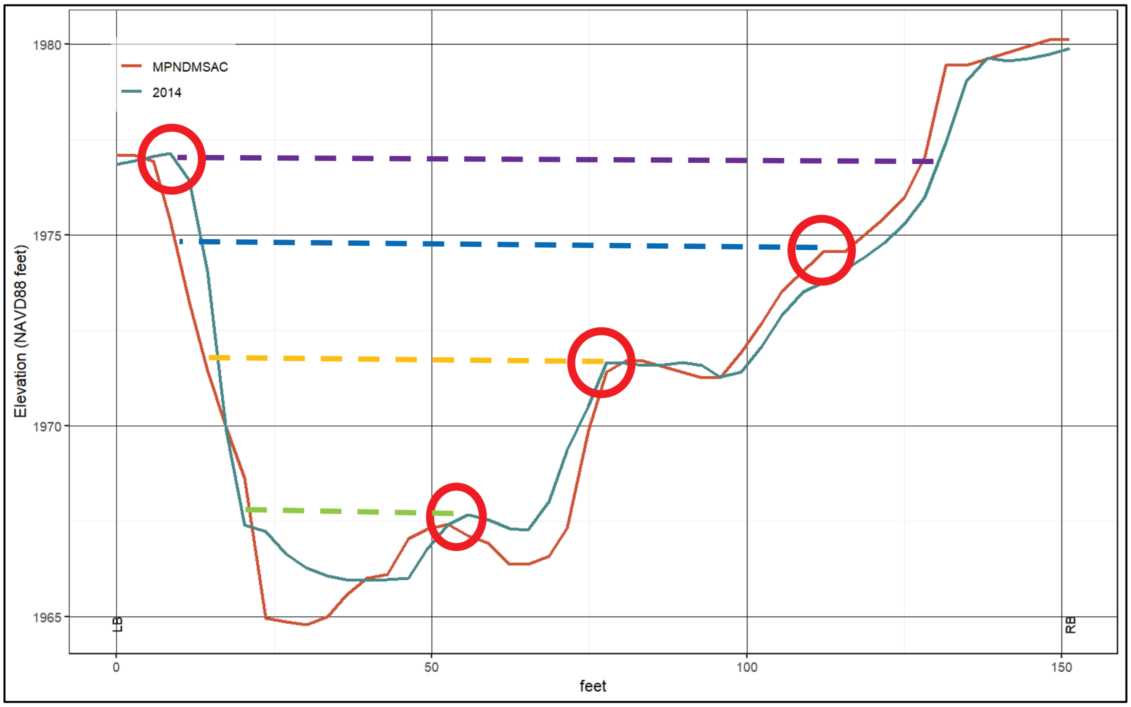

Figure 11. Cross section 121. Solid-red cross section is Antelope Creek (NPNDNMSAC) field survey, June 2017, and solid-blue cross section is 2014 lidar (1 m). Geomorphic indicators (red circles) of potential OHWM locations (green-yellow-blue-purple lines) identified through visual interpretation of the FG-derived cross sections.

When possible, validating bankfull and OHWM elevation identification with multiple cross sections is a good practice. FG plotting tools and reports provide the ability for additional cross-section analysis. In this case study, upstream cross sections of Antelope Creek were analyzed. Cross section 123 (Figures 12–13) has potential OHWM indicators that can be compared to cross section 121 (Figure 11). Visible breaks are noted by dashed lines (Figure 13) at approximate elevations (NAVD88) 1972.5 ft (green), 1974 ft (orange), and 1976 ft (blue). All three of these elevations match within a 0.5 ft to 0.9 ft with the possible OHWM elevations from cross section 121 (Figure 11). The FG analysis, along with other remote data analyses and techniques, can be utilized to target potential locations of the OHWM for additional evaluation in the field but may not be suitable as a sole data source for identifying the final OHWM. Therefore, the FG analysis can either help refine the area where field reconnaissance will occur or can be used as supporting evidence after the field survey has occurred. For instance, the lidar-extracted cross section shows potential locations of the OHWM. The field survey then reveals that the channel is entrenched in its floodplain, which means the upper breaks in slope at the elevation of the purple line is unlikely to be the OHWM. Field observations also provide information on vegetation and soil characteristics. The vegetation at the elevation of the green line is aquatic in nature, and the break in slope there is related to a mid-channel bar. The elevation of the orange line is where woody vegetation is established and the upper limit of sand and gravel deposition.

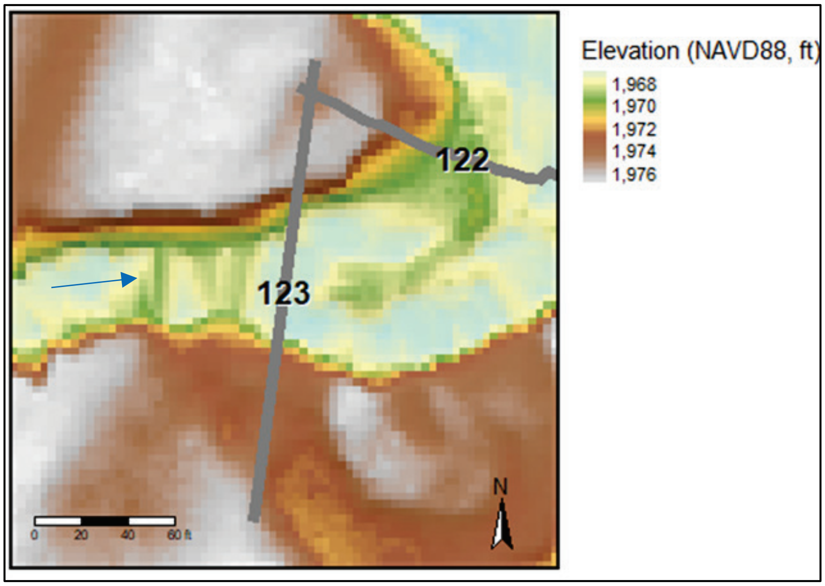

Figure 12. Cross section 123; plan-view map of upstream cross section.

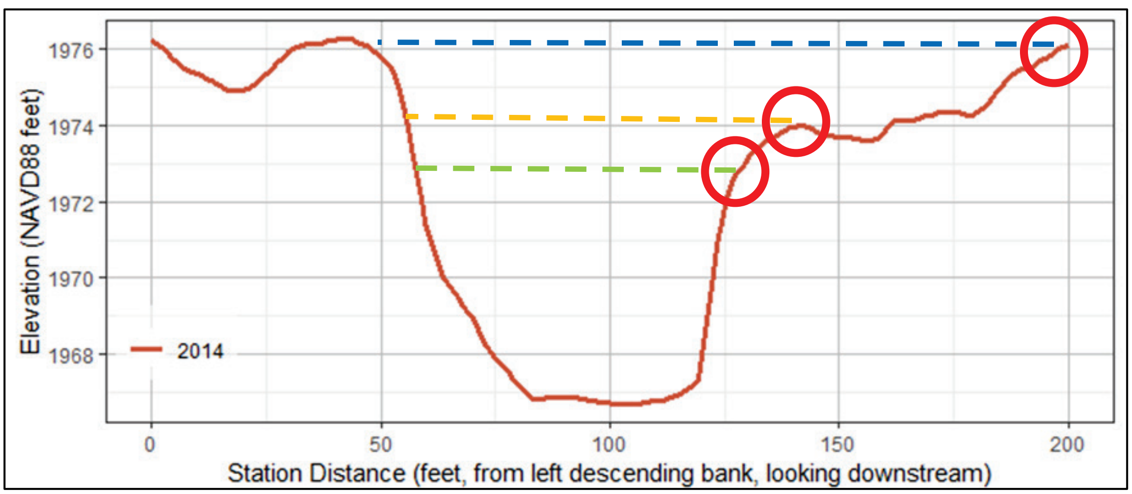

Figure 13. Cross section 123; illustrating geomorphic indicators (red circles) of potential OHWM locations (green-orange-blue lines) identified through visual interpretation of the FG-derived cross sections.

Visual interpretations of upstream cross section 127 (Figures 14–15) also depict geomorphic indicators of the potential OHWM at an approximate elevation (NAVD88) 1974 ft (orange) and 1979 ft (blue). Similarly, a visual interpretation of cross section 132 shows geomorphic indicators noted by dashed lines (Figures 16–17) at approximate elevations (NAVD88) 1974 ft (orange) and 1979 ft (blue). Comparing potential OHWM indicators from the FG cross-section plots suggests that there are consistent channel markers at elevation (NAVD88) 1974 ft and 1979 ft.

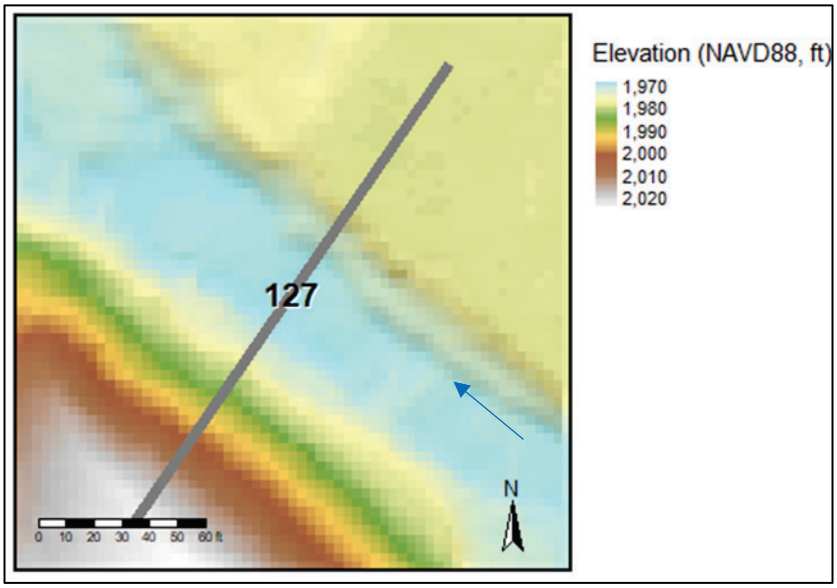

Figure 14. Plan-view map of cross section 127.

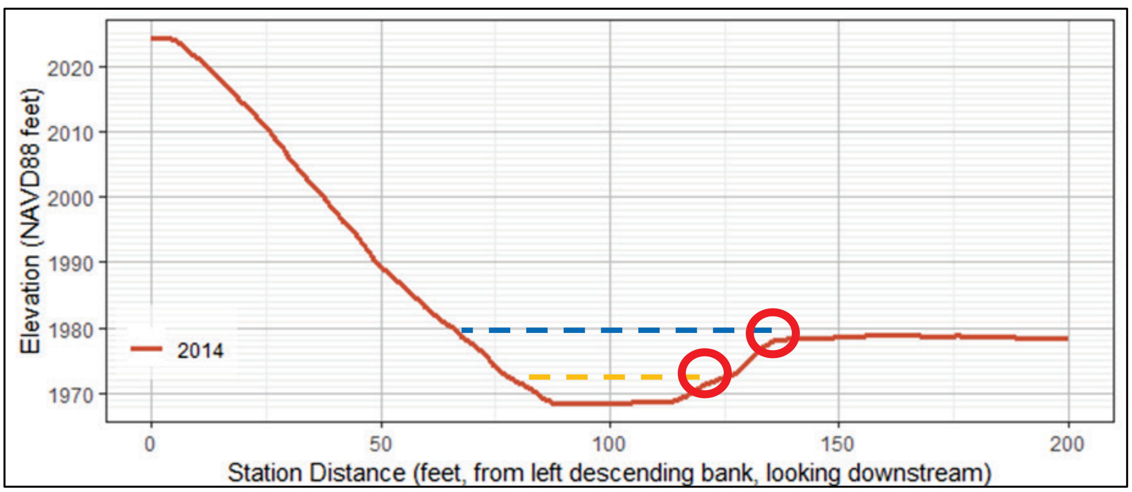

Figure 15. Cross section 127; illustrating geomorphic indicators (red circles) of potential OHWM locations (orange and blue lines) identified through visual interpretation of the FG-derived cross sections.

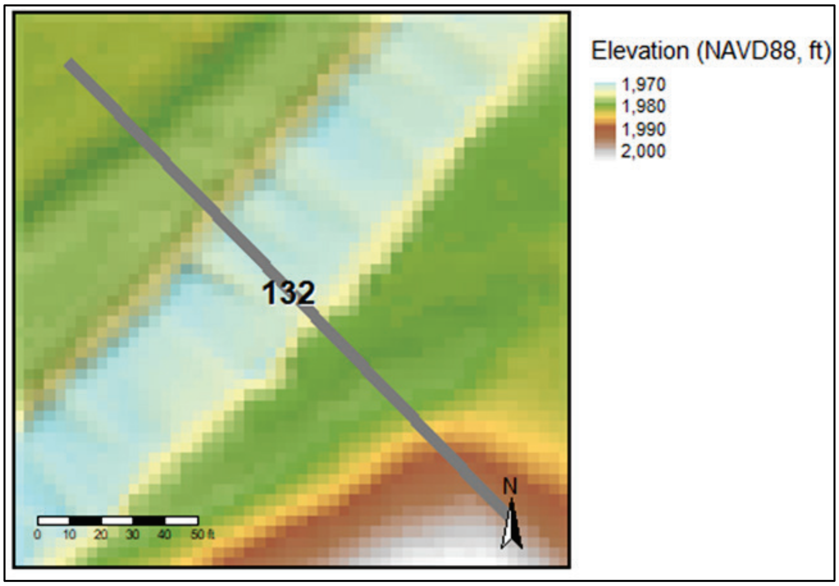

Figure 16. Plan-view map of cross section 132.

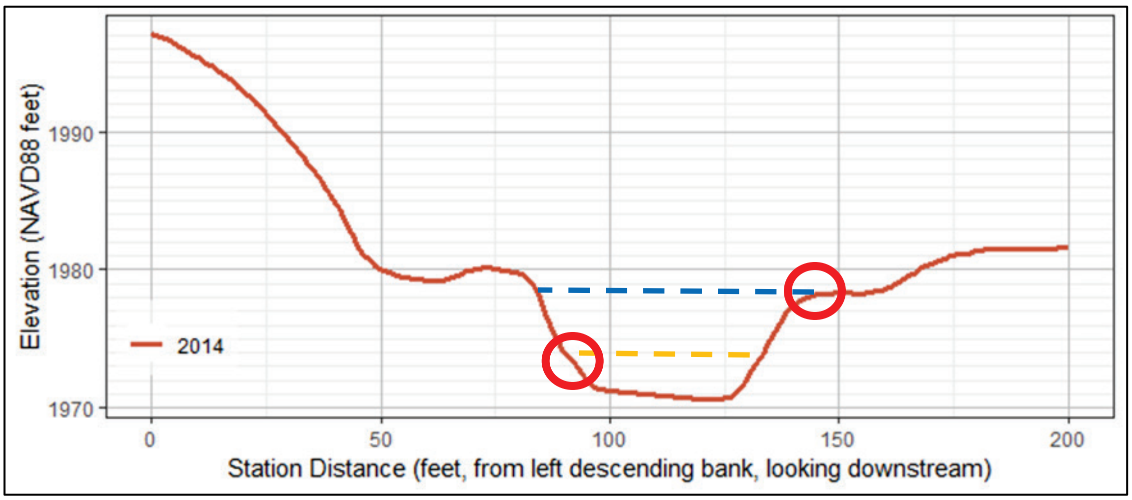

Figure 17. Cross section 132. Geomorphic indicators (red circles) of potential OHWM locations (orange-blue lines) identified through visual interpretation of the FG-derived cross sections.

SUMMARY: The four options described in this document demonstrate the ability to remotely identify channel morphology and provide a set of tools that practitioners, the public, and regulatory project managers can use to assist with OHWM identification (Table 3). As demonstrated by the Antelope Creek cross-section comparison, DEM-derived and lidar-derived cross sections can aid in the remote analysis of physical channel indicators such as breaks in slope, shelving (or floodplain-berm formations), channel bars, and can provide additional lines of evidence to support a field-delineated OHWM. Although the Google Earth Pro option provides a rapid method for investigating elevations within a DEM (Figure 4), the low resolution of the source DEM offered through Google Earth Pro greatly reduces the utility of this method in identifying the OHWM. The ArcGIS Pro option provided better results in using an existing 1 m resolution DEM (Figure 7). Potential OHWM elevations were identified based on breaks in slope along the cross section, and elevation 1972–73 was validated to the field-surveyed elevation of 1972 (Table 3). Arc-GIS provides a relatively rapid approach to determining OHWM depending largely on the availability of high-resolution DEMs (1 m). The two FG options provide higher resolution for comparisons with the field-surveyed cross sections (Figure 11) and can be easily extended upstream and downstream for additional OHWM identifications. However, FG does take more time than the other methods but provides higher resolution and greater spatial analysis extent (if needed). Both the ArcGIS Pro and FG approaches are based on the availability of appropriate high-resolution DEMs (1 m) or modifications to the DEMs (hydro-flattening).

Table 3. Comparison of the OHWM elevations derived from four methods.

<table>
<tr><th>Analysis Method</th><th>Elevations of Potential OHWM</th><th>Time to Complete Analysis (hours)</th></tr>
<tr><td>Field Survey (OHWM)</td><td>1972 (Field Validated)</td><td>Variable</td></tr>
<tr><td>Google Earth Pro</td><td>N/A</td><td>¼ (15 min)</td></tr>
<tr><td>ArcGIS Pro</td><td>1967, 1969–70, 1972–73, 1975, 1977</td><td>1</td></tr>
<tr><td>FG, Level 1</td><td rowspan="2">1967, 1972, 1974.9, 1976.5</td><td>4–8</td></tr>
<tr><td>FG, abbreviated (assuming appropriate DEMs available)</td><td>2–4</td></tr>
</table>

The scope of analysis required for the project requiring determination of an OHWM may influence the method used for the OHWM delineation. If a rapid, exploratory assessment is needed, then the Google Earth Pro option provides low-resolution viewing opportunities with minimal time but may not provide the resolution necessary for OHWM identification. If detailed information is required and there are high-resolution terrain data available (1 m), then using the ArcGIS Pro is the most rapid and efficient process for determining OHWM. However, if more detailed information on potential OHWM elevations is required, or additional geomorphic characteristics are required for other regulatory actions (e.g., stream restoration design or monitoring), then FG should be considered for providing high-resolution data, which can be utilized for both temporal and spatial analyses as well as comparing field surveyed cross sections and remotely sensed cross sections.

FUTURE TOOLS: The report provides four options to support OHWM delineations using remote sensing tools. The level of effort, time, and technical ability to identify potential OHWM elevations increases from the Google Earth Pro to the FG approach. USACE through various programs is continuing to develop additional tools in the FG platform that would automate knickpoint identification (channel bed changes) as well as identify geomorphic breaks in bank slopes within a cross section. The knickpoint identification would increase practitioners' abilities to identify and design appropriate bed and bank stabilization projects, and the bank slope tool would allow for an automated approach to identifying potential OHWM elevations. In addition, FG has the ability of comparing geomorphic survey data and regional hydraulic geometry curves to help identify OHWMs. FG should be further developed for monitoring USACE regulatory stream mitigation and restoration projects. More research and development are needed to further develop, refine, and automate additional OHWM determination approaches.

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