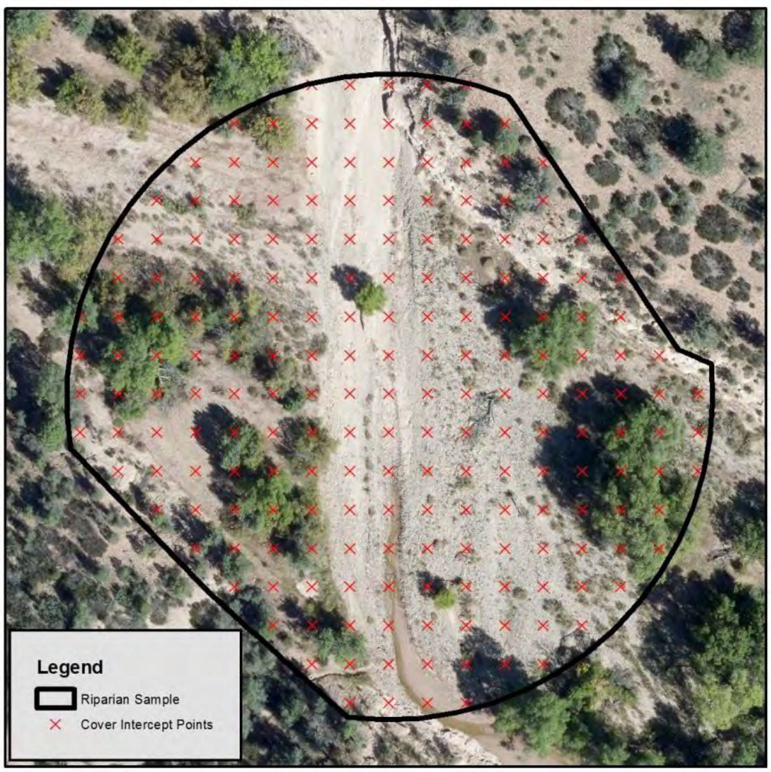
Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Southwestern Region | June 2023

Aquatic-Riparian Inventory Protocols v2.4

Technical Guide



Cover image: Sample frame for an example Aquatic-Riparian Inventory site showing the overall sample frame and the cover intercept points.

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This inventory protocol is to be used in conjunction with the USDA Forest Service R3 GIS and Photogrammetry Guide.

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CONTENTS

OVERVIEW

This document provides protocols for the R3 Aquatic-Riparian Inventory system (ARI), including the sample design, plot method, and a description of all data elements. This document is accompanied by a separate GIS Guide, which provides technical guidance and step-by-step information for applying the protocols using GIS tools in the course of a sampling session.

It is recommended that photo interpreters engage Forest/project team to calibrate photo interpretation. Ideally, photo interpreters would spend time in the field with local experts before beginning the inventory to gain familiarity with local conditions and to help calibrate 3D interpretations. For consistency in the inventory, it would be preferable to have one person with experience in determining bankfull location draw all of the bank lines for the entire project area prior to photo interpretation sampling, rather than having bank lines identified one sample at a time as originally envisioned for the method.

Article I. INTRODUCTION

Riparian and stream systems represent a small but critical part of the landscape, sensitive to climate change. Information on existing conditions in these settings is sparse, inconsistent, largely qualitative, and does not lend itself to a monitoring framework. The spatial extent of these systems has been successfully established for the USFS Southwestern Region through the Regional Riparian Mapping Project (RMAP), TEUI, University of Arizona, and the National Wetlands Inventory; however, resources within those mapped extents have not been inventoried, except by specific project areas (e.g., Muldavin et al. 2011). Additionally, most information collected for riparian areas is subjective or qualitative in nature and difficult to replicate (e.g., PFC, T-walk, pebble counts, etc.).

The ARI represents a continual inventory and monitoring program for determining resource conditions and trends. The program represents one of several corporate resources to support the Regional Strategic Plan, Forest Plan implementation, the R3 Analysis Framework, and to assess riparian and aquatic resources and core indicators formalized in the Regional Riparian-Aquatic Ecosystem Strategy (USDA Forest Service 2020). ARI originated after encountering outdated, qualitative, or missing information sufficient to assess aquatic-riparian resources on many extents during Forest Plan revision. Prior to the development of ARI, a basic set of indicators was identified from Forest Plan assessments, key references, and interviews with hydrology and fisheries specialists. ARI was structured to address these indicators and then worked out through collaboration, vetting, piloting, workshopping, and successful implementation before ARI was adopted as regional program. ARI's strengths, limitations, assumptions, and its ability to detect and characterize observed change over time are addressed in this protocol, the accompanying GIS guide, and in ARI briefings. The desired condition supplement to the Riparian-Aquatic Ecosystem Strategy has table summaries of the indicators, data sources (including ARI), scale of application, analysis methods, and references.

The following protocol represent a systematic and repeat inventory (10-year cycle) of riparian corridors and provides a riparian-stream counterpart to Forest Inventory and Analysis (FIA) for R3. The approach is less intensive than plot sampling and field inventory, with a coarser grade of information supportive of a landscape-level of analysis. The inventory system is designed to provide project teams and managers basic information on riparian resources and is structured to provide consistent and quantitative monitoring into the future. This inventory scheme is intended to provide:

- An all-lands riparian sample based on a systematic design and sample units of at least 1ha to answer important questions at multiple scales.
- A sample framework that can be intensified at mid and local scales to better sample specific map units or other strata, or specific project areas.
- An inventory of medium intensity that leverages remote sensing and high-resolution stereo aerial photography along with local expertise to rapidly generate a sample set representing riparian and stream conditions. It is not meant to take the place of field inventory and assessment.

ARI is accessible through Story Map and Dashboard. These tools are intended to be the main interface for the ARI program and with HUC10-level summaries, with a target audience of National Forest personnel, other agency and partner managers, and natural resource specialists.

Section 1.01 Aerial Photography for Aquatic-Riparian Inventory

The USDA Forest Service Region 3 riparian inventory encompasses over 35 million acres of a diverse landscape in the Southwestern Region of the United States. The riparian plots that have been identified for inventory are one hectare in size, with the exception of wide valley bottoms where belt samples are used (see following description). The plot locations are not only located within USFS boundaries, but extend into watersheds with shared ownership of federal, state, tribal, local governments and private lands. To perform a comprehensive inventory over such a large area, the USFS Regional Office (RO) determined that utilizing large scale 4-band digital aerial photography would provide the most efficient and accurate methodology for the delineation and interpretation of riparian and stream resources. This imagery is collected and photo interpreted in the UTM zone 12N or 13N depending on the forest location. Collection times for acquisitions to date are listed below (Table 1).

Table 1. Imagery acquisition dates by National Forest.

National Forest	Starting Image Acquisition Date	Ending Image Acquisition Data
Cibola	6/11/2013	10/1/2013
Prescott	9/28/2013	9/30/2013
Gila	5/24/2015	8/18/2015
Carson	8/19/2015	9/26/2015
Lincoln	8/11/2019	10/3/2019
Kaibab	8/21/2019	9/30/2019
Coronado	7/1/2021	8/30/2021
Santa Fe	7/1/2021	8/30/2021
Tonto	6/3/2022	6/6/2022
Coconino	10/15/2022	10/20/2022

The base imagery was contracted through the R3 GIS/Photogrammetry staff and acquired during leaf-on seasons prior to inventory. This imagery utilized a Digital Mapping Camera system mounted on a fixed wing aircraft. There are many advantages of using aerial photography to support riparian inventory.

- High-resolution stereo imagery at 5-9cm Ground Sample Distance (GSD) resolution provides accurate details of the inventory plot.
- A base line image of existing ground conditions of the plot that can be viewed in 3D which assists in determining both size and relative scale of vegetation.
- Remote access to inventory plots that are located in hard-to-reach locations and/or that are under other ownership.
- The high-resolution digital stereo photography collects 4 bands of the light spectrum including infrared, red, green, and blue. The high-resolution digital stereo photography is 16 Bit per channel which supports manipulation of the imagery to view features in dark/shadow areas.

Article II. RELATIONSHIP OF ARI TO OTHER DATA SOURCES

Section 2.01 Regional Riparian Mapping Project (RMAP)

The Regional Riparian Mapping Project (RMAP) included riparian extents throughout Forest Service lands of the Southwestern Region as well as intersecting 5th-level watersheds. This undertaking focused primarily on identifying and mapping the *extent* of riparian corridors and identifying major riparian vegetation types or Ecological Response Units (USDA Forest Service 2023). Embedded in RMAP is all available Terrestrial Ecological Unit Inventory (TEUI) mapping and classification at the time of mapping (2012), while TEUI subseries classification formed the basis for most of the RMAP units. As a potential vegetation theme RMAP was not designed or intended to characterize *current* riparian or stream conditions *within* those mapped extents; rather, RMAP provides the spatial and thematic framework for follow-on work including ARI, Riparian Existing Vegetation (REV), Earth Sense Technology (EST) evaluation, field methods, and the subsequent ecological assessments and effects analyses that these information sources collectively support. A full description of RMAP is available in the project report (Triepke et al. 2018) and the map data are now integrated into ERU mapping and available from the R3 GIS Library:

www.fs.usda.gov/detailfull/r3/landmanagement/gis/?cid=stelprdb5201889&width=full

Section 2.02 Riparian Existing Vegetation Mapping (REV)

Existing vegetation mapping provides basic information on the current condition of structure and composition in riparian ecosystems. This mapping was completed through the REV project with GTACT (e.g., Clark et al. 2018) for all National Forests and Grasslands of the Southwestern Region. Like ARI, the extent of REV is coincident with RMAP but REV was limited to Forest Service lands only due to the extent of supporting information including resource photography, LiDAR, and TEUI plot data. REV mapping and project reports can be downloaded from the R3 GIS Library: www.fs.usda.gov/detailfull/r3/landmanagement/gis/?cid=stelprdb5201889&width=full

Section 2.03 Proper Functioning Condition Assessments (PFC)

The assessment of riparian Proper Functioning Condition is a standard methodology employed by land managers throughout the United States as a means for qualitatively assessing functional condition (Prichard et al. 1998). The methodology is well documented and has been employed throughout the Southwestern Region for rapid, site specific assessments using qualitative means for categorizing function using an interdisciplinary team. While the methodology provides a meaningful first assessment of overall riparian system function, it is not typically applied in a geographically systematic fashion. Furthermore, it relies heavily on the subjective, qualitative determinations of interdisciplinary teams. The Regional Aquatic-Riparian Inventory program does not aim to replace the PFC methodology; instead, it strives to complement PFC and consider overall riparian conditions across multiple scales. Further, the Regional Riparian Inventory is intended to provide quantitative metrics of riparian conditions that can be used both for assessment purposes as well as serve as a baseline for repeatable monitoring.

Section 2.04 Integration of Aquatic-Riparian Information Sources

Information sources for riparian and aquatic systems can be integrated for project support as an optimization of needs, available data, and available resources to collect data. Table 2 below captures some initial perspectives on how ARI and REV can be combined with field-based protocols such as Proper Functioning Condition (PFC) (Prichard et al. 1998) for a given set of assessments or indicators. On one end of the spectrum, REV is an affordable and comprehensive data source but is only useful for a small number of indicators. On the other end of the spectrum, field approaches collect information of high thematic detail, including for indicators that can only be assessed in the field, but are relatively expensive and often limited to specific reaches and project areas. ARI is a relatively affordable sample-based approach that provides for a moderate number of indicators within the limits of remote sensing. Table 2 shows how remote sensing resources can be integrated with field-based approaches to 1) accommodate a full set of indicators (structure, composition, process, connectivity), 2) optimize remote sensing and field-based solutions, 3) make the best use of limited resources for field work, and 4) provide a means of cross-validation among data sources for some indicators.

Table 2. Ability of riparian products to provide ecological indicators.

Example List of Indicators	Riparian Existing Vegetation Mapping (REV)	Aquatic-Riparian Inventory (ARI)	Field Sampling (e.g., PFC, MiM, NMRAM)
Plant functional group diversity	√		√
Riparian distribution, abundance	√		
Seral state proportion	√		
Recruitment of woody vegetation	√	√	
Stream cover of vegetation		√	
Stream bank features, stability		√	
Stream incision		√	
Stream channel type		√	
Stream sediment balance		√	
Stream sinuosity		√	
Stream substrate		√ ?	√
Channel form, embeddedness		√ ?	√
Native species (presence/absence)			√
Invasive species presence/absence)			√
Macroinvertebrate diversity			√

Article III. SAMPLE METHODOLOGY

The sampling protocols are intended to guide vegetation specialists and photo interpreters through the inventory process. The sample design is broken into three distinct sections: 1) Sample Design, 2) Sample Unit, and 3) Sampling Protocols. The sample design has been applied to the Southwestern Region and intersected watersheds to generate a sampling framework and inventory protocol given in the descriptions below.

Section 3.01 Sample Design

A fundamental challenge to applying systematic sampling to riparian features is the unique spatial distribution of riparian features on a landscape. As nearly all riparian features in the Southwestern Region follow drainage networks making their spatial distribution not equal between and among watersheds. As a result, the gridded sampling approach akin to FIA was tested and rejected for the following reasons:

1. A grid sample would proportionally sample systems based on area or acreage; however, this approach discounts the linear nature of riparian systems and inherently discounts narrow systems.
2. Because riparian features are confined in space by both climate factors and geomorphology (specifically valley width and form) they are not spatially arranged in a uniform pattern.
3. Valley width and confinement, as well as location in a watershed determine potential energy (flow) in a given hydrologic system. As a result, some riparian systems are more commonly found in narrower systems while others are more commonly found in wider systems.
4. Stream features, as those included with this inventory approach, are features of strictly linear systems, with no bearing on the associated amount of riparian.

As a result, a linear sample design was selected which largely ignored feature width, relying instead on linear length to select samples. In other words, a length of riparian along a narrow, confined valley was equally likely to be sampled as a length of riparian along a wide valley floodplain. There are tradeoffs to this approach, as with any sample design, but it is believed that this approach is more accurate at sampling the non-uniform, primarily linear features that comprise riparian systems.

As previously discussed, this inventory is bounded by area mapped in the RMAP. Because the RMAP spatially delineated polygons, it was necessary to spatially assign centerlines to each polygon feature – an elemental component of the sample design. Initial testing indicated that using hydrography data was inadequate to this task, as its spatial resolution, accuracy, sinuosityi within a feature, and braided nature created unsurmountable problems. As a result, a process for generating feature centerlines using ESRI ArcGIS© software was developed. A full discussion of the issues encountered with hydrography data, and the delineation of riparian feature centerlines is provided in Appendix A.

Using the created centerline features, potential sample center points were generated systematically every 400m along the linear feature. In this design, 400m represents the maximum sample intensity, while 25,600m intervals represent the minimum intensity; that is, the maximum sample densification. This level of sample intensity satisfied a secondary target of at least 10 samples per RMAP units *for most RMAP units*. However, for RMAP units that did not receive at least 10 samples per Forest, the sampling was intensified accordingly. This process resulted in an initial sample number of 280 across the two pilot Forests.

Section 3.02 Sample Unit

Sample units for cover values, bank features, and some stream features were created using Esri Model Builder and are represented in inventory sample frames (Figure 1). For some stream features, such as stream braiding, the sample unit is multiple stream reaches intersected by the sample frame.

For riparian sample frames, individual sample frames were developed so that the spatial geometry of the frame approximated 1ha (Figure 1) using the following process:

- For samples in riparian zones < 112 m across:
    - Multiple circular buffers were generated for each sample center point (using Multiple

Ring Buffer tool) representing 1m radius increments from 56-288m based on a malleable 1ha sample frame that balloons to full extent under the constraints of a narrowing riparian corridor.
    - These buffers were clipped to RMAP boundaries and area calculated (multi-part features were *exploded*, an Esri editing function to make polygons separate from one another).
    - The buffer distance that provided a sample footprint closest to 1ha was selected for each sample center.
- For samples in reaches > 112 m across:
    - Lines perpendicular to RMAP centerlines were generated and length calculated. Lines were buffered into belts using the following formula to determine buffer distance = 10,000/Line Length*0.5. This resulted in sample frames that closely approximate 1ha each.
    - A minimum sample width of 40 m was applied in wide valley settings where 1 ha samples would result in a very long, thin sample. In these cases, the samples are larger than 1 ha, and their area varies.

The following filters were then applied:

- Samples with >75% of their footprint in "Historic" RMAP types (400, 410, 420) were flagged for No- Flight. These samples will be addressed through existing imagery and data, but not flown for high-resolution photography.
- Samples with 100% of their footprint in "Herbaceous" RMAP types (190) were flagged for No-Flight. These samples will be addressed through existing imagery and data, but not flown for high-resolution photography.
- Adjustment for overlapping sample frames: Any sample that overlapped in any part of another sample was flagged as duplicate. "Keep" samples from each pair were identified randomly.

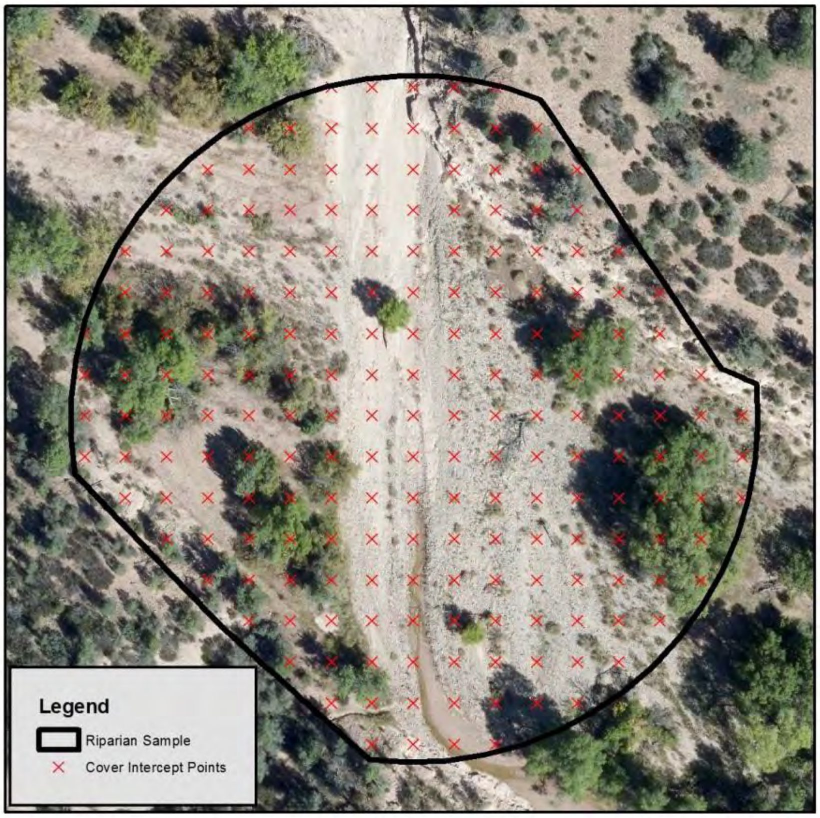

Figure 1: Example of a point-intersect sample grid within one sample frame.

Section 3.03 Sampling Protocols

The following sampling protocols were designed to accommodate in-office sampling using Intergraph Stereo Analyst for ArcGIS alongside RSAC extensions and other tools. Interpreters will need high-resolution aerial photography, ancillary data such as NAIP, and a workstation configured for stereo viewing. **The sampling protocols are broken into four sections – 1. Cover Values, 2. Bank Features, 3. Stream Features, 4. Derived Features**. The GIS Guide contains all sample data elements and their corresponding field IDs from the sample database.

1. Cover Values

Sample unit: Individual riparian sample unit (e.g., black outlined polygon in Figure 1)

Cover values for all data elements in tables 3 and 4 are determined through aerial photo interpretation using point-intersect grids of systematically placed points within the sample unit, each sample being approximately 1 ha in size. A high-resolution Digital Terrain Model (DTM) is required when generating the cover values sample points and a DTM is created for each sample plot. A bare earth model was generated from LiDAR data for the Cibola and Prescott ARI, while 0.3 m Phodar-based digital surface models were created for the remaining Forests. Interpreted cover values for vegetation and other riparian-stream features refer to their measure of aerial extent. Aerial extent is the vertical projection (overhead view) of the amount of surface covered by a feature such as tree canopy, as if polygons were traced around the periphery of the foliage (Figure 2).

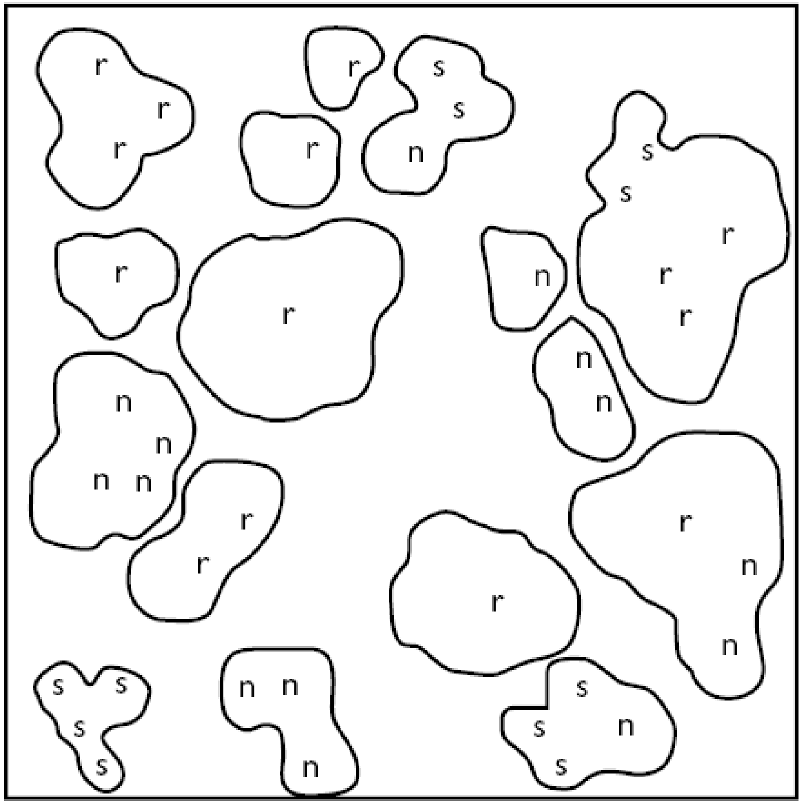

Figure 2: Estimating aerial extent according to canopy outline (USDI Bureau of Land Management 1998). The figure shows several hypothetical plant components (n, r, s) and the outlines drawn around each canopy for estimating aerial extent.

Table 3: Cover class values.

Domain Code	Value
0	Not Assigned (NA)
1	Shrub-Tree (including cacti) (ST)
2	Herbaceous (H)
3	Snag (standing and > 7cm of Dead Vegetation) (SN)
4	Active Channel (AC)
5	Non-Vegetated (NV)
	Unknown (U)

Table 4. Cover subclass values.

Domain Code	Value
0	NA Not Assigned
1	ST Not Assigned
1.1	ST Deciduous
1.2	ST Evergreen (including cacti)
1.3	ST Exotic
1.4	ST Agriculture
1.5	ST Unknown
2	H Not Assigned
2.1	H Natural/Semi-Natural
2.2	H Urban/Residential
2.3	H Agriculture
2.4	H Unknown
3	SN Snag
4	AC Not Assigned
4.1	AC Water
4.2	AC Boulder (60 to 205 cm)
4.3	AC Stone (25 to 60 cm)
4.4	AC Cobble (7 to 25 cm)
4.5	AC Gravel, Fines, Litter (< 7 cm)
4.6	AC Coarse Woody Debris (> 7 cm)
4.7	AC Vegetation
4.8	AC Unknown
4.9	AC Bedrock (> 205 cm)
5	NV Not Assigned
5.1	NV Water
5.2	NV Rock
5.3	NV Soil, Litter, Gravel (< 7 cm)
5.4	NV Coarse Woody Debris (> 7 cm)
5.5	NV Built Structure, Human Other
5.6	NV Improved Road (paved)
5.7	NV Unimproved Road (unpaved)
5.8	NV Unknown
6	U Not Assigned
6.1	U Shadow
6.2	U Other

As a rule of thumb when discerning 'non-vegetated' vs 'herb', the burden of proof is on 'non-vegetated', in that it will not take much vegetation cover to reach the threshold of 10% cover for 'herbaceous', particularly in temperate riparian settings. For an assignment of 'non-vegetated' there should be obvious inferences of tone/color (e.g., rock, pavement), fluvial patterns on and around the sample point, signs of erosion on and around the point, etc.

Point-intersect grids consist of 200[1] or more sample points[2] prior to sampling. Figure 1 shows an example riparian sample frame with a point-intersect grid overlaid. Each sample point will be evaluated for class and subclass values in tables 3 and 4, following steps in the USDA USFS Region 3 Regional Riparian Inventory GIS Guide. Each subclass field is associated with a specific class field. Calls for class and subclass are made according to the feature from tables 3 and 4 that intersects the sample point. For the Cibola-Prescott inventory pilot, Photo Science will use auto-extraction and other automated processes to help generate default values for some data elements.

(a) Vegetation Height (legacy attribute)

While early ARI work included tree-shrub height measurements in the inventory of cover features (e.g., Cibola and Prescott NFs), vegetation height values are instead provided on all Forests through Riparian Existing Vegetation mapping (REV) (e.g., Clark et al 2018). ARI no longer includes plant height measurements.

Quality standard:
If 90% of the measured shrub-tree points fall within the correct height class, where height classes are <0.5m, 0.5-4.9m, 5-11.9m, and >12m. Subclasses are not subject to audit.

(b) Land Use Status

The Land Use Status is a type of activity being carried out on a unit of land. These are typically defined as broad land-use categories. For the Riparian Inventory, Land Use Status is derived from the COVER_CLASS sampling. It is an estimate of the percent of sample frame in each of the following categories:

a) Natural/Semi-Natural
b) Agriculture
c) Urban/Developed
d) Water
e) Unknown

NOTE: Some riparian samples will not be located within a specific National Forest but on another bordering National Forest or other ownership. Ownership location of the sample center is recorded

[1] Beta testing indicated that 200 point samples were effective in reliably estimating cover values for common riparian features, and that additional samples (e.g., 400 samples) did not significantly improve cover estimates. Testing also demonstrated that systematic random point samples returned comparable results to randomized samples, though systematic gridding was selected to ensure an equal sample distribution throughout the sample polygon.

[2] Because of the unique spatial geometry of the riparian sample features, some sample features will receive slightly more or less than 200 sample points.

in FOREST_NUMBER attribute in the main polygon feature class by assigning the appropriate code for each sample (Table 5).

Table 5. National Forest identification number.

Code	National Forest
-1	Non-USFS
1	Apache-Sitgreaves
2	Carson
3	Cibola
4	Coconino
5	Coronado
6	Gila
7	Kaibab
8	Lincoln
9	Prescott
10	Santa Fe
12	Tonto
99	Other NFS areas

2. Bank Features

Sample unit (for all bank features): Individual riparian sample frames (example Figure 1)

In sample units (polygons) where bank features are not evident, (e.g., some dry alluvial washes), or completely obscured (e.g., shadow, overhanging vegetation), no bank feature sampling will occur and will be noted accordingly – Domain code of 0 (see following description).

Where bank features are evident, the inventory of bank features will occur along the bank lines previously delineated by an interpreter within the sample unit according to procedures in the GIS Guide. Bank lines are delineated at the channel's bankfull[ii] lines on the right and left banks (Figure 3), defined by Dunne and Leopold (1978) as "correspond[ing with] the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics." Bankfull indicators for determining bank lines include (Muldavin et al. 2011):

- Changes in bank slope, such as from a steep bank to a more gentle slope or a change from a vertical bank to a flat floodplain;
- Changes in sediment texture of deposited material such as transitions from clay to sand, sand to gravel, or boulders to gravel;
- Vegetation limits or changes in vegetation;
- Consistent alluvial depositional features, such as flood-deposited;
- Scour lines;
- Elevation of point bars and other floodplain features.

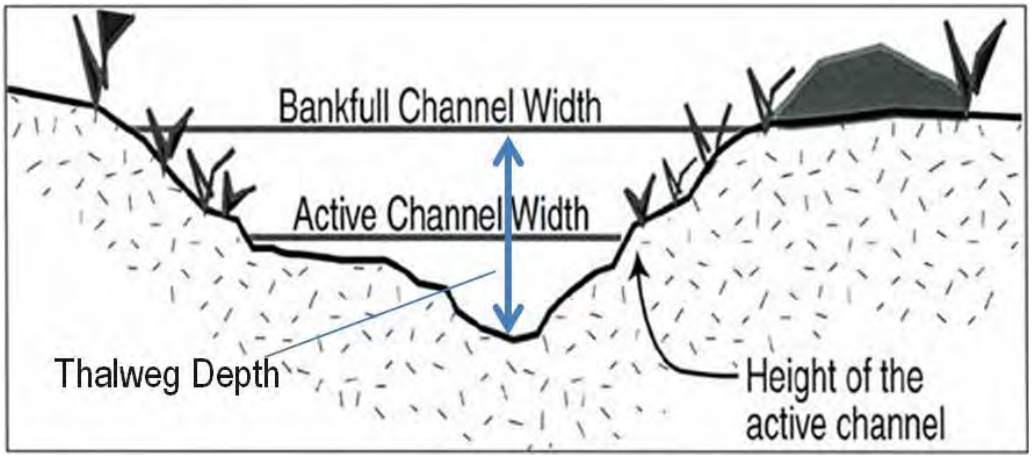

Figure 3: Cross section of a conceptual stream channel, showing the relative elevation of the active channel width and the bankfull channel width (adapted from Taylor and Love 2003).

At least four conditions exist where the inventory protocols are challenged by the complexity in stream pattern:

1. Stream confluence – Where inventory samples fall on the confluence of two streams, inventory and bank line delineation occur only on the longer stream channel. The longer channel is often also wider. Use NAIP imagery and/or the 'stream arcs/routes' shapefiles from the National Hydrography Dataset (NHD): https://www.usgs.gov/national-hydrography
2. Multiple channels – In cases where the stream has multiple channel forms, as with a channel splitting and flowing around a bedrock island, inventory and bank line delineation occur only on the main/larger channel.
3. Braided channel – A braided channel consists of a network of small water courses separated by temporary bar deposits (braid bars). Braided streams occur in areas of high gradient or large sediment load and are characteristic of mountainous and desert regions. Where streams are braided the inventory and bank line delineation take place only at the banks at the outermost extent of the stream channel (Figure 4).

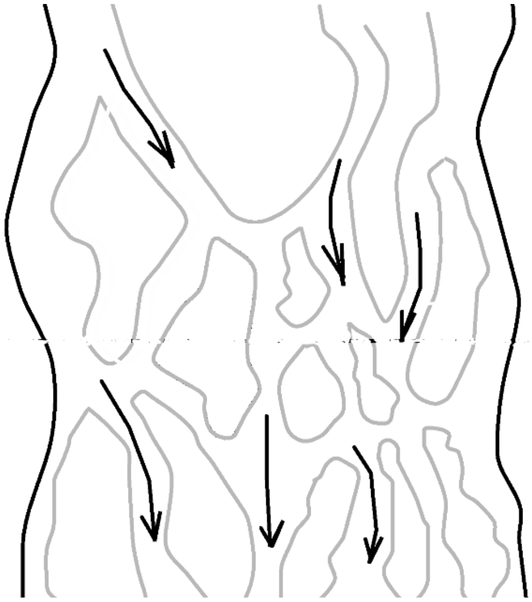

Figure 4: Where streams are braided bank features are inventoried only at the outer banks of the channel profile (outer dark lines).

4. At the interface between streams (lotic) and lakes or ponds (lentic), bank lines will be drawn to capture only stream conditions. High-resolution imagery can allow the interpreter to determine where sediment loading is occurring at the mouth or inlet of a stream as it begins to mix with adjoining lentic features. Using these cues, bank lines will be drawn where sediment loading is most noticeable; that is, before the mixed zone to best capture the lotic system (see Figure 5).

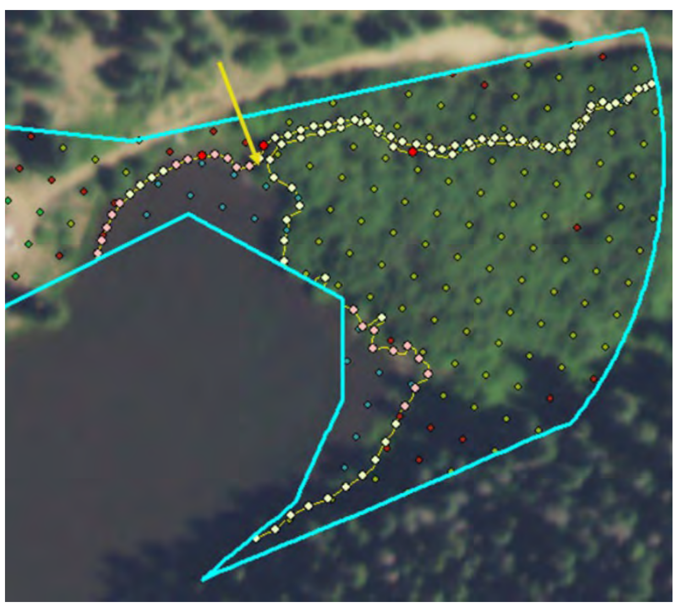

Figure 5: Lentic-lotic interface showing where bank lines will stop (arrow).

Where bank features are obscured by overhanging vegetation, inferences must be used to determined bank location. Several examples of bankfull width determinations are given on the following pages, figures 6 to 17.

Figure 6. Example of bankfull width with a wider meandering channel.

Figure 7. Example of bankfull width in a small channel with overhanging vegetation.


Figure 8. Example of bankfull width with low relief and short riparian vegetation.


Figure 9. Example of bankfull width with banks of differing slopes.

Figure 10. Example of bankfull width with overhanging vegetation and steeper bank slopes.

Figure 11. Example of bankfull width in a canyon setting with riparian vegetation.

Figure 12. Example of bankfull width in an incised stream channel.


Figure 13. To help determine bankfull look for changes in vegetation type and cover.

The following figures, 14 through 17, are taken from Moody et al. (2003)

Figure 14. Whiskey Creek in the Chuska Mountains. Bankfull stage lies as the slope break along the well vegetated point bar on the inside of the meander. On the outside of the meander bankfull lies at the lower charge in slope rather than at the top of bank.

Figure 15. Black Creek at Ft. Defiance. Bankfull stage lies along the change in slope on the point bar along the far bank and along a similar slope change on the near bank. The broad flat feature on right colorized lies 1 ft. above bankfull.

Figure 16. Chilchinbito Wash. Straight channels do not form obvious point bars. However, there are numerous depositional levels along the channel. Bankfull stage lies at a consistent slope break along the base of the tamarisk bushes.

Figure 17. Moenave Wash. Bankfull stage lies along the change in slope on the point bar on the far shore.

(a) Bank Line Confidence

Once bank sample points have been generated, a confidence rating is given for the bank line development (see table 6 below). Record the interpreter's confidence in identifying and drawing the bank line. If the Category Description is coded "Not Assigned", the sample site may be obscured due to heavy vegetation, or occur in a narrow, deep canyon, etc.

Measure: Categorical, qualitative

Table 6. Bank line confidence values.

Domaine Code	Description	Confidence Descriptions
HC	High Confidence	Bank lines not obscured and easy to detect. Indicators listed in protocol are visible (changes in bank slope, change sin sediment texture of deposited material (e.g., clay to sand, sand to gravel, boulders to gravel), vegetation limits/changes in vegetation, consistent alluvial depositional features, scour lines, elevation of point bars). If obscured, they are still obvious bank lines due to streambed/river, as shown in image below. More than 75% of the stream is confidently delineated.
MC	Moderate Confidence	Middle ground between the two categories above: some parts are inferred, but 35-75% of the stream is confidently delineated.
LC	Low Confidence	Streambed partly obscured by trees or shadow on both sides or hard to see, location is mostly inferred and not especially accurate. Less than 35% of the stream is confidently delineated.
NE	Bank Features not Evident	No confidence category assigned since bank features not evident.
NA	Not Assigned	Bank features may be evident, but confidence category not yet assigned.

Once the bank lines are generated, 50 points are automatically populated along left and right bank lines to serve as sample points for the bank features in tables 7 and 8. At each sample point, bank feature values are assigned the class and subclass values in tables 7 and 8 following steps in the GIS Guide. Each subclass field is associated with a specific class field. **No vegetation height values are required for any of the bank features.**

Table 7. Data elements for bank features. All features are measured in percent aerial extent based on point-intersect sampling.

Domain Code	Value
0	Not Assigned (NA)
1	Vegetated Intercept (herbaceous and low shrub <0.5m in height) (VI)
2	Armored Intercept (AI)
3	Bare Bank Intercept (BBI)
4	Obscured Intercept (OI)

Table 8. Data values for bank feature cover subclass values.

Domain Code	Value
0	NA Not Assigned
1.0	VI Not Assigned
1.1	VI Vegetated Intercept (herbaceous, low shrub <0.5m)
2.0	AI Not Assigned
2.1	AI Rock
2.2	AI Coarse Woody Debris (>7cm)
2.3	AI Structure, Human
2.4	AI Other
2.5	AI Unknown
3.0	BBI Not Assigned
3.1	BBI Stable (no evidence of bank erosion)
3.2	BBI Active Erosion (<50% of bank is stable, moderate to heavy erosion)
3.3	BBI Recovering (>50% of bank is stable, some erosion present but usually associated with high flows)
3.4	BBI Unknown
3.5	BBI Active Aggradation
4.0	OI Not Assigned
4.1	OI Vegetation (>0.5m in height)
4.2	OI Overhanging Rock
4.3	OI Overhanging Snag
4.4	OI Human Structure
4.5	OI Other (including shadow)

The bank line may be located over water in some cases, for example when a large amount of rain occurred prior to recording the aerial imagery and collected in a pool (Figure 18). If a bank line point requiring classification is located over water, the analyst should round to the nearest feature. The image below illustrates this case and highlights the bank point over water with a red box. In 3D stereo mode it is visible that the nearest feature is a bare bank intercept, hence the point is classified as such (and not as ‘water’).

Figure 18: Moenave Wash. Bankfull stage lies along the change in slope on the point bar on the far shore.

Figure 19: Example of the difference in bank feature values for 'vegetated intercept' of vegetation <0.5m growing directly at bankfull width and ‘obscured intercept - overhanging vegetation' (>0.5m) of vegetation overhanging the bank.

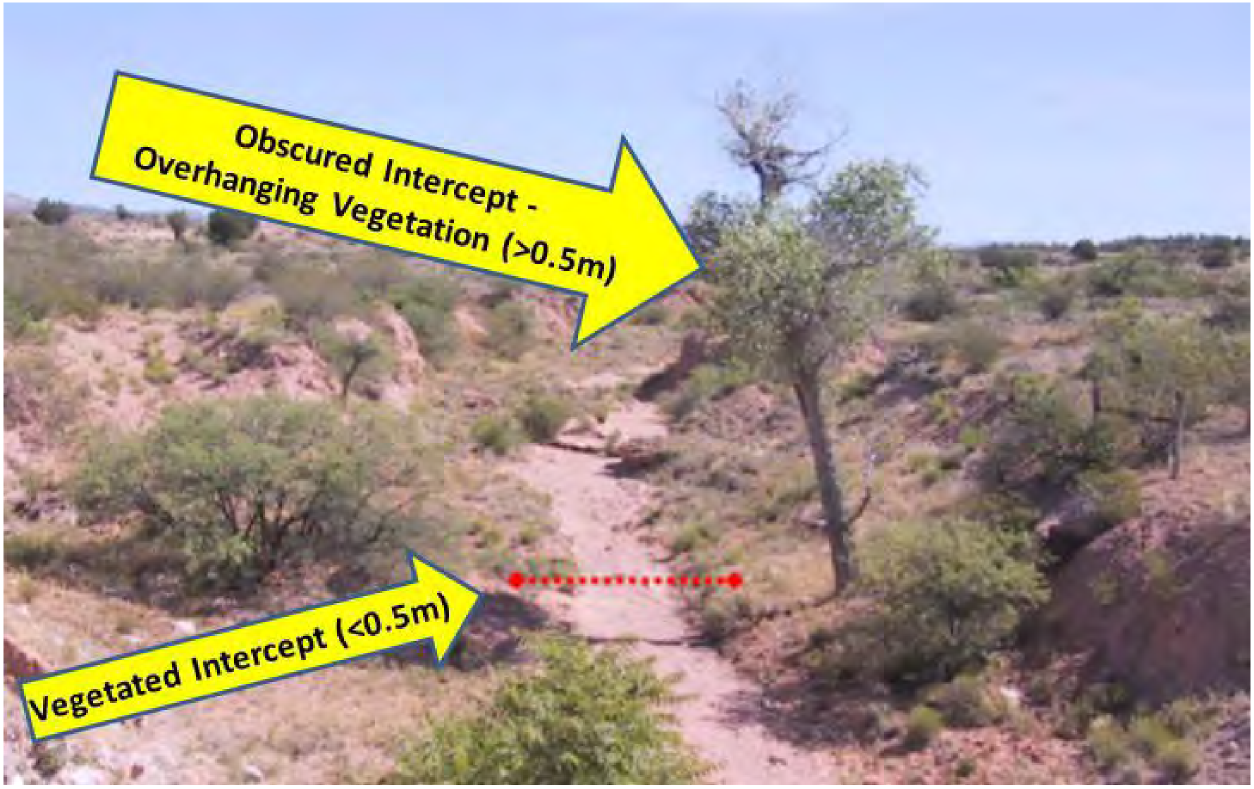

Figure 20: Example of the difference in bank feature values for 'vegetated intercept' of vegetation <0.5m growing directly at bankfull width and 'obscured intercept - overhanging vegetation' (>0.5m) of vegetation overhanging the bank.

(b) Evidence of Incision

Assign incision by making an assessment at each sample point of the bank line and not the site, overall (Prichard et al. 1998, Schumm et al. 1984). Reaches with intensive land use history and associated geomorphological processes have resulted in incised stream conditions on many extents in the region. Downcutting of a stream channel leads to a decrease in the channel bed elevation. Incision is often caused by a decrease in sediment supply and/or an increase in sediment transport capacity (figures 22 to 24). A drop in the bed elevation can cause headcutting that produces incision upstream and aggradation downstream. Useful inferences in heads-up interpretation include sharp and steep bank features and linear shadows (see photo below), straight and concentrated channel features within wider valley bottoms (not confined by topography or bedrock) and exposed and often unvegetated areas that occur just above bankfull. Incised conditions can be particularly difficult to detect where stream incision has grown over with vegetation on dewatered reaches.

Figure 21: Bank incision on an intermittent reach of the Lincoln NF in south-central New Mexico. The black arrow indicates a length of sharp and steep bank features and linear shadows as evidence of incision. Use red and green 3D glasses to see in 3D.

Measure: Categorical, qualitative.

Table 9. Channel incision data values.

Domain Code	Category
AG	Actively Aggrading
AI	Actively Incising (headcut)
IS	Incised, Stable/Recovering
NA	Not Assigned
NO	No Incision Evident
OB	Obscured
UN	Unknown

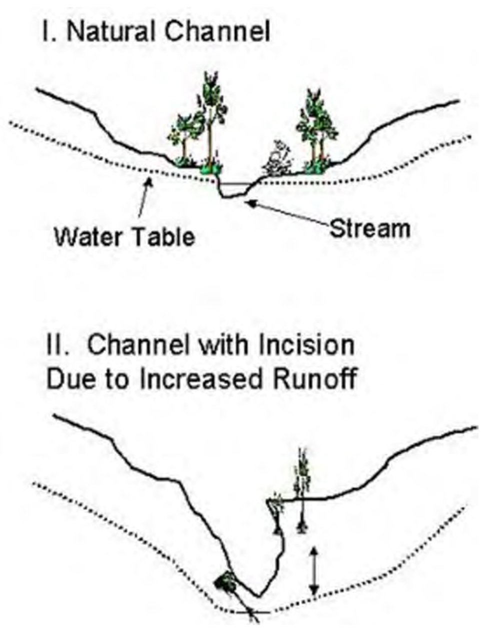

Figure 22. Diagram of water table and vegetation changes in (I) natural and (II) incised channel scenarios.

Figure 23: An incised channel, meaning a channel with no access to its floodplain (from Zeedyk and Clothier (2009)).

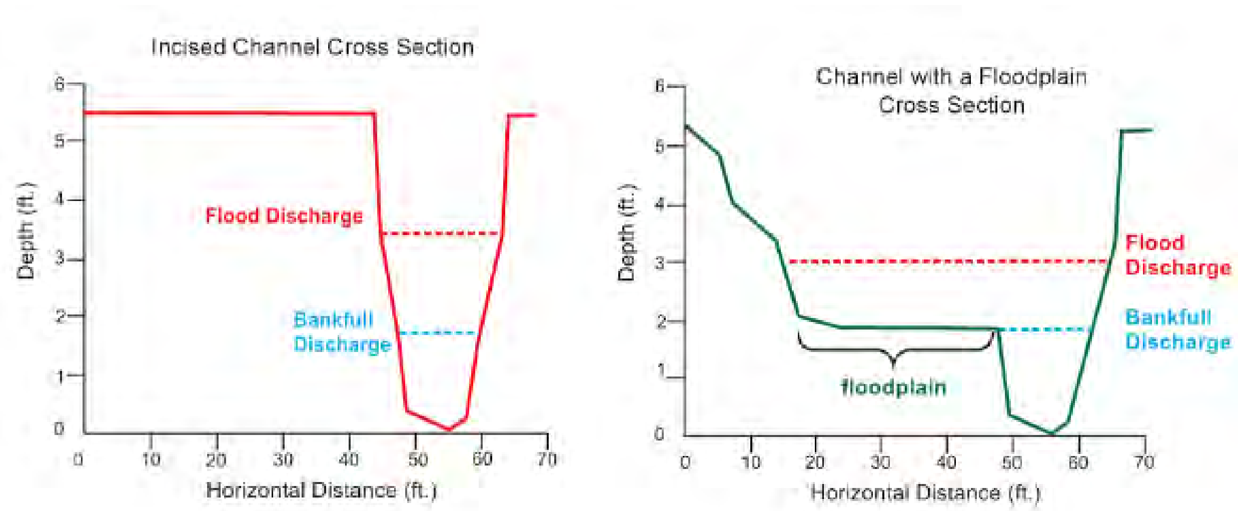

Figure 24: Comparison of cross sections for an incised channel (left) and a channel with a flood plain (right).

3. Stream Features

The following stream features were identified as critical for the riparian inventory. Descriptions are provided for both manual and automated inventory solutions. The GIS Guide provides step-by-step instructions.

(a) Stream Length

Attribute: STREAM_CHANNEL

Sample unit: Length of stream that includes at least two meanders, centered over the 1ha sample frame. This measurement may extend beyond borders of the sample frame and is the same sample unit used to measure valley bottom length and elevation change.

Measure: Meters

Stream length is measured manually and is used to determine sinuosity, a derived feature from the combination of valley bottom length and stream length. Sinuosity describes how the stream has adjusted its slope in relation to the slope of its valley and is quantitatively described as the ratio of stream length to valley bottom length (USFWS 2013). The stream and valley bottom lengths are measured from two common points in a direction parallel with the fall line of the valley (Figure 25). The stream length is measured along a vector representing the center of the active channel across same extent used for determining valley bottom length. See the GIS Guide for instructions on how to digitize the stream length in 3D for the STREAM_CHANNEL line feature class.

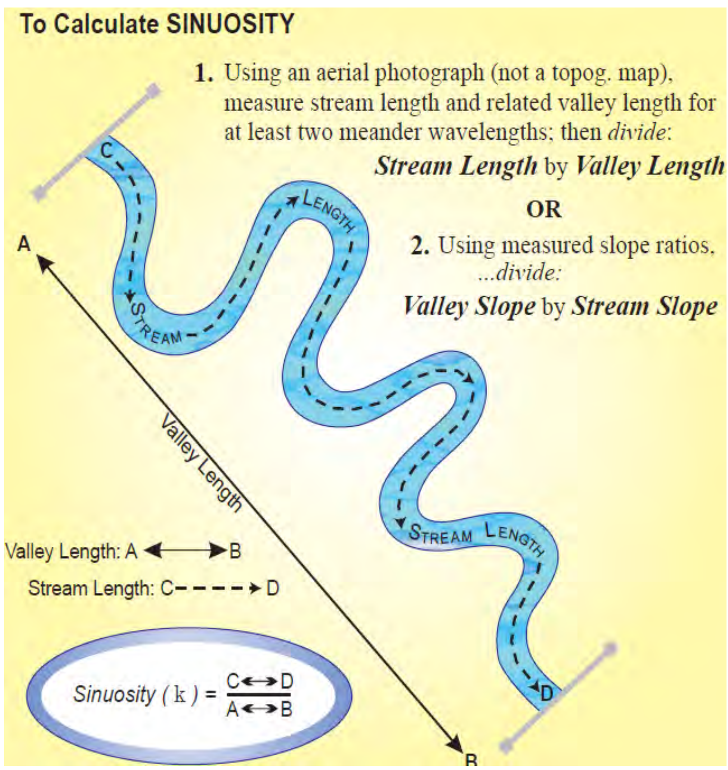

Figure 25. Diagram of how to calculate sinuosity.

(b) Valley Bottom Length (legacy attribute)

Valley bottom length was previously measured to calculate sinuosity but, as of April 2021, is no longer needed as a separate interpretation. If needed, valley bottom length can be determined from sinuosity and stream length values.

(c) Elevation Change

Sample unit: Length of stream that includes at least two meanders, centered over the 1ha sample frame. The sample unit for this element is one and the same with valley bottom length and stream length and differs from the sample frame used for all other data elements.

Measure: Meters

Elevation Change is measured automatically through R script and is used in conjunction with Valley Bottom Length to determine Stream Gradient (see Derived Features). Figure 25 and the previous description for Stream Length are used to help identify the appropriate sample unit. Stream gradient is computed as a derived feature based on Elevation Change over Valley Bottom Length (rise/run).

(d) Stream Braiding (only for samples with recognizable bank features)

Sample unit: Length of stream that includes at least two meanders, centered over the 1ha sample frame

Measure: Categorical, qualitative

Attribute: RIPARIAN_SITES: STREAM_BRAID

If bank features have been identified, the type of stream braid must be noted for the sample unit. Determine if the stream within the sample reaches is a single-thread channel or has multiple channels (Figure 26), recorded as SINGLE or MULTI.

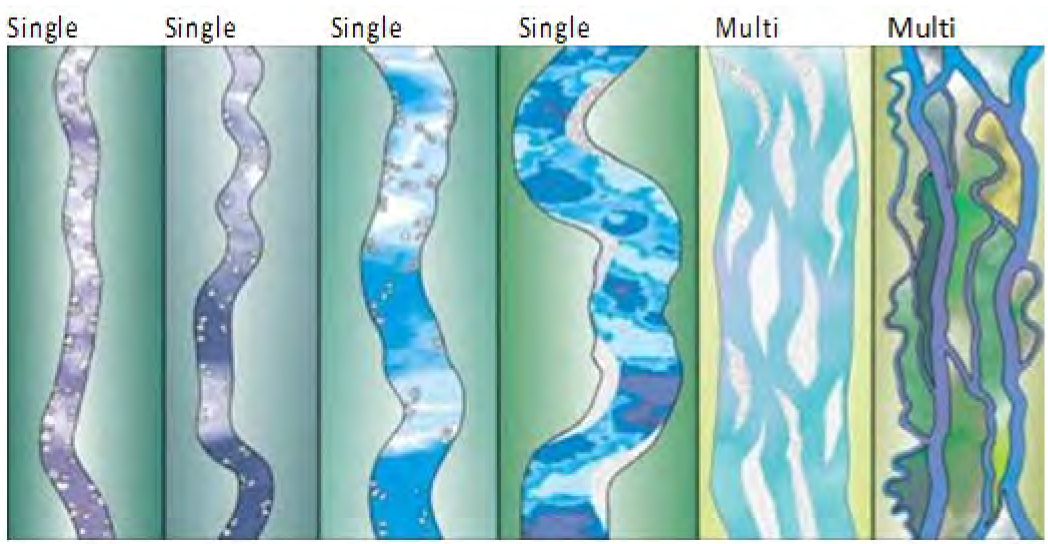

Figure 26: Conceptual diagrams and multiple-channel streams (adapted from Rosgen 1996).

(e) Bankfull Width (only for samples with recognizable bank features)

Sample unit: Individual riparian sample unit

Measure: Meters

Attribute: RIPARIAN_SITES: BF_WIDTH

Manual: Using the measure tool in ArcGIS, record the average bankfull width by taking width measurements at several points between the digitized bank polyline features, and manually computing the average of these measurements.

(f) Thalweg[iii] Depth Below Bankfull (only for dry systems and samples with recognizable bank features)

Sample unit: Individual riparian sample unit

Measure: Meters to the nearest tenth

Attribute: RIPARIAN_SITES: TH_DEPTH

Manual: Using the stereo measure tool determine thalweg depth, the maximum depth below bankfull elevation, at several points along the stream length within the riparian sample unit. This is done by measuring the vertical distance between the bankfull elevation and the bottom of the thalweg (Figure 3).

(g) Average Elevation Above Sea Level (Z) (only for samples with recognizable bank features)

Sample unit: Individual riparian sample unit

Measure: Meters to the nearest tenth

Attribute: CROSS_SECTION: ELEVATION_DEEPEST

Manual: Record the average above mean sea level (Z) elevation in meters at the stream maximum depth line (e.g., 1,232.4 meters). This value is later used to compute *Flood-Prone Height* Above Bankfull (see Derived Features), and figure 27 shows an example of the measurements required.

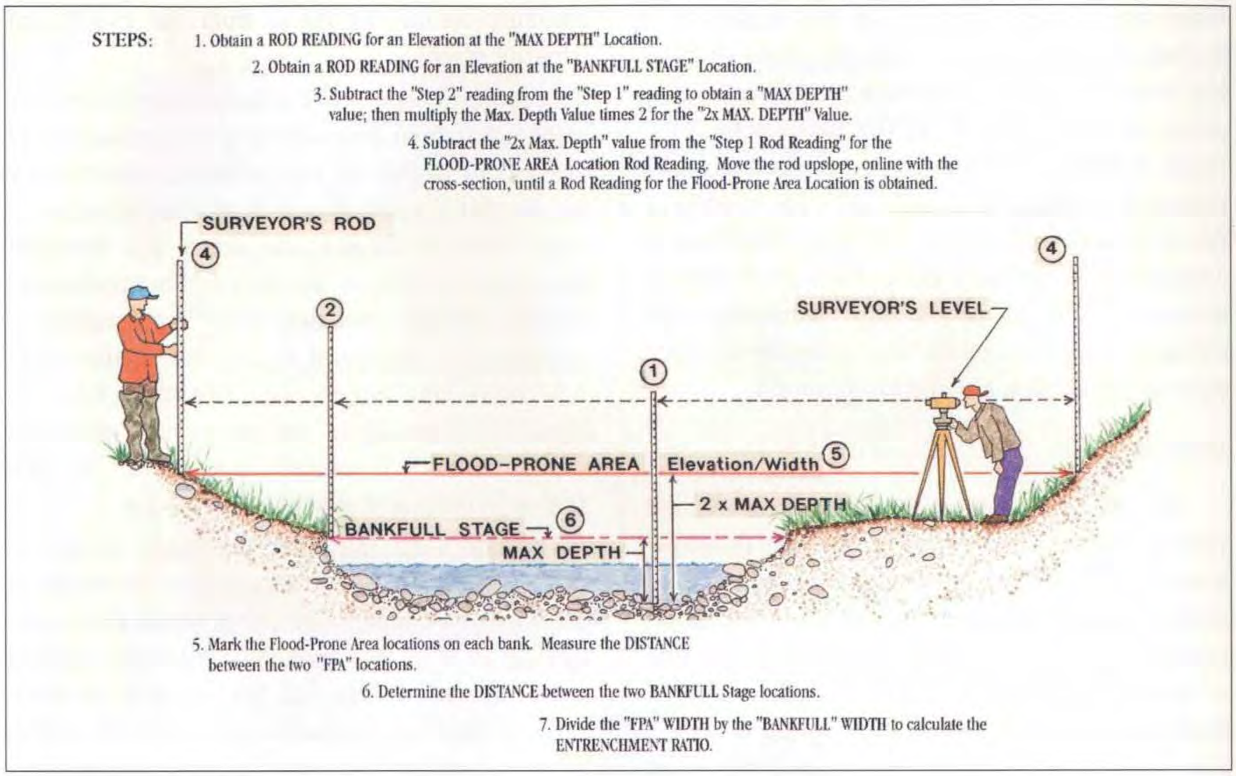

Figure 27: Key riparian area measurements.

(h) Width of the Flood-Prone Area (= flood-prone width)

The flood-prone area (FPA) is the zone bordering a stream that will be covered by waters at a flood stage of twice the bankfull depth (Rosgen 1996). The width of the FPA is measured by the interpreter at the elevation that corresponds to twice the depth/elevation of bankfull (Figure 27). Measurements are taken at three representative cross sections and then used to calculate FPA (width times length). This data element is important for determining the area with the potential for riparian vegetation, and then contrasting that with the current extent of riparian vegetation. This element is also useful for identifying areas at potential risk for building structures.

Sample unit: Individual riparian sample unit

Measure: Meters

Attribute: CROSS_SECTION: FP_HEIGHT

Manual/ field: The *flood-prone width* is determined by measuring the average width of the flood-prone area, as depicted by a level plain intersecting the ground at two times the bankfull depth (Figure 27).

4. Derived Features

The following indicators are derived through processing of related data elements and not through direct inventory. This is a partial list of potential indicators used for riparian areas that are derived.

- Land Cover Areal Extent, Stream Bank Cover, and Instream Cover – These are summaries of the cover features included in tables 3 and 4 (e.g., percent shrub-tree) and tables 7 and 8 (e.g., percent armored bank).
- Sinuosity – Derived from sampling from *stream length* and *valley bottom length.* Calculated as the ratio of stream length (active channel) to the valley length (Figure 24).
- Stream Gradient – The stream gradient is computed by dividing Elevation Change by Valley Bottom Length for any given sample. Stream Gradient represents the same extent used to measure these Stream Features.
- Riparian as a Percentage of Potential Riparian (flood-prone area)– An estimate of the percentage of potential riparian width in the sample location that is currently occupied by riparian vegetation. This feature is derived independently of ARI using specific existing vegetation mapping values relative to the width of the surrounding RMAP polygon.
- Large woody debris (instream) – Estimate of large woody debris occurring within the stream channel based on cover value data. The proportion 'coarse woody debris' within the active channel for a given stream length is converted to tons using coefficients from Brown et al. (2003). Results are then reproportioned for per-mile reporting, with bankline length (left-right average) giving the initial stream length. Method assumes woody debris is 6" or greater at the largest cross section.
- Coarse woody debris (riparian) – Estimate of coarse woody debris occurring within riparian and based on cover value data; i.e., the proportion 'coarse woody debris' of the total area including herbaceous, snag, and non-vegetated (shrub-tree, active channel, and unknown are excluded from calculations). The proportion 'coarse woody debris' is converted to tons per acre using coefficients from Brown et al. (2003), with results reproportioned for per-acre reporting. Method assumes that woody debris is 6" or greater at the largest cross section.
- Flood-Prone Height Above Bankfull (only for samples with recognizable bank features) – Computation of the depth from the bankfull elevation to the stream bed, multiplied by 2 and then added to the average above mean sea level elevation.
- Sediment Balance – Derived from predominant channel substrate sampling. This is an assessment based on the overall temporal and spatial dynamics of a stream in regard to sediment transport. For the moment, sediment balance is considered a derived indicator according to sediment conditions across samples of the same stream system, and over time with repeat monitoring.

Table 10. Sediment balance data values.

Domain Code	Value
EXCS	Excess Sediment
BAL	In Balance
STRV	Sediment Starved

- Entrenchment Ratio (ENTR_RATIO) – Derived from sampling for width of flood-prone area and bankfull width. The entrenchment ratio is the vertical containment of a stream and is calculated by dividing the width of flood-prone area by bankfull depth.
- Predominant Channel Substrate (Active Channel) (CH_SUBSTRATE) – Category based on a percentage of areal extent of Cover Values for the active channel. Categories adapted from RASES (USDA Forest Service 1989). An estimate of the predominant channel substrate for the active channel is made using the “Active Channel” attribute of the COVER_CLASS feature class and the most “Active Channel” sub-class within the active channel and sample frame.

Table 11. Channel substrate values.

Domain Code	Value
NA	Not Assigned
BDRK	Bedrock (>205cm)
LGBD	Boulder (60 to 205cm)
STON	Stone (25 to 60cm)
COBB	Cobble (7 to 25cm)
GRFI	Gravel, Fines, Litter (<7cm)
OTH	Channel Obscured by Other
WTR	Channel Obscured by Surface Water
CWD	Course Woody Debris (>7cm)
VEG	Vegetation
UN	Unknown

- Rosgen Stream Type (ROSGEN_STREAM) – Derived from inventory elements and derivations for *sinuosity, entrenchment ratio, width-to-depth ratio, stream braiding category, gradient, and predominant channel substrate* (Rosgen 1996). Also see figures 28 and 29.

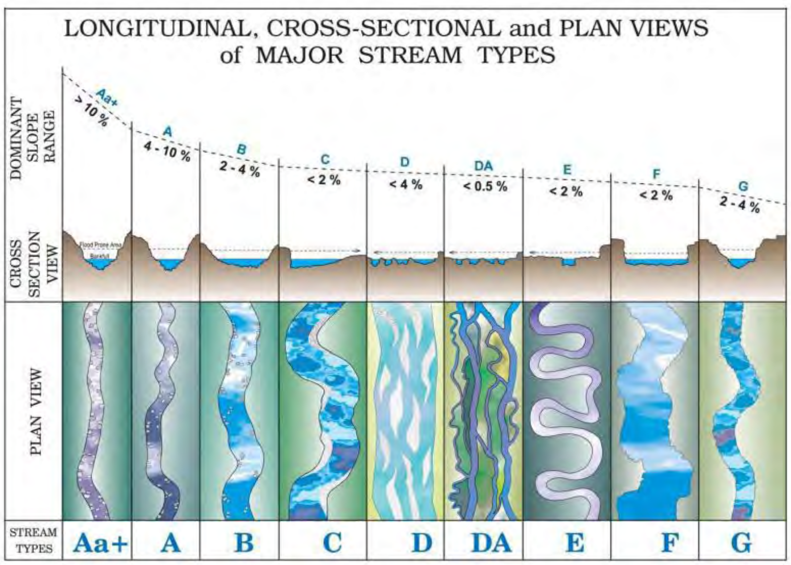

Figure 28: Broad level stream classification delineation showing longitudinal, cross-sectional, and plan views of major stream types (from Rosgen 1996).

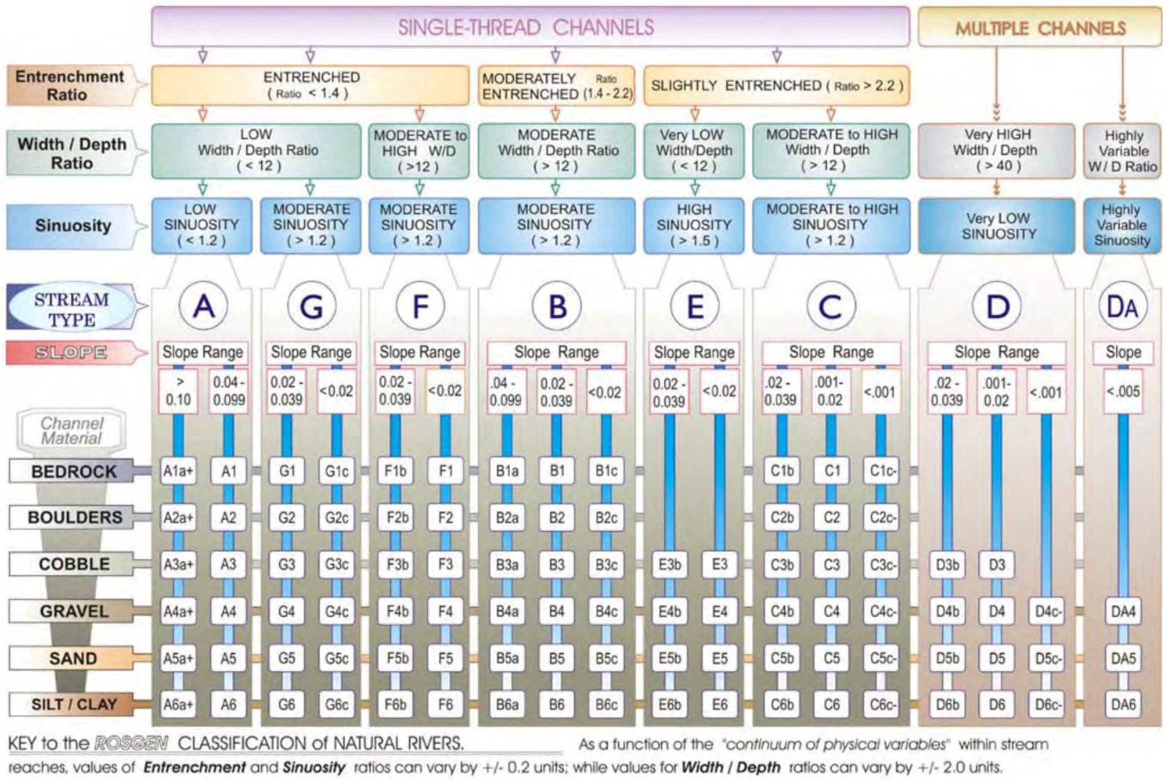

Figure 29: Rosgen classification key for natural rivers (from Rosgen 1996).

In some cases, the derived stream parameters are not suited to the classification parameters displayed in figure 29. For example, a given single-thread stream with an entrenchment ratio of 1.76 would be considered moderately entrenched (ratio 1.4-2.2), but its width/depth ratio is 4.98 and should be >12 according to the classification chart. Rosgen (1994) suggests the variations listed in table 12 below.

Table 12. Entrenchment ratio suggested variation.

Parameter	Suggested variation
Entrenchment ratio	±0.2
Width/depth ratio	±2.0
Sinuosity	±0.2

If the suggested variation is not sufficient to reach a classification category based on the average (mean) values, all three (possibly five) cross sections are classified separately. The most frequent classification result (mode) is then chosen.

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APPENDIX: Number of Cross Sections for Stream Parameters

As described in the GIS manual under 4.0 stream features, Manual Method for Bankfull Width and Thalweg Depth, the cross sections for deriving thalweg depth, floodprone width, bankfull width, entrenchment ratio and width/depth ratio are drawn manually in Stereo/3D (Figure 30).

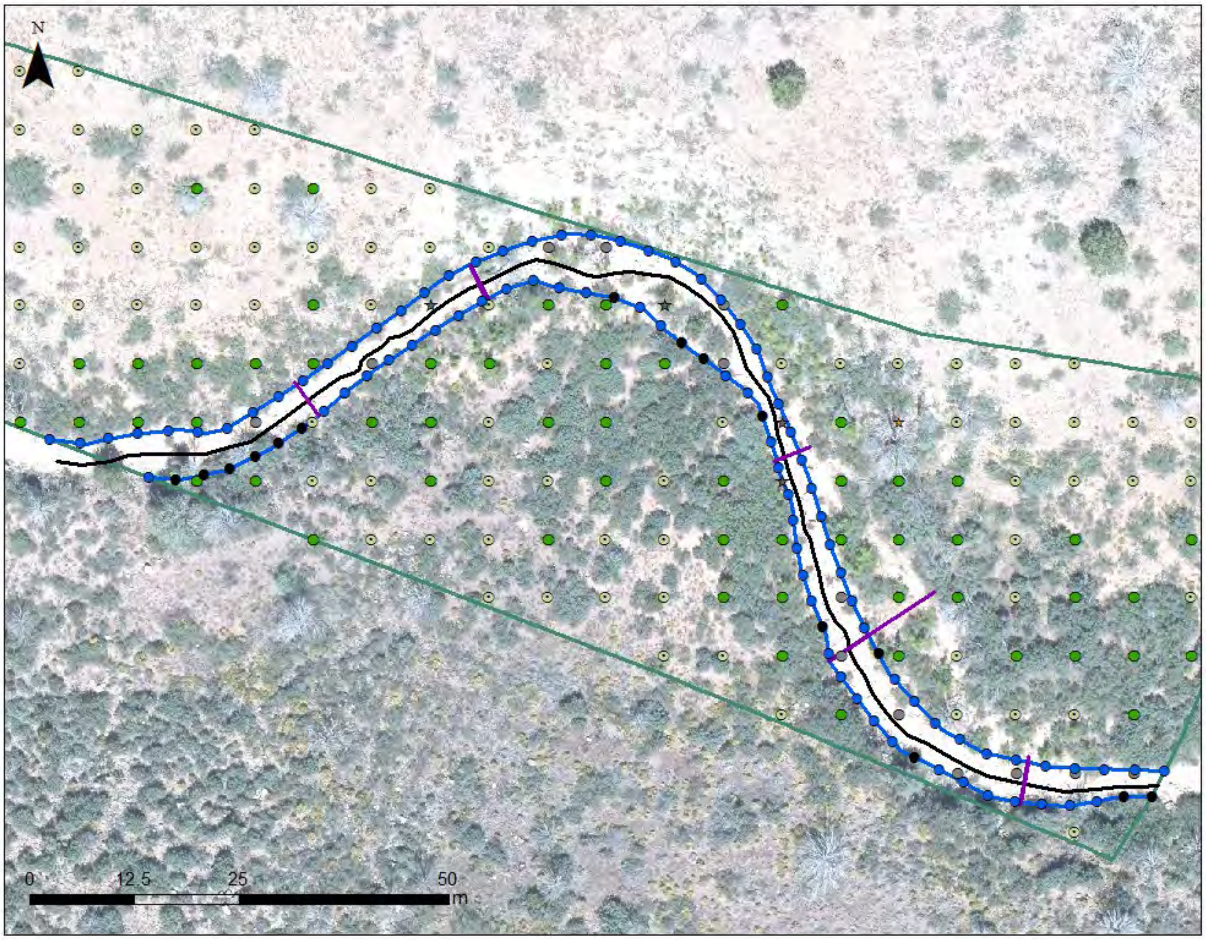
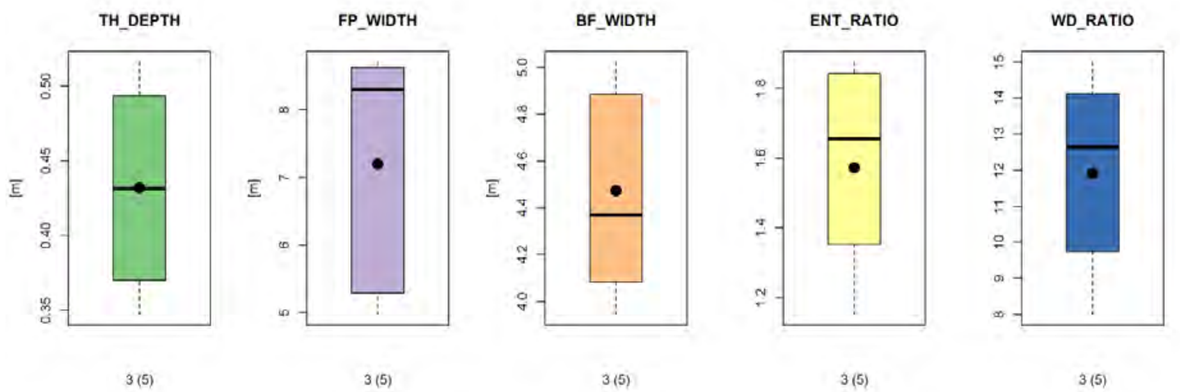


Figure 30: Example ARI inventory sample with bank lines and cross sections drawn.

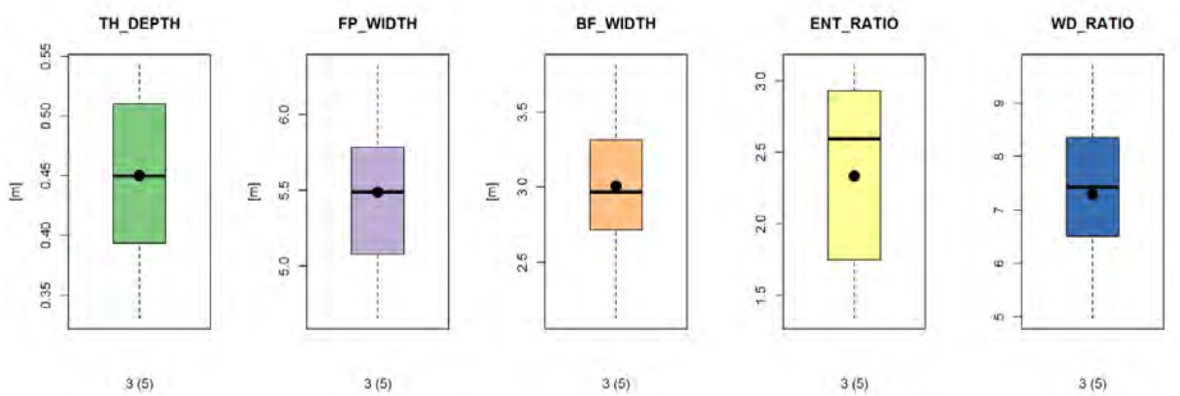
The number of cross sections should represent the stream parameters well. An analysis for three sample sites was conducted in order to examine the effect of three or five cross sections on derived stream characteristics.

After measuring five cross sections pairs for each the bankfull and floodprone width, ten different combinations for combining three of the five cross sections are possible. The boxplots below show the distribution of the stream parameters for three cross sections. The mean of all five cross sections is marked with a black point.

Site 43520:



Site 41600:



Site 35840:

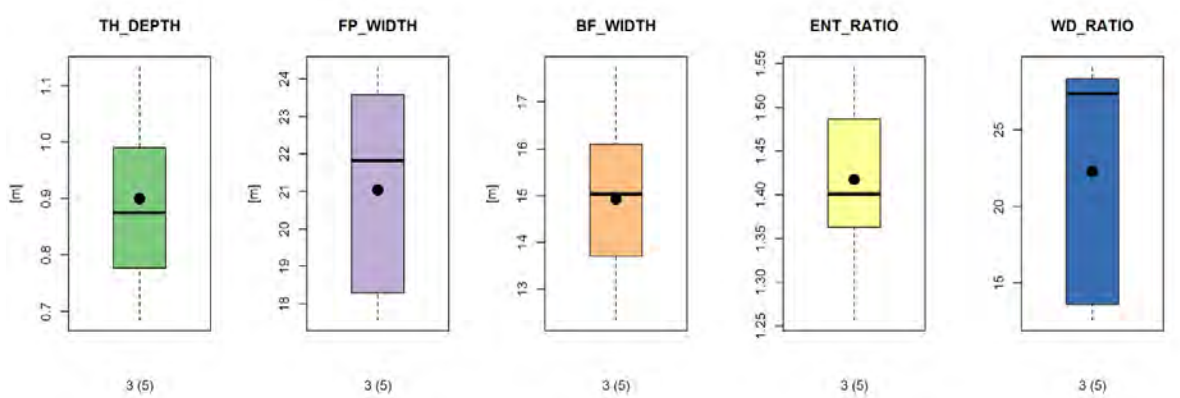


Figure 31. Boxplots that show the distribution of the stream parameters for three cross sections of the stream shown above in Figure 30. TH_DEPTH = Thalweg depth, FP_WIDTH = floodprone width, BF_WIDTH = bankfull width, ENT_RATIO = entrenchment ratio, WD_RATIO = width/depth ratio.

The relevant thresholds for the Rosgen stream classification are:

- Entrenchment ratio: <1.4, 1.4-2.2., >2.2 (suggested variation: ±0.2, Rosgen 1994)
- Width/depth ratio: < or > 12 (for single channel) (suggested variation: ±2, Rosgen 1994)

The boxplots show that the median of the three cross sections and the mean of five cross sections are quite similar and lead to the same Rosgen stream classification categories. The results suggest that taking three cross sections is generally sufficient. Regardless the number of cross sections, it is important to measure the cross sections across the straight portion of the stream at top of a riffle (Zeedyk & Clothier, 2009) and not in the broader bends of the river where point bars and cut banks may occur.

The stream length of the riparian areas in this project varies. Therefore, some streams which are comparatively long and have a complex morphology may require five cross sections.

Five cross sections are recommended when the stream is quite long, the stream width varied and sufficient banklines well visible to draw five cross sections. Figure 31 example below shows a 350 m long stream with variations in stream width.

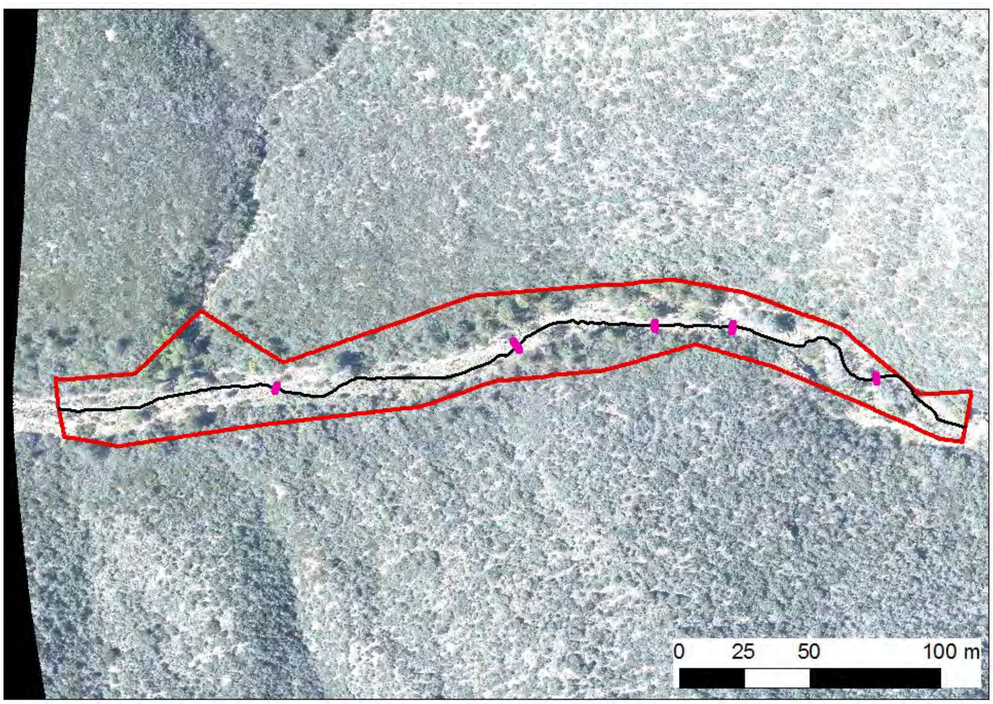


Figure 32: Five cross sections for a 350m long stream with well visible bank lines and variations in stream width and depth. Cross sections are marked in pink and displayed with a thickened line.

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[i] Sinuosity equals mapped channel length divided by mapped valley length.

[ii] Correspond[ing with] the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics.

[iii] A line connecting the lowest points of successive cross-sections along the course of a valley or river.