



MEMORANDUM

DATE: January 30, 2026
TO: MHFD Staff (Bao Chongtoua and Jennifer Winters)
FROM: Dr. Brian Murphy, River Works and Josh Gilbert (Anabran Solutions)
REVIEWED BY: Troy Thompson, ERC; Dr. Joel Sholtes, Wash Water Science and Engineering; Jeff Sickles, Olsson Associates
SUBJECT: Stream Management Corridor Regression-based Analysis

Abstract

The Mile High Flood District (District) initiated a comprehensive review of its Stream Management Corridor (SMC) methodology after recognizing limitations in the original shear-stress-based approach—namely, its tendency to underestimate widths in low-gradient systems and overestimate them in steep streams. A multi-disciplinary working group evaluated alternative methods that could better represent the physical processes governing urban stream function while still providing a district-wide, planning-level tool. After assessing shear stress, stream power, FEMA/MHFD regulatory floodplains, and Colorado’s Fluvial Hazard Zone (FHZ) protocols, the group determined that a regression-based method using valley-bottom widths derived from the Valley Bottom Extraction Tool (VBET) offered the most practical, scalable, and geomorphically meaningful solution.

Using VBET data across District watersheds, and sampling valley bottom polygons in the District’s stream network that were near natural or adjusting naturally¹ the team developed power-law regression equations relating upstream drainage area to maximum elevated valley-bottom width, then applied those relationships as stream-centerline buffers to map new SMCs. The resulting corridors aligned well with mapped FHZs in areas where fluvial signatures remain intact and consistently produced more appropriate, planning-level widths than the previous shear-stress version. Although intentionally planning-level guidance and not regulatory, the updated SMCs offer a more robust, consistent, and data-driven foundation for local government partners to use during their development review process, with the expectation that project-scale analyses will refine these widths based on site-specific conditions.

Introduction

The Mile High Flood District (District) developed stream management corridors (SMCs) as a planning-level tool to protect and preserve urban stream corridors while also identifying an overall width that the stream may require to function without conflicting with development (MHFD 2022). SMC boundaries approximate that area identifying an overall width that the stream may require to function without encroachment. Unlike a "reach scale" study, which involves detailed field visits and engineering, SMCs are developed using a desktop-based "watershed scale" analysis (i.e.,

¹ See Murphy et al. 2025 for information on the stream typology used to select reaches to include in this analysis

planning-level) that applies GIS data and automated modeling to provide a broad estimate for large areas. SMCs can be used as a starting point to depict the area that can accommodate flooding, allow for and even encourage natural fluvial geomorphic processes as streams erode, transport, and deposit water, sediment, and woody material.

In 2018, the District developed SMCs for all streams that have a tributary area greater than 130 acres using a threshold approach based solely on shear stress and an automated GIS buffering method (Matrix 2018). Several iterations were performed to understand the sensitivity of the SMC based on valley slope and estimated flow. Approximate SMC widths were calculated by targeting 1 pound per square foot (lb/ft²) shear stress for lower gradient streams (slope < 2%) or 4 lb/sf shear stress for higher gradient streams (slope > 2%). The higher target values were used for steeper, headwater streams located in the foothill or mountain areas. Because slope is a multiplier in shear stress equation ($\tau = \rho gRS$), a steep stream naturally generates more force. Using too small of a shear force value in a high gradient stream would generate narrow SMCs and using too large of a shear force in a low gradient stream would generate overly wide SMCs.

Width was calculated using a simplified Manning's equation solving for width using slope and 1-percent annual chance flow rate (i.e., 100-year flood). Flow rates were calculated using a District-wide hydrology regression equation based on upstream drainage area. Once approximate widths were found that allowed for adequate floodplain shear stresses (1 or 4 lb/ft²), the SMC was created by buffering these widths from the stream centerline.

The District published these SMCs on their GIS mapping platform for local communities to guide development and land use decisions in stream corridors. They were intended to be high level, identifying the general width that the stream may need to function without encroachment or be restored to a functional condition. However, the District identified areas on the eastern side of the District's service area where the shear force-based approach resulted in SMC widths that were too narrow in lower gradient streams, for example, approximating only the channel width and not the broader floodplain width. Similarly, SMCs in steeper slopes tended to overstate needed corridor space. In effect, the SMCs were underestimated or overestimated due to the sensitivity of slope in the shear stress calculation.

The District started a working group in 2023 to review the shear force-based method, evaluate alternative methods, and recommend a path forward. Members of the working group included:

- Bao Chongtoua, MHFD
- Jon Villines, MHFD
- Jeff Sickles, Olsson
- Troy Thompson, ERC
- Brent Kaslon, Valerian
- Josh Gilbert, Anabran
- Jennifer Winters, MHFD
- Jeff Battiste, MHFD
- Brian Murphy, River Works
- Joel Sholtes, Wash Water Science & Engineering
- Jesse Clark, Stream Landscape Architecture

The working group's objective was to develop a simple method to provide planning-level SMC widths that accounts for the District's five elements of urban stream function: community values, hydrology, hydraulics, geomorphology, and vegetation. Note that after discussion, the working group decided to not include community values because the incorporation of community values comes into play at the project/reach scale and therefore is dependent on the project context and local government and stakeholders' goals.

This memorandum provides a summary of the working group's findings and recommendations, including the method and results for the application selected by the working group to replace the shear force-based method.

SMC methods review

The working group reviewed three possible methods to replace the shear force-based planning-level SMCs:

1. Re-apply shear stress calculations that are similar to the current method and include or replace shear stress-based widths with stream power-based widths solving for the width using published values of stream power.
2. Utilize FEMA and MHFD regulatory floodplain widths and associated tributary drainage area to develop empirical relationships based on regression analysis.
3. Apply protocols from CWCB's Fluvial Hazard Zone (FHZ) Program (Blazewicz et al. 2020) to develop FHZ delineations.

The working group discussed advantages and disadvantages for each of the methods (see Table 1). They also evaluated the methods against their objective: develop a planning-level SMC method that considers the four physical elements (hydrology, hydraulics, geomorphology, and vegetation). Solutions to address the limitations of the shear stress and stream power-based method were considered, but all were found to be too complex, time-consuming, and potentially leading to the same problem (i.e., under or over predicting widths). The working group strongly considered the FHZ protocols, but the anthropogenic alterations to many of the landscapes on the eastern side of MHFD's service area have erased the fluvial signatures across MHFD's service area. Further, FHZ studies are relatively expensive to complete compared to a desktop-based analysis and are time intensive. For these reasons, the FHZ protocols were excluded from further consideration for the District-wide SMC update. While FHZ protocols were not used for District-wide SMC updates, the working group decided to use previously developed FHZs for specific streams (e.g., Sand Creek, First Creek, Box Elder Creek) to evaluate and validate regression-based SMCs, especially in mid- to large drainage area streams with fluvial geomorphic signatures still present in the landscape.

The FEMA and MHFD floodplains-based regression method also had limitations, but the working group decided to move forward with developing this method due to the large database available to develop best fit empirical relationships and MHFD's previous work using GIS tools to assess stream conditions (i.e., urban stream assessment [USAP] and stream typology).

Table 1. Methods reviewed for MHFD stream management corridors

Method	Advantages	Disadvantages
Shear stress/stream power	<ul style="list-style-type: none"> ● Simple calculations ● Industry standard shear stress/stream power values for varying channel types 	<ul style="list-style-type: none"> ● Emphasizes a static condition by only considering hydrology and hydraulics Elements with vegetation included in the roughness value ● Known to be very sensitive to slope; narrow in low gradient & wide in steep gradient reaches ● Uniform buffer widths do not account for geomorphic processes or landforms
Regression analysis using FEMA and MHFD floodplains	<ul style="list-style-type: none"> ● Most major streams have mapped regulatory floodplain and valley bottom extents ● Considers variations in topography, flows, and vegetation (roughness value) 	<ul style="list-style-type: none"> ● Emphasizes a static condition by only considering hydrology and hydraulics Elements with vegetation included in the roughness value ● Relies on static landform data (floodplain and valley-bottom) and does not account for potential stream movement (i.e., space for geomorphic processes). ● Strongly influenced by valley margin width, which may be anthropogenically influenced, so widths can vary greatly along same stream ● Not an indicator of geomorphic condition because narrow floodplains associated with incised channels is not indicative of the space a stream needs to function
Fluvial hazard zone (FHZ)	<ul style="list-style-type: none"> ● Solid technical basis for hydrology, hydraulics, and geomorphology Elements ● Represents SMC from a process (fluvial geomorphology) standpoint 	<ul style="list-style-type: none"> ● Limited availability of published FHZ studies in MHFD service area ● Relatively expensive to complete, though less so than a floodplain study ● Not suited for headwater streams (i.e., 1st order); developed for small to larger stream systems (2nd order and larger)*

* *Stream order is a numerical ranking system used to classify the size and hierarchy of paths within a river network based on how many tributaries have joined together.*

Regression analysis method development

The working group identified a series of questions to consider during development of the floodplain-based regression method. These questions included:

1. What floodplains database(s) (e.g., FEMA, MHFD, fluvial hazard zones, valley bottoms, etc.) should be included in the method?
2. Should the analysis use floodplain widths associated with annual exceedance probabilities (AEP) of 10%, 1%, 0.2%, or a combination of those AEP widths?
3. Should a factor (1.5x, 2x, etc.) be applied to determine the SMC widths? What variables should inform this factor?
4. Are existing or future condition floodplains more appropriate to extract widths?
5. Is a regression analysis using floodplain widths (dependent variable) and drainage basin area (independent variable) appropriate due to development altering flows?

Answering the first question required reviewing available floodplain data from different sources and developing a process to sample the widths and associated upstream drainage area using GIS tools.

Where mapped, regulatory floodplains (e.g., FEMA flood insurance rate maps or FIRMs, MHFD led floodplain studies) have informed or been used as SMCs; however, the working group decided regulatory floodplain maps may not be the best tool for identifying the space a stream needs to provide room for geomorphic processes. FIRMs provide a single snapshot of the estimated maximum extent of flood inundation that has a 1-percent change of occurring in any given year (i.e., 100-year flood). However, as noted by Blazewicz et al. (2020), FIRMs but do not inform...

“an area’s susceptibility to erosion, deposition, or avulsion either within or outside of the areas prone to inundation by floodwaters. As a result, areas located well above the FIRM’s Base Flood Elevations or outside of FEMA floodplain boundaries are often affected by floods yet communities in these areas are unaware of and unprepared for the potential impacts.”

Therefore, a geomorphic floodplain, defined as the corridor along a stream influenced by erosional and depositional processes under the prevailing flow and sediment regime, that includes adjacent hillslopes susceptible to fluvial hazards better represents the space that the group believed was appropriate for a planning level tool like the SMC(e.g., Figure 1).

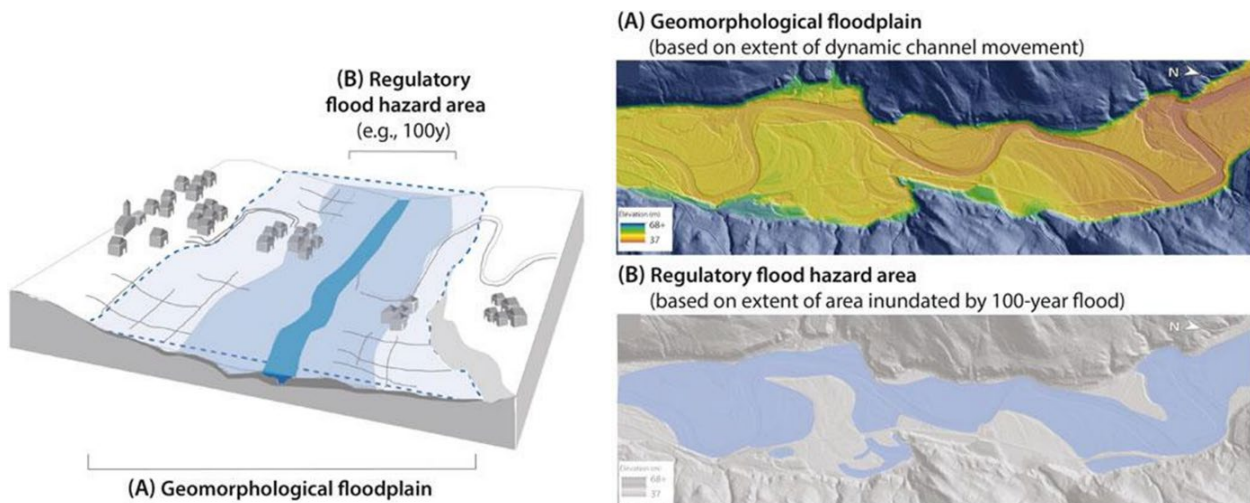


Figure 1. Comparison of (A) geomorphological floodplain (defined herein as valley bottom) and (B) regulatory flood hazard area.

Further, the working group raised the following concerns with sampling FEMA and MHFD regulatory floodplains:

- In urban areas the regulatory floodplain has been encroached by manmade changes to the topography and is no longer representative of a geomorphic floodplain.
- In undeveloped areas in MHFD’s service area, mapped regulatory floodplain or historical land use data may not exist to determine a stream corridor width, notably in the east where areas of the landscape remain undeveloped.
- Regulatory floodplains are based on hydrology and topography that can change over time. For example, the versions of the models used to develop hydrology for a floodplain study

may have been updated since the floodplain was originally mapped. In the case of topography, new development, roads or other manmade features can change the stream corridor width. Additionally, streams can migrate within or outside of the mapped regulatory floodplain over time.

- Floodplain analyses only rely on two of the five Elements of urban stream function (hydrology and hydraulics) with vegetation considered secondarily through roughness values.

Instead of using hydraulic model derived floodplains in the regression analysis, the working group chose to use a publicly available dataset of stream corridor valley bottom extents based on the Valley Bottom Extraction Tool (VBET; Gilbert 2016). By definition, a valley bottom is comprised of the stream channel and the associated low-lying, contemporary floodplain (Wheaton et al. 2015). Valley bottoms are a critical fluvial landform with geomorphic, hydrologic, and ecological significance. Therefore, analyzing the valley bottom extent, as well as size and shape, is key to understanding a stream’s geomorphic processes (Gilbert et al. 2016). Measures of confinement (confined, partly confined, and unconfined) are used to differentiate valley bottom settings. The degree of valley confinement controls the ability of a channel to adjust laterally and, to some extent, vertically on the valley floor (see Figure 2).

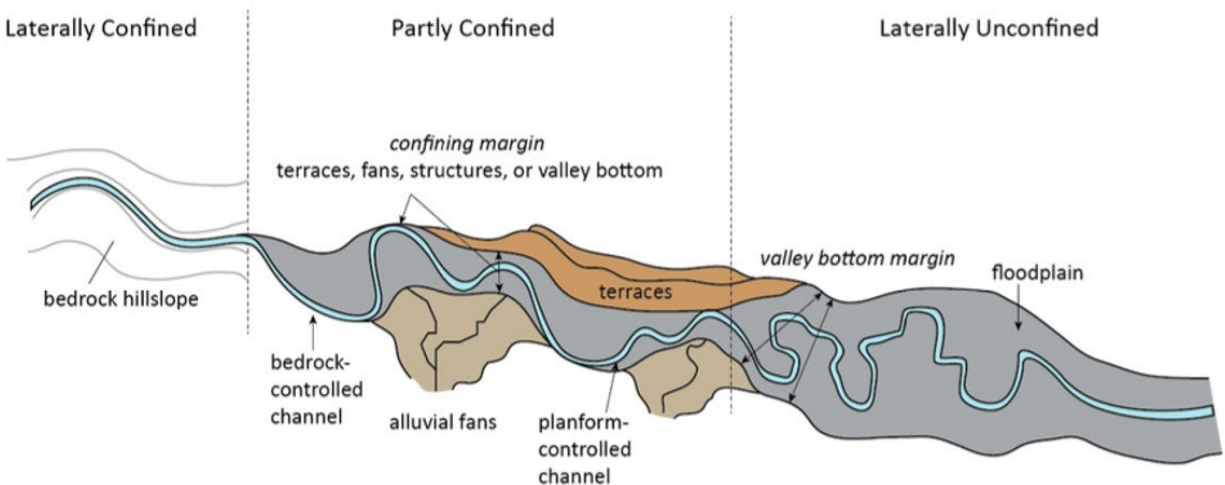


Figure 2. Conceptual schematic of valley setting along three distinct reaches. Gray background indicates floodplain within a valley bottom. In confined valley settings, the channel is between narrow valley walls and contains little or no floodplain (from O’Brien et al. 2015 reproduced by permission of the authors).

The use of valley bottoms to inform SMC widths rather than FEMA or MHFD derived floodplains address the uncertainties posed by Questions 2, 4, and 5, above. The valley bottom data represents the maximum extent of plausible flooding, therefore AEPs that represent existing and future conditions should be captured within valley bottom extent. The working group also elected not to apply a factor (Question 5) for the same reason; however, 95% confidence band for the nonlinear regression between drainage area and valley bottom width was reviewed to determine if

a factor should be applied. The working group decided the fitted line (average response) from the regression analysis resulted in approximate widths sufficiently accurate to develop planning-level stream management corridor boundaries across a wide range of drainage areas.

Regression analysis

Conceptually, SMCs based on a regression analysis require delineating a buffered width off a stream centerline. This width is calculated from an empirical relationship derived from regression of drainage area associated with a stream reach and valley bottom extent data. The process to generate these empirical relationships is described in this section. The full workflow is included in Attachment 1.

The VBET datasets were downloaded for the HUC-10s in the District's service area from the Riverscapes Consortium (data.riverscapes.net). This dataset is publicly available for all hydrologic unit code watersheds (i.e., HUC-10s) nationwide based on 10-meter digital elevation models (DEMs). Two topographic analyses of the DEM are used in delineating these valley bottoms: slope and height above nearest drainage (HAND). The HAND method is similar to the relative elevation model (REM) used in the FHZ protocol (Blazewicz et al., 2020). A combination of slope and HAND data are combined in the VBET algorithm to delineate the extent of the valley bottom. Using a 10-meter DEM (USGS 2025) and a channel area network as inputs (Moore et al. 2019), VBET estimates the valley bottom extents, which includes a channel, topographically low-lying valley bottom (i.e., active floodplain), and an elevated valley bottom (i.e., distal inactive floodplain, Figure 3). In addition to delineating the extent of valley bottom, VBET segments the valley bottom output into discrete polygons and attributes each polygon with VBET analytical outputs (e.g., width, upstream drainage area, etc.).

The working group applied the VBET-derived outputs to develop the empirical relationships (i.e., regression equations) between drainage area and valley bottom width. The two valley bottom definitions (low-lying and elevated valley bottom) were evaluated in their ability to represent the geomorphic floodplain and, ultimately, best define the SMC width. Minimum, mean, and maximum values of low-lying and elevated valley bottom widths were calculated for a subset of valley bottom polygons. For example, the working group focused on sampling valley bottom polygons that had similar lateral extents as overlapping regulatory floodplains. The working group also decided to sample the entire stream network, focusing on valley bottom polygons in the MHFD stream network that were near natural or adjusting naturally² for width and drainage area to address concerns with including human-modified narrow valley bottoms and irregularly shaped valley bottom polygons in shallow slope areas. Using these polygons limited skewing the input data with

² Murphy et al. (2025) defined near natural as “no clear evidence of channel change so that bed and banks appear stable, appropriate geomorphic units, and natural interaction of channel and floodplain. Vegetation is appropriate for the ecoregion.” Adjusting naturally was defined as “signs of an adjusting channel, which could be due to increased runoff from impervious urban areas, include bank erosion (possibly on both sides), undercut trees, channel widening or deepening, silting in channel, sediment accretion above crossings, or buried structures. No culverts or crossing structures. Vegetation is appropriate for the ecoregion.” See Murphy et al. 2025 for information on the stream typology used to select reaches to include in this analysis.

artificially narrow or wide valley bottom polygons manipulated by flood control and/or development projects. See Attachment 1 for further information on the GIS workflow.

We then summarized valley bottom widths for each floodplain polygon and plotted them against the upstream drainage areas for an initial visual review (e.g., Figure 4). Though variability exists in the log-log scatterplots of drainage area vs. valley bottom width, all relationships were approximately linear, indicating that a power law function is reasonable to use in regression analysis between these two variables.

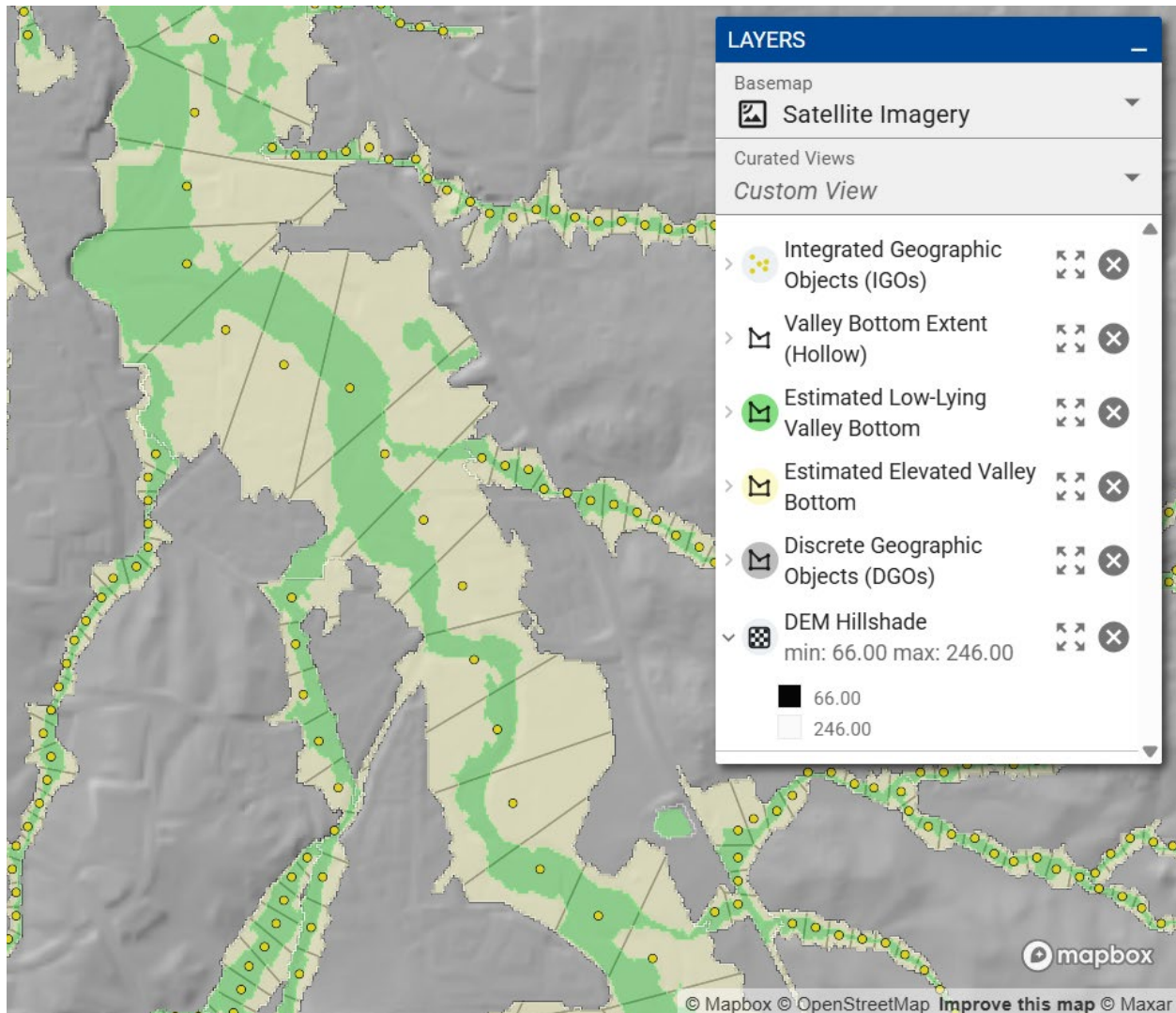


Figure 3. VBET polygons are represented as the combination of green (low lying valley bottom) and beige (elevated valley bottom).

Drainage Area vs Max Valley Bottom Width

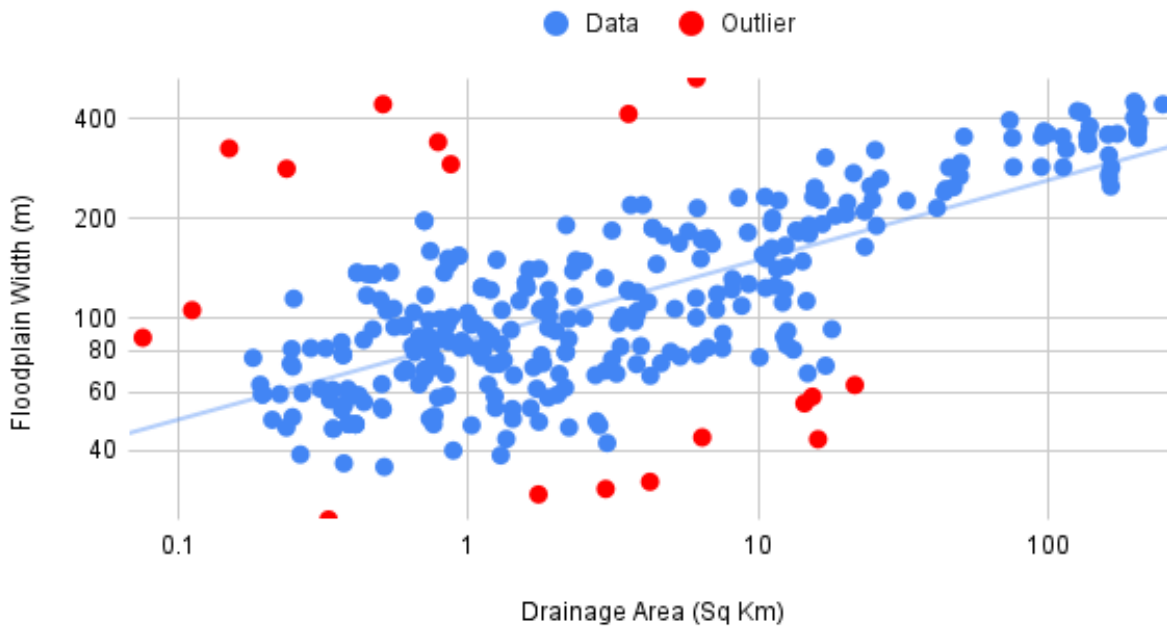


Figure 4. Example plot of width and drainage area for the Sand Creek watershed with outliers shown in red circles.

We reviewed each plot for data points falling far above or below a preliminary regression line, removing outliers distal from the main cluster of data points. We verified removing the outlying data points by identifying their location in the stream network and the context that influenced their variation from more proximate data points. For example, data points below the regression line typically represented narrow floodplains with high drainage area due to confined valley setting. Outliers well above the regression line were from extremely wide floodplains along small streams that shared a comingled floodplain at their confluence with a larger stream.

A power law function was fit to the culled dataset for a particular watershed, generated by the steps outlined above, with the form of:

$$Width = a * Area^b$$

Where *Width* is the SMC width in meters, *Area* is the tributary area draining to that point in km², and *a* and *b* are the fitted coefficients.³

Polygon buffers based on these power law functions were generated from MHFD's stream centerlines in GIS. SMCs from each valley bottom definition (low-lying and elevated) and statistical metric values (minimum, mean, and maximum) were then visually compared to legacy SMCs, FHZs, and regulatory floodplains. The working group selected the stream centerline buffered width

³ Note that the power law regression function in Excel conducts an ordinary least squares (OLS) regression on log-log transformed data, which is subject to transformation bias and under prediction of the nonlinear relationship. Therefore, true nonlinear regression is recommended for developing power law functions. The nonlinear regression was conducted in R using the `nls()` function in the `stats` package (R Core Team 2023). Where the non-linear regression function was not able to converge, the OLS regression approach was used with a bias correction factor. Metric units were used for width and drainage area because those are the native units for the input data (DEMs and HUC-10s).

from the regression equation based on the VBET max elevated valley bottom and drainage area was chosen as the method to delineate all SMCs. We verified this application of this method by developing individual regression equations for each major watershed within the District’s service area (see Figure 5) rather than applying one universal regression equation for all streams.

Results

The VBET max elevated valley bottom sampled data points were used to develop regression equations (i.e., power law functions) and plot widths in GIS as continuous function of drainage area in km². See Table 2 for the coefficients for the nonlinear and ordinary least squares (OLS) regression equations and Figure 6 for the associated regression equation plots.

Table 2. Nonlinear regression equation coefficients for streams within each MHFD watershed

Watershed	lla	llb	bcf	llr2	nla	nlb	nlr2
Boulder Creek	33.487	0.487	1.22	0.7	38.675	0.467	0.78
Sand Creek	87.804	0.272	1.04	0.8	91.227	0.268	0.89
Plum Creek	52.019	0.254	1.028	0.82	50.218	0.27	0.87
Box Elder Creek	98.182	0.258	1.076	0.65	88.516	0.332	0.76
First Creek	85.999	0.345	1.072	0.74	85.927	0.366	0.67
Cherry Creek	60.73	0.309	1.058	0.66	54.3	0.362	0.82
Clear Creek	33.031	0.366	1.077	0.72	34.838	0.381	0.86
South Platte River Lakewood	73.511	0.169	1.02	0.51	74.905	0.201	0.62
Big Dry	52.007	0.436	1.109	0.67	54.774	0.444	0.55
Chatfield/Bear	35.095	0.264	1.153	0.67	NA	NA	NA

ll = log-log transformed data (i.e., OLS); bcf = bias correction factor; nl = nonlinear; r2 = coefficient of determination (R²)

Units for drainage area km² and for width are meters

* highlighted cells indicated model coefficients used in plots

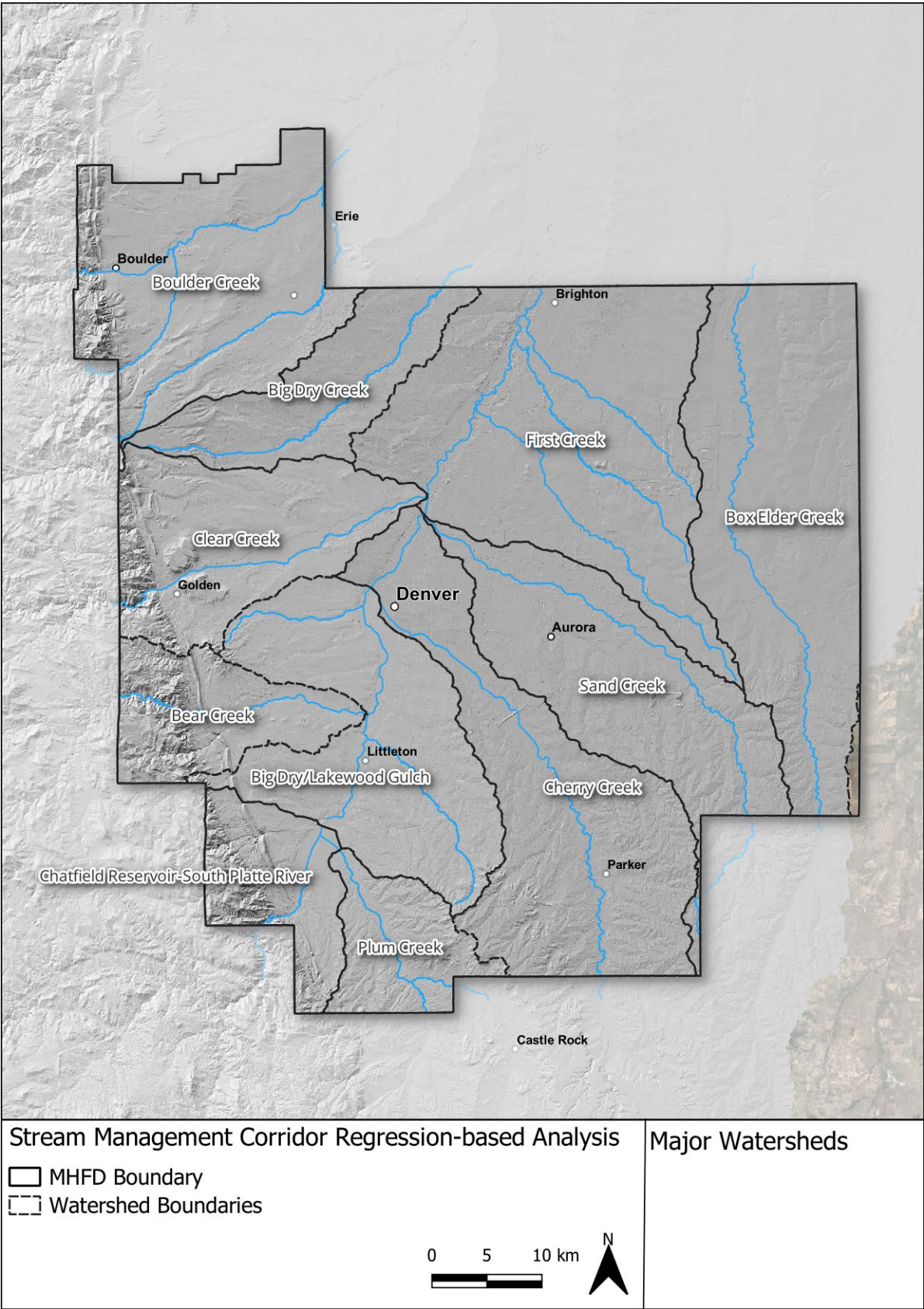


Figure 5. Watersheds included in the regression-based SMC analysis.

We applied the nonlinear regression equations for streams in all major watersheds (e.g., Figure 5) except Chatfield/Bear. For those two watersheds the nonlinear regression function would not converge due to the large drainage area compared to large width values. The OLS regression approach did not have this problem. Table 2 has coefficients for both nonlinear and OLS regressions with a calculated bias correction factor (*bcf*). Utilizing the bias correction factor corrects the OLS regression to better match the nonlinear regression as follows:

$$Width = lla * bcf * Area^{llb}$$

Where *lla* and *llb* are OLS generated model coefficients. This equation was used for these two watersheds.

MHFD SMC Width Regression Equations

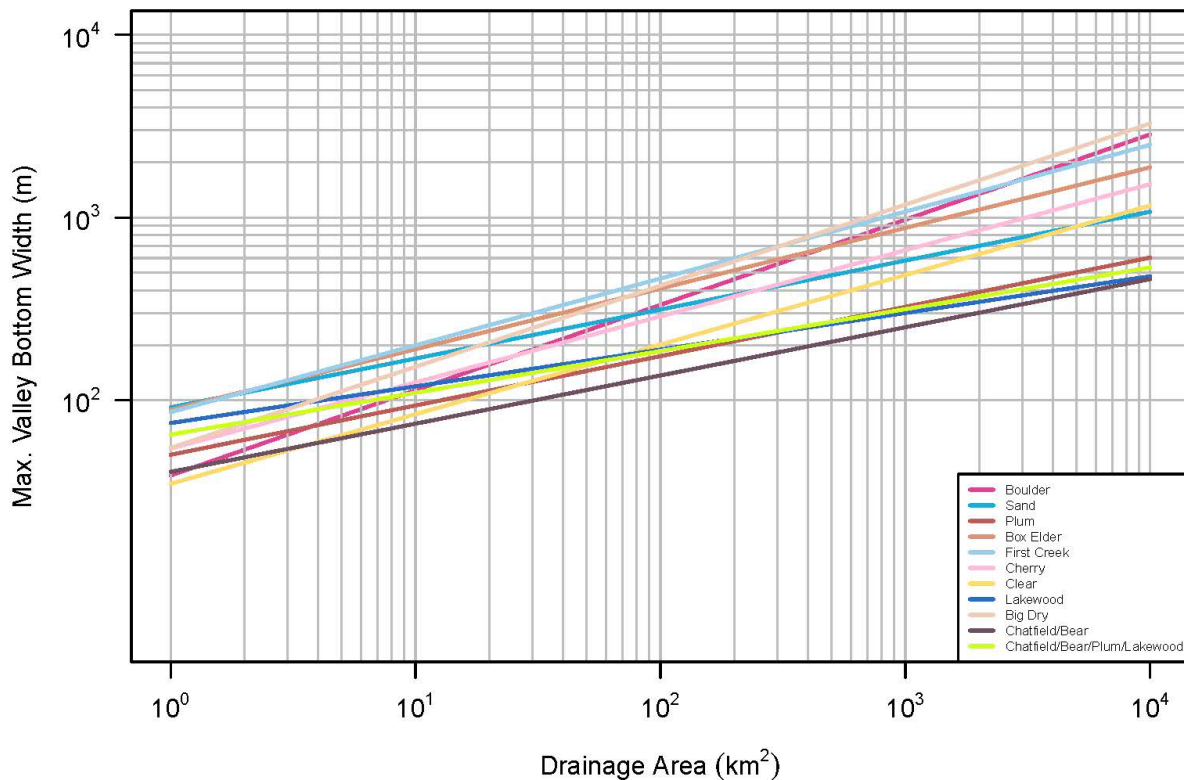


Figure 6. Output of regression equations between drainage area and valley bottom width for SMCs

The regression equations developed for each watershed as presented in Table 2 and Figure 6 were then used to delineate the SMC for each watershed based on a MHFD stream network and reach-averaged drainage area. An example regression-based SMC mapping output for Sand Creek is provided below (Figure 7). Regression equation-based plots for each watershed are included in Attachment 2. The stream network mapping of the regression equations is available on the District's Confluence site.

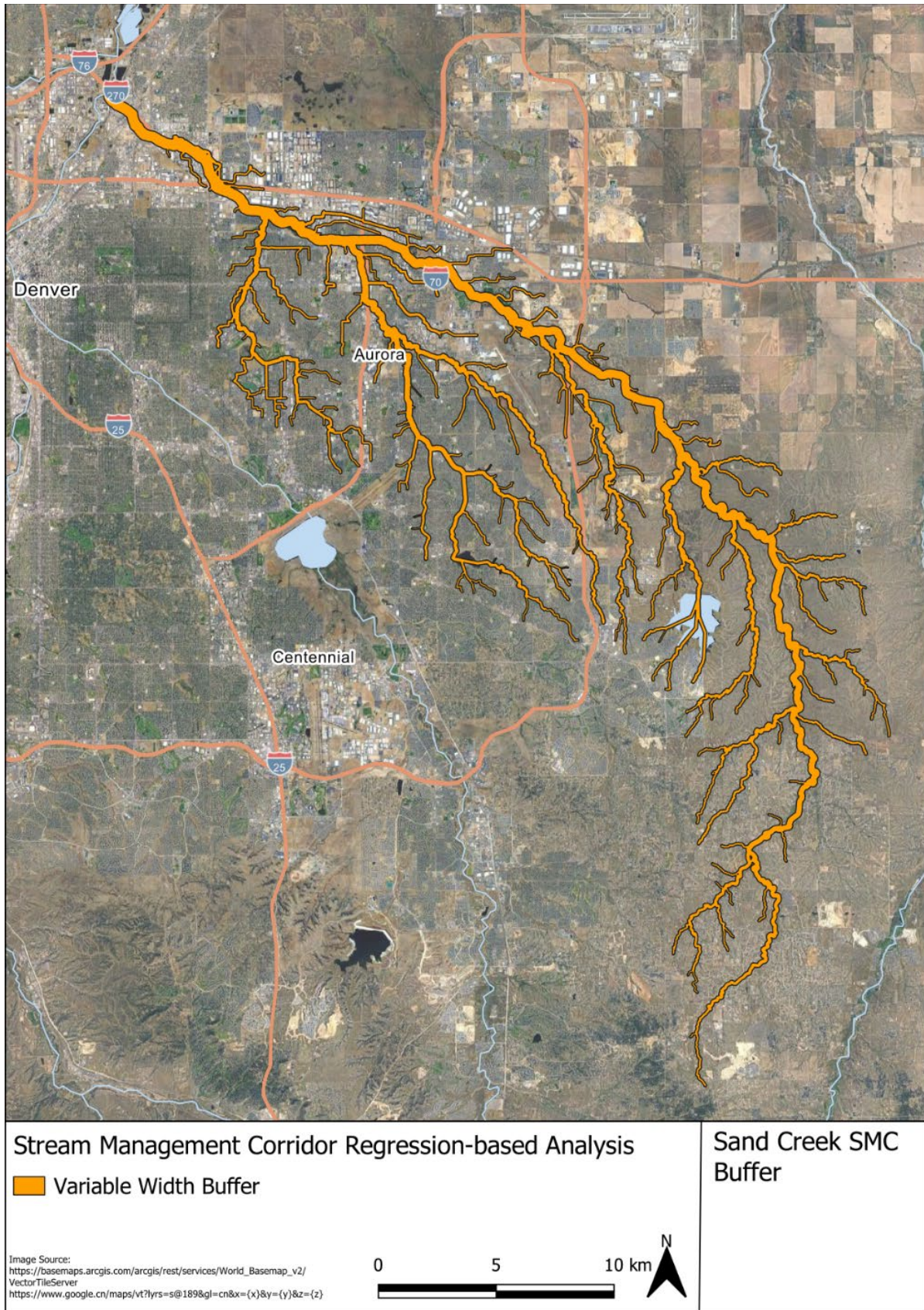


Figure 7. Example variable SMC width along the Sand Creek watershed stream network, where width increases in size as upstream drainage area increases.

Validation

The working group validated the regression equation-based SMCs through visual comparison with other mapped definitions of the SMC including the active stream corridor (valley bottom) component of FHZs (i.e., the highest standard) mapped along Box Elder Creek and Sand Creek as well as regulatory floodplains (FEMA and MHFD) and the previous shear stress version of the SMC. We observed continuity in the definition of fluvial features between the regression equation-based SMCs and fluvial signatures-derived FHZs (see Figure 8). In particular, the Box Elder Creek FHZ widths aligned closely with the regression equation-based SMCs. The working group also validated the regression equation-based SMCs by comparing FHZ delineations on First Creek and Plum Creek (Figure 9 and Figure 10, respectively).

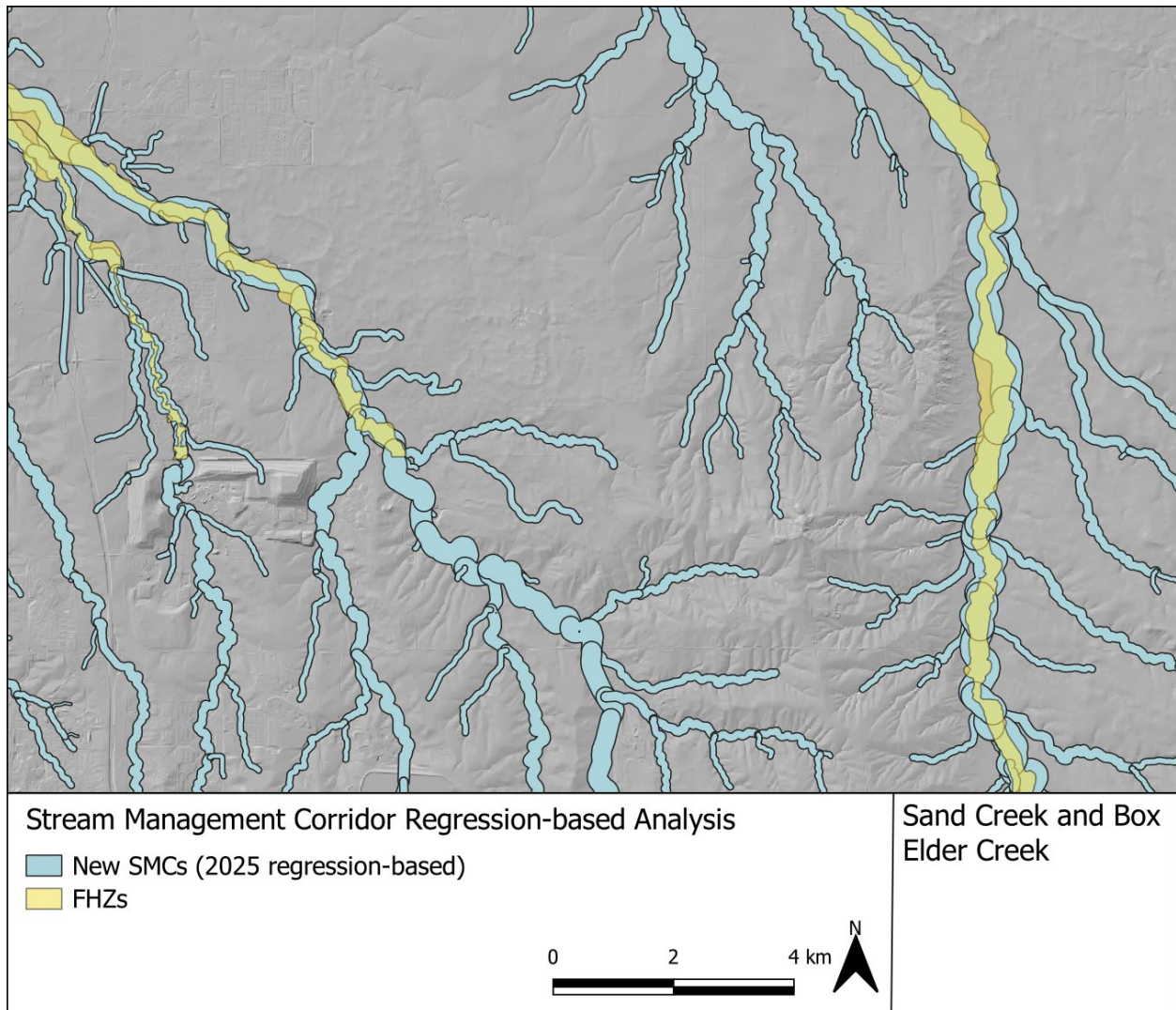


Figure 8. Box Elder Creek and Sand Creek Watersheds with new SMCs (blue) and FHZs (gold)

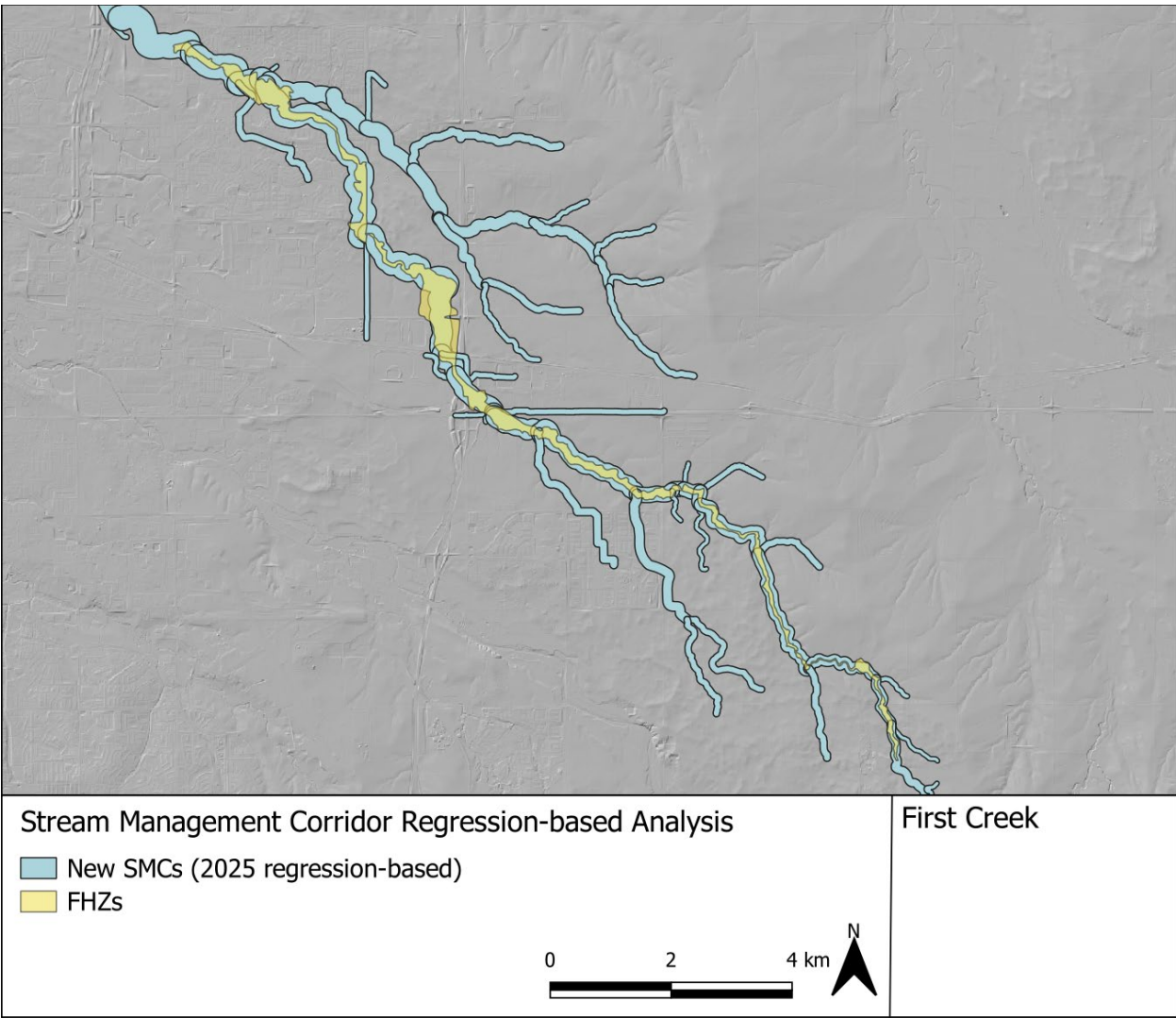


Figure 9. First Creek Watersheds with new SMCs (blue) and FHZs (gold)

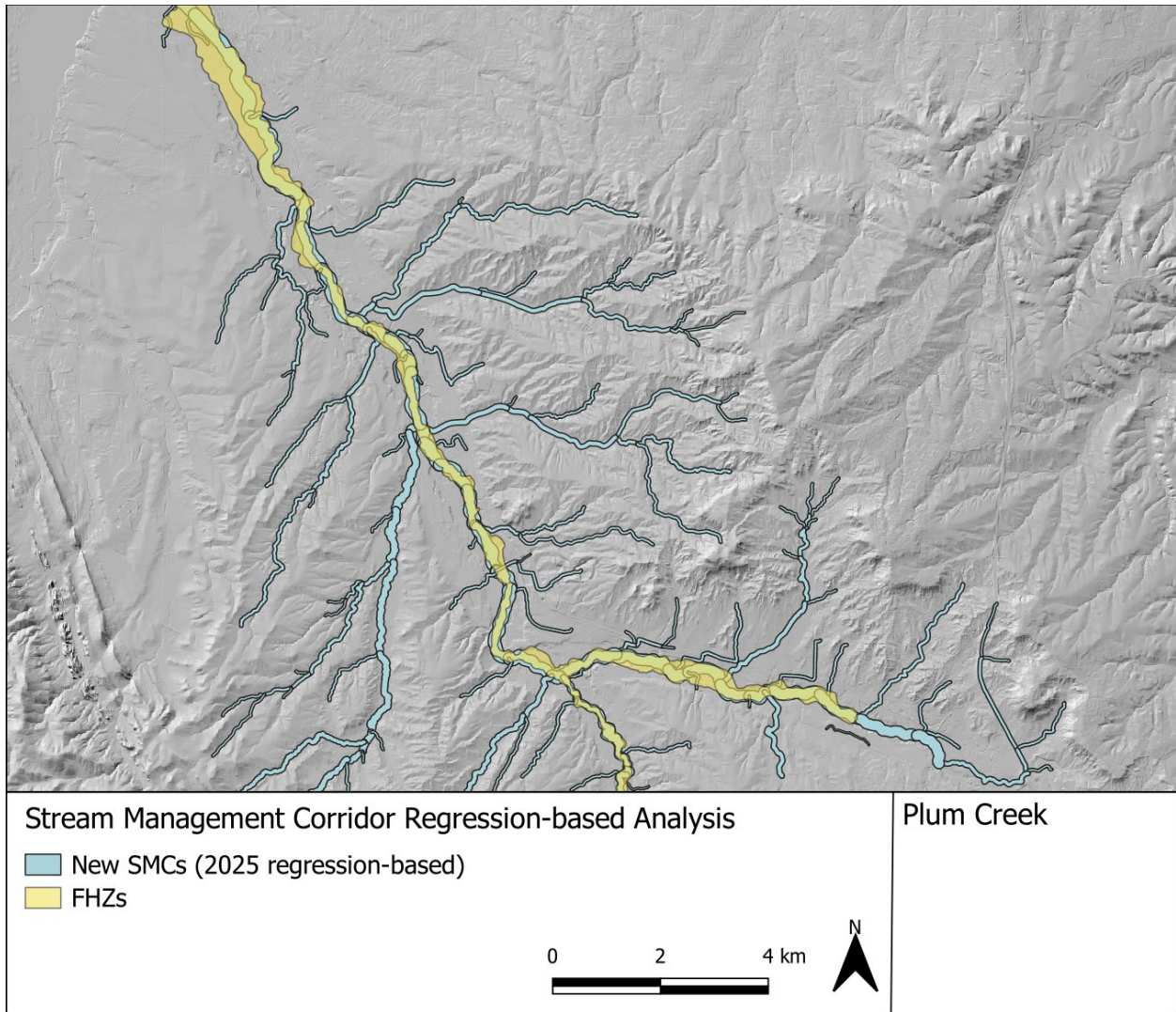


Figure 10. Plum Creek Watersheds with new SMCs (blue) and FHZs (gold)

We noted the increase in the regression equation-based SMCs widths compared to the sheer stress-based SMCs (see Figure 11, Figure 12 and Figure 13), which further confirmed the outcome as reasonable for a planning-level tool.

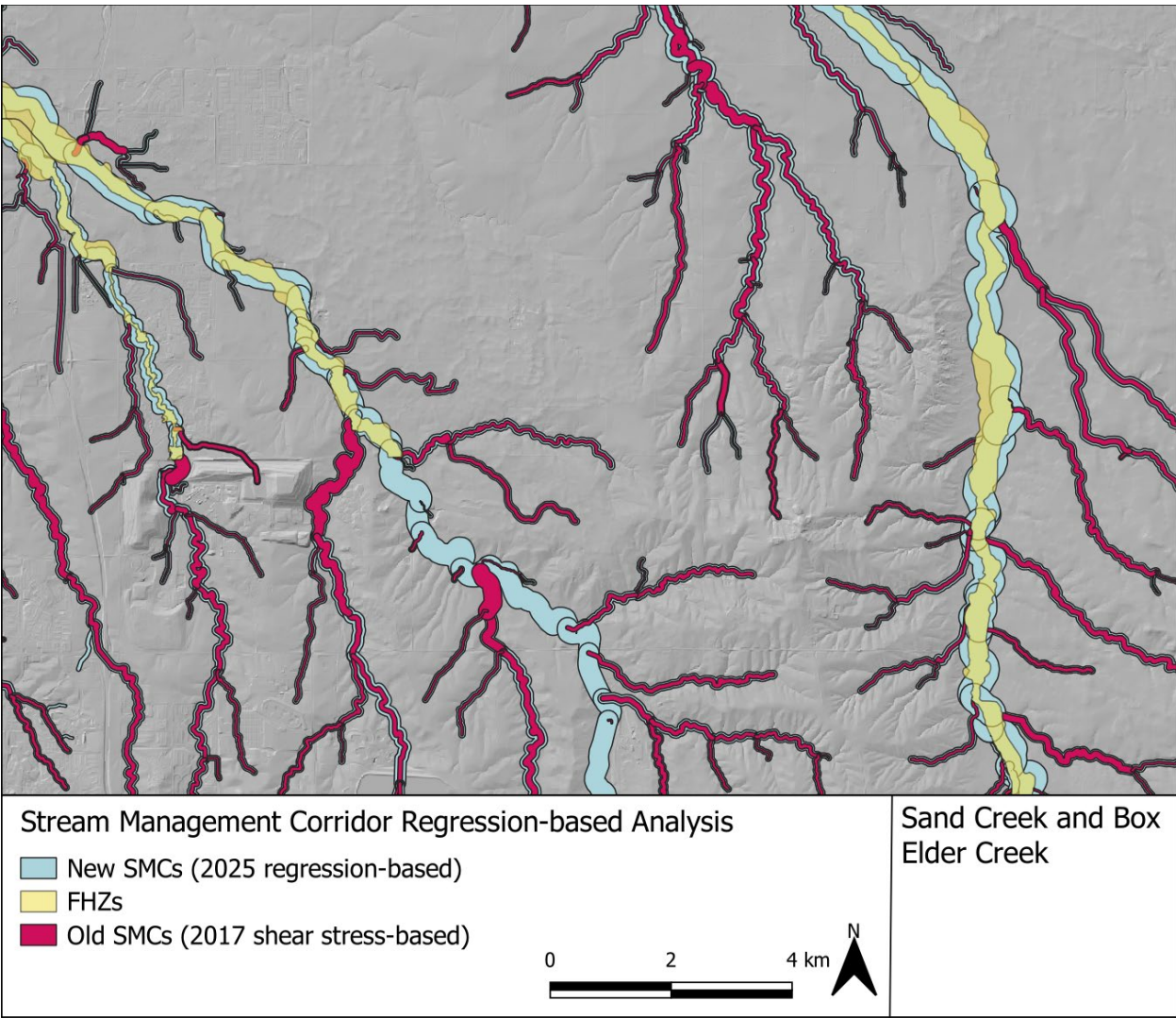


Figure 11. Box Elder Creek and Sand Creek Watersheds with old SMCs (red), new SMCs (blue), and FHZs (gold)

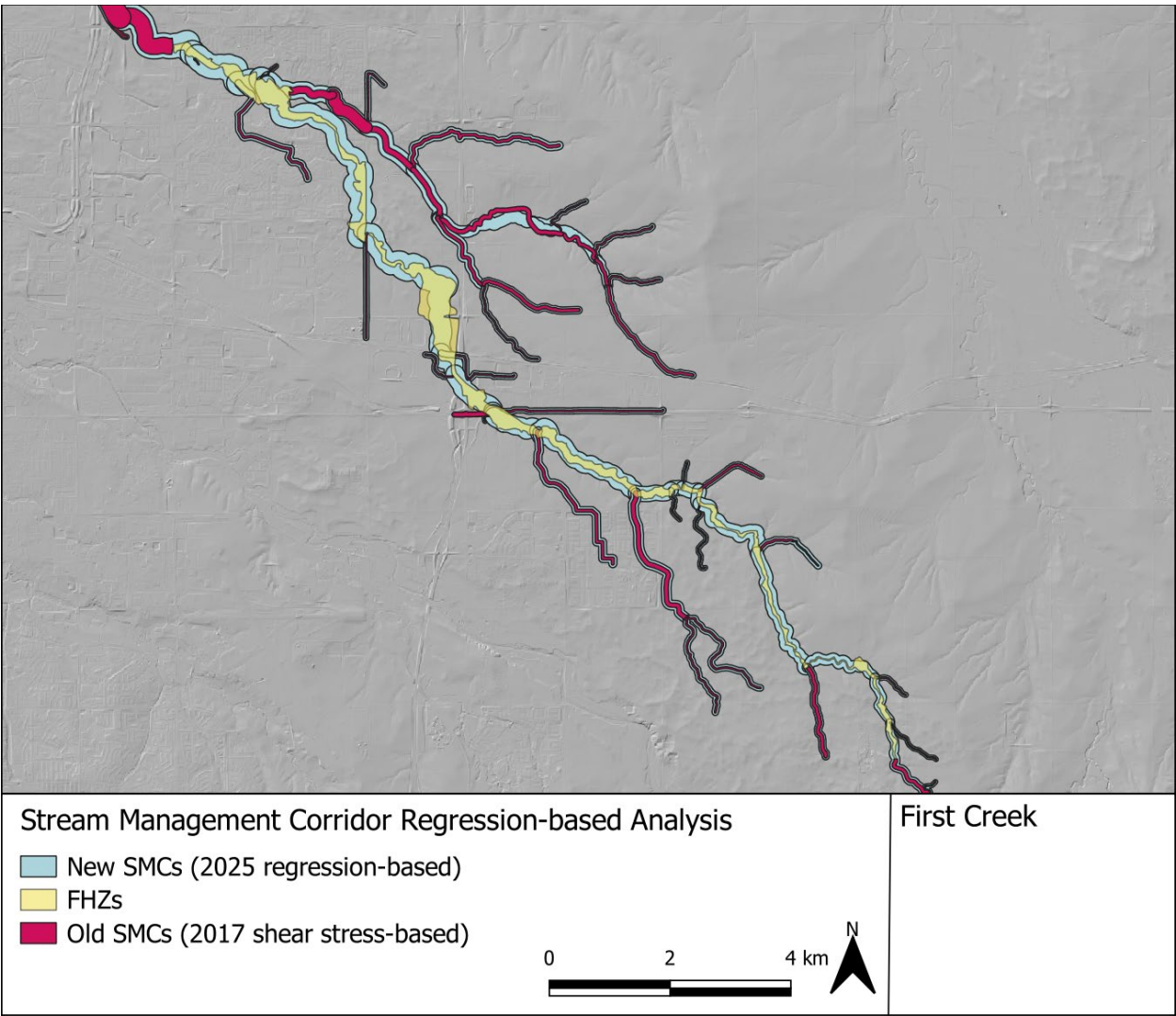


Figure 12. First Creek Watersheds with old SMCs (red), new SMCs (blue), and FHZs (gold)

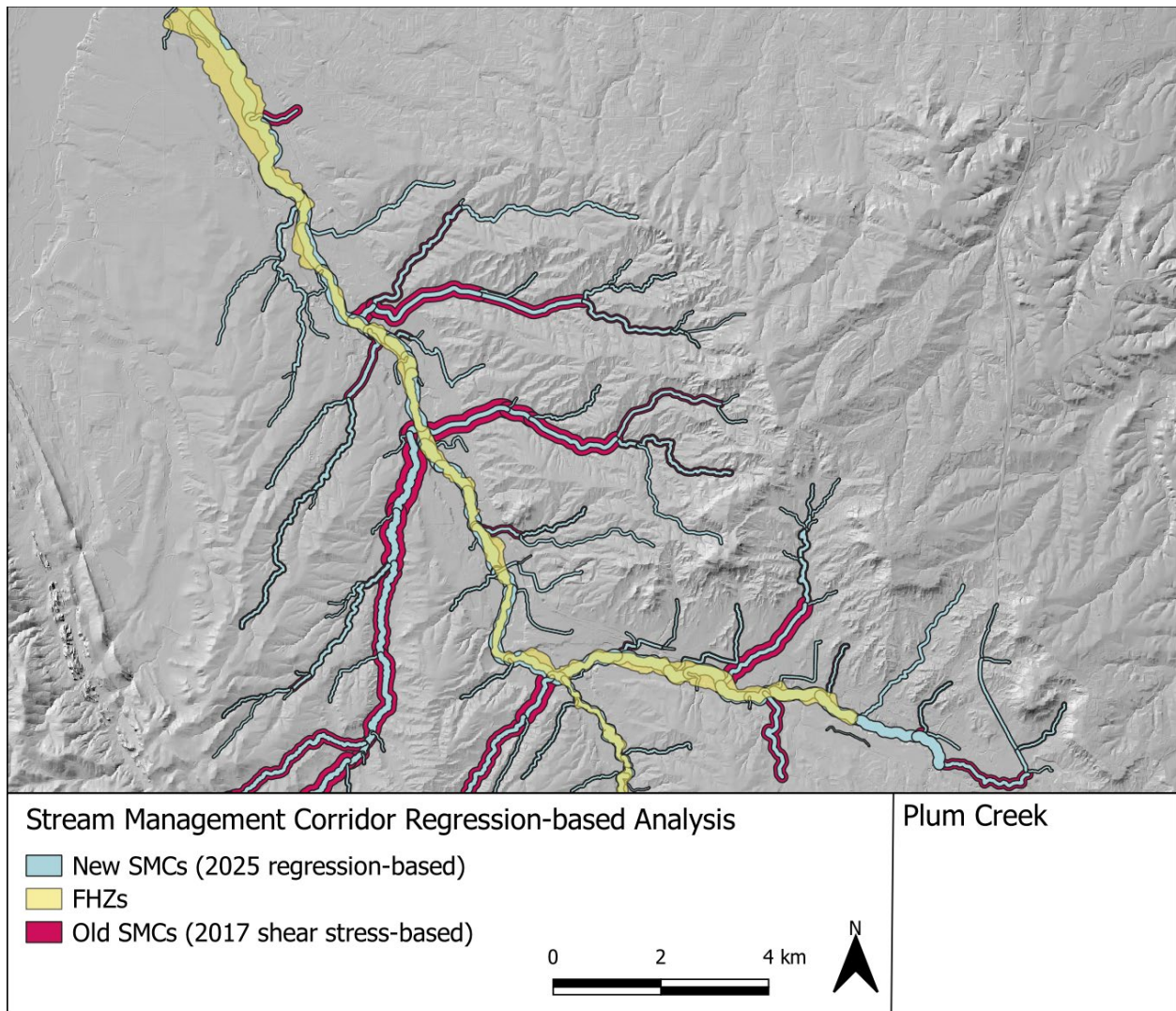


Figure 13. Plum Creek Watersheds with old SMCs (red), new SMCs (blue), and FHZs (gold)

Conclusions

A regression-based approach using stream centerline buffers and contributing drainage basin areas as an independent variable to predict valley bottom width appears to be an appropriate method to establish planning-level SMC boundaries. The regression equations calculate a continuous relationship between drainage area and SMC widths that account for elements of urban stream function: hydrology, hydraulics, geomorphology, and vegetation. The working group specifically decided the fitted line (average response) from the regression analysis was a data-driven approximate method to calculate planning-level SMC widths across a wide range of drainage areas. Regression-based SMCs, therefore, can be used as a starting point to depict the area that can accommodate flooding, allow for and even encourage natural stream processes without conflicting with development. The regression-based SMCs are not to be construed as a regulatory tool and project sponsors have the opportunity for more detailed to inform a site-specific stream management corridor.

SMC map information is believed to be accurate based on the analysis described herein, but any errors or omissions should be reported to the MHFD GIS Manager. Also, given the stream centerline buffer approach used to map the SMC, a specific SMC delineation may not account for local valley or geomorphic variability. The District cannot guarantee accuracy; however, District staff will review potential errors as they are identified.

When requested, the District will provide the GIS database used to develop the regression analysis for informational purposes only. The regression analysis relies on publicly available datasets from USGS 10-meter DEM data. While higher-resolution topographic data, such as LiDAR, may more accurately define the valley bottom extent, the GIS processing time and available tools limit the use of that data. Further, floodplain widths that reflect the broader geomorphic floodplain within urban areas are inherently difficult to delineate on a large scale. However, the FHZ Protocol (Blazewicz 2020) does include an approach to link topographic data and floodplain widths in channelized streams at the reach to segment scale.

References

Blazewicz M, Jagt K, Sholtes J. (2020) Colorado fluvial hazard zone delineation protocol version 1.0. Colorado Water Conservation Board.

Gilbert, JT, Macfarlane W, and Wheaton JM. (2016) The Valley Bottom Extraction Tool (V-BET): A GIS tool for delineating valley bottoms across entire drainage net-works. *Computers & Geosciences*. 97,1–14. doi:10.1016/j.cageo.2016.07.014.

Matrix Design Group (2018) Stream Management Corridor Buffer Calculations for Auto-Generation. Revised November 19.

MHFD (2022) Stream Management Corridors Memorandum. February 18.

MHFD (2025) Stream network. Available to download here: <https://gis-mhfd.hub.arcgis.com/search?categories=%252Fcategories%252Fhydrology%2Chydrologic>

Miguez F (2023). *_nlraa: Nonlinear Regression for Agricultural Applications_*. R package version 1.9.7, <<https://CRAN.R-project.org/package=nlraa>>.

Moore RB, McKay LD, Rea AH, Bondelid TR, Price CV, Dewald TG, Johnston CM (2019) User's guide for the national hydrography dataset plus (NHDPlus) high resolution: U.S. Geological Survey Open-File Report 2019–1096:1-66. <https://doi.org/10.3133/ofr20191096>

Murphy B, Nelson PA, Gilbert J, Sholtes J (2025) What is an urban riverscape? Typological naming of urban riverscapes to support planning and management. *PLOS Water* 4(4): e0000345. <https://doi.org/10.1371/journal.pwat.0000345>
O'Brien G, Wheaton JM. River styles report for the Middle Fork John Day Watershed, Oregon. Logan (UT): Ecogeomorphology and Topographic Analysis Lab, Utah State University, Prepared for EcoLogical Research, and Bonneville Power Administration; 2014. 215 p.

R Core Team (2023). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria. <<https://www.R-project.org/>>.

USGS [U.S. Geological Survey] (2025) 10-Meter Resolution Digital Elevation Model. <https://www.usgs.gov/the-national-map-data-delivery>.

Wheaton J, Fryirs K, Brierley G, Bangen S, Bouwes N, O'Brien G. (2015) Geomorphic mapping and taxonomy of fluvial landforms. *Geomorphology*. 248:273–95. <https://doi.org/10.1016/j.geomorph.2015.07.010>

Attachment 1: GIS Workflow

Attachment 1 GIS Workflow

Valley bottom extraction tool overview

The valley bottom extraction tool (VBET) is used to identify the valley bottom of a riverscape, and roughly separate it into geomorphic units (channel, active floodplain, and inactive floodplain). A combination of slope and HAND data are combined in the VBET algorithm to delineate the extent of the valley bottom. Using a 10m digital elevation model (DEM; USGS 2025) and a channel area network as inputs (Moore et al. 2019), VBET estimates the valley bottom extents, which includes a channel, topographically low-lying active floodplain (low lying valley bottom), and an elevated, more distal floodplain (elevated valley bottom)

In addition to delineating the extent of valley bottom, VBET segments the valley bottom output into discrete polygons, whose size varies based on the size of the stream. These polygons are called discrete geographic objects (DGOs) that VBET used to calculate discrete measurements related to stream corridors such as valley bottom width and upstream drainage area. At the center of each DGO, VBET places a point, referred to as an integrated geographic object (IGO), which captures the DGO measurements calculated over a moving window (i.e., the average width value of IGOs that fell within one MHFD stream segment [there could be one than one IGO in one MHFD stream network reach]; see **Figure 1**). The VBET derived information summarized in the IGOs was used to develop the empirical relationships between drainage area and SMC width (valley bottom width).

The GIS analysis process to develop these relationships is summarized below.

Workflow

To develop an empirical relationship (i.e., regression) between tributary area and floodplain widths, the working group created the following workflow:

1. Download valley bottom extraction tool (VBET) models of MHFD from Riverscapes Consortium data.riverscapes.net
2. Using QGIS or ArcGIS, extract Integrated Geographic Object (IGOs), which contain data for a moving window analysis of the valley bottom polygons such as area, width, etc.
3. Open the valley bottom polygons as well as the MHFD segmented floodplain polygons.
4. Within a watershed, select features from the MHFD floodplain layer that has similar feature representation as the valley bottom polygons as well as good overlap with IGOs. Select as many floodplain segments as possible sampling all parts of the watershed.
5. Buffer selected MHFD polygons by 50-100m to capture any VBET IGOs that fall outside its existing boundary. See **Figure 2** for example of this process.
6. Delete IGOs from within floodplain segments where they don't belong, this usually occurs at tributary junctions where two floodplains meet. These IGOs can skew the width.
7. Use a spatial join with the buffered MHFD floodplain polygons as the bounding feature and the IGOs as the input from which to join attribute data. Do a one-to-many join since many

IGOs are contained within a floodplain polygon. Select the integrated width attribute as the attribute to join to the floodplain polygon.

8. Use the aggregate tool to summarize the IGOs for each floodplain polygon. Use unique ID from the floodplain layer as the 'aggregate by' field and use the function 'mean' to average the IGO integrated width values across the floodplain segment.
9. Export attribute table as .csv to open in Excel.
10. Once in Excel, plot the upstream drainage area 'Catch_SUM' of the floodplain segment by the aggregated width value from step 8.
11. By looking at the plot identify any extreme outliers and remove as a data point from the plot. These outliers are usually very narrow floodplain with high drainage area, resulting from the encroached urban setting of most downstream ends of rivers. They could also be from rivers found in confined settings. Some outliers representing extremely wide floodplains exist on but were found to be less common.
12. Obtain a nonlinear regression equation between floodplain width and drainage area from plot and obtain confidence intervals. The equation typically takes the form of a power law: $[SMC\ WIDTH] = a[DRAINAGE\ AREA]^b$. See the discussion below regarding regression analysis methods.
13. Using the MHFD stream network as the input, create a buffer using the width from the regression equation. To do this, create a new buffer field in the stream network attribute table and use the field calculator to input the regression equation with the field containing upstream drainage area as the input variable for the regression.
14. Buffer the network by the resulting attribute value and map the results.

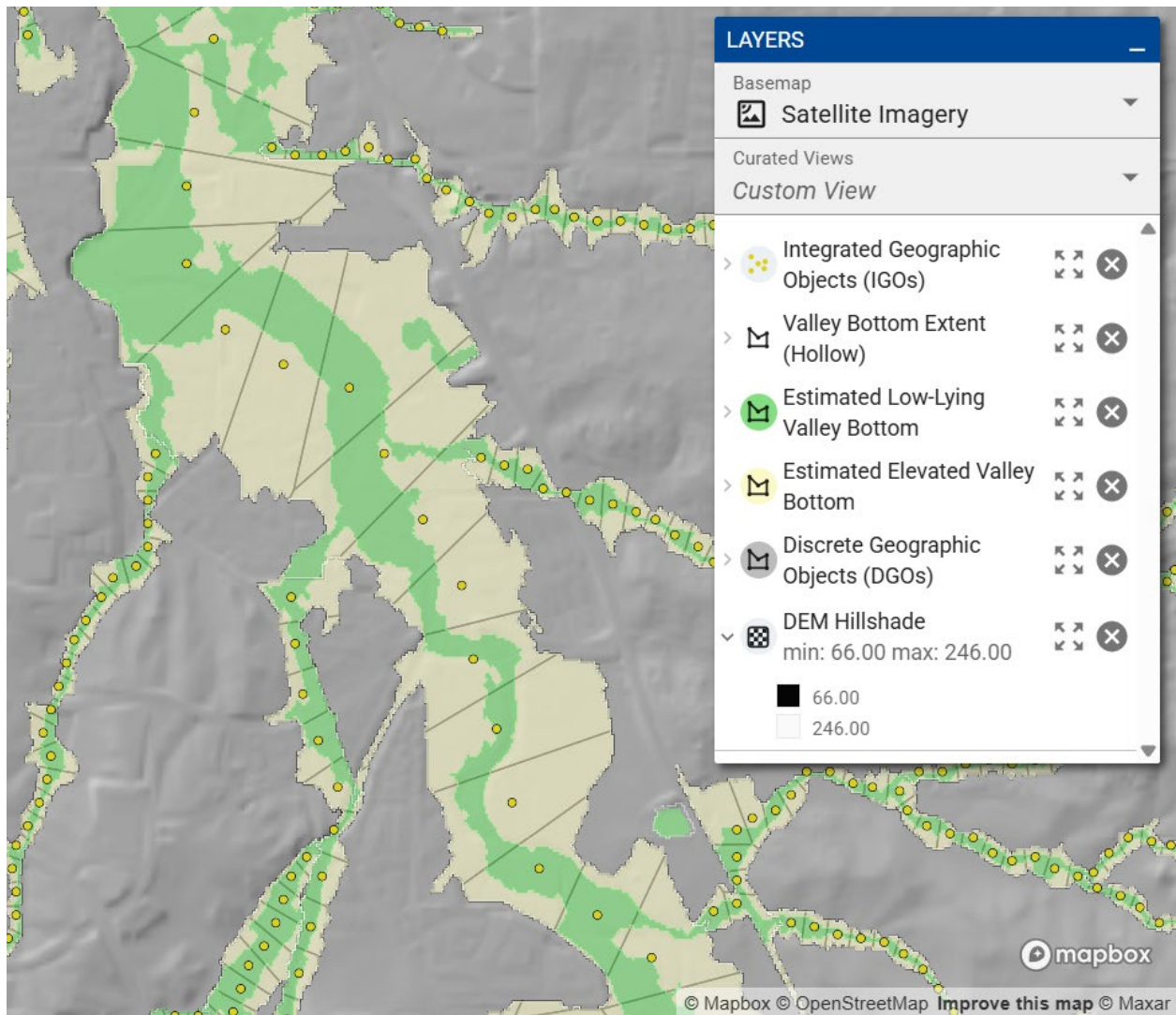


Figure 1. VBET polygons are represented as the combination of green (low lying valley bottom) and beige (elevated valley bottom). The yellow dots are the IGOs. The black outlines are the DGOs.

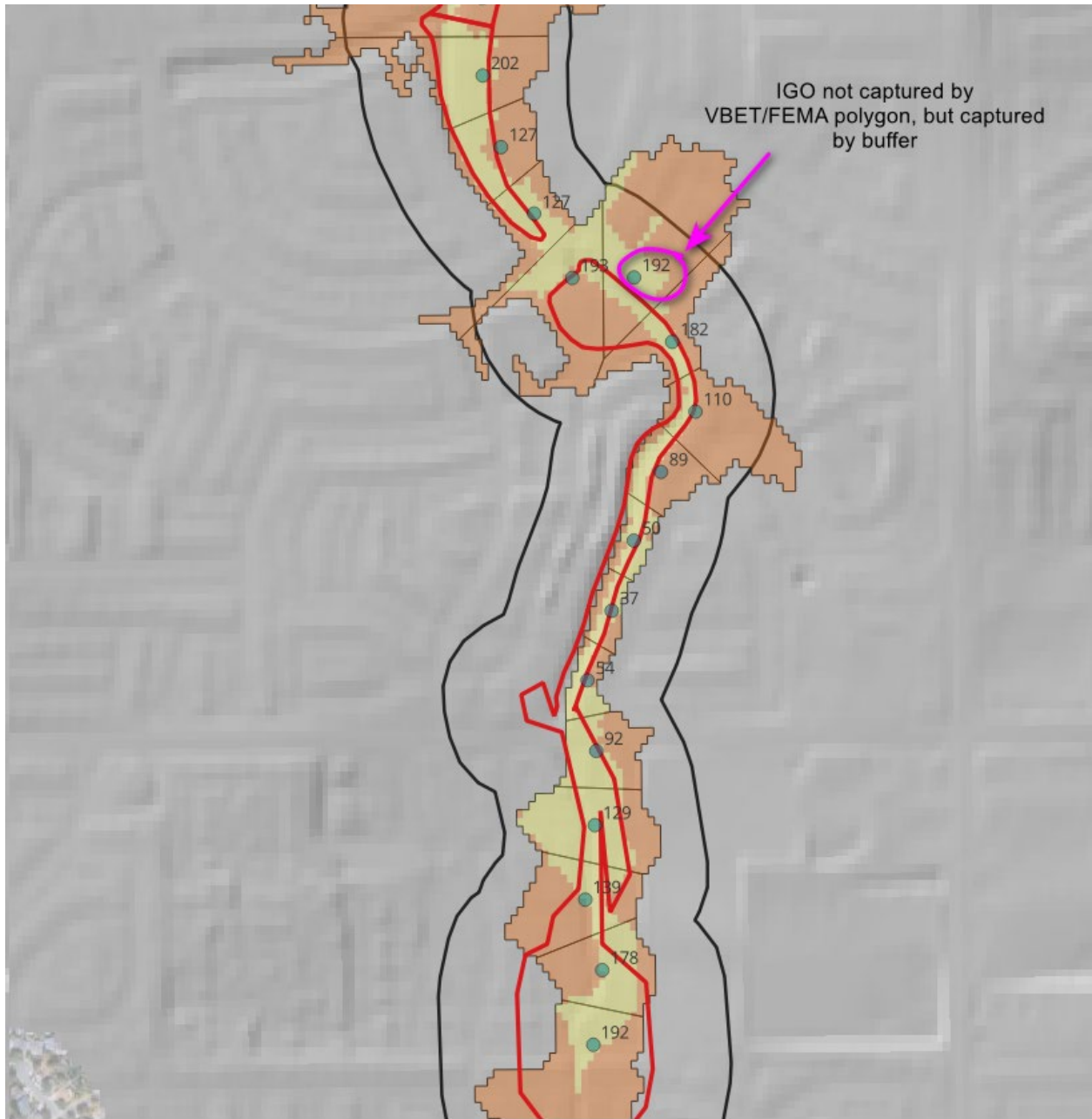
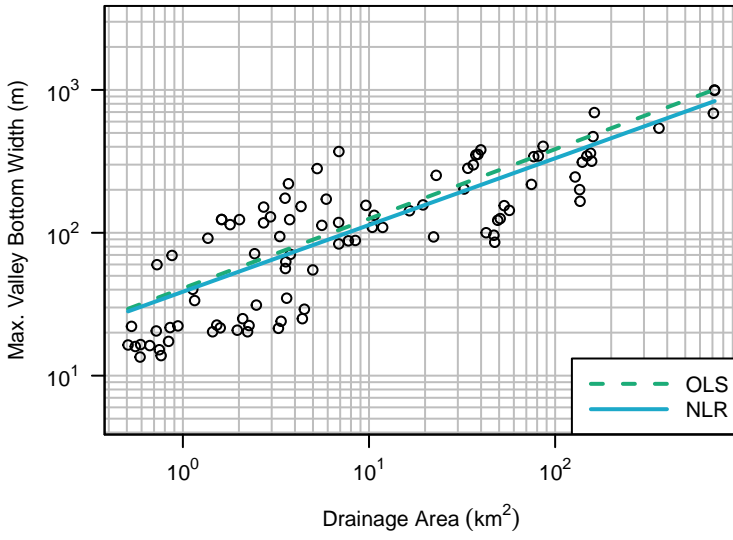


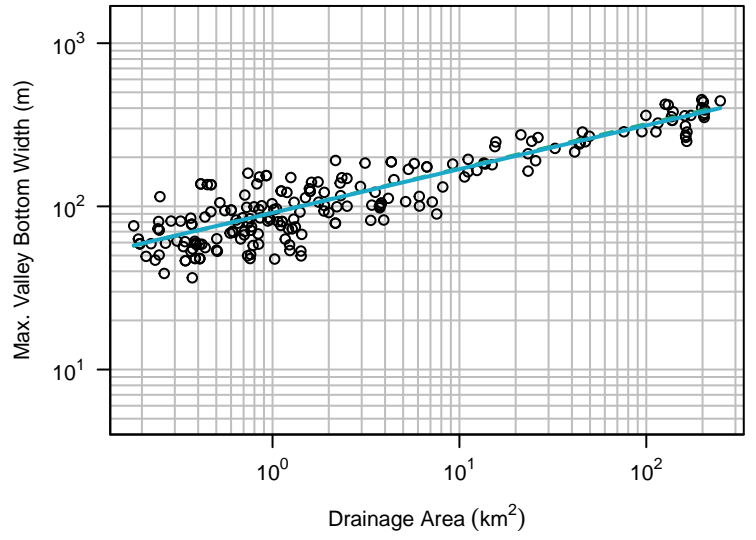
Figure 2. This represents the process in steps 4-5. The VBET polygons are represented as the combination of orange and yellow. The red outline represents the MHFD floodplain polygons. The green dots are the IGOs. The Black outline is the selected and buffered MHFD polygon.

Attachment 2: Regression equation plots

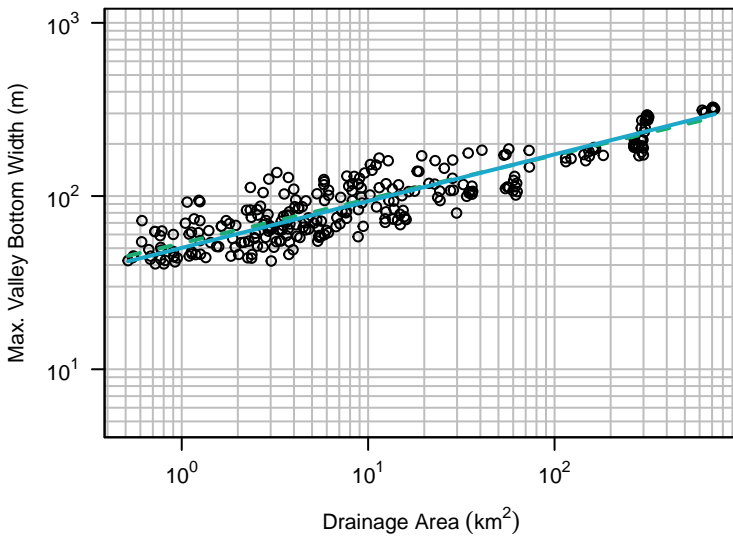
Boulder



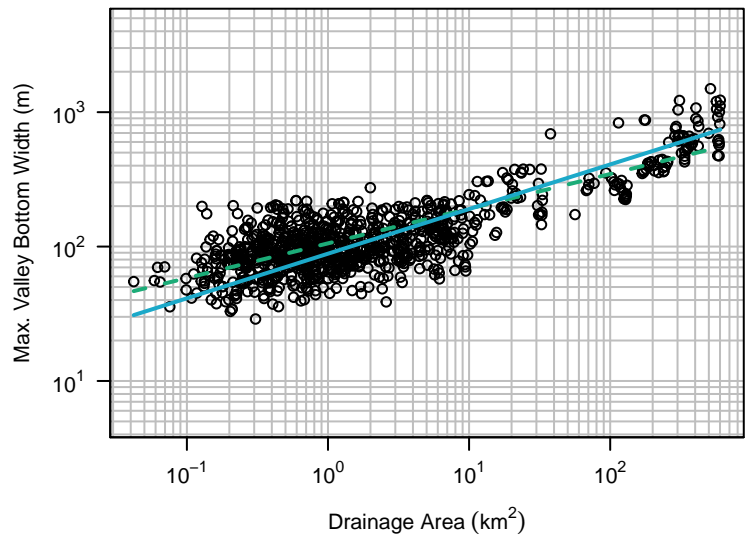
Sand



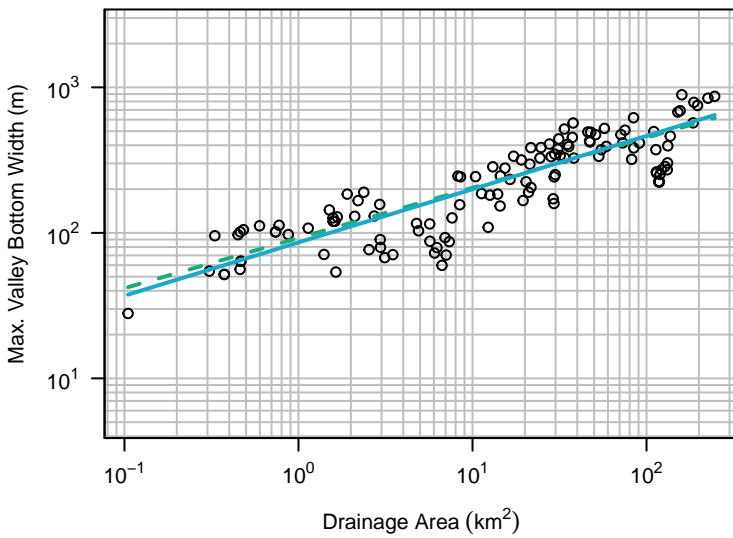
Plum



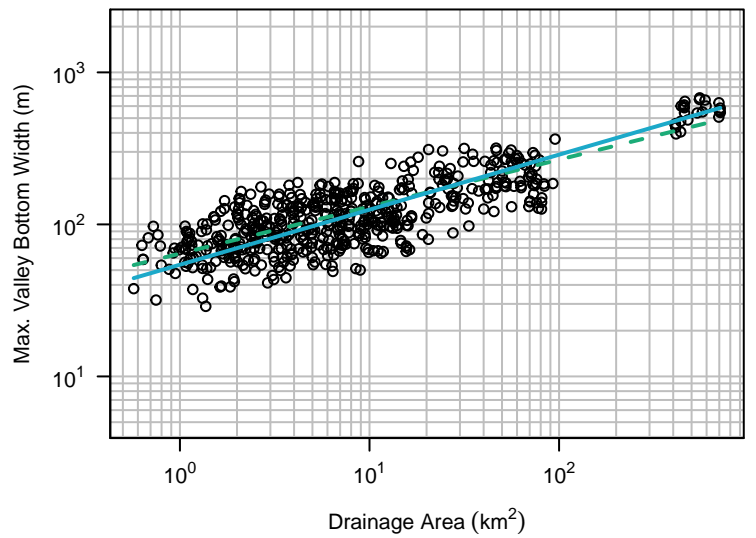
Box Elder



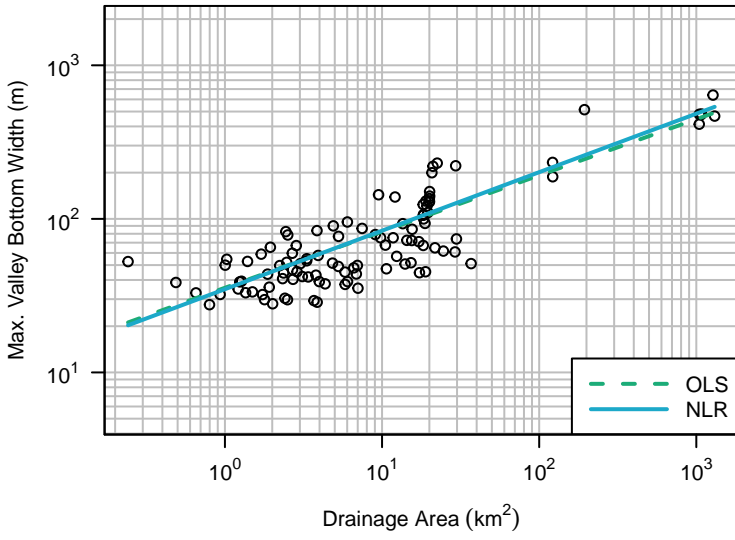
First Creek



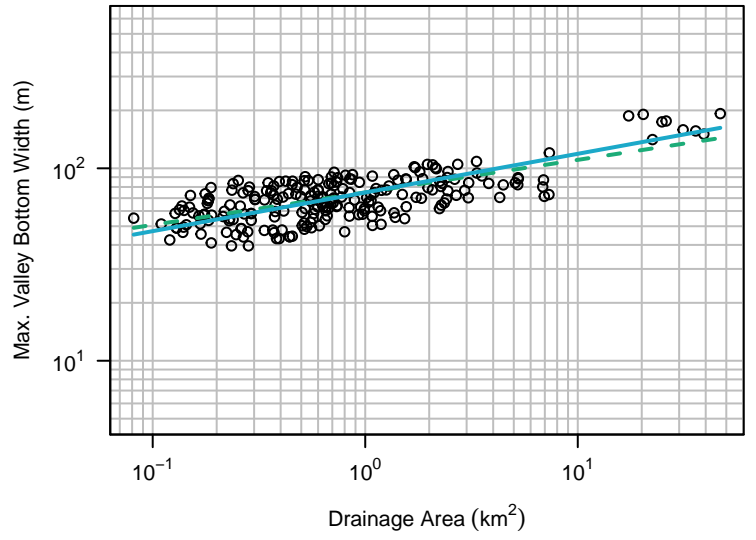
Cherry



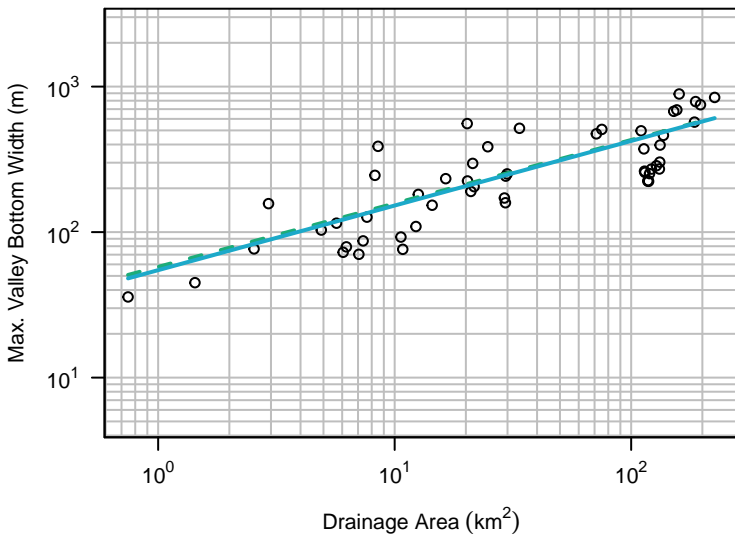
Clear



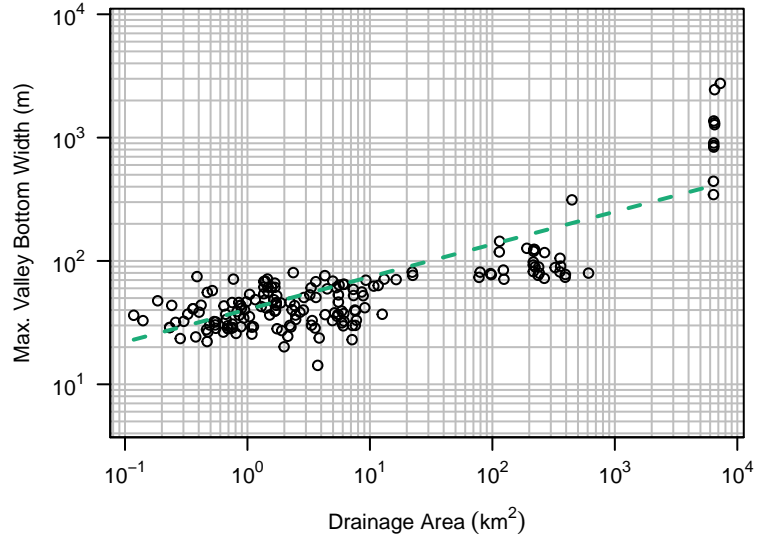
Lakewood



Big Dry



Chatfield/Bear



Chatfield/Bear/Plum/Lakewood

