APPENDIX B: CHANNEL MIGRATION ANALYSIS

Document Creation: Generated on Aug. 13, 2019 by Elizabeth Langford, Michael Blazewicz, and Katie Jagt.

Updates: None.

GENERAL INFORMATION

Title of Dataset: Historic Channel Margin Delineations for Select Stretches of the Rio Grande and Conejos Rivers, Colorado

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Funding sources: The *Rio Grande, Conejos River, and Saguache Creek Stream Management Plans: Phase 1, Geomorphic Assessment* is funded by Rio Grande Headwaters Restoration Project through a grant provided by the Colorado Water Conservation Board (CWCB).

Intended Use: Historic channel margins were delineated using available aerial photography for the years 1960, 1975, 1998 and 2017. These delineations identify an approximated, but not exact, location of the channel margin at the time the image was taken. Error exists in the delineations both as a result of difficulties in identifying the banklines due to obscurance from vegetation, clarity of the photographs, and multiple channel threads that make it difficult to choose a main bankline. Additionally error is introduced where the photos have been shot at an oblique angle and/or where georectification of the photos is inexact despite our best efforts to rectify them. These files are intended to be used to investigate at the reach level (1:8000 or greater) locations where significant channel migration have occurred in recent history in order to assist in the geomorphic assessment of the streams for stream management planning. These delineations are not intended to be used for calculating channel migration or bank erosion rates and SHOULD NOT be used for identification or location of fluvial hazards.

SHARING/ACCESS INFORMATION

Licenses/restrictions placed on the data, or limitations of reuse: None

Recommended Citation: Rio Grande Headwaters Restoration Project (2019). Rio Grande, Conejos River, and Saguache Creek Stream Management Plans: Phase 1, Geomorphic Assessment. Report prepared for the Colorado Water Conservation Board and the Rio Grande Basin Roundtable Alamosa, CO.

Citation for and links to publications that cite or use the data:

Rio Grande Headwaters Restoration Project. (2019). Rio Grande, Conejos River, and Saguache Creek Stream Management Plans: Phase 1. Report prepared for the Colorado Water Conservation Board and the Rio Grande Basin Roundtable Alamosa, CO.

STUDY INFORMATION

Study Dates: June-August 2019

Source of Aerial Photos: All Aerials are from The Land Processes Distributed Active Archive Center (LP DAAC), located at USGS/EROS, Sioux Falls, SD. http://lpdaac.usgs.gov

Years of imagery delineated: 1960/1966, 1975, 1998, 2017. These years were selected based on data availability, hydrology data, and interval between photos.

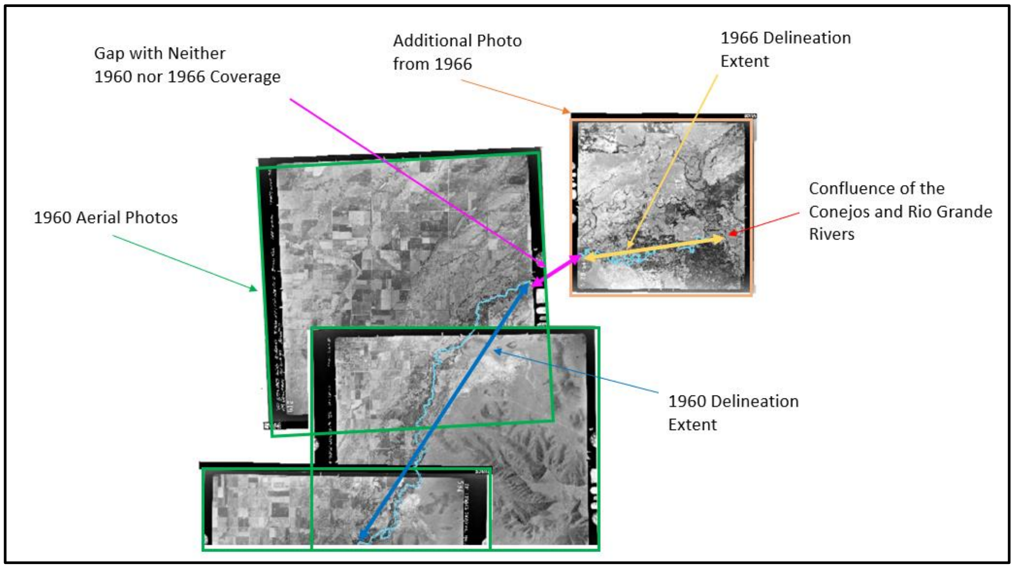
Geographic Area Covered: Conejos: Start: 106°11’16.293”W 37°3’14.678”N

End: 105°44’1.584”W 37°18’14.543”N

Rio Grande: Start: 105°58’46.123”W 37°33’49.439”N

End: 105°50’31.579”W 37°27’41.114”N

Data gaps: There is one data gap in the 1960 Conejos delineation--the image for the river stretch immediately upstream of the confluence of the Conejos and the Rio Grande. A portion of this area is covered by an image from 1966, however, a gap remains between the 1960 imagery and the 1966 imagery. The aerial image from 1966 is listed under 1SVBBI00100341.tif and covers the stretch from 105°47’45.488”W, 37°17’50.898”N to 105°44’1.584”W 37°18’14.543”N. This is the only reach in the 1960 delineations that is from 1966 data.



DATA & FILE OVERVIEW

File list (filenames, directory structure (for zipped files) and brief description of all data files):

1960 Conejos.shp_v1: Channel Margin Delineation for the Conejos River in 1960.

1975 Conejos.shp_v1: Channel Margin Delineation for the Conejos River in 1975.

1998 Conejos.shp_v1: Channel Margin Delineation for the Conejos River in 1998.

2017 Conejos.shp_v1: Channel Margin Delineation for the Conejos River in 2017.

1960 Rio Grande_v1.shp: Channel Margin Delineation for the Rio Grande in 1960.

1975 Rio Grande_v1.shp: Channel Margin Delineation for the Rio Grande in 1975.

1998 Conejos_v1.shp: Channel Margin Delineation for the Rio Grande in 1998.

2017 Conejos_v1.shp: Channel Margin Delineation for the Rio Grande in 2017.

Each .shp consists of the following individual files: .shp, .shx, .prj, .dbf, .sbn .xml, .sbx, .cpg

Additional related data that is not included in the current data package:

Additional reaches of the Rio Grande had channel margins delineated by Joel Sholtes, University of Colorado as a portion of the Colorado Fluvial Hazard Mapping Pilot Project, CWCB, 2019.

Rio Grande: Start: 106°50'34.81"W, 37°47'0.47"N

End: 105°58’46.123”W, 37°33’49.439”N

Projected Coordinate System: NAD_1983_UTM_Zone_13N

Geographic Coordinate System: GCS_North_American_1983

Datum: D_North_American_1983

Prime Meridian: Greenwich

False Easting: 500000

False Northing: 0

Base Projection: Transverse_Mercator

Scale Factor: 0.99960000

Central_Meridian: -105.0

Latitude of Origin: 0.0

Attribute data: FID: EMPTY

SHAPE: POLYLINE

RIVER NAME: The river the margin delineation is for (Rio Grande or Conejos)

YEAR: Aerials from this year were used in the creation of the file. Note, 1966 is listed as 1960 for the one reach where 1966 photos were used.

METHODOLOGICAL INFORMATION

Description of methods used for collection/generation of data:

Memo: “Delineating Channel Margins” by Joel Sholtes, PhD, University of Colorado:

- Yellow lines indicate channel margins of “active channel”. This includes un-vegetated bars and islands.
- Use vegetation as a guide to channel margin: un-vegetated bars and islands are considered active channel
- Where tall trees are on stream banks and obscure bank line, approximate channel margin as middle of closest tree canopy.
- Keep polyline endpoints in same direction.

Standards and calibration information, if appropriate: Range of scale used in Arcmap used for visual delineations: 1:2,000-1:4,000

Describe any quality-assurance procedures performed on the data: Data was compared with LiDAR to ensure no major bedrock formations were mapped as part of the historic channels.

ADDITIONAL DATA-SPECIFIC INFORMATION

Georectification: The 1960 and 1975 aerial imagery was georectified by Daniel Boyes at the Rio Grande Headwaters Restoration Project in Fall 2018. In some locations (Rio Grande 1960, Conejos 1975) the georectification was adjusted by Elizabeth Langford in the Summer of 2019. The adjustments were done by manually adding additional feature-to-point control points based on the local roads of Colorado shapefile (CDOT) as well as the NHD Stream layer, where appropriate. Elizabeth Langford also georectified raw aerial imagery for the 1975 Rio Grande delineation. A combination of raw data and previously georectified images were used for the 1975 Conejos delineation.

Local Roads of Colorado (downloaded July 2019): https://data.colorado.gov/Transportation/Local-Roads-in-Colorado/qvrk-xsmj

National Hydrography Dataset (downloaded July 2019): https://viewer.nationalmap.gov/basic/?basemap=b1&category=nhd&title=NHD%20View

Aerial Images Used:

CONEJOS

1960
1SVBBI00100341.tif
A5504201106121.tif
A5504200703221.tif (up to 30m off)
A5504201105961.tif (up to 20m off)
A5504201105941.tif
A5504201105631.tif
A5504201105661.tif (up to 40m off)
A5504201105651.tif

1975
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1VDSD003400621.tif
1VDSD0039001412.tif
1VDSD003900031.tif

1998
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03710664.NWS.1034019.tif
03710664.NES.1034018.tif
03710663.SES.1034044.tif
03710557.NWS.1032813.tif
03710557.NES.1032812.tif
03710550.NWS.1032730.tif
03710549.SWS.1032703.tif
03710549.SES.1032702.tif
03710549.NES.1032700.tif
03710542.SWS.1032728.tif
03710542.SES.1032727.tif

2017
ortho_1-1_1n_s_co021_2017_1sid

RIO GRANDE

1960
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A5504200602581.tif

1975
1VDSD003400671.tif

1998
03710525.NWS.1032689.tif
03710534.NWS.1032721.tif
03710533.NES.1032692.tif
0310525.SWS.1032691.tif
03710525.SES.1032690.tif

2017
ortho_1-1_1n_s_co003_2017_1.sid

APPENDIX C: SMP TRACER GRAVEL STUDY

RIO GRANDE STATE WILDLIFE AREA CHANNEL BED MOBILITY STUDIES

An important part of river function is the movement of sediment through a river corridor and mobilization of the sediments on the channel bed. These studies look at how much flow is needed in the Rio Grande to pick up and move the bed material and how frequently these flows occur.

IMPORTANCE OF BED MOBILITY

Rivers adjust their shape and composition in response to the sediment and water supplied from the watershed and adjacent hillslopes and channel banks. The movement of sediment on a streambed affects instream and riparian habitat at various scales: At smaller scales, a lack of bed mobility may allow the buildup of fine particles such as sands and silts in the interstitial spaces between larger grains of sediment such as cobbles and gravels. These interstitial spaces are important for fish species but also for key components to the food web such as algae, zooplankton, phytoplankton, and macroinvertebrates.

At larger scales, the mobilization and deposition of bed sediments creates and maintains pools and riffles. Over the long term, changes in the bed surface caused by the mobility of the sediment on the bed are necessary to maintain habitat quality in river systems. Evacuating fine sediment from pools and the deposition of coarse sediment on bars may increase the quality and quantity of habitat used for spawning and rearing. Conversely, a lack of flows that trigger bed mobility will tend to cause either long-term scour or aggradation and tends to simplify the channel, reduce bedform variability, and homogenize aquatic and riparian habitat. Riparian vegetation establishment and succession is dependent upon the mobilization and deposition of sediment within the stream corridor.

The Rio Grande at the State Wildlife Area near Monte Vista, looking upstream on August 29, 2019. Approximate flow 300 cfs.

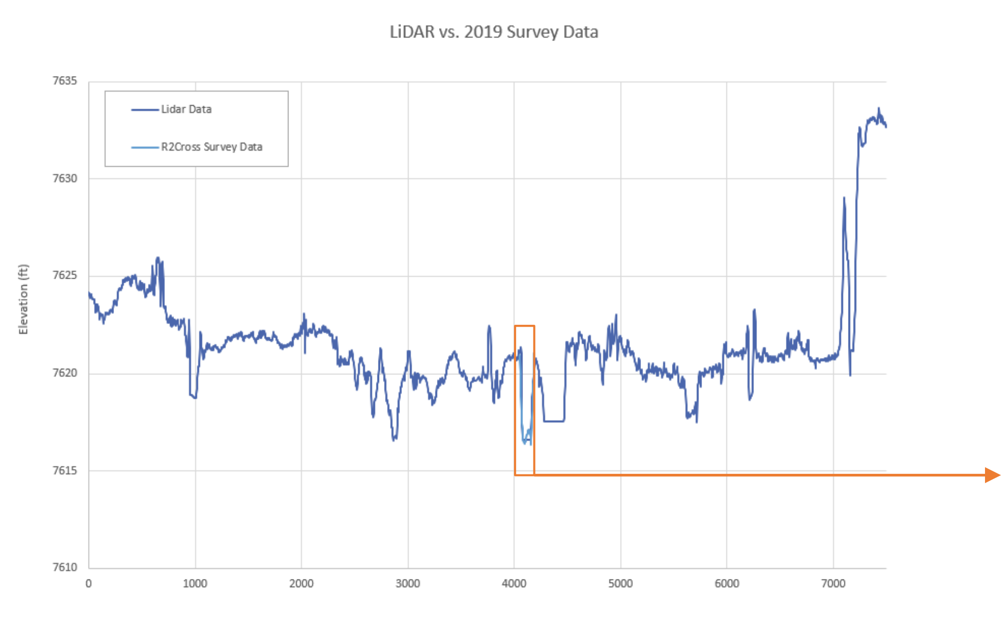
SEDIMENT CHARACTERISTICS

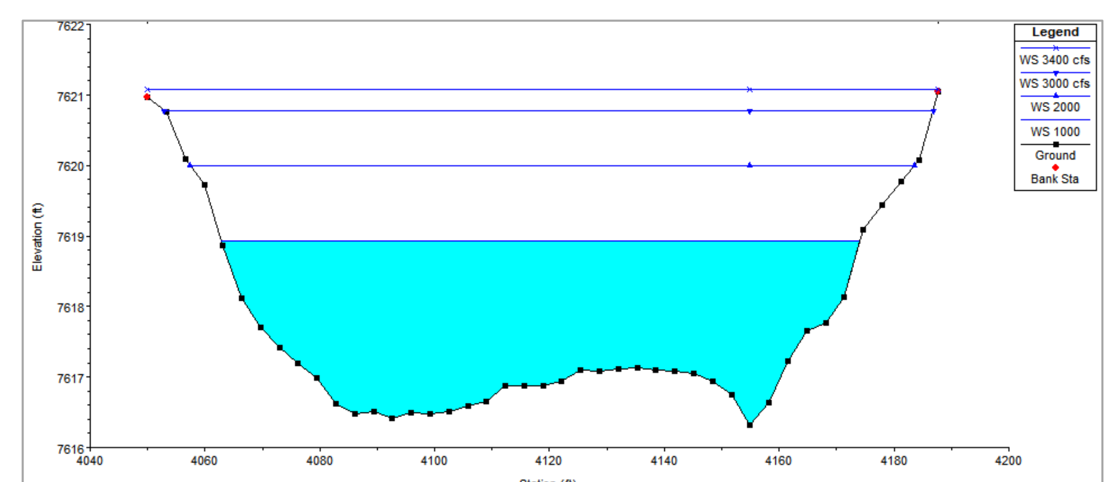
Description of Particle Size	Size (mm)	Pebble Count
Sand and Silts	<2	0
Very Fine Gravel	2 - 4	0
Fine Gravel	4 - 6	0
Fine Gravel	6 - 8	0
Medium Gravel	8 - 11	1
Medium Gravel	11 - 16	6
Coarse Gravel	16 - 22	8
Coarse Gravel	22 - 32	22
Very Coarse Gravel	32 - 45	26
Very Coarse Gravel	45 - 64	27
Small Cobble	64 - 90	9
Small Cobble	90 - 128	1
Large Cobble	128 - 180	0
Large Cobble	180 - 256	0

The Rio Grande channel bed at the State Wildlife Area has an average grain size of 29mm, which is classified as a coarse gravel.

CHANNEL GEOMETRY AND HYDRAULICS

The Rio Grande State Wildlife Area has full topographic coverage by the LiDAR. This was supplemented with survey data collected by the RGHRP in the summer of 2019. Hydraulic calculations were done using the survey data. For the purposes of this study, we are concerned only with flows that remain in the main channel of the Rio Grande. Simple calculations were done using the manning's equation to determine that the maximum capacity of the main channel is approximately 3400 cfs to 3600 cfs.





INCIPIENT MOTION CALCULATIONS—WHEN DO THE PARTICLES ON THE CHANNEL BED MOVE?

For the Rio Grande at the State Wildlife Area near Monte Vista, CO, flows between **900 and 1200 cfs** begin to mobilize the particles on the channel bed.

There are two ways we can calculate this:

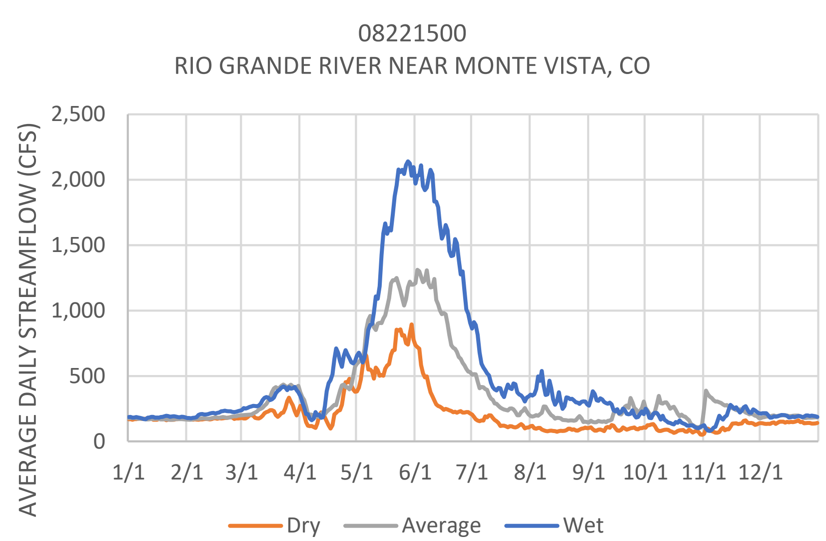
1) We calculate the critical shear stress, which uses a standardized value (0.047) for the "average" critical value of the Shields Parameter (t_{*c}) that has been observed to cause particle movement in a suite of flume and channel experiments as well as the average grain size in the channel which our team has measured. We then compare the critical shear stress to the shear stress in the channel as calculated using a hydraulic model—when the channel shear stress exceeds the critical shear stress, the average grain size is said to be mobilized.
2) By using the Shields diagram, which illustrates the mobilization threshold as a function of two variables: the critical shear force (t_*) and the particle Reynolds number (Re_*). Each of these variables is calculated for every flow that is expected in the channel and uses the average grain size of the channel bed. The τ_* and Re_* are plotted for each flow and if the point is above the line on the Shields diagram, the flow can mobilize the grains on the bed. For this gravel-bedded system, the critical shear force threshold is approximate 0.050 for all particle Reynolds numbers (the area shaded in blue, below).

CRITICAL SHEAR STRESS

Flow (cfs)	D50 of Channel Bed (mm)	Particle Class	τ_o Channel Shear from HEC-RAS (lb/ft2)	τ_c Critical Shear Stress (lb/ft2)	Conclusion
100	29	coarse gravel	0.14	0.4606	No Movement
200	29	coarse gravel	0.20	0.4606	No Movement
300	29	coarse gravel	0.24	0.4606	No Movement
400	29	coarse gravel	0.28	0.4606	No Movement
500	29	coarse gravel	0.32	0.4606	No Movement
600	29	coarse gravel	0.35	0.4606	No Movement
800	29	coarse gravel	0.41	0.4606	No Movement
1000	29	coarse gravel	0.47	0.4606	Flow Moves Particle
1200	29	coarse gravel	0.52	0.4606	Flow Moves Particle
1400	29	coarse gravel	0.56	0.4606	Flow Moves Particle
1600	29	coarse gravel	0.6	0.4606	Flow Moves Particle
1800	29	coarse gravel	0.63	0.4606	Flow Moves Particle
2000	29	coarse gravel	0.66	0.4606	Flow Moves Particle
2200	29	coarse gravel	0.69	0.4606	Flow Moves Particle
2400	29	coarse gravel	0.72	0.4606	Flow Moves Particle
2600	29	coarse gravel	0.75	0.4606	Flow Moves Particle
2800	29	coarse gravel	0.78	0.4606	Flow Moves Particle
3000	29	coarse gravel	0.81	0.4606	Flow Moves Particle
3200	29	coarse gravel	0.83	0.4606	Flow Moves Particle
3400	29	coarse gravel	0.86	0.4606	Flow Moves Particle

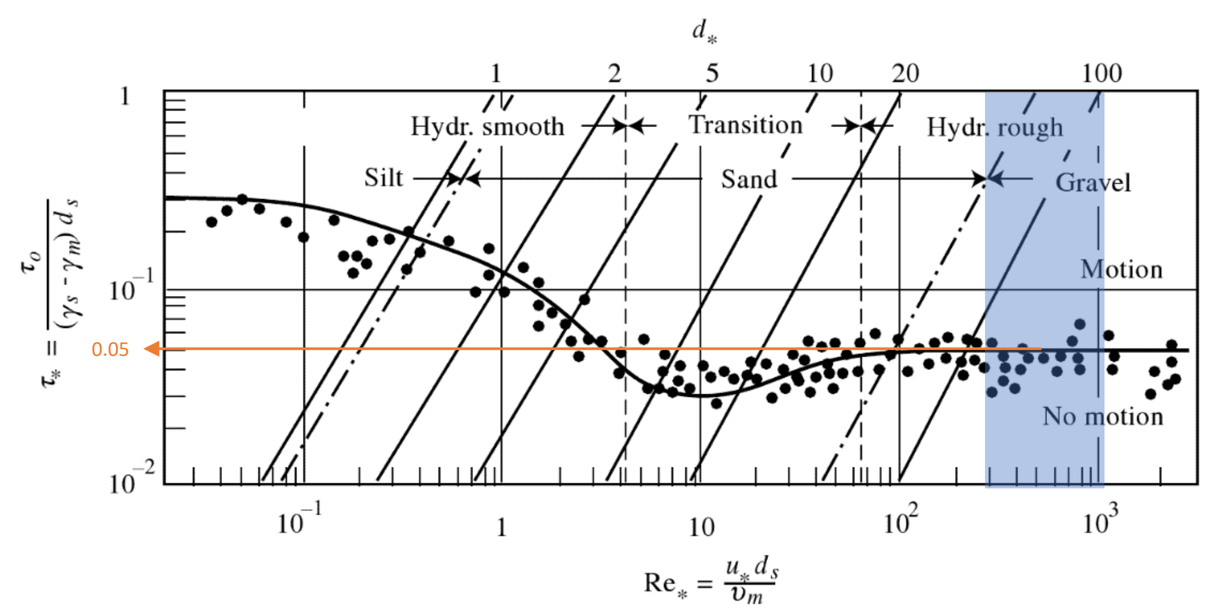
According to the analysis of historic flows, bed mobilizing flows are present in the channel at the Monte Vista gauge for approximately 30 days during Average years and for 55 days during Wet years.

However, if significant flow (greater than approximately 200cfs) is diverted out of the channel between the gauge and the State Wildlife Area during peak of runoff in Average years, these flows will no longer have the strength to mobilize the channel bed.



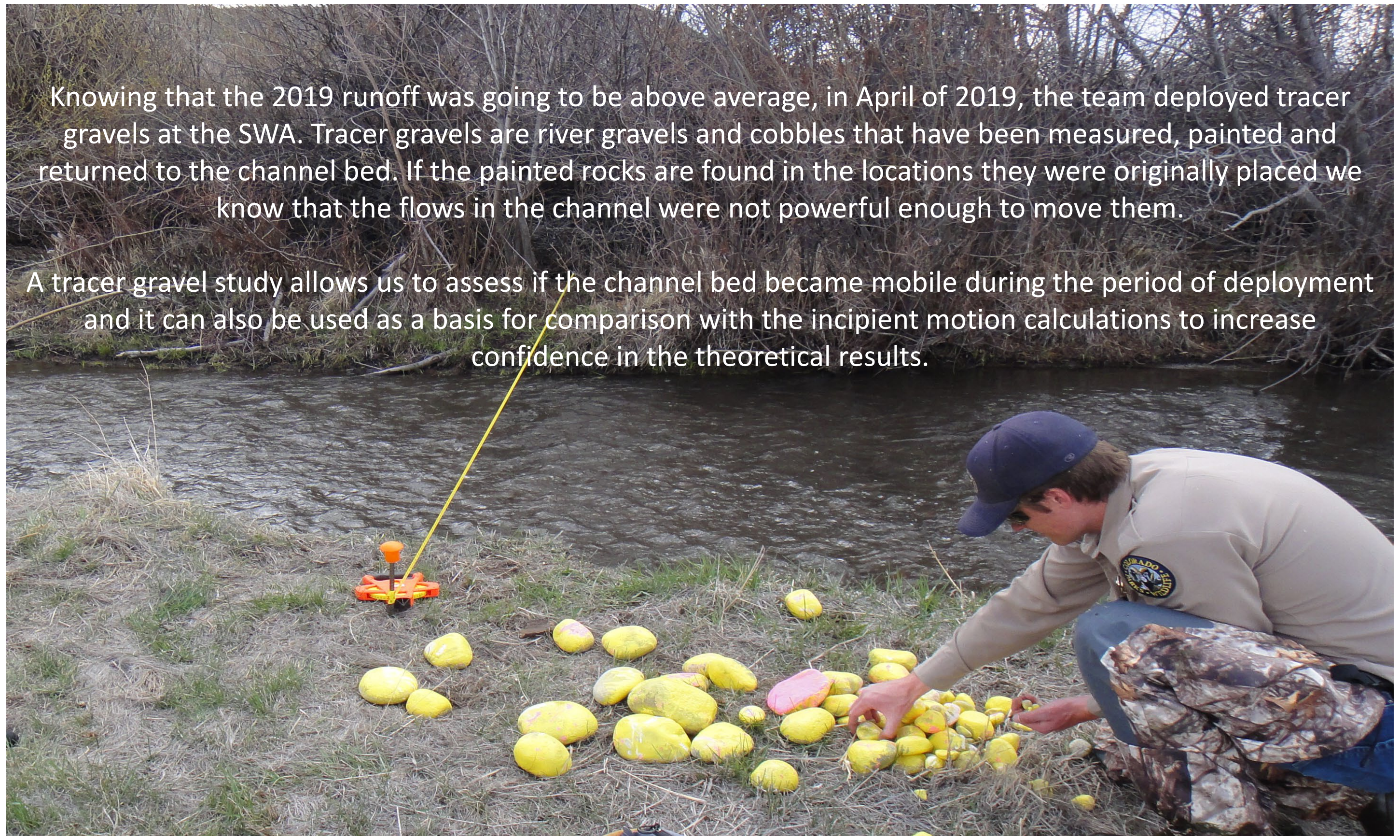
SHIELDS DIAGRAM

Flow (cfs)	D50 of Channel Bed (mm)	Particle Class	τ_* Critical Shear Force (unitless)	Re_* Particle Reynolds number (unitless)	Location on Shields Diagram	Conclusion
100	29	coarse gravel	0.014	320		
200	29	coarse gravel	0.020	383	Below	No movement
300	29	coarse gravel	0.024	419	Below	No movement
400	29	coarse gravel	0.029	453	Below	No movement
500	29	coarse gravel	0.033	484	Below	No movement
600	29	coarse gravel	0.036	506	Below	No movement
800	29	coarse gravel	0.042	548	Below	No movement
1000	29	coarse gravel	0.048	587	Below	No movement
1200	29	coarse gravel	0.053	617	Below	Flow moves particle
1400	29	coarse gravel	0.057	641	Below	Flow moves particle
1600	29	coarse gravel	0.061	663	Below	Flow moves particle
1800	29	coarse gravel	0.064	679	Below	Flow moves particle
2000	29	coarse gravel	0.067	695	Above	Flow moves particle
2200	29	coarse gravel	0.070	711	Above	Flow moves particle
2400	29	coarse gravel	0.073	726	Above	Flow moves particle
2600	29	coarse gravel	0.077	741	Above	Flow moves particle
2800	29	coarse gravel	0.080	756	Above	Flow moves particle
3000	29	coarse gravel	0.083	770	Above	Flow moves particle
3200	29	coarse gravel	0.085	780	Above	Flow moves particle
3200	29	coarse gravel	0.085	821	Above	Flow moves particle



TRACER GRAVEL STUDY—WHAT BED MOBILITY WAS OBSERVED IN 2019?

During the 2019 runoff we observed a highly mobile channel bed at the Rio Grande State Wildlife Area.

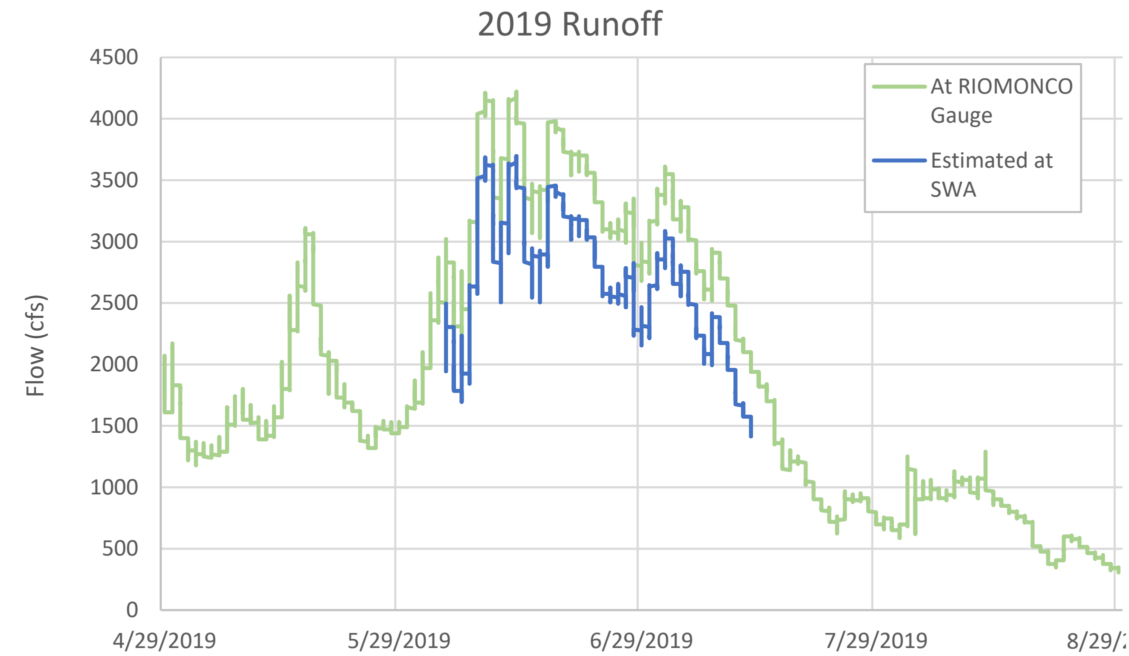


We deployed 99 gravels and cobbles at the Rio Grande State Wildlife Area on April 29, 2019 and recovered the tracer gravels on August 29, 2019. We recovered 100% of the tracer gravels that were larger than 64 mm either at the transect or immediately downstream. We recovered two of the 22 tracer gravels that were between 32mm and 64 mm downstream of the transect. We recovered no gravels smaller than 32mm.

This leads us to conclude that the flows in 2019, which peaked around 3500 cfs, were strong enough to mobilize gravels (grains smaller than 64mm) but not cobbles (grains larger than 64mm). The native bed material has only a very small fraction of particles larger than 64mm which leads us to conclude that between May and August, the entire bed of the Rio Grande became mobilized.

Tracer Gravel Counts

Size (mm)	Native Material	Deployed Gravels	Deployed and Recovered at Transect	Deployed and Recovered d/s of Transect	Percent of Tracers Recovered
< 4	2				n/a
4 - 8					n/a
8 - 16	7	25	0	0	0%
16 - 32	48	30	0	1	3%
32 - 64	35	22	0	2	9%
64 - 128	5	16	16	0	100%
128 - 256		6	4	2	100%



For the Rio Grande at the State Wildlife Area near Monte Vista, CO, experienced peak flows around **3500 cfs.** This is calculated by looking at the flows measured at the RIOMONCO gauge and subtracting the flows diverted out of the channel by the water delivery infrastructure—the average diversion was approximately 525 cfs through the peak of runoff.

The Rio Grande State Wildlife Area on June 18, 2019, near the peak of flows for 2019. While the off-channel and floodplain areas are certainly wet, the difference in the color of the water (brown in the channel and blue on the floodplain and in the oxbow lakes) indicate that the channel is not actively overtopping to the south at the time of this photo.

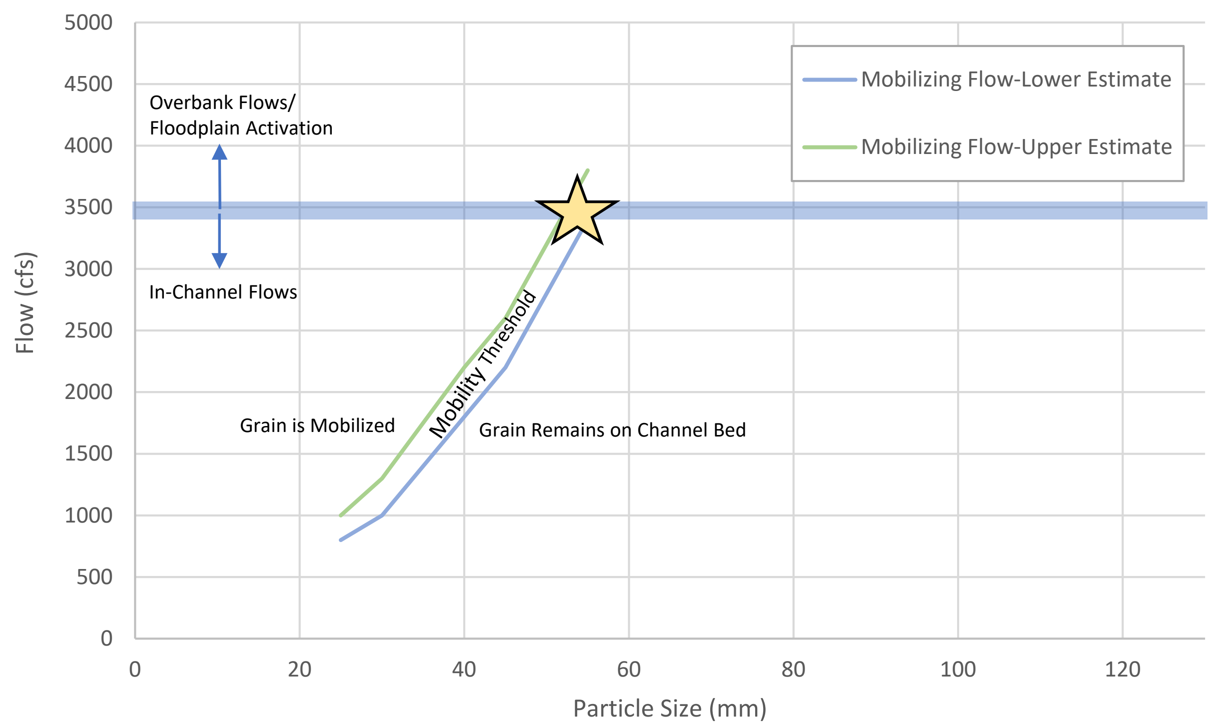
TRACER GRAVEL STUDY—HOW DO THE CALCULATIONS COMPARE TO THE INCIPIENT MOTION CALCULATIONS?

The results from the tracer gravel study support the incipient motion calculations. The gravels that we placed before runoff, and then found, on the channel bed after runoff are the sizes that we would expect to persist in place based on the flows that this reach of the Rio Grande experienced between May and August 2019. The material that was mobilized are of sizes that the calculations suggest should have been mobile during the 2019 flows.

This analysis increases confidence in the ability of the Incipient Motion Calculations to predict bed mobility for the Rio Grande.

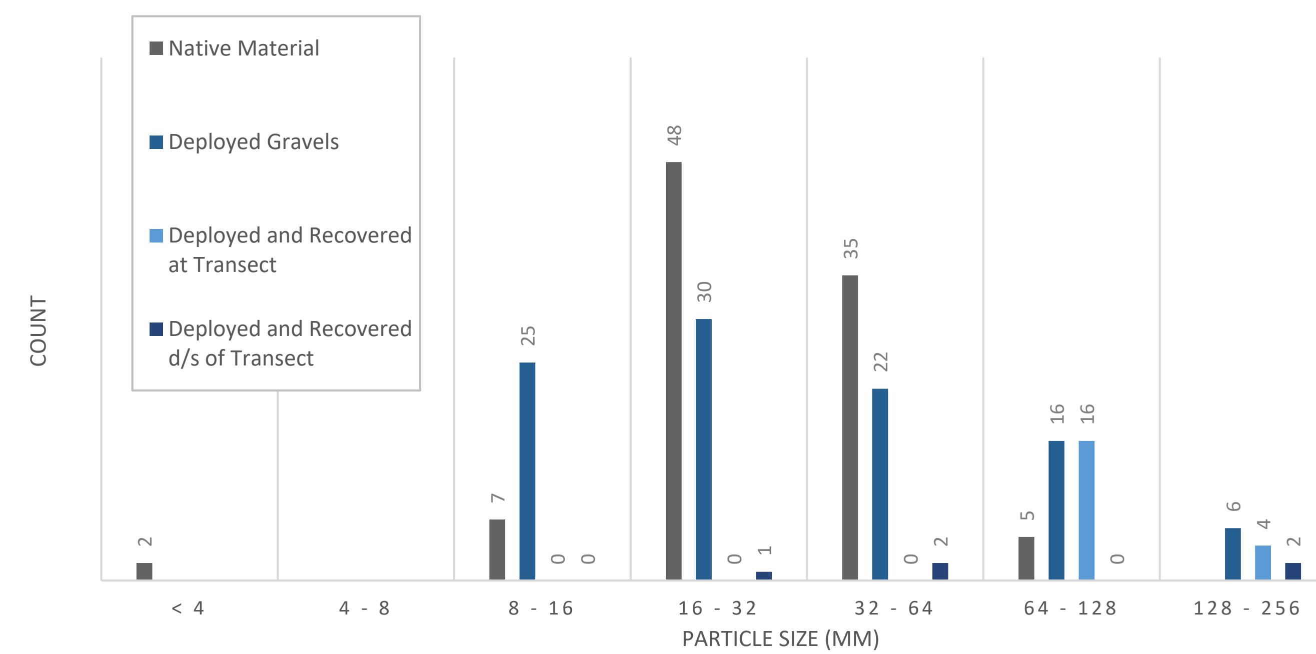
CALCULATED BED MOBILITY

The calculated flows that are necessary to trigger the mobilization of sediment of various sizes within this reach are shown below. According to these calculations, the flows experienced by this reach in 2019, approximately 3500 cfs, had enough energy to mobilize sediment particles smaller than approximately 55mm (denoted by yellow star). Particles smaller than 55mm should have been picked up and transported as bedload; particles larger than 55mm should have remained on the channel bed.



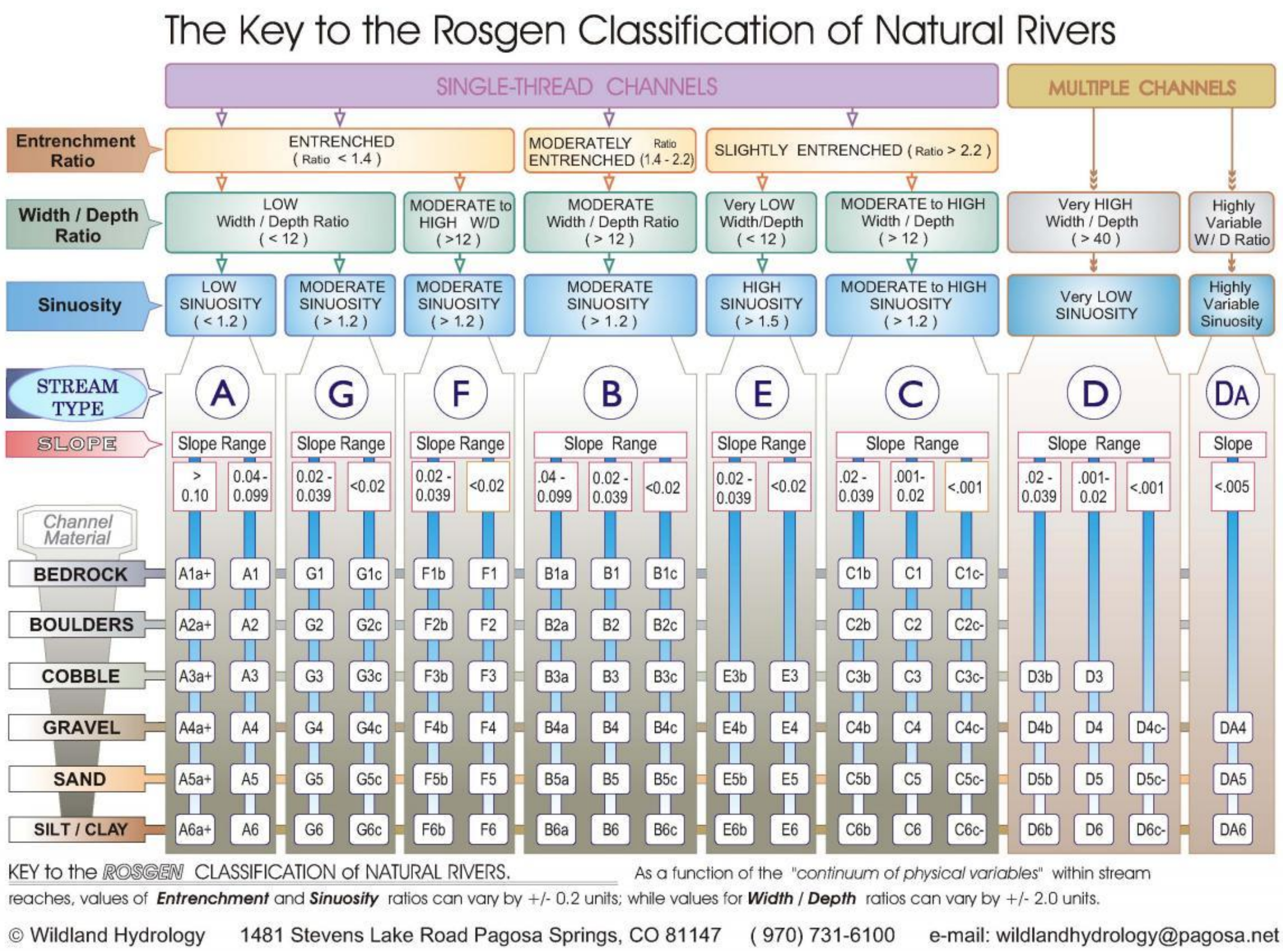
OBSERVED BED MOBILITY

The RGHRP team recovered all tracer gravels larger than 64 mm. Two of these had moved slightly downstream and were found within 100 feet of their initial placement locations. All tracer gravels that were between 32 and 64 mm were mobilized; two of this size class were recovered within 100 feet of their placement locations—and both recovered gravels were measured at 55mm. All grains smaller than 32mm were mobilized and only one was recovered within 100 feet of the placement cross-section.



APPENDIX D: STREAM CLASSIFICATION SYSTEM SUMMARIES

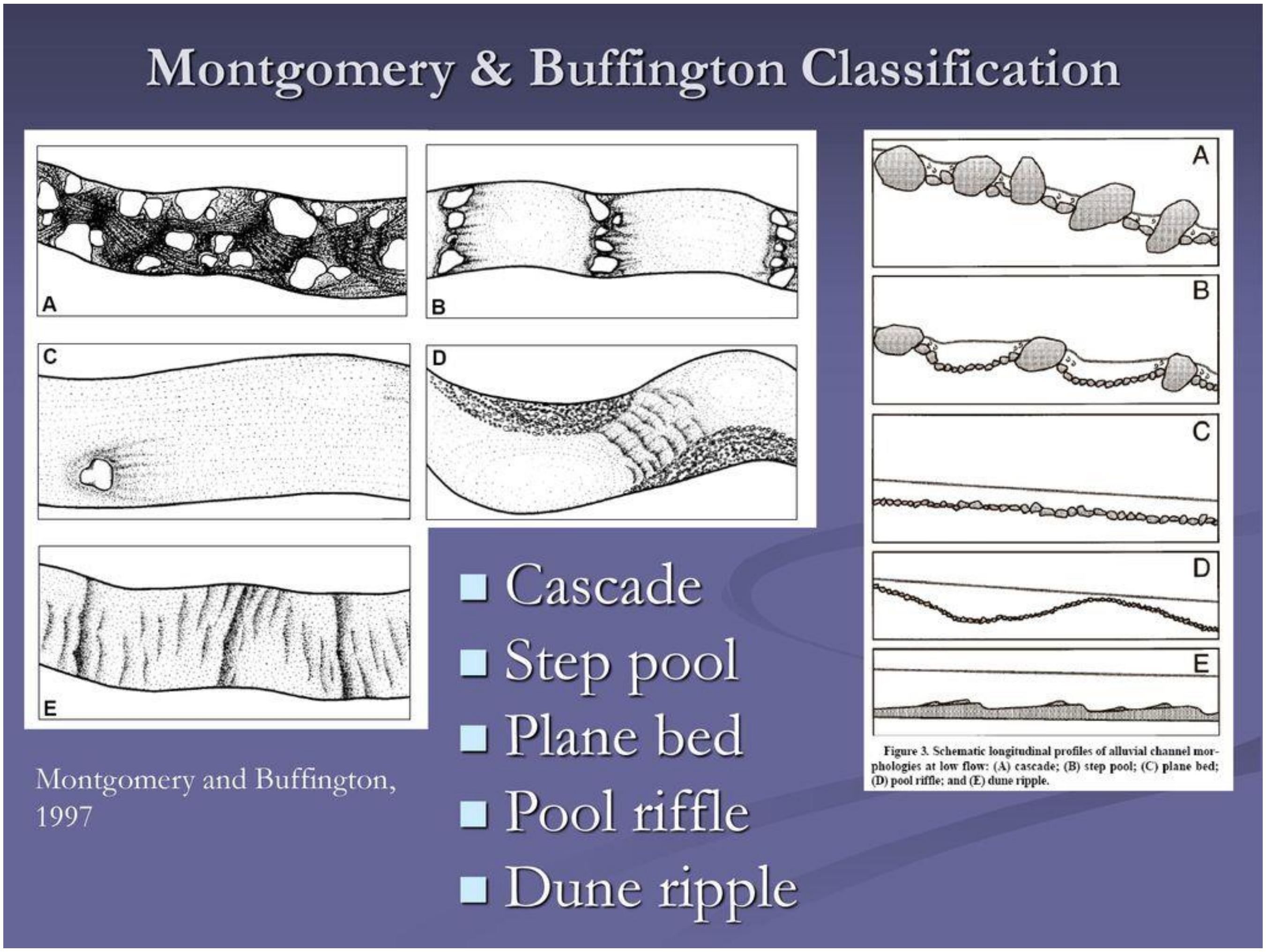
Rosgen Stream Classification System:
A classification system developed by David Rosgen, Ph.D., in which morphological arrangements of stream characteristics are organized into relatively homogeneous stream types using an alphanumeric system. The classifications assigned in this Rapid Geomorphic Assessment would be considered Level II classification, although for a true Level II classification the Rosgen system stipulates that field data must be collected which was not possible given the limited budget assigned for this project.



Reference: Rosgen, D. L. (1996). *Applied river morphology*. Pagosa Springs, Colo: Wildland Hydrology.

Montgomery-Buffington Bedform Classification System:

A classification system that couples reach-level channel processes with the spatial arrangement of reach morphologies, their links to hillslope processes, and external forcing by confinement, riparian vegetation, and woody debris defines a process-based framework within which to assess channel condition and response potential in mountain drainage basins.



Reference: David R. Montgomery, John M. Buffington; Channel-reach morphology in mountain drainage basins. *GSA Bulletin* ; 109 (5): 596–611. doi: https://doi.org/10.1130/0016-7606(1997)109<0596:CRMIMD>2.3.CO;2

Stream Evolution Model:

The Stream Evolution Model (SEM) described by Cluer and Thorne in 2014 was used to assess the current channel condition and active processes in terms of streambed adjustment.

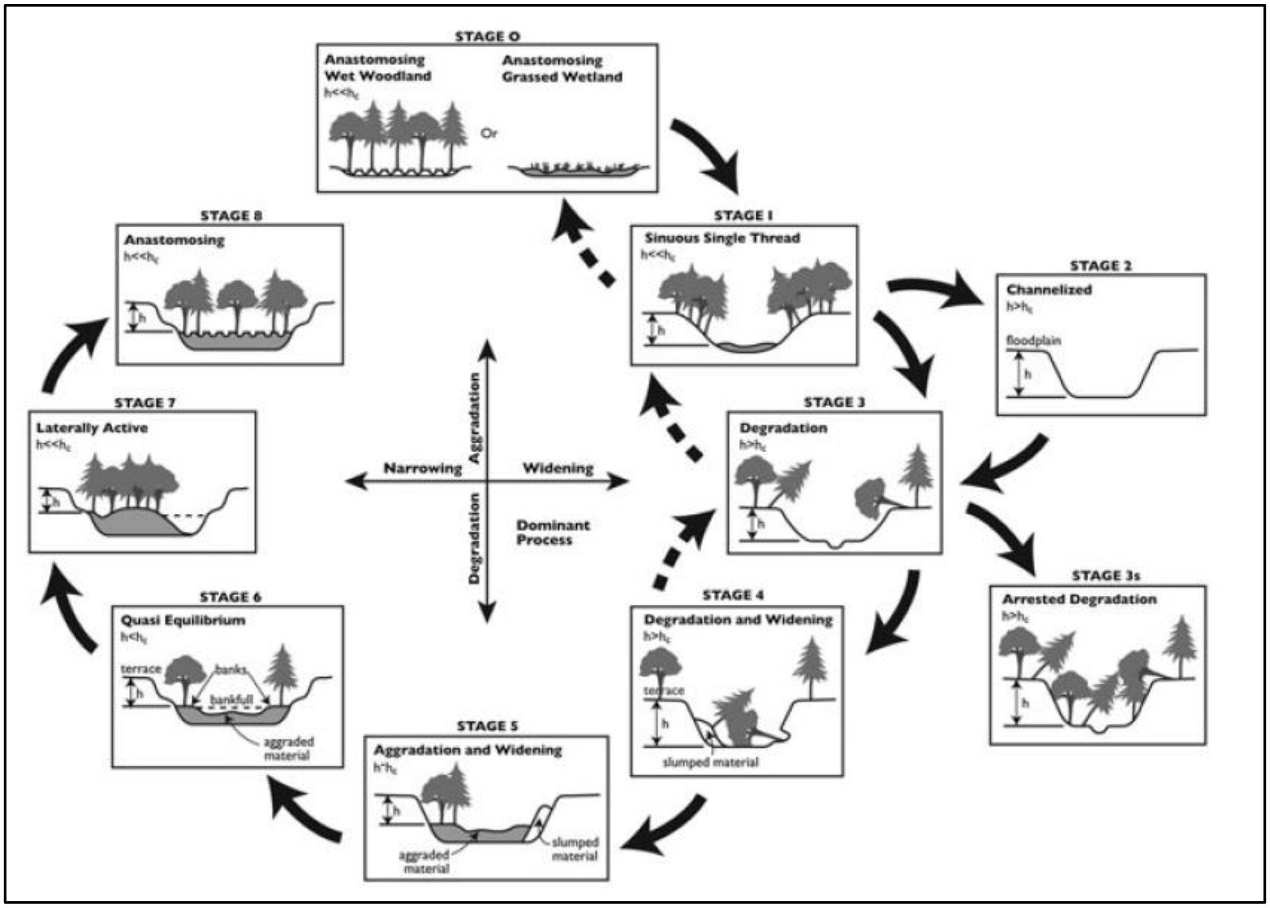


Figure 5. Stream Evolution Model showing geomorphic changes through the four processes of narrowing, widening, aggrading, and/or degrading (Cluer and Thorne, 2014).

Table I. Previous Channel Evolution Models and the proposed Stream Evolution Model with description of reach-average characteristics, or stages

Schumm *et al*., 1984	Simon and Hupp, 1986	SEM		Description
		0. Anastomosing		Pre-disturbance, dynamically meta-stable network of anabranching channels and floodplain with vegetated islands supporting wet woodland or grassland. $Qs_{in} \geq Qs_{out}$, $h \ll h_c$
I. Undisturbed	I. Pre-modified	- Single Thread Channels -	1.Sinuous	Dynamically stable and laterally active channel within a floodplain complex. Flood return period 1-5 yr range. $Qs_{in} \geq Qs_{out}$, $h \ll h_c$
	II. Constructed		2. Channelized	Re-sectioned land drainage, flood control, or navigation channels. $Qs_{in} \leq Qs_{out}$, $h > h_c$
II. Degradation	III. Degradation		3. Degrading	Incising and abandoning its floodplain. Featuring head cuts, knick points or knick zones that incise into the bed, scours away bars and riffles and removes sediments stored at bank toes. Banks stable geotechnically. $Qs_{in} < Qs_{out}$, $h > h_c$
			3s. Arrested degradation	Stabilized, confined or canyon-type channels. Incised channel in which bed lowering and channel evolution have been halted because non-erodible materials (bed rock, tight clays) have been encountered. $Qs_{in} \sim Qs_{out}$, $h > h_c$
III. Rapid Widening	IV. Degradation and widening		4. Degradation and widening	Incising with unstable, retreating banks that collapse by slumping and/or rotational slips. Failed material is scoured away and the enlarged channel becomes disconnected from its former floodplain, which becomes a terrace. $Qs_{in} < Qs_{out}$, $h > h_c$
			4-3. Renewed incision	Further head cutting within Stage 4 channel. $Qs_{in} < Qs_{out}$, $h \gg h_c$
IV. Aggradation	V. Aggradation and widening		5. Aggrading and widening	Bed rising, aggrading, widening channel with unstable banks in which excess load from upstream together with slumped bank material build berms and silts bed. banks stablizing & berming. $Qs_{in} > Qs_{out}$, $h \sim h_c$
V. Stabilization	VI. Quasi-equilibrium		6. Quasi-equilibrium	Inset floodplain re-established. quasi-equilibrium channel with two-stage cross-section featuring regime channel inset within larger, degraded channel. Berms stabilize as pioneer vegetation traps fine sediment, seeds and plant propagules. $Qs_{in} \sim Qs_{out}$, $h < h_c$
	VII. [1]Late-stage evolution		7. Laterally active	Channel with frequent floodplain connection develops sinuous course, is laterally active and has asymmetrical cross-section promoting bar accretion at inner margins and toe scour and renewed bank retreat along outer margins of expanding/migrating bends. $Qs_{in} \geq Qs_{out}$, $h \ll h_c$
		8. Anastomosing		Meta-stable channel network. Post-disturbance channel featuring anastomosed planform connected to a frequently inundated floodplain that supports wet woodland or grassland that is bounded by set-back terraces on one or both margins. $Qs_{in} \geq Qs_{out}$, $h \ll h_c$

[1] Suggested by Thorne (1999)

Table II. Physical and vegetative attributes for each stage in the Stream Evolution Model

SEM Stage		Physical Attributes			Vegetation Attributes
		Hydrologic Regime	Hydraulics and Substrate	Dimensions and Morphology	
0. Anastomosing. Dynamically meta-stable network of anabranching channels with vegetated islands.		Floods diffused over the full width of the floodplain so flood peaks are maximally attenuated. Flood pulses diffused and subdued. High water table and close connection between stream flow and ground water ensures reliable base flows and continuous hyporhesis, though flow in smaller anabranches may be ephemeral.	Multiple channels provide maximum in-channel hydraulic diversity through partition of discharge between branches that widens range of in-channel depth/velocity combinations. Anabranches create multiple, marginal deadwaters. Wide range of substrate grain sizes arranged into numerous, well-sorted bed patches.	Multiple anabranches, islands and side channels maximize. Morphological features abound in-channel and on the extensive and fully connected floodplain, providing a high capacity to store sediment and wood and supporting diverse wetlands. Bank heights are low with stability enhanced by riparian margins, but some rive cliffs are generated by localised erosion. Network and floodplain are highly resilient to disturbance, buffering the system.	Frequent, small channel adjustments and high, reliable water table create ubiquitous settings for proliferation and succession of aquatic, emergent, riparian and floodplain plants. Wet woodlands on islands and floodplain supply and retain wood, and widespread vegetation proximal to channels produce abundant leaf litter.
Single Thread Channels	**1.Sinuous, single-thread .** Stable and laterally active. Sediment sorting and transfer.	Floods up to bankfull discharge retained in-channel reducing attenuation. Larger floods still spill to floodplain, attenuating their peaks. Close connection between groundwater and stream flow ensures reliable base flows and good hyporhesis.	Range of in-channel depth/velocity combinations up to bankfull flow provides moderate hydraulic diversit and frequent deadwaters along remaining channel boundaries. Substrate sorting varies between thalweg and alternate or point bars, with different degrees of armoring. Variation in bed morphology continues to supports a high degree of substrate patchiness.	Wetted area relative to flow, shoreline length and complexity decrease due to switch to single channel. Though bedforms and bars remain widespread, frequency of islands, confluences and diffluences is greatly reduced, adversely affecting capacity to stor sediment and wood. Higher banks are less stable with river cliffs found along outer margins of bends. Floodplain extent and connectivity undiminished, but number of side channels and functionality of connected wetlands reduced.	Decreases in hydraulic and morphological diversity trigger reductions in quantity and quality of aquatic, riparian and, especially, emergent plants. Floodplain communities remain diverse, but transition from wetland to more terrestrial assemblages. Reductions in extent of woodlands due to switch from multiple t a single channel decrease recruitment of wood and leaf litter.
	2. Channelized. Re-sectioned land drainage, flood control, or navigation channels.	Flood flows retained in-channel up to desig discharge, enhancing flood pulses. Flood attenuation reduced. Efficient drainage speeds post-flood recession and lowers groundwater, so base flows and hyporhesis are impaired.	Artificially high in-channel discharge capacity coupled with uniformity of depth/velocity combinations reduces hydraulic diversity and compromises functionality of any marginal deadwaters. Bed substrate scoured, with sorting impacted and patchiness reduced through extreme armoring or paving.	channelization reduces wetted area, shoreline length and complexity relative to flow. Some bedforms and bars remain but islands, side channels, and confluences/diffluences are eradicated. Capacity to store sediment and wood reduced, or eliminated by channel maintenance. Banks stable or revetted, with river cliffs eliminated. Extent, connectivity and functionality of riparian zone, floodplain and wetlands all diminished.	Aquatic and emergent plants destroyed during construction with recovery limited to patches and narrow belts. Riparian plants only contribute wood and leaf litter if some of riparian corridor is left in place. Floodplain vegetation communities disconnected from channel may transition further to terrestrial assemblages.
	3. Degrading. Incising and abandoning its floodplain. Banks stable geotechnically.	Concentrates progressively greater flood peaks in-channel, further amplifying flood pulse Flood attenuation ineffective. Groundwater recharge is minimal, making base flow unreliable. Hyporheic zone damaged or destroyed by scour at bed and bank toes.	Bed lowering, removal of bars and riffles and scour a bank toes reduces hydraulic diversity means there are few, if any, marginal deadwaters. Bed substrate continues to be scoured, with sorting impacted and patchiness reduced through extreme armoring or paving.	Degradation reduces wetted area, shoreline length and complexity relative to flow compared to Stage 1. Bedforms, bars and islands scoured, confluences/diffluences eradicated and side channels, floodplain and wetlands abandoned. Capacity to store sediment and wood effectively lost. Banks mostly stable with local river cliffs. Functionality of the riparian zone is diminished due to reduced connectivity with channel.	Aquatic and most emergent plants destroyed by incision; only seasonal and annual species remain. Riparian vegetation undercut and increasingly unstable leading to artificially elevated inputs of wood. Input of leaf litter, seeds and propagules continues, but retention reduced. Floodplain vegetation stressed due to lower water table.
	3s. Arrested degradation. Confined or canyon-type channels.	Concentrates a wide range of flood peaks, providing no effective flood attenuation and maximal flood pulse effects. Groundwater recharge is minimal, base flow unreliable and hyporheic zone remains damaged or destroyed.	Similar to Stage 3, though there may be some limited recovery of hydraulic diversity due to presence of invasive or remnant riparian plants and accumulation of log jams formed by tress that have fallen into the degraded channel. Limited sediment retention, sorting and patch development.	Natural or artificial stabilization locks in dimensions and morphology developed in Stage 3. Limited capacity to store sediment and wood once degradation ceases. Banks mostly stable but extent of river cliffs may increase. Functionality of the riparian zone remains diminished and channel is permanently disconnected from its floodplain and wetlands.	Relative stability allows for early succession in emergent and riparian plant communities, improving supply of leaf litter. Wood recruitment continues, limited by the proximity, width and contiguity of woodlands on surrounding floodplain and terrace surfaces.
	4. Degradation and widening. Incising with unstable, retreating banks.	Concentrates an extreme range of flood peaks, negating flood attenuation and furthe amplifying flood pulse effects. Groundwate recharge, base flow generation and hyporheic connectivity are all dysfunctional	Hydraulic diversity remains low due to channel scour and efficient downstream transport of woody debris. Deadwaters continue to be absent or dysfunctional. Bed scour continues to adversely impact substrate sorting and patchiness.	Sediment inputs from bank retreat initiates limited bedform and ba development, but mass failures eliminate stable banks and increas the extent of river cliffs that destroy riparian margins. Wetted area shoreline length and complexity relative to flow all remain low. No recovery of capacity to store sediment and wood, and floodpla still disconnected.	Aquatic plant community remains dysfunctional due to on-going bed degradation and riparian plants are destroyed by rapid widening. Wood recruitment may increase if banks are forested, though retention depends on trees being large relative to increasing channel width.
	4-3. Renewed incision. Further head cutting within Stage 4 channel.	Increased range of floods retained in-bank continues to amplify flood pulse effects. Flood attenuation, groundwater recharge, base flow generation and hyporheic connectivity all remain dysfunctional.	Renewed incision maintains limited range of depth/velocity, combinations and so hydraulic diversity remains low. No new marginal deadwaters are created. Channel scour effectively eliminates functionality of substrate sorting and patchiness in providing habitat and ecosystem benefits.	Renewed scour removes embryonic bedforms and bars formed in Stage 4. Degree of disconnection of side channels, floodplain and wetlands due to channel incision increases. Any stored sediment c wood is flushed downstream. Continued bank retreat forms river cliffs that erode any remaining riparian fringe.	Aquatic, emergent, riparian and floodplain plant communities all depleted and dysfunctional. Low supply of leaf litter but wood recruitment maintained until proximal supply is exhausted. Retention depends on trees being large relative to increasing channel width.
	5. Aggrading and widening. Bed rising, banks stablising & berming.	No significant improvement in flood attenuation but flood pulse effects not quite as marked. Groundwater recharge remains dysfunctional, and base flows are still unreliable, but some hyporheic connectivity is recovered.	Aggradation renews depth/velocity variability that to improve hydraulic diversity. Small marginal deadwaters may develop, but these are not yet functional in providing habitat and ecosystem benefits. Bars and log jams begin to improve sediment sorting and patchiness.	Wetted area, shoreline length and complexity relative to flow all remain low. Aggradation generates some bedforms and bars but channel remains dysfunctional with regard to effective storage of sediment and wood. Bank stability improves marginally compared to Stage 4 allowing some recovery in riparian fringe. Floodplain connectivity begins to recover due to aggradation at bed and berm formation at banks.	Some return of aquatic plants. Bars and berms provide opportunities for emergent and riparian plants. Floodplain plant community remains isolated from channel physically and hydrologically. Widening may continue to recruit wood if there are proximal trees and supply of leaf litter may be renewed as well.
	6. Quasi-equilibrium. Regime channel and proto-floodplain re-established.	Remains disconnected from former floodplain, but increased boundary roughness and emergent riparian stands damp flood pulse effects and reintroduce some flood attenuation. Groundwater recharge and base flow functions begin to recover and hyporhesis continues to improve.	Developing regime channel interacts with proto-floodplain surfaces to dissipate energy and increase hydraulic diversity. Accumulation of sediment and colonization of bars and berms by emergent and riparian vegetation increases number and functionality of marginal deadwaters. Patches of contrasting substrate size and sorting develop accordingly.	Wetted area, shoreline length and complexity relative to flow all remain low. Bedforms and bars recover to pre-disturbance levels restoring some capacity to storage of sediment and wood. Bank stability continues to improve at expense of river cliffs, allowing further recovery in riparian fringe. Floodplain connectivity continues to recover and new side channels may be created, thoug wetlands remain disconnected.	Relatively stable channel margins and inset features provide sites for development of aquatic, emergent and riparian plant communities. Aggradation improves connectivity with and functionality of floodplain plants, maintaining wood recruitment and enhancing supply of leaf litter.
	7. Laterally active. Regime channel develops sinuous course.	Increases in flow resistance due to development of channel and inset floodplain roughness further damp flood pulse effects while returning groundwater recharge, base flow and hyporheic functionality back close to Stage 1 level.	Development of planform sinuosity and interaction with maturing floodplain enhance hydraulic diversity and make marginal deadwaters fully functional. Substrate sorting enhanced and patchiness becomes fully functional. Hydraulic and substrate attributes recover to Stage 1 levels.	Growth of sinuous channel increases wetted area, shoreline length and complexity. Bedforms and bars persist and new islands, confluences and diffluences develop, increasing capacity to storag of sediment and wood. Renewed bank erosion at bends broadens range of bank morphologies. Extent of new side channels increase with some wetlands created.	Extent of riparian and floodplain plant communities increases at expense of opportunities for emergent plants. Stabilisation of banks reduces wood recruitment but extension and maturing of riparian and floodplain communities maintain supply of leaf litter.
8. Anastomosing. Meta-stable anabranching network.		Hydrologic attributes and functions similar to Stage 0 but network inset within the channel created in Stage 4 as modified in Stage 7.	Hydraulic and substrate attributes and functions similar to Stage 0, but network inset within the channel created in Stage 4 as modified in Stage 7.	Morphological attributes and functions similar to Stage 0, but wetted area, shoreline length, and extent of floodplain and its features diminished because network is inset within the valley created in Stage 4.	Hydrological, hydraulic and morphological attributes and functions similar to those of Stage 0 allow vegetation attributes to recover to pre-disturbance levels.

Reference: Cluer, B. and Thorne, C. 2014. A Stream Evolution Model Integrating Habitat and Ecosystem Benefits. River Res. Applic., 30: p.135-154. doi:[10.1002/rra.2631](https://doi.org/10.1002/rra.2631)

Sediment Regime:

The size, quantity, sorting, and distribution of sediments, which may differ between stream types due to their proximity to different sediment sources, their hydrologic regime, their stream, riparian and floodplain connectivity, and valley and stream morphology.

Sediment Regime	Narrative Description
Transport	Steeper bedrock and boulder/cobble cascade and step-pool stream types; typically in more confined valleys, do not supply appreciable quantities of sediments to downstream reaches on an annual basis; little or no mass wasting; storage of fine sediment is negligible due to high transport capacity derived from both the high gradient and/or natural entrenchment of the channel.
Confined Source and Transport	Cobble step pool and steep plane bed streams; confining valley walls, comprised of erodible tills, glacial lacustrine, glacial fluvial, or alluvial materials; mass wasting and landslides common and may be triggered by valley rejuvenation processes; storage of coarse or fine sediment is limited due to high transport capacity derived from both the gradient and entrenchment of the channel. Look for streams in narrow valleys where dams, culverts, encroachment (roads, houses, etc.), and subsequent channel management may trigger incision, rejuvenation, and mass wasting processes.
Unconfined Source and Transport	Sand, gravel, or cobble plane bed streams; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to entrenchment or incision and associated bed form changes; these streams are not a significant sediment supply due to boundary resistance such as bank armoring, but may begin to experience erosion and supply both coarse and fine sediment when bank failure leads to channel widening; storage of coarse or fine sediment is negligible due to high transport capacity derived from the deep incision and little or no floodplain access. Look for straightened, incised or entrenched streams in unconfined valleys, which may have been bermed and extensively armored and are in Stage II or early Stage III of channel evolution.
Fine Source and Transport & Coarse Deposition	Sand, gravel, or cobble streams with variable bed forms; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to vertical profile and associated bed form changes; these streams supply both coarse and fine sediments due to little or no boundary resistance; storage of fine sediment is lost or severely limited as a result of channel incision and little or no floodplain access; an increase in coarse sediment storage occurs due to a high coarse sediment load coupled with the lower transport capacity that results from a lower gradient and/or channel depth. Look for historically straightened, incised, or entrenched streams in unconfined valleys, having little or no boundary resistance, increased bank erosion, and large unvegetated bars. These streams are typically in late Stage III and Stage IV of channel evolution.
Coarse Equilibrium (in = out) & Fine Deposition	Sand, gravel, or cobble streams with equilibrium bed forms; at least one side of the channel is unconfined by valley walls; these streams transport and deposit coarse sediment in equilibrium (stream power—produce as a result of channel gradient and hydraulic radius—is balanced by the sediment load, sediment size, and channel boundary resistance); and store a relatively large volume of fine sediment due to the access of high frequency (annual) floods to the floodplain. Look for unconfined streams, which are not incised or entrenched, have boundary resistance (woody buffers), minimal bank erosion, and vegetated bars. These streams are Stage I, late Stage IV, and Stage V.
Deposition	Silt, Sand, gravel, or cobble streams with variable and braided bed forms; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to changes in slope and/or depth resulting in the predominance of transient depositional features; storage of fine and coarse sediment frequently exceeds transport**. Floodplains are accessed during high frequency (annual) floods. Look for unconfined streams, which are not incised or entrenched, have become significantly over-widened, and if high rates of bank erosion are present, it is offset by the vertical growth of unvegetated bars. These regimes may be located at zones of naturally high deposition (e.g., active alluvial fans, deltas, or upstream of bedrock controls), or may exist due to impoundment and other backwater conditions above weirs, dams and other constrictions.

** Use of the "Deposition" regime characterization may be rare, but valuable as a planning tool, where the reach is storing far more than it is transporting during some defined planning period. The extreme example would be that of an impounded reach where all of the course and a great percentage of the fine sediments are being deposited, rather than transported downstream. This man-made condition may change, thereby changing the sediment regime, but is not likely over the period at which the corridor plan will be used.

Reference: https://dec.vermont.gov/sites/dec/files/wsm/rivers/docs/rv_rivercorridorguide.pdf

River Styles

A scientific tool used to describe and explain the diversity and distribution of river types in a catchment according to river character and behavior. The River Styles Framework differs from other classification systems (e.g. Rosgen Stream Classification) in that it provides an open-ended process for description rather than fitting rivers into pre-existing categories. It was developed by researchers at Macquarie University.

Reference: https://www.mq.edu.au/about/about-the-university/faculties-and-departments/faculty-of-science-and-engineering/departments-and-centres/department-of-environmental-sciences/engage/river-styles-framework