Stillwater Sciences

2855 Telegraph Ave, Suite 400, Berkeley, CA 94705
phone 510.848.8098 fax 510.848.8398

TECHNICAL MEMORANDUM

DATE: Monday, December 16, 2013

TO: Elizabeth Bickmore

FROM: Bruce Orr, Glen Leverich, Tom Dudley,

SUBJECT: Mormon Mesa Ecohydrology Assessment Final Report

This reach-scale ecohydrology assessment of the lower Virgin River in the Mormon Mesa area was prepared by Restoration Science Team members from Stillwater Sciences and UC Santa Barbara for Clark County under Project Number 2011-PIC-915B with Partners in Conservation. Additional information on the surrounding area, including information provided by the Great Basin Institute after their field reconnaissance and initial site clearing activities in October, are provided in the separate Clark County Mormon Mesa Parcel Restoration Plan (Project 2009-PIC-805V).

1 BACKGROUND

The Clark County parcel (the Property) is located in the Mormon Mesa reach (the Reach) along the lower Virgin River in Nevada (Figure 1). The Reach comprises geomorphic reaches 1A and 1B as previously defined by Stillwater Sciences (2012) during the Phase 1 ecohydrology assessment funded by the Walton Family Foundation. The Reach covers approximately 15 miles of the lower Virgin River upstream of the river's terminus in Lake Mead (Figure 1). The Property lies in the upper half of Reach 1B (Figure 1) and comprises approximately 80 acres of river and floodplain habitat in an area that is known to provide breeding habitat for the endangered southwestern willow flycatcher (SWFL; *Empidonax traillii extimus*). Prior SWFL surveys performed in support of the Bureau of Reclamation's *Lower Colorado River Multi-Species Conservation Program* have identified locations in the Reach where pairs nested in previous years (e.g., Mormon Mesa North, Mormon Mesa South, Hedgerow, Virgin River #1 North and South, Virgin River #2), and much of the Property lies within the Virgin River #1 South unit in those surveys (McLeod and Pellegrini 2013). A high value SWFL nesting area (informally called "smelly jelly" by survey crews) covers roughly 100 acres immediately north of the Property and includes about 2 acres of habitat within the Property near the northwestern boundary. This area supported 14 breeding pairs of SWFL in 2012, but only 7 pairs in 2013 (M. McLeod, pers. comm., 28 September 2013). The decline of the SWFL breeding population at this location and throughout much of the lower Virgin River in 2013 coincided with decreased habitat quality associated with extensive defoliation of tamarisk by the tamarisk leaf beetle (*Diorhabda carinulata)*, a biological control agent that was first documented to cause defoliation in the Mormon Mesa reach just one year before. The potential for continued adverse impacts to SWFL breeding habitat over the next few years due to tamarisk defoliation by the beetle highlights the need for rapid implementation of efforts to promote re-establishment of willows and other native riparian plants in the area.

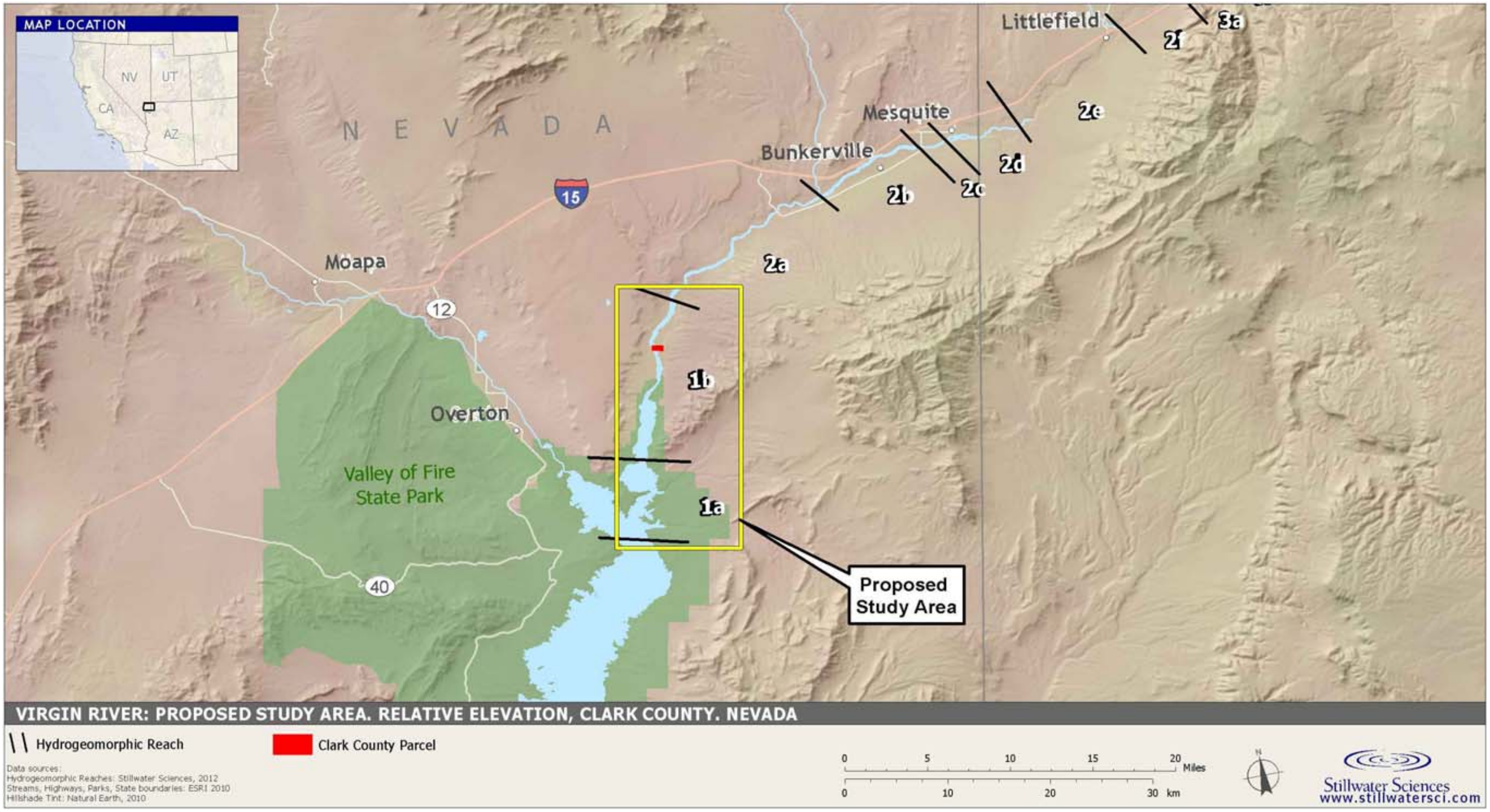

Figure 1. General location of the Mormon Mesa ecohydrology assessment area (= reaches 1a and 1b as defined in Stillwater Sciences 2012) on the lower Virgin River, Clark County, Nevada.

The Property and other areas within the Mormon Mesa reach also have substantial potential to provide enhanced habitat for other native wildlife, such as the western yellow-billed cuckoo (*Coccyzus americanus*), Arizona Bell's vireo (*Vireo bellii arizonae*), and vermillion flycatcher (*Pyrocephalus rubinus*), if native riparian vegetation is restored.

2 PROJECT GOAL AND APPROACH

The goal of this project was to conduct an ecohydrological assessment and field surveys to develop detailed maps of relative elevation, vegetation canopy height, and a field assessment of surface water and soils. This reach-scale assessment was required to provide an improved understanding of the key factors affecting restoration opportunities and constraints on the Property. Results of this assessment will be used to make recommendations on locations and strategies for restoration of the Property. The results will also be valuable to the County (and other local partners) in evaluating additional parcels that might be considered for acquisition in the future for habitat restoration and conservation purposes.

To attain this goal, we conducted the following tasks:

Ecohydrological Assessment: Ecological and hydrological factors affecting river and riparian habitat dynamics were assessed for the Mormon Mesa reach of the Virgin River using GIS analysis combined with field survey data (see Figure 1 for map of the primary assessment area).

- **Relative Elevation Mapping**: A GIS layer representing ground surface height above the low flow water surface of the river was generated from existing high-resolution LiDAR data collected by Utah State University's Remote Sensing/GIS Laboratory (USU RS/GIS) in November 2011. Relative elevation provides a very useful tool for restoration planning and can serve as a proxy for depth to groundwater.
- **Vegetation Canopy Height:** A GIS layer representing vegetation canopy height was generated using the existing the November 2011 LIDAR data. Vegetation canopy height is very useful in characterizing existing habitat structure and suitability for wildlife species of interest, and in assessing vegetation growth potential.
- **Synthesis:** A GIS analysis was conducted using multiple sources (NRCS soils mapping, historical flood-scour mapping, vegetation type and canopy height, relative elevation, distance to surface water, etc.) to identify different restoration zones within the property, and restoration strategies appropriate for each zone.

Field Surveys were conducted in September 2013 to help ground-truth the remote sensing data and provide more site-specific information for restoration plan development under this contract (2011-PIC-915B) and Project 2009-PIC-805V.

- **Field-based Vegetation Mapping:** Native and non-native vegetation on the Property were identified and mapped during field surveys. This provided a finer resolution vegetation map for the property than was currently available. Field surveys focused on those areas considered most likely to have high restoration potential based on the remote sensing and GIS analyses.
- **Field Assessment of Surface Water and Soils:** A focused field assessment of the distribution of surface water (based on visual observation of topographic low points), soil moisture (near surface conditions measured with a soil moisture probe or visual observations from shallow soil pits), and other soil conditions (such as texture, pH, salinity) were conducted in selected sites on the Property (e.g., areas likely to have high restoration potential based on the GIS analyses conducted under Task 1).

3 METHODS AND RESULTS

3.1 Field Survey

The Restoration Science Team conducted a multi-day site assessment field survey in September 2013 to characterize existing conditions and restoration potential on the Property and adjacent lands in the floodplain (Figure 2). Pre-trip planning used high resolution natural color imagery from November 2011 (Appendix 1) and Google Earth imagery from May 2013, coupled with flood scour (Appendix 2) and relative elevation (Appendix 3) maps to determine potential site access routes and primary areas to focus on during the field surveys. The results of this assessment are described in the Clark County Mormon Mesa Parcel Restoration Plan (Orr et al. 2013).

The Reach and the Property are both currently dominated by dense stands of non-native tamarisk shrubland, primarily *Tamarix ramosissima* (or the hybrid form *T. ramossisima x chinensis*), with some willows and other native species found in small patches, generally in wetter areas. Some mesquite and other native shrubs are scattered in a narrow zone of transition from floodplain to upland along the edges of the floodplain in various locations. Upland vegetation in the area is primarily creosote bush scrub.

The dominance of tamarisk vegetation in the lower Virgin River has been reported as a fairly uncommon situation in which a relatively unregulated major river floodplain is nonetheless heavily infested, presumably owing to a variety of environmental factors that promote tamarisk expansion and inhibit establishment of native woody species (Mortenson and Weisberg 2010, Dudley and Brooks 2011). An important factor determining vegetation structure and composition in this river segment is wildfire, which in our site surveys was evident in several areas based on burned stems, charrate and many standing dead trees, assumed to be mostly *Salix gooddingii* (Goodding's willow); the subtlety of the observed indicators suggests that fire was at least 10 years prior, and probably older. This represents a widespread phenomenon, in which tamarisk invasion increases probability of ignition (both natural and anthropogenic) and, because tamarisk is tolerant of fire while native trees are generally intolerant of burning, tamarisk subsequently expands in a trajectory toward complete dominance (Drus 2013). The semi-natural hydrological regime of the Virgin River, and the anticipated reduction in tamarisk cover owing to biological control, suggests that the probability of restoration success is relatively high because as tamarisk declines, the environmental conditions suitable for native recovery are enhanced, including enhanced groundwater resources as evapotranspiration from tamarisk is strongly reduced.

Table 1 lists the plant species that were observed on the Property during the September 2013 field visit. The upland areas at the eastern edge of the Property, which were not surveyed, support creosote bush (*Larrea tridentata*) scrub vegetation. An additional non-native noxious weed species, camelthorn (*Alhagi pseudalhagi*), was observed near the upstream road access point and might occur on the Property.

Table 1. Riparian plant species observed on the Property during the September 2013 site visit.

Scientific name	Common name	Native or Introduced	Habitat
Anemopsis californica	yerba mansa	N	forb
Atriplex lentiformis	quailbush, big saltbush	N	shrub
Baccharis salicifolia	mulefat, water-willow	N	shrub
Carex sp.	sedge	N	graminoid
Cynodon dactylon	Bermuda grass	I	graminoid
Heliotropium currassavicum	salt heliotrope	N	forb
Juncus sp.	rush	N	graminoid
Lepidium latifolium	perennial pepperweed, tall whitetop	I	forb
Lycium andersonii	Anderson wolfberry, boxthorn	N	shrub
Pluchea odorata	saltmarsh fleabane, sweetscent	N	forb
Pluchea sericea	arrowweed	N	shrub
Prosopis glandulosa var. *torreyana*	honey mesquite	N	shrub
Prosopis pubescens	screwbean mesquite	N	shrub
Salix exigua	coyote willow	N	shrub
Salix gooddingii	Goodding's willow	N	tree
Tamarix 'ramosissima'	tamarisk, saltcedar	I	shrub

The majority of the Property lies in the alluvial floodplain of the lower Virgin River at an elevation of approximately 1,260 ft (384 m), with fine to medium texture soils. Soil salinity in the upper 30 cm ranged from 4 to 16 ppt at seven soil sites sampled in September 2013 (Table 2, Figure 2). The eastern boundary of the Property occurs in an upland area at approximate elevations of 1,300–1,350 ft. The alluvial floodplain is generally 1–4 m above the low-flow water surface in the main channel, but some low-lying areas, especially the side channel network in the eastern portion of the Property, are 1–2 m below the main channel (see Section 3.3 Relative Elevation and Tile 8 in Appendix 3).

Table 2. Soil characteristics and vegetation documented during September 2013 field surveys.

Sample site	Texture	pH	Salinity	Vegetation
1	clay	8.44	4	Unit 7: *Tamarix* dominant
2A	silty loam	8.75	9	Unit 7: *Tamarix* dominant, some *Atriplex lentiformis*, *Lepidium latifolium*, *Baccharis salicifolia*, *Pluchea odorata*
2B	sandy loam	8.46	5	
2C	sandy loam	8.60	6	
2D	silty clay	8.73	12	
3A	clay	8.77	15	Unit 7: *Tamarix* dominant
3B	clay	8.51	15	
4A	clay loam	8.35	7	Unit 5: *Tamarix* dominant, with *Pluchea odorata* common in understory
4B	silty clay	8.40	6	
5A	silty clay	8.43	5	Unit 4: *Tamarix* dominant, with *Pluchea odorata* common in understory
5B	silty clay	8.63	7	
6A	clay	8.55	6	Unit 5: *Salix gooddingii* and *Tamarix* co-dominant, with mixed natives and some *Lepidium latifolium*
6B	clay	8.53	5	
7A	silty loam	8.63	9	Transition between Units 4&5: *Tamarix* dominant and sparse *Salix gooddingii*, with *Lepidium latifolium* common in understory
7B	silty loam	8.90	16	

Observations made during the field survey in September 2013 suggested that shallow sub-surface water flow was generally in a north-south direction upstream of the Property in the main "Virgin River #1" SWFL sites, but near the Property's upstream boundary the flow path shifted to more of a northwest-southeast direction in the western and central portion of the Property, with likely continued north-south subsurface flow in the eastern portion containing the side channel network. It was also apparent in the field, and on the relative elevation map (see Tile 8 in Appendix 3), that portions of the old access roads that had been bulldozed years ago had become incised due to fluvial erosion, and been captured by the side channel network. This can be seen elsewhere in Reach, just upstream and downstream of the Property (see Tiles 7–9 in Appendix 3).

Fifteen "Vegetation Management Units," or "Units," were delineated on or adjacent to the Property based on field observations and remote sensing data (Table 3, Figure 2). Units 4, 5, 7, and 13 appear to have the greatest potential for restoration of native cottonwood-willow riparian vegetation and enhancement of SWFL habitat quality (see Orr et al. 2013 for more detailed discussion of restoration potential of the four units). Other units are less suited for restoration, particularly for SWFL breeding habitat, as they have relatively higher elevation or generally drier conditions indicating lesser sub-surface flows and/or greater depth to groundwater. These low-priority areas could eventually be targeted for restoration for broader biodiversity or ecosystem function objectives, but are unlikely to support SWFL nesting owing to inadequate moisture. We anticipate that irrigation will not be used during this restoration program because it would not be cost-effective when other suitable areas exist at the Property, although it is likely that groundwater is sufficiently near the surface in low-priority areas such that some mesic species

Table 3. Current conditions and potential restoration targets and priorities, by Vegetation Management Unit.

Vegetation Management Unit	Size (acres)	Current conditions	Restoration target	Priority
1*	NA	Tamarisk; high flood reset risk	NA	NA
2	<0.1	Tamarisk; high relative elevation; dry	Coyote willow - mulefat	Low
3	12.4	Tamarisk; dry; moderate flood reset risk	Coyote willow - mulefat,	Low
4	10.7	Tamarisk with scattered willows; favorable surface/soil moisture	Cottonwood-willow; SWFL habitat	High
5	2.5	Goodding's willow with mixed Tamarisk; favorable surface/soil moisture; Occupied SWFL Habitat	Protect existing SWFL habitat, restrict cattle if possible, consider future enhancement plantings with native species if tamarisk dies off	High
6	3.1	Tamarisk; dry	Cottonwood-willow	Medium
7	12.8	Tamarisk with scattered willows; favorable surface/soil moisture, especially in lower areas (channels)	Cottonwood-willow; SWFL habitat	Medium–High
8	2.3	Tamarisk; dry	Cottonwood-willow	Medium
9	1.2	Tamarisk; dry	Cottonwood-willow	Medium
10	8.5	Tamarisk; dry	Mesquite	Low
11	0.8	Mesquite (Transition)	Enhanced Mesquite	Low
12	11.2	Creosote Bush Scrub (Upland)	No Change	No Action
13	12.4	Riverwash—wet; with herbaceous wet meadow species; high flood reset risk	Establish small patches of willows and cottonwoods to serve as seed sources for natural revegetation; need to install fencing to protect from cattle	High if low-cost methods can be applied
14*	NA	Riverwash—dry; with <5% vegetation; high flood reset risk	NA	NA
15	2.4	Tamarisk; dry	Mesquite	Low

* NA = not applicable: Units 1 and 14 occur adjacent to but not on the Property, so area, restoration target, and priority categories do not apply

(e.g., *P. fremontii*) could tolerate conditions if deep-drilled (i.e., using the technique of augering planting holes for large pole cuttings 3-m or greater in length so that perennial contact is made with groundwater). For the immediate project (both for restoration on the Property and identifying potential priority areas elsewhere in the Reach), it is better to focus effort into priority areas where species can be installed that are dependent on high moisture conditions and can be established without irrigation.

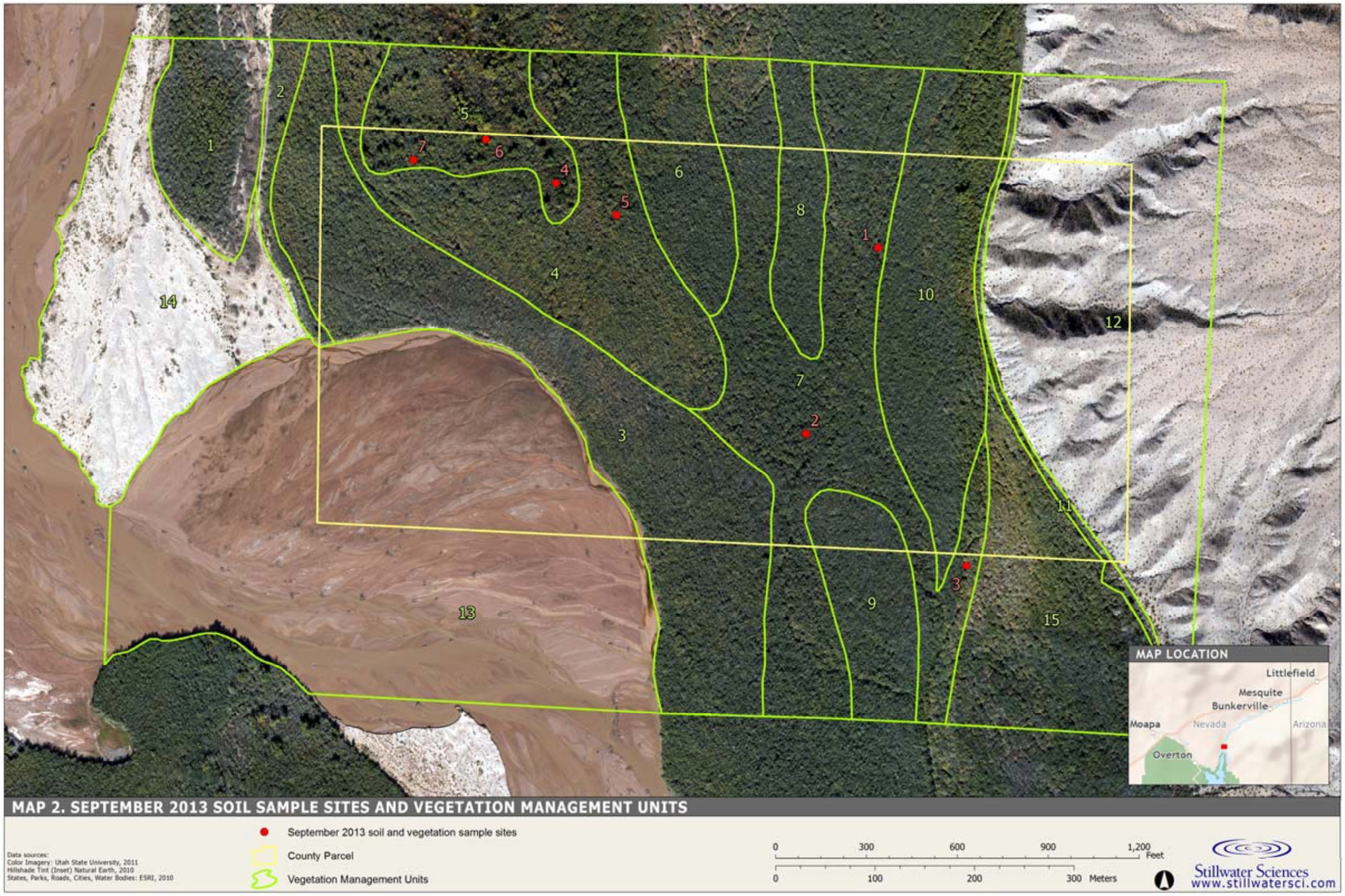

Figure 2. Soil sample sites surveyed during the September 2013 field visit, and vegetation management units developed for the County Property from field and GIS data.

3.2 Flood Reset Zone

As part of our Phase I restoration planning efforts, we delineated flood-scour potential throughout the river corridor based on three of the most recent large flood events, as represented in aerial photography taken shortly after each event: 1989, 2005, and 2010 floods. Briefly, this entailed mapping flood-induced channel disturbance (typically scouring or burial of riparian vegetation) within the "hydrogeomorphically active channel"—that part of the mainstem channel bed that carried a significant part of the flood and sediment discharge during a given flood event. The frequency of flood disturbance to the river channel and floodplain was thus mapped to inform on potential future flood-scour risks during the next large event, which is particularly important for restoration planning in order to conserve limited resources and ensure re-vegetation success. The details of this analysis are summarized in Stillwater Sciences (2012).

The flood-scour mapping (Appendix 2) was refined to guide restoration planning at the Property and throughout the Mormon Mesa reach by delineating the "Flood Reset Zone," which was accomplished as follows:

- Considered those areas of the active channel having >30% flood-scour frequency (i.e., approximately, scoured in 2 out of the 3 mapped floods), and
- Considered those areas mapped as "high" flood-disturbance activity—areas severely disturbed by flow, typically scoured to bare substrate retaining ≤10% apparent riparian vegetative cover—during the most recent flood of 2010.

Within the Property boundaries, the Flood Reset Zone is limited to the southwestern corner where the current active channel shifted during the December 2010 flood. The reset zone also occurs as an isolated pocket near the southeastern corner of the Property, which appears to have formed via overbank scour upon the floodplain during the 1989 flood, but has steadily filled in with vegetation (mostly tamarisk) since that very large event. However, as described below, due to the current position of the main channel and likely scour path during the next big flood events, we consider this area to be at relatively low risk and therefore likely outside of the primary flood reset zone in the near future.

The Property is presently situated near a highly dynamic, S-shaped bend in the river's course which formed during the December 2010 flood event. Prior to this event, the river flowed along a southerly course closer to the western side of the valley, and began to veer more toward the center of the valley slightly crossing the southwestern corner of the Property, as observed in aerial imagery collected since the early 1990s. During the 2010 flood, the river's course shifted to its present position forming the S-shaped bend via a deflection off of the right-bank (west) side of the active channel (first bend) pushing the channel farther to the left-bank (northeast) side and into the Property (counter to the valley's north-south orientation), which then eventually deflected the channel back towards the south (second bend) and downstream of the Property. The November 2011 imagery shows the dominant low-flow channel to be positioned along the river-left side of the second bend crossing the southwestern corner of the Property. The river's course has since shifted away from this side to an orientation closer to its pre-2010 flood position, based on a review of 2013 aerial imagery in Google Earth. Given this recent change along with the very tight radius of curvature of the first bend in the S-shaped bend and the low-lying side channels situated down-valley upon the floodplain, it appears most likely that future channel migration and/or avulsion will continue into this first bend rather than farther into the Property.

In summary, planning in the Property should consider flood-scour risks to any active planting restoration within the southwestern corner that has been mapped within the Flood Reset Zone, but risks to the remainder of the Property appear to be minimal based on the present trajectory of the active channel.

3.3 Relative Elevation

Existing information in the scientific literature and personal observations and unpublished data indicate that native riparian plant species tend to occur in particular topographic positions relative to the river channel. In particular, we have found that relative elevation above the low-flow, or baseflow, water surface in the river channel is a useful indicator for restoration potential. Relative elevation in a floodplain is generally correlated with depth to groundwater, and frequency of surface saturation and inundation.

Thus relative elevation, which combined with other GIS layers and field data, provides a powerful tool for assessing restoration potential via passive (natural recruitment processes) or active (horticultural restoration) approaches. Although successful germination of native riparian seedlings depends on a variety of hydrologic and geomorphic variables, seedling survival of phreotophytes such as cottonwoods and willows following germination (or of planted cuttings or container stock under horticultural restoration) is above all contingent on constant contact with the water table and/or its capillary fringe throughout the growing season (McBride and Strahan 1984, Stromberg et al. 1991). Research indicates that when the water table decline is more rapid over a long period than the rate of root growth, seedlings of phreatophytic species become isolated from their water source and suffer high mortality (McBride et al. 1989, Stromberg et al. 1996). In addition to the importance of groundwater levels for seedling survival, research indicates that groundwater levels play an integral role in determining sapling survivorship and adult riparian community composition (Smith et al. 1991).

Furthermore, comparative studies indicate that some non-native invasive plant species (such as tamarisk) tend to be more drought-tolerant than natives, and thus better able to compete along reaches with extreme inter- and intra-annual water table fluctuations (Smith et al. 1991, Freidman et al. 1995, Shafroth et al. 1998, 2000). Thus, in order to restore self-sustaining hardwood riparian forest, we need to better understand the role of groundwater in species survivorship across time and across species.

In the absence of data on groundwater depth, relative elevation can serve as a very useful proxy. Ideally, relative elevation mapping can be coupled with groundwater monitoring stations to increase our understanding of groundwater dynamics and increase rate of success when implementing riparian restoration.

A relative elevation map was produced for the entire Reach using the bare-earth LiDAR data collected in November 2011 (Appendix 3). The map displays topographic elevations relative to the low-flow channel elevation with the following categories: less than -3, -3 to -2, -2 to -1, -1 to -0.5, -0.5 to 0, 0–0.5, 0.5–1, 1–2, 2–3, 3–4, 4–5, 5–7.5, 7.5–10, 10–20, and greater than 20 m. The map reveals that the floodplain is generally higher than the active channel, along with several floodplain areas lying below the low-flow channel most commonly associated with side-channels. Many of these side channels appear to hold surface water based on review of recent aerial imagery. Within the Property, much of the eastern half lies near or below the low-flow channel indicating a shallow water table suitable to support active planting of native vegetation is available.

3.4 Vegetation

The Reach is dominated by dense stands of tamarisk, with smaller patches of Goodding's willow and other native vegetation. The main patches of Goodding's willow can be identified in the GIS using vegetation canopy height information derived from the LiDAR data collected in November 2011. Mature trees of Goodding's willow tend to form an emergent crown greater than 7 m in height, which extends above the typically dense layer of tamarisk, so we can readily pick up individual trees and stands by mapping all vegetation >7 m in canopy height. Most tamarisk stands do not exceed 5 m in canopy height, but in the most productive sites taller plants are found and canopy height may be in the 5–7 m range. If other factors (such as relative elevation and soil salinity) are suitable, these taller, more productive tamarisk stands can be used as an indicator of areas likely to be suitable for revegetation by native woody species. The relationships between vegetation canopy height and presence of Goodding's willow, and likely restoration potential, are also supported by field observations and careful review of natural color aerial imagery from 2011(Appendix 1) and 2013 (Google Earth).

A canopy-height map was produced for the entire Reach using the first-return LiDAR data collected in November 2011 (Appendix 4). The map displays the following height categories: 0–1, 1–3, 3–5, 5–7, 7–10, 10–20, and >20 m. Canopy heights within the Property boundaries generally extend up to 7 m, with some instances of heights reaching the 7–10 m size class. This condition indicates that vegetation-growth potential for native woody species, such as willows, is good.

3.5 Soils

Analysis of soils data contributes to more realistic projections of potential woody riparian vegetation expected under various management scenarios, as we can exclude areas with soils unsuitable for hardwoods such as cottonwoods and willows (using NRCS/SCS info on salinity, soil texture, etc.). By linking our understanding of natural riparian vegetation recruitment processes and native woody plant life history requirements with soils information, our predictions of locations and total area suitable for passive revegetation (i.e., revegetation via restoration of natural seed dispersal/germination/root growth/inundation and water table recession processes) can be made more reliable. However, our primary purpose in the present analysis is to use soils data to explore the potential for use of active revegetation techniques (i.e., horticultural restoration) to establish various native riparian trees, shrubs, and herbaceous species in the study area to restore or enhance suitable habitat for SWFL and other wildlife species of interest.

The NRCS SSURGO spatial dataset (produced before the 2010 flood event) was used to produce a soils map for the Reach displaying soil salinity and texture (Appendix 5). Soil salinity and soil texture were based on the electrical conductivity and particle size categories, respectively, in the SSURGO dataset. Salinity classes present within the Reach include: very slightly saline (2–4 mmhos/cm), slightly saline (4–8 mmhos/cm), and strongly saline (>16 mmhos/cm). Soils <2 mmhos/cm were considered non-saline. Soil texture classes present in the Reach include: not classified, fine-silty, fine-silty over sandy or sandy-skeletal, sandy, and sandy-skeletal. Within the Property boundaries, soil salinity classes present are very slightly saline and strongly saline, and soil texture classes present are not classified for the floodplain and sandy-skeletal for the active channel.

Sampling and mapping soils in a dynamic alluvial reach with difficult access due to dense tamarisk vegetation is very challenging. Such is the case in Mormon Mesa. Given these challenges, we decided to use NRCS soil map data, primarily soil salinity, as a secondary factor in determining restoration potential. The NRCS soils data should be used as a general indication of what soils might be like in a given restoration area, but final decisions on restoration priority and design should be based as much as possible on field data collected on site (as was done for the Property and described above in Section 3.1)

3.6 Vegetation Restoration Priority Areas

Potential priority restoration areas were then identified based on suitable characteristics, primarily location relative to the Flood Reset Zone, elevation above baseflow, vegetation canopy height, existing vegetation patterns visible in the November 2011 natural color imagery and more recent GoogleEarth imagery from May 2013. As described above (Section 3.5), NRCS soils map data were not used as a primary factor in identifying restoration potential. However, soil salinity information is listed for each potential restoration area in Table 4 and should be considered in future refinement of priorities for field surveys (including surveys to collect site-specific soil samples) and restoration design and implementation. It is important to note that many other factors, including shade tolerance and other competitive abilities, proximity to seed source, intensity of herbivory, and presence of disease, can contribute to the success of plant establishment and species distributions within riparian zones.

The criteria for areas having the greatest potential for restoration suitability were as follows:

- Within the riparian corridor (i.e., valley floor, excluding tributary alluvial fans and other upland areas)
- Outside of the Flood Reset Zone
- The above combined with areas having low-lying elevations (i.e., shallow water table) and tall canopy heights (i.e., most productive for woody vegetation):
  - "High" restoration potential:
    - Relative elevation: <0–0.5 m and Canopy height: >5 m
    - Relative elevation: 0.5–2 m and Canopy height: >7m
  - "Medium" restoration potential:
    - Relative elevation: 0.5–2 m, Canopy height: 5–7 m
    - Relative elevation: 2–3 m, Canopy height: >5 m

The results of the analysis produced distributions of color-coded pixels along the entire Reach representing points of "High" or "Medium" restoration potential. The distributions displayed discrete groupings of suitable areas that were finalized by manually encircling them with polygons of the same priority classification. We identified 34 potential restoration areas: 10 high priority and 24 medium priority areas (Table 4). Figure 3 provides an example of the potential restoration areas identified in the vicinity of the Property. A full set of maps for the Reach is provided in Appendix 6.

The 10 high priority areas total approximately 500 acres, and range in size from about 7 acres to 96 acres. Field reconnaissance should be conducted to confirm general restoration potential at these sites, and likely habitat suitability for SWFL and other wildlife species of interest. If restoring habitat for SWFL is the primary concern, it appears that Areas 22, 23, 26, 29, and 31 offer the most immediate potential for enhancing current or recently occupied habitat to counteract potential adverse effects of defoliation caused by the tamarisk leaf beetle. If restoration is considered in these areas, the adjacent medium priority areas should be included in initial field assessment to see if they should also be included. As discussed in the Clark County Mormon Mesa Parcel Restoration Plan (Orr et al. 2013), small patch clearing and treatment of tamarisk and planting with Goodding's willow and other native plants is likely the most viable and effective rapid implementation option. Measures to restrict potential damage from trespass cattle would likely be required unless cattle are removed from the Reach.

Table 4. Characteristics of potential restoration (revegetation) priority areas in the Mormon Mesa Reach, beginning at the downstream end and working upstream (north).

Restoration area ID	Size (acres)	Priority	Notes[1]
1	80.4	medium	Appears to support Goodding's willow; restoration may be particularly susceptible to changes in reservoir water levels
2	8.6	medium	Coincides with historically occupied SWFL site
3	4.7	medium	May have relatively high flood reset risk
4	16.4	medium	Slightly saline soils, contains or borders small secondary channels
5	18.3	medium	Coincides with historically occupied SWFL site
6	6.7	medium	Strongly saline soils; borders side channel that appears to maintain perennial surface water
7	8.5	medium	Potentially non-saline soils; borders side channel that appears to maintain perennial surface water
8	10.1	medium	Strongly saline soils; some small channel microtopography
9	10.9	medium	Strongly saline soils
10	96.3	high	Very slightly saline to strongly saline soils; some small side channels
11	100.5	medium	Very slightly saline to strongly saline soils; some small side channels
12	5.4	medium	Strongly saline soils; borders side channel may maintain perennial surface water
13	65.1	medium	Non-saline to strongly saline soils
14	85.7	high	Non-saline to strongly saline soils; some side channels
15	6.7	high	Strongly saline soils; small channel microtopography
16	45.7	high	Slightly saline to strongly saline soils; side channel runs through middle of the area
17	34.2	medium	Slightly saline to strongly saline soils
18	48.1	medium	Strongly saline soils; large side channel runs along eastern edge
19	67.3	high	Very slightly saline to strongly saline soils; some small side channel microtopgraphy
20	14.9	medium	Very slightly saline soils; large side channel

Restoration area ID	Size (acres)	Priority	Notes[1]
21	39.6	medium	Slightly saline to strongly saline soils; coincides with Virgin River #2 SWFL site
22[2]	8.3	high	Strongly saline soils; small channel; coincides with Virgin River #2 SWFL site
23[2]	9.8	high	Strongly saline soils; small channel; coincides with Virgin River #2 SWFL site
24	31.4	medium	Non-saline soils; coincides with Virgin River #2 SWFL site
25	15.4	medium	Very slightly to strongly saline soils
26	96.2	high	Primarily very slightly saline soils, with some strongly saline soils; coincides with Virgin River #1 SWFL site
27	11.9	medium	Very slightly saline soils; coincides with Virgin River #1 SWFL site
28	15.7	medium	Non-saline to strongly saline soils
29	44.5	high	Slightly to strongly saline soils; coincides with Mormon Mesa South SWFL site
30	11.6	medium	Slightly saline soils; coincides with historically occupied Hedgerow SWFL site
31	36.9	high	Non-saline to strongly saline soils; coincides with Mormon Mesa North SWFL site
32	18.1	medium	Strongly saline soils
33	39.6	medium	Strongly saline soils
34	7.5	medium	Strongly saline soils
Total	**1121**		

[1]Notes include comments on soil salinity indicated in NRCS soils maps and other information sources such as SWFL survey reports and color aerial imagery.
[2]Areas 22 and 23 could be extended in an upstream direction, potentially increasing area to 20-25 acres

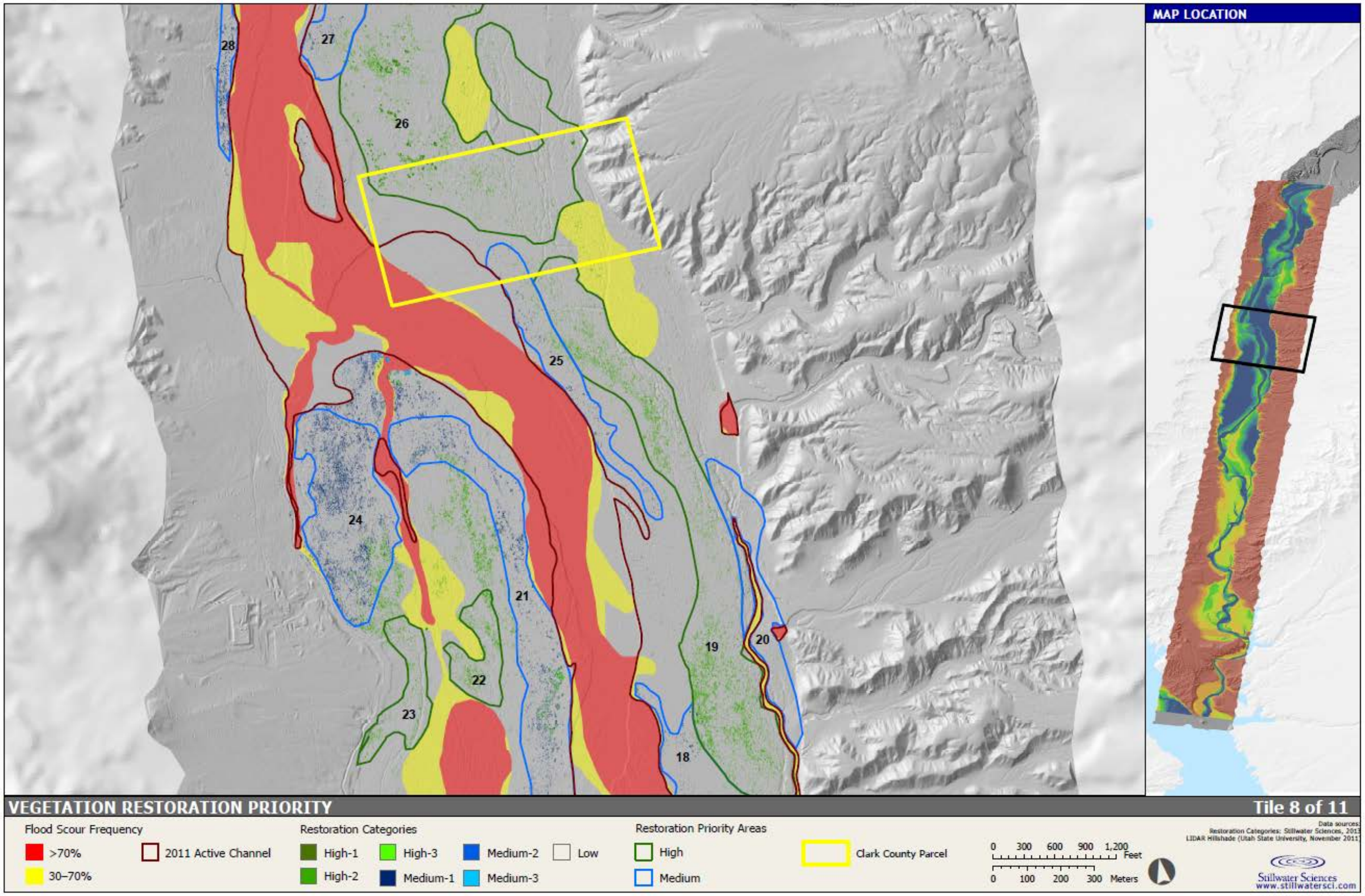

Figure 3. Potential restoration priority areas in the vicinity of the Clark County Property in Mormon Mesa, overlaid on the flood reset zone (historical flood scour frequency of 30% or greater) and pixel-based restoration categories (derived from LIDAR-based data on relative elevation and vegetation canopy height).

4 RECOMMENDATIONS

- Use the results of this ecohydrological assessment to inform restoration on the Property, as described in the Clark County Mormon Mesa Parcel Restoration Plan (Orr et al. 2013)
- Look for additional opportunities to conduct revegetation/restoration in high priority areas in the immediate vicinity of the Property through acquisition of new lands or cooperation with other landowners interested in restoration
- Conduct additional site surveys to refine boundaries and acquisition or restoration priorities for each polygon; particularly for high priority areas within the known recently or historically occupied SWFL habitat areas (primarily those shown on map tiles 7-9 in Appendix 6)
- Update the vegetation restoration priority coverage as new data (particularly field data on soils, depth to groundwater, and current vegetation) become available
- Consider initiating groundwater monitoring on the Property and work with other landowners to establish additional groundwater monitoring sites in other high priority areas
- Develop and implement an active adaptive management program as restoration implementation progresses in the Reach
- Conduct demonstration restoration projects on the County Parcel, and other sites as appropriate and feasible, and then monitor to test our working hypotheses about physical site conditions, feasibility of restoration of native woody species and other plants, and site suitability for SWFL and other wildlife species of interest
- Before considering restoration in the lower portion of the Reach (Reach 1a in Figure 1), consider potential effects on restoration potential of climate change and declining reservoir levels in Lake Mead that may cause downcutting of the Virgin River, decoupling from its historic floodplain, and localized lowering of the groundwater table

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Appendices

The following appendices are available electronically as PDF files. Each appendix contains a set of 11 map tiles covering the Mormon Mesa Ecohydrology Assessment Reach. Note: in some cases (such as in Appendix 2), the key mapped data sources do not cover the downstream portion of the Reach

Appendix 1. Natural Color Imagery, November 2011
Appendix 2. Active Channel Historical Position (Flood Reset Zone)
Appendix 3. Relative Elevation (Height Above River Channel)
Appendix 4. Vegetation Canopy Height
Appendix 5. NRCS Soil Salinity and Texture
Appendix 6. Vegetation Restoration Priority Areas

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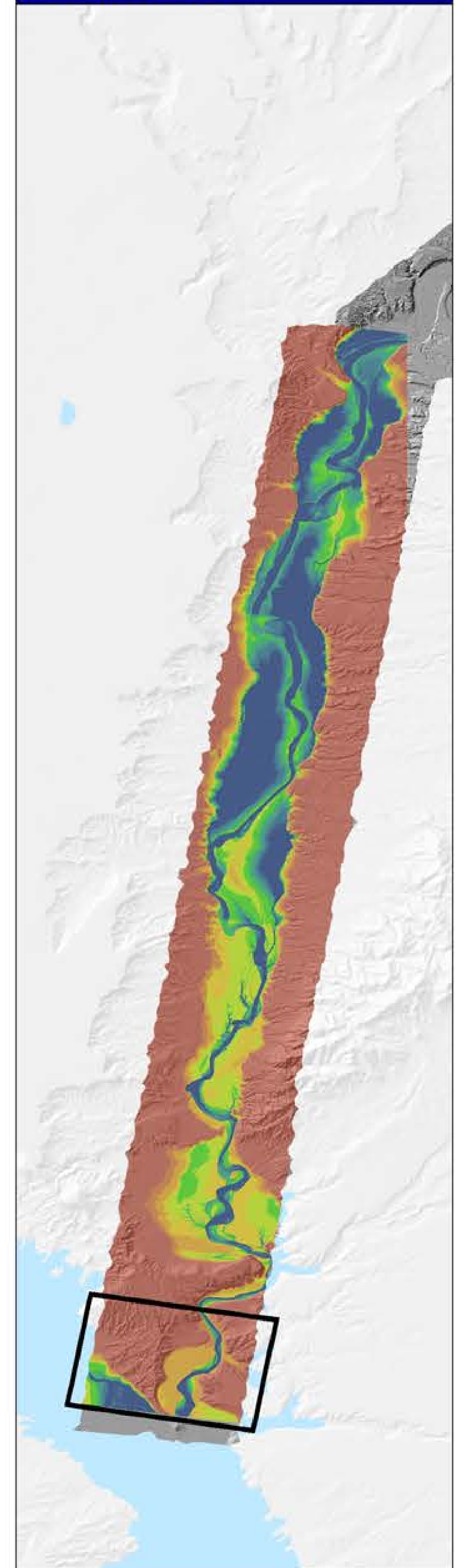


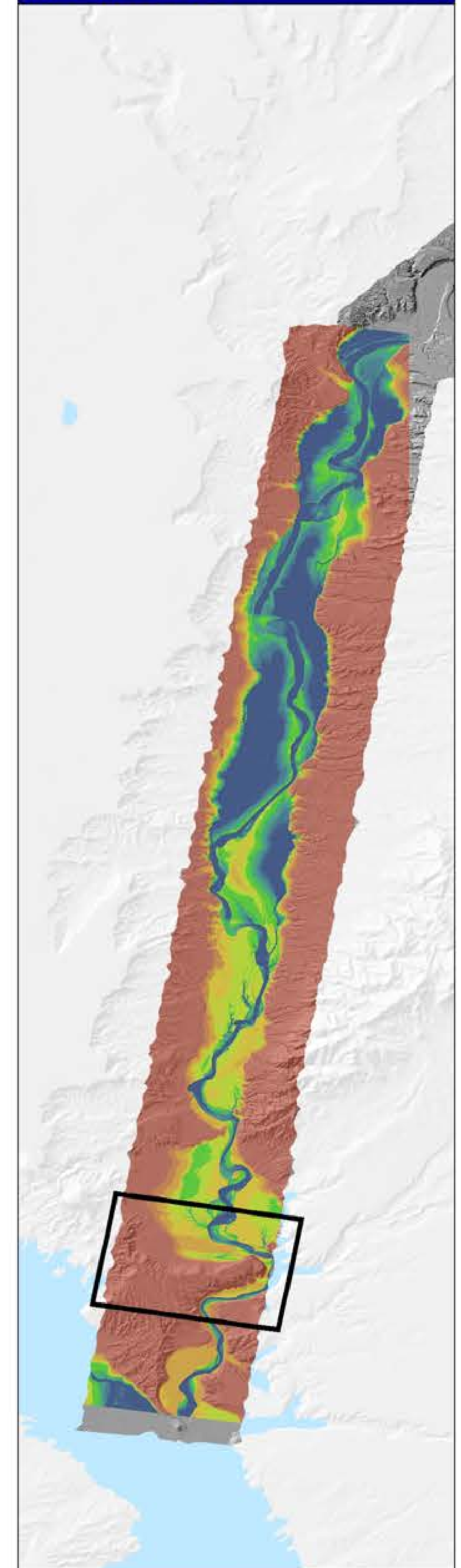
MORMON MESA, NATURAL COLOR IMAGERY (NOVEMBER 2011)

0 500 1,000 1,500 2,000 Feet
0 200 400 600 Meters

Stillwater Sciences
www.stillwatersci.com

Data sources:
LIDAR Hillshade & color imagery: Utah State University, November 2011

MAP LOCATION



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Stillwater Sciences
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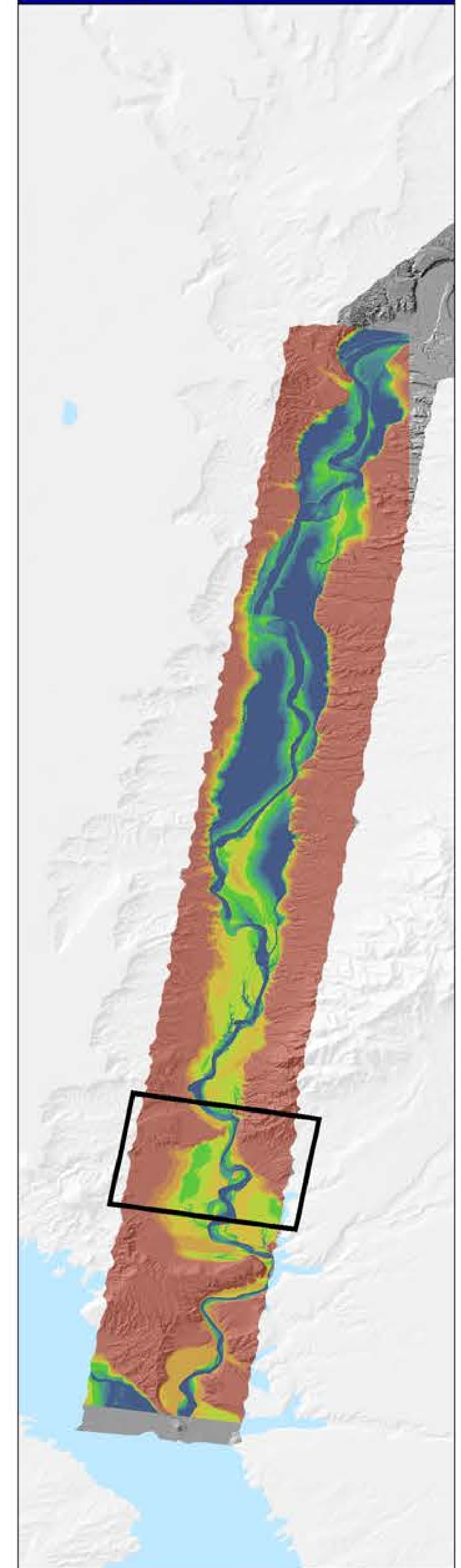
MAP LOCATION



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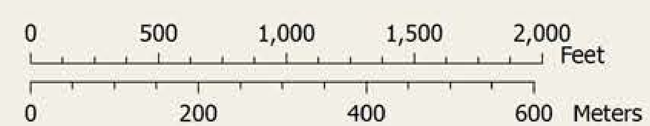
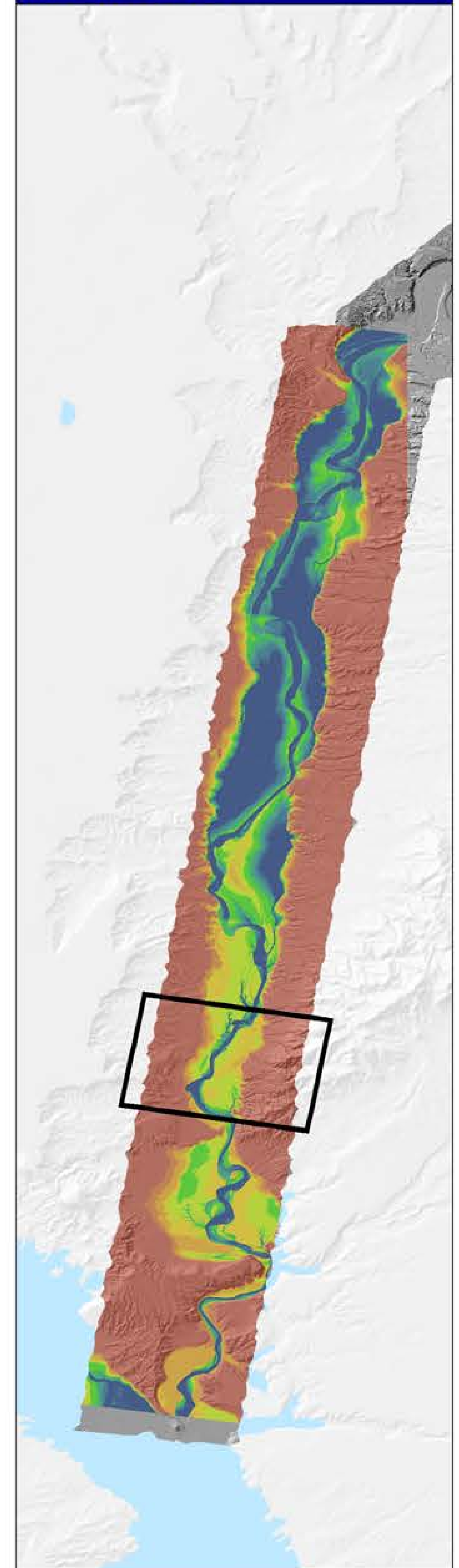


Stillwater Sciences
www.stillwatersci.com

Data sources:
LIDAR Hillshade & color imagery: Utah State University, November 2011

MAP LOCATION



MORMON MESA, NATURAL COLOR IMAGERY (NOVEMBER 2011)

Tile 4 of 11

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Stillwater Sciences
www.stillwatersci.com

Data sources:
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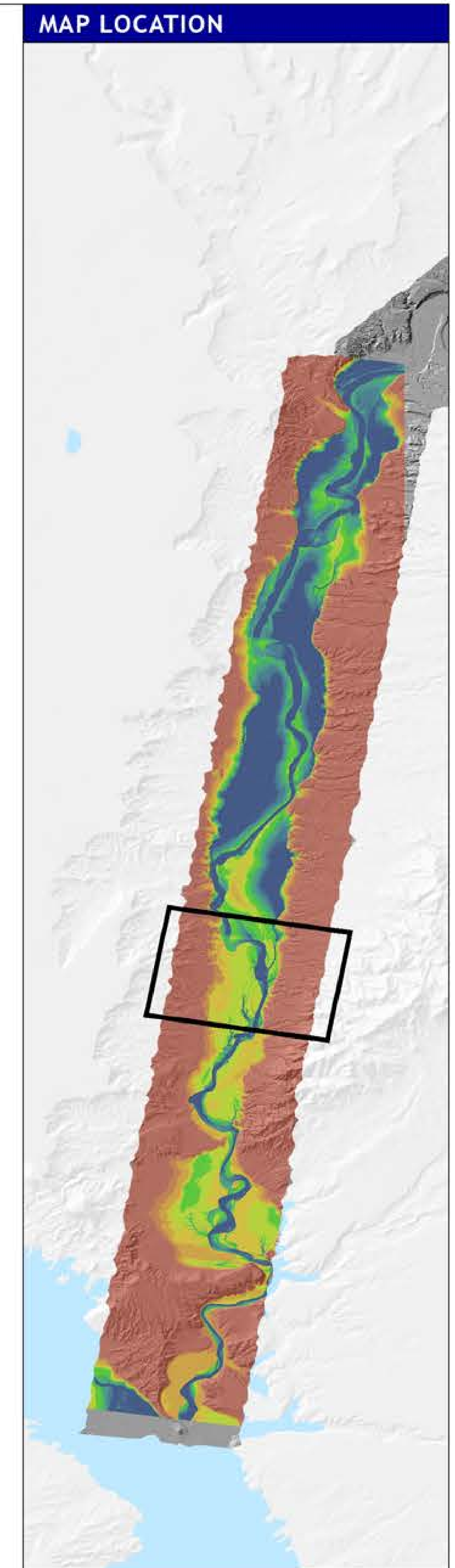

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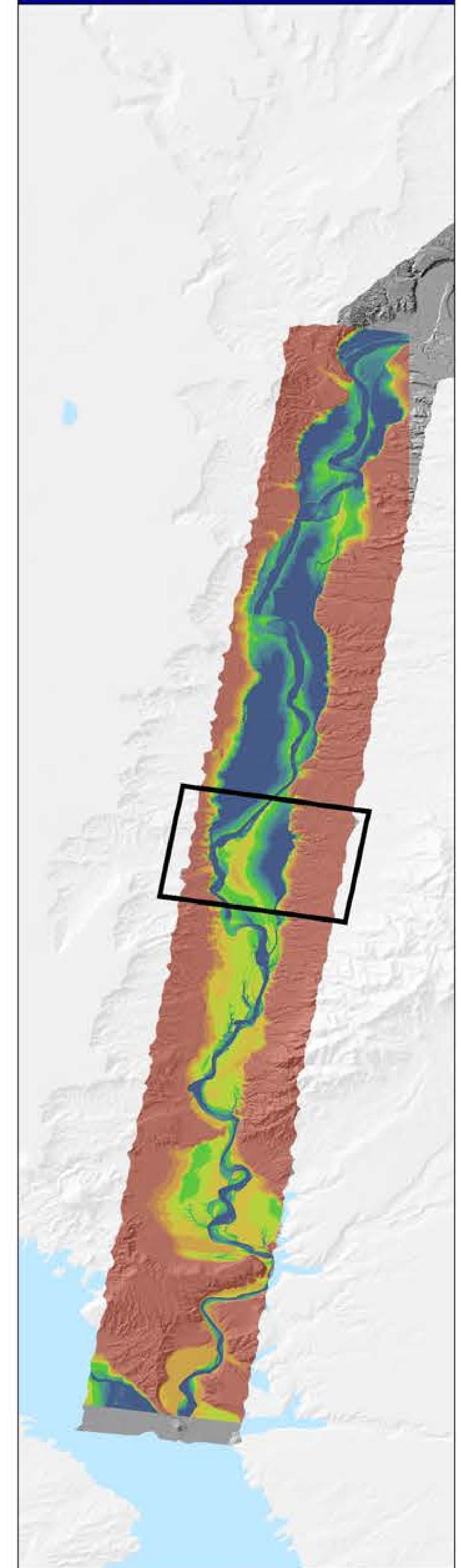
LIDAR Hillshade & color imagery: Utah State University, November 2011

Stillwater Sciences
www.stillwatersci.com

MAP LOCATION



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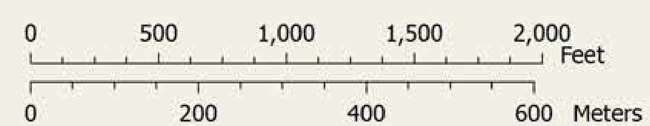

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Stillwater Sciences
www.stillwatersci.com

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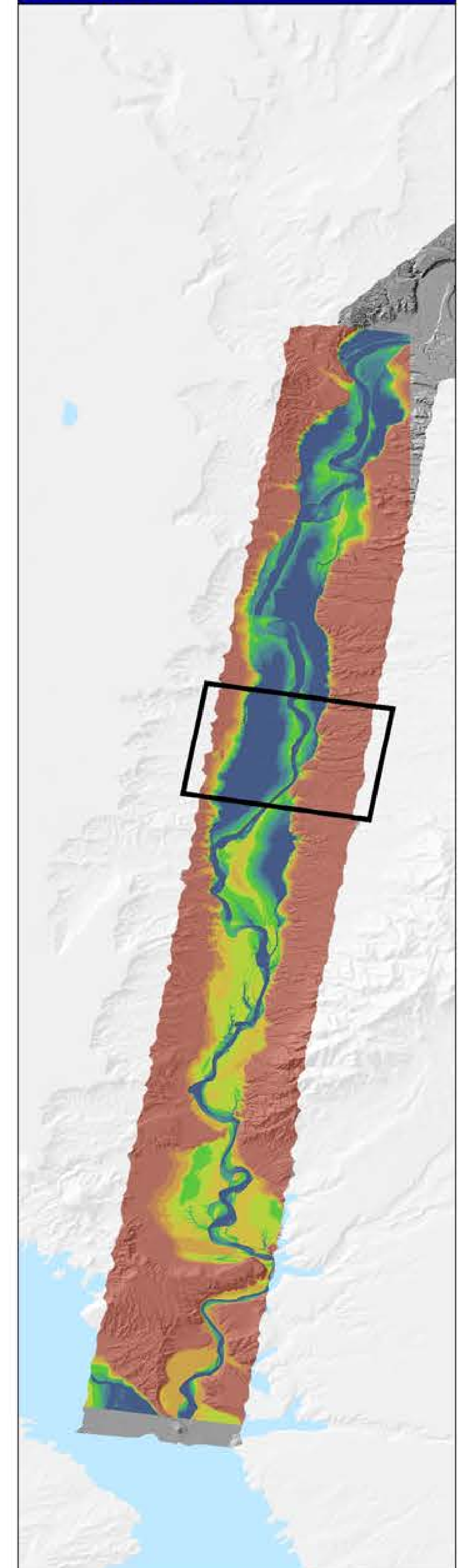

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LIDAR Hillshade & color imagery: Utah State University, November 2011

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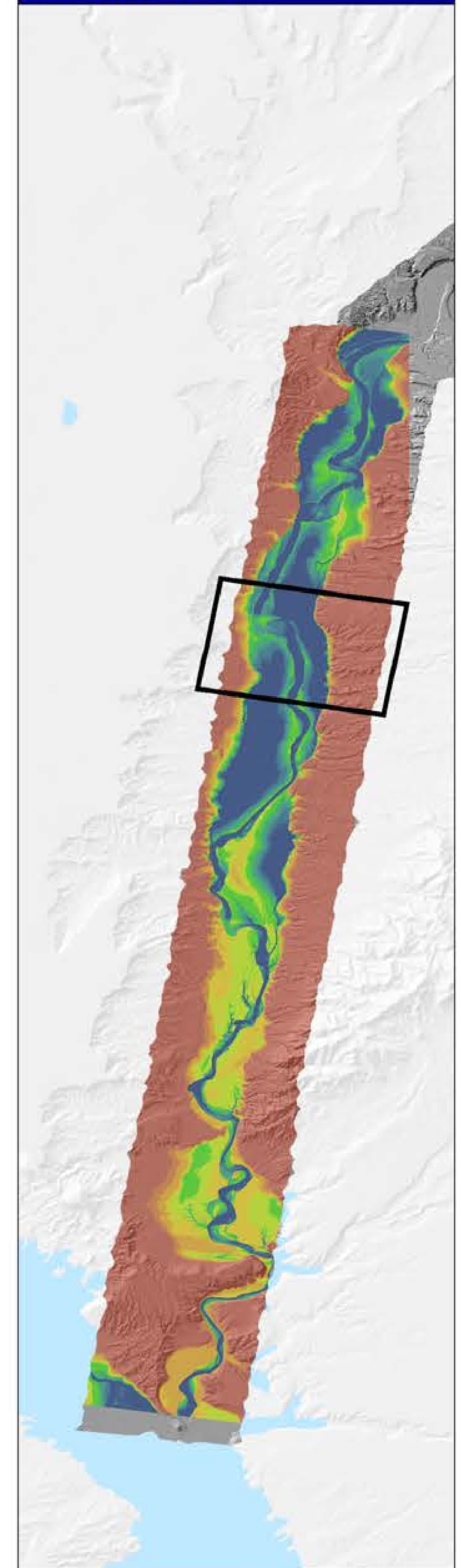
www.stillwatersci.com



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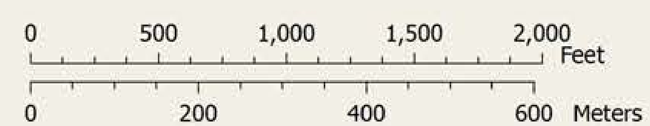
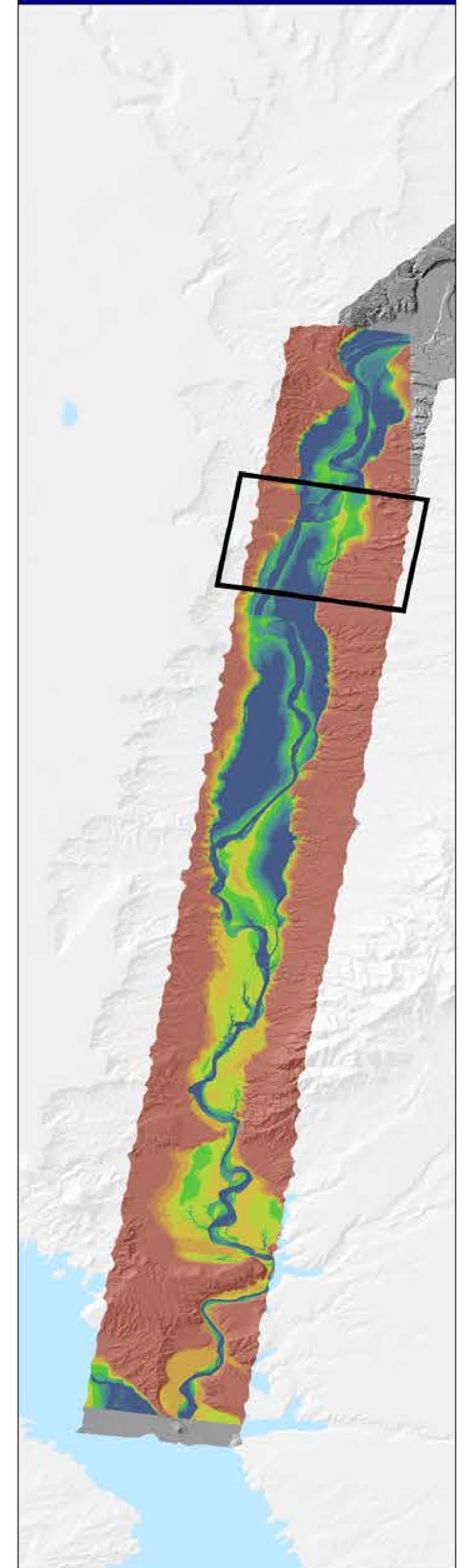
Tile 8 of 11



Stillwater Sciences
www.stillwatersci.com

Data sources:
LIDAR Hillshade & color imagery: Utah State University, November 2011

MAP LOCATION



MORMON MESA, NATURAL COLOR IMAGERY (NOVEMBER 2011)

Tile 9 of 11

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Stillwater Sciences
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LIDAR Hillshade & color imagery: Utah State University, November 2011

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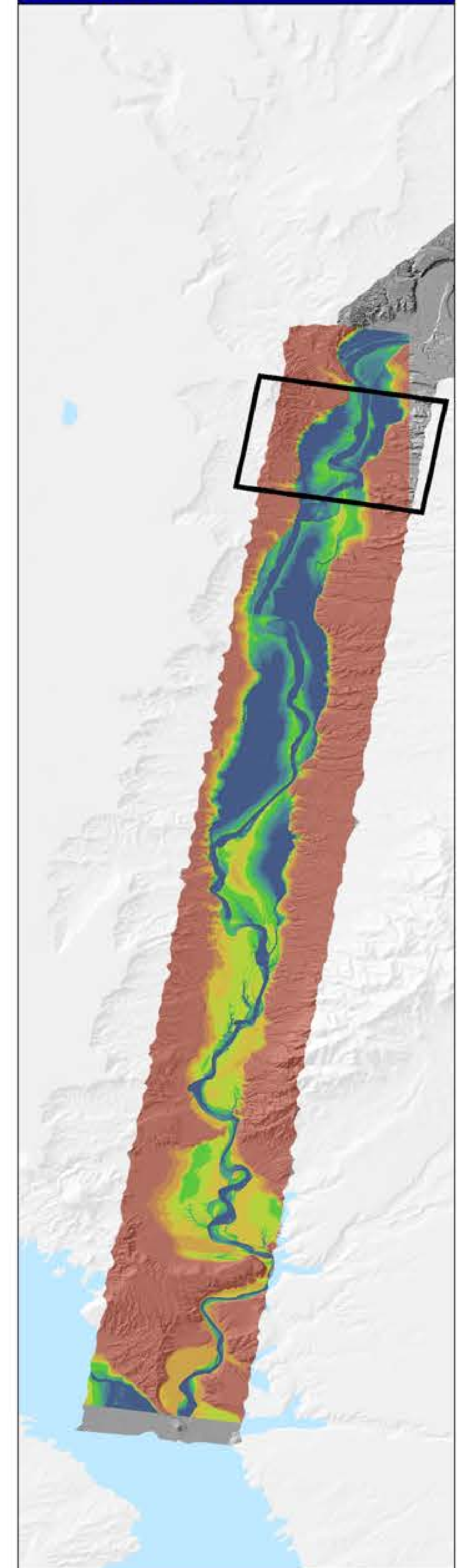

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Stillwater Sciences
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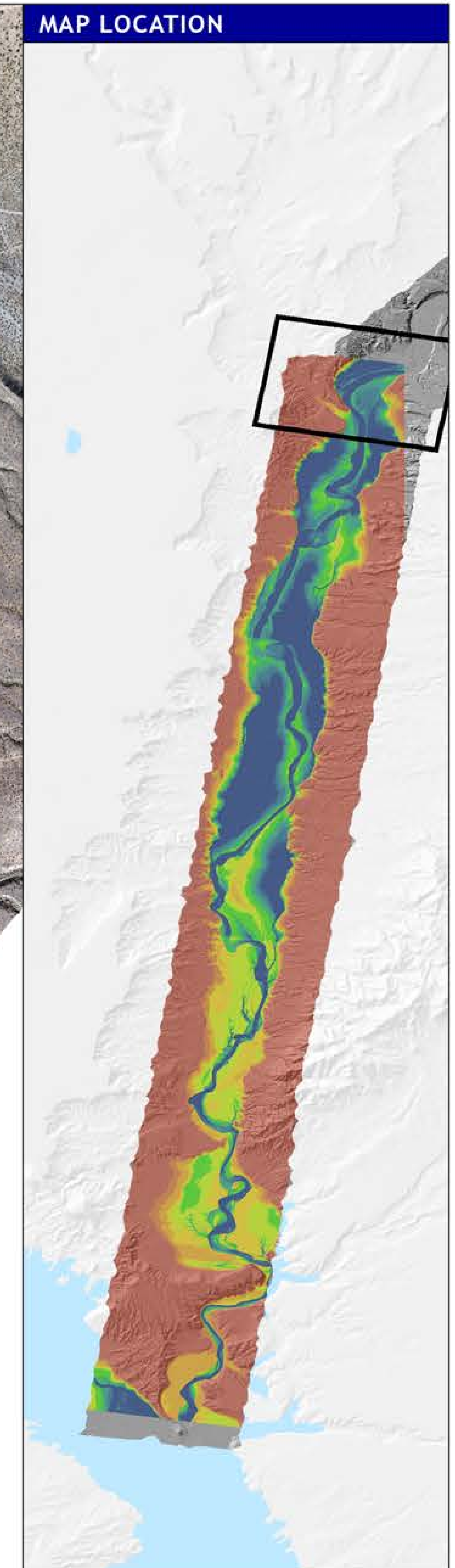

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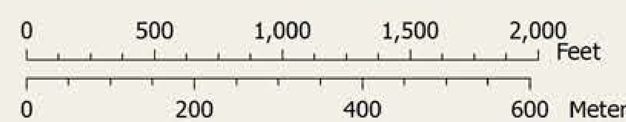

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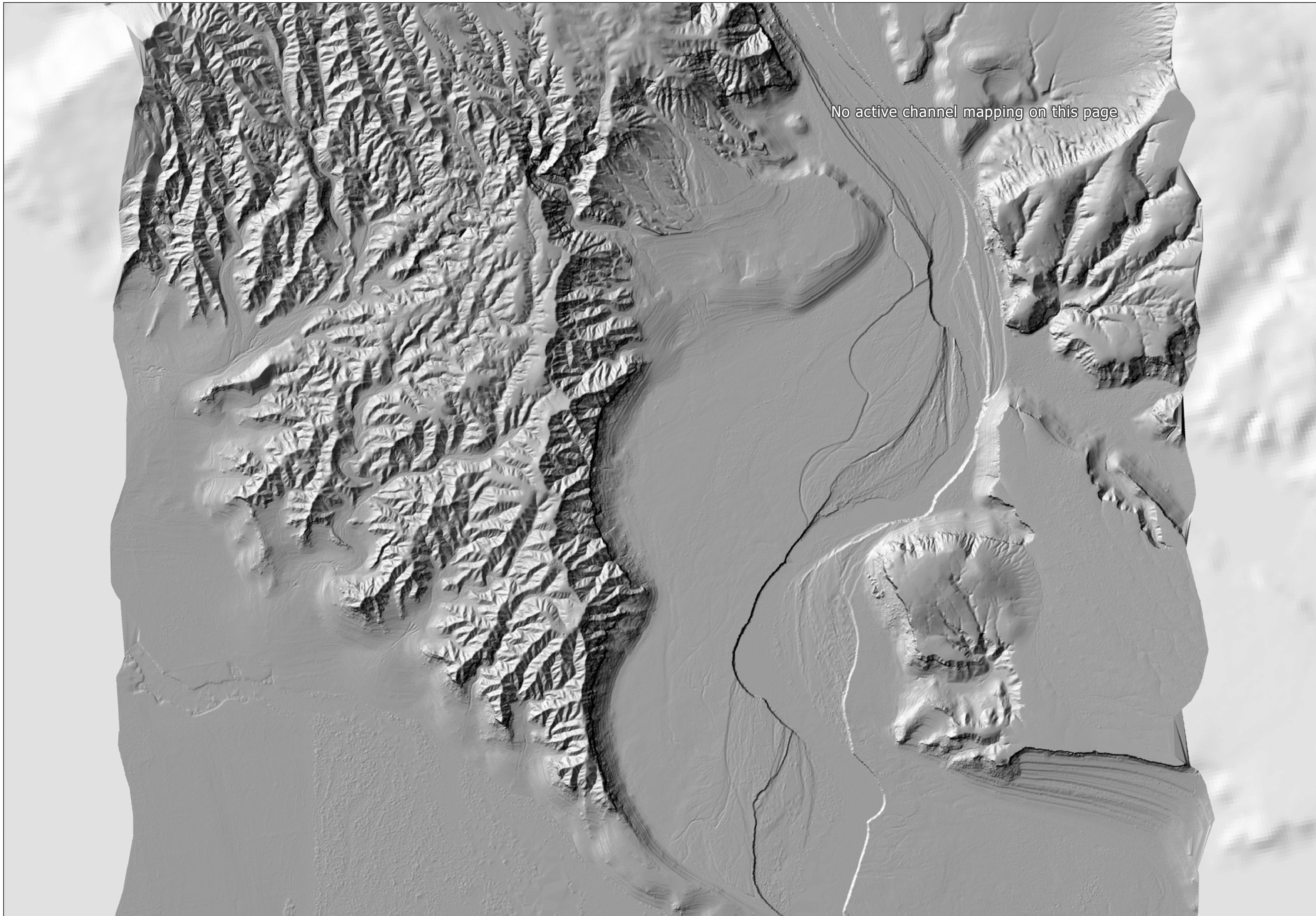
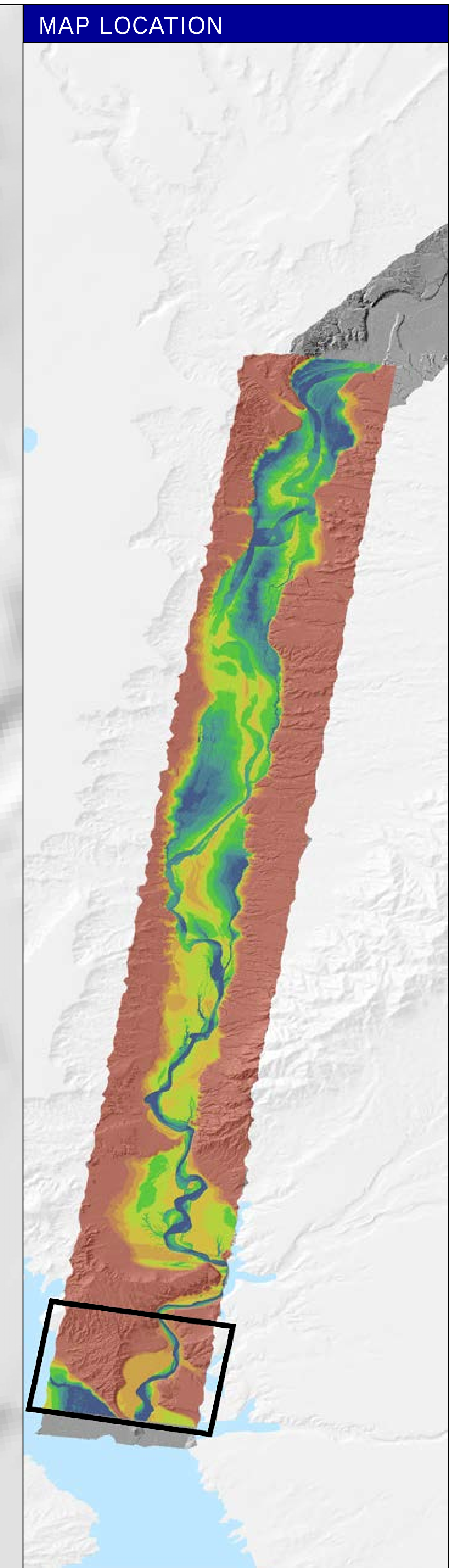
Stillwater Sciences
www.stillwatersci.com





MORMON MESA, ACTIVE CHANNEL HISTORICAL POSITION

Active Channel Historical Position

>70% 30–70% <30%

Data sources:
Active channel position: Stillwater Sciences, 2013
LIDAR Hillshade: Utah State University, November 2011

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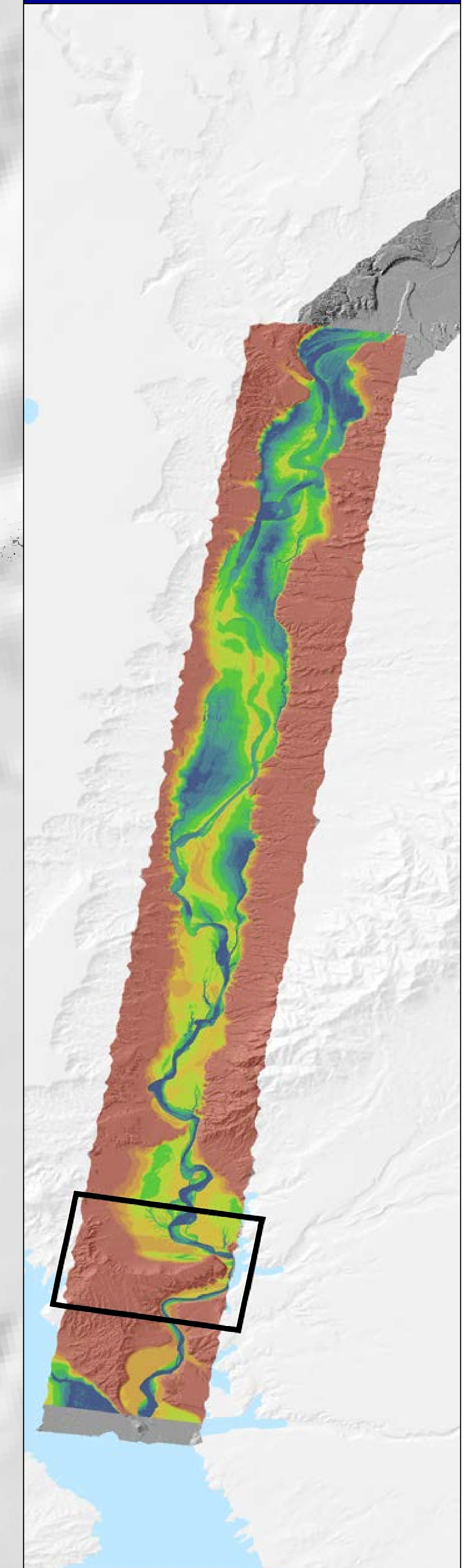
Stillwater Sciences
www.stillwatersci.com

MAP LOCATION



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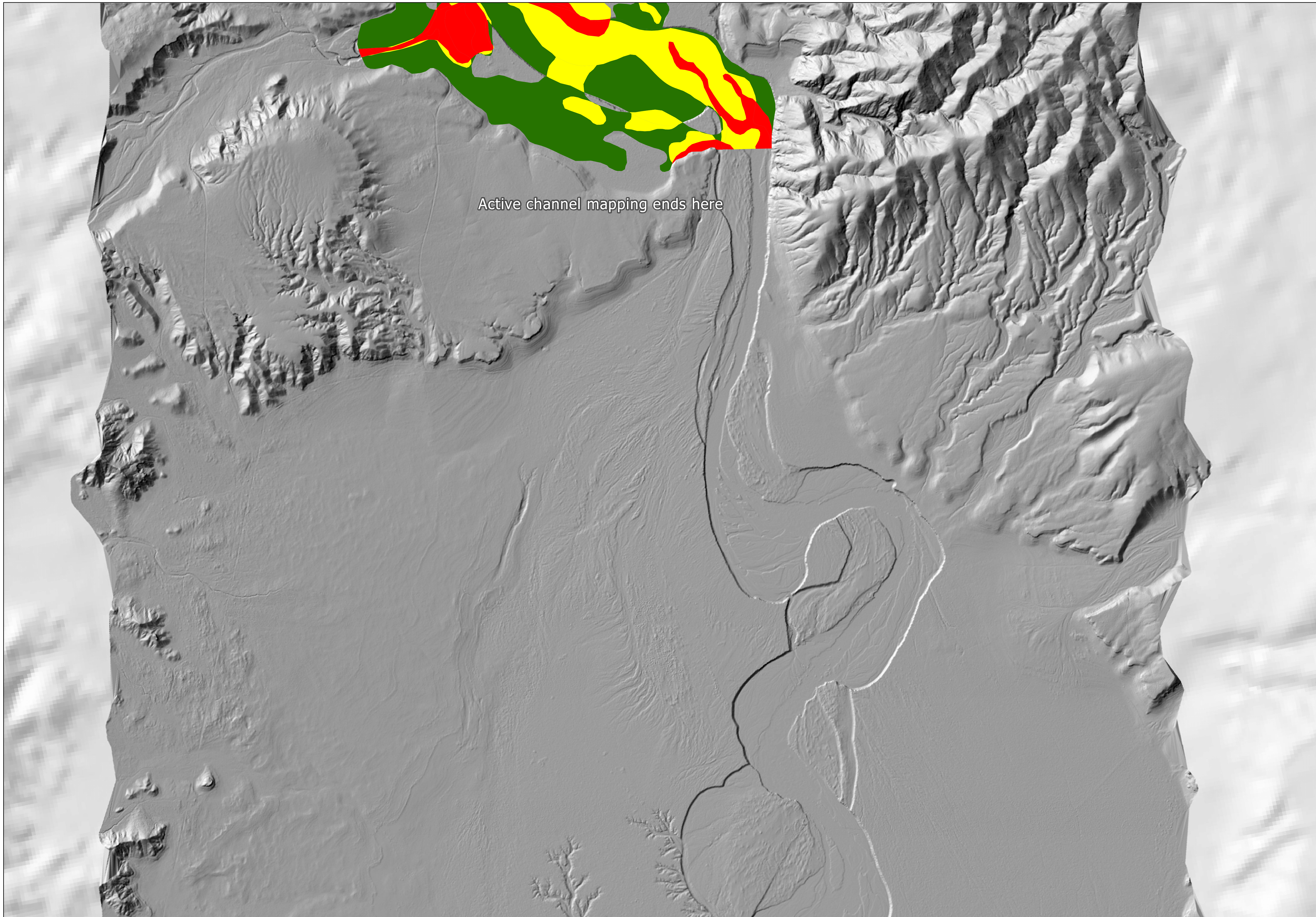

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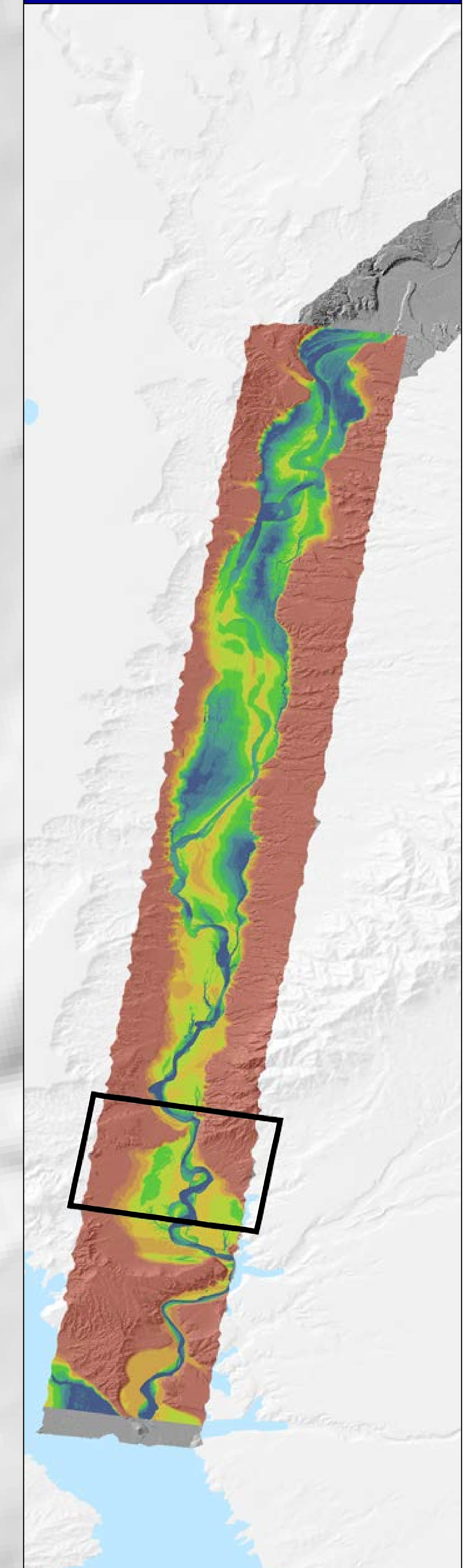

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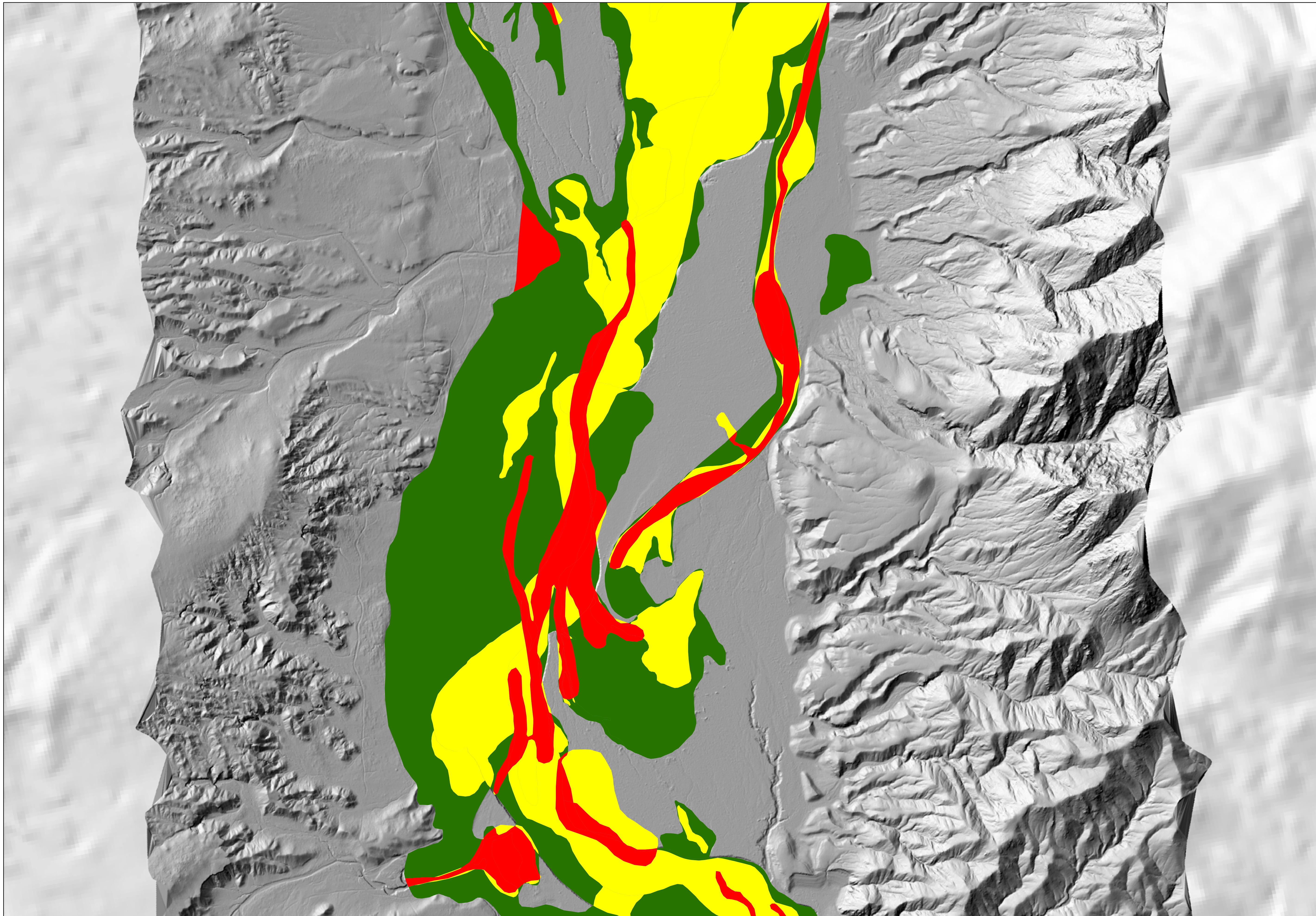

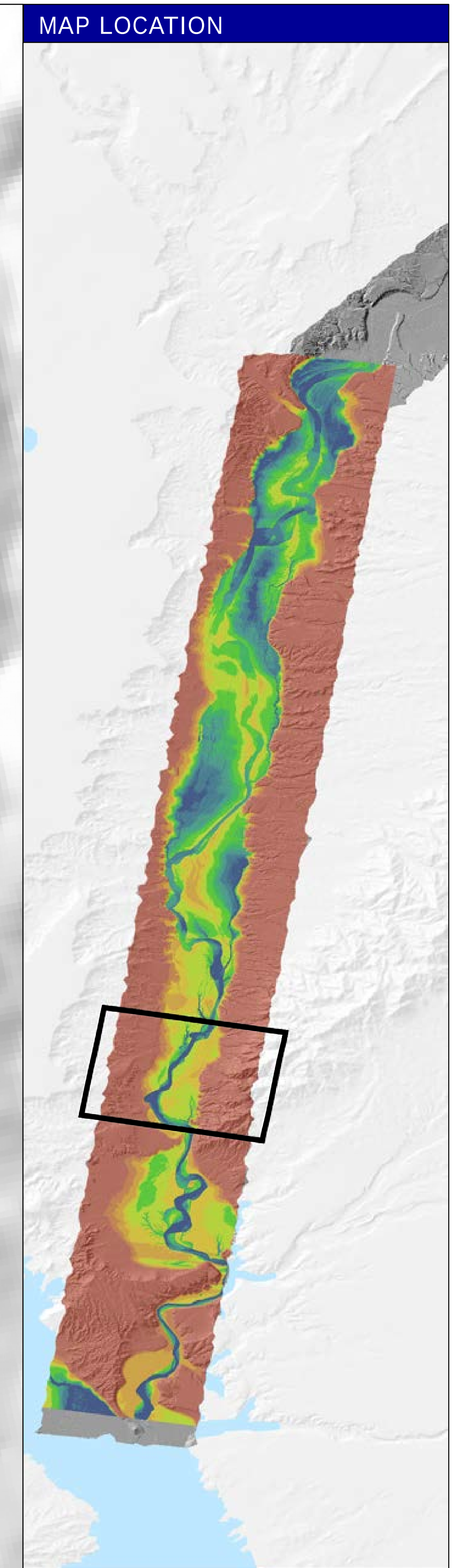

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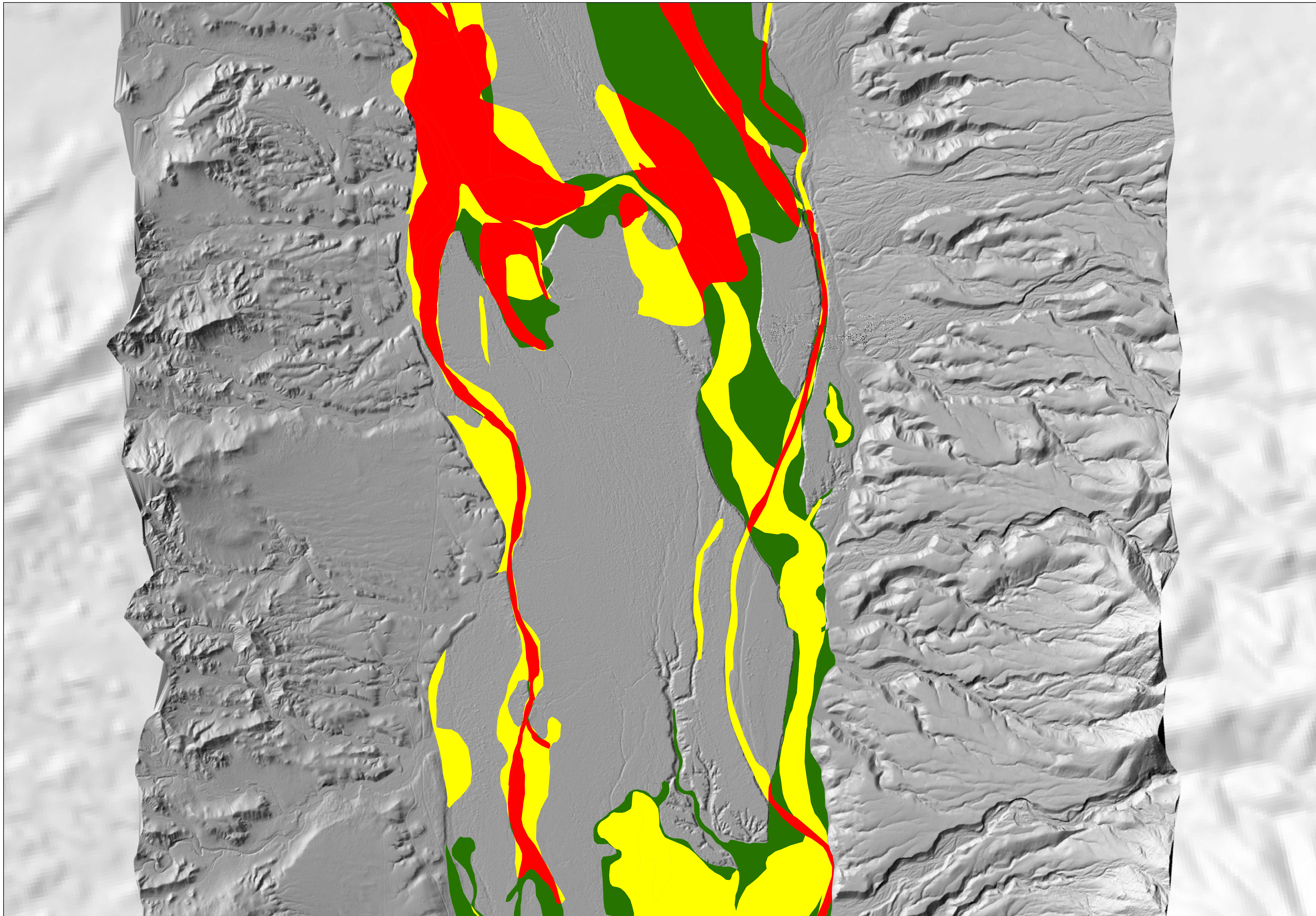

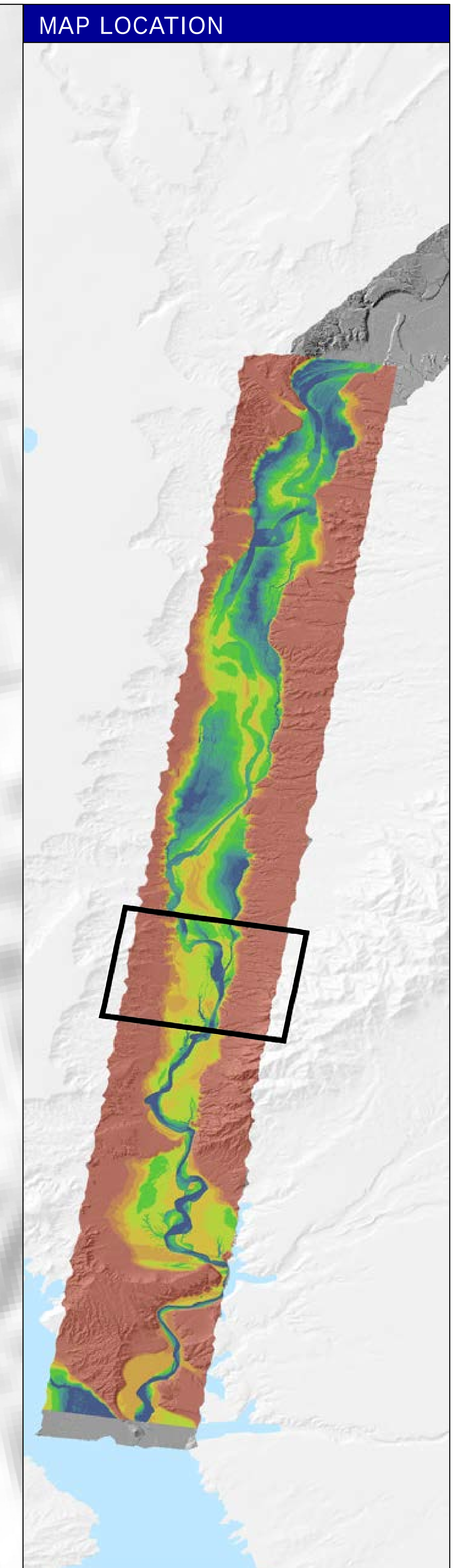

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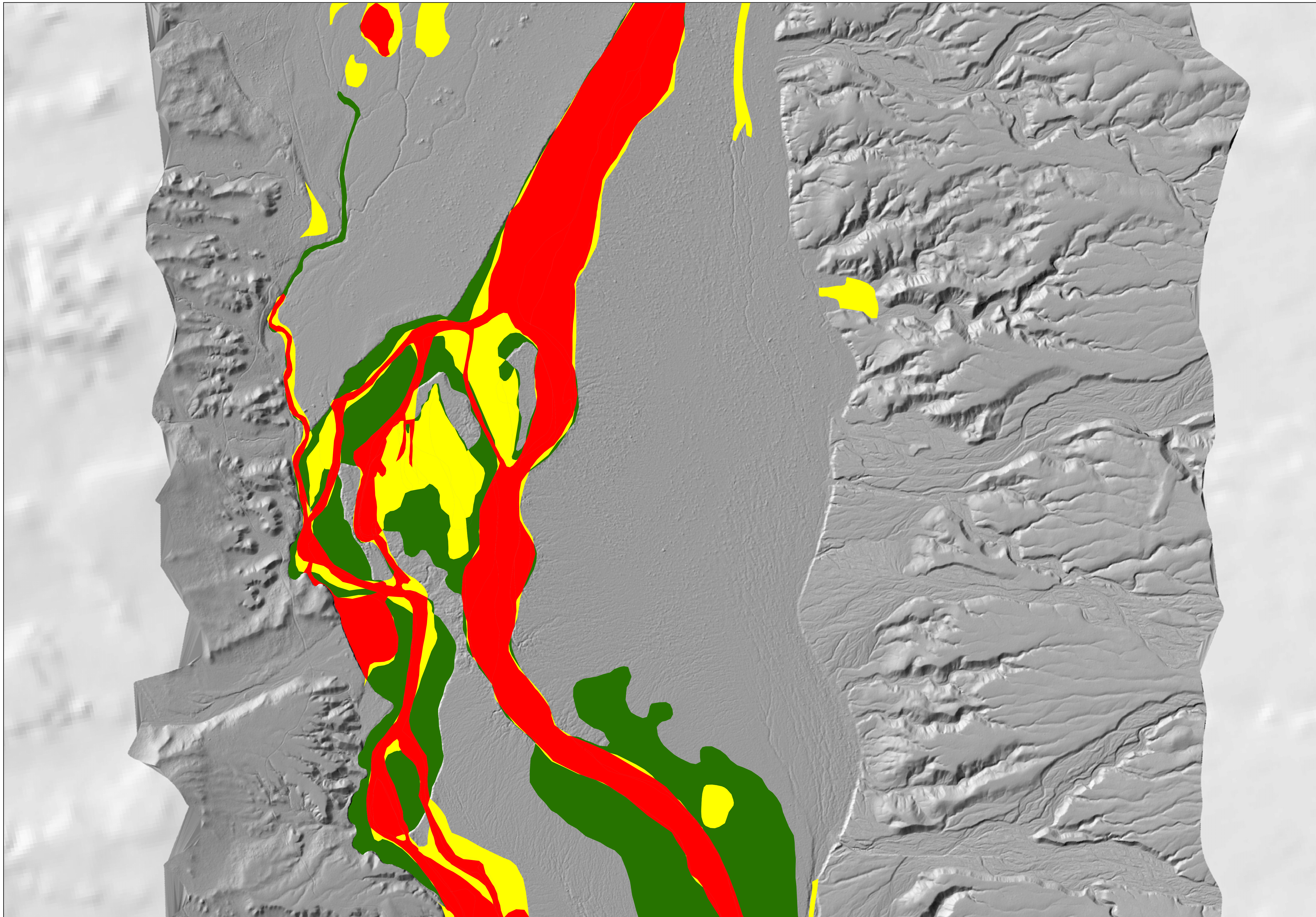

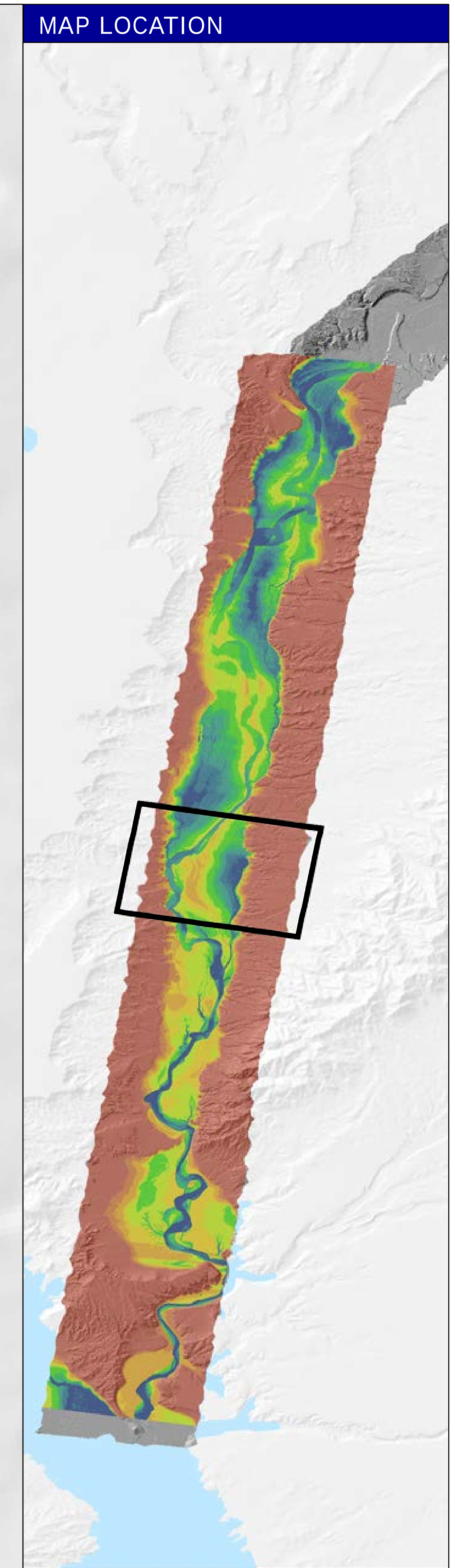

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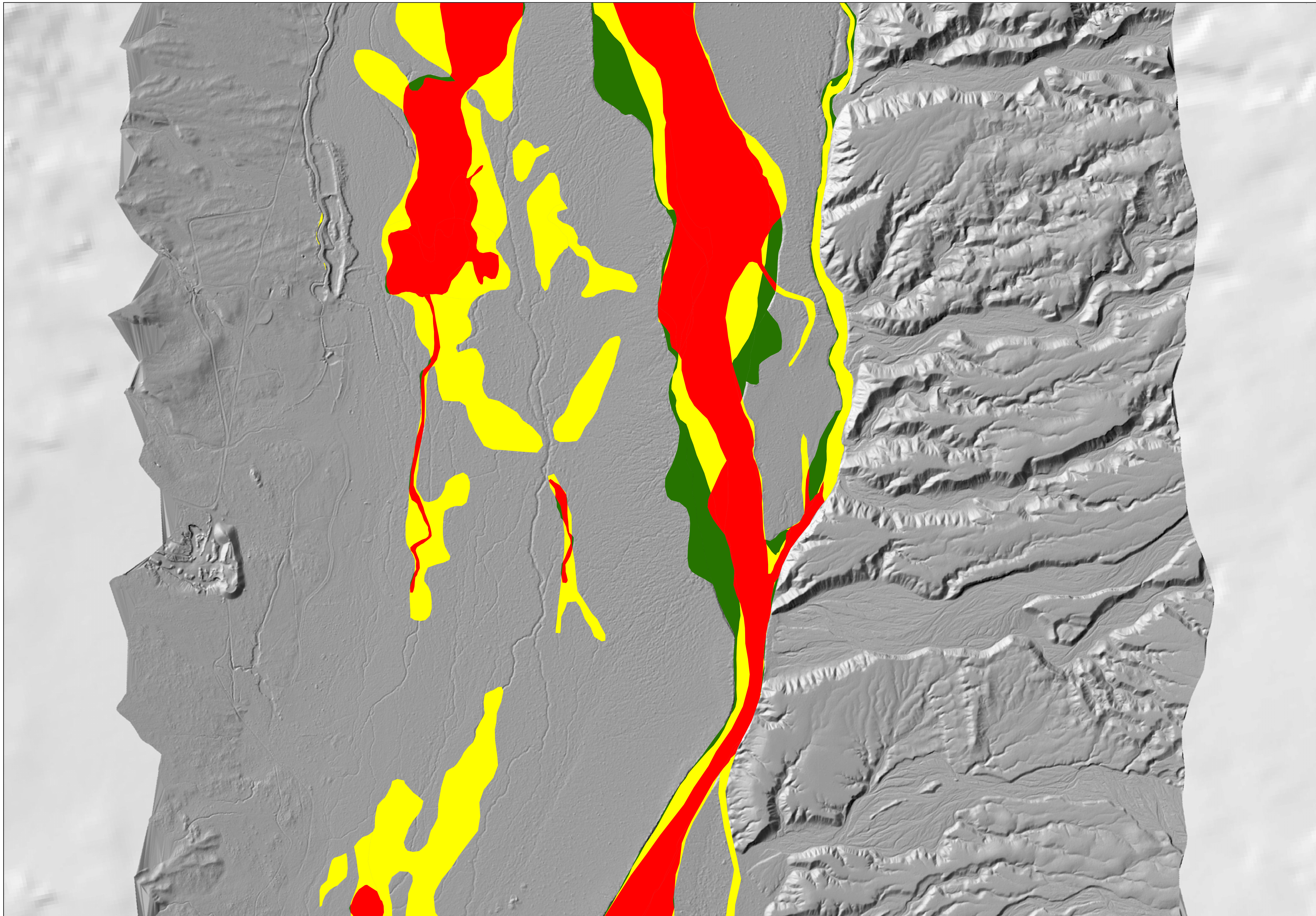

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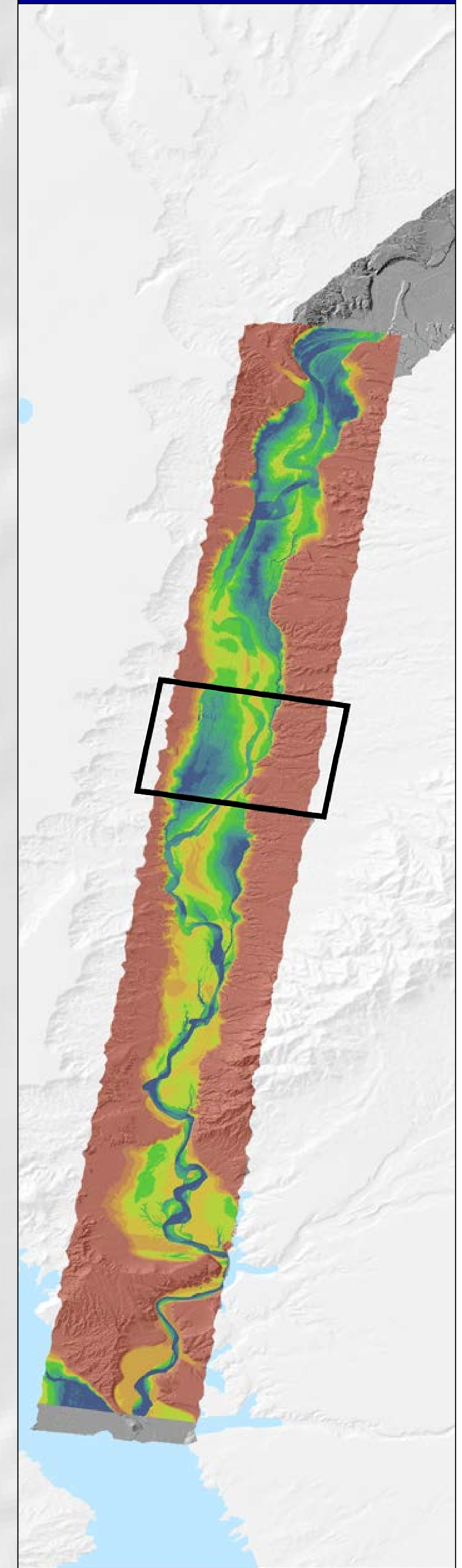

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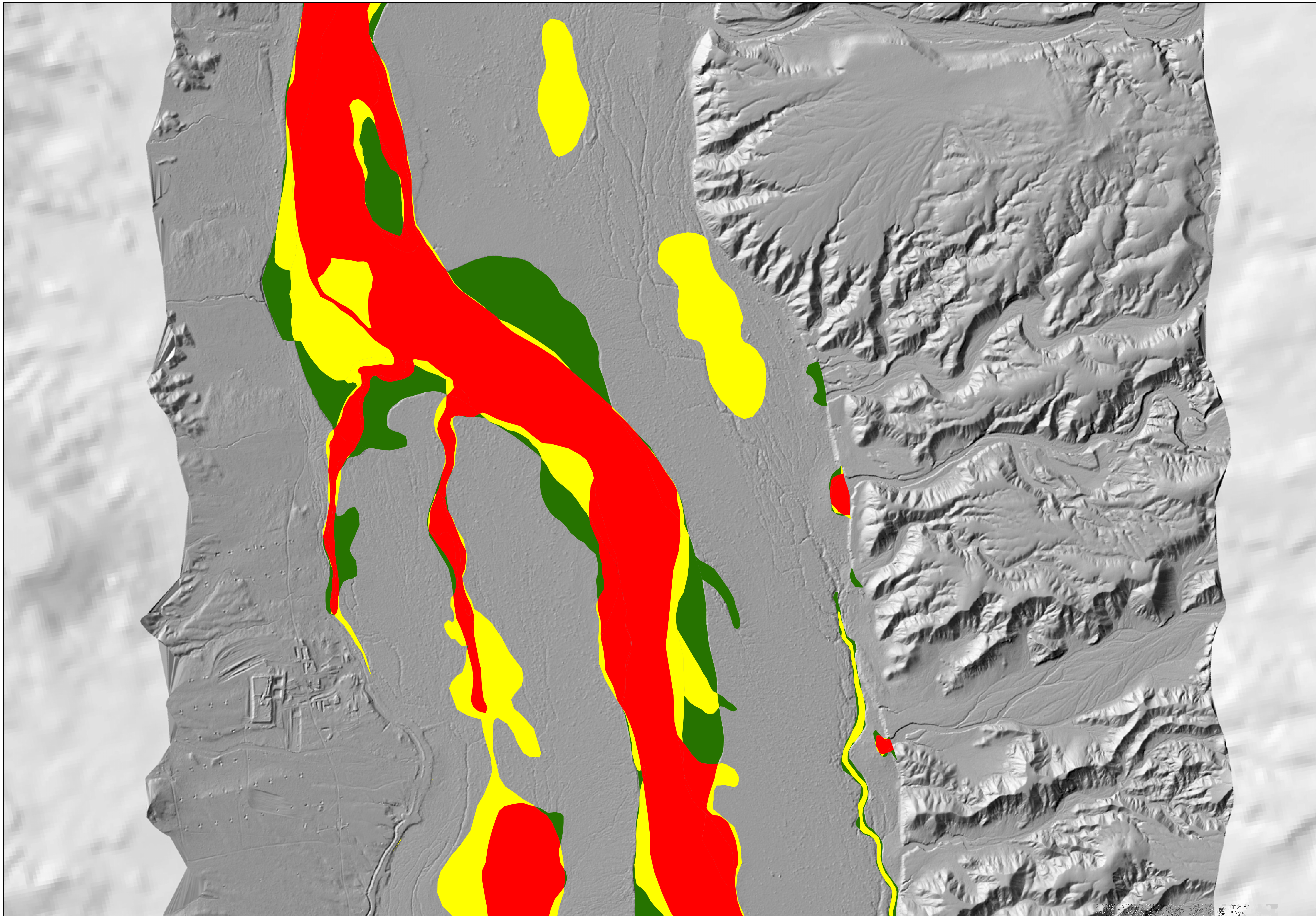
Stillwater Sciences
www.stillwatersci.com



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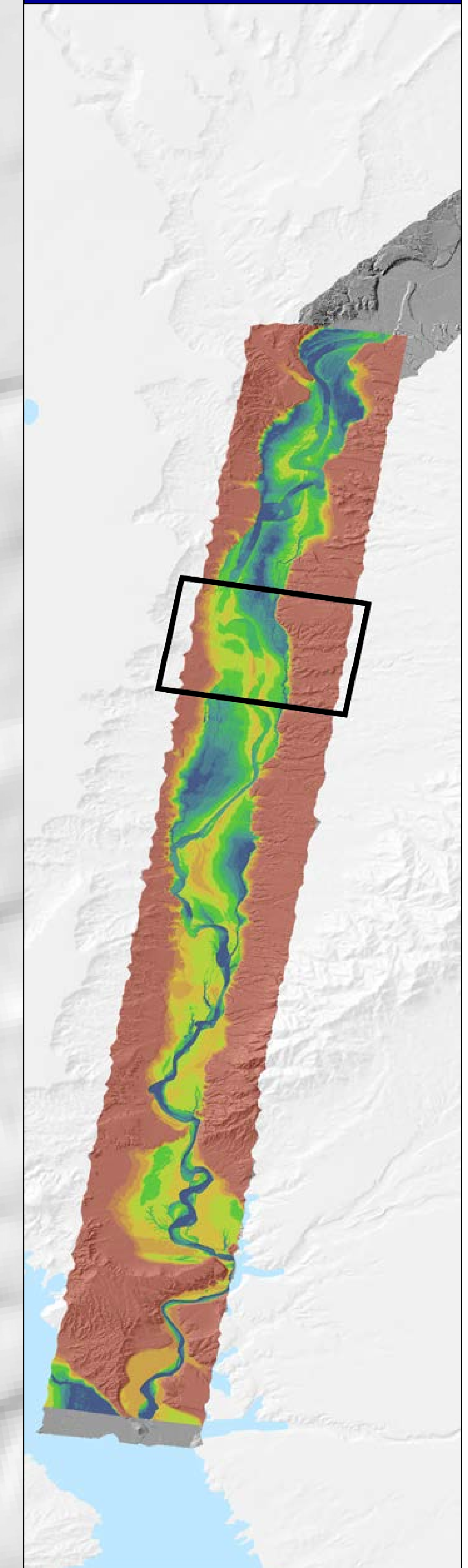

MORMON MESA, ACTIVE CHANNEL HISTORICAL POSITION

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Data sources:
Active channel position: Stillwater Sciences, 2013
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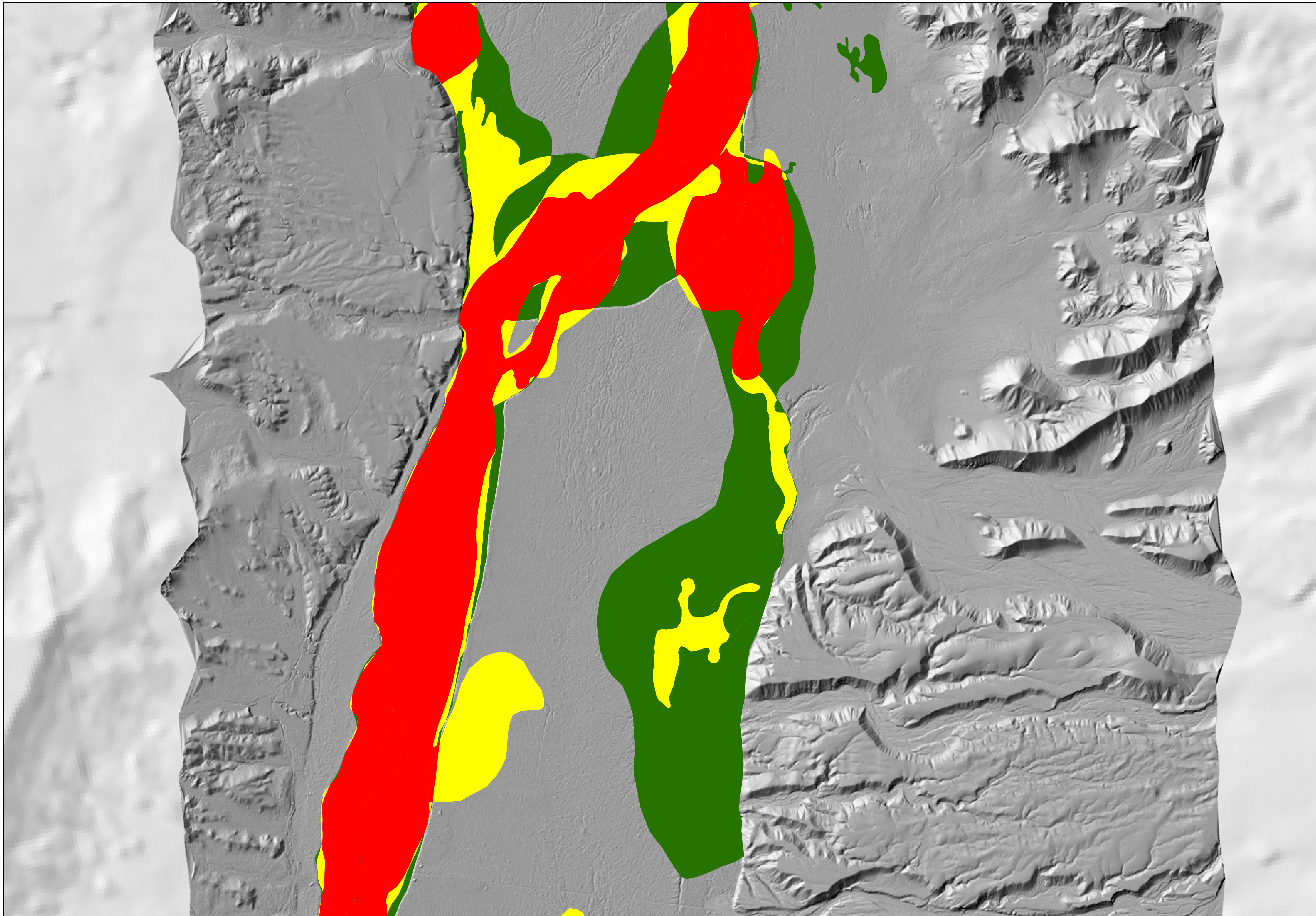

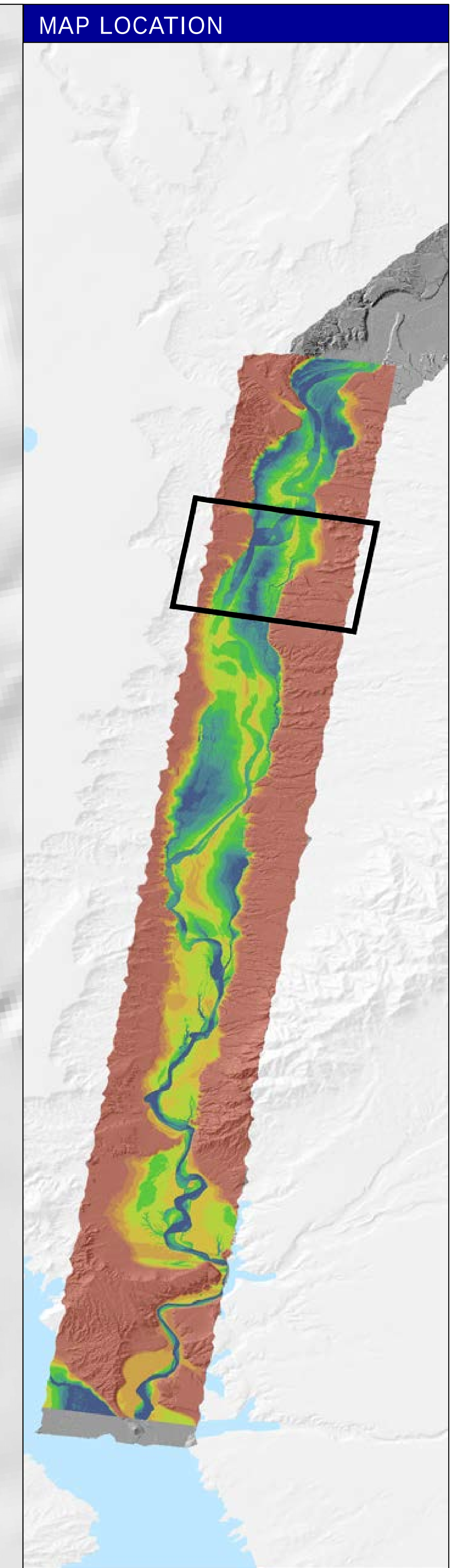

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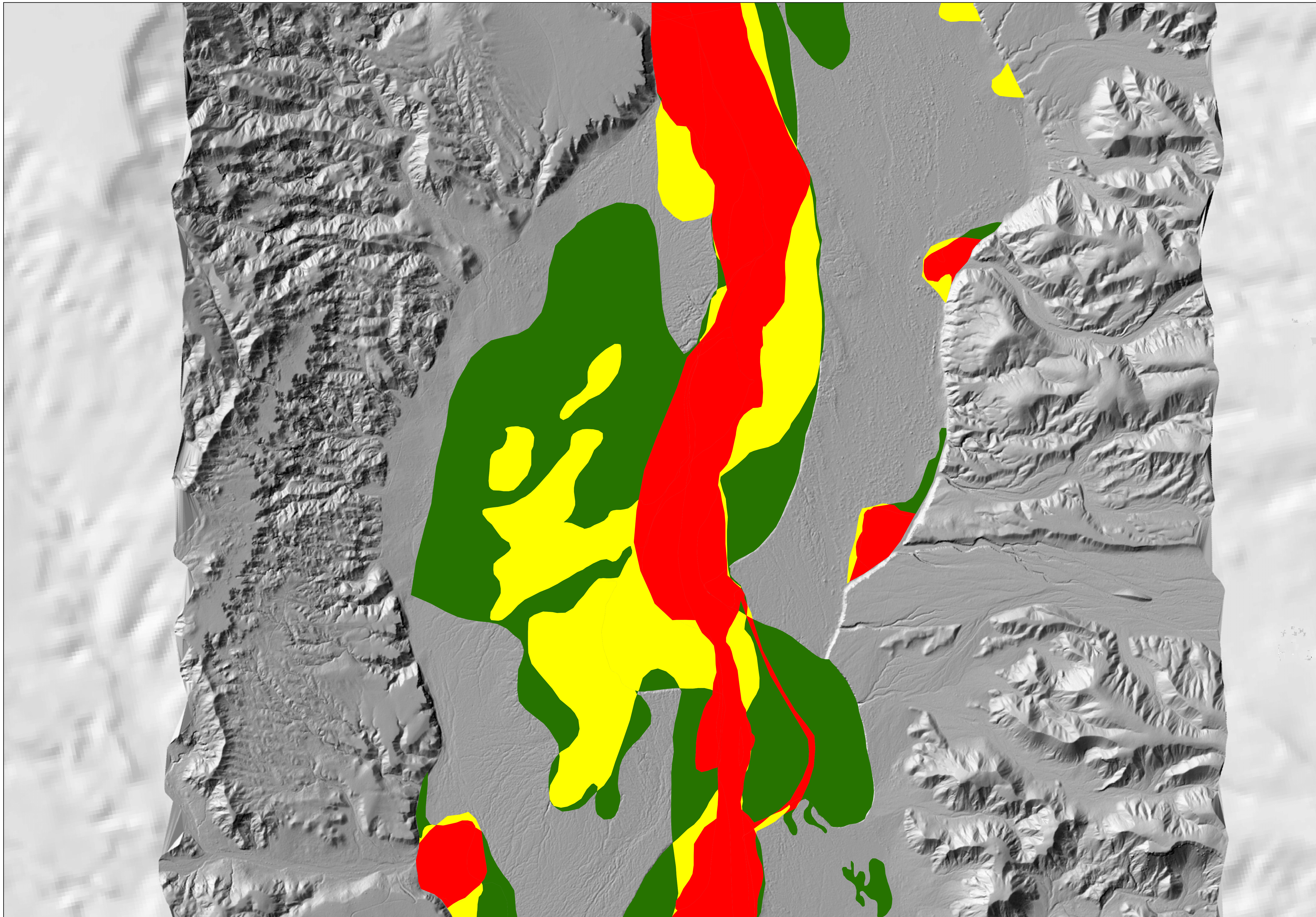
Active channel position: Stillwater Sciences, 2013
LIDAR Hillshade: Utah State University, November 2011

Stillwater Sciences
www.stillwatersci.com



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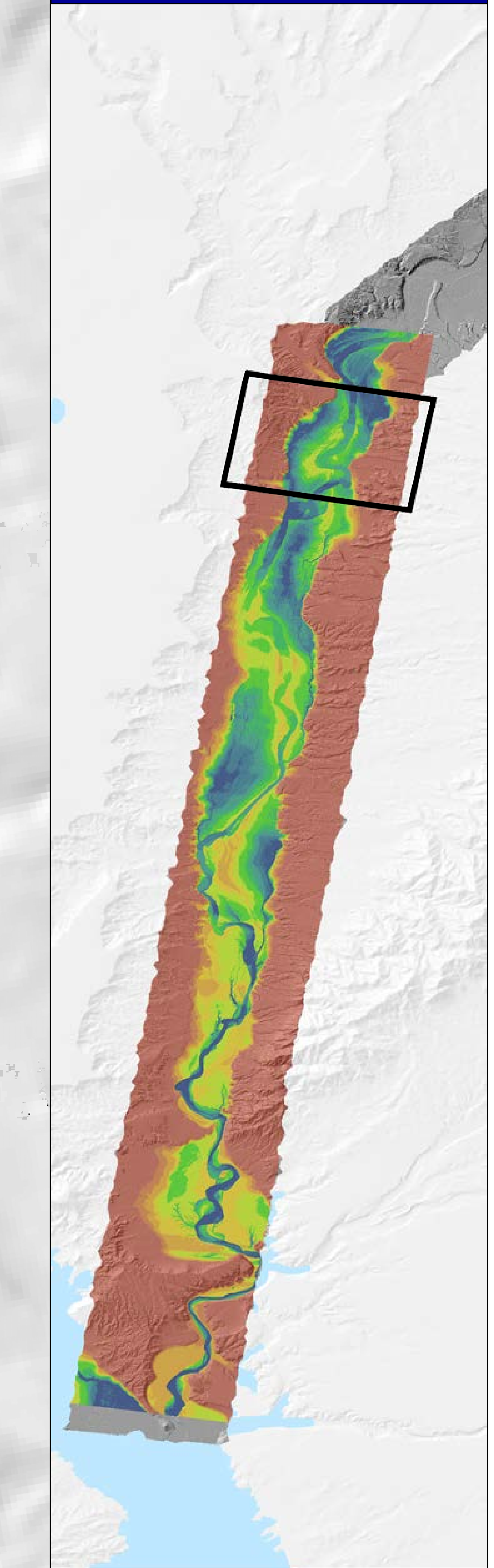


MORMON MESA, ACTIVE CHANNEL HISTORICAL POSITION

Active Channel Historical Position

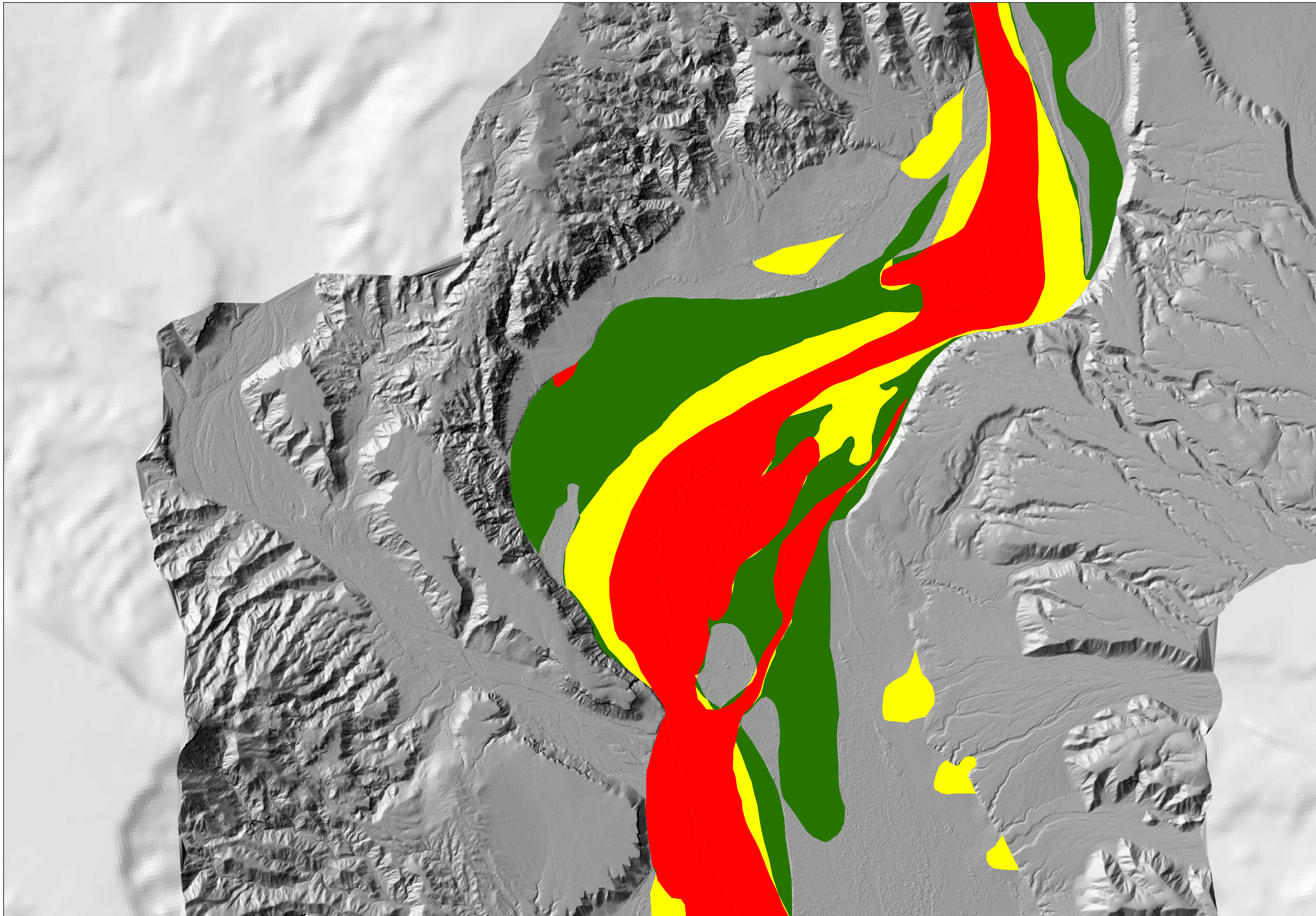
>70% | 30–70% | <30%

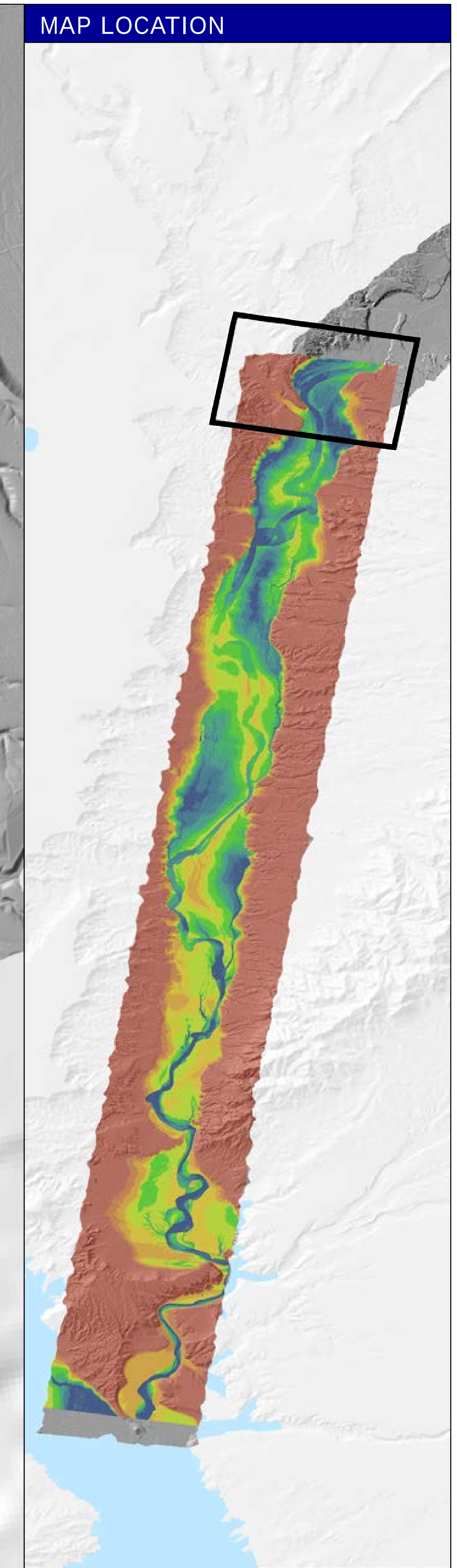
Data sources:
Active channel position: Stillwater Sciences, 2013
LIDAR Hillshade: Utah State University, November 2011

0 | 500 | 1,000 | 1,500 | 2,000 Feet

0 | 200 | 400 | 600 Meters

Stillwater Sciences
www.stillwatersci.com





MORMON MESA, ACTIVE CHANNEL HISTORICAL POSITION

Active Channel Historical Position

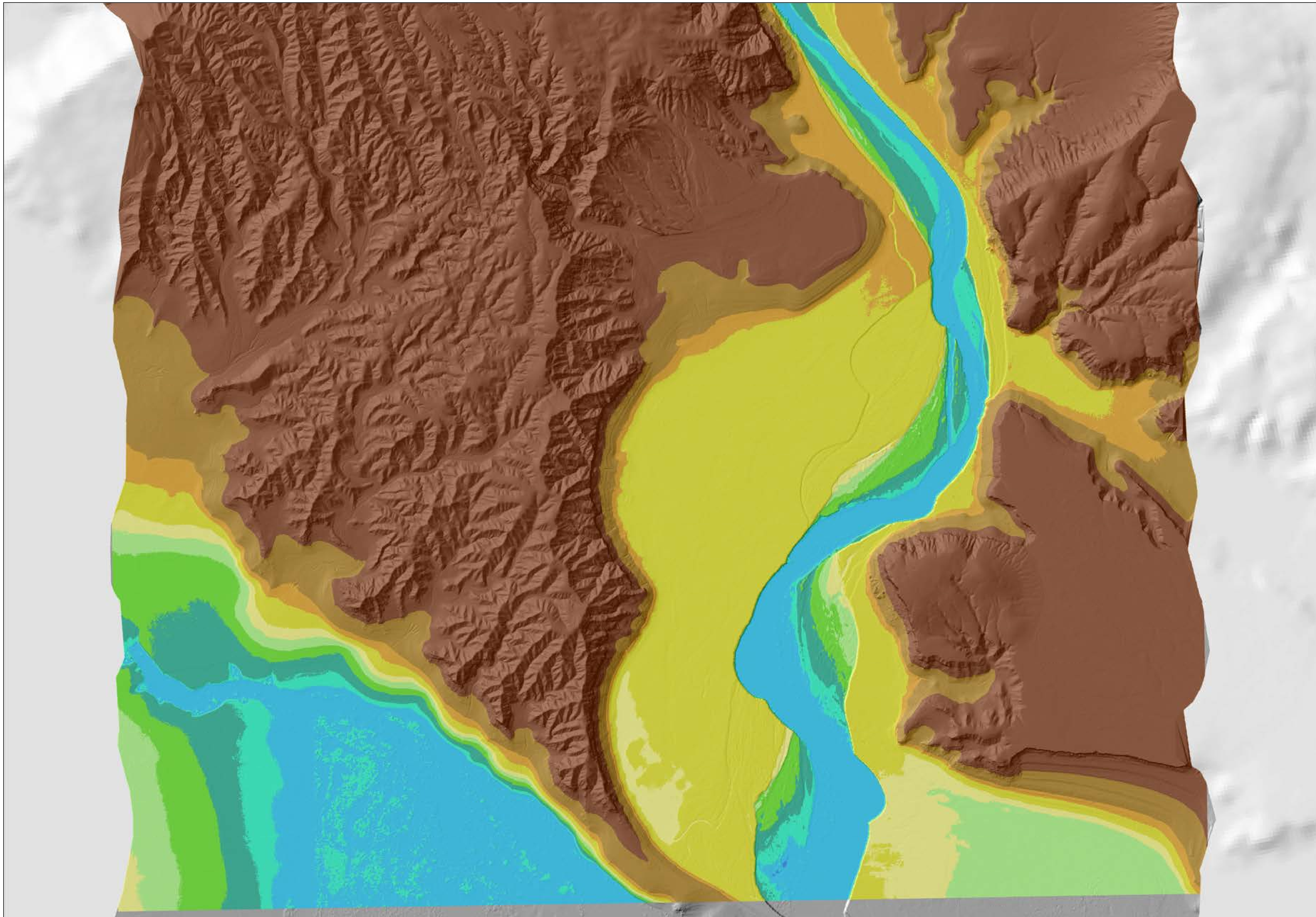
>70%   30–70%   <30%

0 500 1,000 1,500 2,000 Feet

0 200 400 600 Meters

Data sources:
Active channel position: Stillwater Sciences, 2013
LIDAR Hillshade: Utah State University, November 2011

Stillwater Sciences
www.stillwatersci.com



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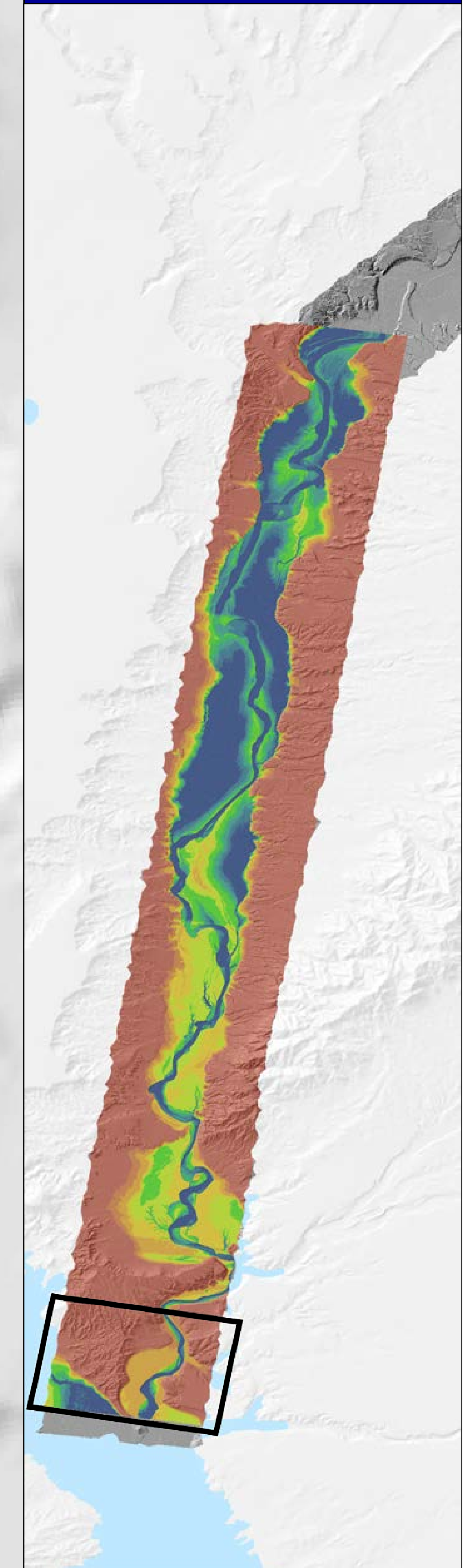


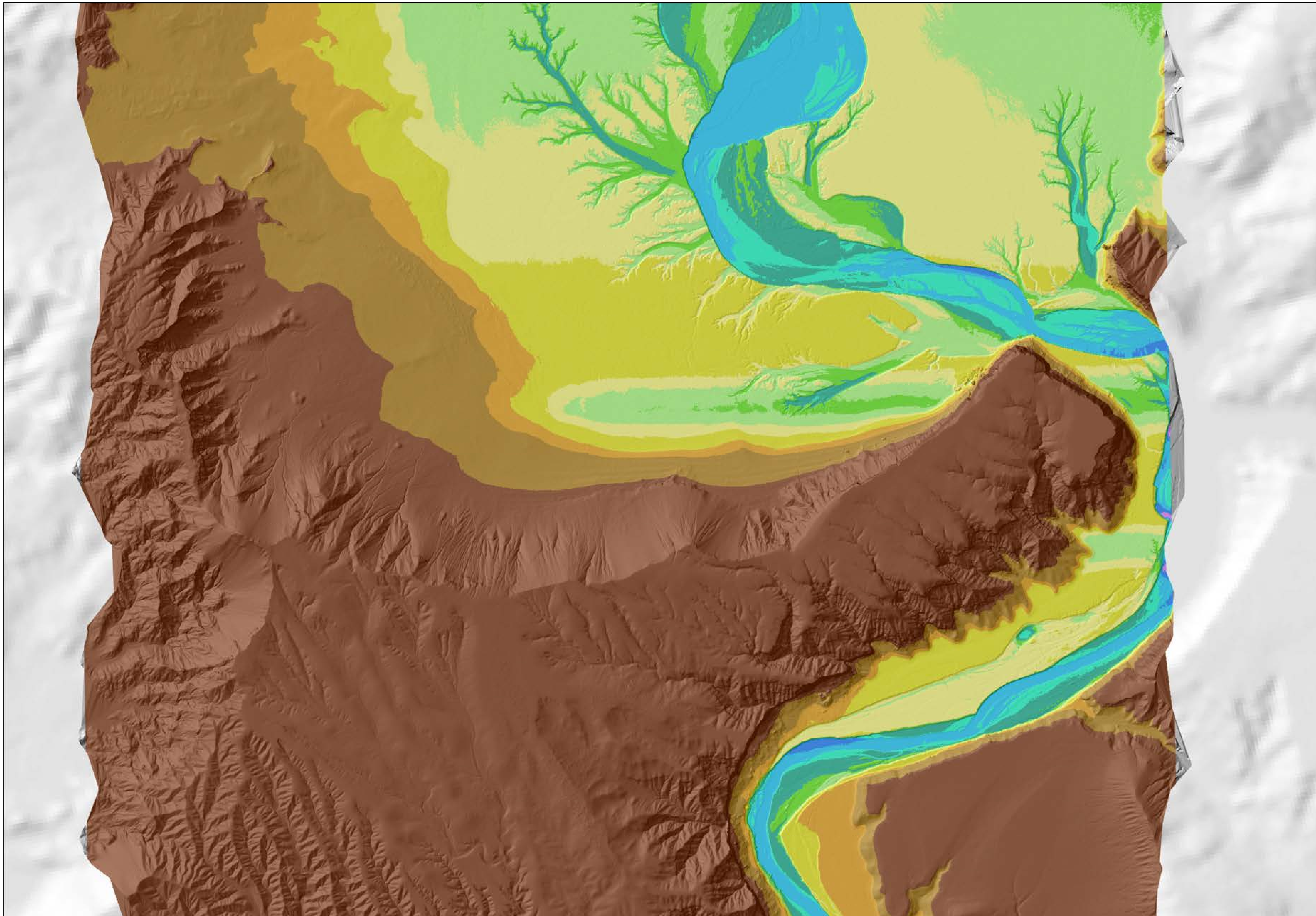
MORMON MESA, RELATIVE ELEVATION (m)

< -3 m	-0.99 - -0.5	0.51 - 1	3.01 - 4	7.51 - 10
-2.99 - -2	-0.49 - -0.05	1.01 - 2	4.01 - 5	10.01 - 20
-1.99 - -1	-0.04 - 0.5	2.01 - 3	5.01 - 7.5	> 20 m

Data sources:
Relative Elevation: Stillwater Sciences, 2013
LIDAR Hillshade: Utah State University, November 2011

0 500 1,000 1,500 2,000 Feet
0 200 400 600 Meters

Stillwater Sciences
www.stillwatersci.com



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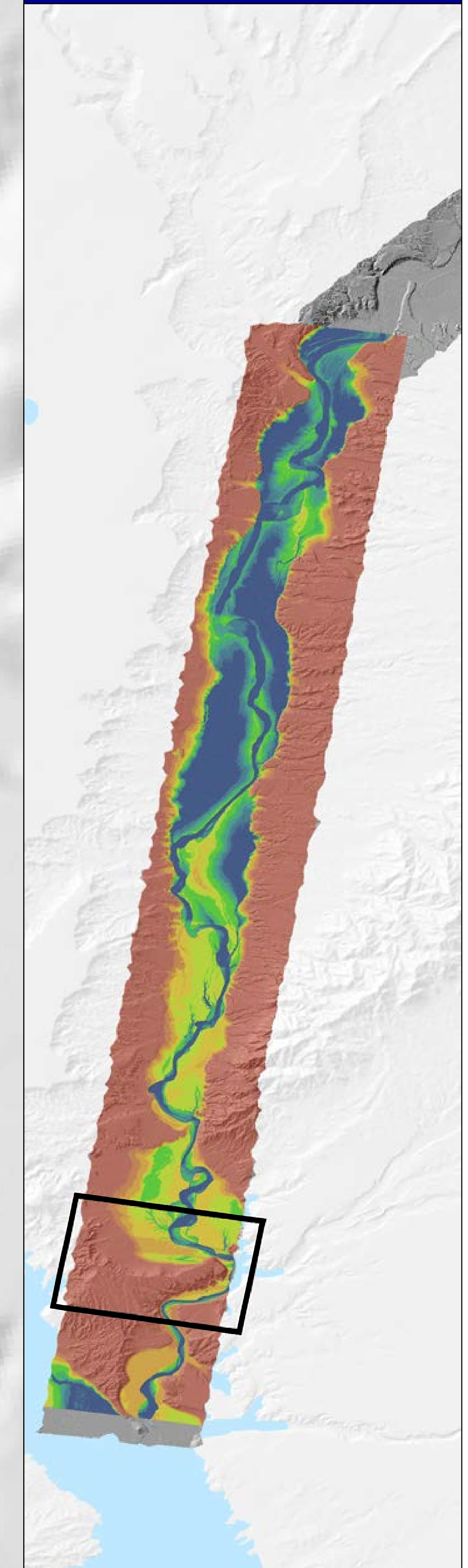


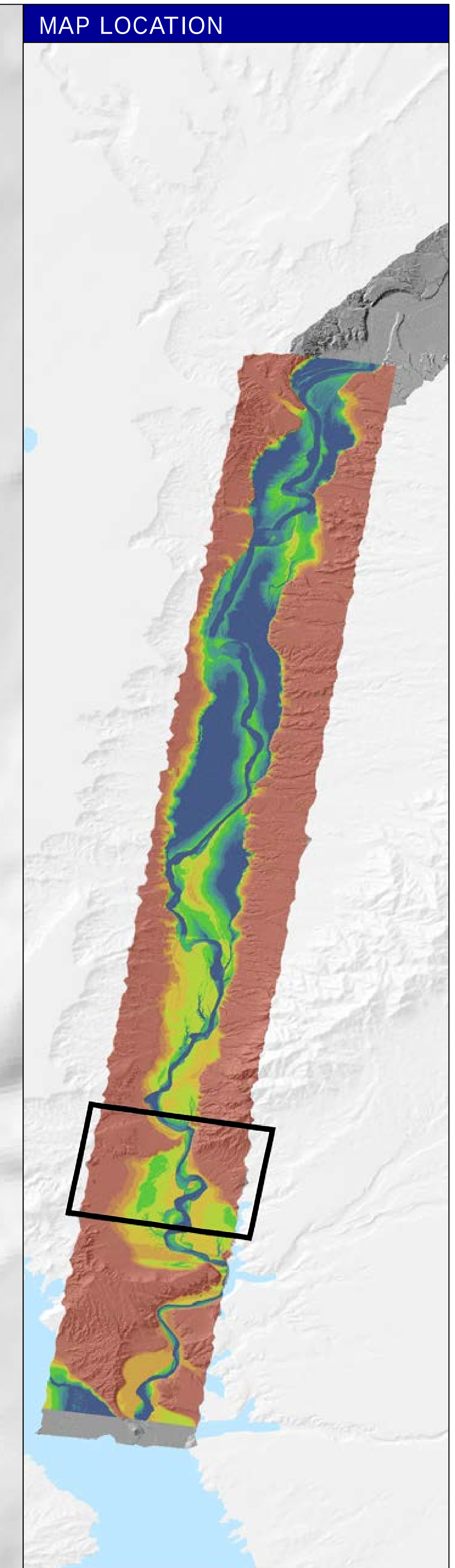
MORMON MESA, RELATIVE ELEVATION (m)

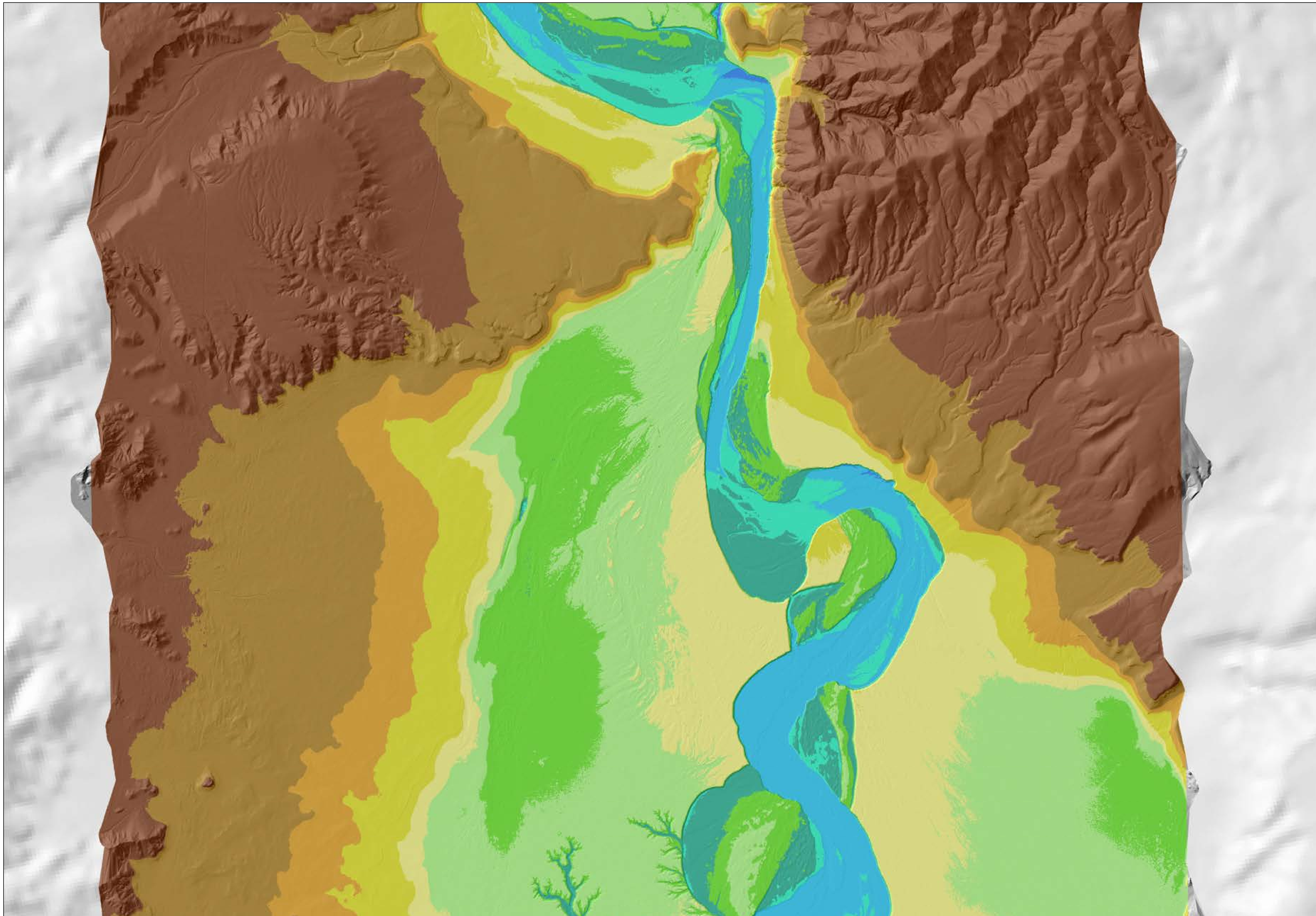
< -3 m	-0.99 - -0.5	0.51 - 1	3.01 - 4	7.51 - 10
-2.99 - -2	-0.49 - -0.05	1.01 - 2	4.01 - 5	10.01 - 20
-1.99 - -1	-0.04 - 0.5	2.01 - 3	5.01 - 7.5	> 20 m

Data sources:
Relative Elevation: Stillwater Sciences, 2013
LIDAR Hillshade: Utah State University, November 2011

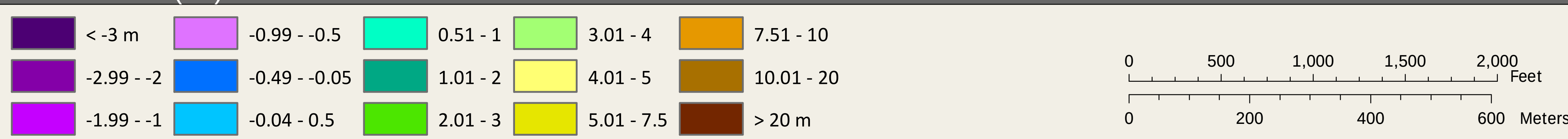
0 500 1,000 1,500 2,000 Feet
0 200 400 600 Meters

Stillwater Sciences
www.stillwatersci.com





MORMON MESA, RELATIVE ELEVATION (m)



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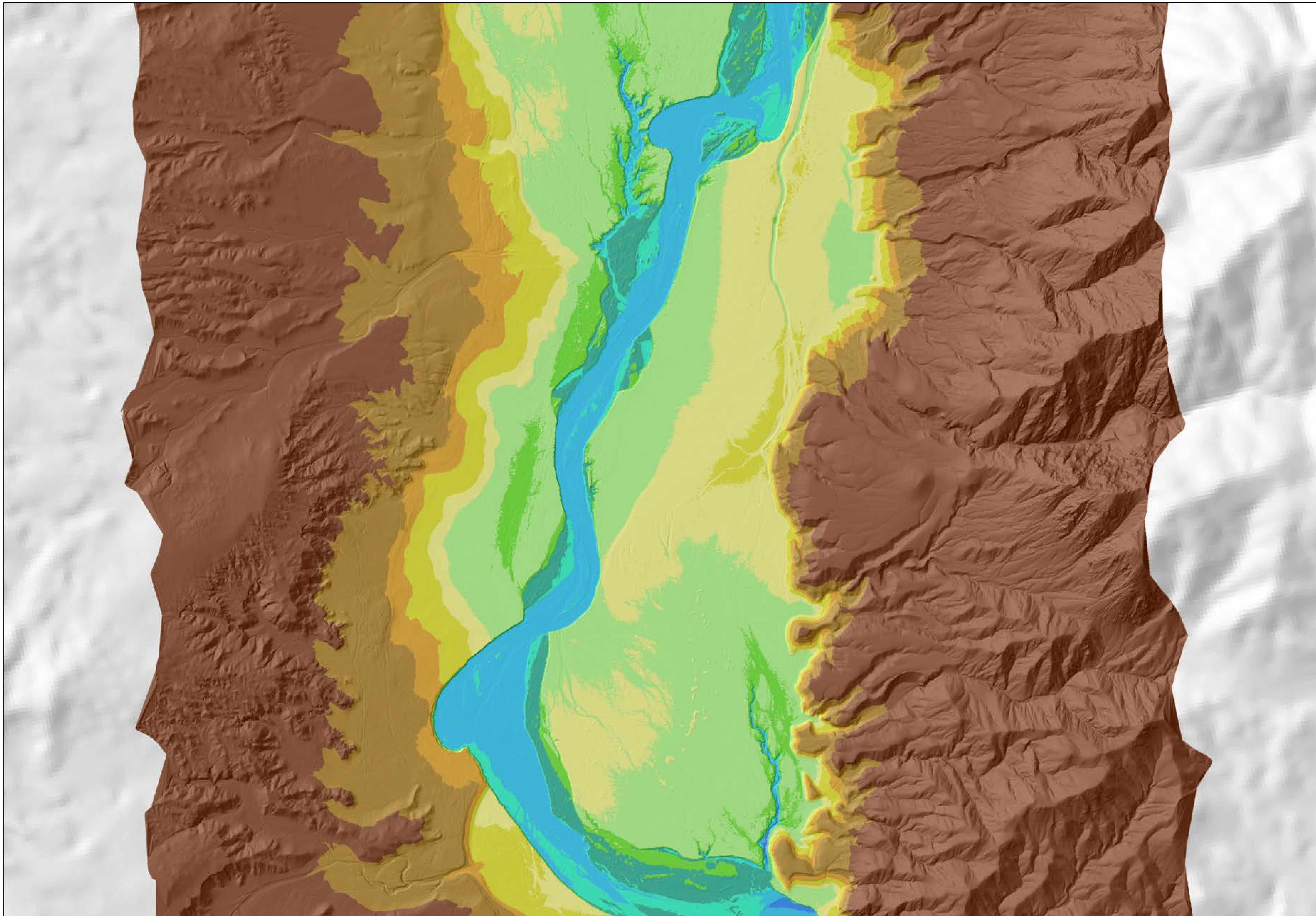
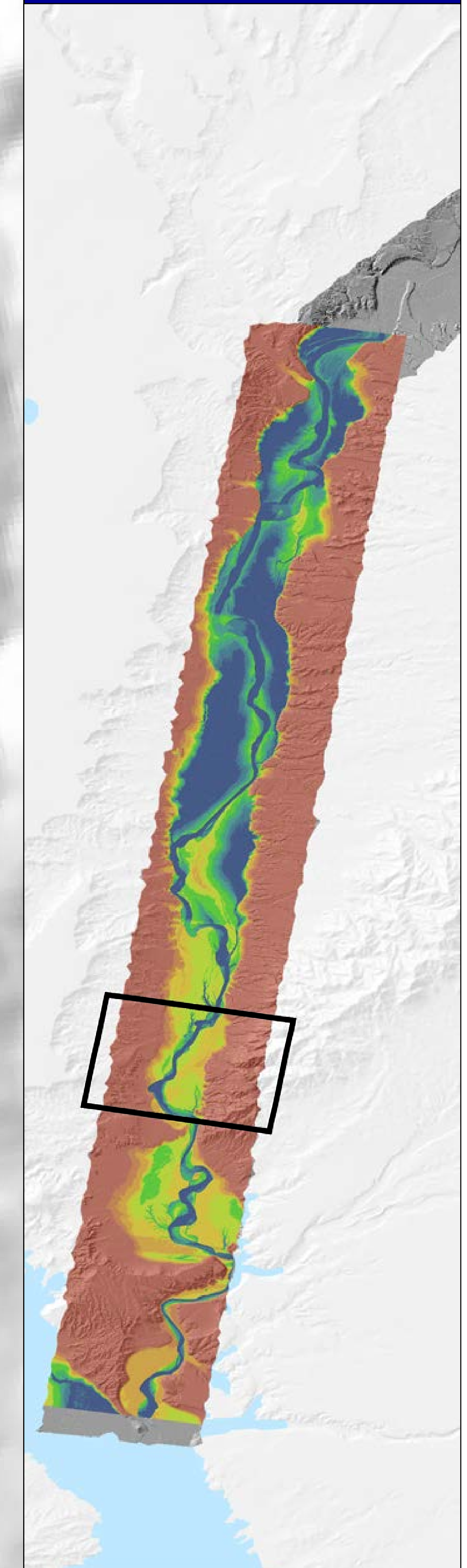


MAP LOCATION



MORMON MESA, RELATIVE ELEVATION (m)

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Relative Elevation: Stillwater Sciences, 2013
LIDAR Hillshade: Utah State University, November 2011

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- 7.51 - 10
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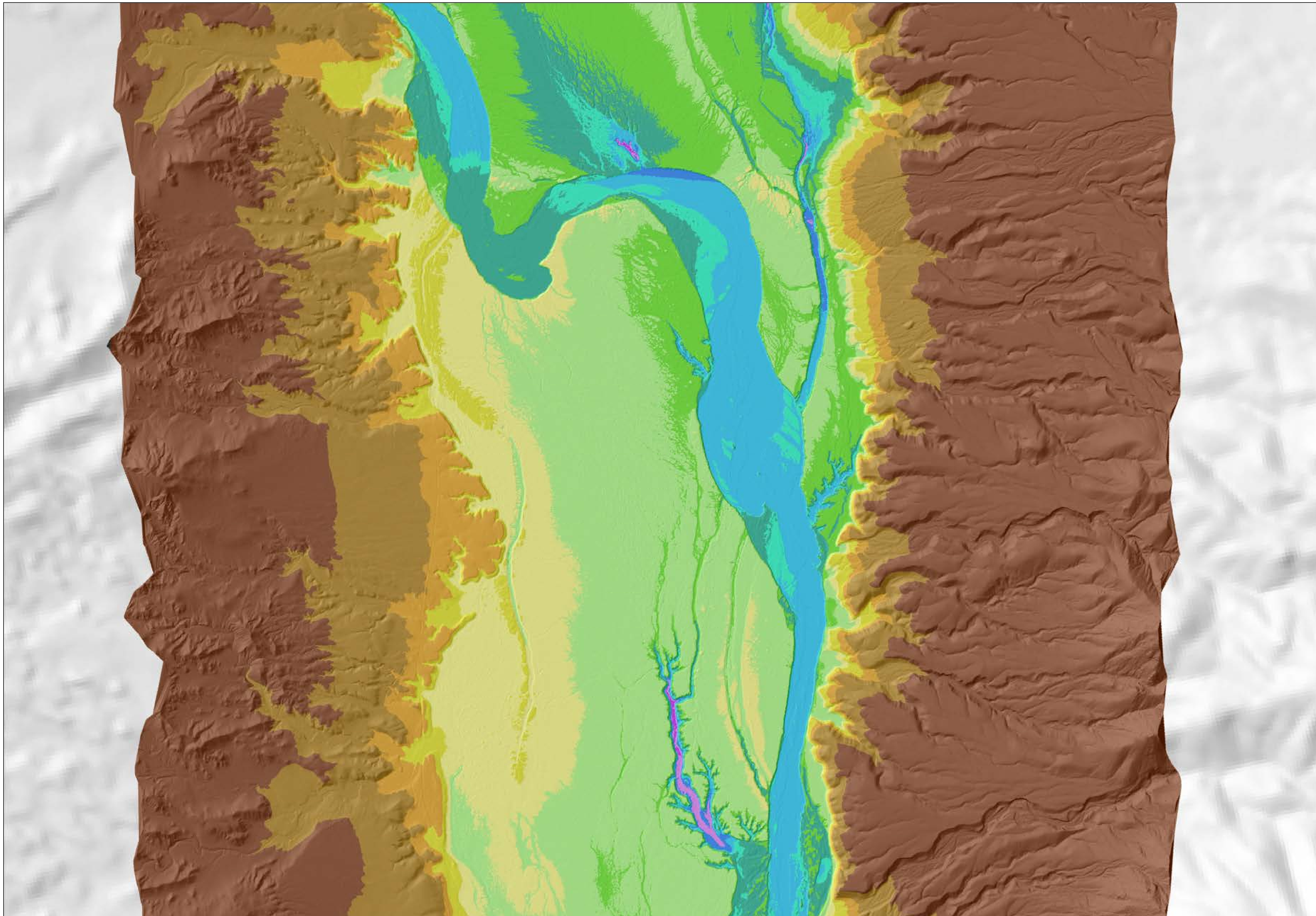

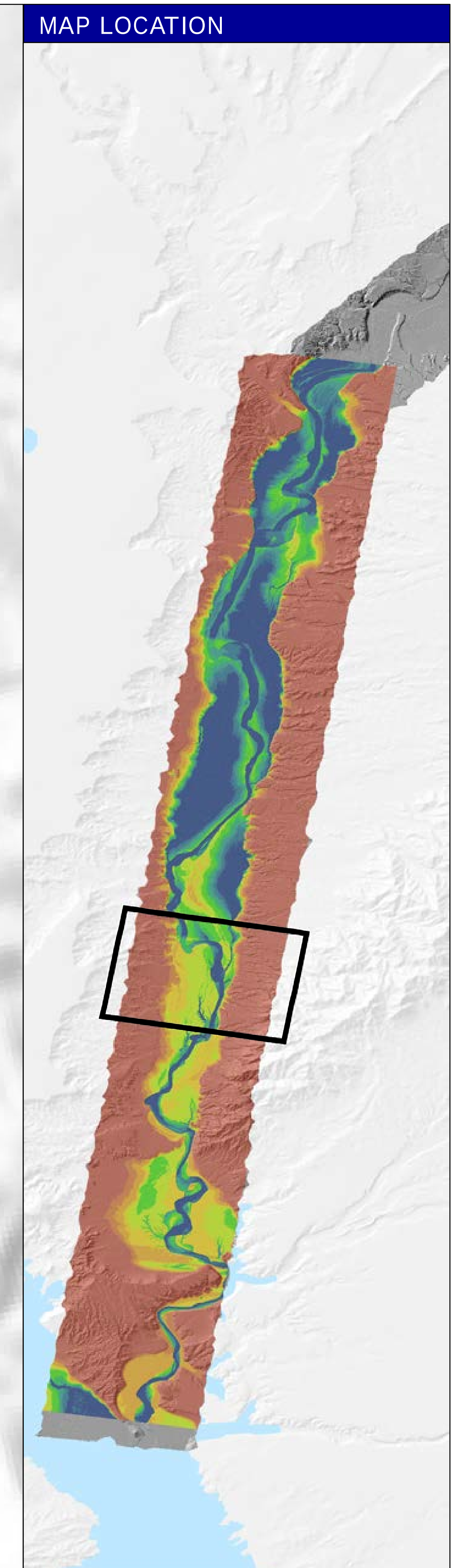

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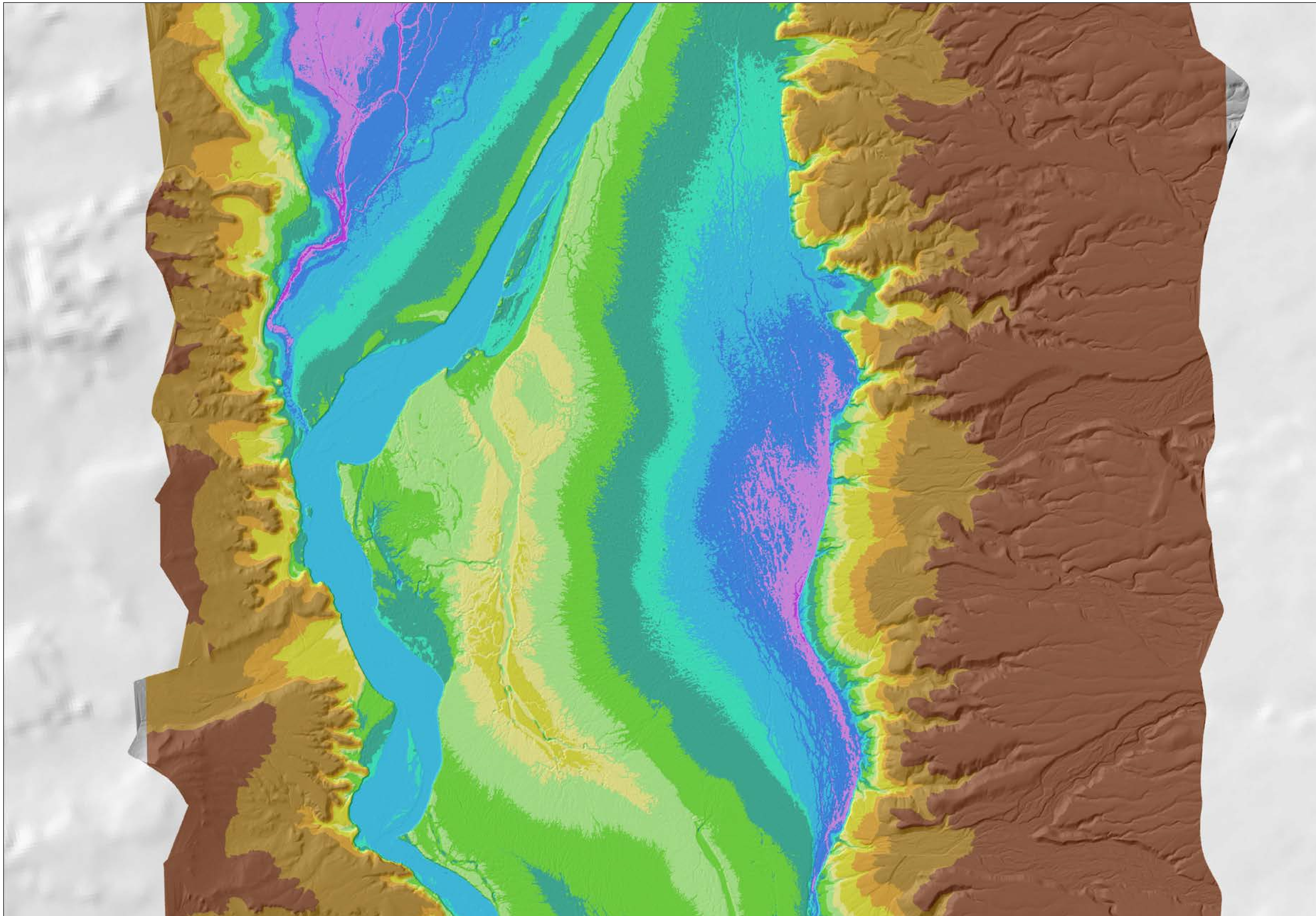

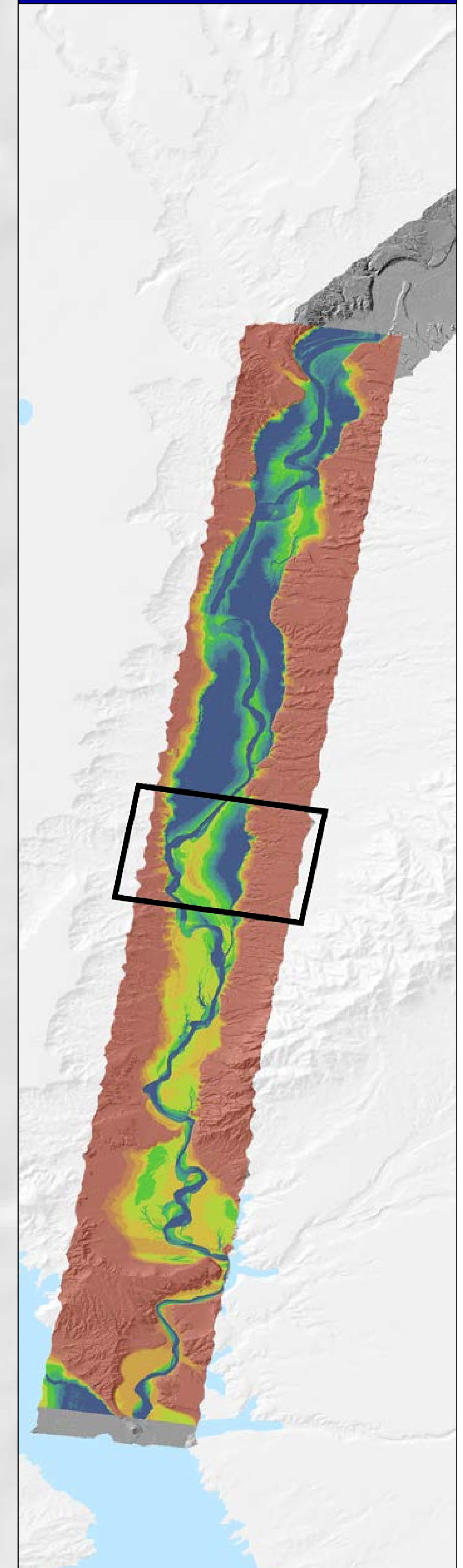

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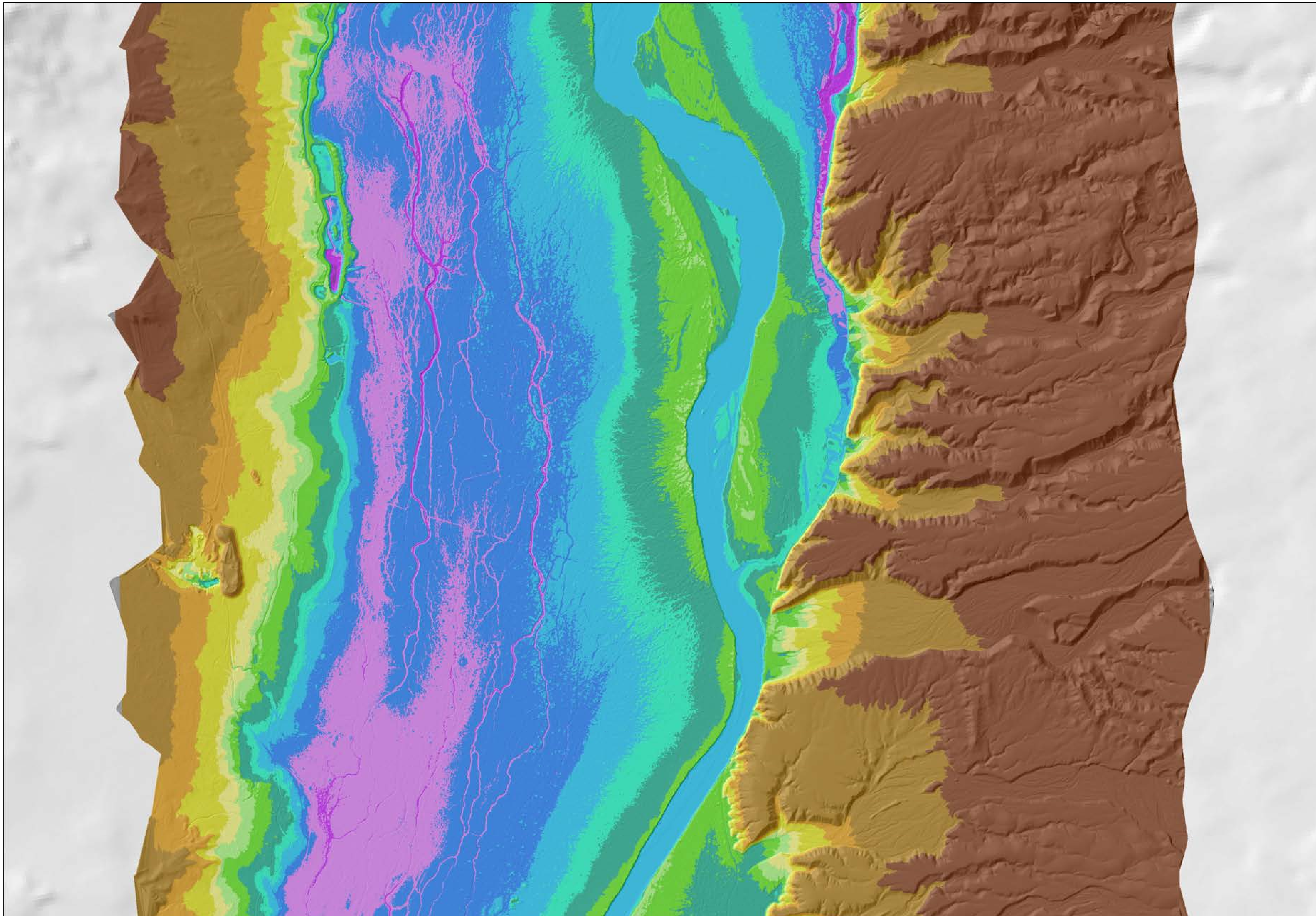

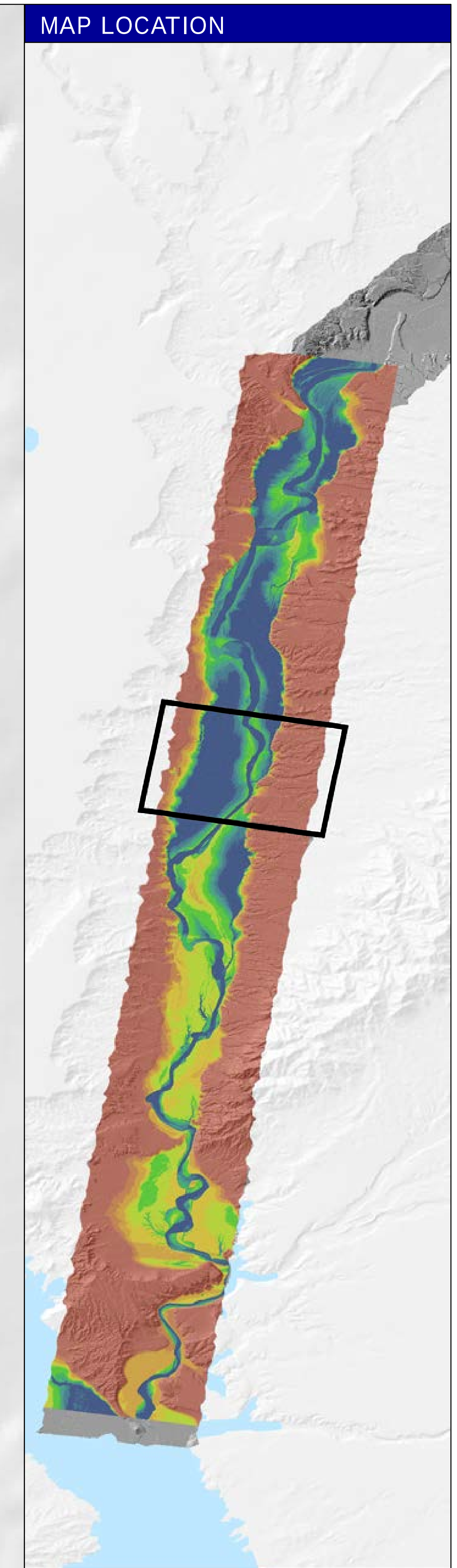

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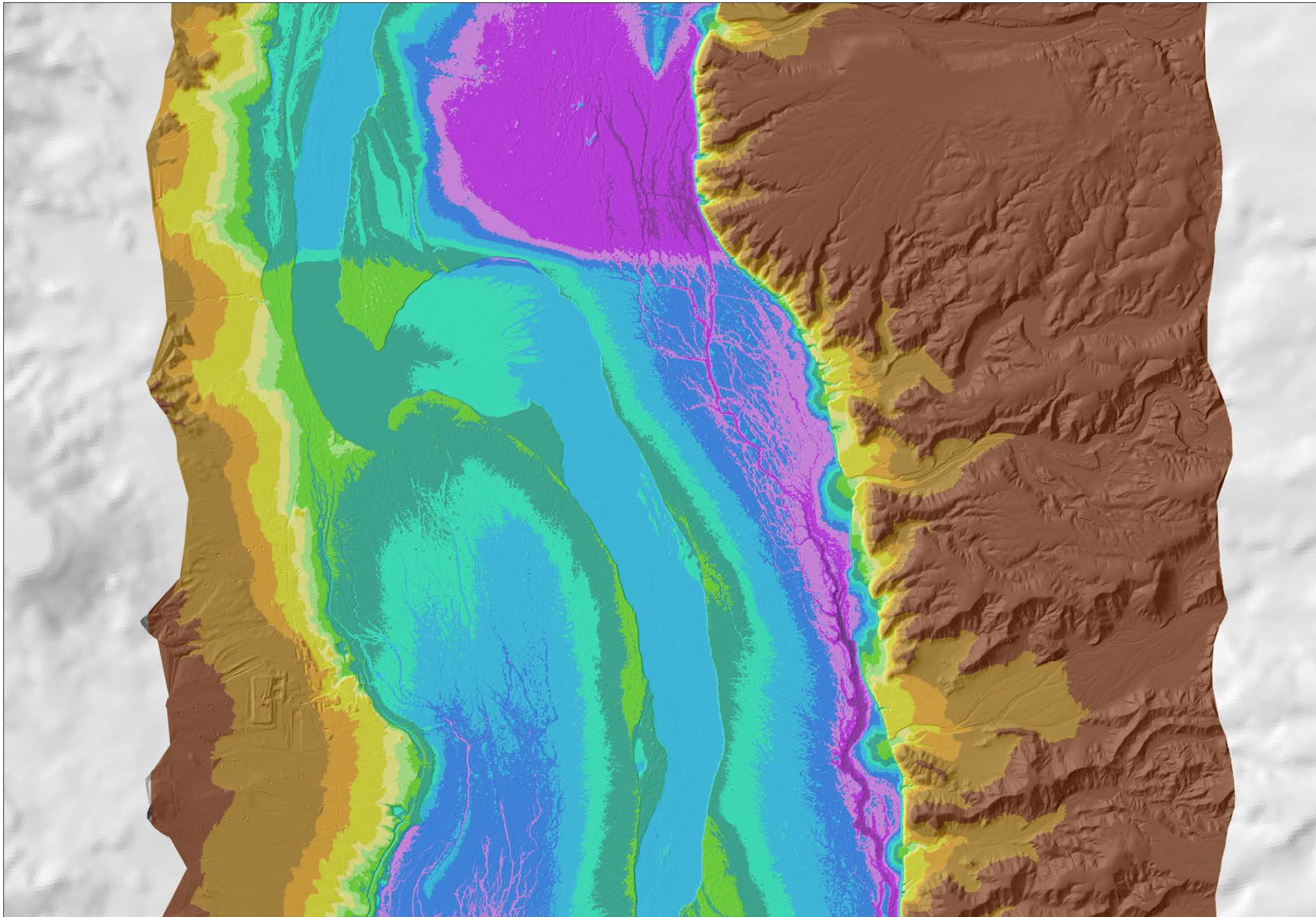

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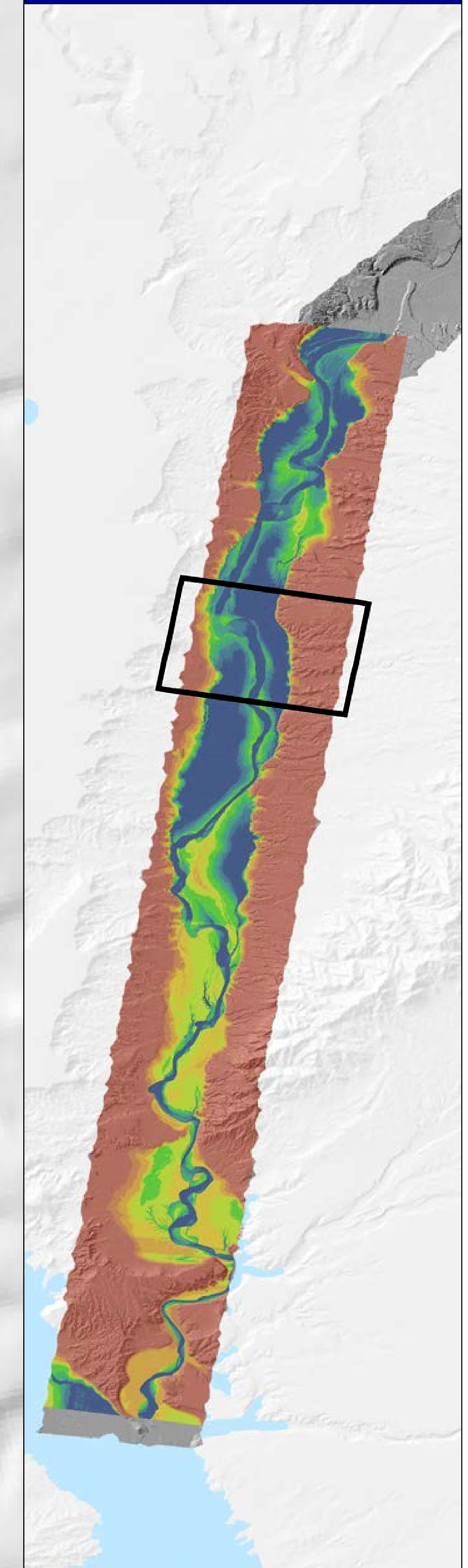

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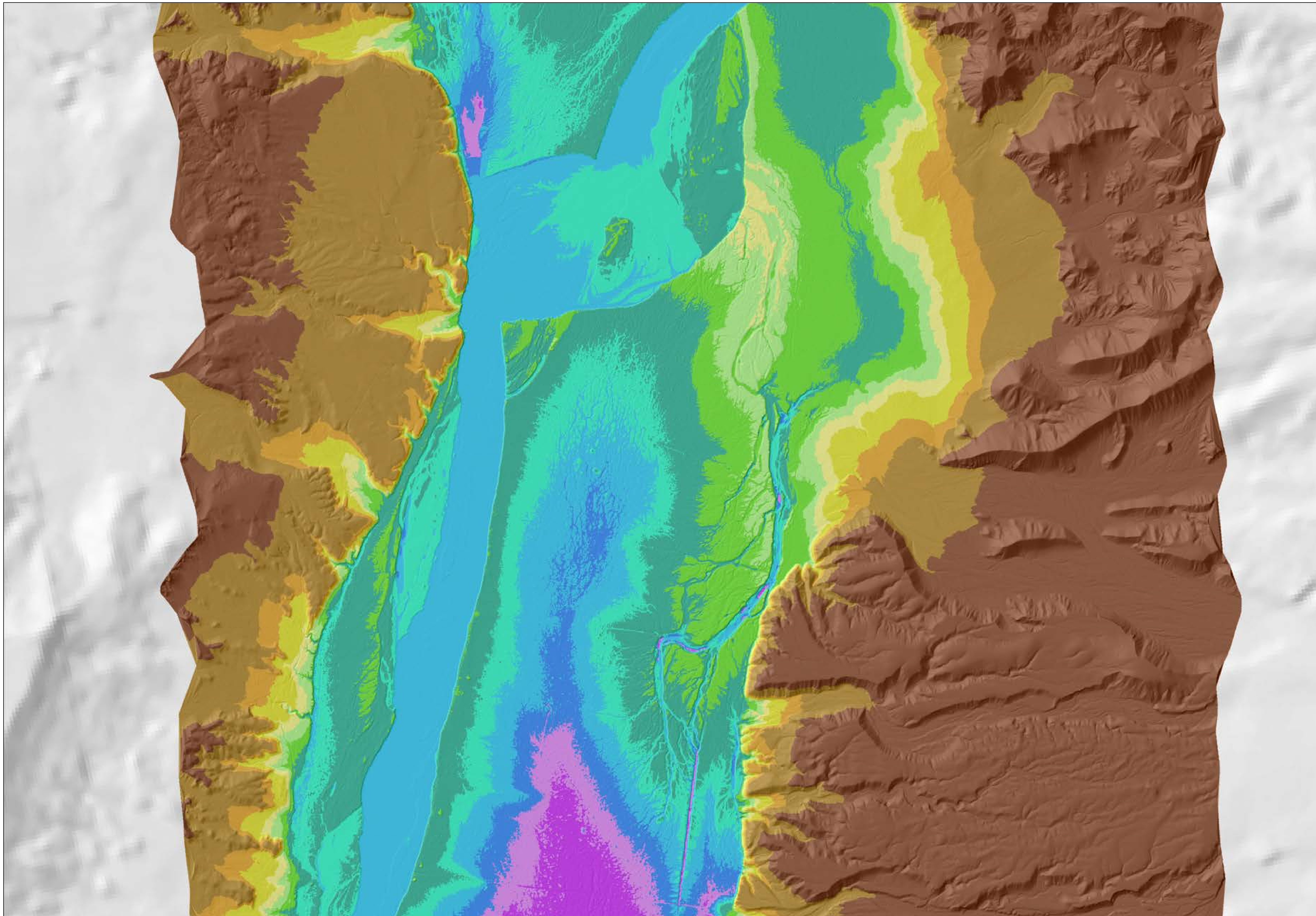

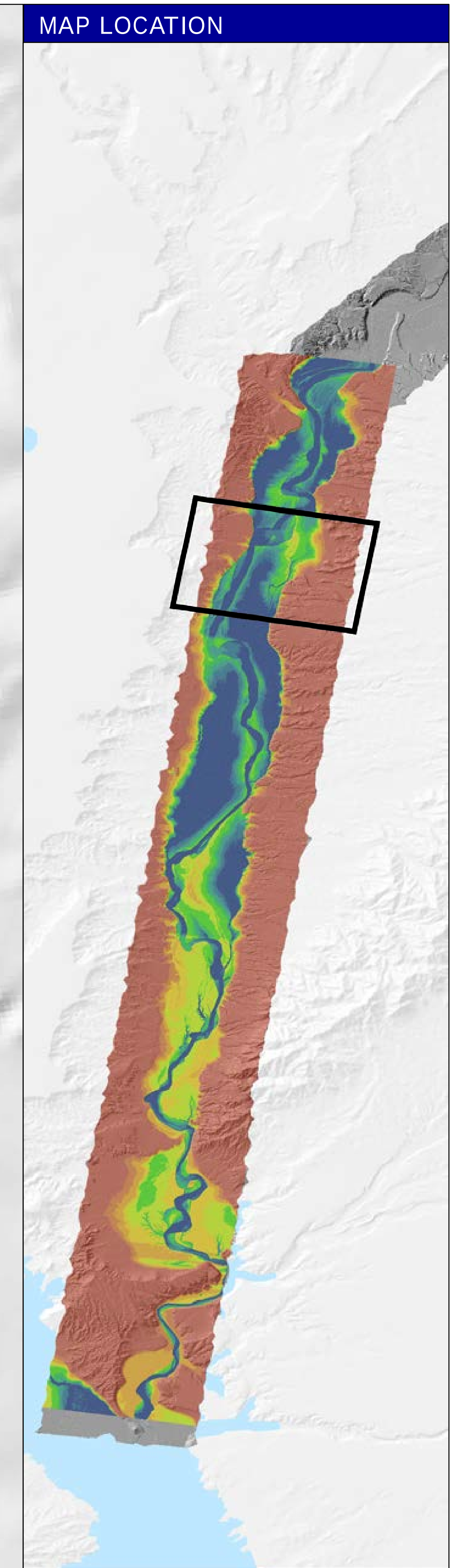

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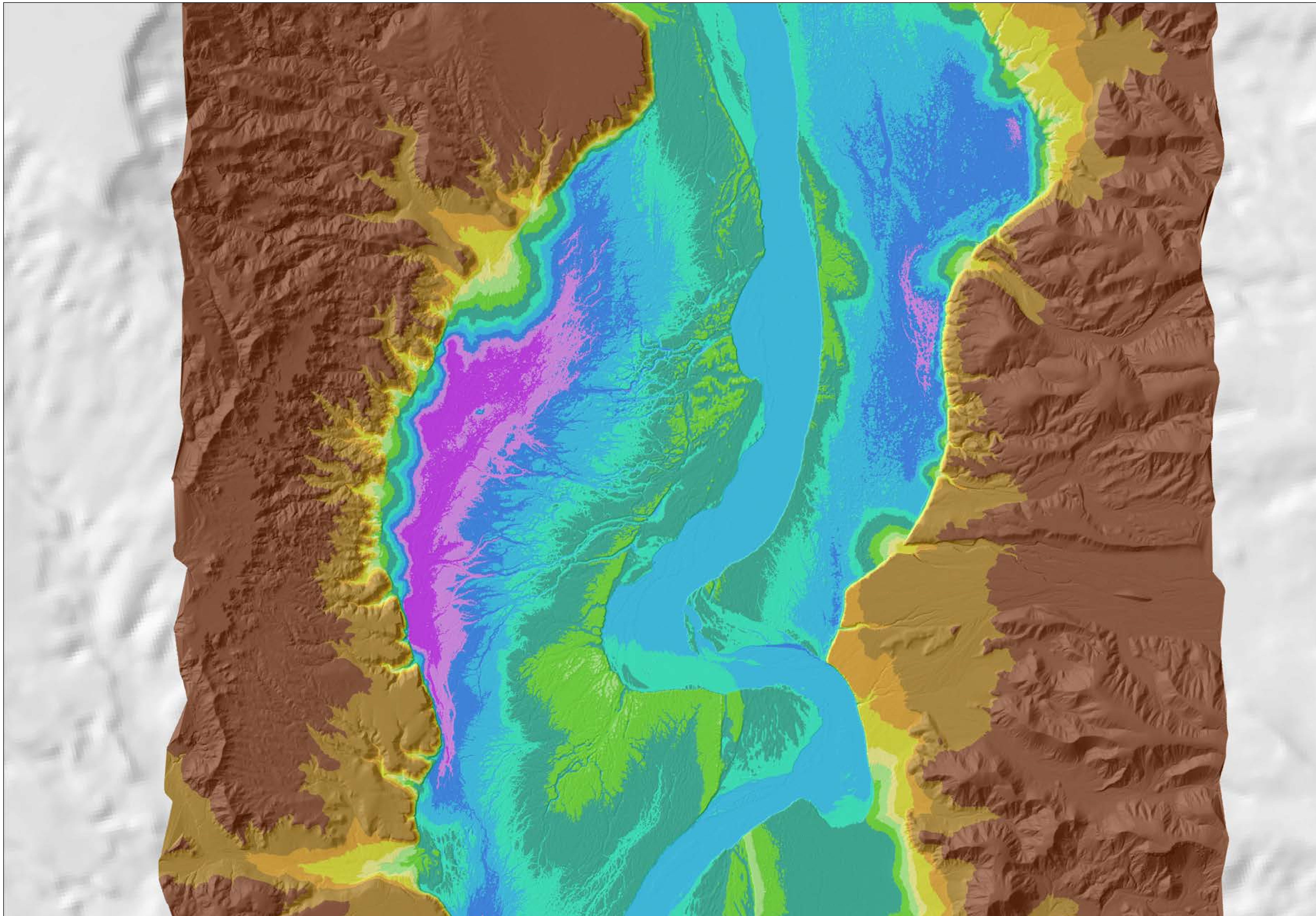

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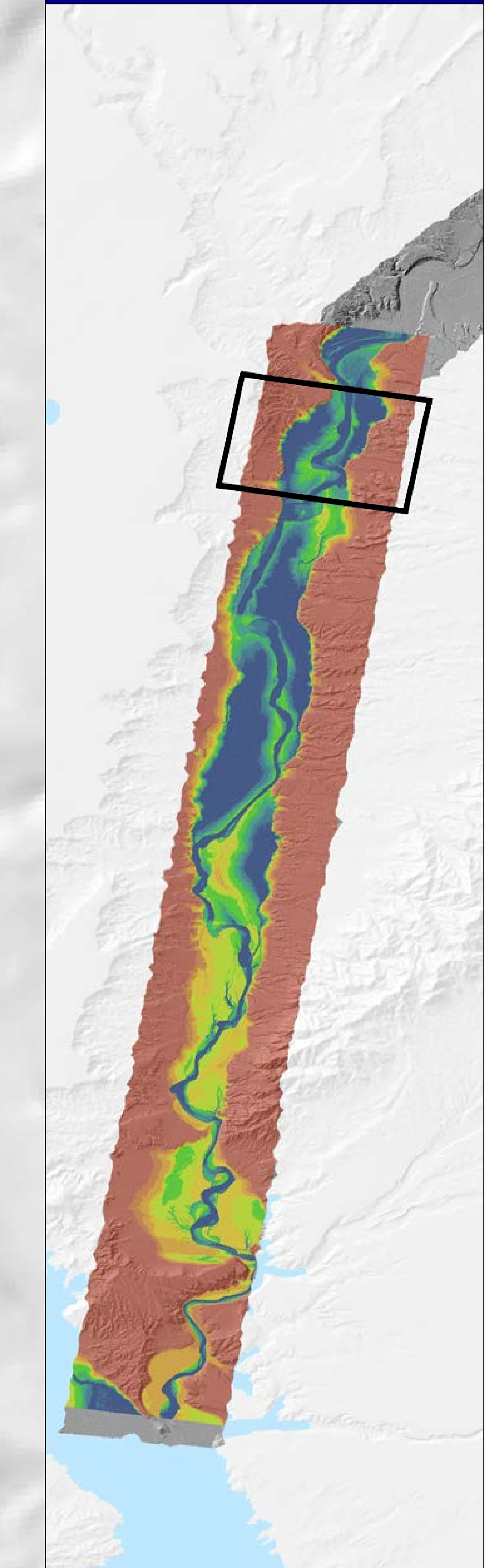

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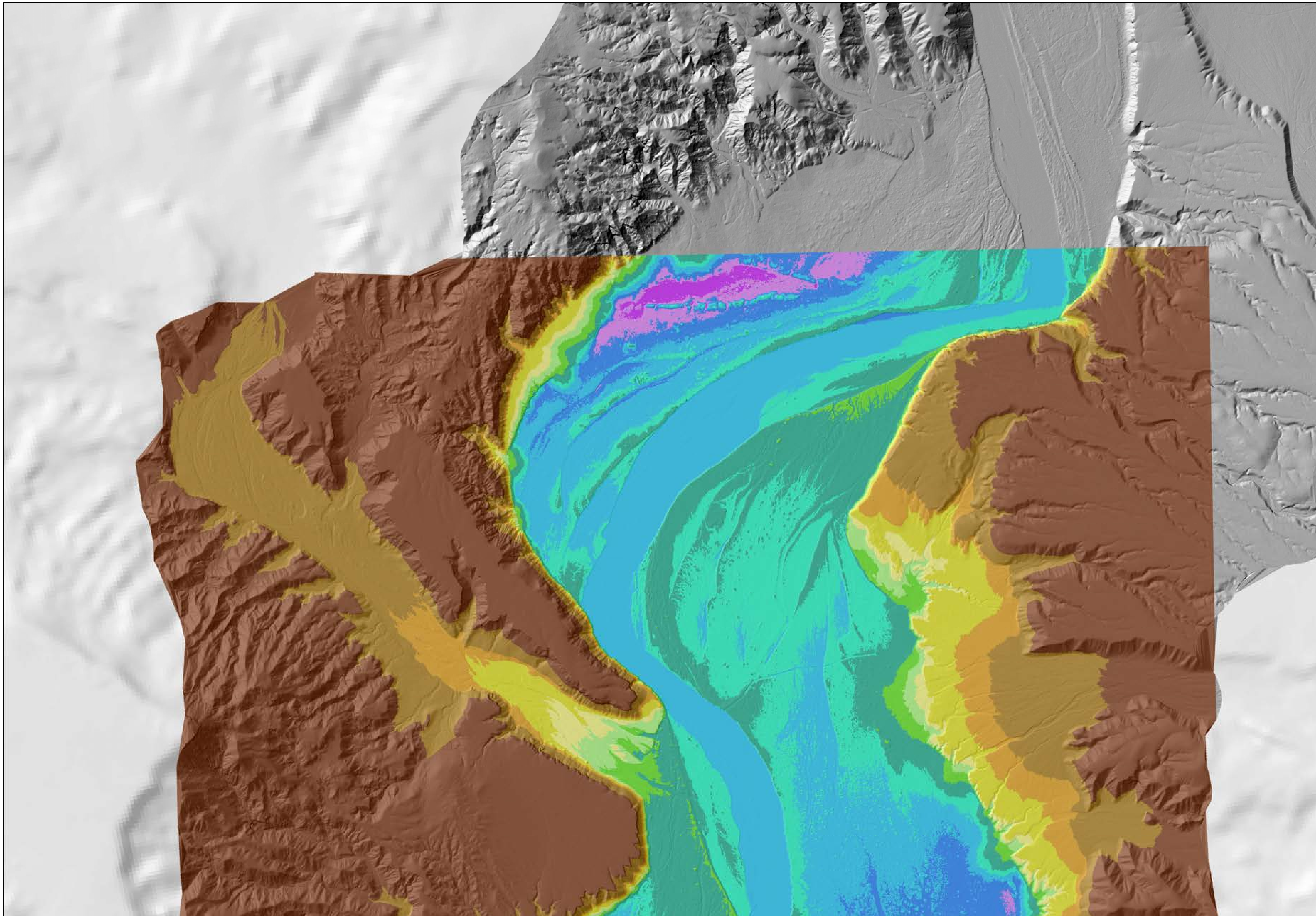

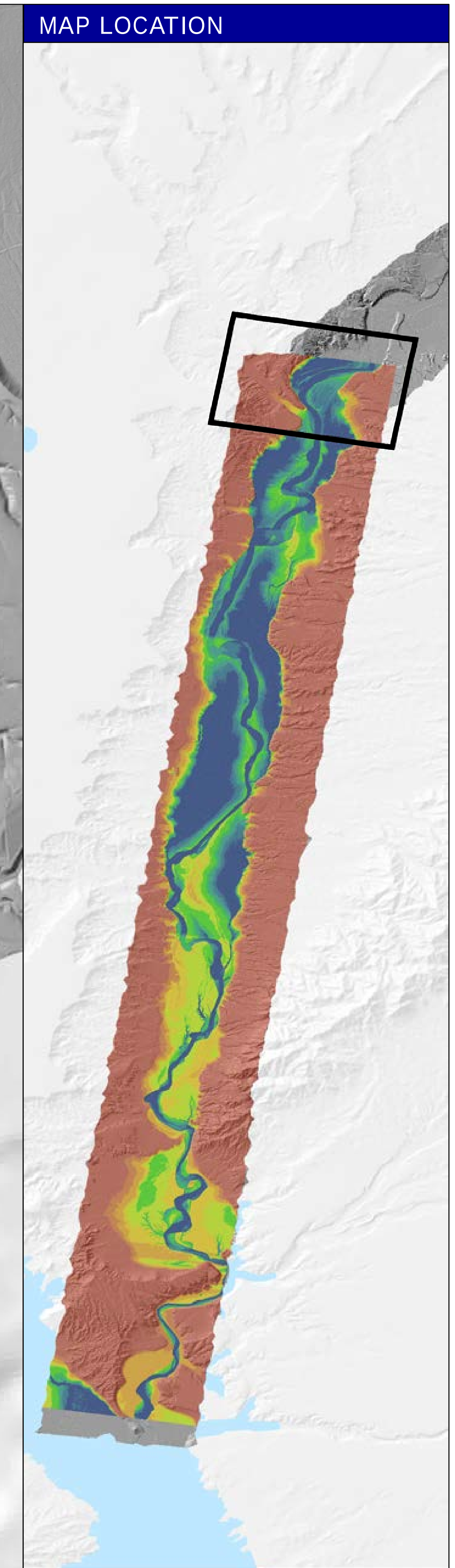

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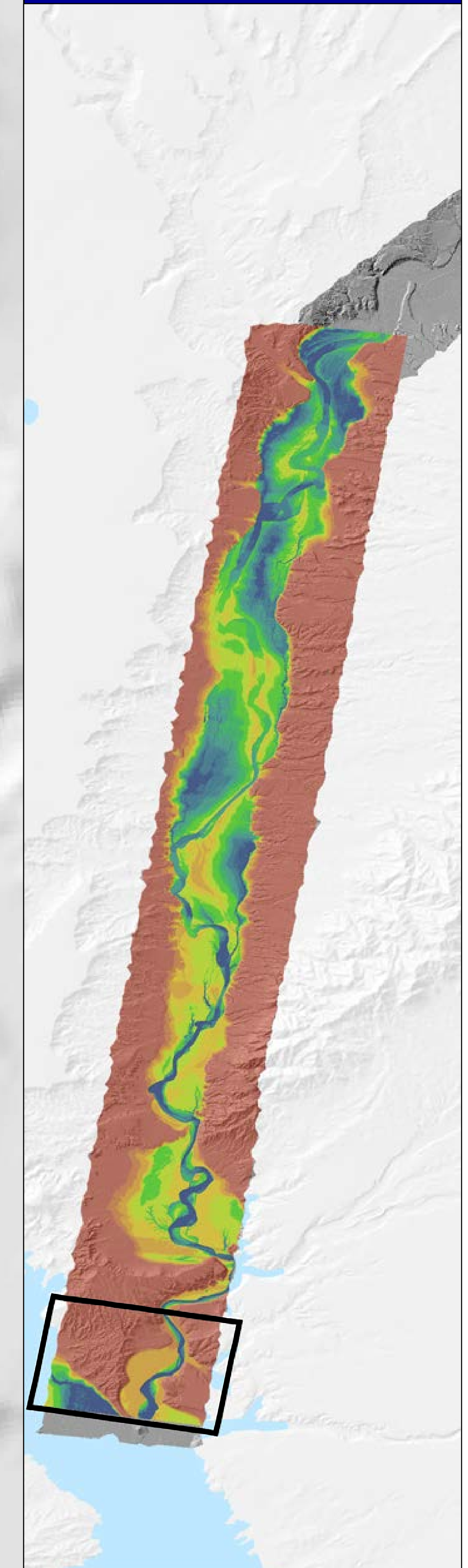


MORMON MESA, VEGETATION CANOPY HEIGHT

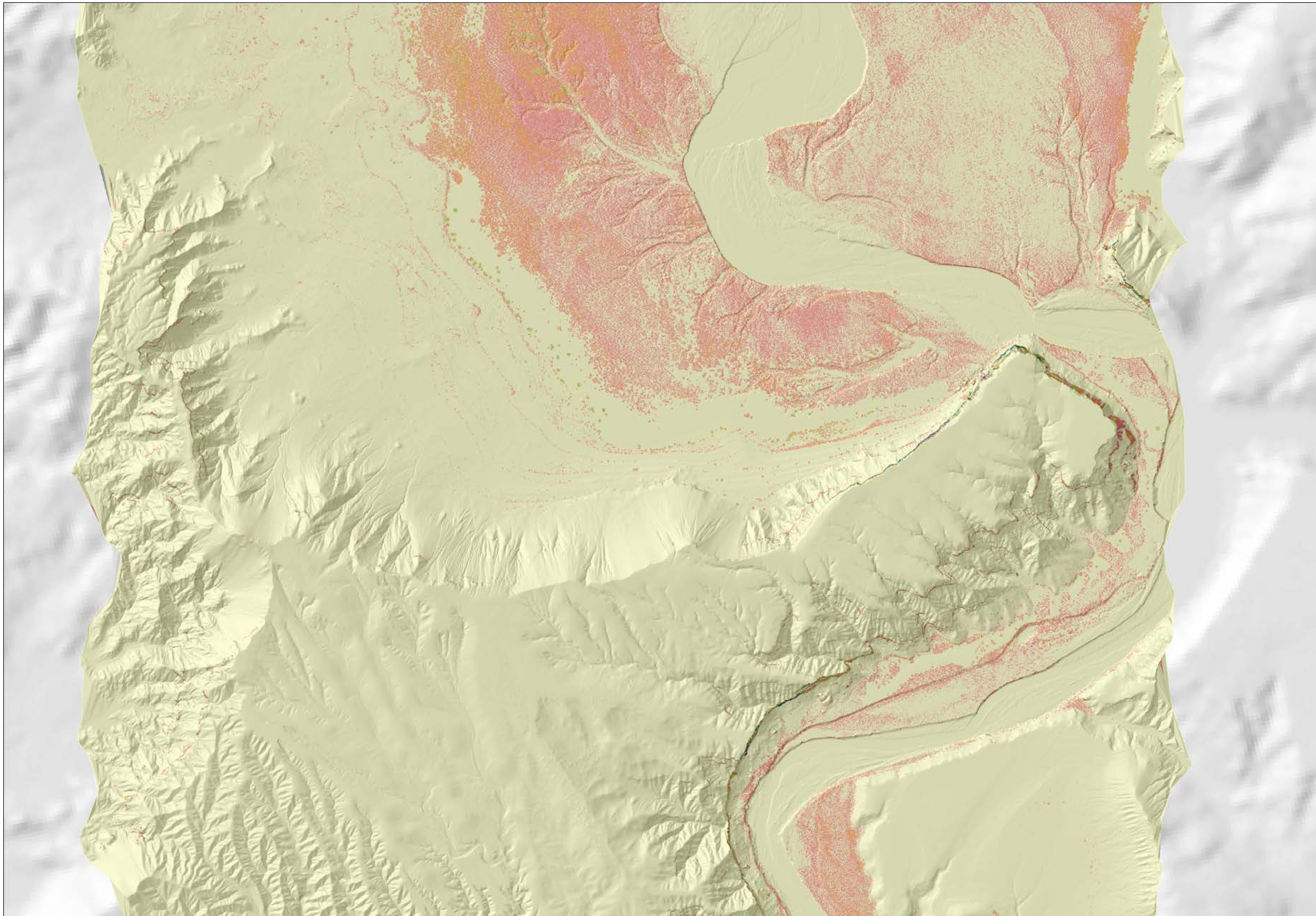
Vegetation Canopy Height in meters

- 0 - 1
- 1.1 - 3
- 3.1 - 5
- 5.1 - 7
- 7.1 - 10
- 10.1 - 20
- > 20

Data sources:
Canopy Heights: Stillwater Sciences, 2013
LIDAR Hillshade: Utah State University, November 2011

0 500 1,000 1,500 2,000 Feet
0 200 400 600 Meters

Stillwater Sciences
www.stillwatersci.com



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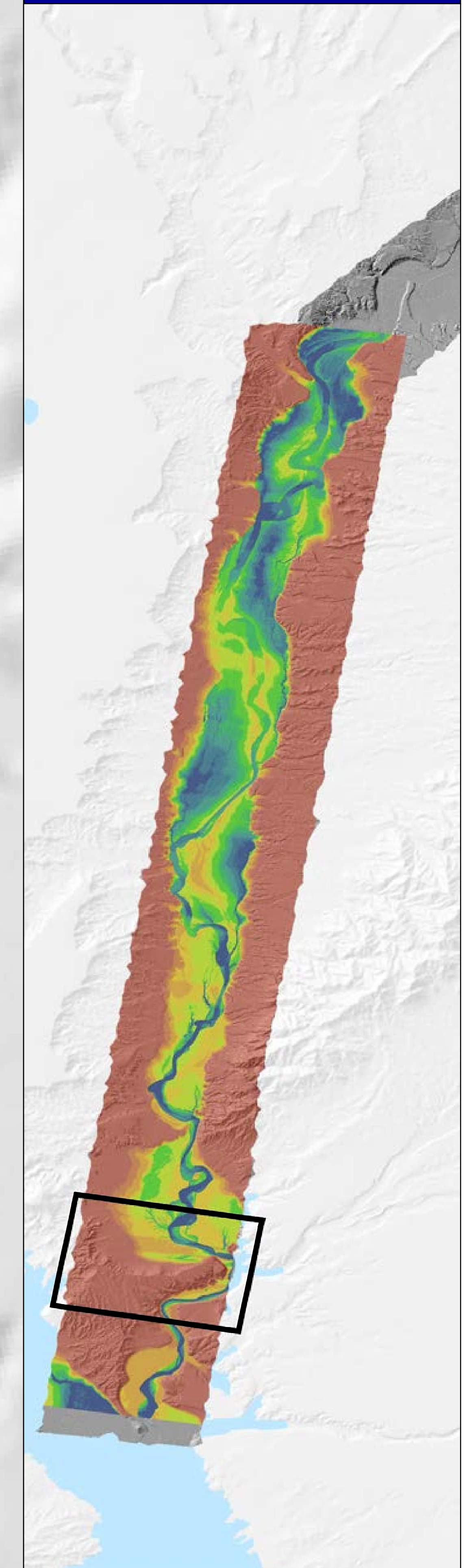

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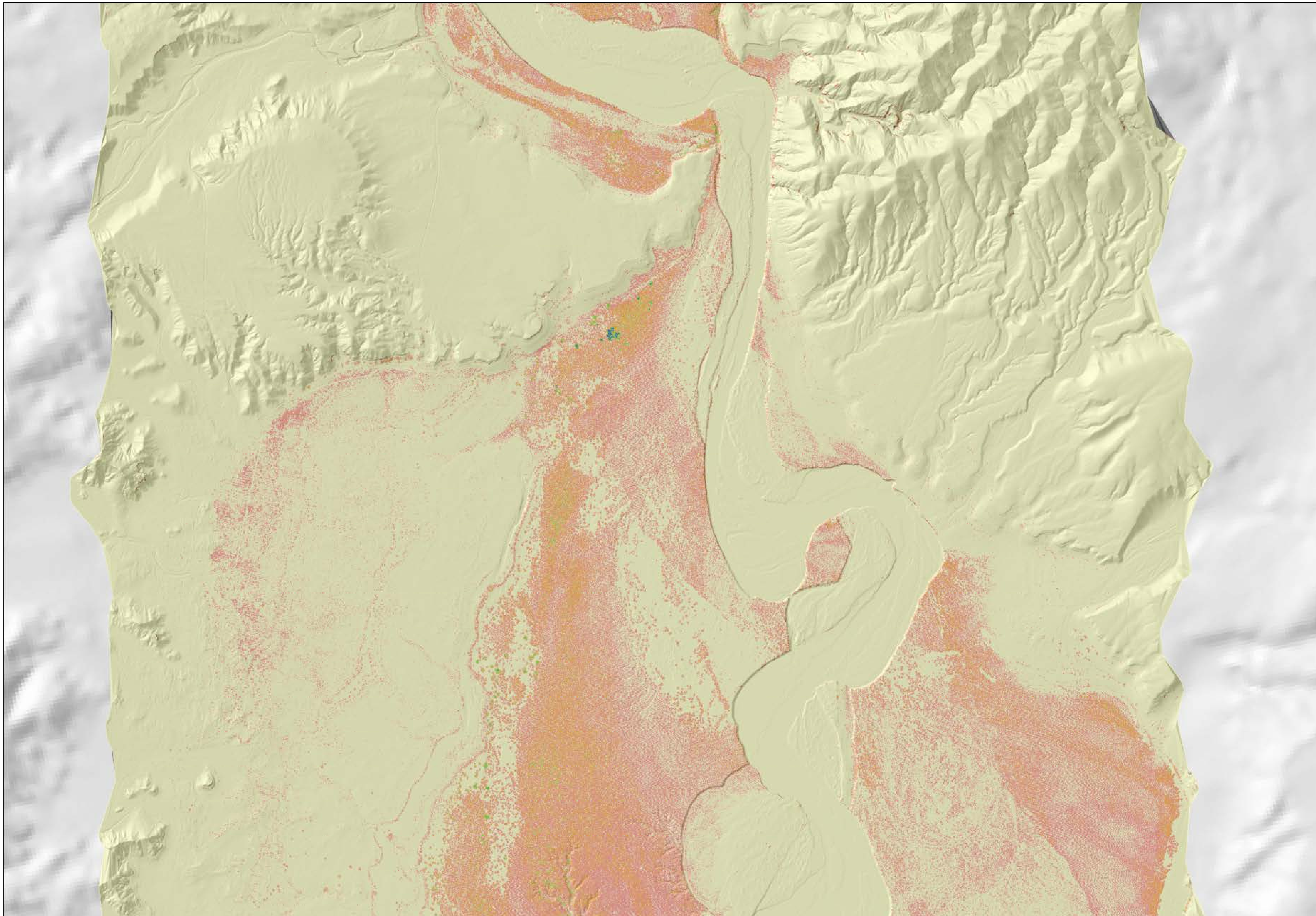

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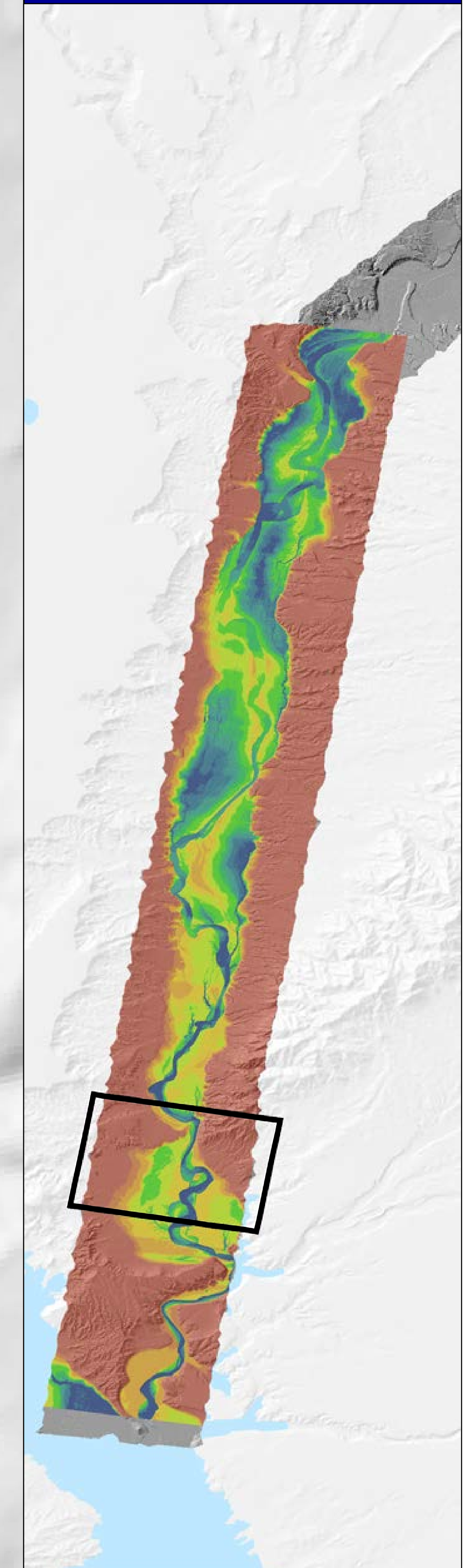

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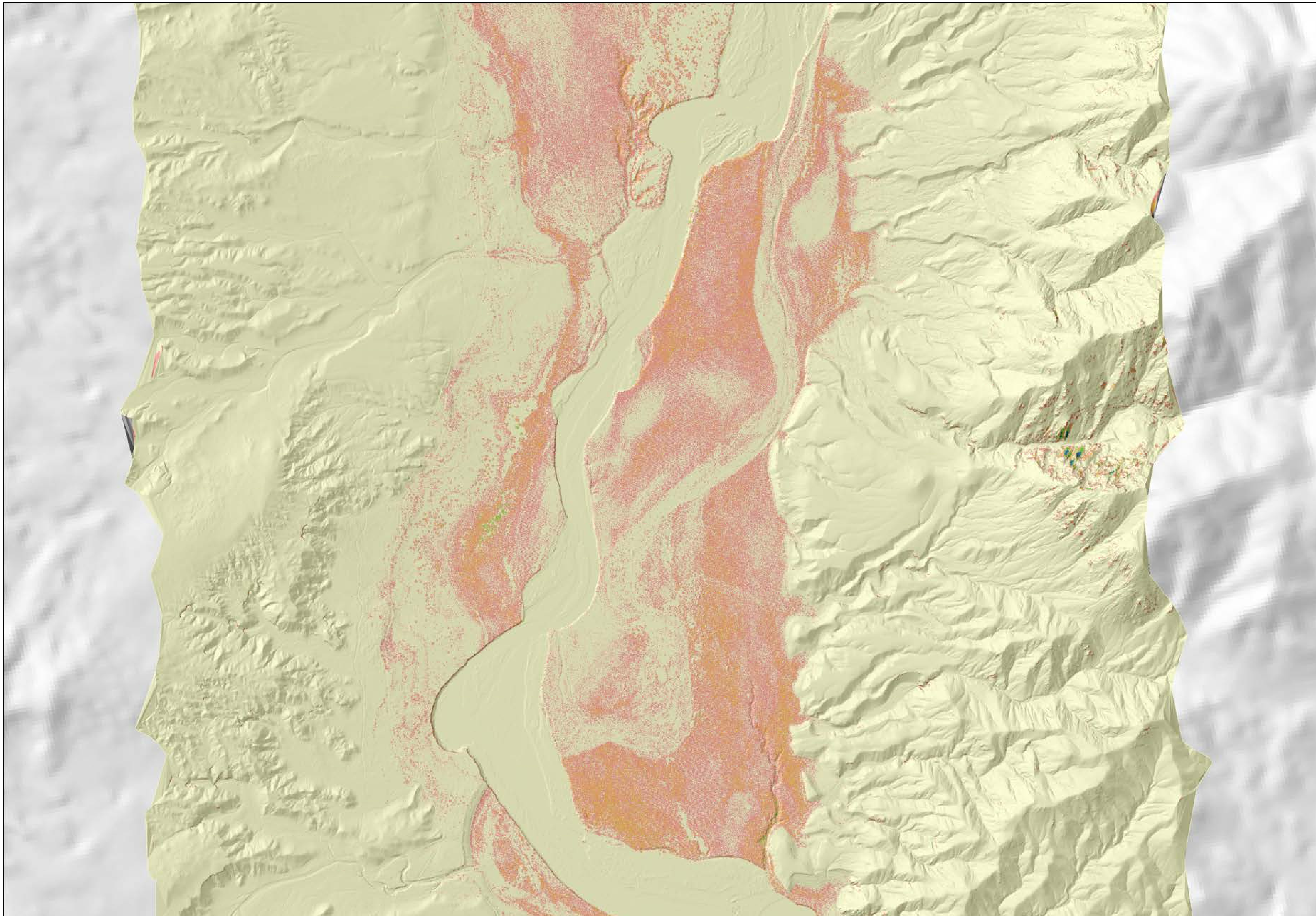

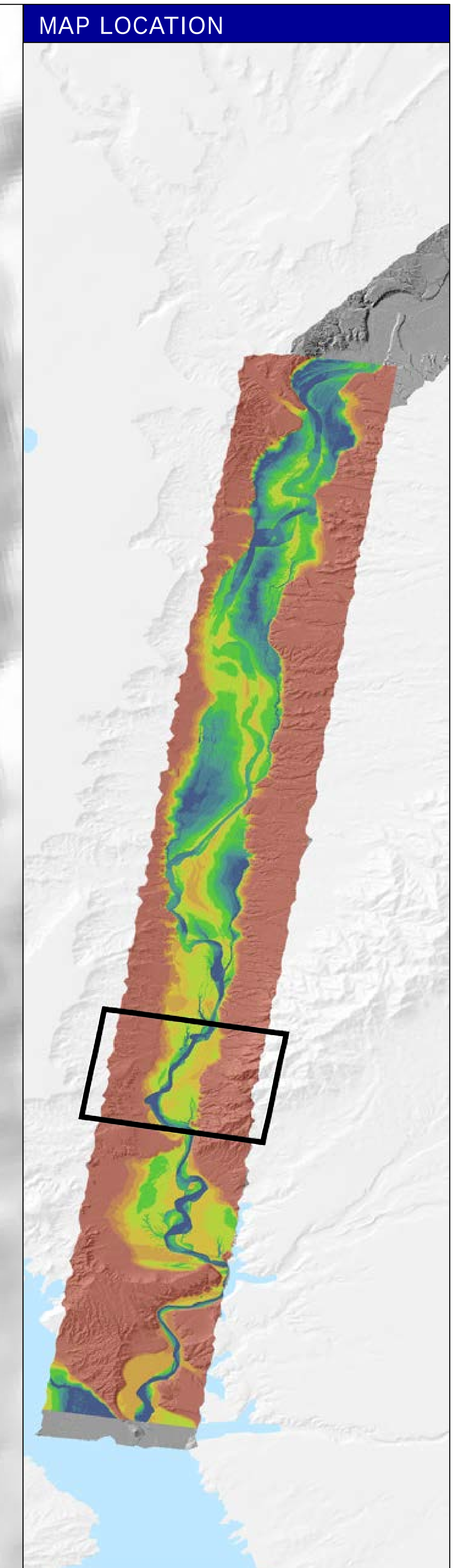

MORMON MESA, VEGETATION CANOPY HEIGHT

Vegetation Canopy Height in meters

0 - 1	3.1 - 5	7.1 - 10	> 20
1.1 - 3	5.1 - 7	10.1 - 20	

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Stillwater Sciences
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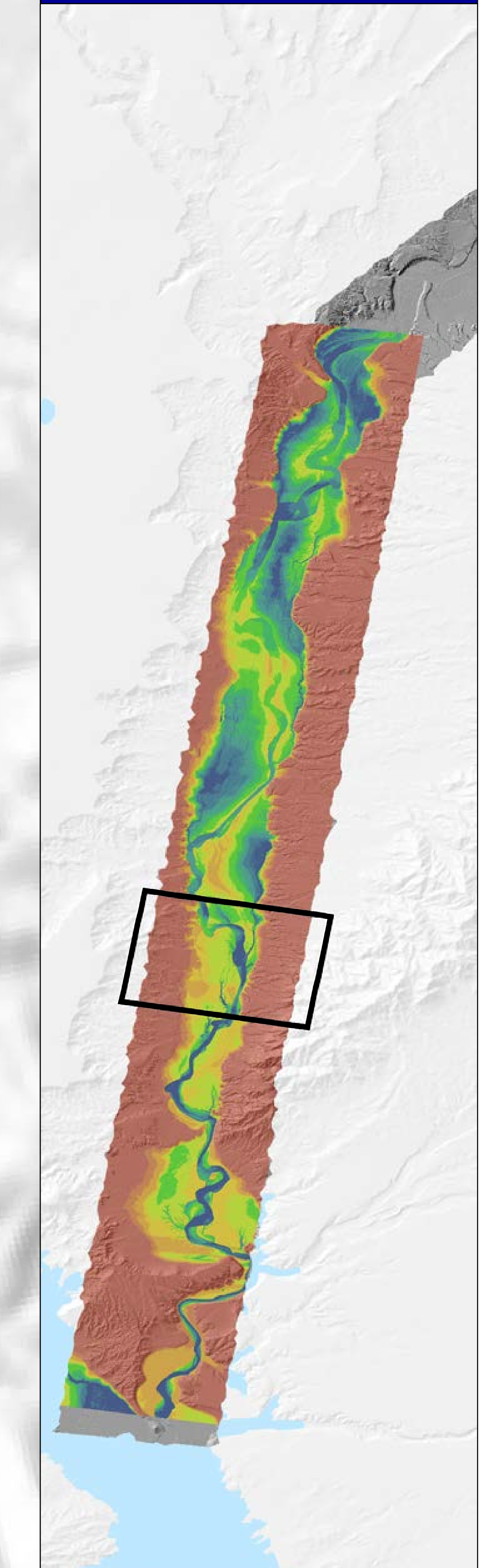

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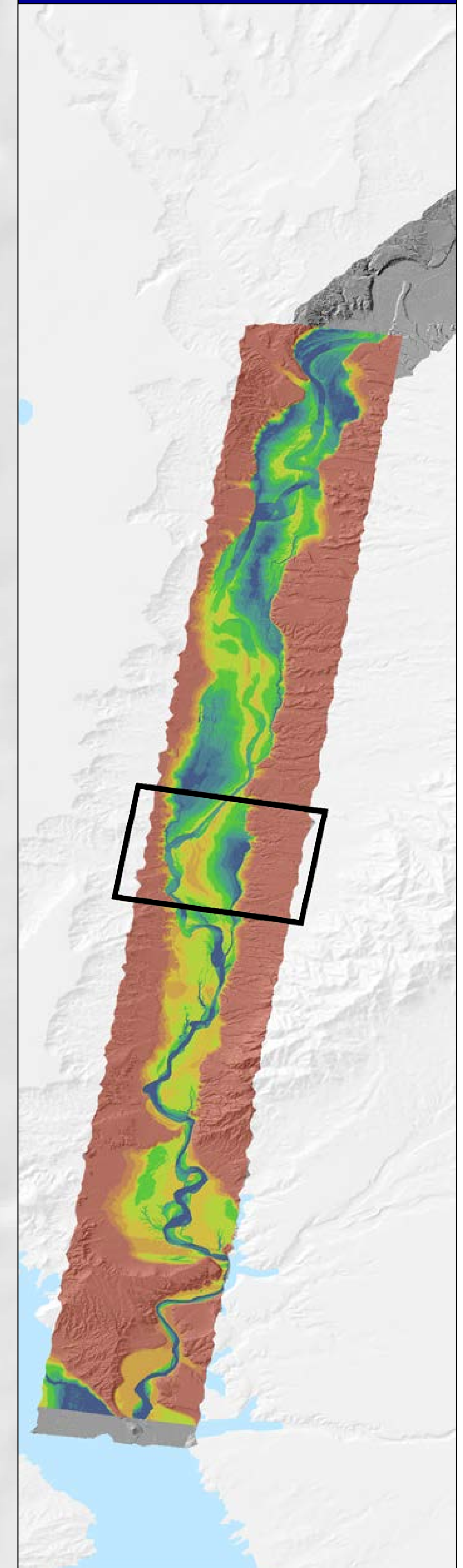

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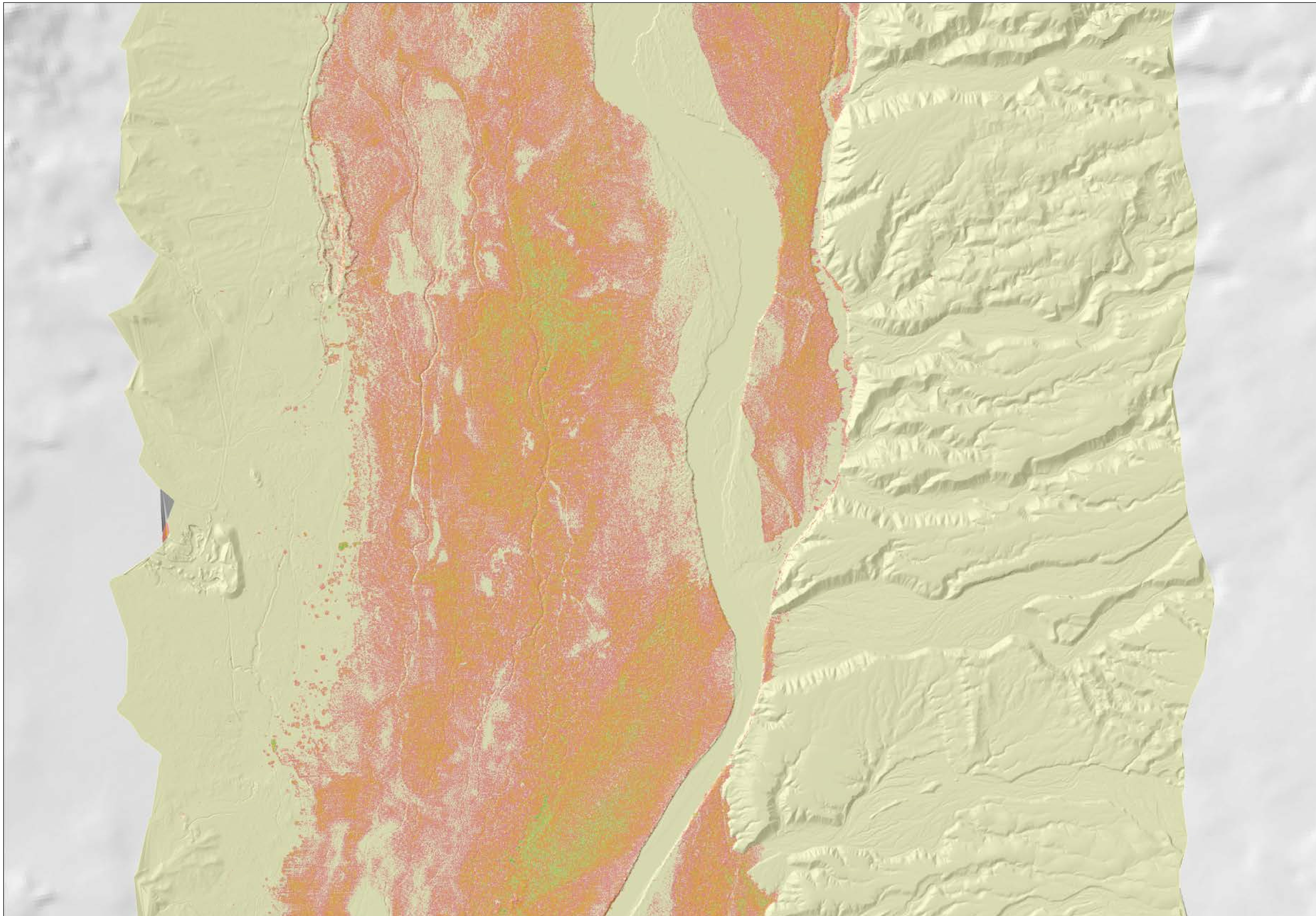
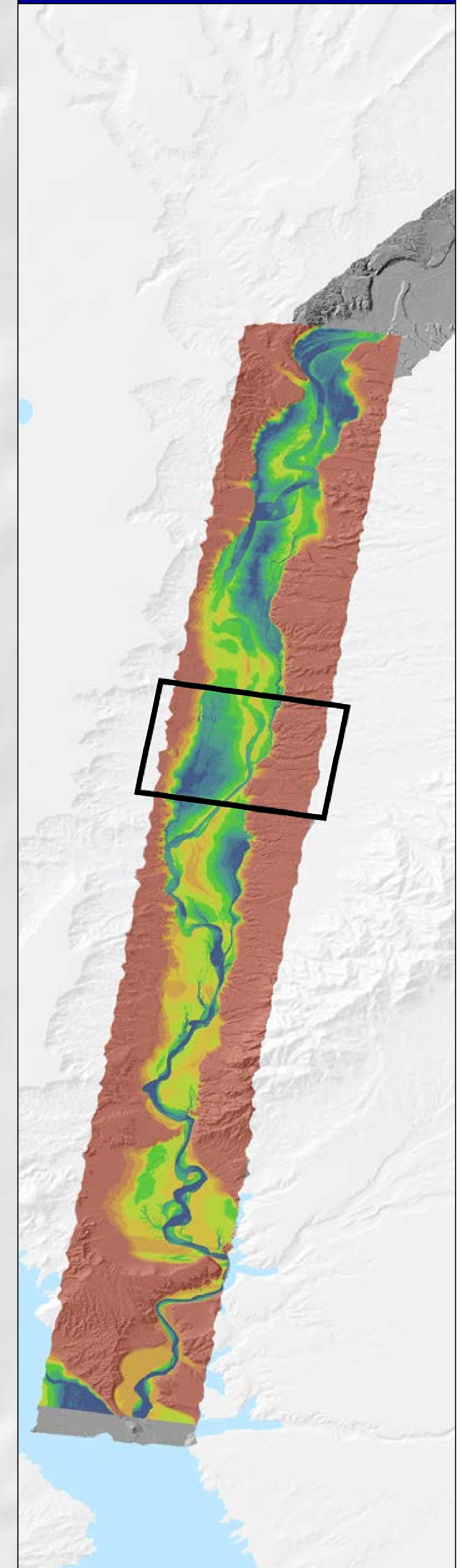


MAP LOCATION



MORMON MESA, VEGETATION CANOPY HEIGHT

Vegetation Canopy Height in meters

0 - 1	1.1 - 3
3.1 - 5	5.1 - 7
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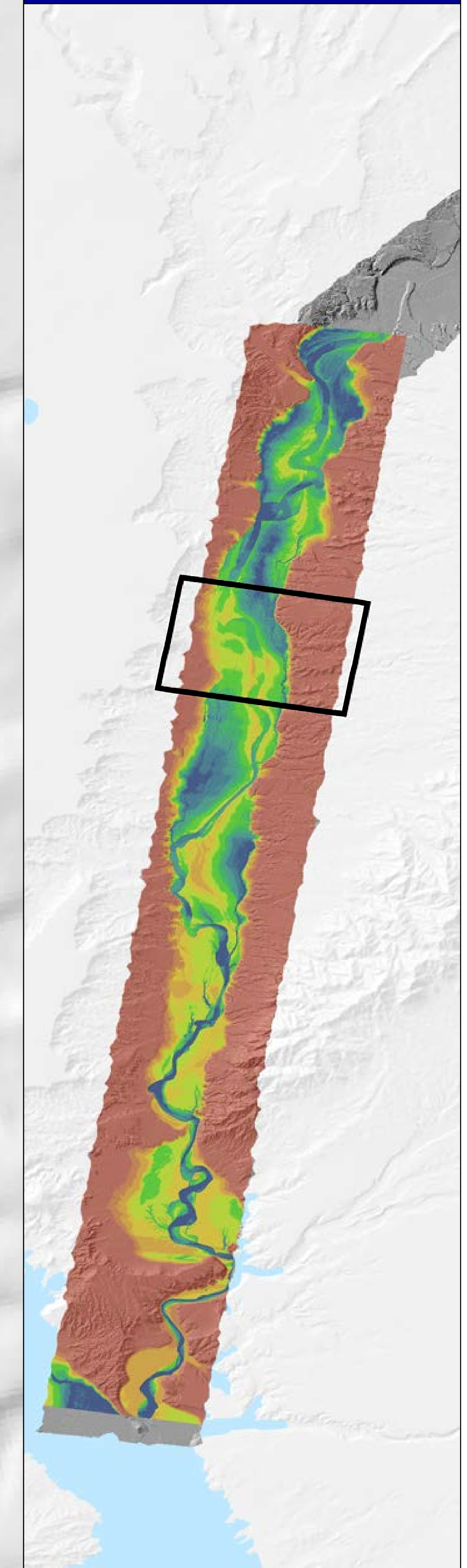

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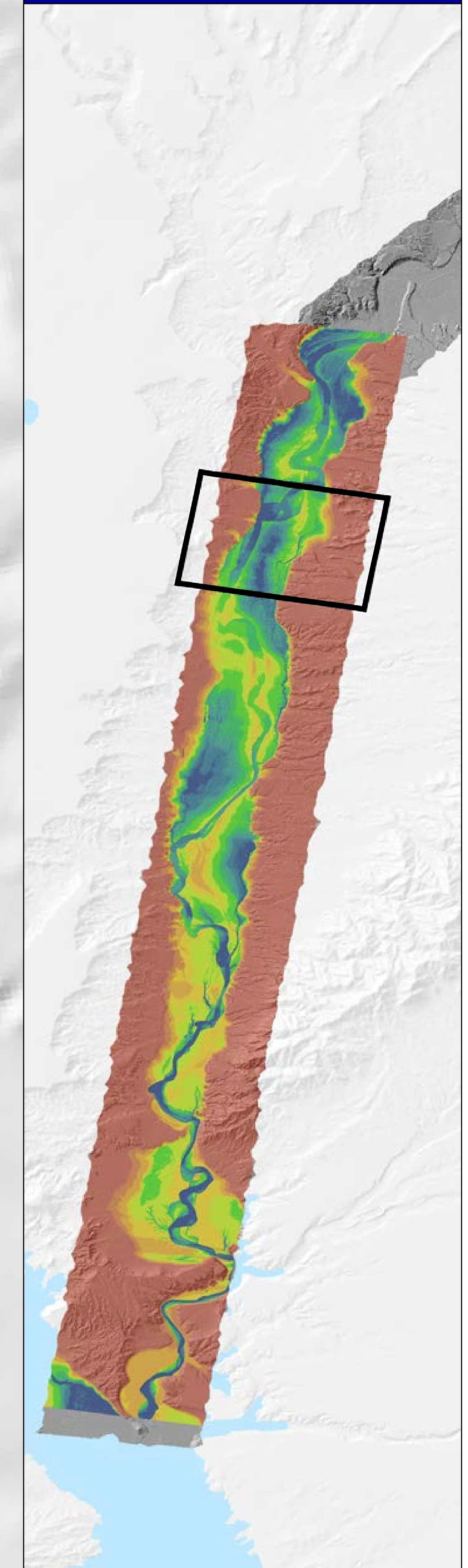

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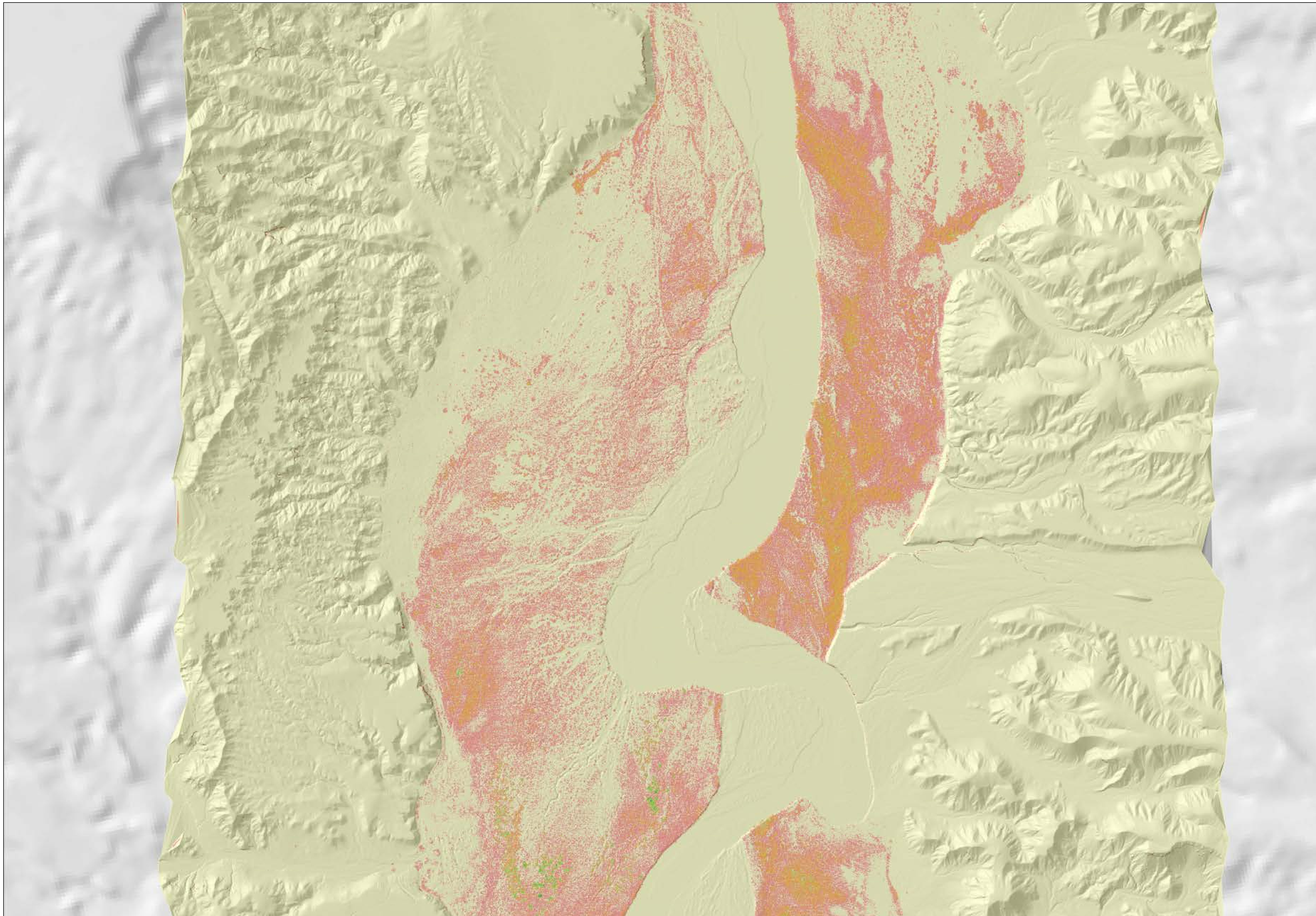

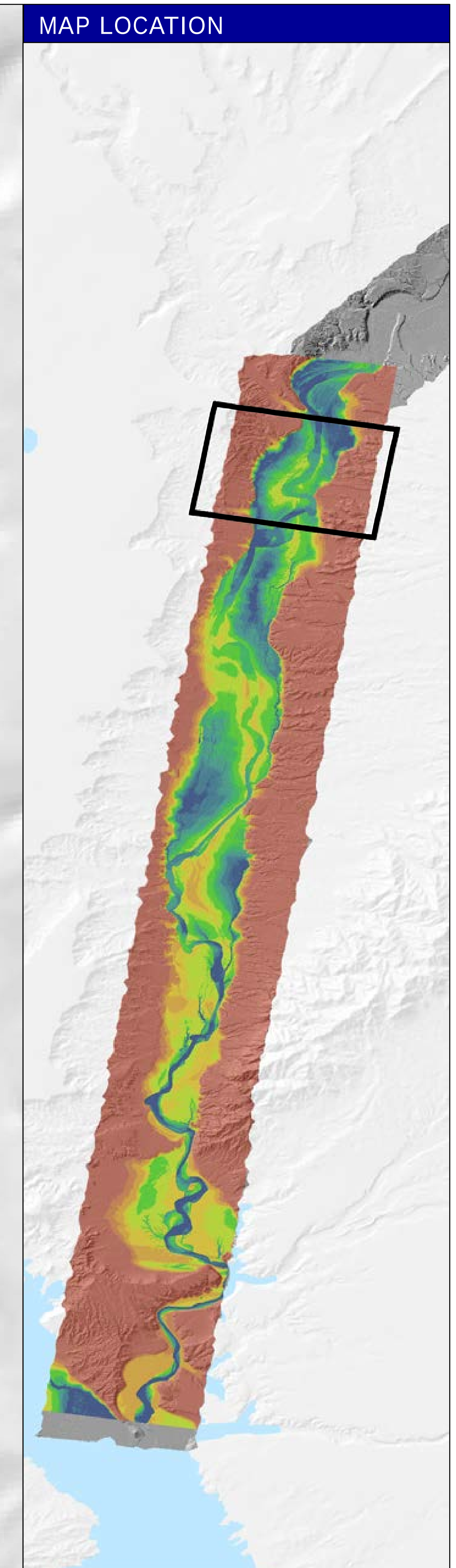

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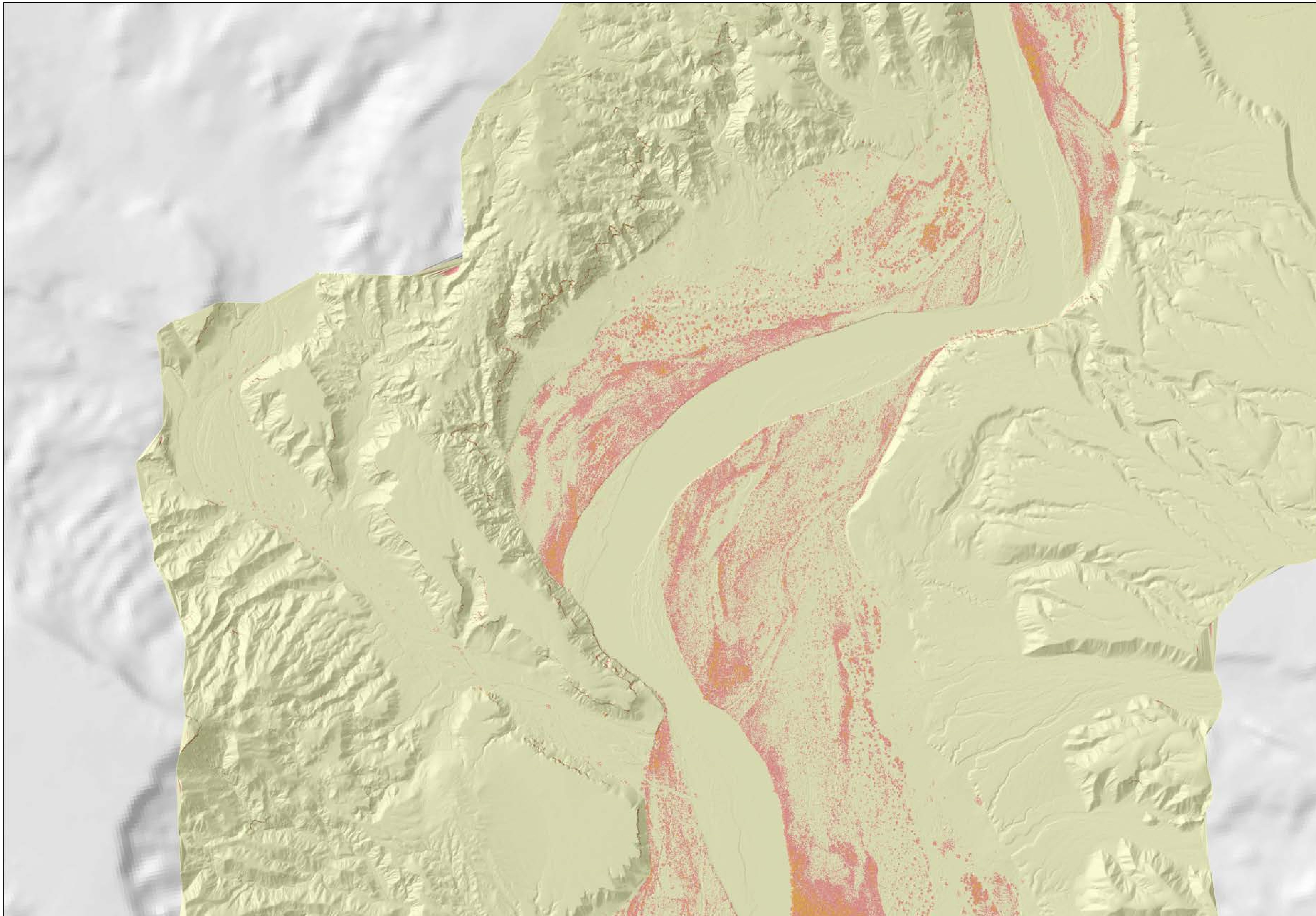

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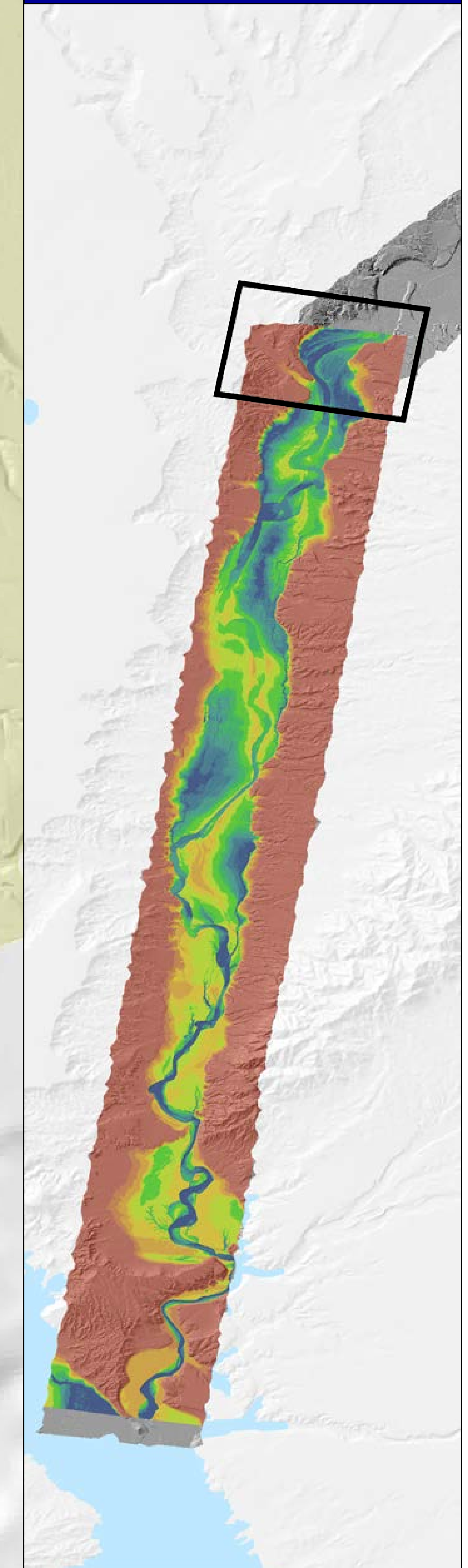

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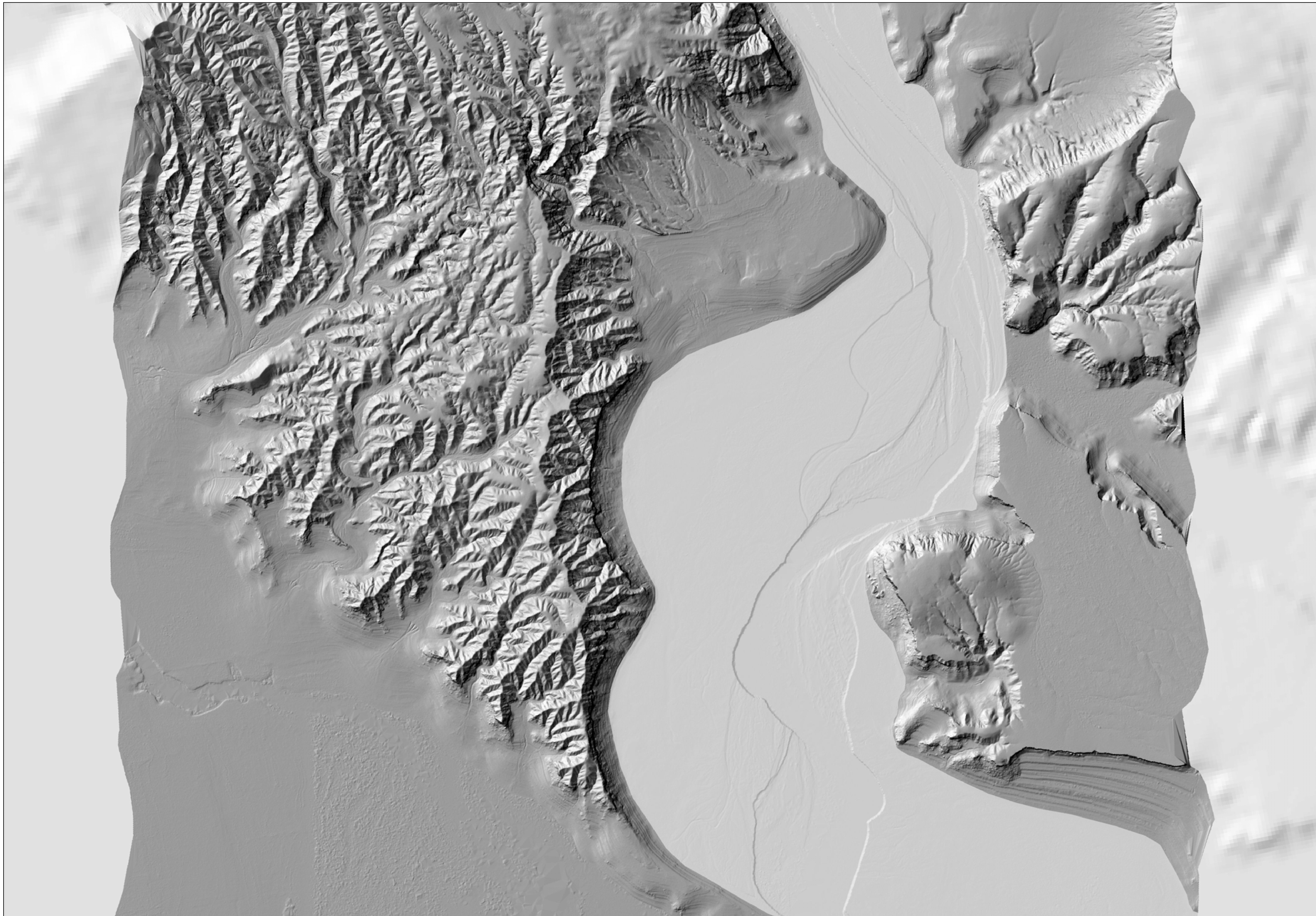

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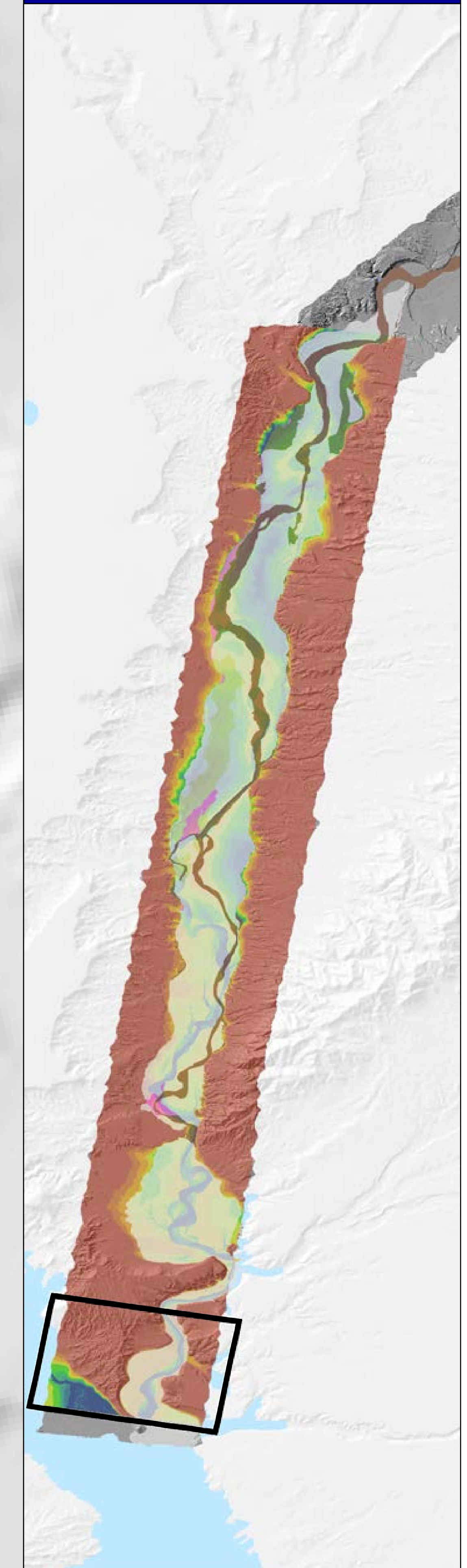

NRCS SOIL TYPE

Salinity

very slightly saline

strongly saline

slightly saline

Particle size

not classified

loamy-skeletal

Data sources: Soil type & soil salinity (NRCS, SSURGO); LIDAR Hillshade (Utah State University, November 2011)

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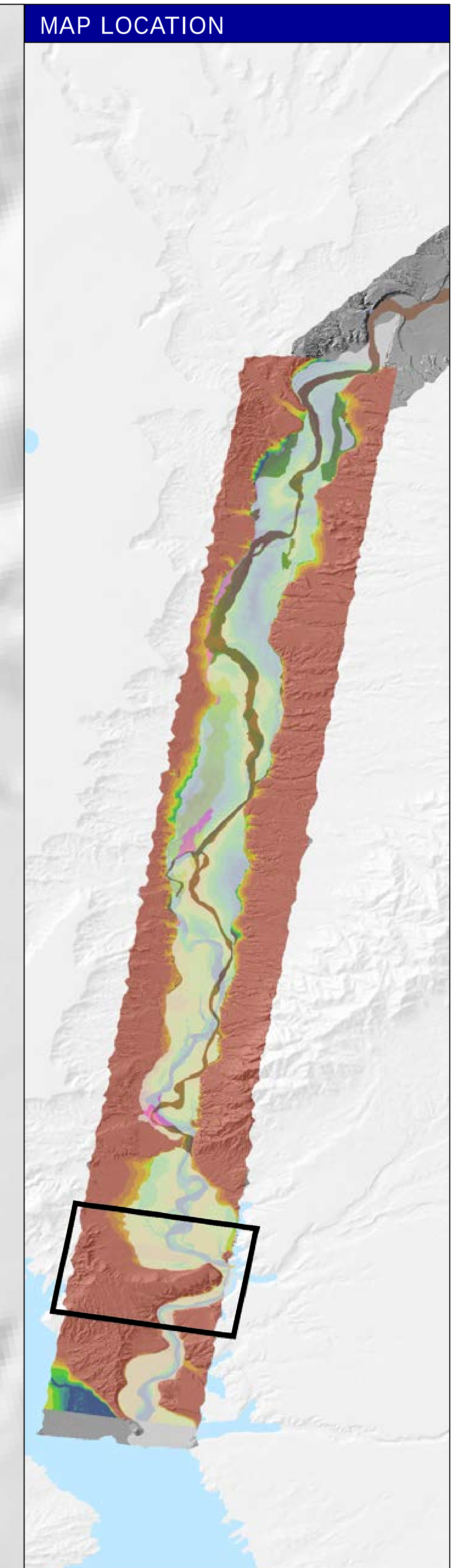

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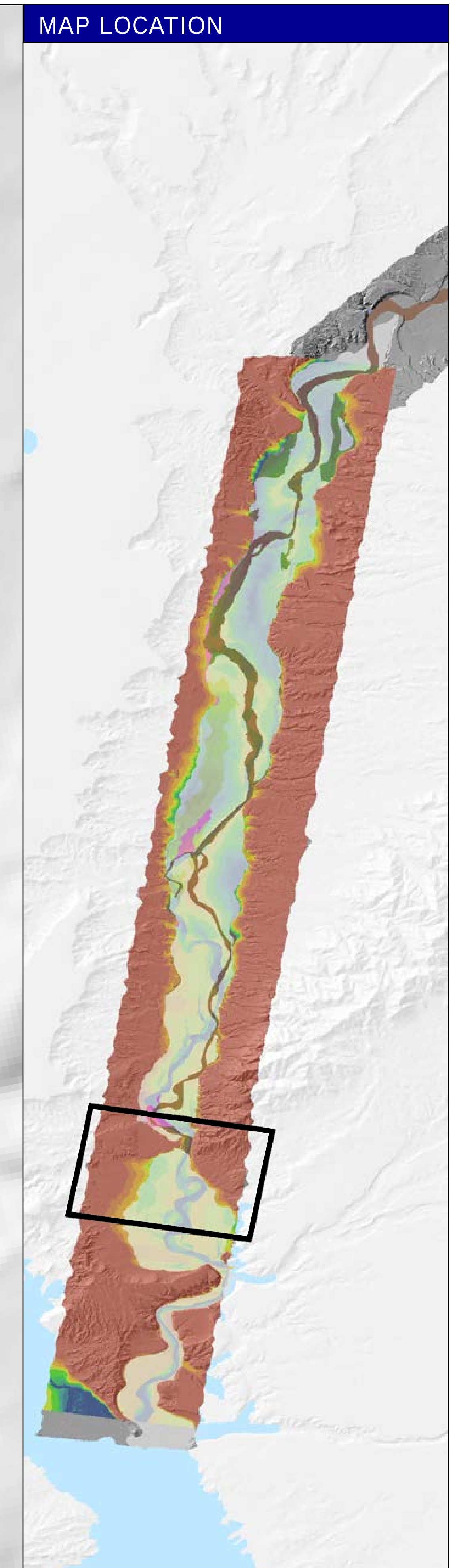

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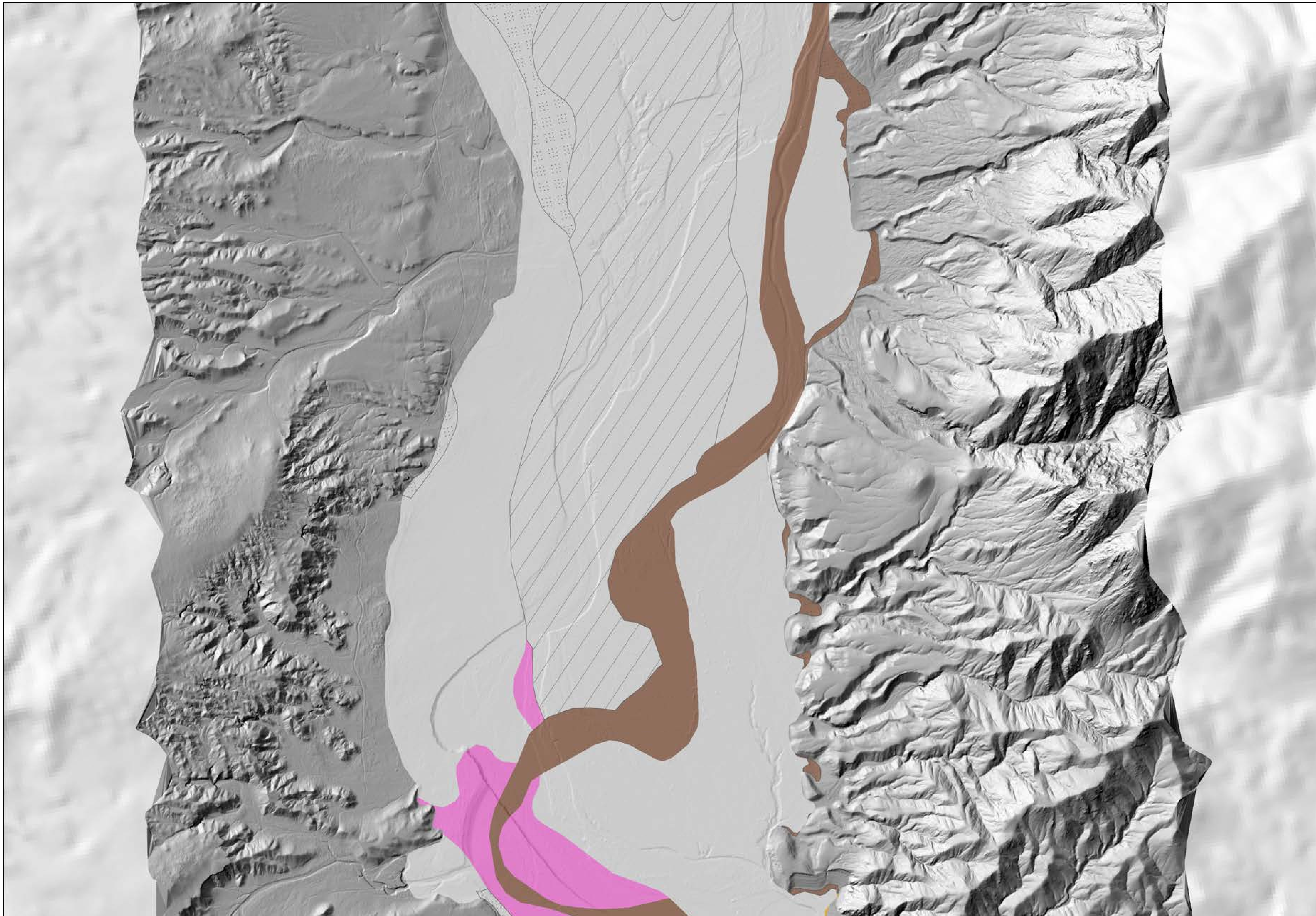
Stillwater Sciences
www.stillwatersci.com



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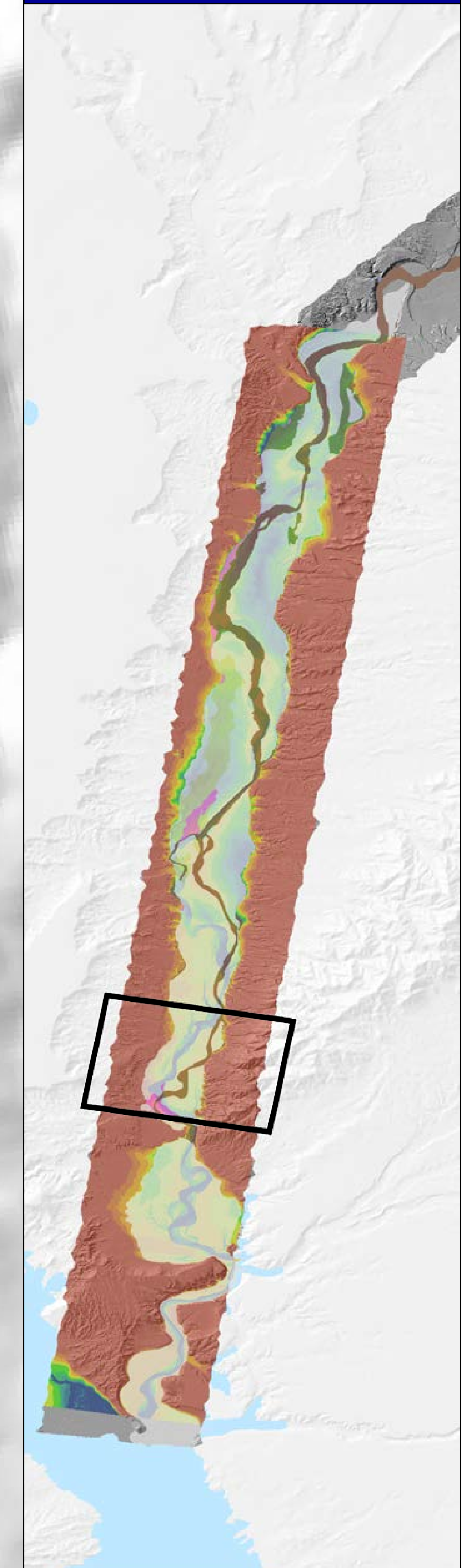

NRCS SOIL TYPE

Tile 4 of 11

Data sources: Soil type & soil salinity (NRCS, SSURGO); LIDAR Hillshade (Utah State University, November 2011)

Salinity
- very slightly saline
- strongly saline
- slightly saline

Particle size
- not classified
- sandy
- loamy-skeletal
- sandy-skeletal

0 500 1,000 1,500 2,000 Feet

0 200 400 600 Meters

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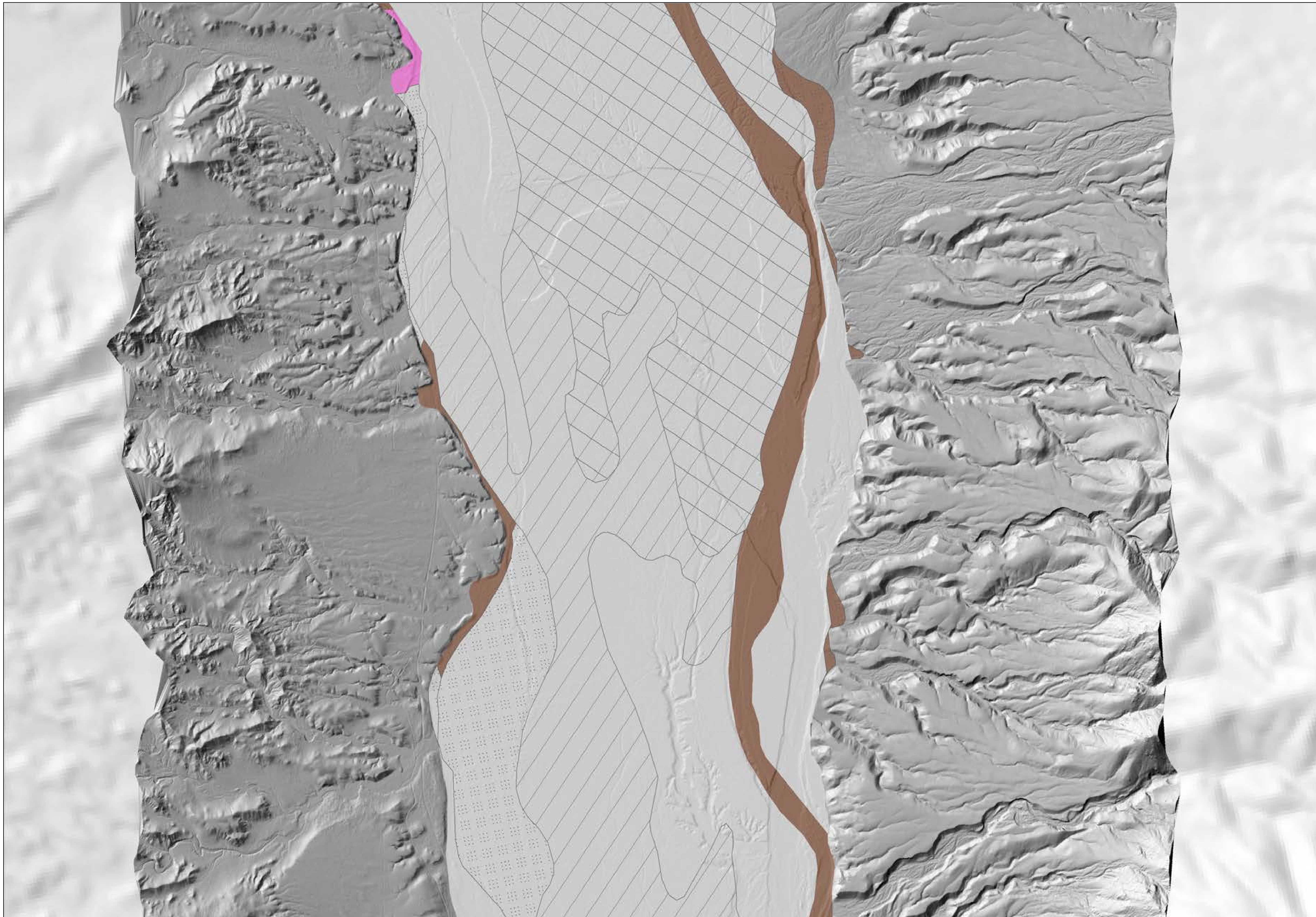

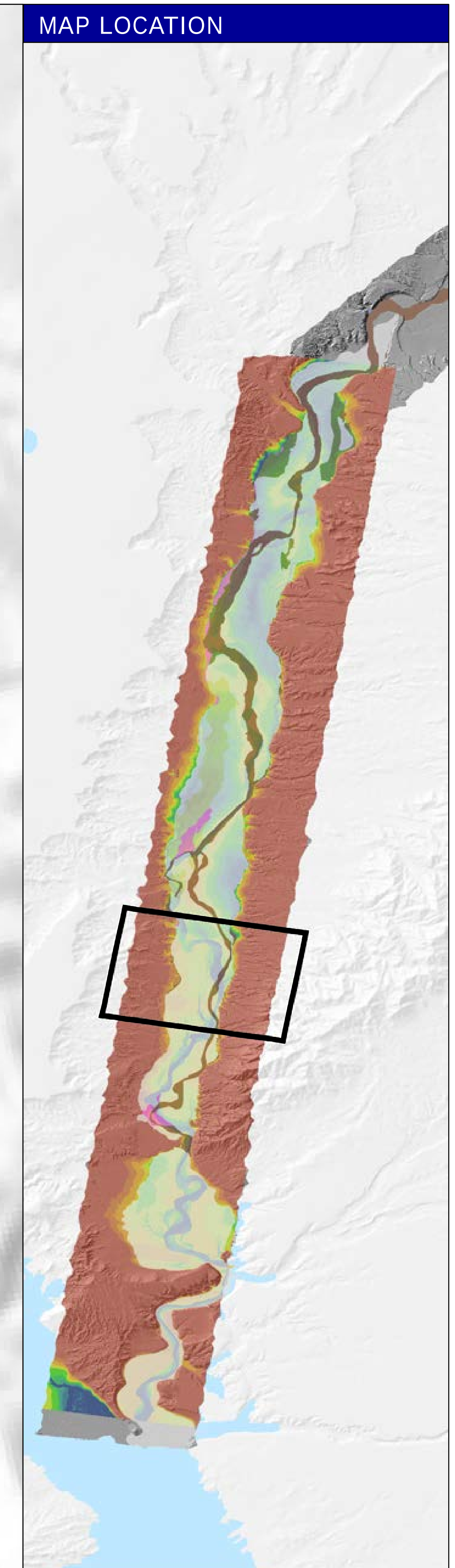

NRCS SOIL TYPE

Salinity

- very slightly saline
- strongly saline
- slightly saline

Particle size

- not classified
- sandy
- sandy-skeletal

Data sources: Soil type & soil salinity (NRCS, SSURGO); LIDAR Hillshade (Utah State University, November 2011)

0 500 1,000 1,500 2,000 Feet

0 200 400 600 Meters

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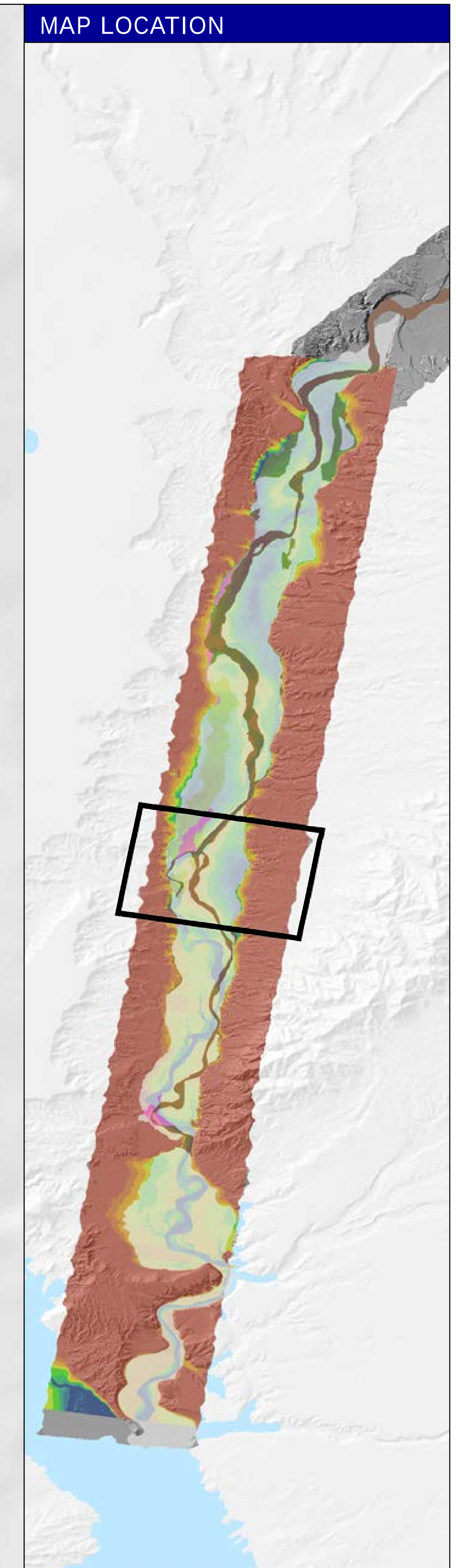

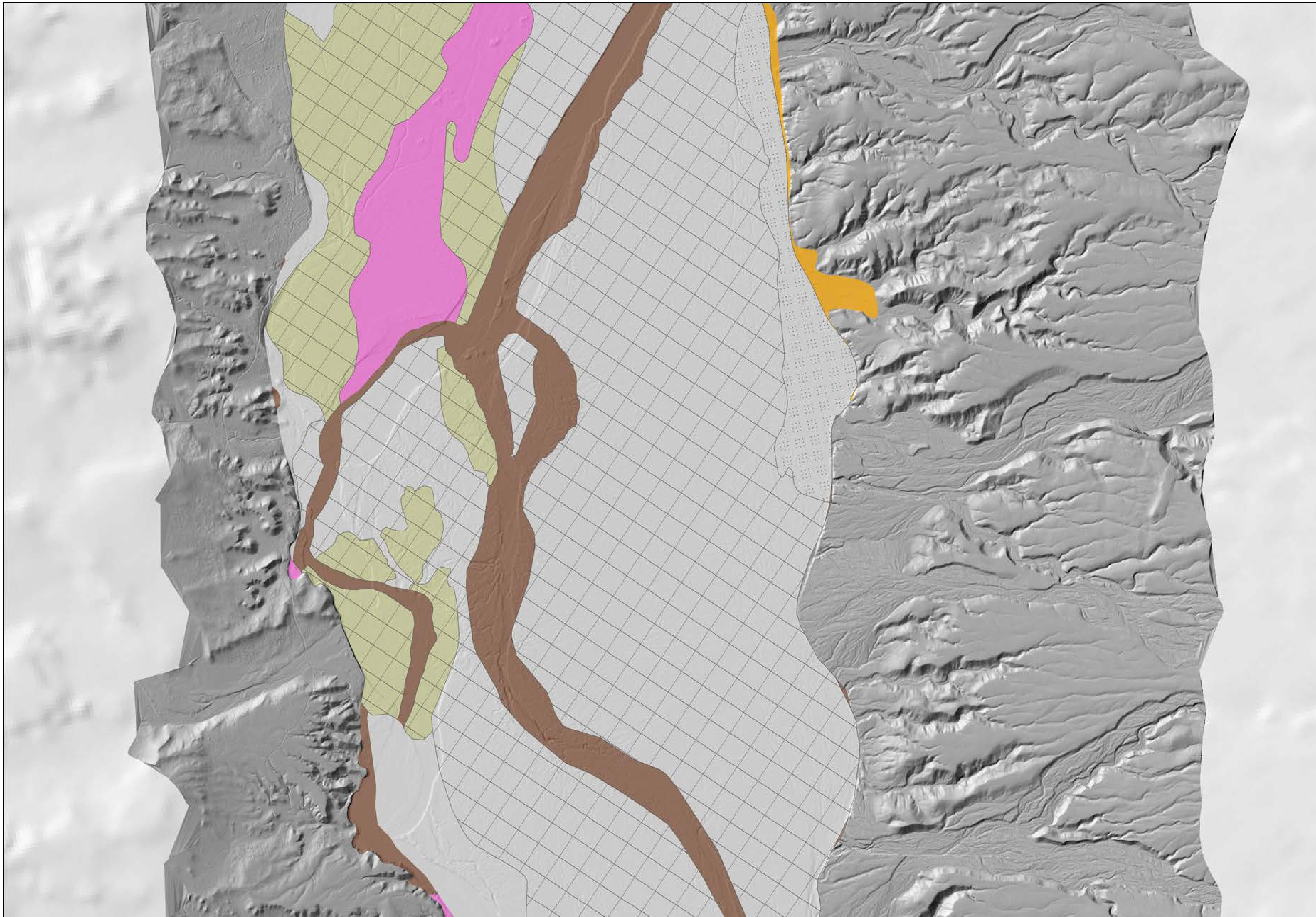

NRCS SOIL TYPE

Data sources: Soil type & soil salinity (NRCS, SSURGO); LIDAR Hillshade (Utah State University, November 2011)

Salinity
- very slightly saline
- strongly saline
- slightly saline

Particle size
- not classified
- loamy-skeletal
- sandy-skeletal
- fine-silty
- sandy

0 500 1,000 1,500 2,000 Feet

0 200 400 600 Meters

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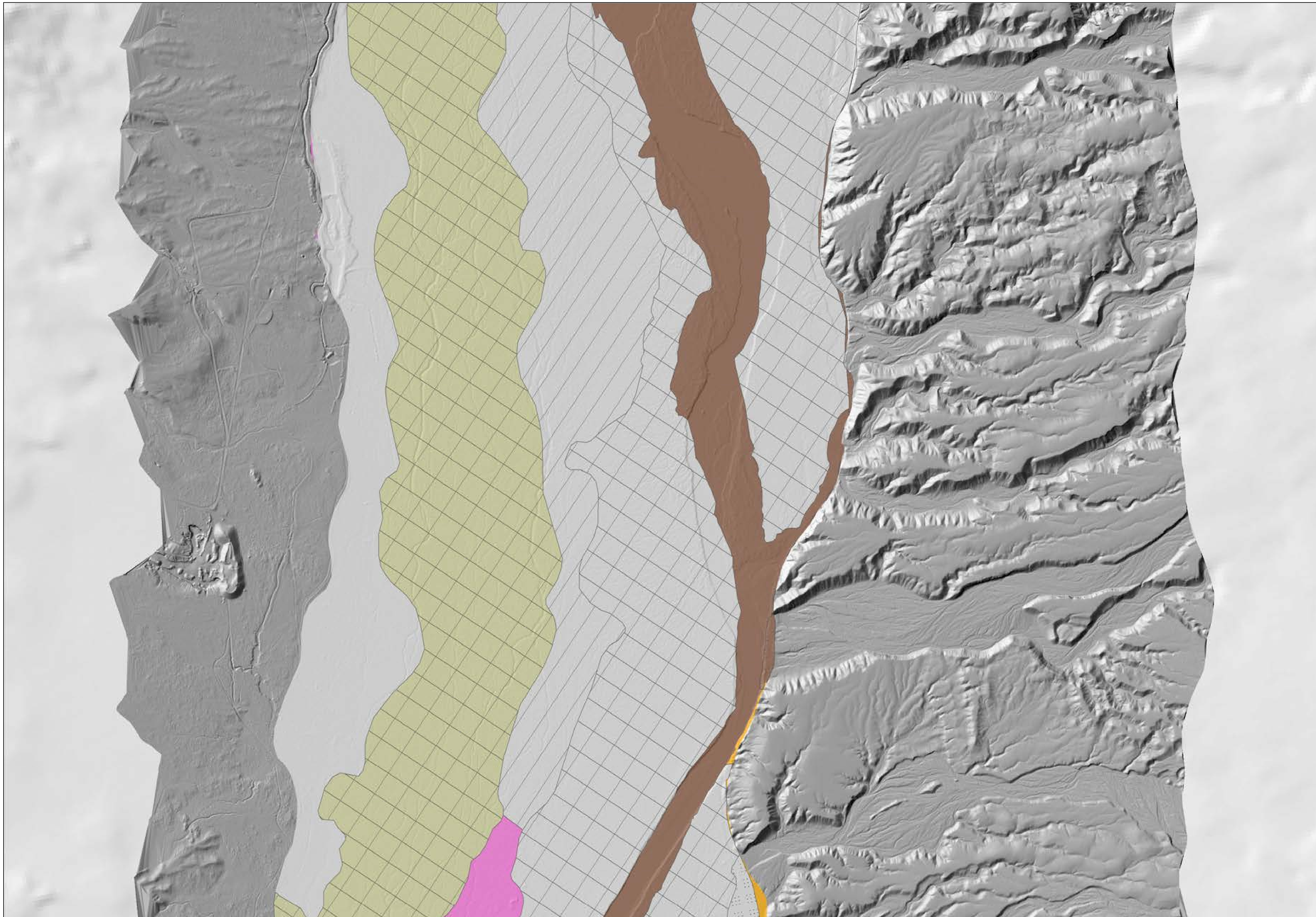

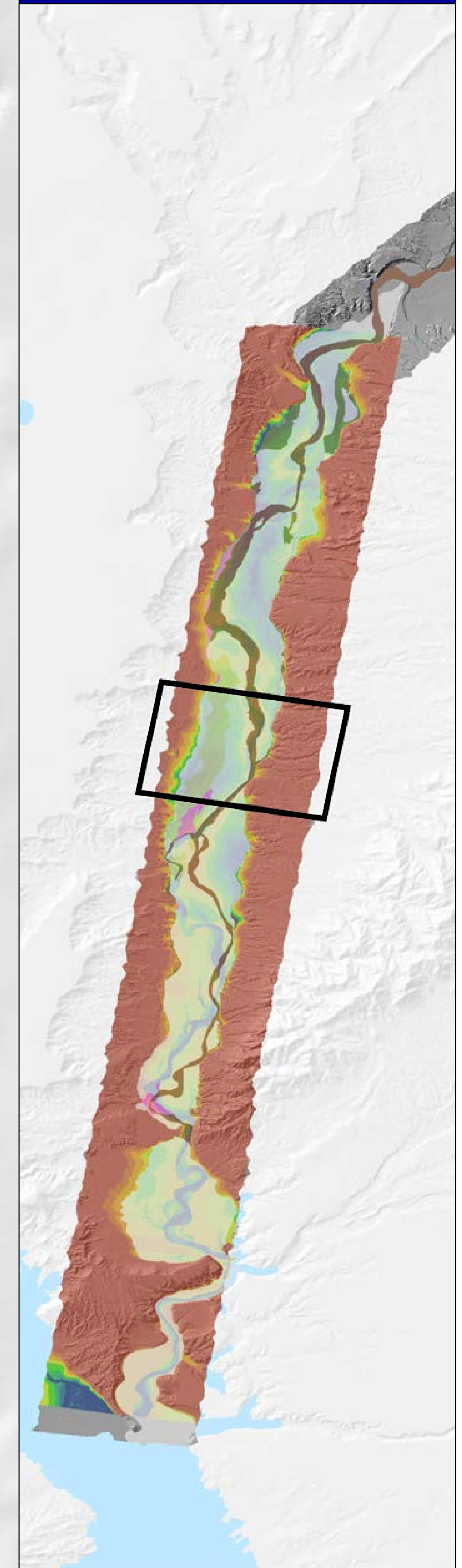

NRCS SOIL TYPE

Salinity
- very slightly saline
- strongly saline
- slightly saline

Particle size
- not classified
- loamy-skeletal
- sandy-skeletal
- fine-silty
- sandy

Data sources: Soil type & soil salinity (NRCS, SSURGO); LIDAR Hillshade (Utah State University, November 2011)

0 500 1,000 1,500 2,000 Feet

0 200 400 600 Meters

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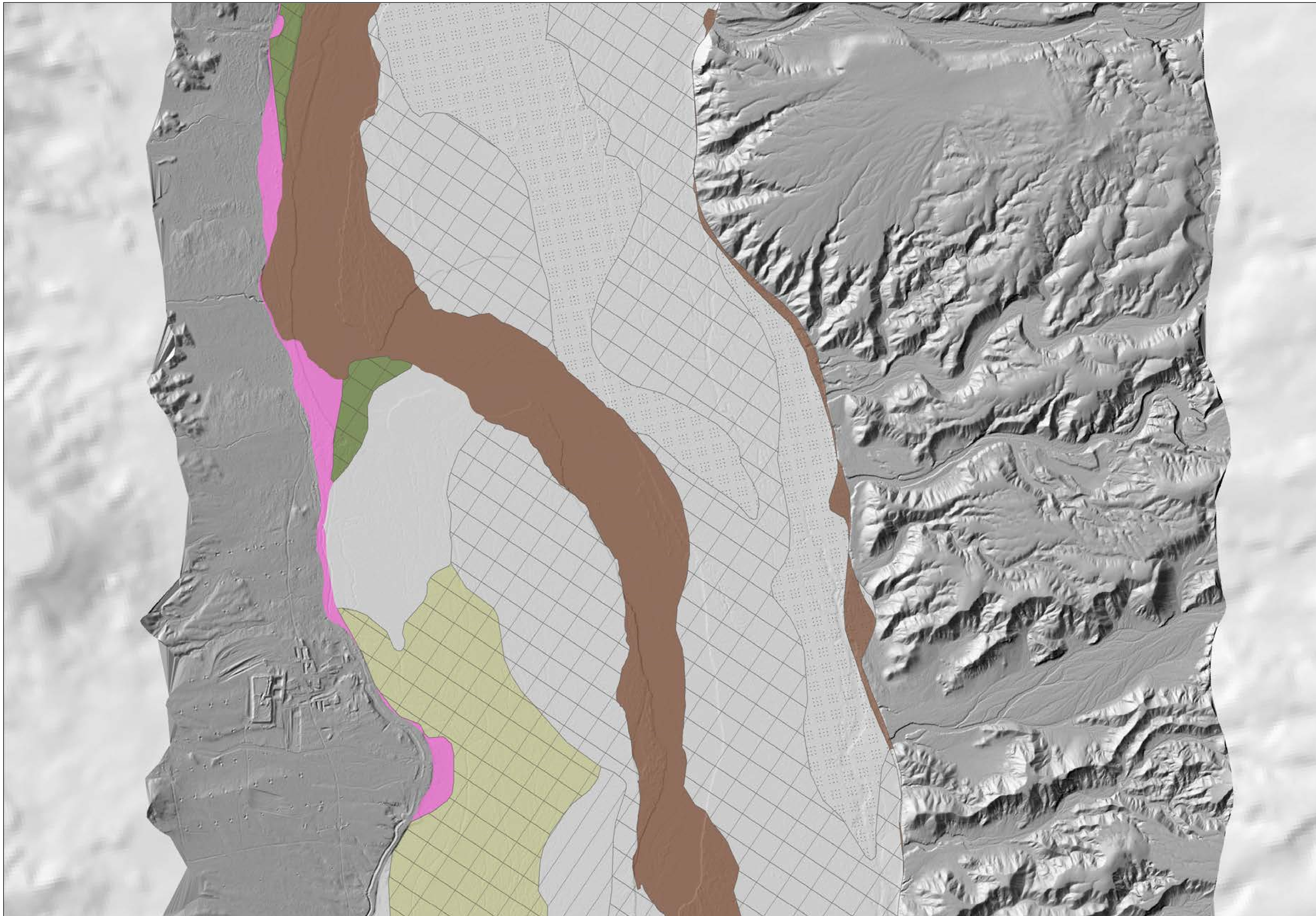

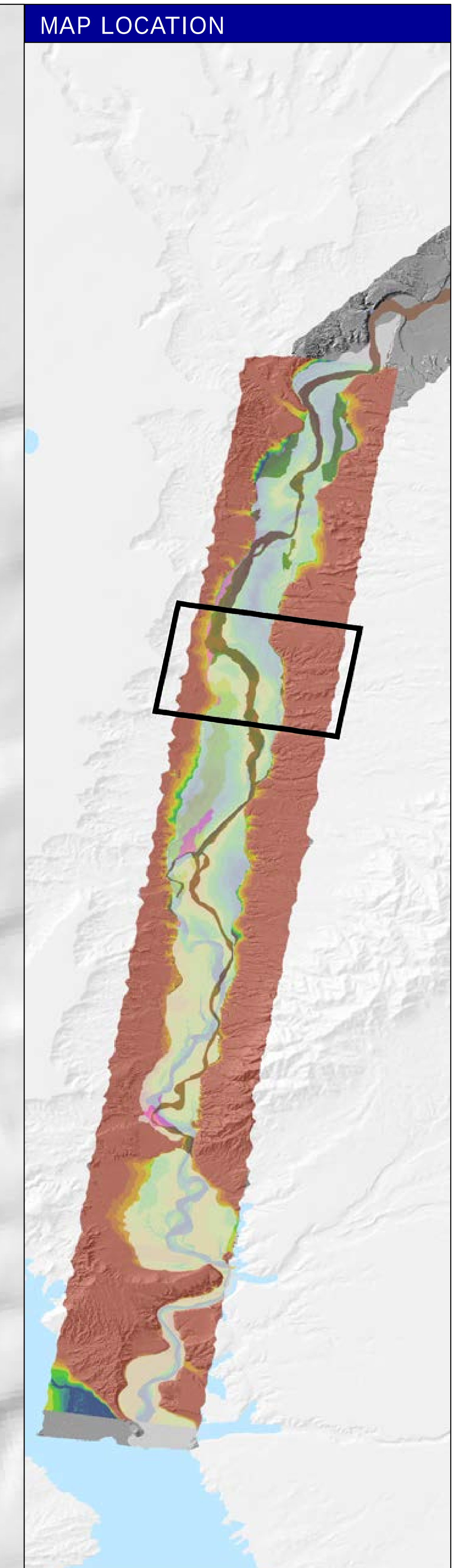

NRCS SOIL TYPE

Data sources: Soil type & soil salinity (NRCS, SSURGO); LIDAR Hillshade (Utah State University, November 2011)

Salinity

- very slightly saline
- strongly saline
- slightly saline

Particle size

- not classified
- fine-silty over sandy or sandy-skeletal
- sandy-skeletal
- fine-silty
- sandy

0 500 1,000 1,500 2,000 Feet

0 200 400 600 Meters

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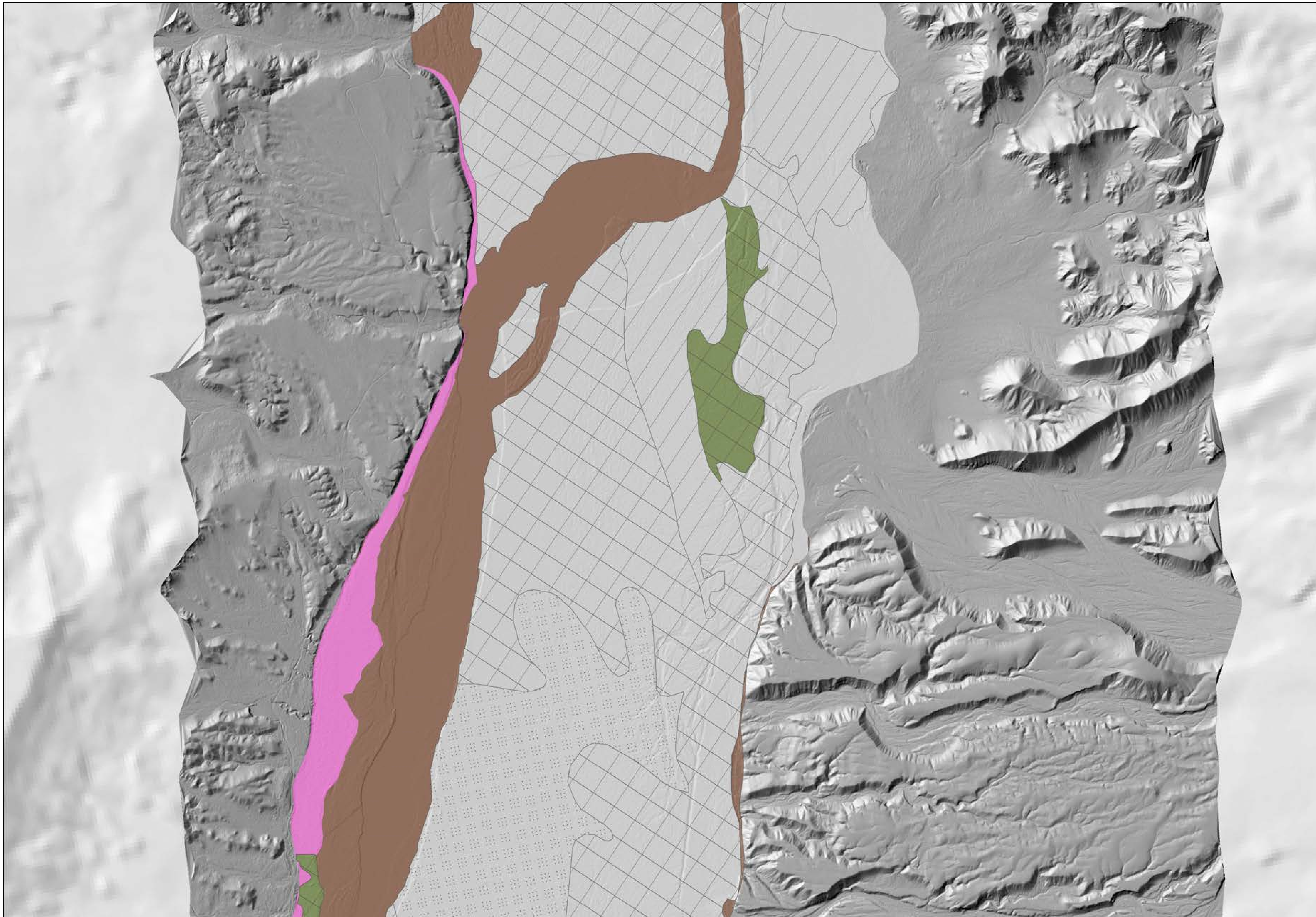

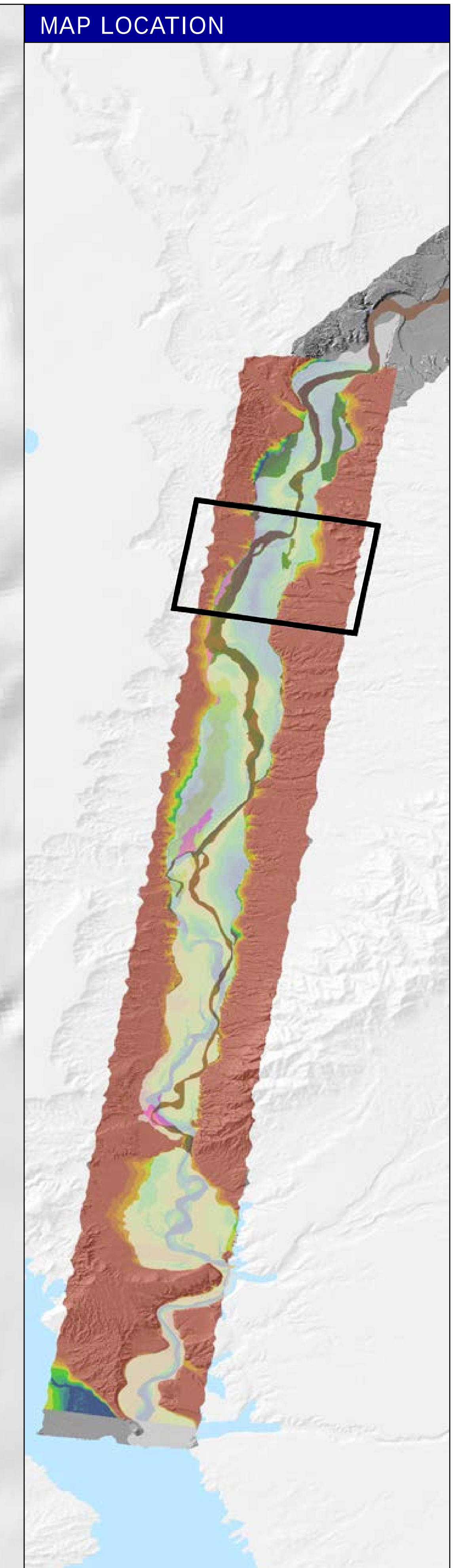

NRCS SOIL TYPE

Salinity

- very slightly saline
- strongly saline
- slightly saline

Particle size

- not classified
- fine-silty over sandy or sandy-skeletal
- sandy
- sandy-skeletal

Data sources: Soil type & soil salinity (NRCS, SSURGO); LIDAR Hillshade (Utah State University, November 2011)

0 500 1,000 1,500 2,000 Feet

0 200 400 600 Meters

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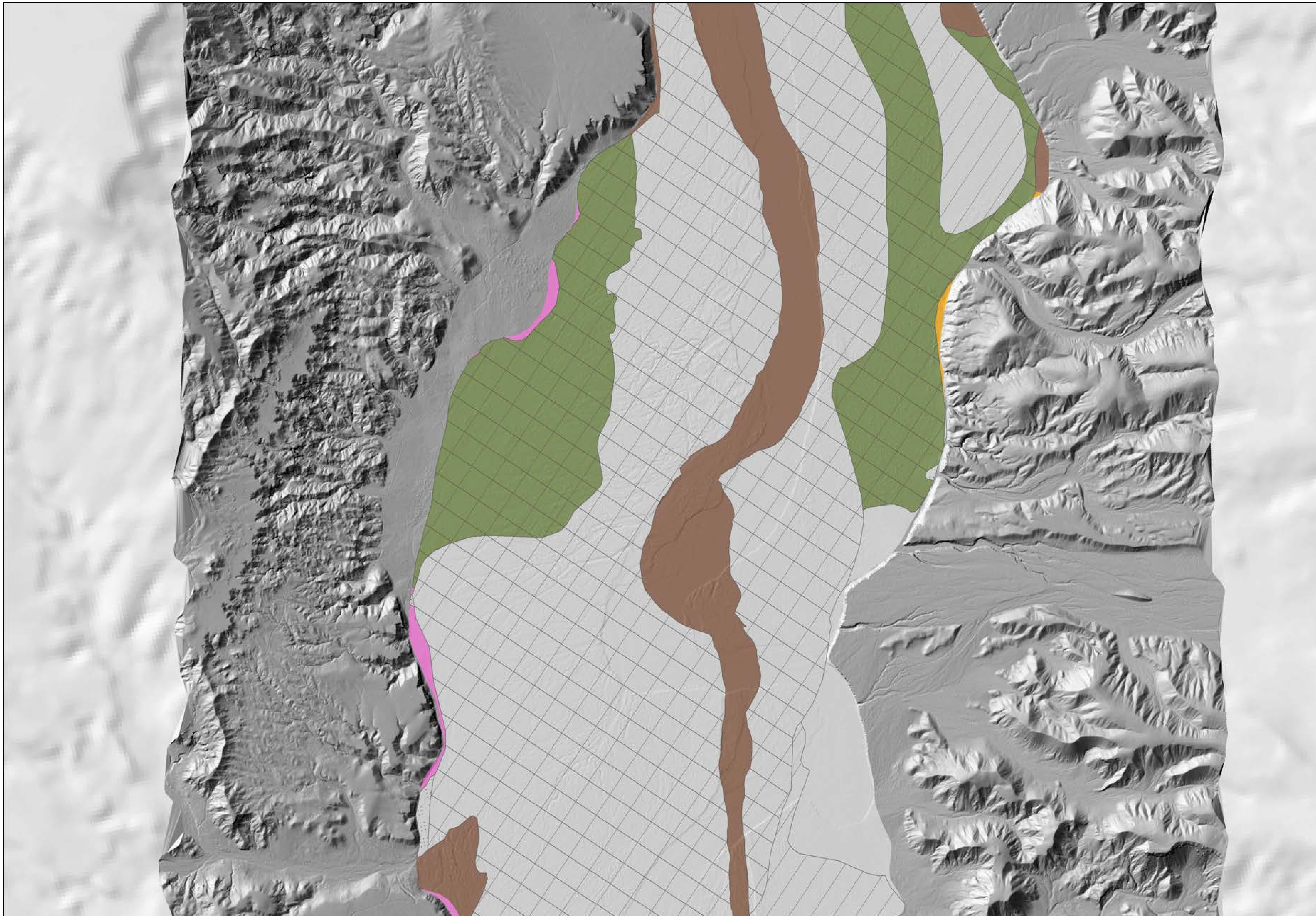

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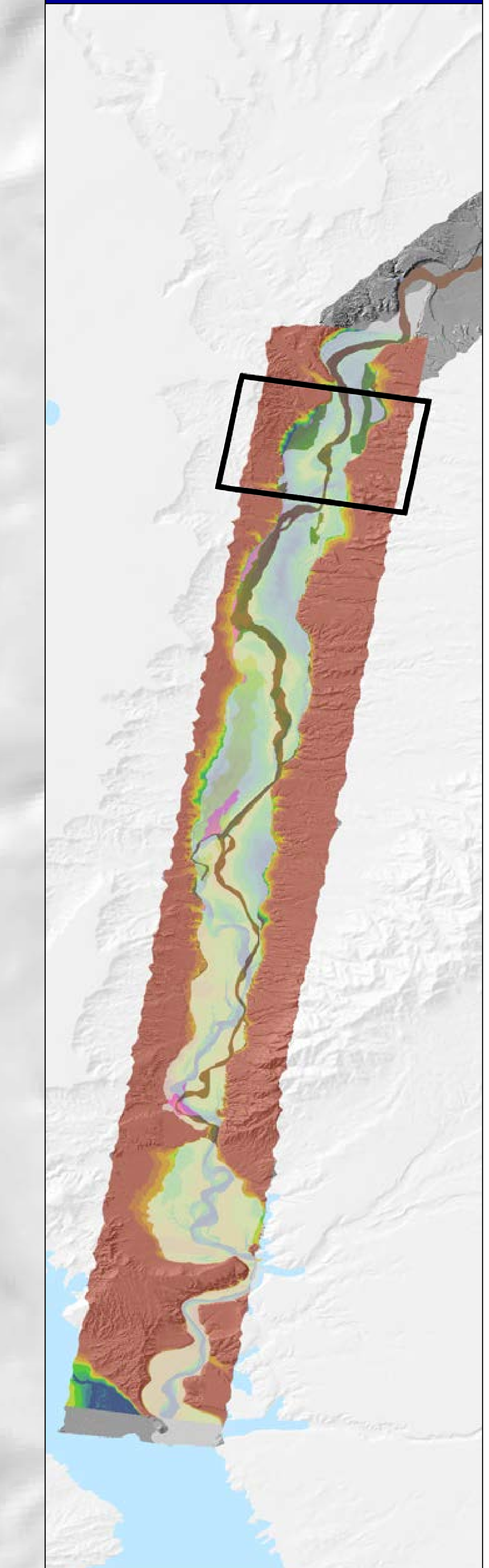

NRCS SOIL TYPE

Data sources: Soil type & soil salinity (NRCS, SSURGO); LIDAR Hillshade (Utah State University, November 2011)

Salinity

- very slightly saline
- strongly saline
- slightly saline

Particle size

- not classified
- fine-silty over sandy or sandy-skeletal
- loamy-skeletal
- sandy
- sandy-skeletal

0 500 1,000 1,500 2,000 Feet

0 200 400 600 Meters

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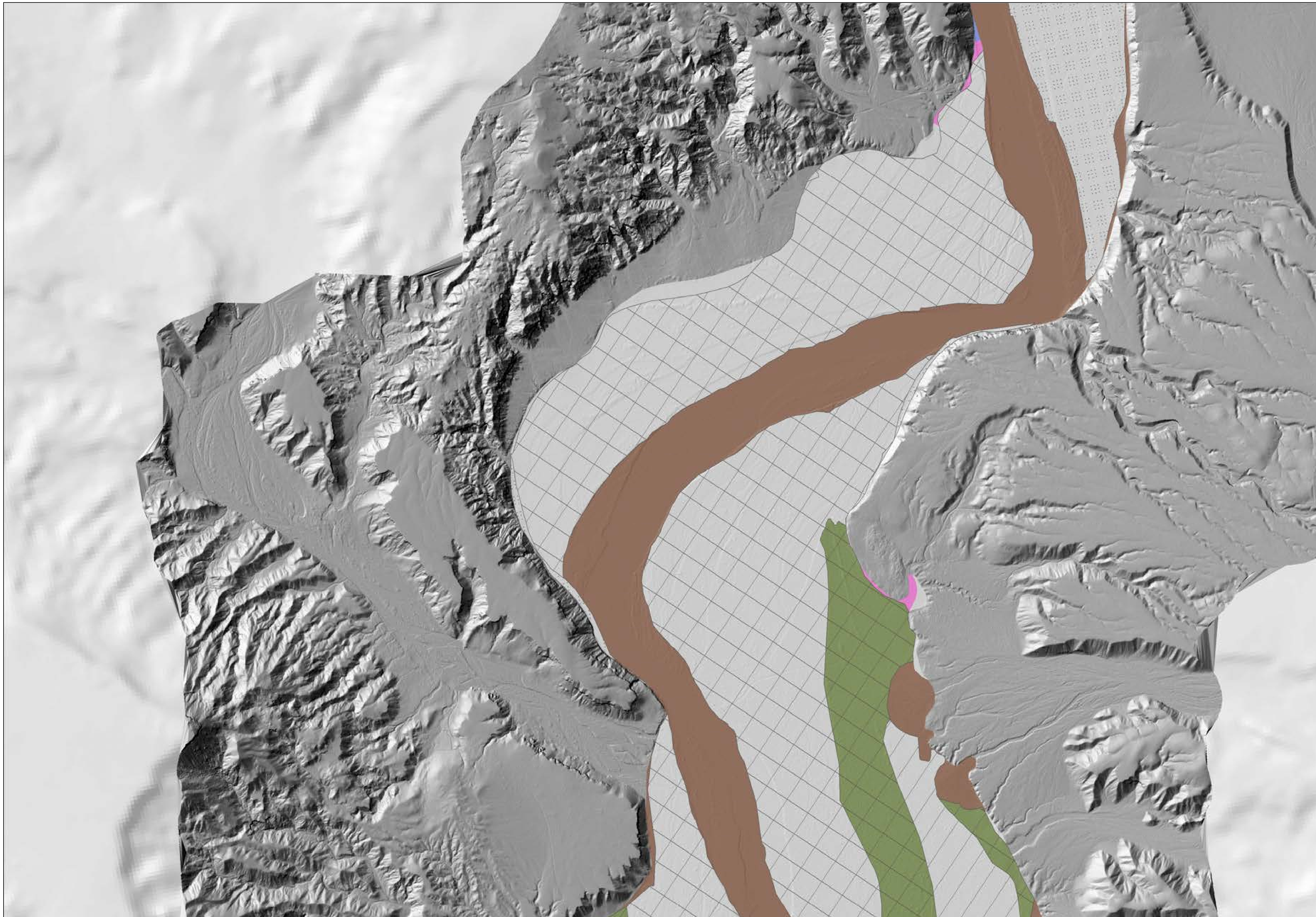

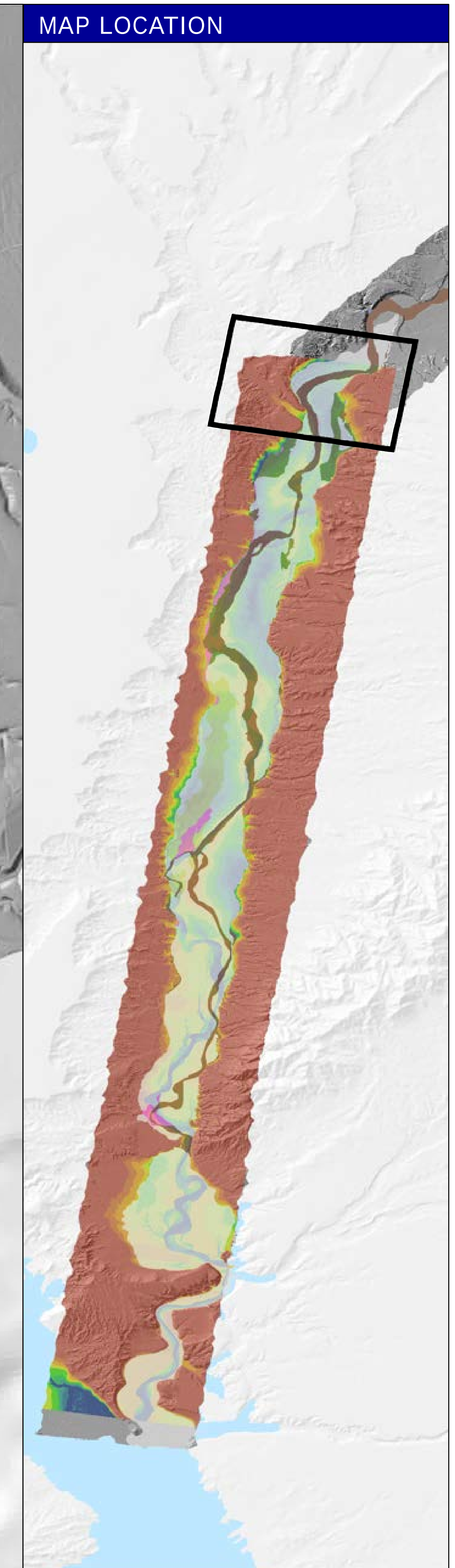

NRCS SOIL TYPE

Data sources: Soil type & soil salinity (NRCS, SSURGO); LIDAR Hillshade (Utah State University, November 2011)

Salinity

- very slightly saline
- strongly saline
- slightly saline

Particle size

- not classified
- fine-silty over sandy or sandy-skeletal
- sandy
- coarse-loamy
- loamy-skeletal
- sandy-skeletal

0 500 1,000 1,500 2,000 Feet

0 200 400 600 Meters

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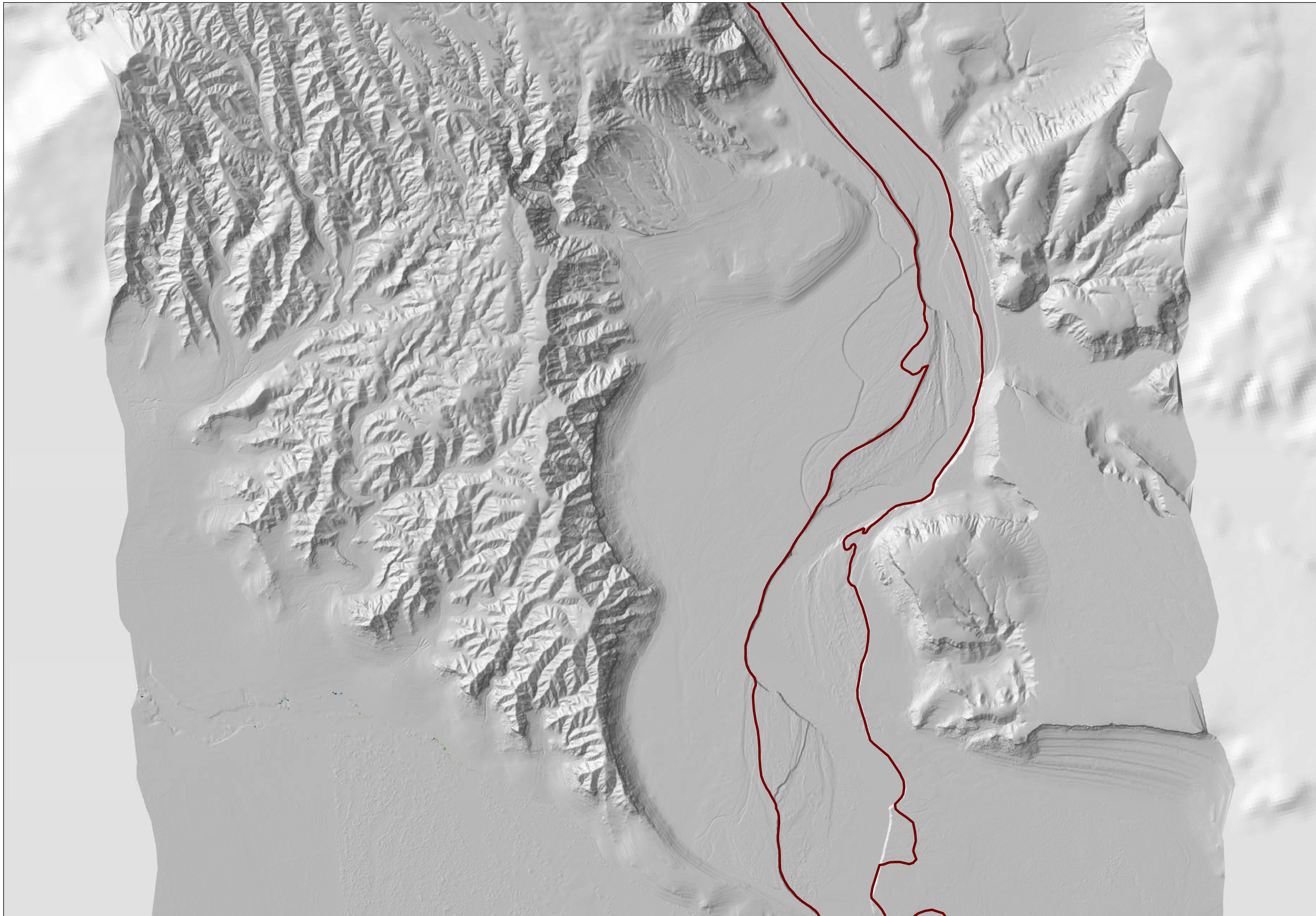
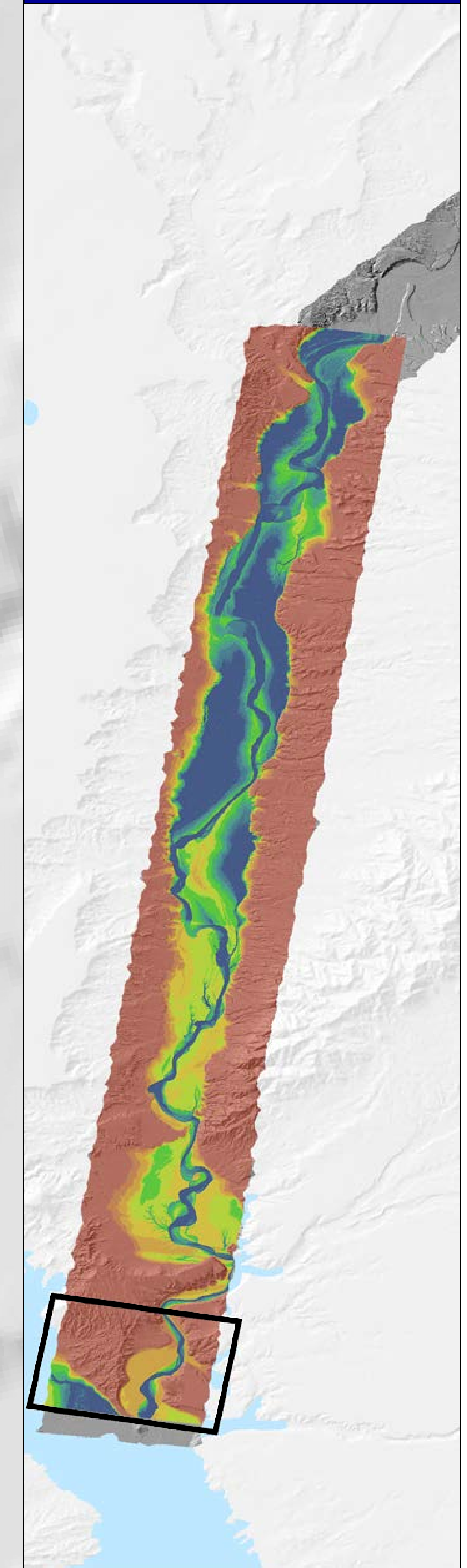


MAP LOCATION



VEGETATION RESTORATION PRIORITY

Flood Scour Frequency

- >70%
- 30–70%
- 2011 Active Channel

Restoration Categories

- High-1
- High-2
- High-3
- Medium-1
- Medium-2
- Medium-3
- Low

Restoration Priority Areas

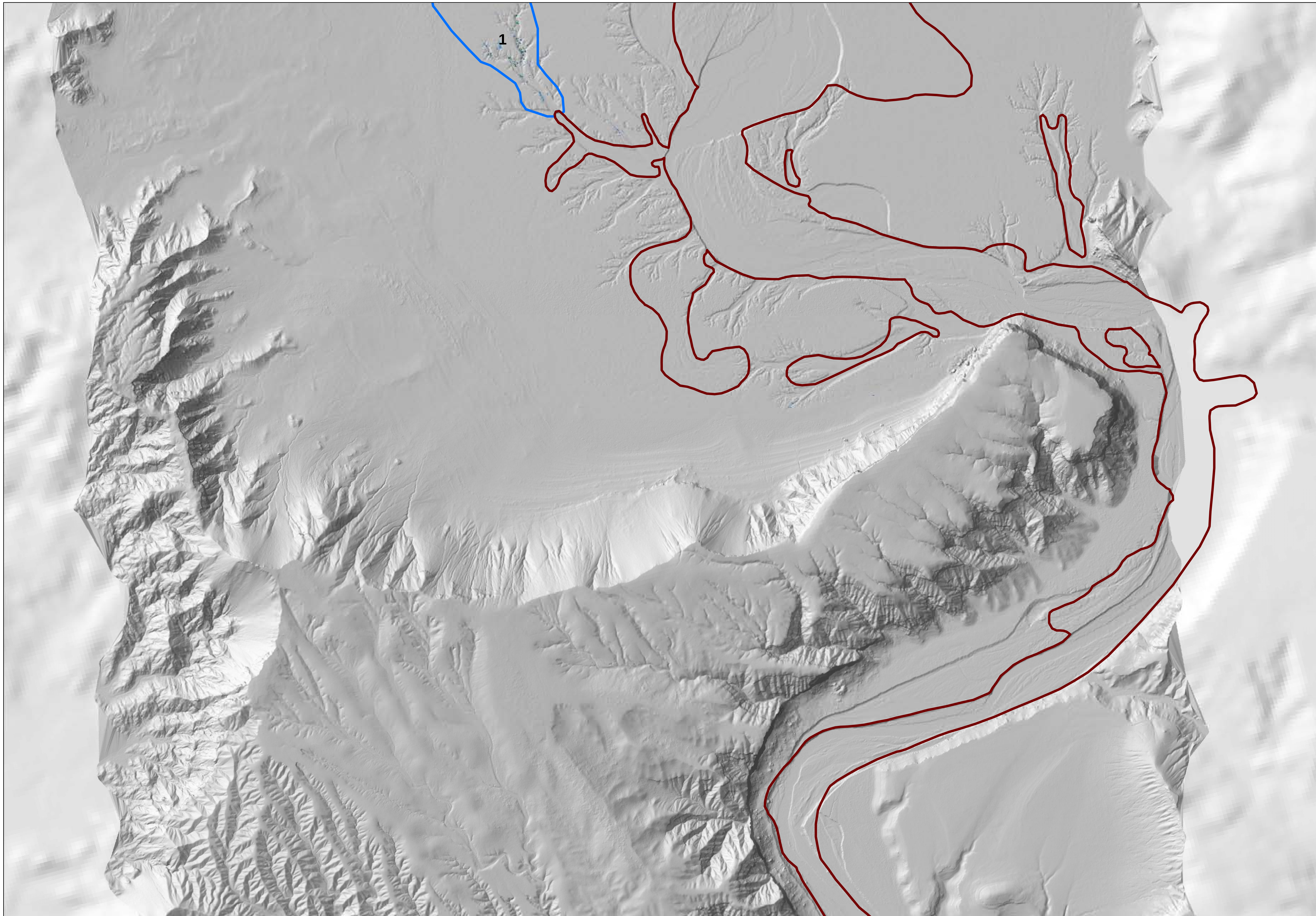
- High
- Medium

0 300 600 900 1,200 Feet

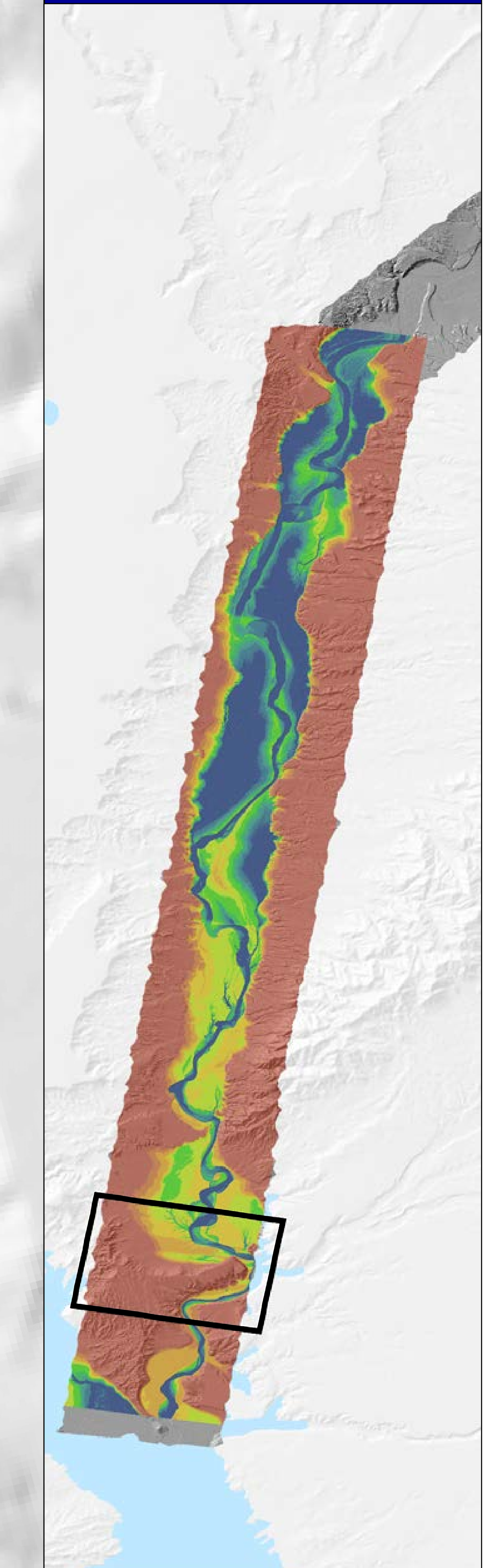
0 100 200 300 Meters

Data sources:
Restoration Categories: Stillwater Sciences, 2013
LIDAR Hillshade (Utah State University, November 2011)

Stillwater Sciences
www.stillwatersci.com



MAP LOCATION



VEGETATION RESTORATION PRIORITY

Flood Scour Frequency
- >70%
- 30–70%
- 2011 Active Channel

Restoration Categories
- High-1
- High-2
- High-3
- Medium-1
- Medium-2
- Medium-3
- Low

Restoration Priority Areas
- High
- Medium

0 300 600 900 1,200 Feet
0 100 200 300 Meters

Data sources:
Restoration Categories: Stillwater Sciences, 2013
LIDAR Hillshade (Utah State University, November 2011)

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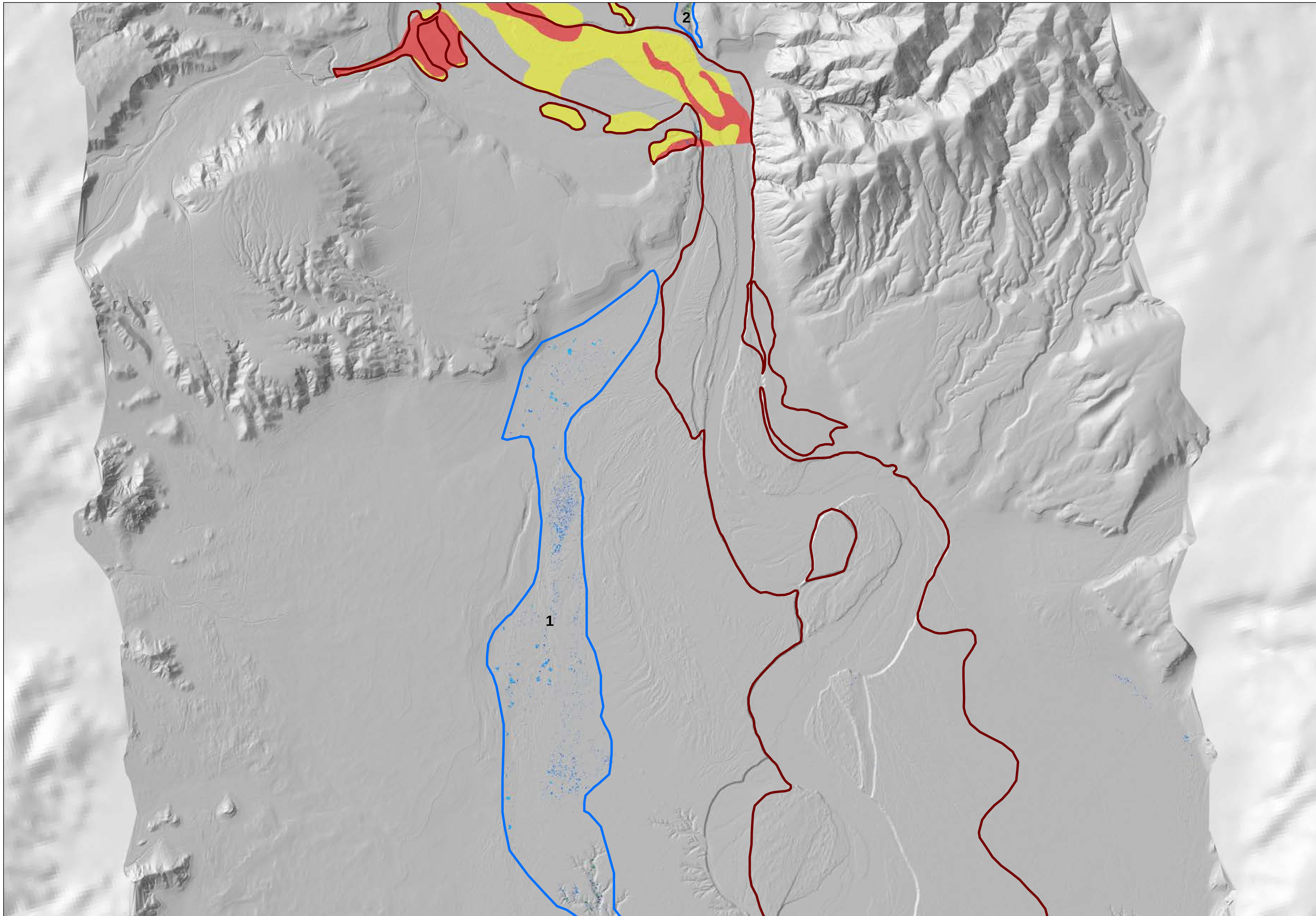
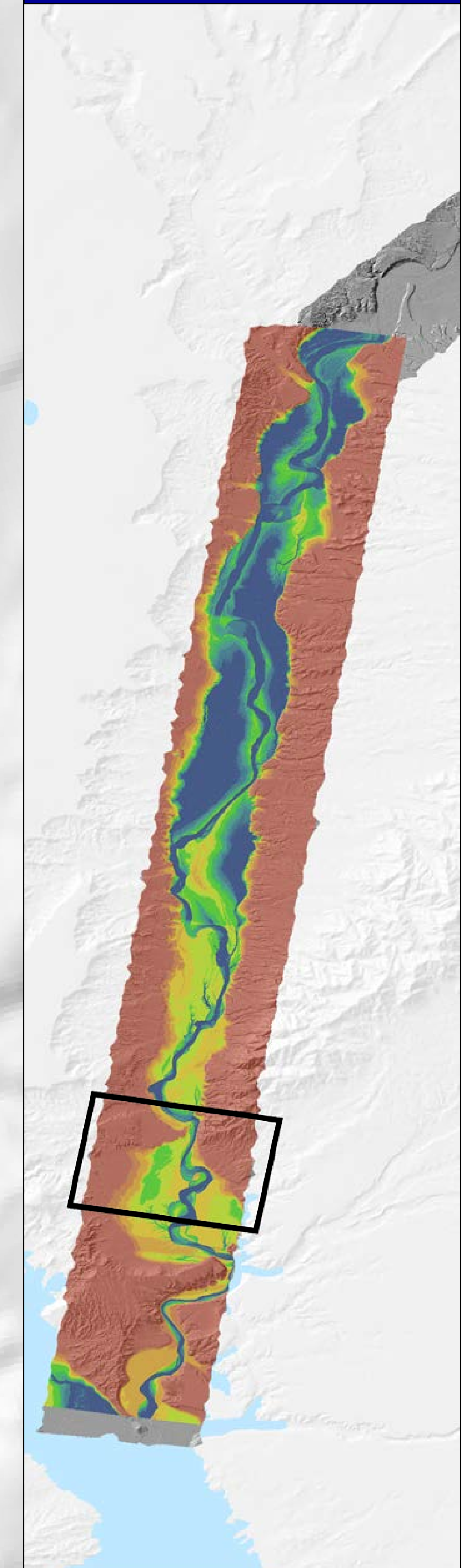


MAP LOCATION



VEGETATION RESTORATION PRIORITY

Flood Scour Frequency

- >70%
- 30–70%
- 2011 Active Channel

Restoration Categories

- High-1
- High-2
- High-3
- Medium-1
- Medium-2
- Medium-3
- Low

Restoration Priority Areas

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- Medium

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0 100 200 300 Meters

Data sources:
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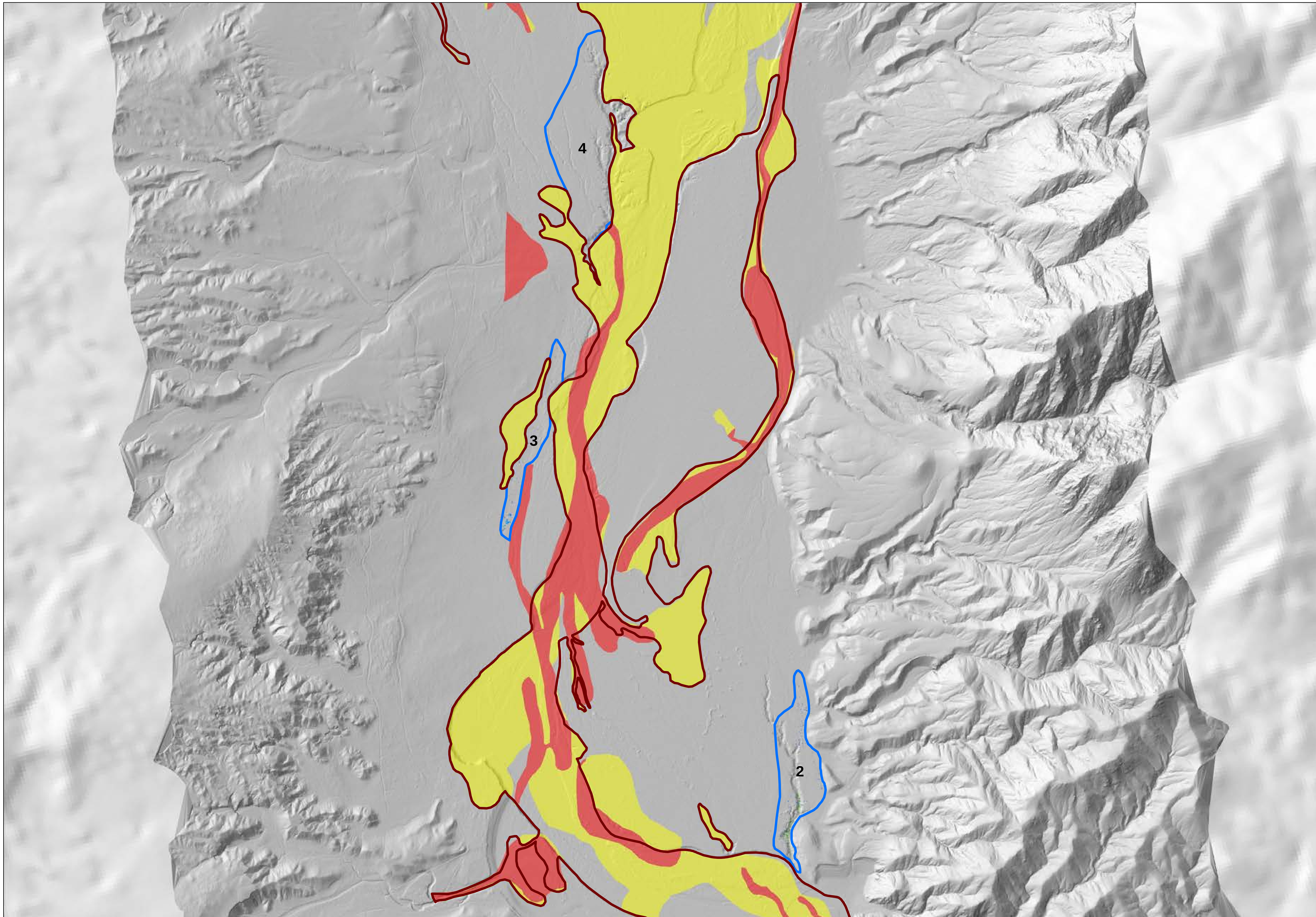
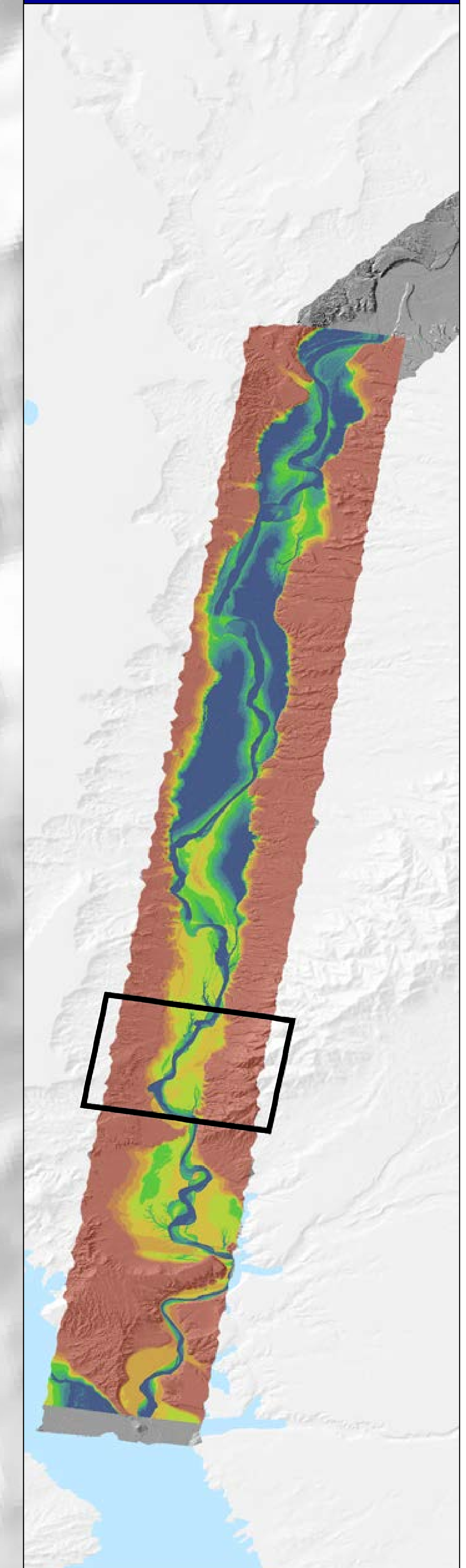


MAP LOCATION



VEGETATION RESTORATION PRIORITY

Flood Scour Frequency
- >70%
- 30–70%
- 2011 Active Channel

Restoration Categories
- High-1
- High-2
- High-3
- Medium-1
- Medium-2
- Medium-3
- Low

Restoration Priority Areas
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- Medium

0 300 600 900 1,200 Feet
0 100 200 300 Meters

Data sources:
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LIDAR Hillshade (Utah State University, November 2011)

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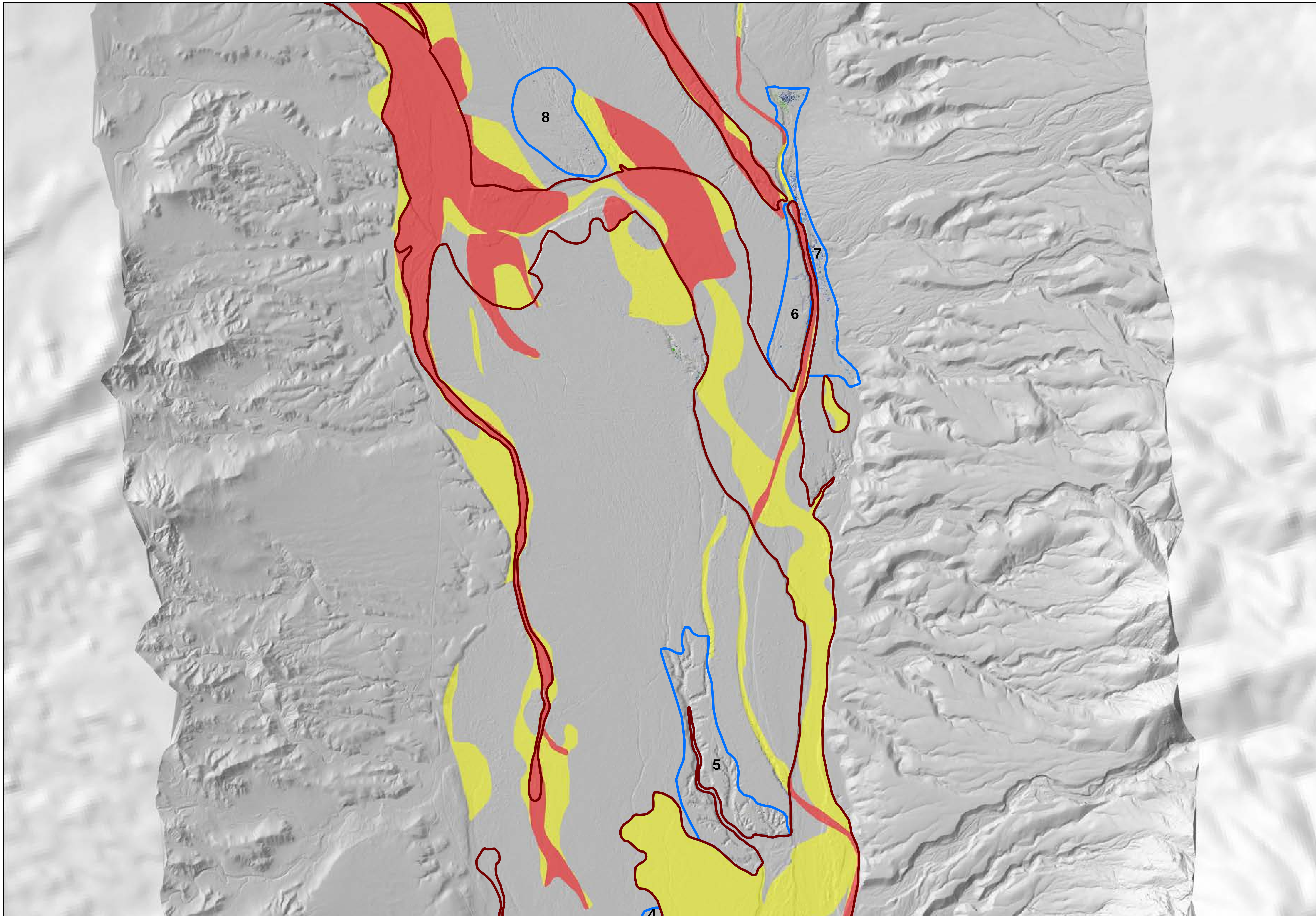

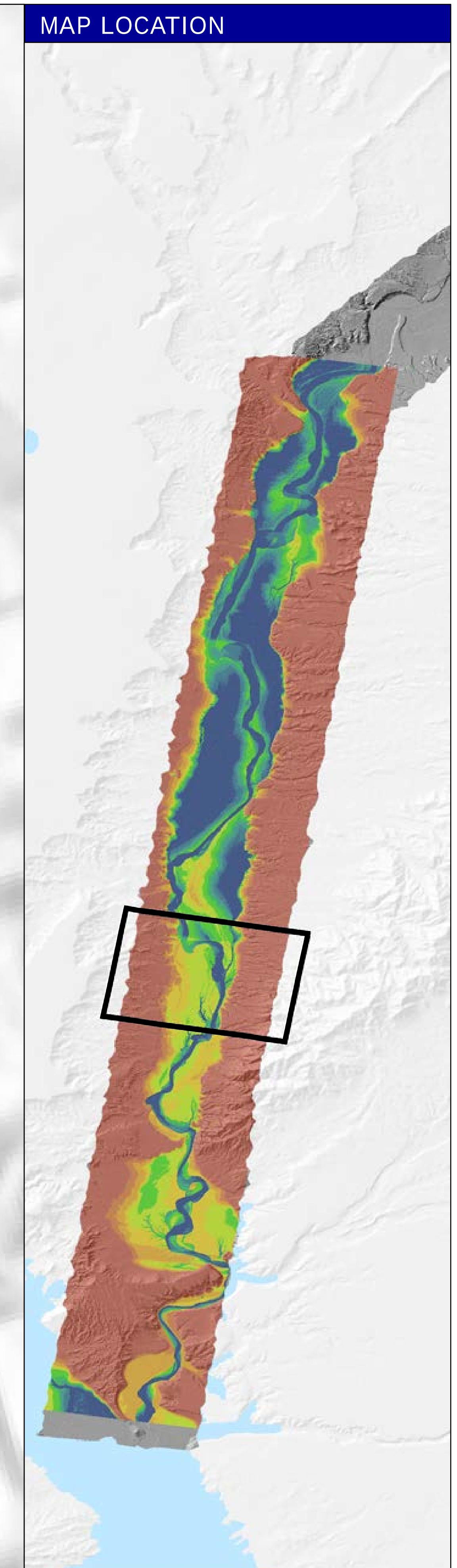

VEGETATION RESTORATION PRIORITY

Flood Scour Frequency

- >70%
- 30–70%
- 2011 Active Channel

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- High-1
- High-2
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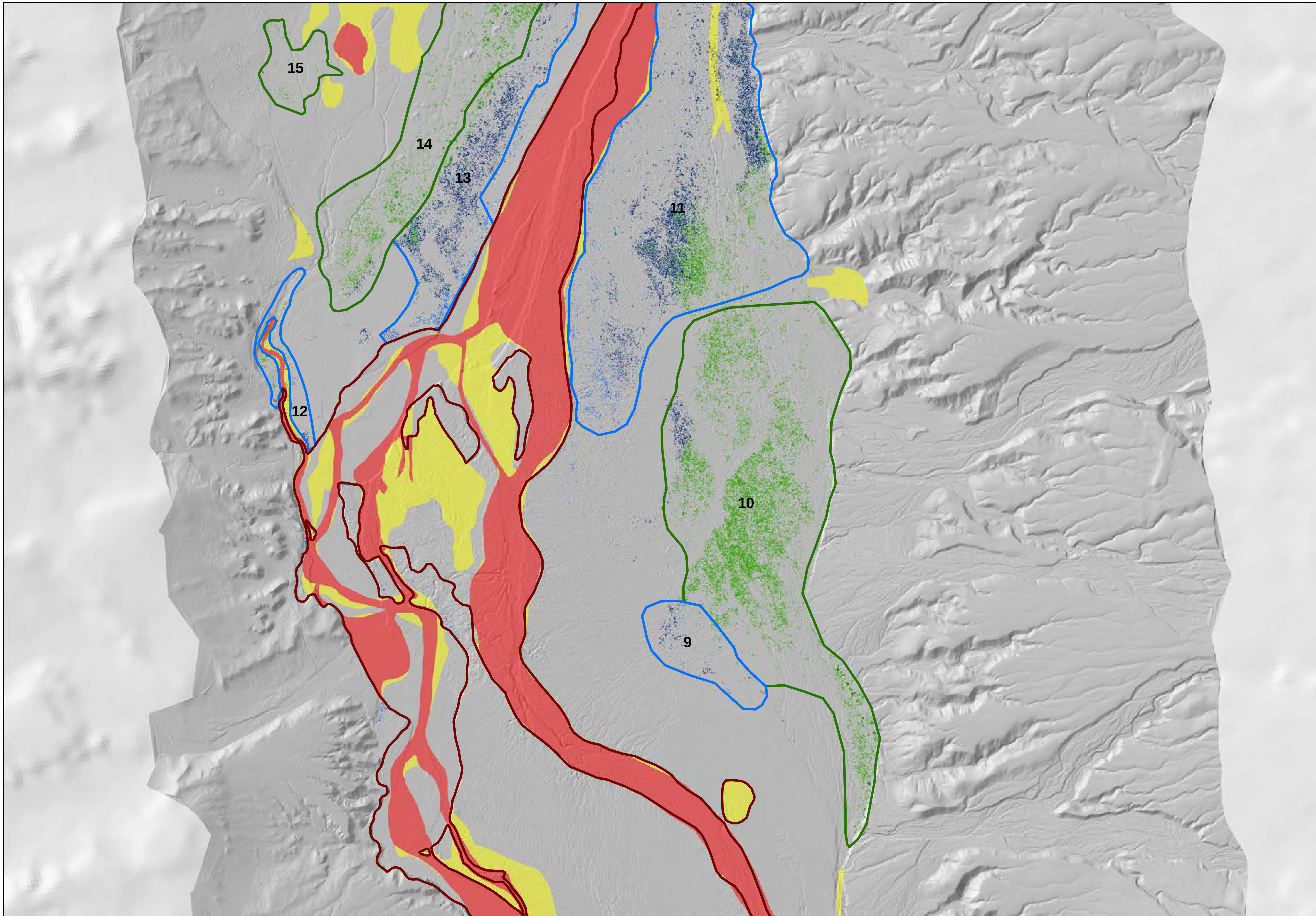
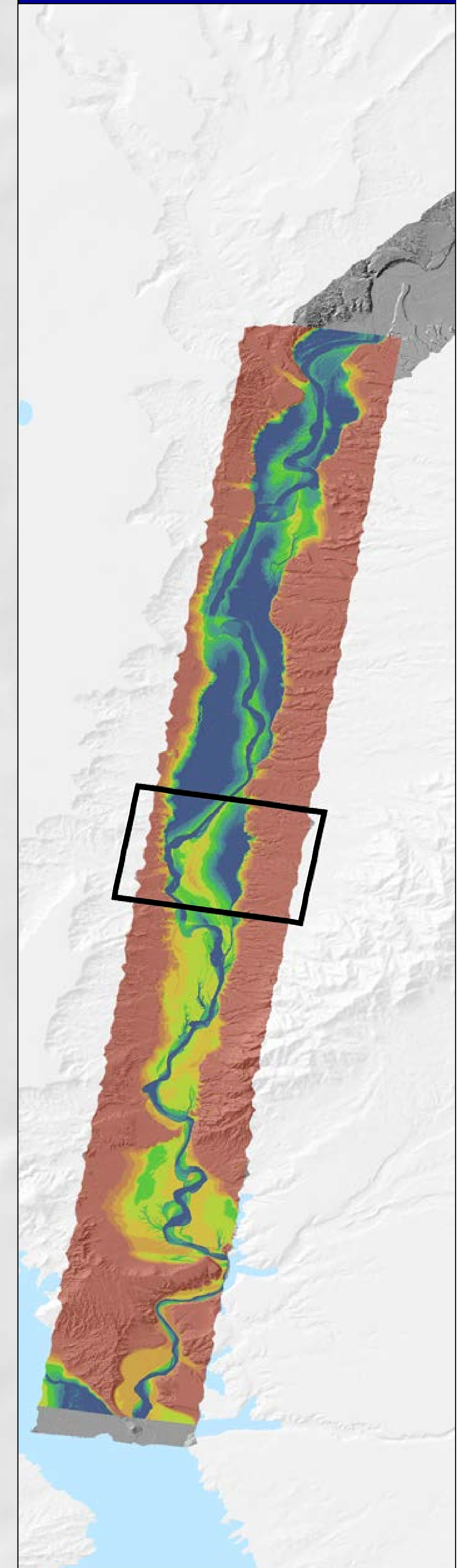


MAP LOCATION



VEGETATION RESTORATION PRIORITY

Flood Scour Frequency
- >70%
- 30–70%
- 2011 Active Channel

Restoration Categories
- High-1
- High-2
- High-3
- Medium-1
- Medium-2
- Medium-3
- Low

Restoration Priority Areas
- High
- Medium

0 300 600 900 1,200 Feet
0 100 200 300 Meters

Data sources:
Restoration Categories: Stillwater Sciences, 2013
LIDAR Hillshade (Utah State University, November 2011)

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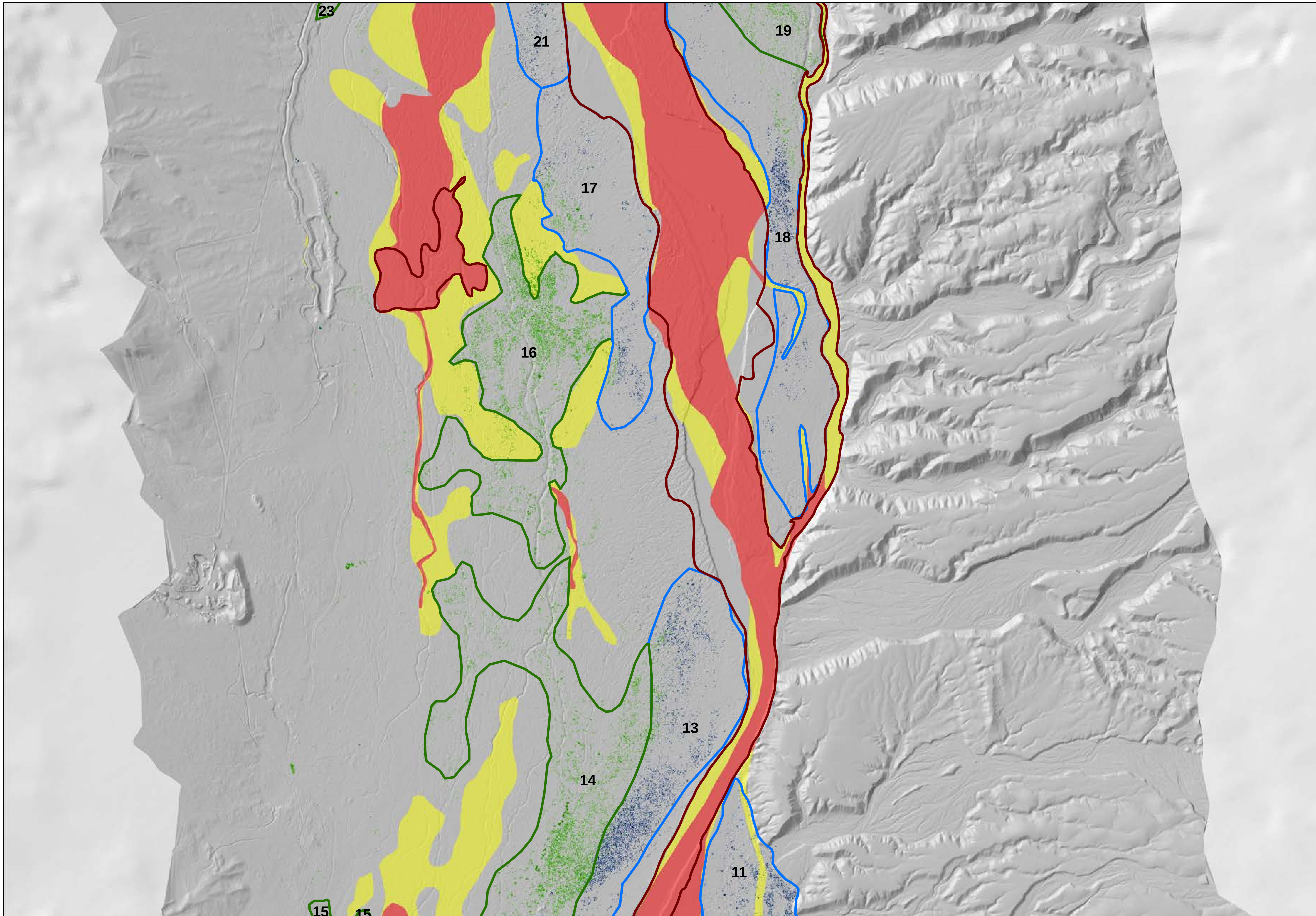

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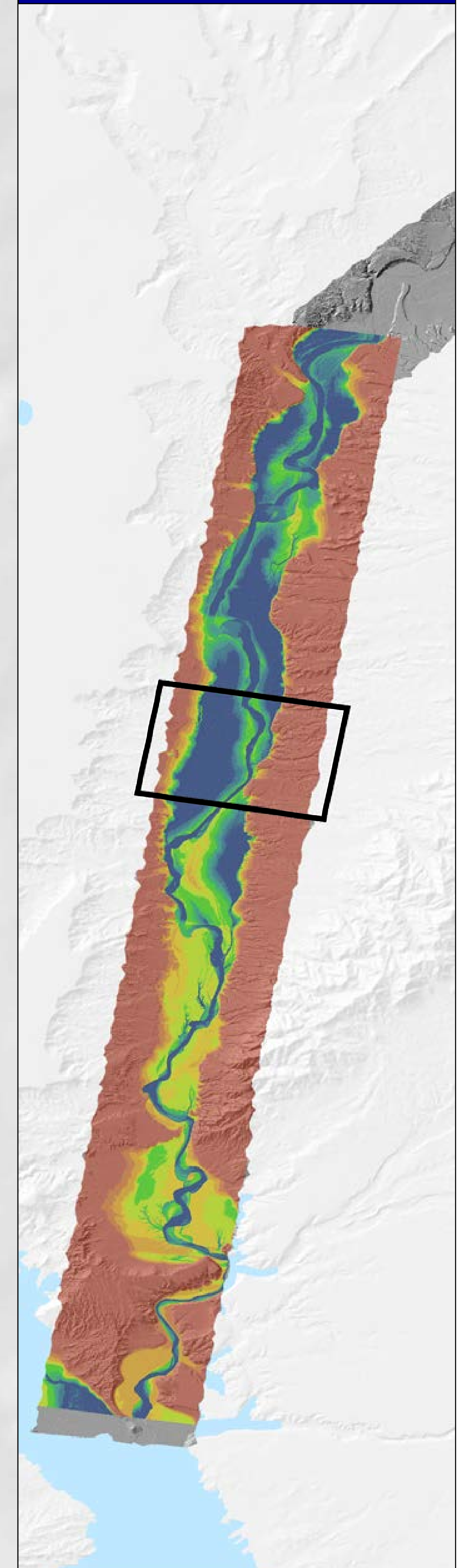

VEGETATION RESTORATION PRIORITY

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- 2011 Active Channel

Restoration Categories

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- High-3
- Medium-1
- Medium-2
- Medium-3
- Low

Restoration Priority Areas

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- Medium

0 300 600 900 1,200 Feet

0 100 200 300 Meters

Data sources:
Restoration Categories: Stillwater Sciences, 2013
LIDAR Hillshade (Utah State University, November 2011)

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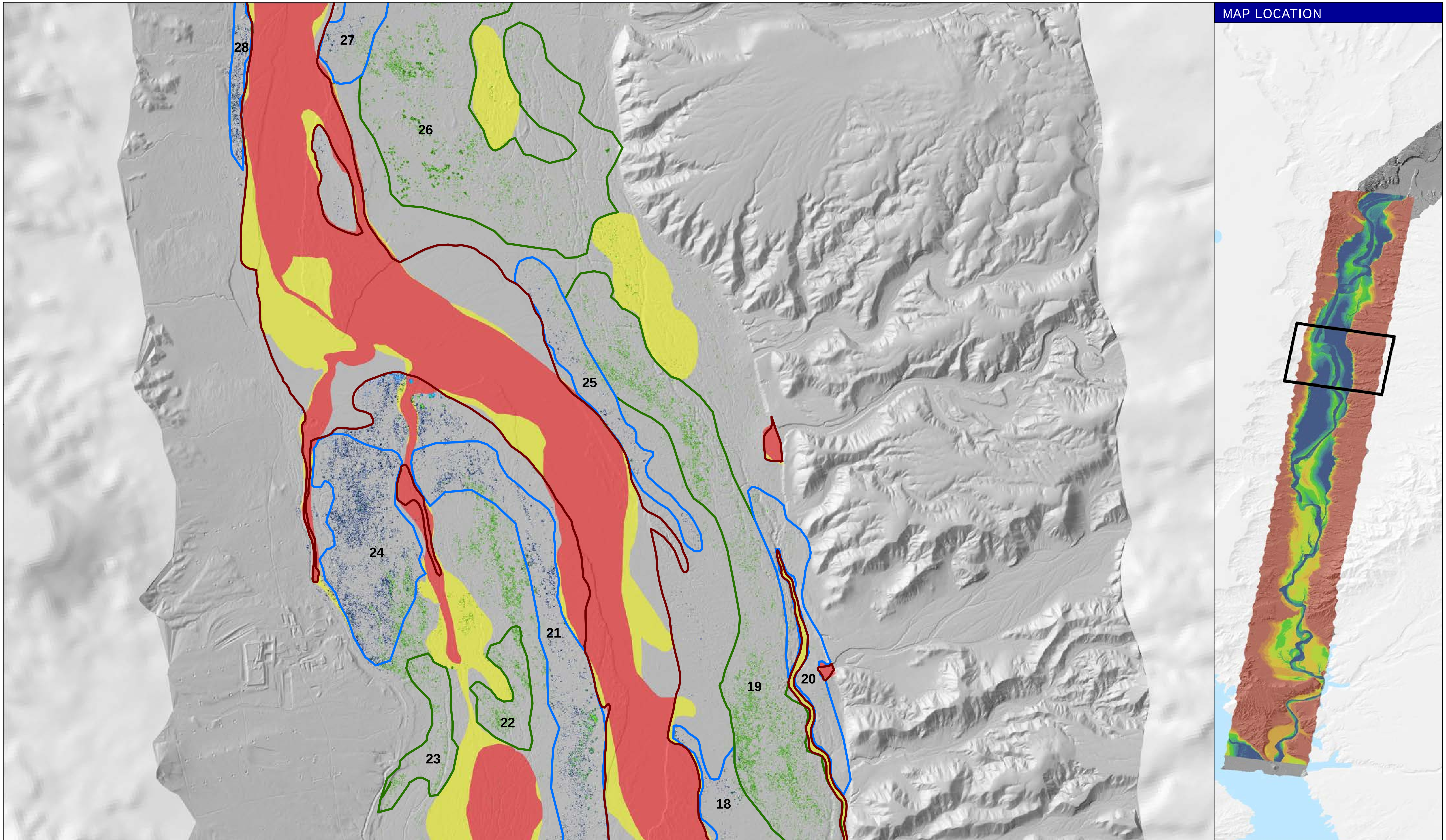

VEGETATION RESTORATION PRIORITY

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- 30–70%
- 2011 Active Channel

Restoration Categories

- High-1
- High-2
- High-3
- Medium-1
- Medium-2
- Medium-3
- Low

Restoration Priority Areas

- High
- Medium

0 300 600 900 1,200 Feet

0 100 200 300 Meters

Data sources:
Restoration Categories: Stillwater Sciences, 2013
LIDAR Hillshade (Utah State University, November 2011)

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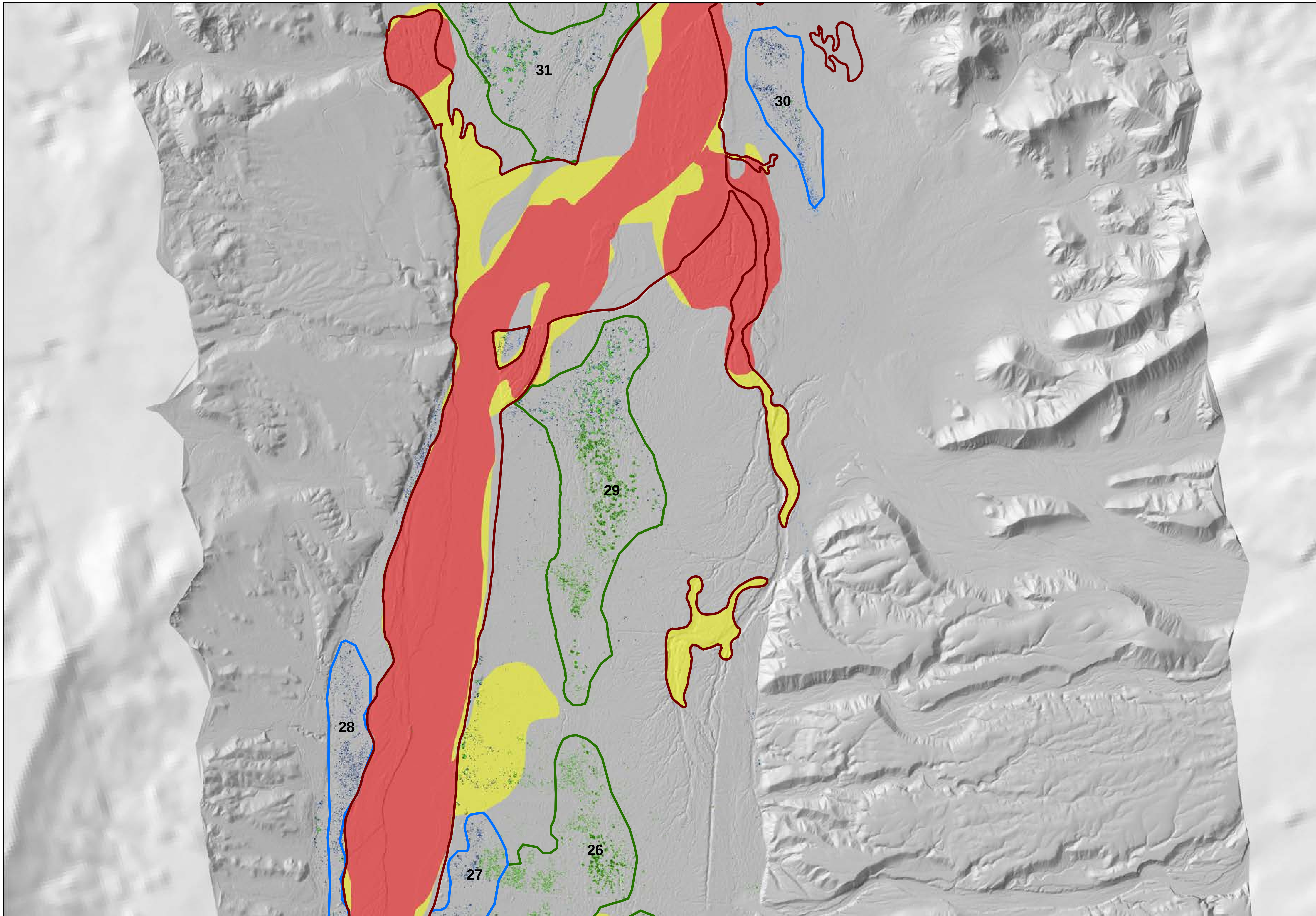

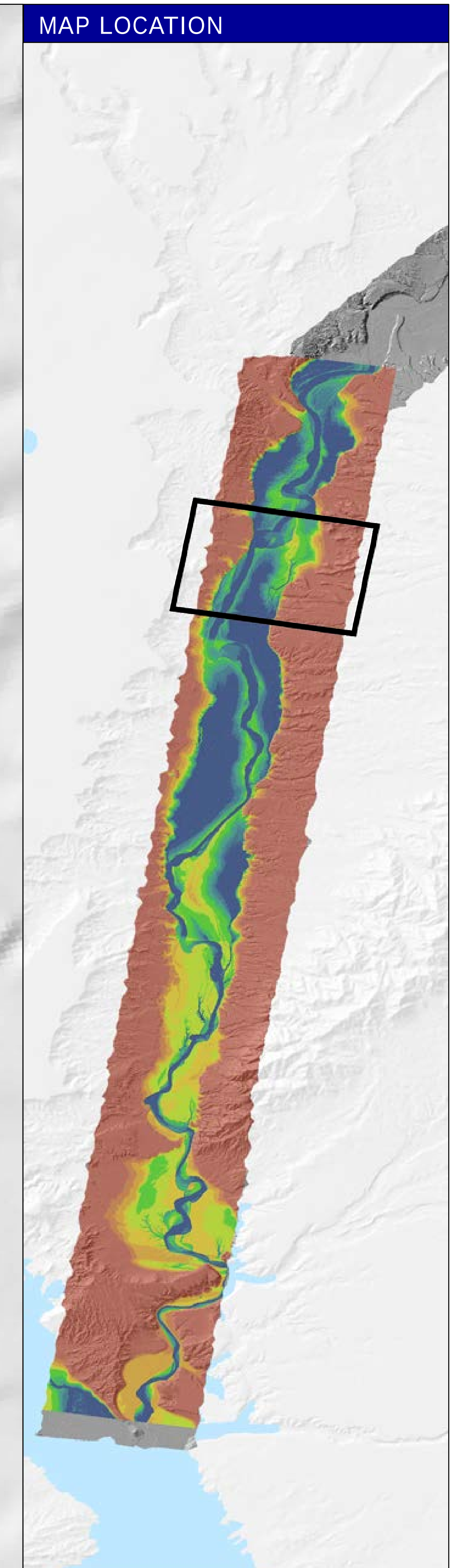

VEGETATION RESTORATION PRIORITY

Tile 9 of 11

Flood Scour Frequency
- >70%
- 30–70%
- 2011 Active Channel

Restoration Categories
- High-1
- High-2
- High-3
- Medium-1
- Medium-2
- Medium-3
- Low

Restoration Priority Areas
- High
- Medium

0 300 600 900 1,200 Feet
0 100 200 300 Meters

Data sources:
Restoration Categories: Stillwater Sciences, 2013
LIDAR Hillshade (Utah State University, November 2011)

Stillwater Sciences
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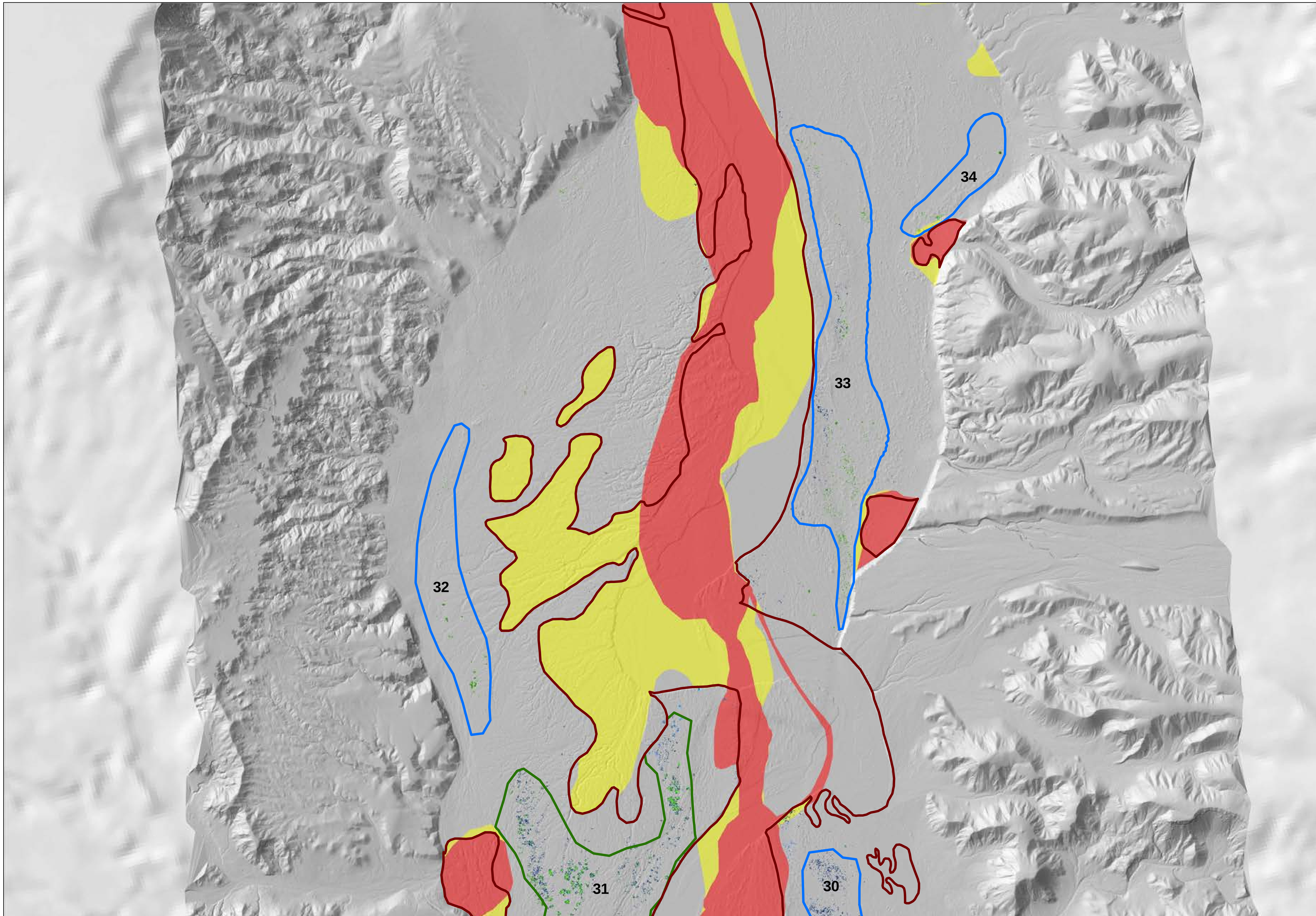

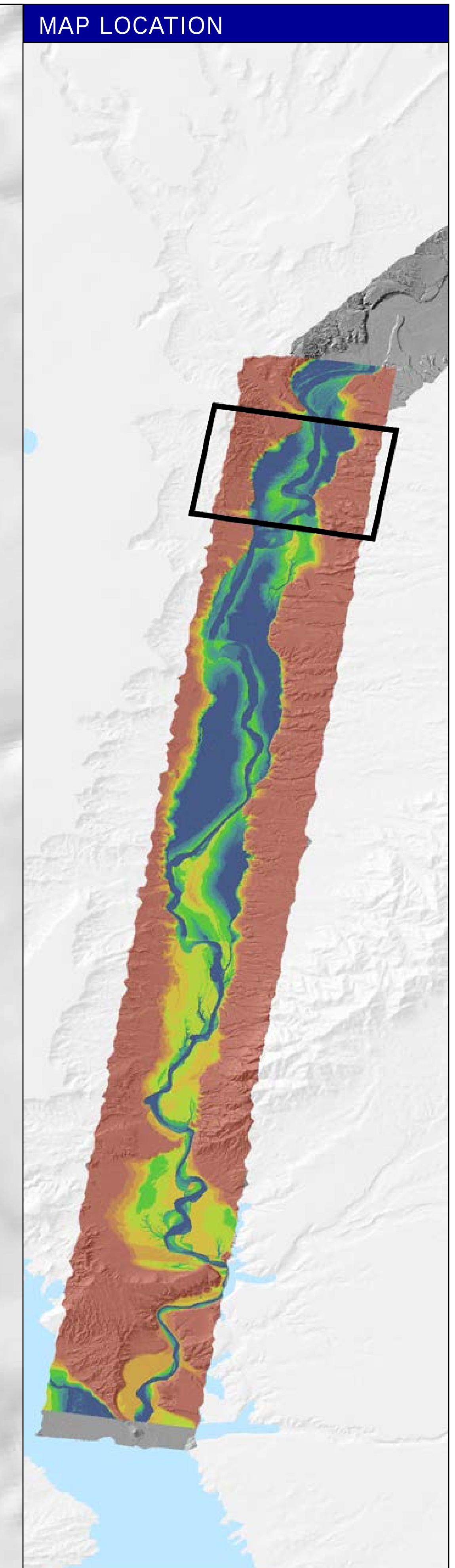

VEGETATION RESTORATION PRIORITY

Flood Scour Frequency

- >70%
- 30–70%
- 2011 Active Channel

Restoration Categories

- High-1
- High-2
- High-3
- Medium-1
- Medium-2
- Medium-3
- Low

Restoration Priority Areas

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- Medium

0 300 600 900 1,200 Feet

0 100 200 300 Meters

Data sources:
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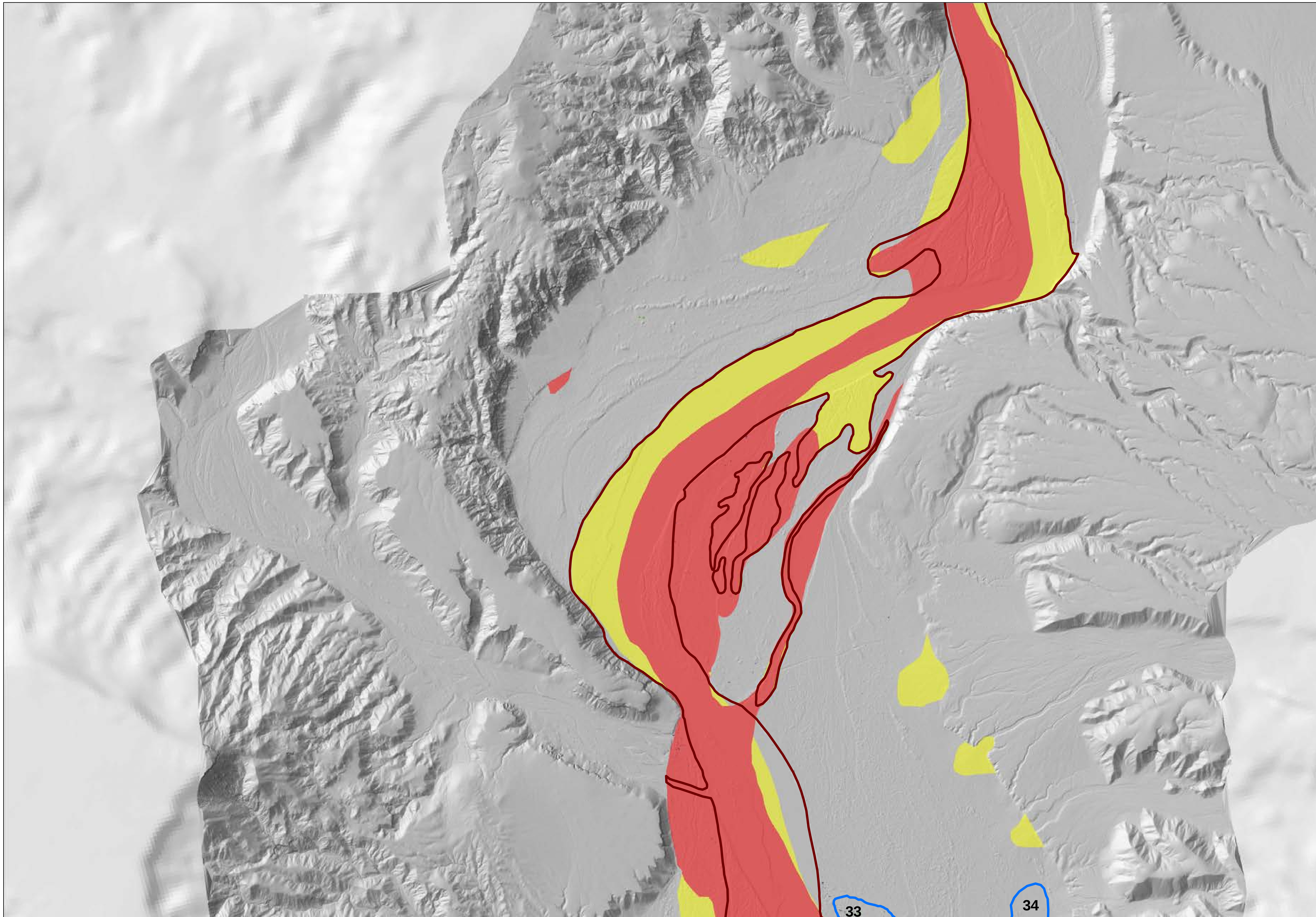
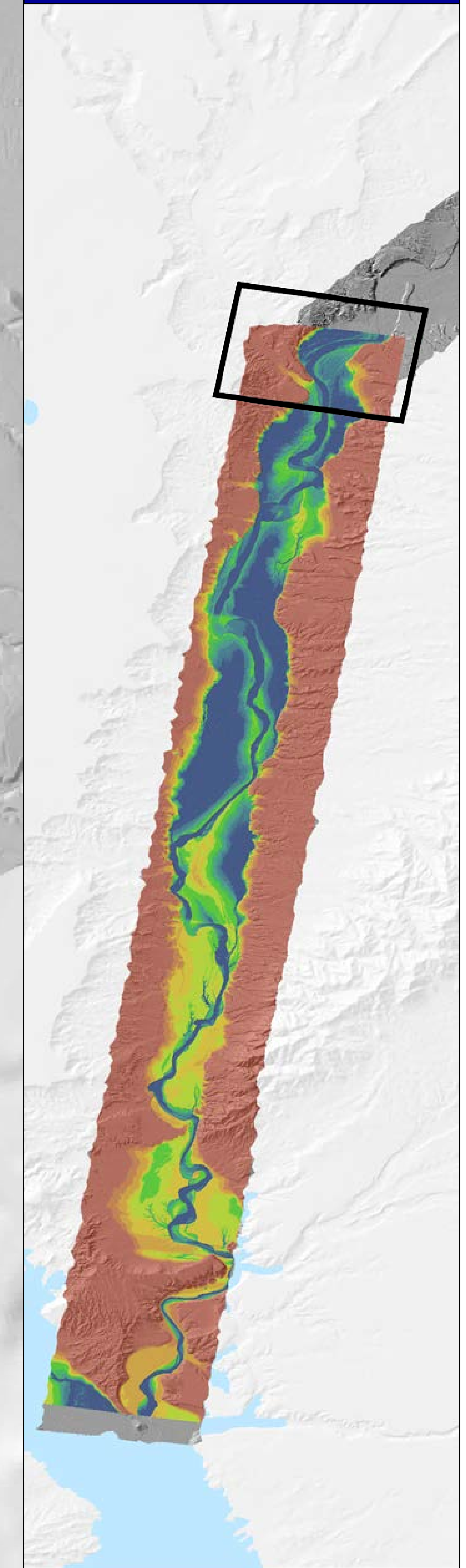


MAP LOCATION



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- 2011 Active Channel

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- High-3
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- Medium-2
- Medium-3
- Low

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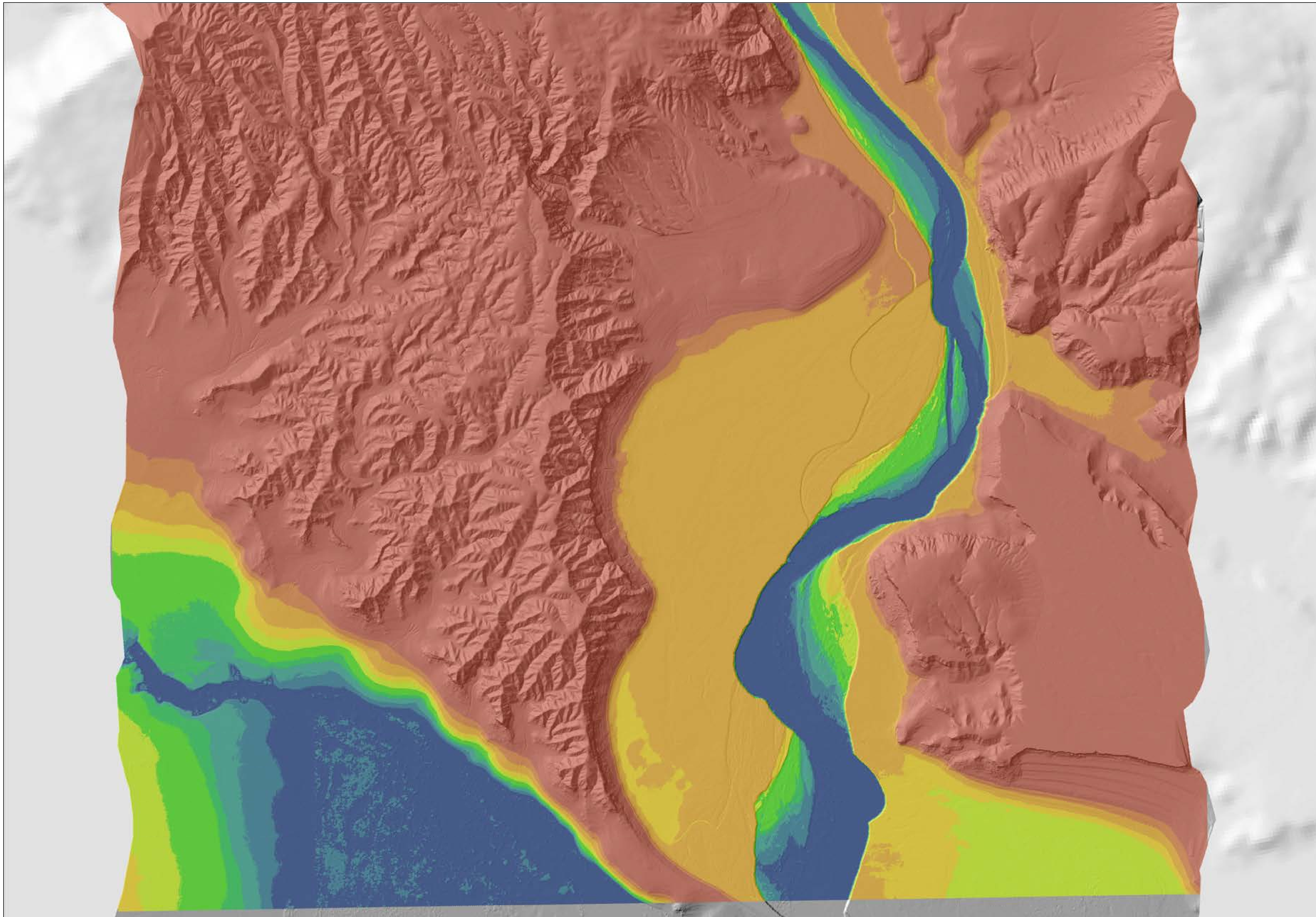
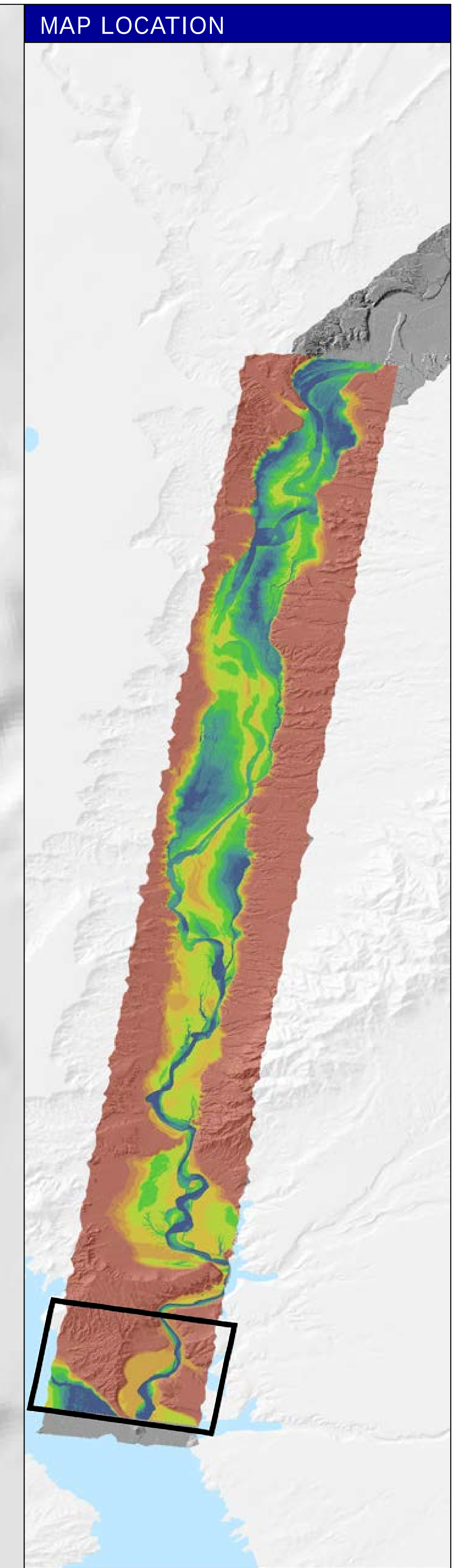




MORMON MESA, RELATIVE ELEVATION

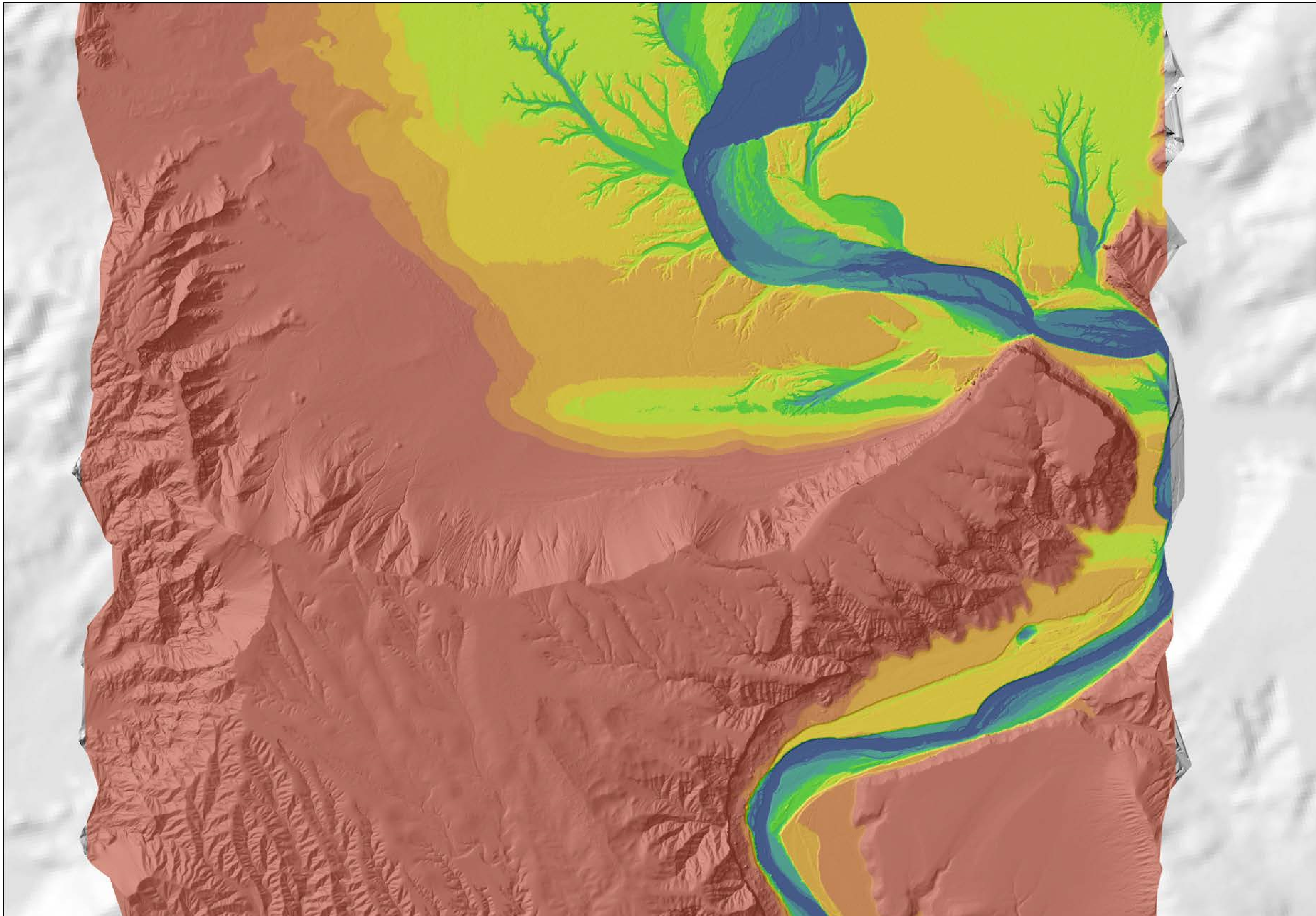
Relative Elevation in meters

0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 3
3.0 - 4
4.0 - 5
5.0 - 7.5
7.5 - 10
> 10

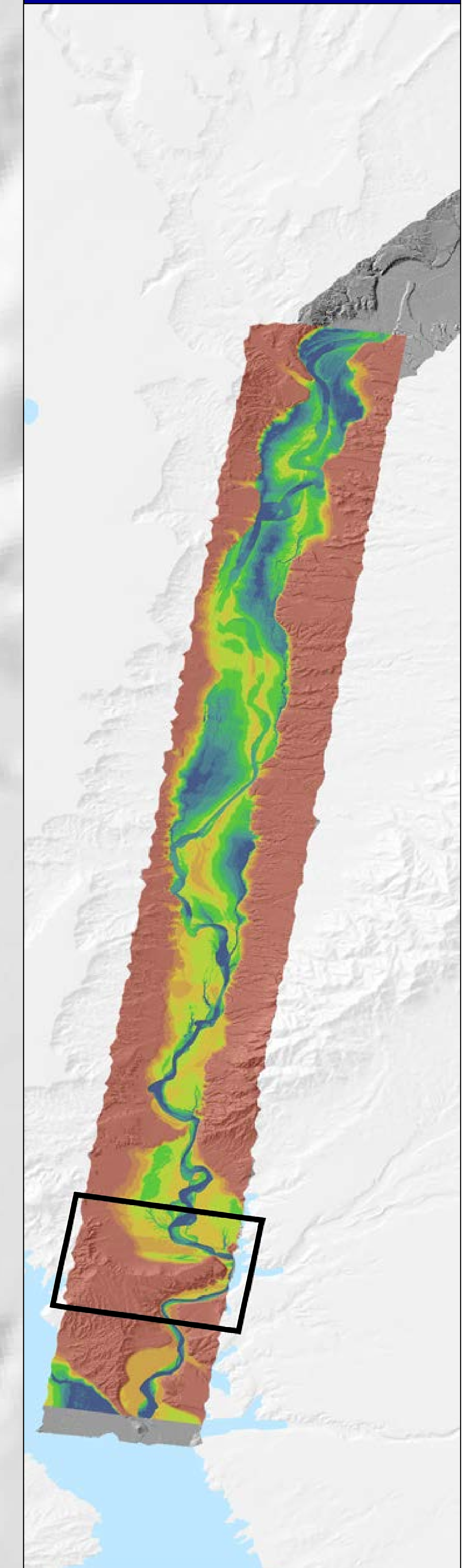
Data sources:
Relative Elevation: Stillwater Sciences, 2013
LIDAR Hillshade: Utah State University, November 2011

0 500 1,000 1,500 2,000 Feet
0 200 400 600 Meters

Stillwater Sciences
www.stillwatersci.com



MAP LOCATION



MORMON MESA, RELATIVE ELEVATION

Relative Elevation in meters

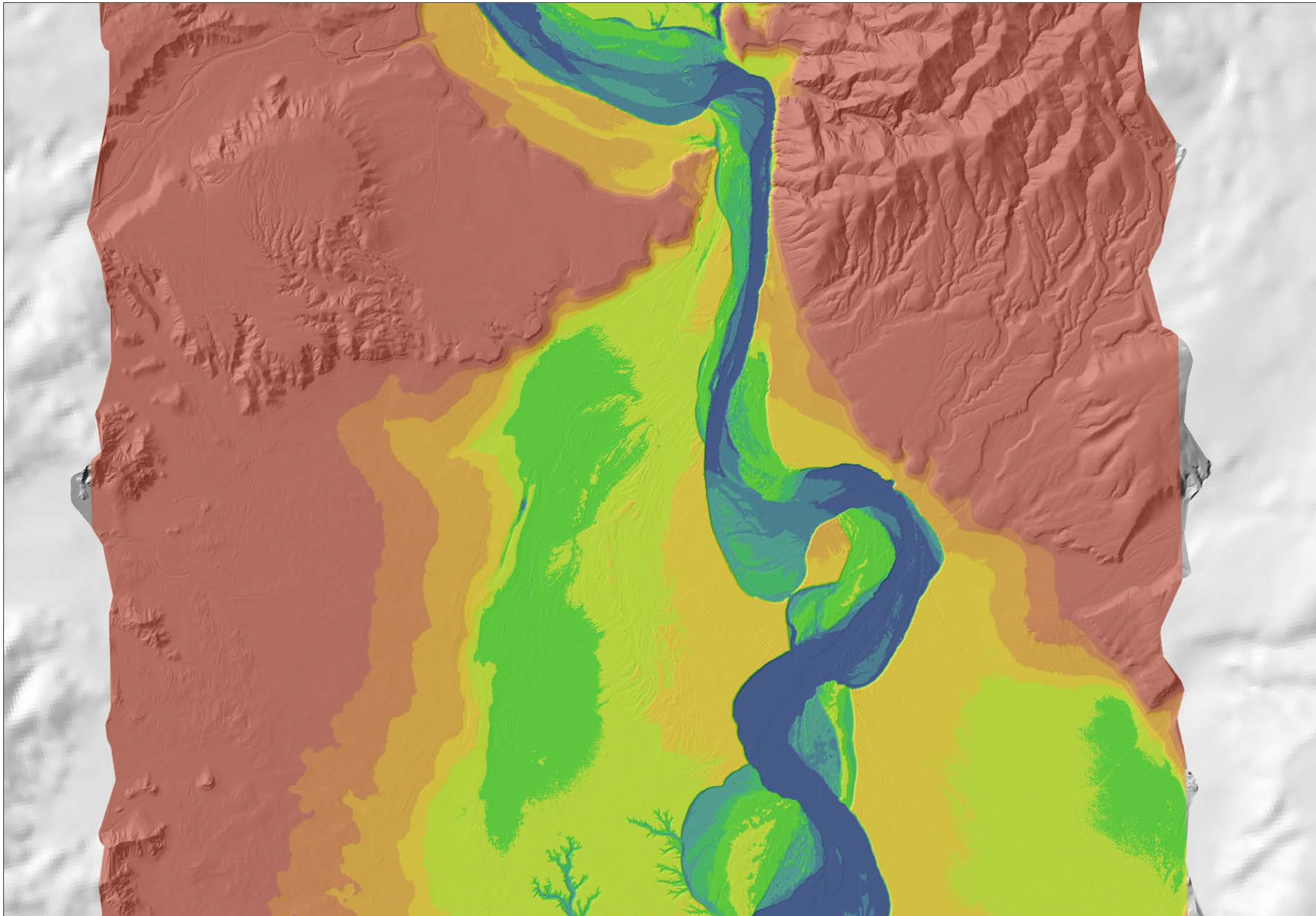
0 - 0.5	1.0 - 1.5	2.0 - 3	4.0 - 5	7.5 - 10
0.5 - 1	1.5 - 2	3.0 - 4	5.0 - 7.5	> 10

Data sources:
Relative Elevation: Stillwater Sciences, 2013
LIDAR Hillshade: Utah State University, November 2011

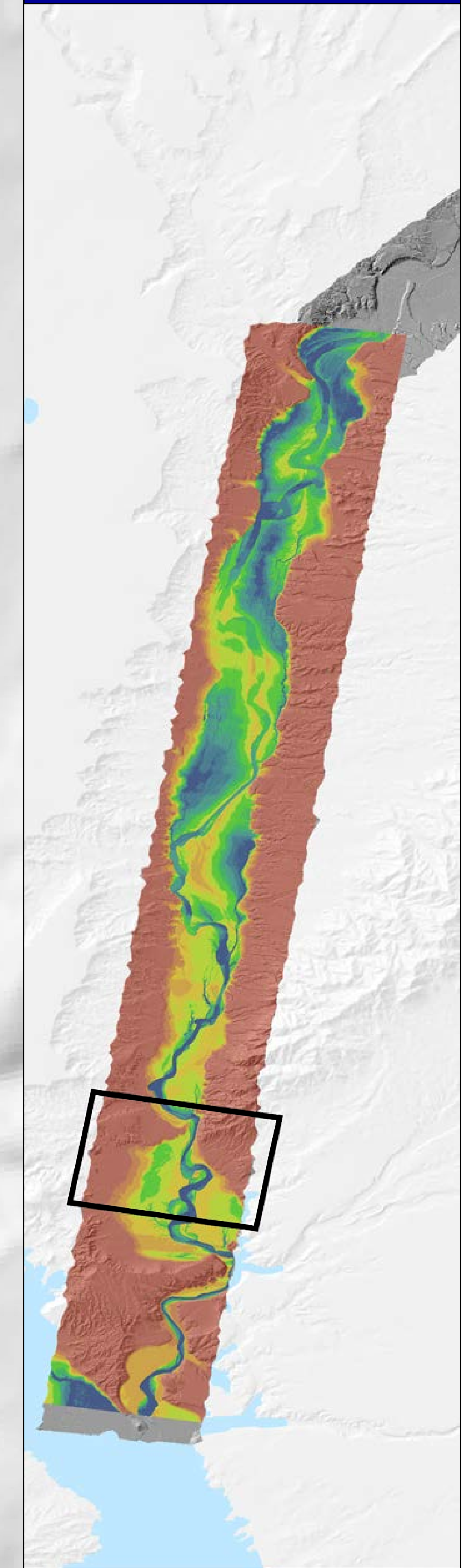
0 500 1,000 1,500 2,000 Feet

0 200 400 600 Meters

Stillwater Sciences
www.stillwatersci.com



MAP LOCATION



MORMON MESA, RELATIVE ELEVATION

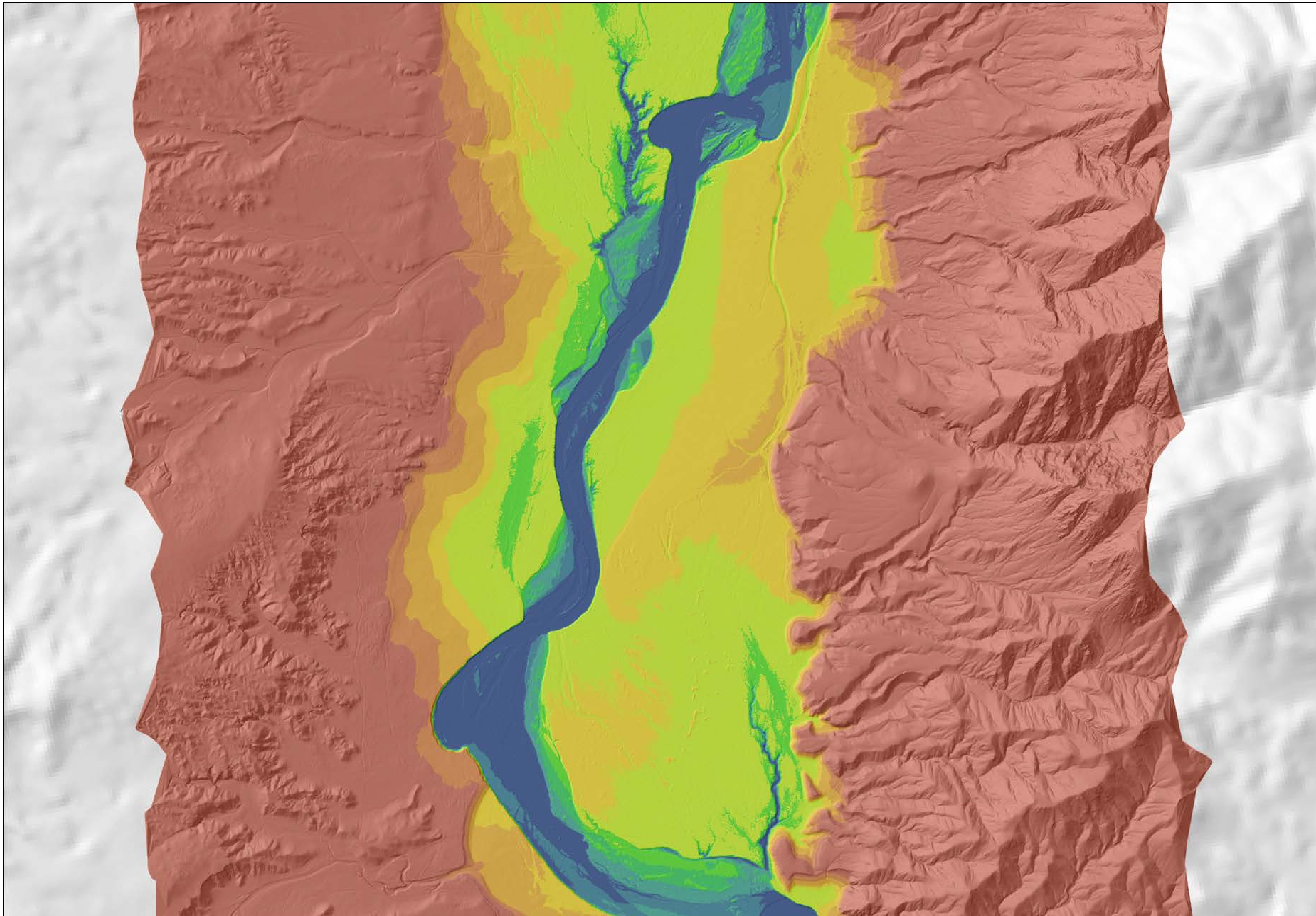
Relative Elevation in meters

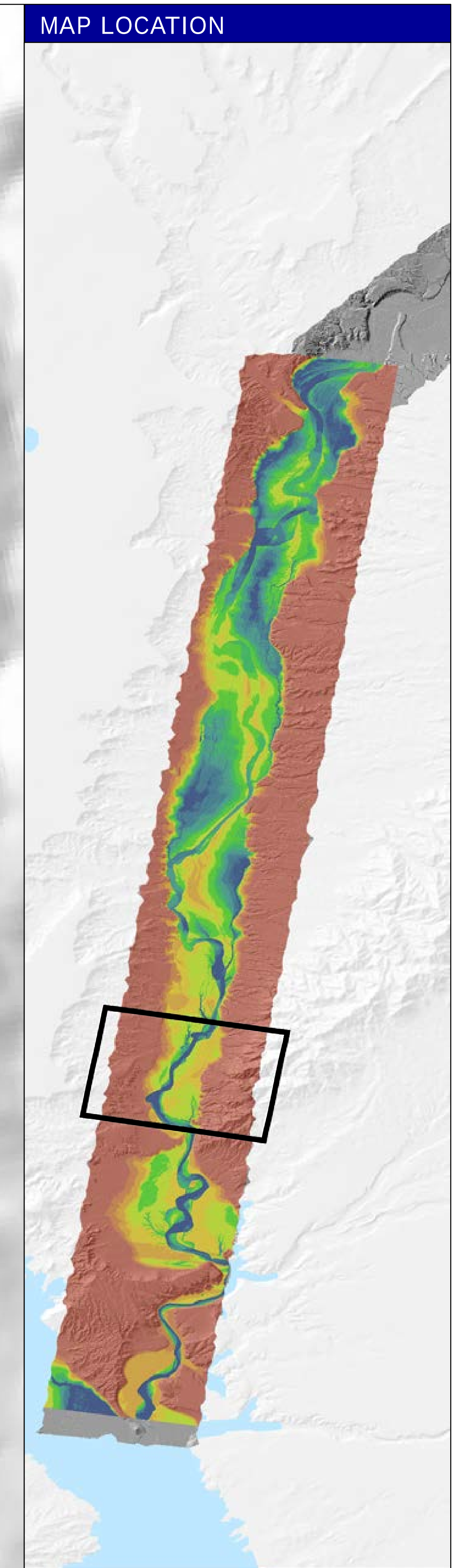
0 - 0.5	1.0 - 1.5	2.0 - 3	4.0 - 5	7.5 - 10
0.5 - 1	1.5 - 2	3.0 - 4	5.0 - 7.5	> 10

Data sources:
Relative Elevation: Stillwater Sciences, 2013
LIDAR Hillshade: Utah State University, November 2011

Scale: 0 500 1,000 1,500 2,000 Feet
0 200 400 600 Meters

Stillwater Sciences
www.stillwatersci.com





MORMON MESA, RELATIVE ELEVATION

Relative Elevation in meters

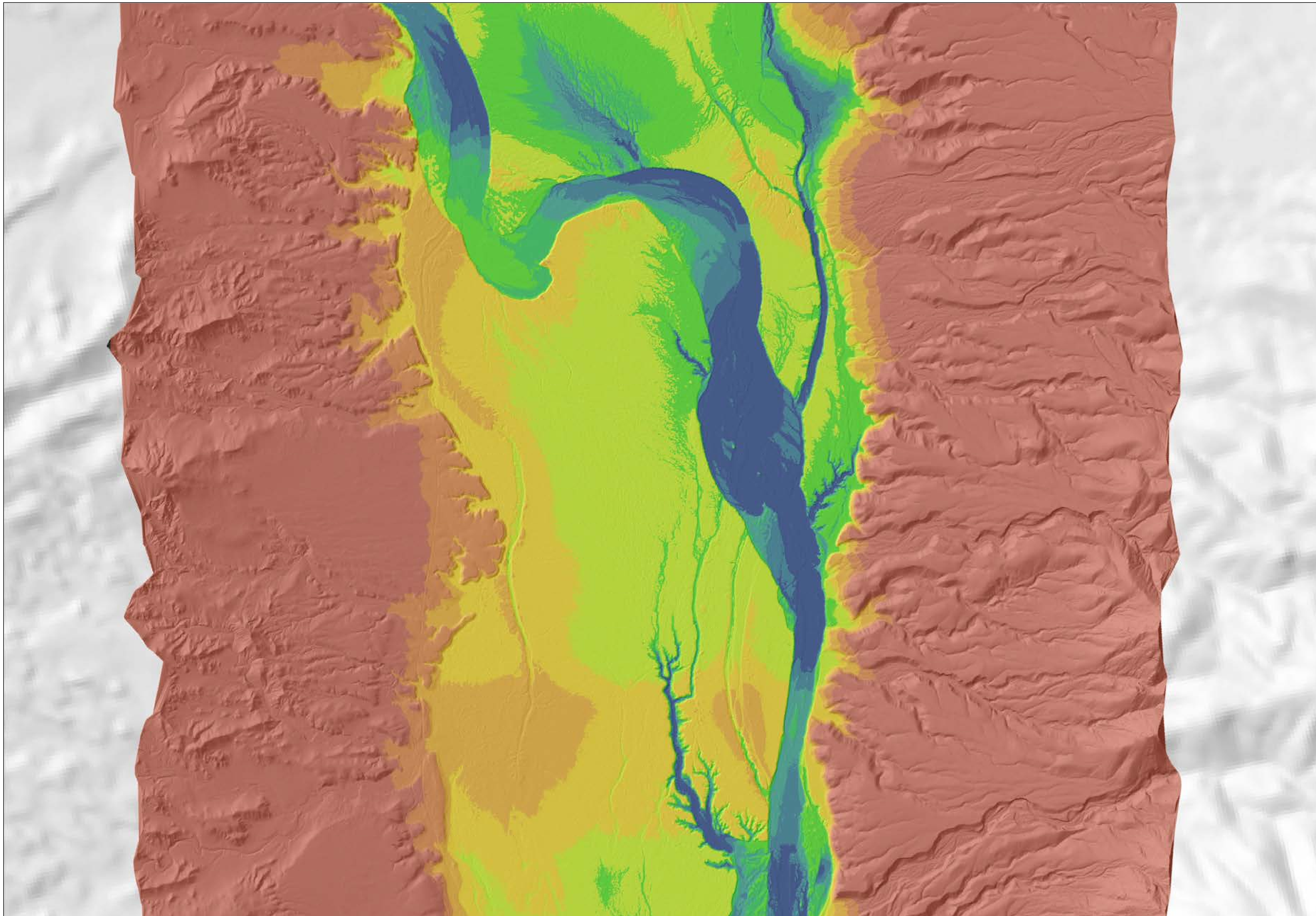
0 - 0.5	1.0 - 1.5	2.0 - 3	4.0 - 5	7.5 - 10
0.5 - 1	1.5 - 2	3.0 - 4	5.0 - 7.5	> 10

Data sources:
Relative Elevation: Stillwater Sciences, 2013
LIDAR Hillshade: Utah State University, November 2011

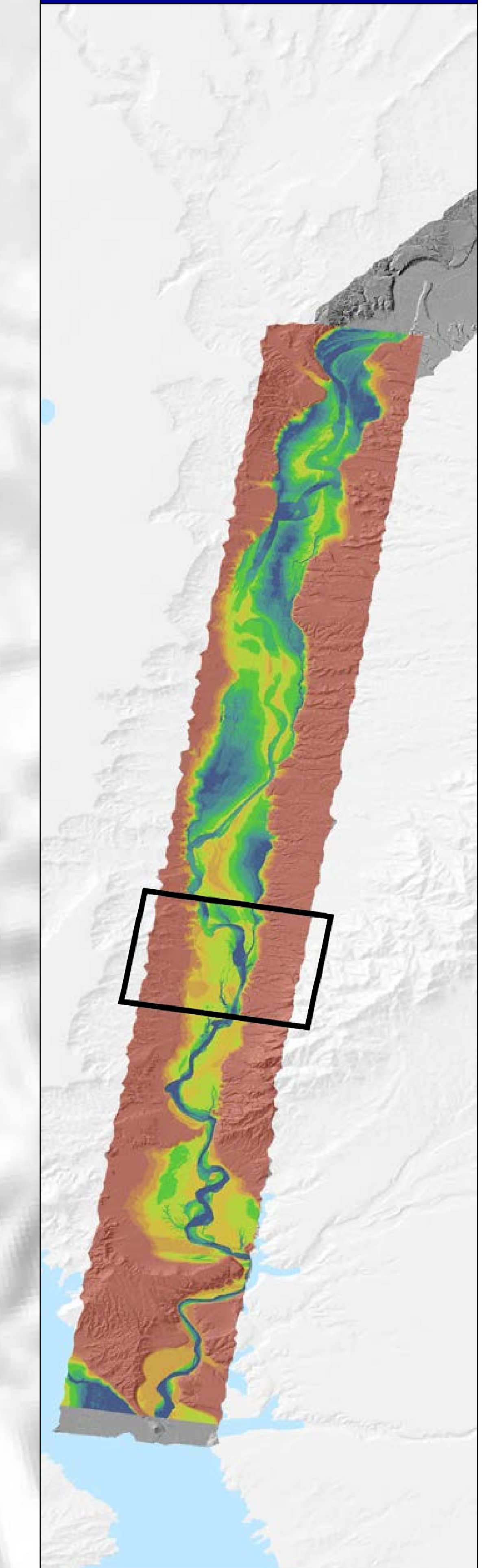
0 500 1,000 1,500 2,000 Feet

0 200 400 600 Meters

Stillwater Sciences
www.stillwatersci.com



MAP LOCATION



MORMON MESA, RELATIVE ELEVATION

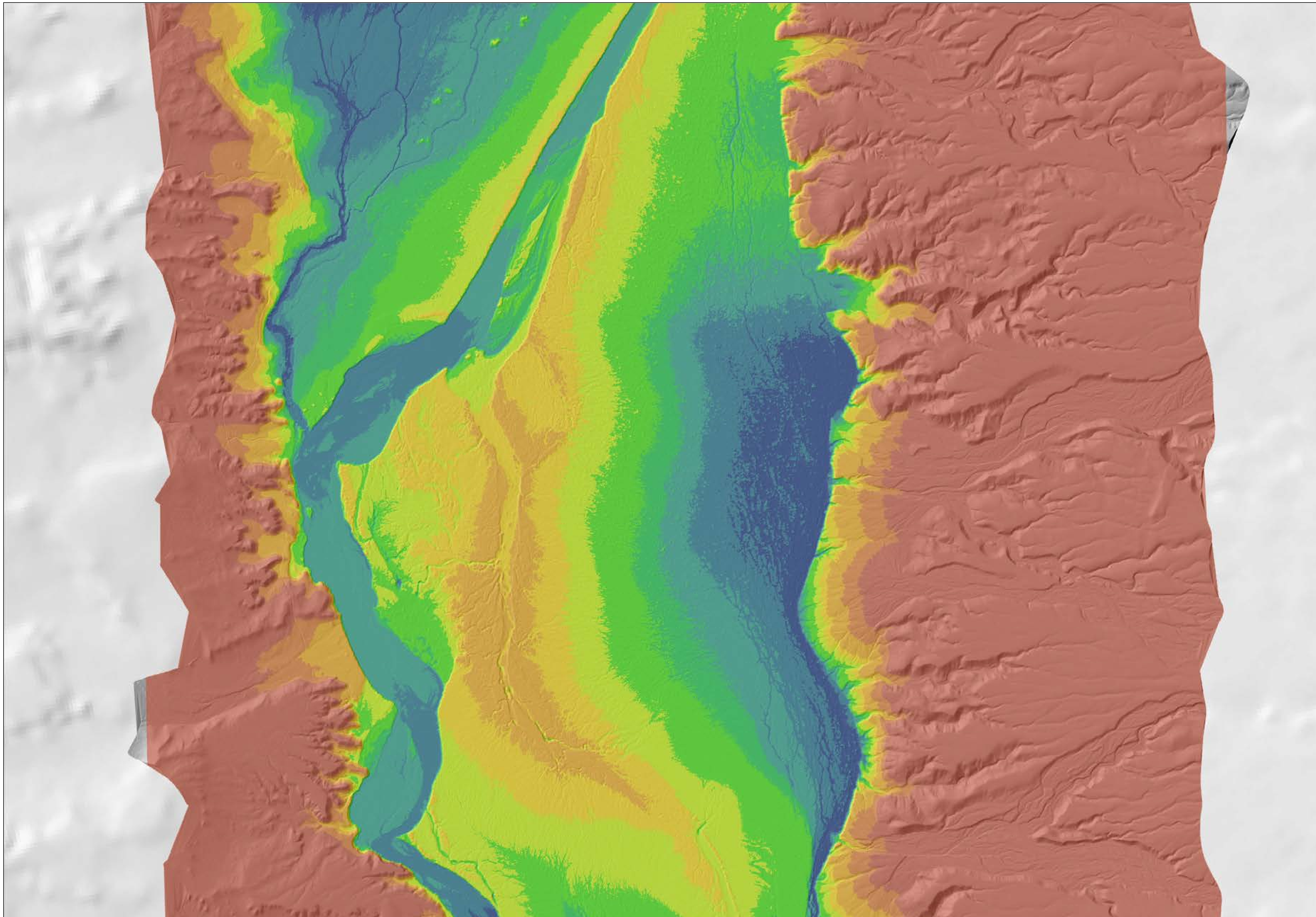
Relative Elevation in meters

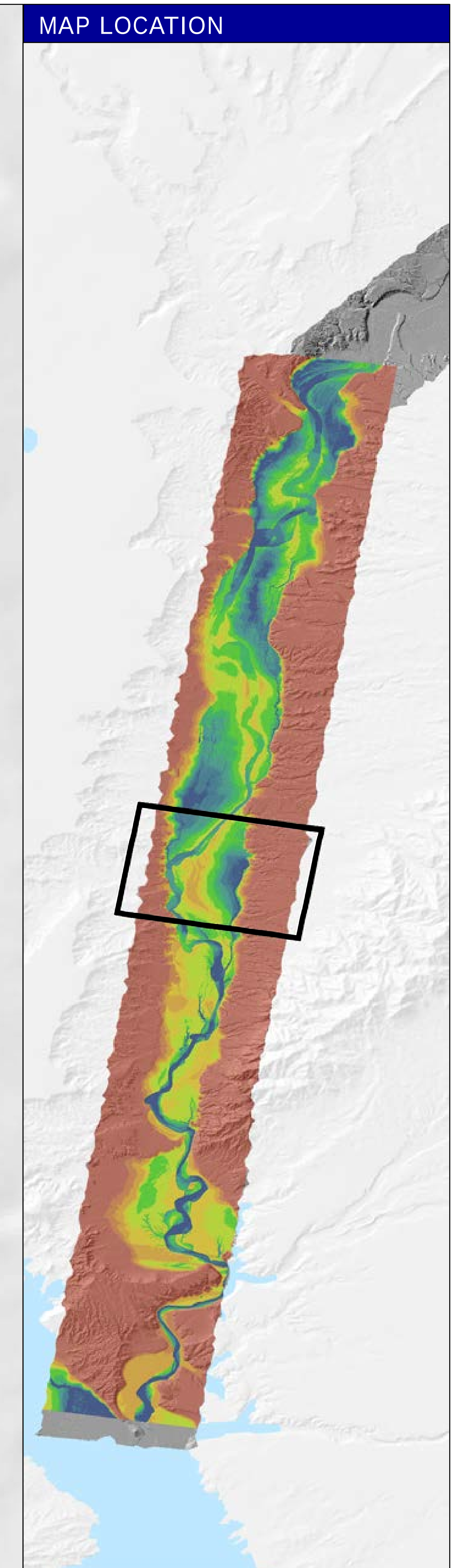
0 - 0.5	1.0 - 1.5	2.0 - 3	4.0 - 5	7.5 - 10	
0.5 - 1	1.5 - 2	3.0 - 4	5.0 - 7.5	> 10	

0 500 1,000 1,500 2,000 Feet

0 200 400 600 Meters

Data sources:
Relative Elevation: Stillwater Sciences, 2013
LIDAR Hillshade: Utah State University, November 2011





MORMON MESA, RELATIVE ELEVATION

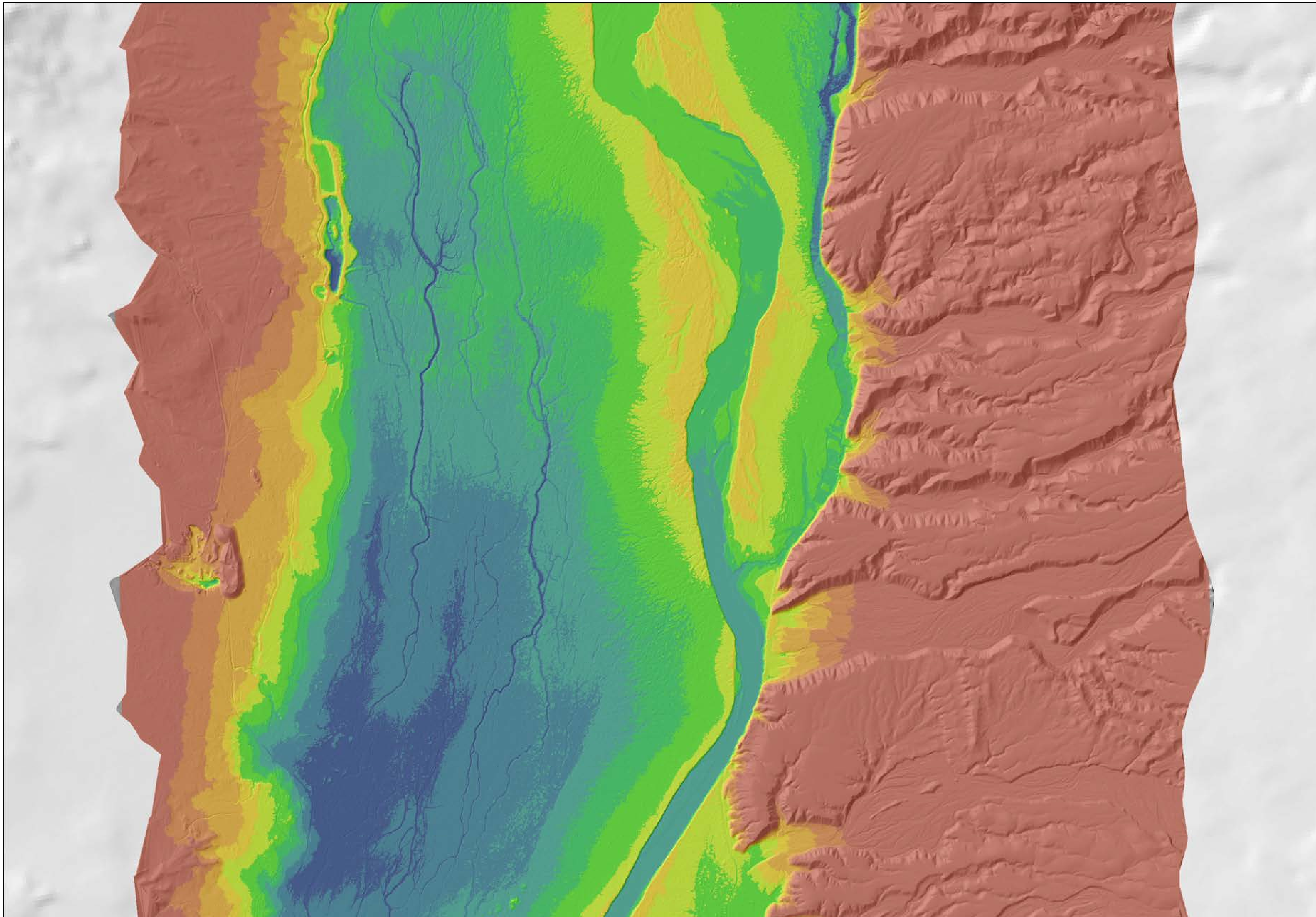
Relative Elevation in meters

0 - 0.5	1.0 - 1.5	2.0 - 3	4.0 - 5	7.5 - 10
0.5 - 1	1.5 - 2	3.0 - 4	5.0 - 7.5	> 10

Data sources:
Relative Elevation: Stillwater Sciences, 2013
LIDAR Hillshade: Utah State University, November 2011

0 500 1,000 1,500 2,000 Feet
0 200 400 600 Meters

Stillwater Sciences
www.stillwatersci.com



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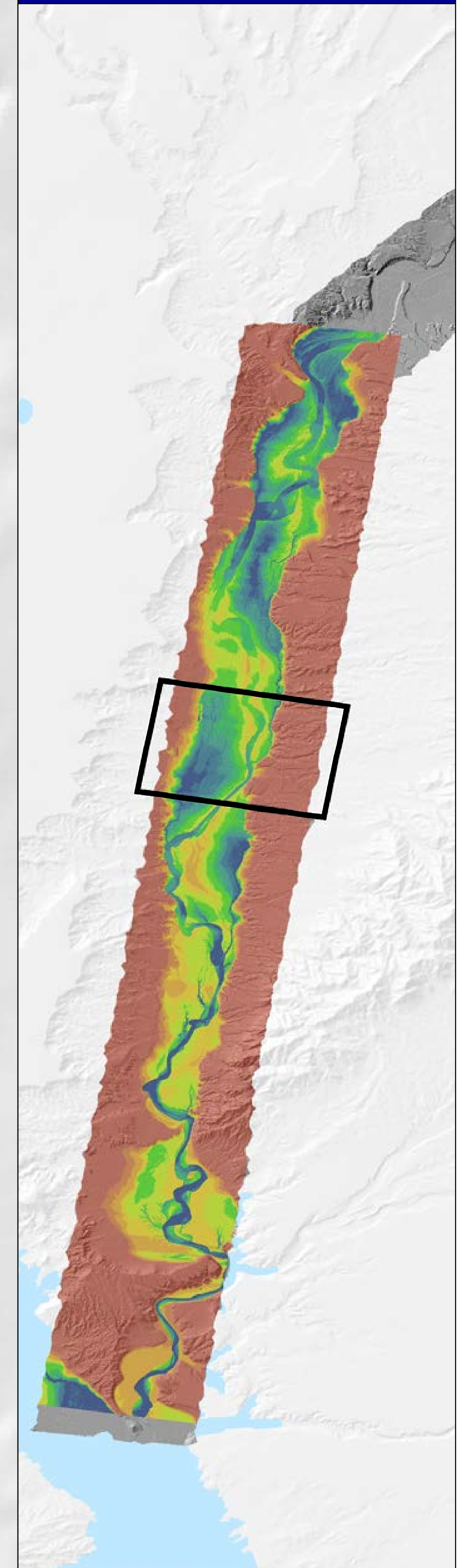


MORMON MESA, RELATIVE ELEVATION

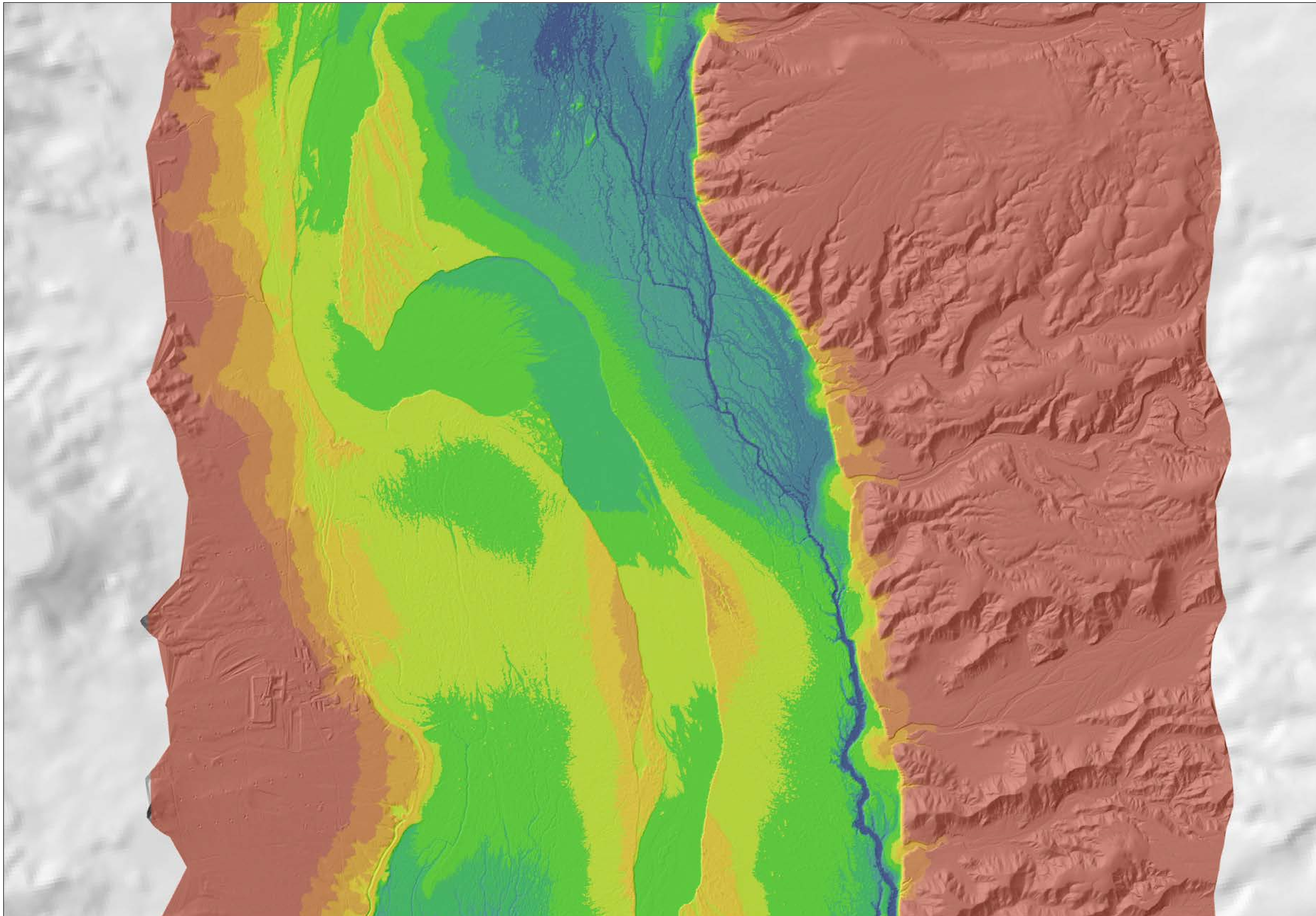
Relative Elevation in meters

0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 3
3.0 - 4
4.0 - 5
5.0 - 7.5
7.5 - 10
> 10

Data sources:
Relative Elevation: Stillwater Sciences, 2013
LIDAR Hillshade: Utah State University, November 2011

0 500 1,000 1,500 2,000 Feet
0 200 400 600 Meters

Stillwater Sciences
www.stillwatersci.com



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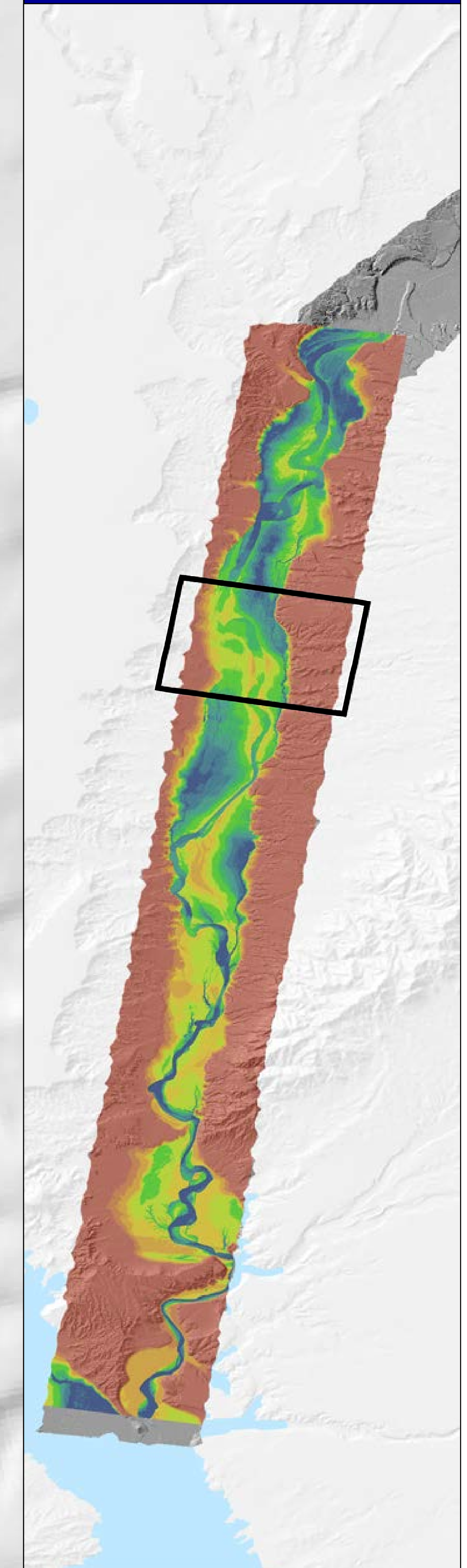


MORMON MESA, RELATIVE ELEVATION

Tile 8 of 11

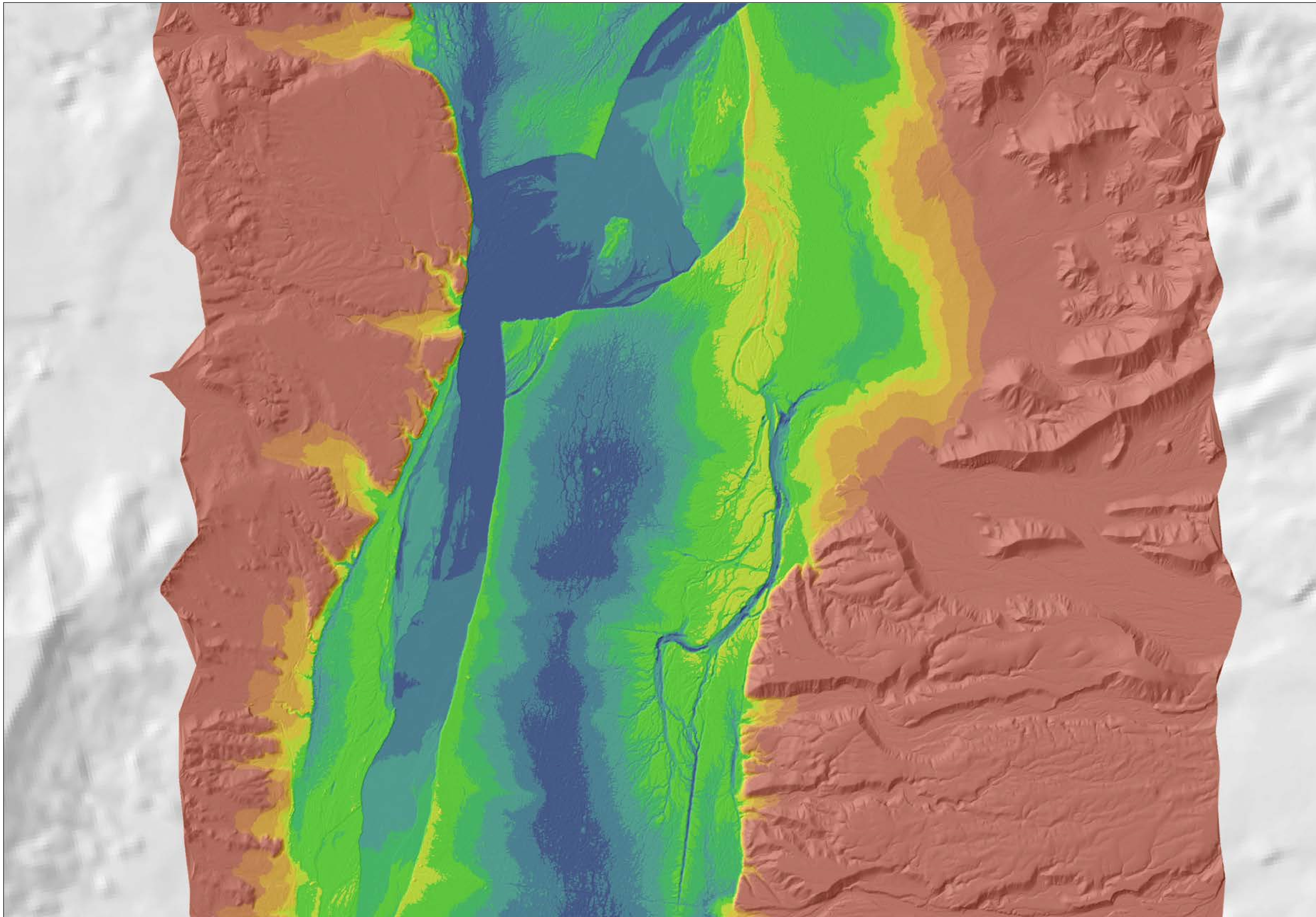
Relative Elevation in meters

0 - 0.5	1.0 - 1.5	2.0 - 3	4.0 - 5	7.5 - 10
0.5 - 1	1.5 - 2	3.0 - 4	5.0 - 7.5	> 10

Data sources:
Relative Elevation: Stillwater Sciences, 2013
LIDAR Hillshade: Utah State University, November 2011

0 500 1,000 1,500 2,000 Feet
0 200 400 600 Meters

Stillwater Sciences
www.stillwatersci.com



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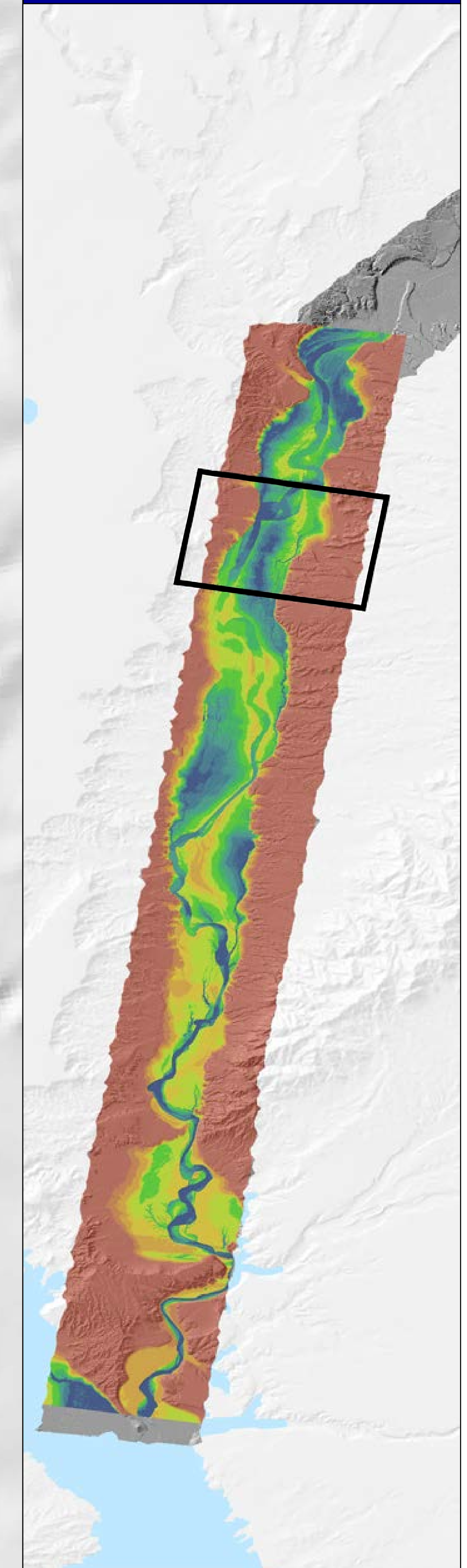


MORMON MESA, RELATIVE ELEVATION

Relative Elevation in meters

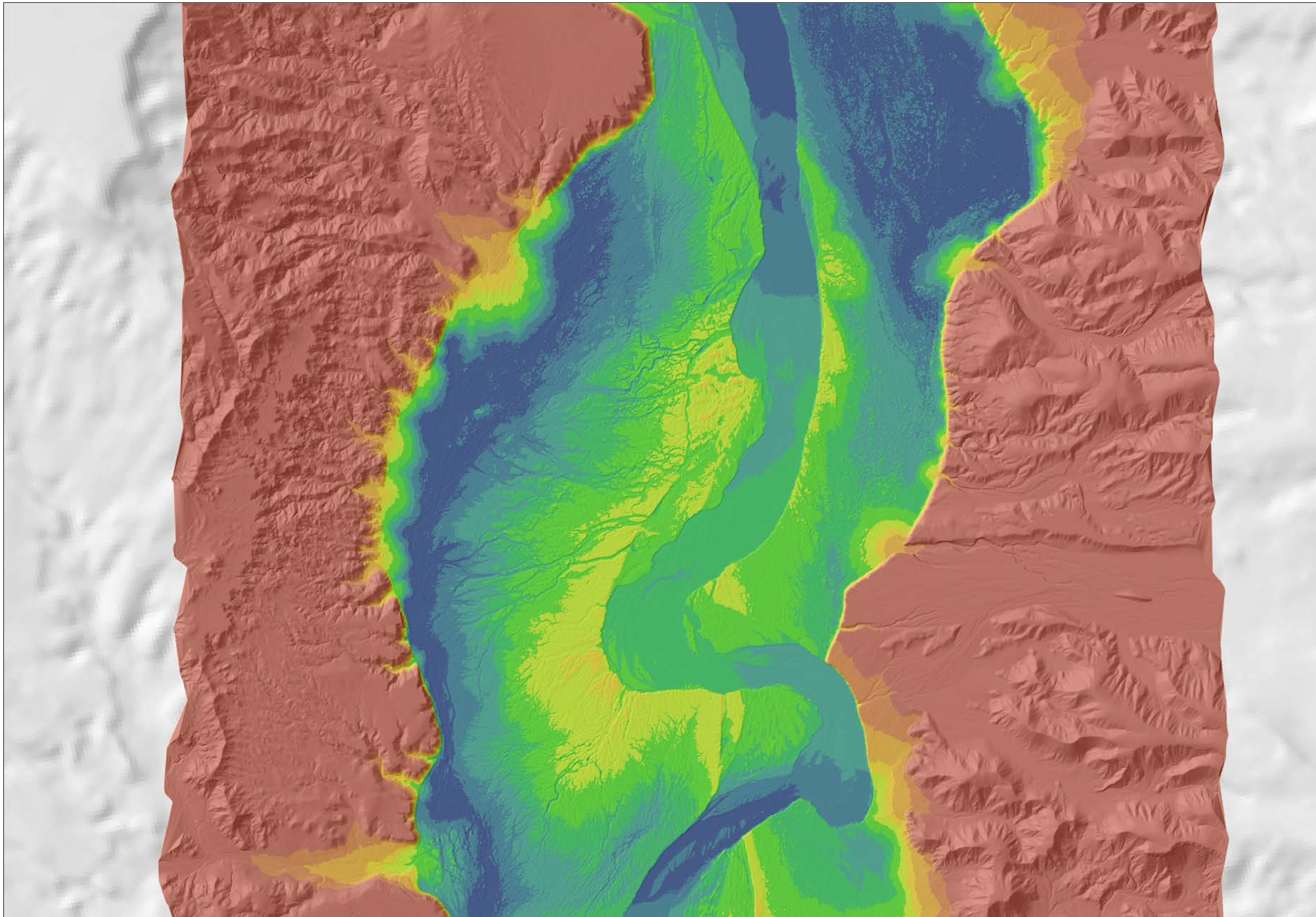
0 - 0.5	1.0 - 1.5	2.0 - 3	4.0 - 5	7.5 - 10
0.5 - 1	1.5 - 2	3.0 - 4	5.0 - 7.5	> 10

Data sources:
Relative Elevation: Stillwater Sciences, 2013
LIDAR Hillshade: Utah State University, November 2011

0 500 1,000 1,500 2,000 Feet

0 200 400 600 Meters

Stillwater Sciences
www.stillwatersci.com



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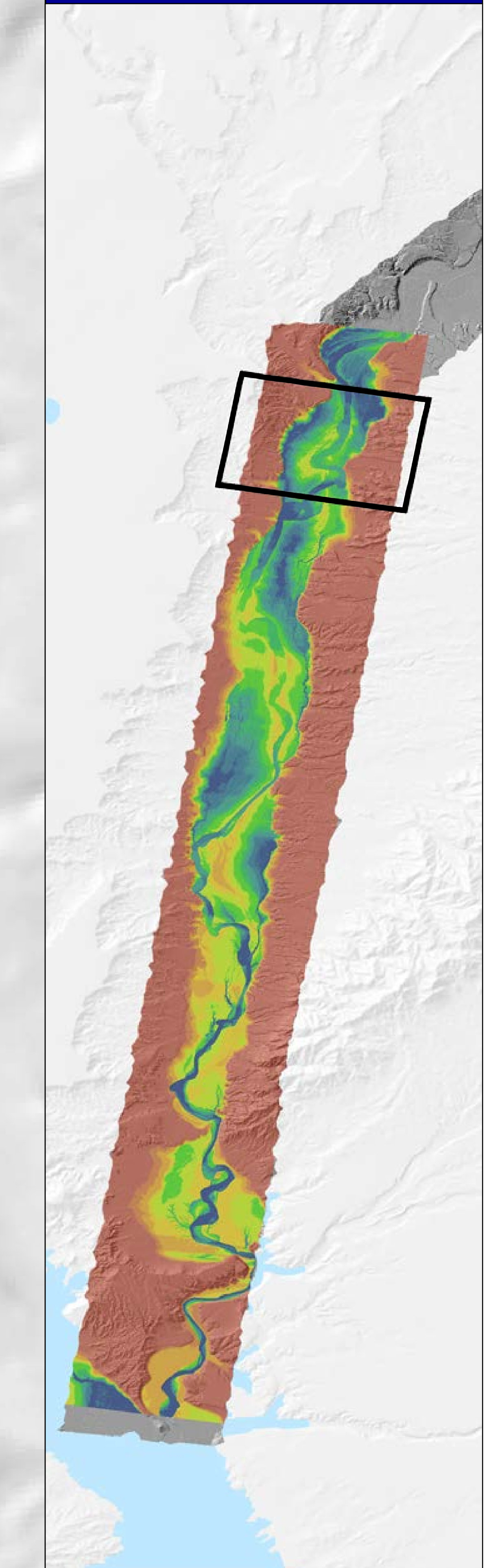


MORMON MESA, RELATIVE ELEVATION

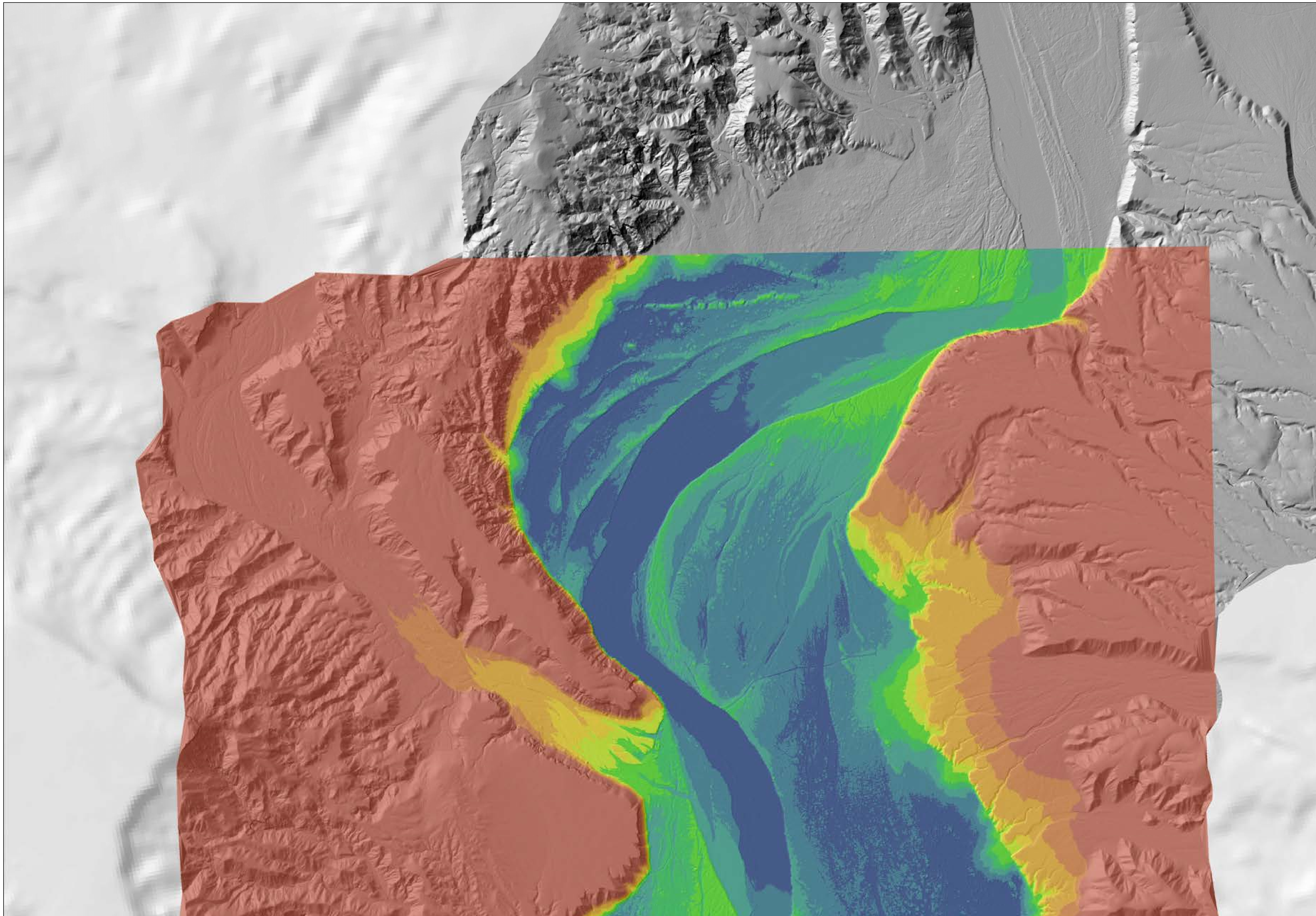
Relative Elevation in meters

0 - 0.5	1.0 - 1.5	2.0 - 3	4.0 - 5	7.5 - 10
0.5 - 1	1.5 - 2	3.0 - 4	5.0 - 7.5	> 10

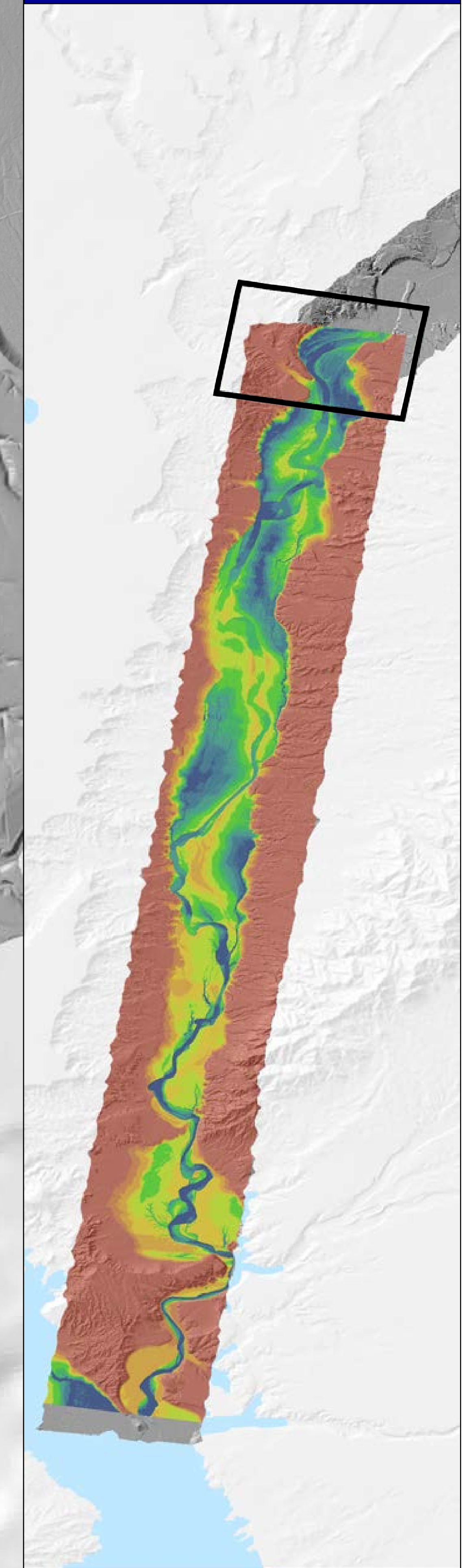
Data sources:
Relative Elevation: Stillwater Sciences, 2013
LIDAR Hillshade: Utah State University, November 2011

0 500 1,000 1,500 2,000 Feet
0 200 400 600 Meters

Stillwater Sciences
www.stillwatersci.com



MAP LOCATION



MORMON MESA, RELATIVE ELEVATION

Relative Elevation in meters

0 - 0.5	1.0 - 1.5	2.0 - 3	4.0 - 5	7.5 - 10
0.5 - 1	1.5 - 2	3.0 - 4	5.0 - 7.5	> 10

Data sources:
Relative Elevation: Stillwater Sciences, 2013
LIDAR Hillshade: Utah State University, November 2011

0 500 1,000 1,500 2,000 Feet

0 200 400 600 Meters

Stillwater Sciences
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