Drought Related Site Distribution of Prehistoric Irrigation Farmers

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1-Introduction

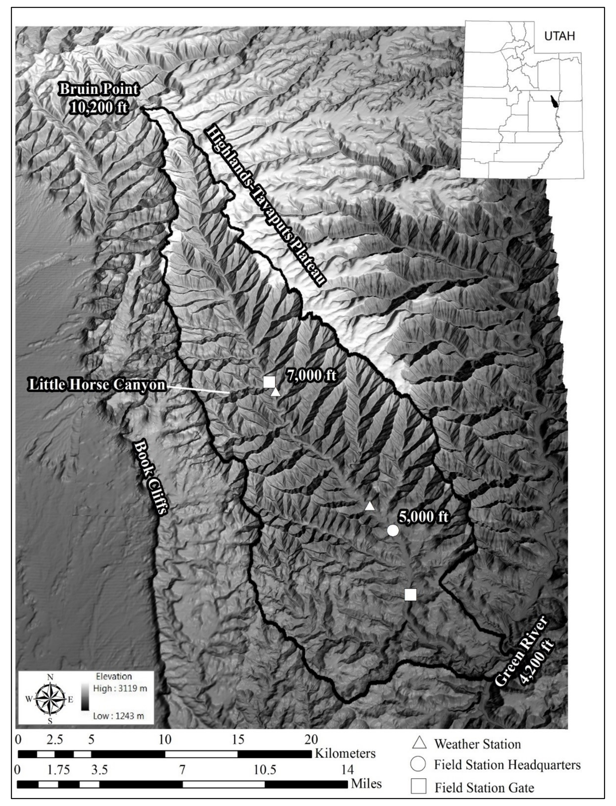

Figure 1. Relief map of Range Creek Canyon. The study area is located along the creek between the Field Station Gates.

Range Creek Canyon (RCC) is a rugged and remote canyon located in the West Tavaputs Plateau in east-central Utah. The 145 square mile watershed is drained by Range Creek, a perennial tributary to the Green River. The University of Utah Archaeological Field School has been documenting the remarkably intact record of the Fremont occupation of the canyon between about A.D. 900-1200.

The overarching goal of the research is to explore the adaptations of arid-land foragers and farmers within the broader context of Southwestern prehistory. Integrated archaeological, experimental, and paleoenvironmental investigations suggest that farming was an important source of food and would have required using the water in Range Creek for irrigation. Several years of measurements of the stream flow in Range Creek document the spatial and temporal variation in stream flow during the growing season. In the summer of 2018, due to successive poor snow packs and general drought conditions, sections of the creek channel dried up completely due to a drop in the alluvial water table. For farmers reliant on surface irrigation, low stream flow may have constrained farming activities; the lack of stream flow would have curtailed all farming.

We compare stream flow measurements with the 2018 dry reaches of the creek, and both measures of available water with the known density and distribution of Fremont archaeological sites. Our results show that the most densely populated section of the canyon is one with a consistently regular flow, even during drought years, but stream flow (or lack there of) does not fully explain the distribution of residential sites adjacent to the creek in other sections.

2-Context

Environment. Water is critical to successfully farming maize in near desert environments. The last 30 years of temperature and precipitation in RCC has been analyzed using PRISM estimates (Boomgarden 2015, Daly and Bryant 2013). The modern growing season climate is warm and dry, with suitable growing season temperatures below 7,000 ft. Growing season precipitation is meager and even annual precipitation is borderline arid (Boomgarden 2015). Tree-ring reconstruction of prehistoric precipitation patterns on the West Tavaputs Plateau during the Fremont occupation of RCC (AD 900-1200) estimate an annual average of 37.6 cm of precipitation, comparable to modern records. This period is also characterized by a number of significant droughts (Boomgarden 2015, Knight et al 2010). Range Creek, the principal water source in the canyon, probably had a water volume flow similar to that in the creek today.

Prehistoric Farming. Archaeological and paleoenvironmental evidence from RCC indicates that maize agriculture was a significant part of the Fremont diet. This evidence includes stable carbon isotope and pollen from several sediment cores, large numbers of maize cobs, groundstone tools, and storage granaries. Paleoenvironmental reconstructions and maize farming experiments suggest irrigation would have been necessary to productively farm maize in RCC, both now and in the past. We expect Fremont farmers relied on surface diversion irrigation to water their maize fields to maximize their harvest yield relative to time spent farming.

Cost/Benefit Experiments. A common view is that irrigation is too expensive for many small-scale farmers. Two sets of farming experiments conducted in RCC since 2013 have gathered empirical data on the costs and benefits of irrigating maize fields (Boomgarden 2015, Boomgarden et al. 2018 *in review,* and Simons 2017). The benefits experiments examined the relationship between the amount of additional irrigation water and increased harvest yield. The maize in plots that received no irrigation water died within a month of planting. In plots receiving additional water, the greater the amount of water added, the greater the harvest yield. The cost experiments focused on a large plot that was irrigated using a diversion dam, ditches, and furrows constructed using only technology available to the Fremont (sticks and hands for digging, Figure 2). The time spent building the irrigation systems was significantly less costly than originally expected, and participants quickly learned techniques for efficiently damming the creek, digging ditches and furrows, and directing water applied to the plot.

Modern Stream Flow. The farming experiments in RCC have shown that irrigation is necessary for successful farming but how much water is available for irrigation? The creek is fed by snow field meltwater and precipitation runoff, groundwater, and possibly some deeper artesian springs. The volume of water in Range Creek varies along its course, as well as seasonally and annually. Some sections of the creek channel are often dry during recent droughts (especially in late summer), while other sections further down the channel maintain stream flow.

In 2015, we began systematically measuring stream flow using a hand-held current meter (Baldwin 2017 and Potter 2016). Stream flow gauging stations (GS) were established at roughly 5 km intervals along the creek to assess spatial variation in stream flow (Figures 3 and 4, Potter 2016 and Baldwin 2017). Stream flow measurements demonstrate decreasing water volume through the upper portion of the study area (GS 1 to GS 3), but a significant increase somewhere between GS 3 and GS 4 (Figure 5). Between GS 4 and GS 5 water flow again decreases, due in part to ongoing irrigation of the fields around the field station but also due to direct evaporation.

In 2018, the water in the creek was so low that it was impossible to measure steam flow. Instead, sections of the channel that were dry were mapped five times during the 2018 growing season. Mapping was completed using handheld GPS receivers and photographs were taken of section boundaries. Jeanie Jensen, who was raised in RCC, said she had never witnessed or heard any report of large sections of Range Creek drying up during her life time. Fields adjacent to these dry sections would be impossible to irrigate. The question becomes, if this occurred in the past, did it influence the locations of farm fields and, by extension, settlement locations?

Figure 2. Photographs of the maize farming experiments in RCC showing dam construction (left) and ditch construction (right) using only wood and stone technology.

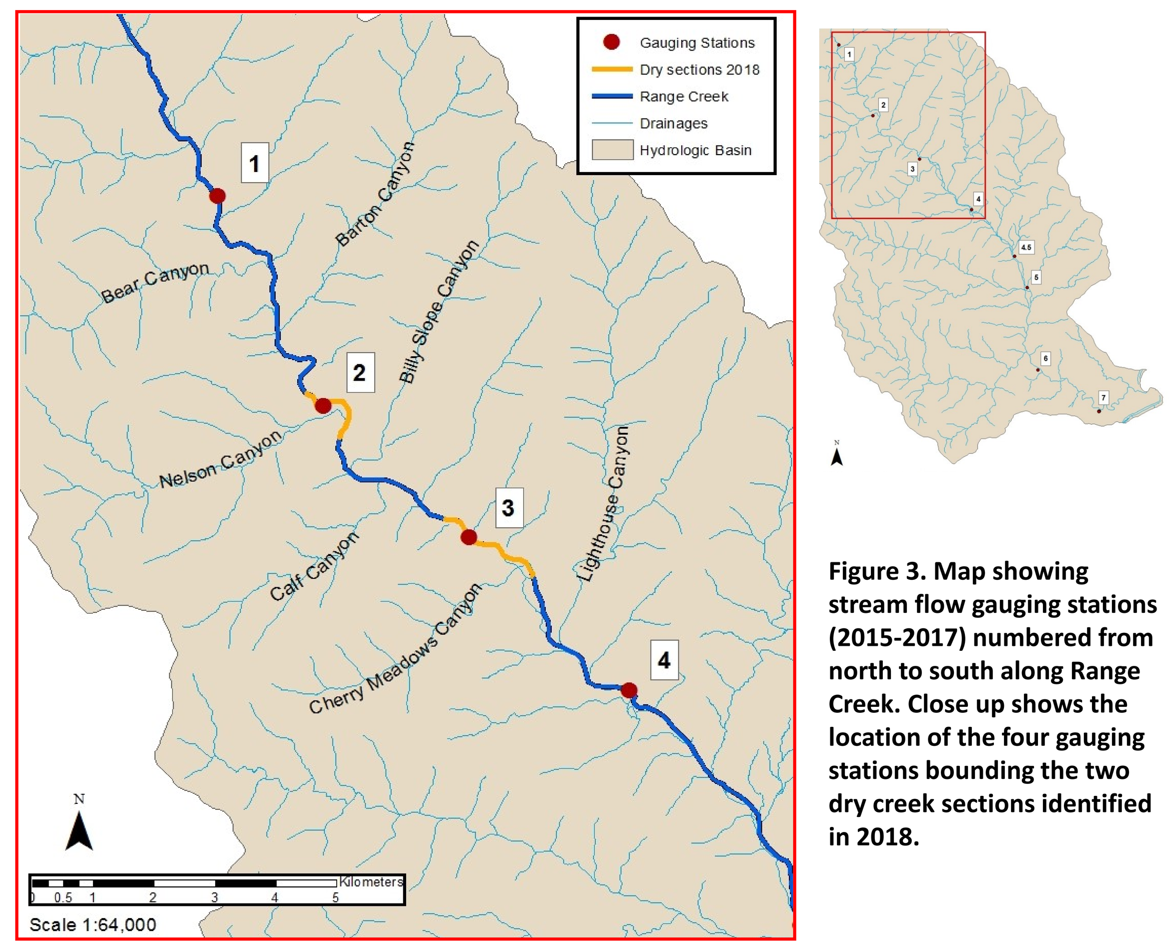

Figure 3. Map showing stream flow gauging stations (2015-2017) numbered from north to south along Range Creek. Close up shows the location of the four gauging stations bounding the two dry creek sections identified in 2018.

Figure 4. Staff and students taking stream flow readings at gauging stations located ~5 k apart north to south along the creek.

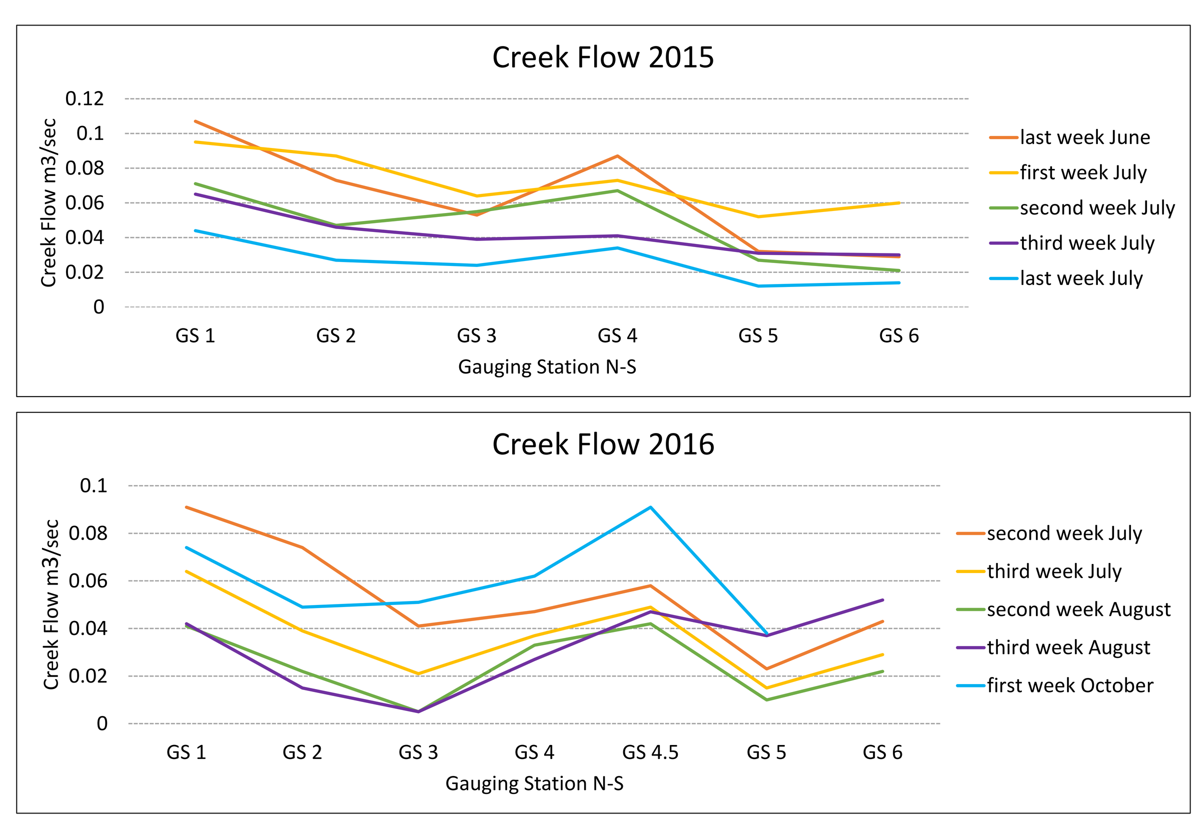

Figure 5. Graphs showing the stream flow fluctuations throughout the growing season in 2015 and 2016 (Potter 2016 and Baldwin 2017). Gauging Stations 2 and 3 fall within the 2018 dry sections.

3-Methods-Variability in Stream Flow and Distribution of Residential Sites

Expectations. Given the constraints imposed by diversion irrigation, the locations of Fremont fields would have been limited to the alluvial deposits adjacent to the creek. The farmers in RCC had 744 hectares spread along 26 km of canyon bottom from which to choose the locations of their fields (Boomgarden 2015). Did the Fremont in RCC prefer to farm in those areas associated with consistent stream flow during years of drought? Does the settlement pattern reflect a preference?

Analysis. Maps were generated showing the changes in extent of dry creek sections throughout the 2018 growing season (Figure 6). Points every 200 m along the creek were generated to facilitate analysis and Thiessen polygons were generated for each point using ArcGIS 10.4. The number of structures (proxy for population) at residential sites adjacent to the creek were counted within each polygon. Any site that falls within a Thiessen polygon is closer to its associated creek point than to any other point along the creek. The distribution north to south along the creek and the number of structures within each polygon was tallied in relation to the nearest section of the creek. The density of residential structures north to south is shown in Figure 8 grouped by kilometer. The shaded areas indicate the full extent of both the Nelson Canyon and the Cherry Meadows dry sections compared with the density of residential structures (Figure 8).

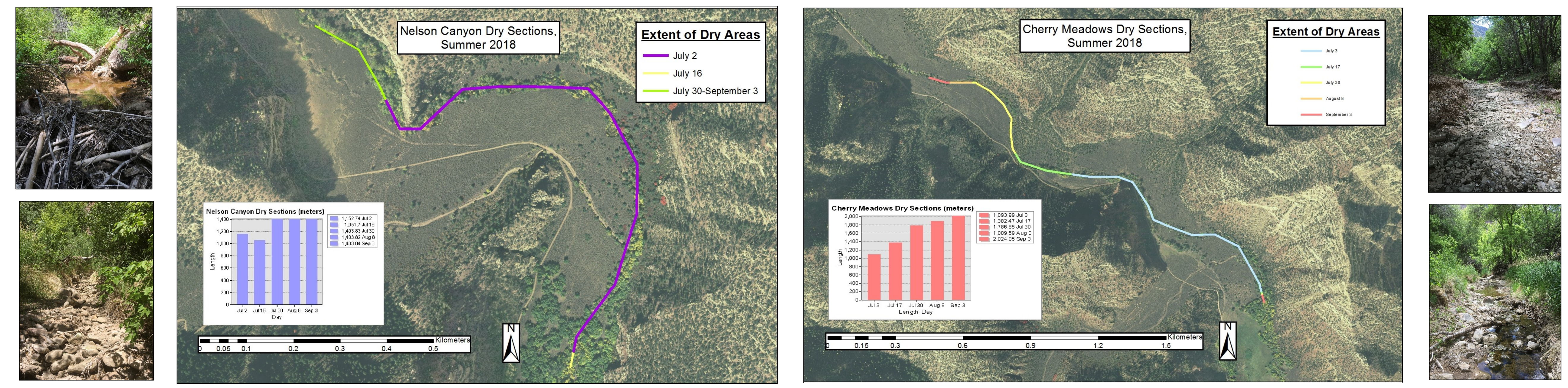

Figure 6. Maps and photographs showing the growing extent of dry sections of Range Creek near Nelson Canyon and Cherry Meadows Canyon. Charts show the changes in length (meters) of each dry section by date.

4-Results-Variability in Stream Flow and Distribution of Residential Sites

Stream Flow Measurements vs Dry Reaches. The gauging stations (GS) spaced roughly 5k apart have captured the general trend in stream flow for the past 3 years. The full extent of the dry reaches is located between the first four gauging stations with GS 2 and GS 3 falling within each dry section (Figures 3). Looking only at stream flow readings, the trend between GS 2 and GS 3 is toward decreasing stream flow (Figure 5). Stream flow then tends to go up toward GS4. The maps of dry sections show that something is occurring between these two gauging stations that brings water back to the surface (between Billy Slope and Calf Canyons) during drought years. A stream flow gauging station placed between GS 2 and GS 3 might show an increase in water flow in this area during non-drought years that we miss with the spacing of our gauging stations at 5k. The increased flow at GS 4 does correlate with the increase in site density there but when compared with the dry reaches tracked on foot in 2018, we can see that a more detailed analysis of water distribution might be necessary when investigating irrigation potential and density of sites in relation to water availability.

Distribution of Residential Sites. When the location and number of residential sites are compared to areas of the creek with continuous flow, we see that some areas show a correlation and some do not. The dry section around Nelson Canyon (Figure 8) has a relatively low density of residential structures located adjacent to the creek. The most densely populated section of the canyon is evident in the spike in number of residential structures south of the Cherry Meadows dry section (11-12 km, Figure 8). While number of residential structures steadily declines moving south past the peak, the area between 11 and 16 km is more densely populated compared to the sections north and south. There is not an even number of residential structures located adjacent to areas with continuous flow as we might expect if continuous water flow during droughts was the only factor driving the settlement of farmers along the flanks of Range Creek.

Discussion. Analysis of site distribution and loci of contiguous arable land suggest there might be other factors in addition to continuous flow of creek water that come into play to explain the increased population in the center of the study area (Boomgarden 2015). There are reasons to suspect that the larger area of contiguous arable land that we see in Section 2 (Figure 9) might be more desirable for irrigation farming because it allows fewer diversions to water more area, compared to Section 3 which is broken up topographically by ridgelines. The costs involved in the construction and maintenance of a larger irrigation system may be less, as measured by cost per hectare, for a simple system watering a larger area. Section 2 would also allow farmers to grow the size of their fields over time. When farmers are investing heavily in their fields, especially with irrigation, the ability to expand the size of their fields. During good times, is likely to be a huge benefit. Section 2 might provide the potential for cooperation. Cooperating families could share the costs of the capital investments associated with an irrigation system that served more than one family's fields. And if they used a single diversion to feed a ditch that runs the length of a larger farmable area. Any family willing to share in the construction and maintenance could benefit by reducing the cost per family. These factors along with water reliability might help explain the larger population in Section 2. Population spikes outside hotspots require further analysis (i.e. 3-3.999 km Figure 8).

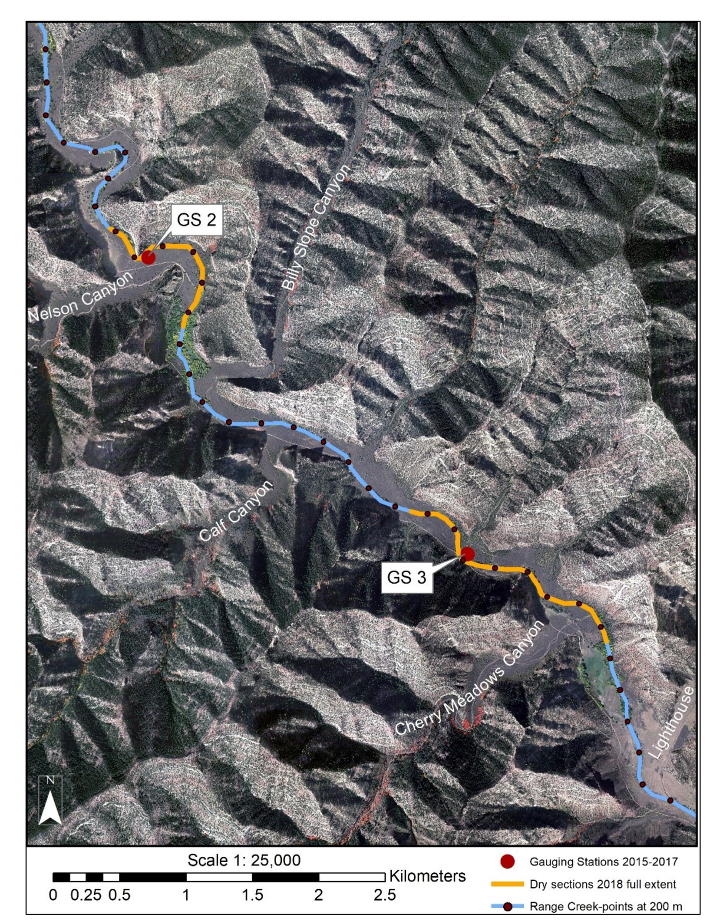

Figure 7. Map showing the full extent of two dry creek sections mapped in 2018. Points along the creek mark 200 meter sections used to map the density and distribution of the nearest surface structures at residential sites.

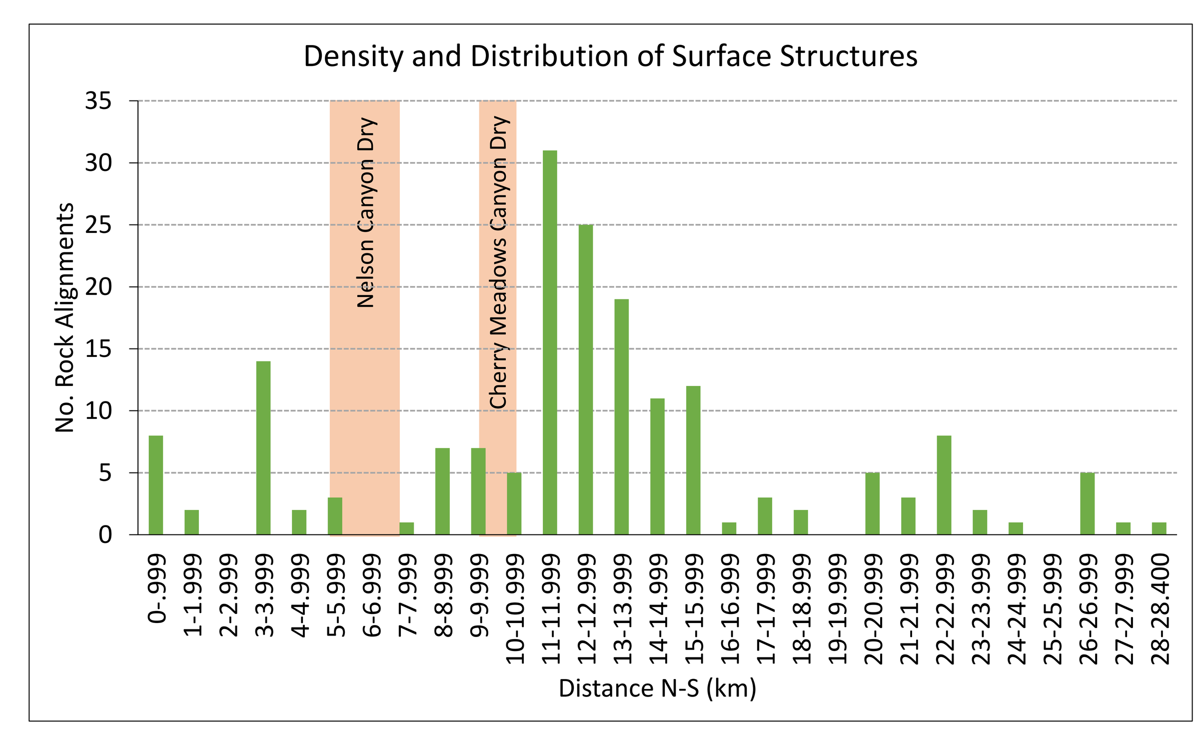

Figure 8. Chart showing the density of surface structures at residential sites relative to points along Range Creek north to south. Shaded sections indicate the full extent of each dry section mapped in 2018. Dashed horizontal lines indicate location of gauging stations.

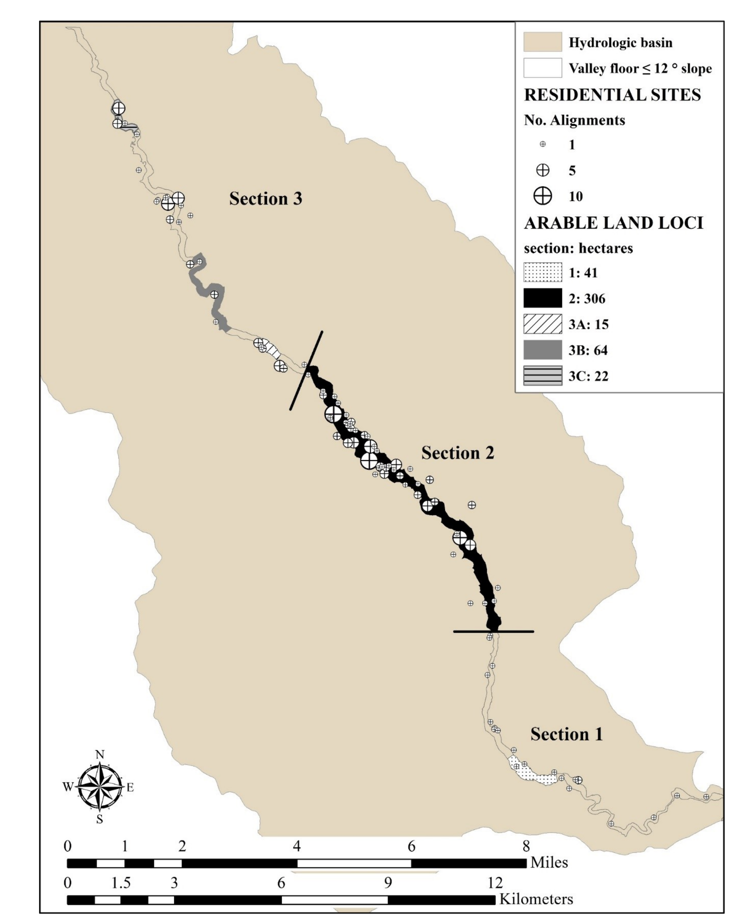

Figure 9. Map showing 3 distinct sections of the canyon. Sections 1 and 3 are topographically distinct from Section 2 which is essentially one large continuous area of arable land not bisected by ridgelines from side canyons. Loci for improved irrigation farming are indicated.