GIS and the Characterization of Quaternary Alluvial Gravel Deposits in the Grand Staircase Region of Southern Utah

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Objectives and Goals

In this study quaternary alluvial gravel deposits were analyzed and interpreted using GIS in an attempt to reconstruct elevations of fluvial terraces. The objective was to first identify which individually mapped deposits can be grouped together as representing one terrace surface based on their location, slope and elevation. Secondly the slopes of these terraces and deposits were compared to the slope of the modern day channel and one another to make preliminary hypothesis as to the fluvial evolution of the Grand Staircase.

Motivation

A broad area of southern Utah is characterized by a unique "stair step" topography and is an area of some of the thickest and relatively complete sedimentary successions of the ancient rock record. Mapped along the plateaus of these steps are groupings of alluvial gravels which are interpreted to be Pleistocene in age (2.588 million years ago to 11,700 years ago). Particular interest has recently developed in these deposits as possible indicators of paleoclimate indicators during the Pleistocene and are key deposits in reconstructing the evolution of this landscape due to river processes. This project will identify a method for using GIS to reconstruct these surfaces and yield preliminary insight into their morphology.

Fluvial Geomorphology – Terraces as Paleochannel Indicators

The driving concept behind the analysis in this study is that terraces are indicators of past river morphology. (Pazziglia, 1998). The deposits of interest (shown in blue Fig. 3) are mapped as quaternary alluvial gravels. Being alluvial, these sediments were last incorporated in a fluvial system before final deposition in their current locations. They are therefore interpreted to be terrace deposits, or deposits directly associated with the modern streams but no longer under their morphological influence. These terraces mark the paleochannel of the associated modern river and will grant insight into characteristics of that channel as compared to present day (Merrits et al. 1994).

Geographic Setting

The region of study is commonly known as the Grand Staircase, just south of the Escalante desert (Fig 1). Notable proximal geologic deformation structures include the San Rafael Swell to the north (a result of subterraneous magmatic channels or dikes) and the Sevier fault line to the east. Apart from these structures the Grand Staircase and the surrounding region of the Colorado Plateau are relatively un-deformed by tectonic activity. This contrasts with the highly deformed and highly active (presently or historically) Rocky Mountain region to the east and Basin-and-Range region to the west.

The stair steps of the Grand Staircase were first described and divided by color in the 1870s by geologist

Clarence Dutton. These has since been further subdivision based on lithology and other facies characteristics but for the purposes of this study Dutton's classification will be used (Fig 2).

Figure 1: Physiographic map of Utah and surrounding states (nps.org/greatbasin)

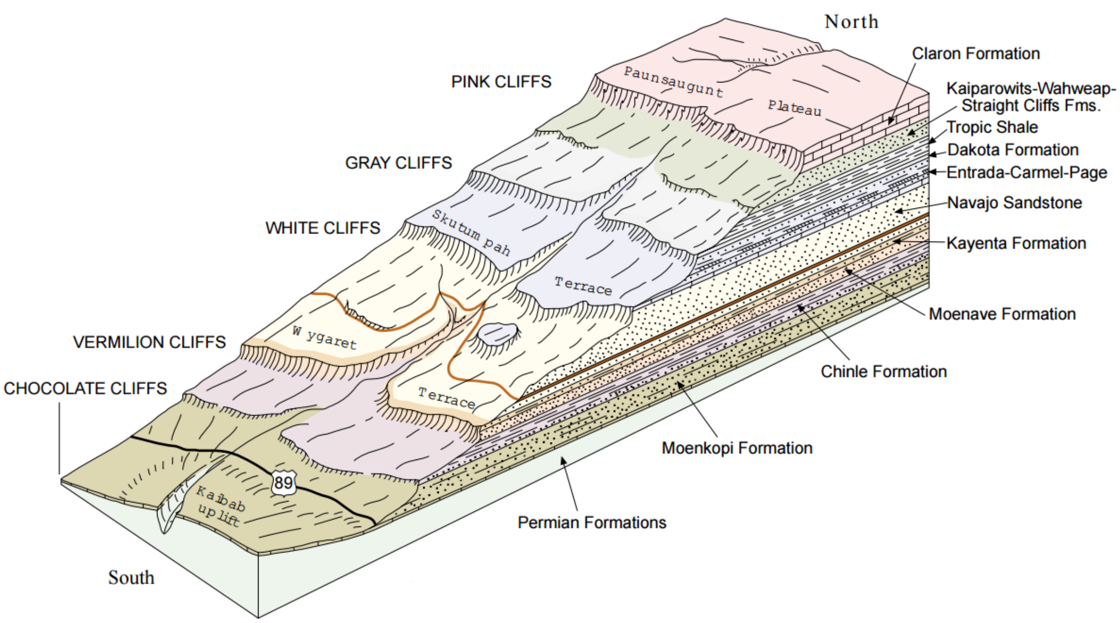


Figure 2: Steps of the Grand Staircase, after (nps.org/grandstaircase)

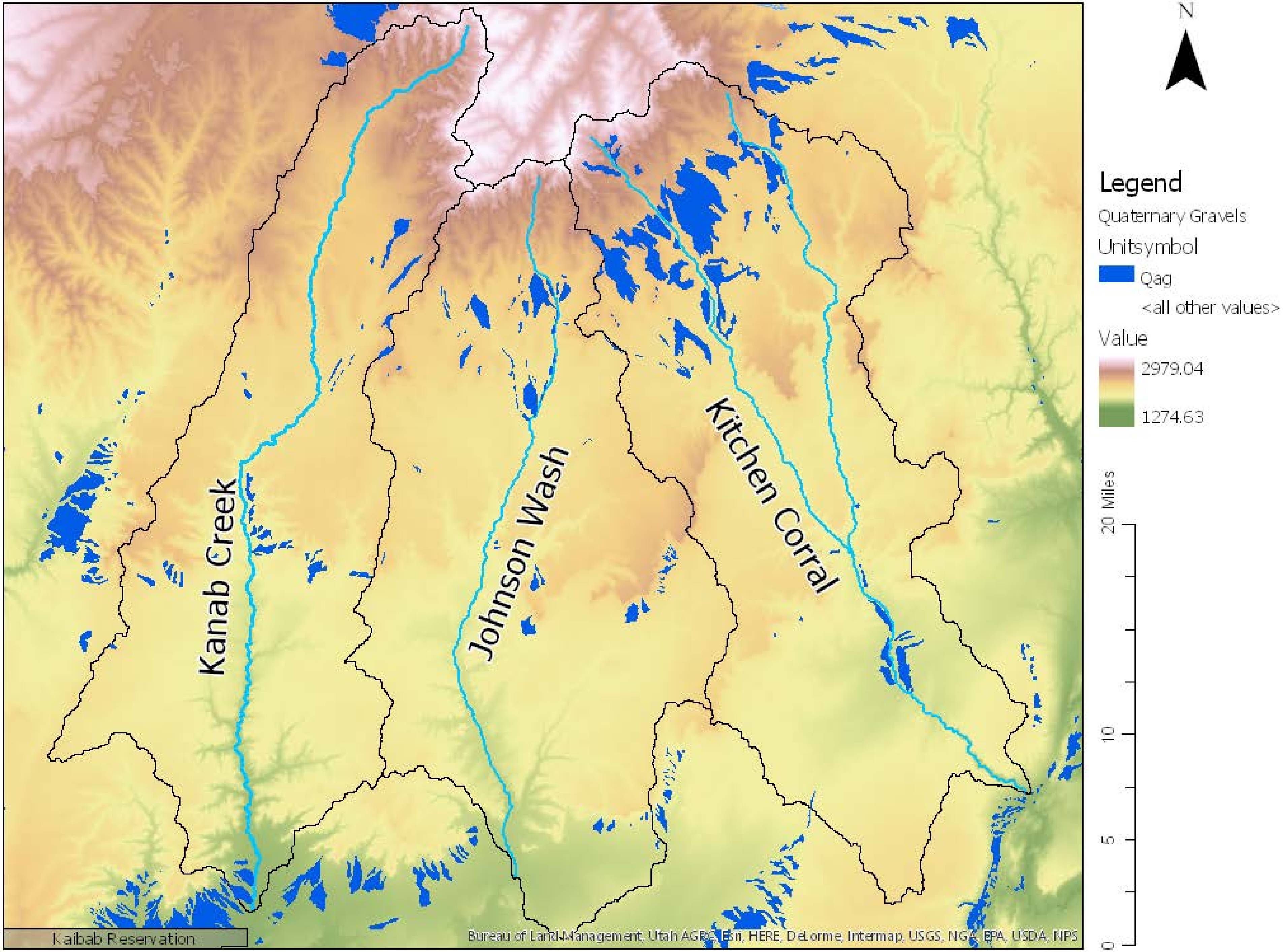


Figure 3: Delineated watersheds for Kanab Creek, Johnson Wash and Kitchen Corral. In blue are the gravel deposits as mapped by the UGS. The base layer is a 10m DEM.

At the top of the stair case are the Pink Cliffs stepping down into the Gray, White, Vermillion and Chocolate cliffs.

This study focuses on a subsection of the Grand Staircase region delineated by the area of the watersheds of Kanab Creek, Johnson Wash and Kitchen Corral; all tributaries to the Colorado River (Fig 3).

Methods

The three watersheds were delineated using the Watershed Delineation tool. The streams were then mapped and extracted using the NHD Plus data provided by the United States Geologic Survey (USGS) National Map Portal. Digital Elevation Data (DEM) data was downloaded from this portal as well. The gravel deposit locations were imported from the Smokey Mountain, Panguitch, Escalante (not yet published) and Kanab 30' x 60' geologic quadrangles available from the Utah Geologic Survey (UGS) GIS data portal. These geologic maps divide each mapped geologic unit into an individual polygon. They can be manipulated by common age, lithology and description. To identify the deposits needed for this analysis, all deposits marked "Qag" or described as alluvial gravel were exported to their own feature dataset and are shown in blue in Figure 3. Data gaps are present in the very south western corner of the study area due to land ownership by the Kaibab Tribe of Native Americans.

With this data points were then generated along the stream reaches and hand mapped lines drawn down the longitudinal axis of the deposits (generally north-south). Elevation data was then extracted from the underlying DEM and X, Y (UTM) data was subsequently added. The data was then extracted to and manipulated in excel.

To do this multiple times for multiple watershed and deposits a model was built using the Model Builder function.

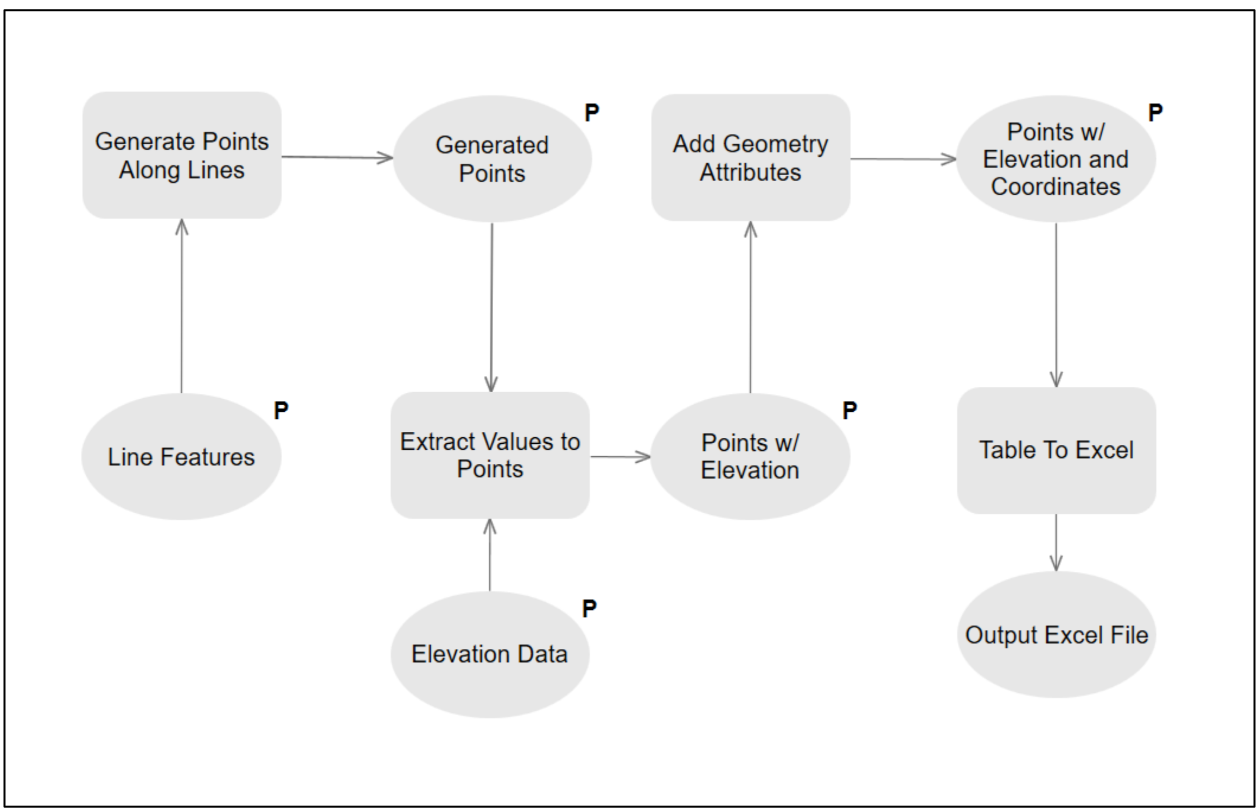


Figure 4: "Profile along a Line" tool developed to derive elevation profiles.

It is noted that ArcGIS Pro has an "Elevation Profile Tool" however there are no resources or help pages yet availabe on how to use the tool, the outputs are non-intuitive and were therefore unusable at this stage. A model like the one above is entirely redundant of the 3D Analyst – Profile tool previously available in ArcGIS 10.3. This method was only developed due to the incompatability of the two versions of ArcGIS. Once the model was run the slope of the deposists were analyzed and paleoterrace surfaces were constructed in excel.

Results and Discussion

The resulting profiles are included at the end of this section. They are plots of the longitudinal profiles of the rivers (blue) and the quaternary alluvial deposits most proximal to their channel banks. They are numbered to match the deposits shown in the accompanying map view images.

Some deposits showed clear signs of incision and post-deposition alteration. Incision was interpreted as large gradient changes over a relatively short distance along the deposits length. To calculate the slope of these deposits only the points of the unaltered/un-incised surface were used. Furthermore, only deposits with 2 or more points along an unaltered surface that were in context (had data available on either side) were used in terrace surface reconstruction.

Johnson Wash

The profile for Johnson Wash yielded the most coherent and easily interpreted results. Deposits in the northern reach were largely unaltered by severe incision/erosion. Deposit 3 was not included in the analysis because its profile crosses that of the modern channel suggesting that this deposit is likely associated with some other additional processes or was incorrectly mapped.

Deposits along northern Johnson Wash indicate multiple terrace levels by their difference in elevation. The deposits likely forming parts of the same terrace are T2 and T4. The other deposits likely represent their own individual terraces. The slopes of all included terraces are very similar to one another and to the slope of the modern channel.

The deposits along the southern reach of Johnson Wash were also largely unaltered. Deposits 8, 11 and 15 were treated as having been incised and only select points were used in slope calculations as described above. Deposits 6, 14 and 15 were interpreted to represent the surfaces of a single terrace due to their similar slope, elevation and R^2 value of the fitted trend line. A second terrace surface was interpreted from the surfaces of deposits 5 and 8. Deposits 10 and 11 were essentially flat lying. Because of their proximity to deposit 15, a deposit which demonstrates high amounts of incision, deposits 10 and 11 may be remnants of severely altered terraces. The slope of the reconstructed terraces are similar to one another but steeper than the current stream gradient.

Kanab Creek and Sink Valley Wash

In the Kanab Creek watershed many of the deposits aligned along the banks of Sink Valley Wash instead of the main stem of Kanab Creek. Deposits 5-15 are therefore plotted against Sink Valley Wash. The deposits were also highly eroded and incised. No flat lying deposits were found and therefore slopes and terrace reconstruction is based off of points along the interpreted unaltered surfaces.

In the Northern reach of Sink Valley Wash deposits 14 and 15 intersect the modern channel and are therefore not analyzed. This leaves a scarcity of deposit data and therefore a focus is given to the southern reach. In the southern reach deposits 4, 6 and 8 demonstrated similar profiles and their unaltered surface points were used to reconstruct a terrace surface. Deposits 5, 7 and 10 were too altered to map their slope so no interpretation was able to be made. The slope of the terrace that was reconstructed was approximately twice that of the modern channel.

Kitchen Corral

The results for Kitchen Corral were anomalously much distorted and clearly subject to an unknown source of error in either process or data collection, therefore they were not able to be meaningfully analyzed and are unfortunately not included in this report.

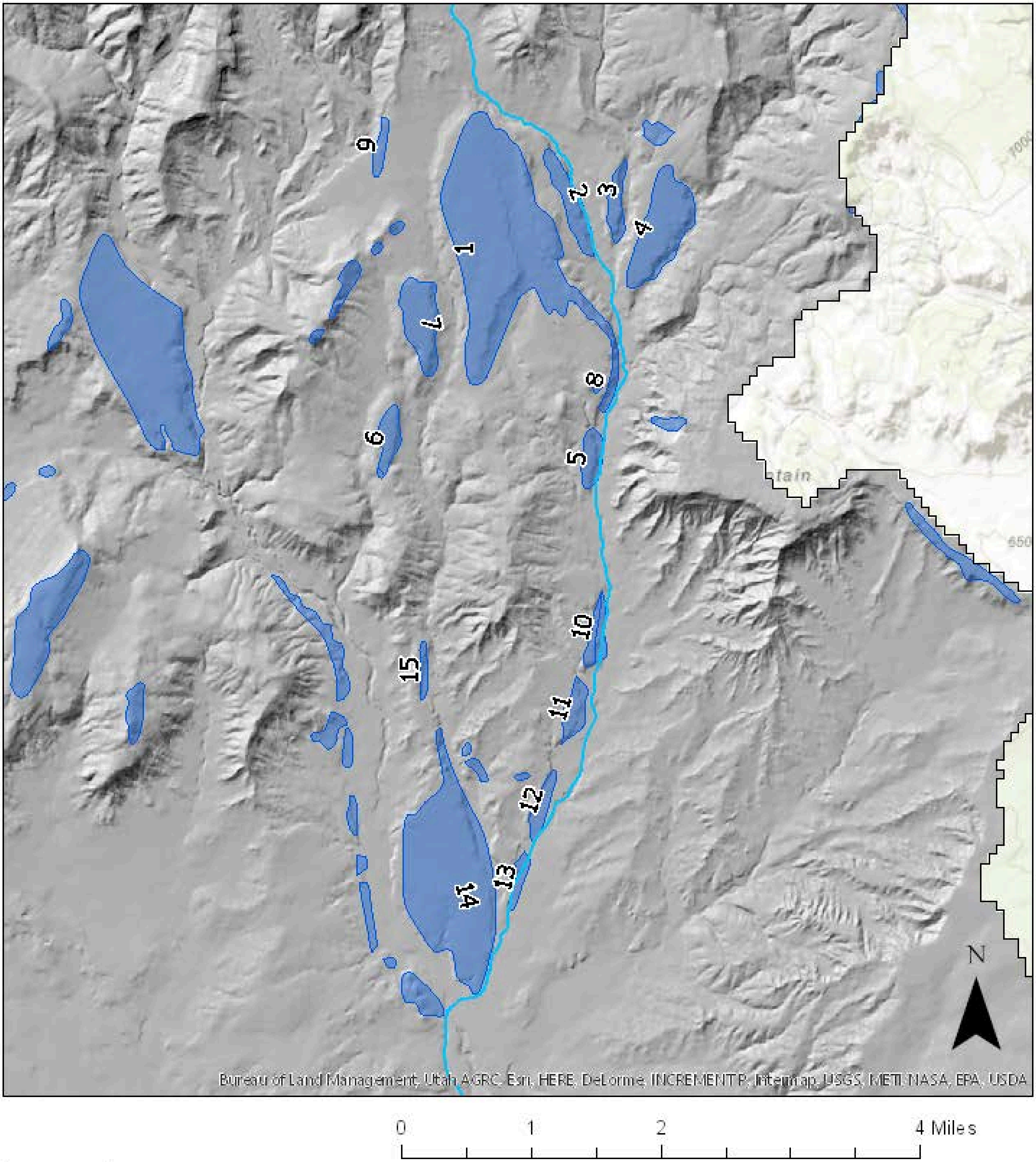
Conclusions

The method of defining terraces based on similar slope and elevation of individually mapped deposits was successfully done using GIS. The reconstructed terraces and the deposits themselves grant us some insight into the evolution on the Grand Staircase. Considering the slope of the deposits themselves and their similarity, it suggests a system in equilibrium during the Pleistocene (Pazziglia, 1998). If the system were in flux we would expect to see larger deviation in individual deposit slopes and this method of terrace reconstruction would likely have been unsuccessful. The main allogenic influence on fluvial systems is tectonic activity followed closely by climate. Because the deposits are demonstrating an equilibrated system, it is hypothesized that during the interval between their deposition there was very little tectonic activity or climate fluctuation. However, compared to the modern channel the deposits are much steeper (in terms of river slopes) and this change suggests a climactic fluctuation between the time of terrace deposition and present day (Merritts et al. 1994). Tectonics is not considered to be as important in this region because of the characteristically flat lying strata of the Colorado Plateau and the Grand Staircase.

This is an ongoing project and is a small step in the thesis work that will be conducting. No definitive conclusions can be made at this time. In addition to GIS analysis, age data for these deposits will be collected. While some dates are available there are too few to make any meaningful conclusions. In the future as an end result of the thesis work related to this term project there will hopefully be a development of a correlation between terrace age, slope and elevation that can be demonstrated and used to predict what age one might expect a deposit to be based on its morphology and location. These ages may also correlate to established events in earth history and further develop the fluvial evolution of this landscape.

Johnson Wash Figures

Quaternary Alluvial Gravel Deposits Along Johnson Wash



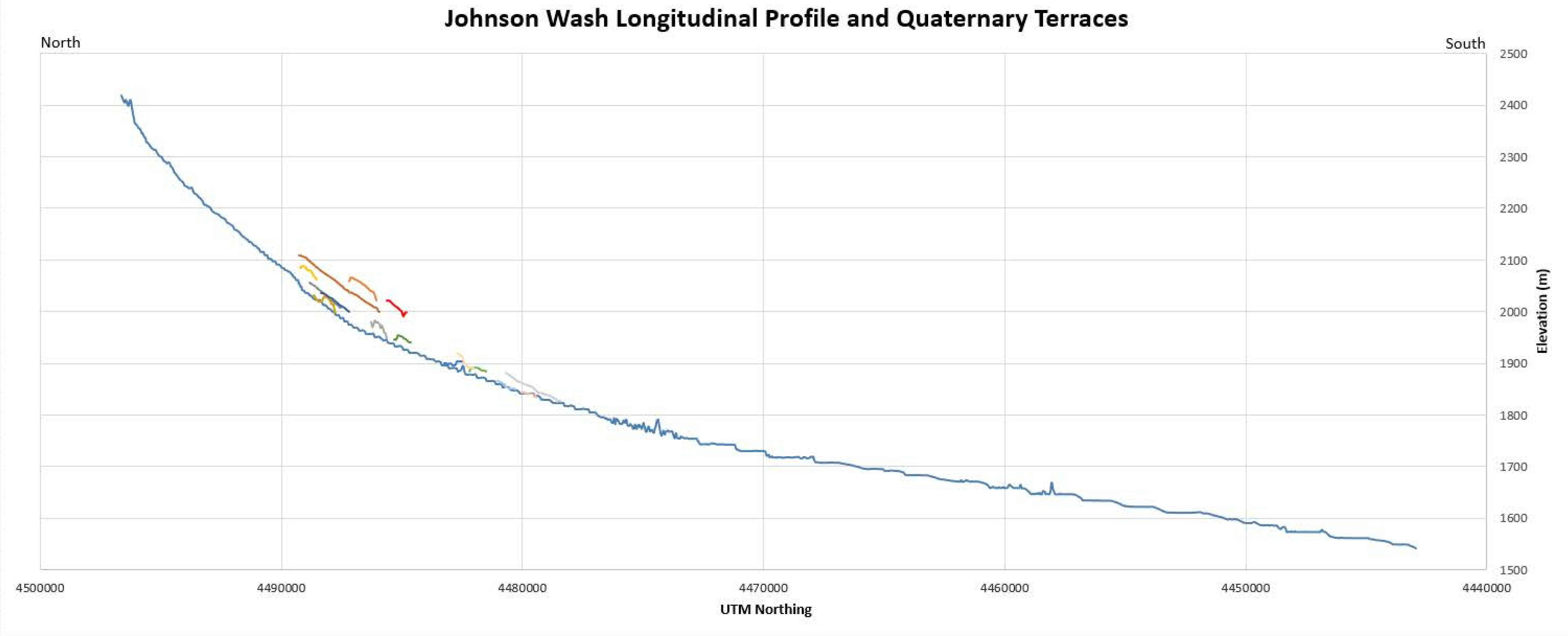
Legend

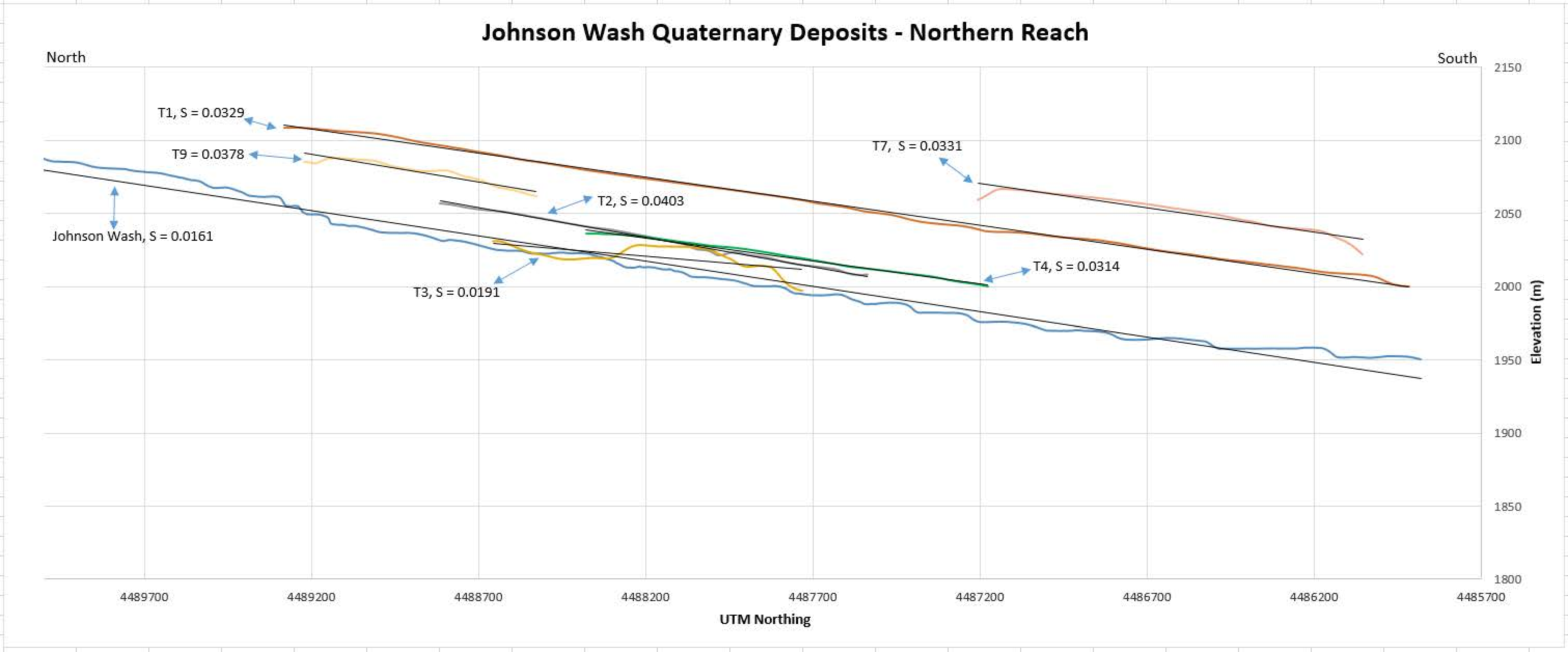
Quaternary Alluvial Gravels

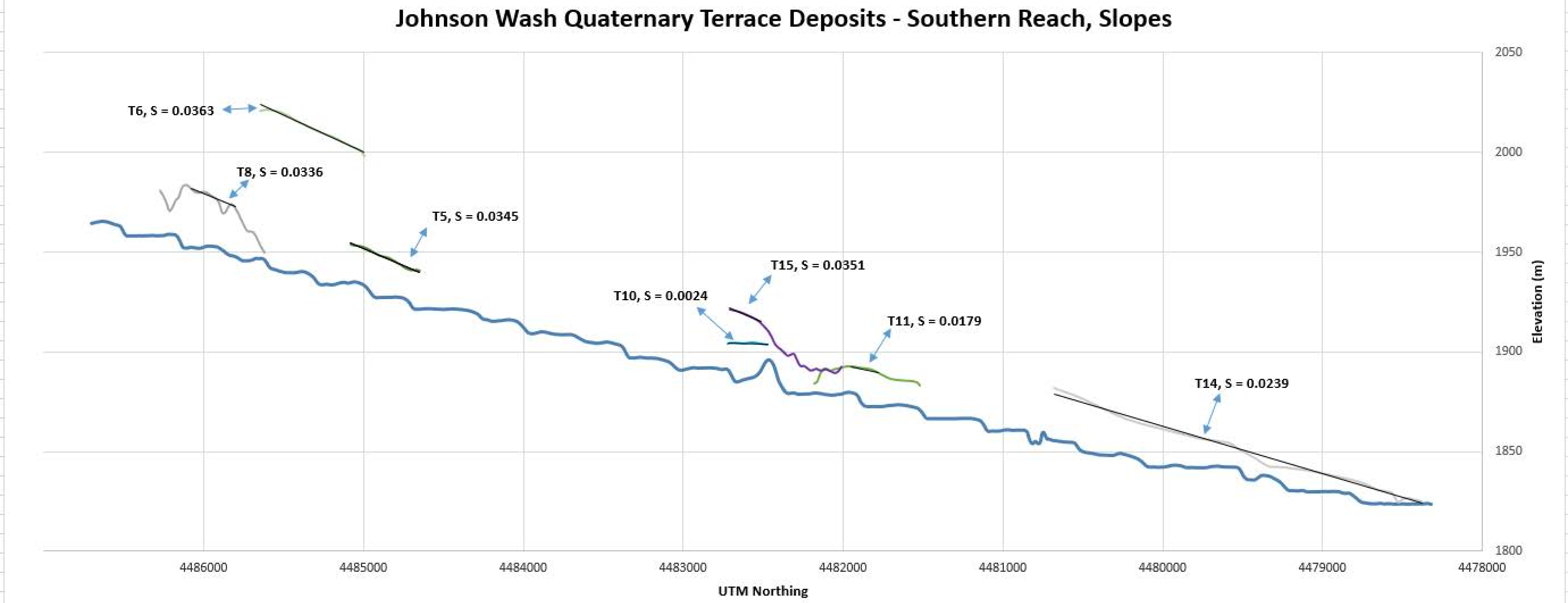
Unitsymbol

Qag

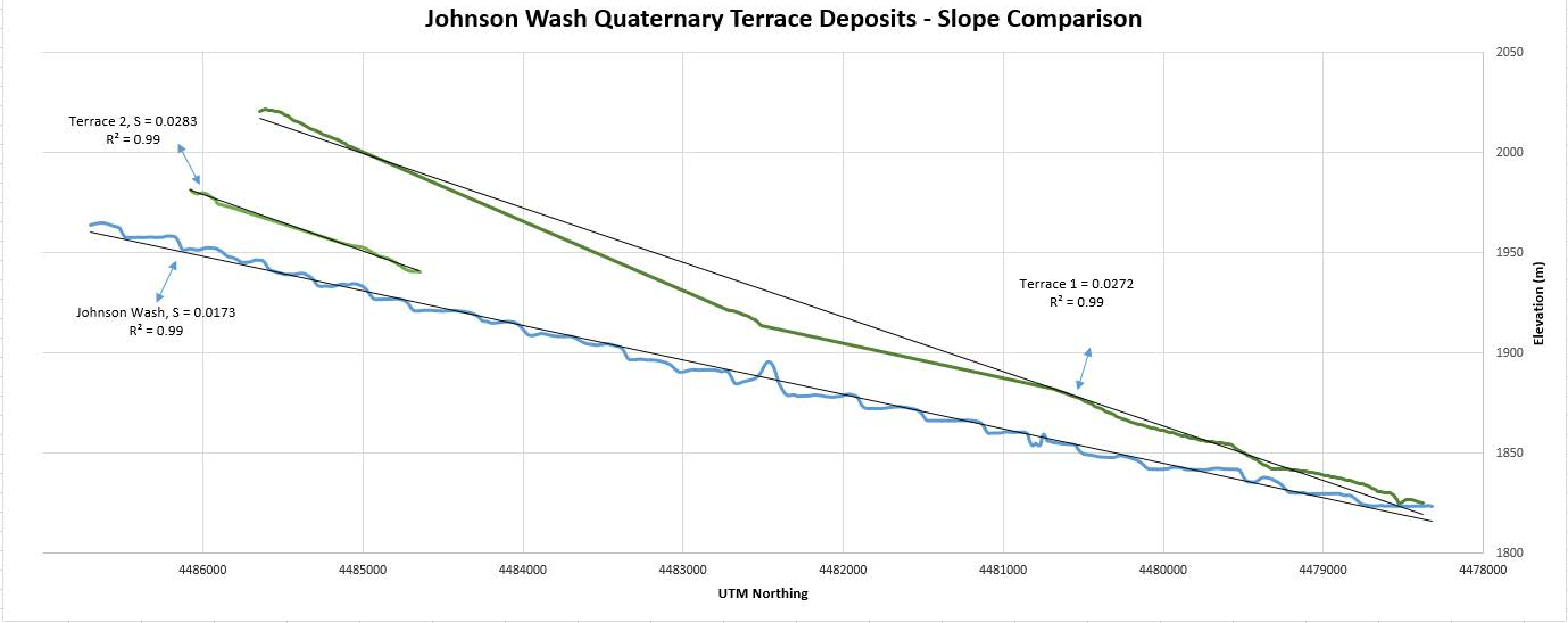
<all other values>


Johnson Wash Longitudinal Profile and Quaternary Terraces
North
South
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
Elevation (m)
4500000
4490000
4480000
4470000
4460000
4450000
4440000
UTM Northing


Johnson Wash Quaternary Deposits - Northern Reach
North
South
T1, S = 0.0329
T9 = 0.0378
T7, S = 0.0331
T2, S = 0.0403
Johnson Wash, S = 0.0161
T4, S = 0.0314
T3, S = 0.0191
2150
2100
2050
2000
1950
1900
1850
1800
Elevation (m)
4489700
4489200
4488700
4488200
4487700
4487200
4486700
4486200
4485700
UTM Northing



Johnson Wash Quaternary Terrace Deposits - Southern Reach, Slopes
T6, S = 0.0363
T8, S = 0.0336
T5, S = 0.0345
T15, S = 0.0351
T10, S = 0.0024
T11, S = 0.0179
T14, S = 0.0239
2050
2000
1950
1900
1850
1800
Elevation (m)
4486000
4485000
4484000
4483000
4482000
4481000
4480000
4479000
4478000
UTM Northing

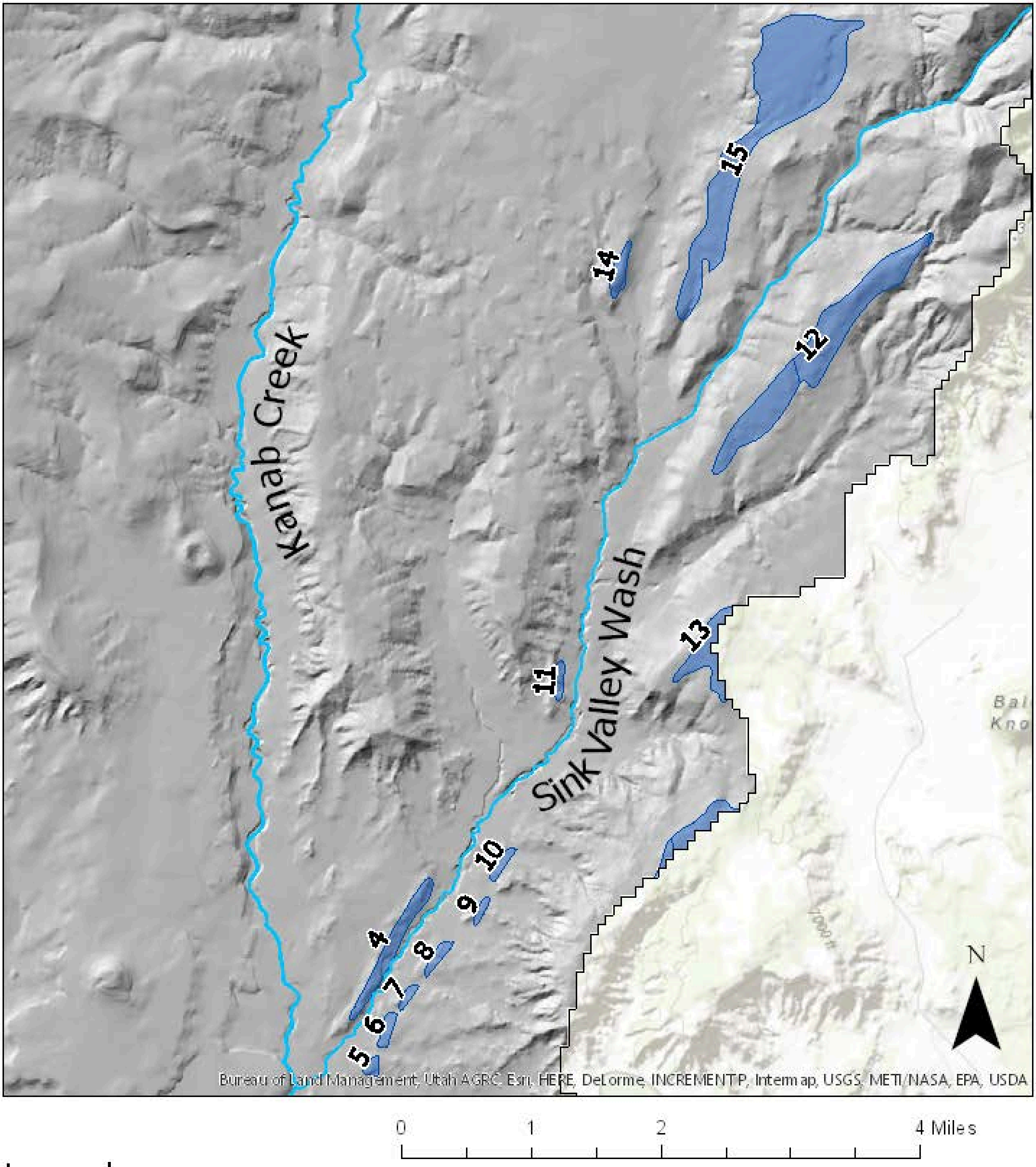


Johnson Wash Quaternary Terrace Deposits - Slope Comparison
Terrace 2, S = 0.0283
R^2 = 0.99
Johnson Wash, S = 0.0173
R^2 = 0.99
Terrace 1 = 0.0272
R^2 = 0.99
2050
2000
1950
1900
1850
1800
Elevation (m)
4486000
4485000
4484000
4483000
4482000
4481000
4480000
4479000
4478000
UTM Northing

Sink Valley Wash Figures

1. Map View of Deposits
2. Sink Valley Longitudinal Profile
3. Sink Valley Wash Southern Deposits
4. Reconstructed Terrace
5. Slope Comparison

Quaternary Alluvial Gravel Deposits Along Sink Wash



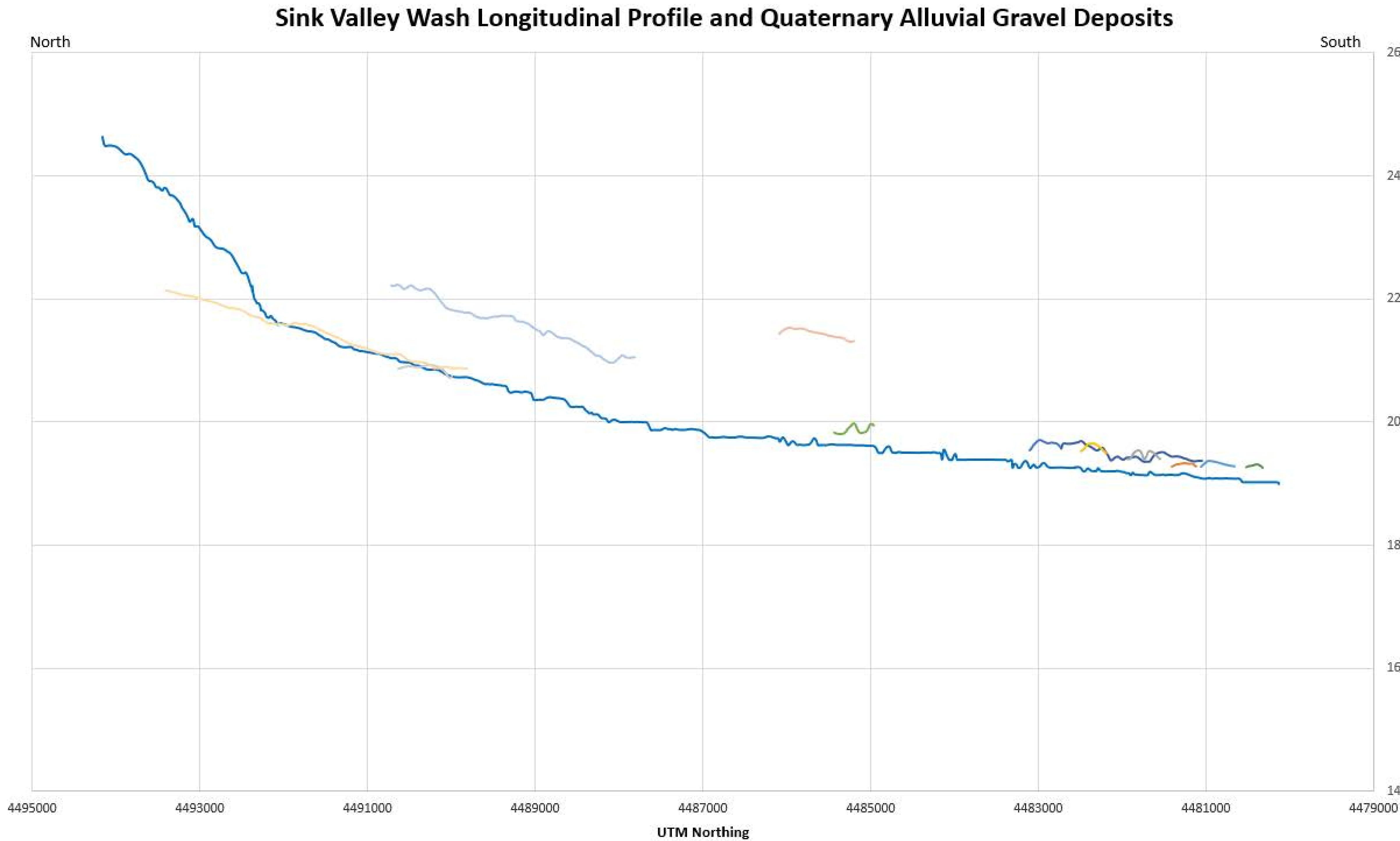
Legend

Quaternary Gravels

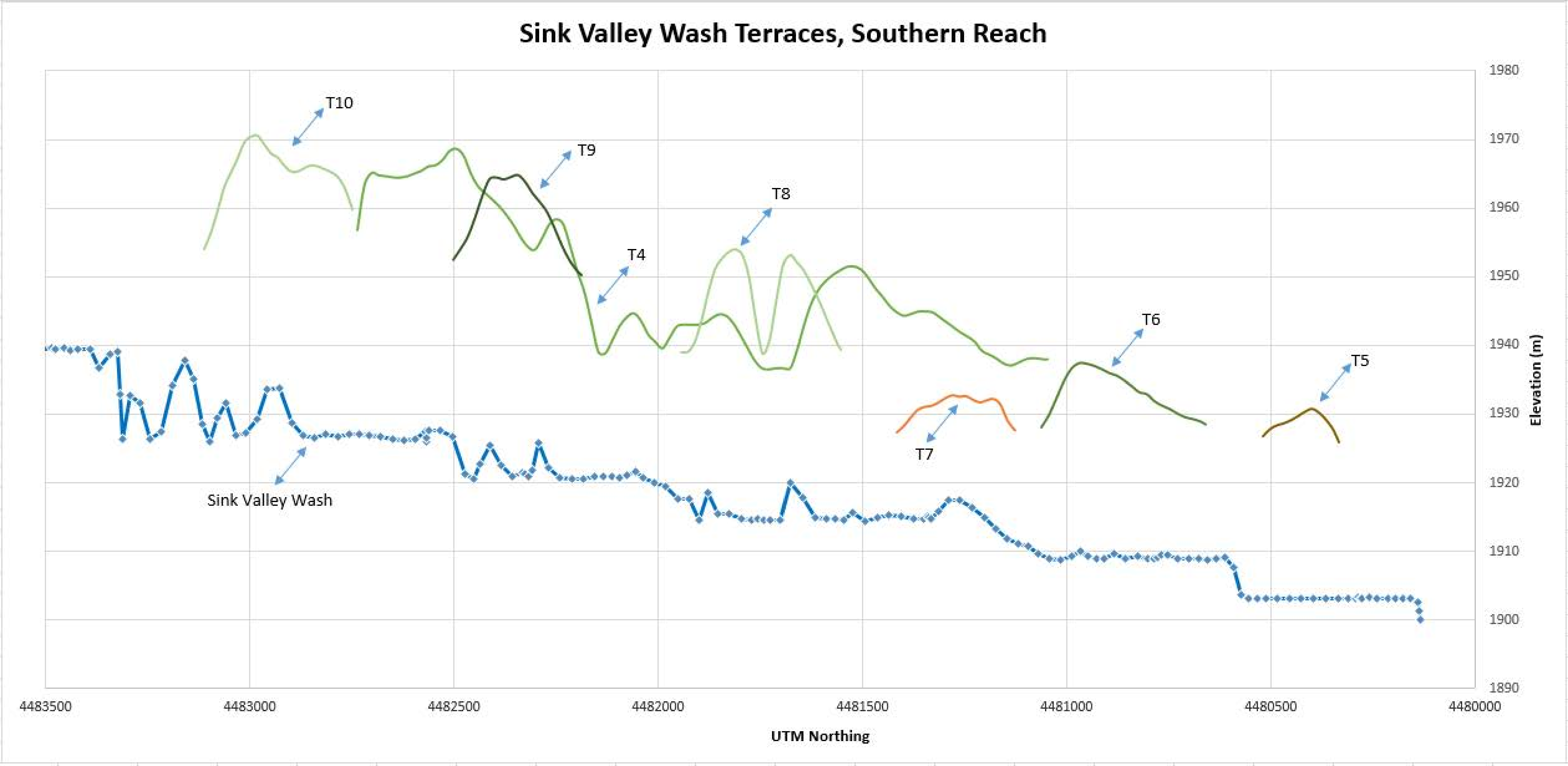
Unitsymbol

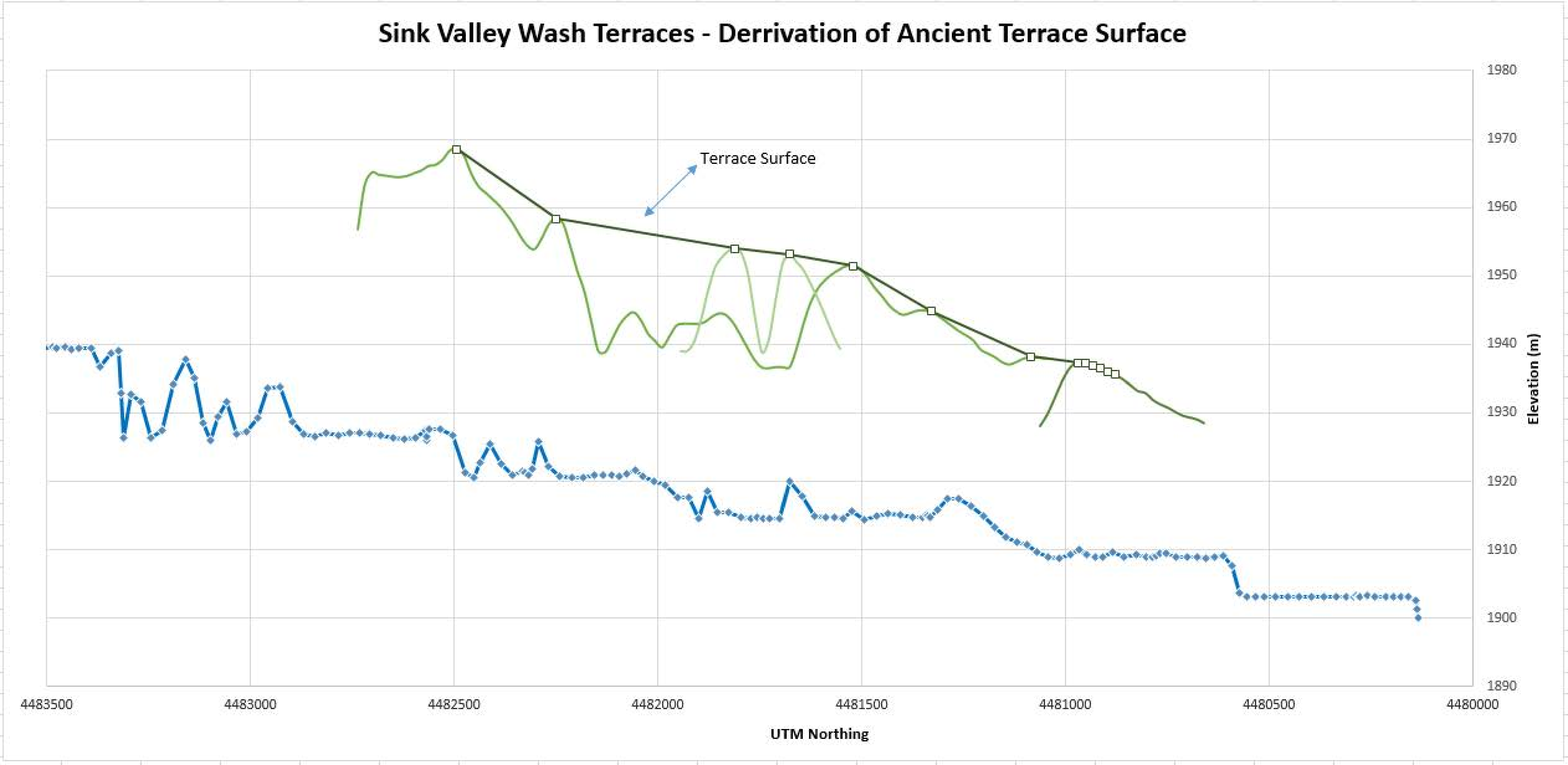
Qag

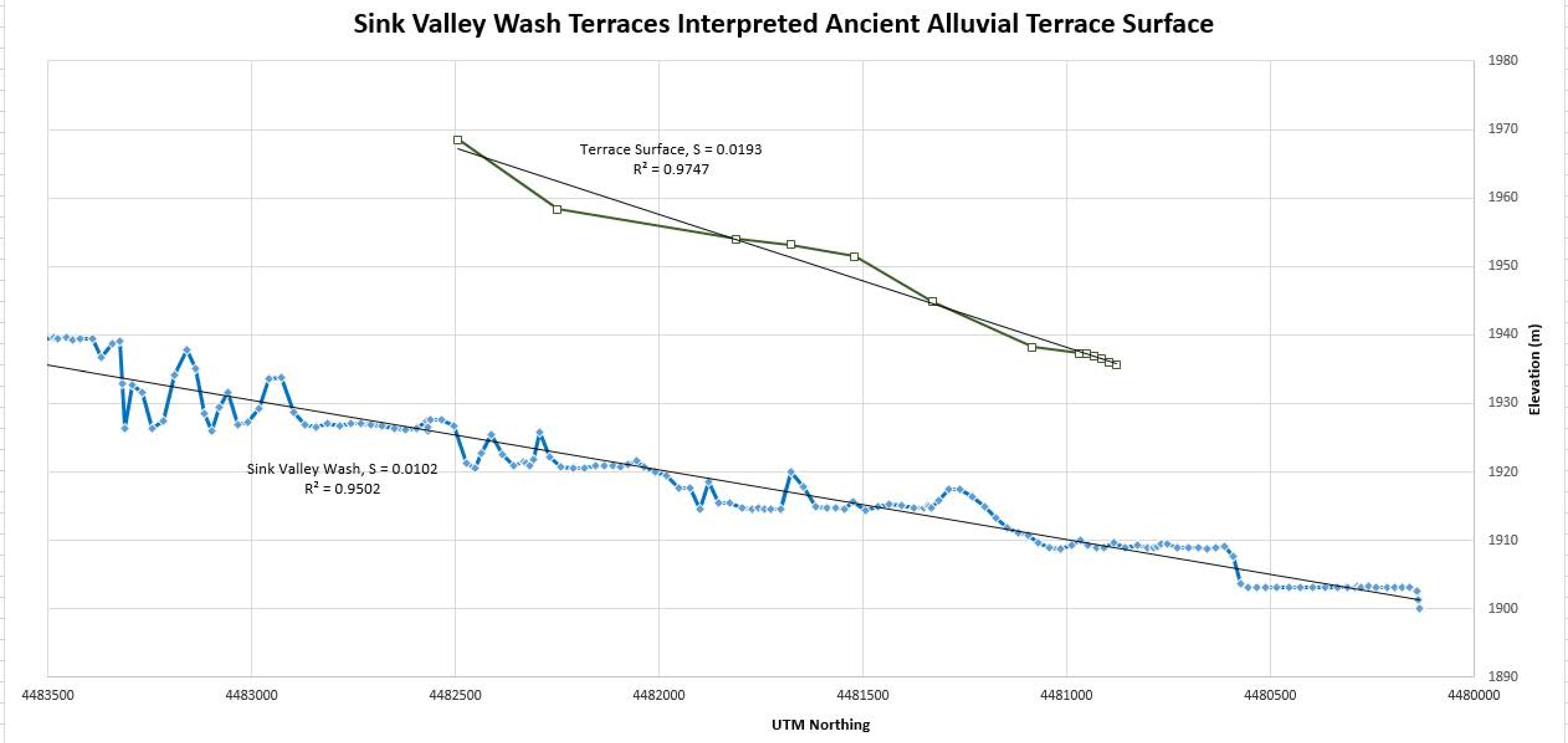
<all other values>



Sink Valley Wash Longitudinal Profile and Quaternary Alluvial Gravel Deposits
North
South
2600
2400
2200
2000
1800
1600
1400
Elevation (m)
4495000
4493000
4491000
4489000
4487000
4485000
4483000
4481000
4479000
UTM Northing


Sink Valley Wash Terraces, Southern Reach
T10
T9
T8
T4
T6
T5
T7
Sink Valley Wash
1980
1970
1960
1950
1940
1930
1920
1910
1900
1890
Elevation (m)
4483500
4483000
4482500
4482000
4481500
4481000
4480500
4480000
UTM Northing


Sink Valley Wash Terraces - Derrivation of Ancient Terrace Surface
Terrace Surface
Elevation (m)
UTM Northing
1980
1970
1960
1950
1940
1930
1920
1910
1900
1890
4483500
4483000
4482500
4482000
4481500
4481000
4480500
4480000



Sink Valley Wash Terraces Interpreted Ancient Alluvial Terrace Surface
Terrace Surface, S = 0.0193
R² = 0.9747
Sink Valley Wash, S = 0.0102
R² = 0.9502
1980
1970
1960
1950
1940
1930
1920
1910
1900
1890
Elevation (m)
4483500
4483000
4482500
4482000
4481500
4481000
4480500
4480000
UTM Northing

References

Pazzaglia, F.J., Gardner, T.W., and Merritts, D.J., 1998, Bedrock fluvial incision and longitudinal profile development over geologic time scales determined by fluvial terraces: Rivers Over Rock: Fluvial Processes in Bedrock Channels Geophysical Monograph Series, p. 207–235, doi: 10.1029/gm107p0207.

Merritts, D.J., Vincent, K.R., and Wohl, E.E., 1994, Long river profiles, tectonism, and eustasy: A guide to interpreting fluvial terraces: Journal of Geophysical Research: Solid Earth, v. 99, p. 14031–14050, doi: 10.1029/94jb00857.