Skunk Camp Tailings Storage Facility

Dripping Spring Wash Geomorphic Impact Assessment

April 2020

prepared for
Resolution Copper LLC

JE FULLER
8400 S Kyrene Rd, STE 201
Tempe, AZ 85284
www.jefuller.com

Table of Contents

List of Figures

List of Tables

Appendices

Appendix A – Field Photographs

1 PURPOSE

Resolution Copper LLC (RC) is proposing to develop an underground copper mine project near the community of Superior, Arizona. The project will result in approximately 1.4 billion tons of tailings over the mine's expected 41-year life span. The preferred alternative identified in the Draft Environmental Impact Statement (DEIS) (Alternative 6) is in the upper watershed area of Dripping Spring Wash which is located approximately 1 mile to the northeast of the Asarco Ray open pit mine (Figure 1-1). Alternative 6 is referred to as the Skunk Camp Tailings Storage Facility (TSF) in the DEIS; named for one of the tributary drainages of Dripping Spring Wash. Additionally, a Public Notice for a Clean Water Act (CWA) Section 404 permit has been released for comment for the Skunk Camp TSF.

Key design elements of the Skunk Camp TSF outlined in the DEIS include:

- *Alternative 6 would use a centerline-raised compacted cycloned sand embankment. A portion of the scavenger tailings would be cycloned to create two products: cycloned (underflow) sand used to construct the embankment; and finer overflow tailings would be deposited into the scavenger beach.*
- *Pyrite tailings would be discharged subaqueously from a floating barge or pipelines directly into the reclaim pond, to maintain pyrite tailings saturation during operations for the benefit of water quality.*
- *Low-permeability, segregated pyrite tailings cells contained by downstream-raised embankments incorporating engineered low-permeability layers to manage downstream water quantity and quality. The reclaim pond would be maintained within the pyrite tailings cell. Pyrite tailings would be kept saturated to prevent oxidation, in order to control water quality concerns associated with pyrite tailings.*
- *Tailings will be piped to the Skunk Camp TSF site from West Plant via a pipeline.*
- *Tailings would be pumped to the TSF rather than flow by gravity to increase reliability and reduced potential for pipeline upsets (i.e. sanding of the lines) and associated spills.*

The main benefits of Alternative 6 are:

- *that it is located far from population centers and close to other mining areas, in an area of low-density population, and generally out of public view;*
- *that the site location reduces thousands of acres of impact to National Forest System lands;*
- *Incorporates a robust and resilient tailings approach aligned with the most stringent criteria per international standards and federal and state regulations. This includes a double-embankment approach with a centerline and a downstream dam, in one impoundment;*
- *that it has topography that is amenable for embankment construction and tailings storage, and;*
- *that the Gila River, the downstream receiving water body is located approximately 13 miles from the TSF.*

Site details for the Skunk Camp TSF were provided as digital GIS shapefiles by RC and are shown in Figure 1-2. The individual elements shown in the figure will be referenced throughout this report.

The overall purpose of this study is to investigate the potential geomorphic impacts to Dripping Spring Wash downstream from the Skunk Camp TSF project.

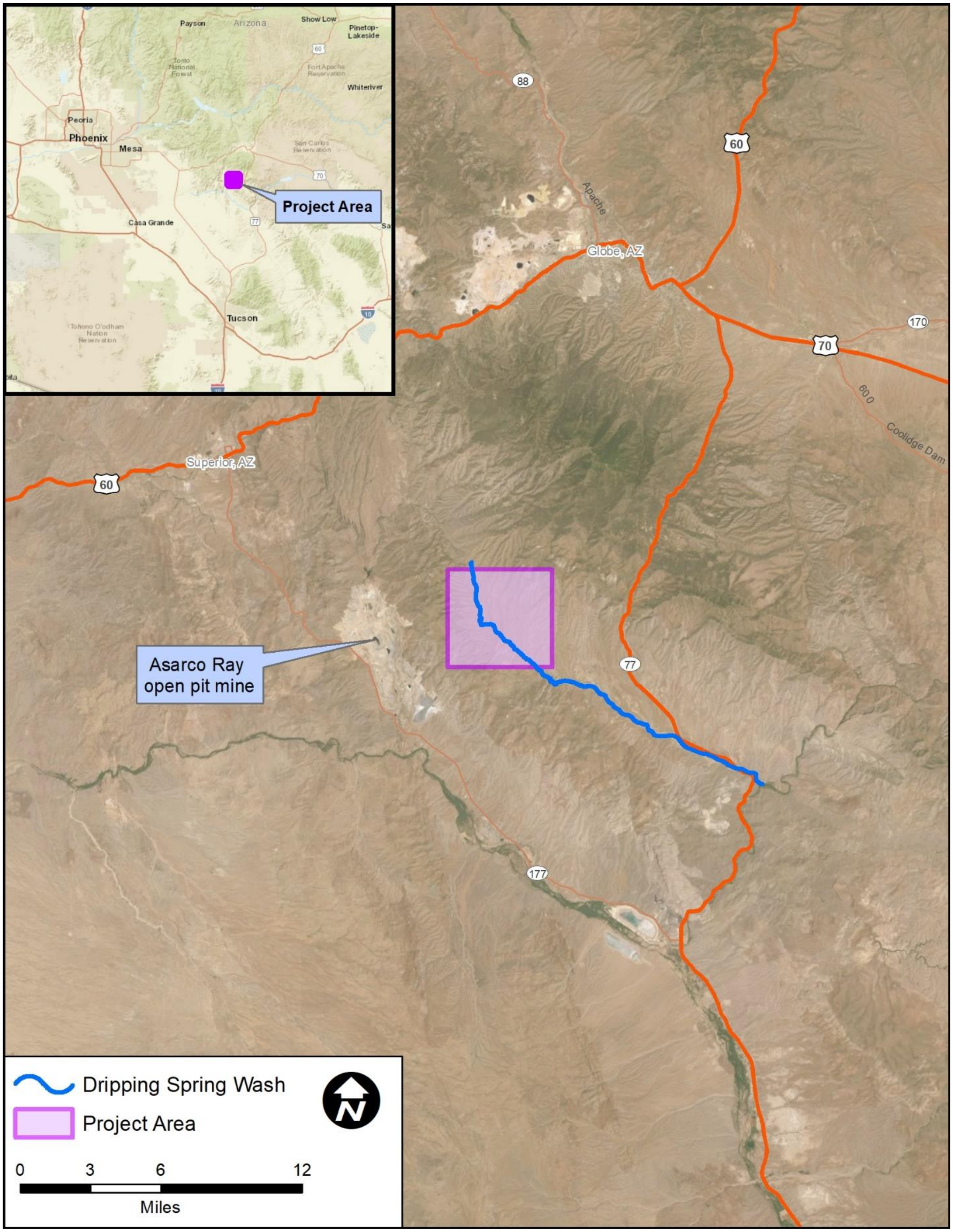


Figure 1-1. Project vicinity map

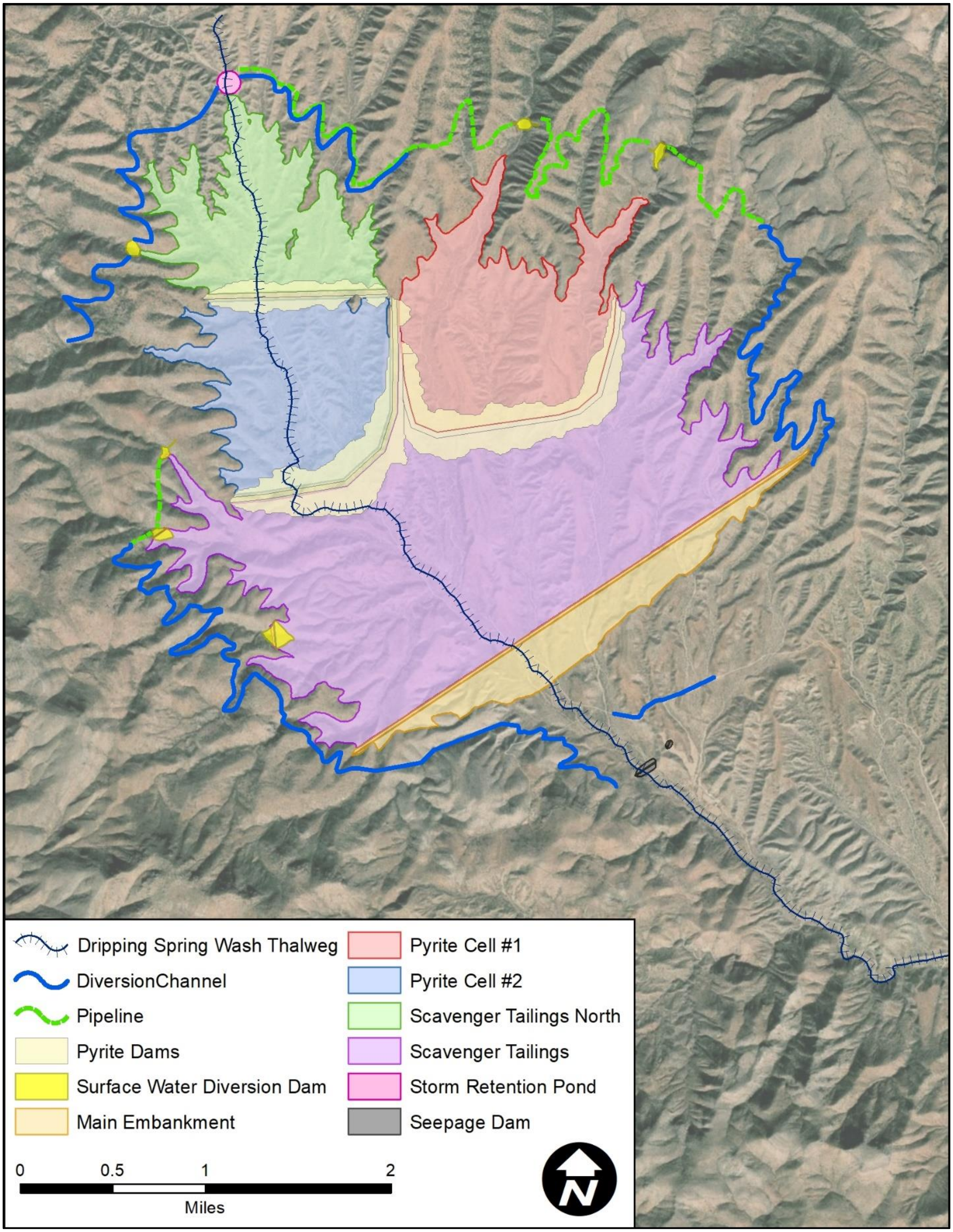


Figure 1-2. Skunk Camp TSF site details (source: RC)

2 Geomorphic Assessment

2.1 Geologic Setting

Dripping Spring Wash is a tributary to the Gila River and has a total watershed area of 117 square miles. The main channel thalweg is approximately 18 river miles in length as measured from the headwater to the Gila River confluence. The active channel corridor can be generally described as an incised alluvial valley with widths varying from less than 200 feet near the headwater to over 1,200 feet in the lower watershed area. The alluvial valley is bound by older geologic surfaces (primarily Pleistocene[1] to Miocene[2] in age) (Banks et al. 1977, Cornwall et al. 1978) which have well-developed tributary drainage networks indicating their geologic maturity. Dripping Spring Wash can be logically divided based on active channel corridor width into an upper watershed area extending from the headwaters to Dripping Spring, and a lower watershed area extending from the Dripping Spring to the Gila River. The active channel corridor within the downstream watershed area is significantly wider than the lower watershed area due to the addition of many large tributaries (including Silver Creek which comprises 23% of the total watershed area of Dripping Spring Wash) (Figure 2-1).

2.2 Channel Pattern

The slope of a stream has a strong influence on the channel pattern for a given discharge. Numerous researchers have used empirical data, flume studies, and other physical relationships to establish a threshold slope that separates stream patterns. Comparing the empirical relationships to what is observed in the existing conditions can help determine whether a drainage system is in an equilibrium condition (stable) or in a state of disequilibrium (unstable/recovery). Channel slope, discharge, and sediment transport all play a role in the morphology of the system.

2.2.1 Slope

A longitudinal profile of Dripping Spring Wash was created using available topographic data sources. The purpose of the slope analysis is to segregate the thalweg into reaches of similar slope to assess the channel pattern. Two topographic sources were used for this analysis:

- 2-foot contour-interval GIS shapefiles provided by RC
- U.S. Geological Survey (USGS) 10-meter digital elevation model (DEM) raster files

The contour shapefiles did not cover the entire reach that was needed for this analysis, so the USGS data was used to supplement. Figure 2-2 shows the extents of each topographic data set. After assessing the profile plot, the study reach was divided into seven segments based on major slope changes. A longitudinal profile plot illustrating the limits of each reach segment, its average slope, and geographic references is shown in Figure 2-3. The average slope for each reach segment is listed in Table 2-1. The results indicate that the slope of Dripping Spring Wash is consistently around 2% through most of the reach within the Skunk Camp TSF.

[1] Geologic Epoch spanning the past 2.6 million years.
[2] Geologic Epoch spanning the past 23 million years.

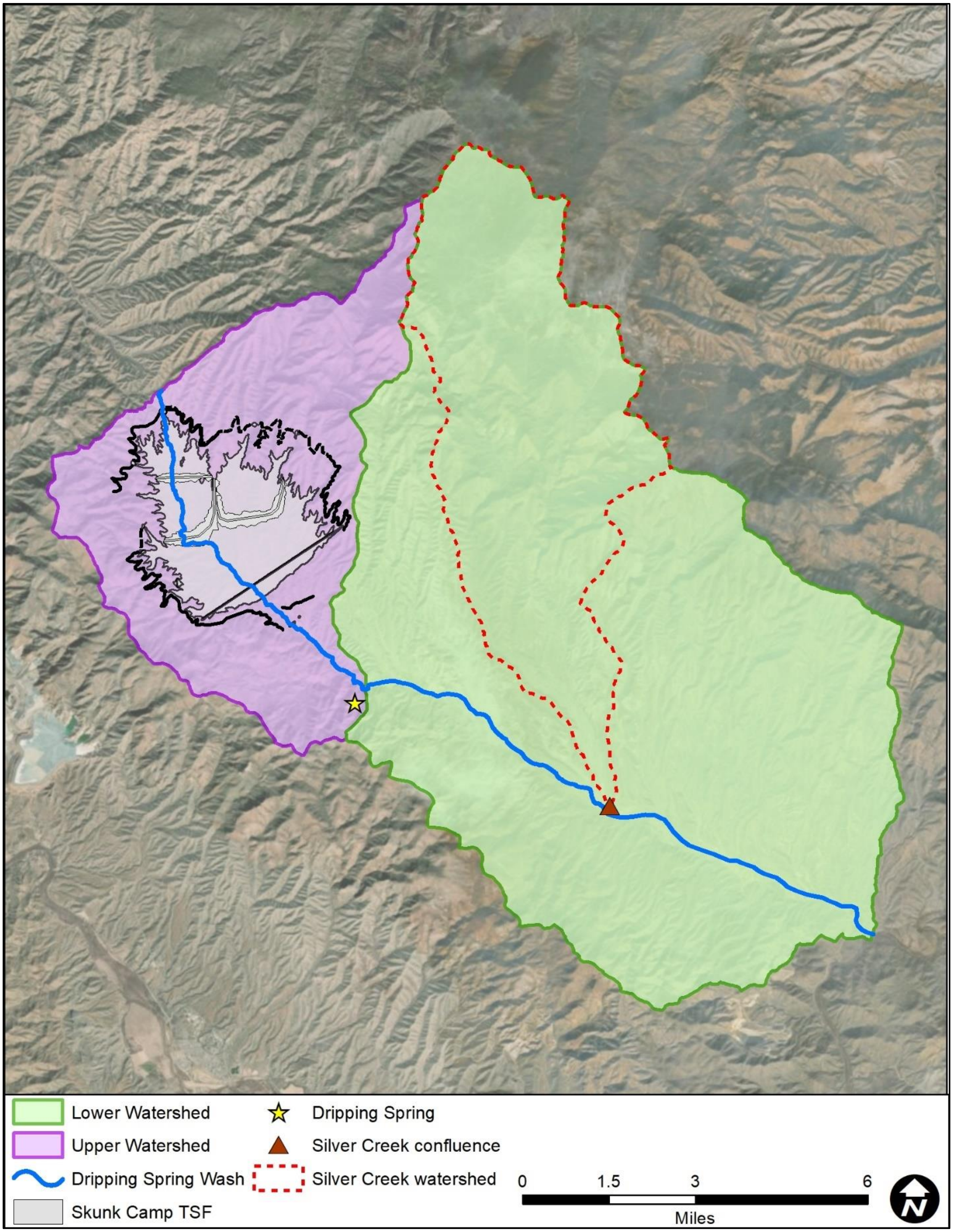


Figure 2-1. Upper and lower watershed demarcation

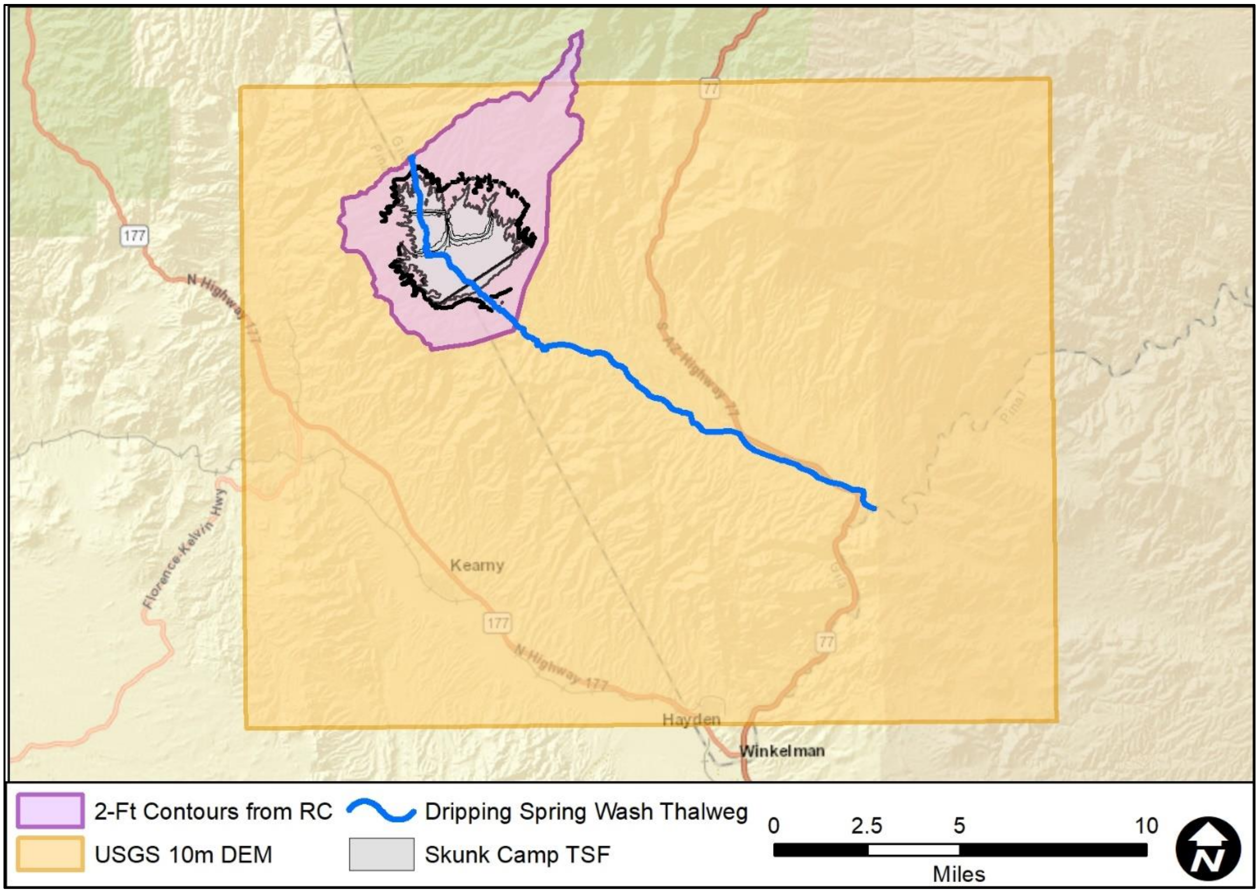


Figure 2-2. Topography data sources

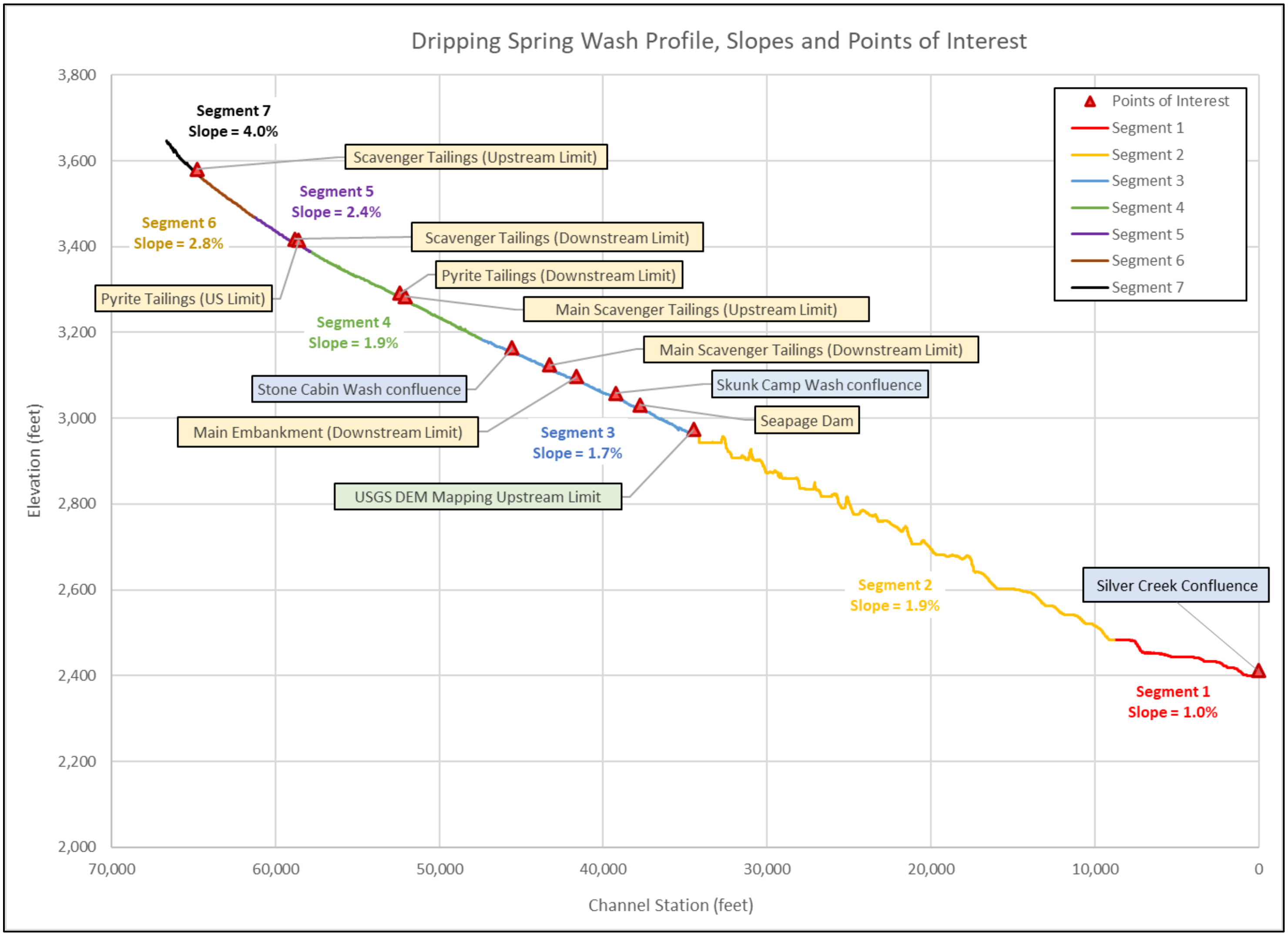


Figure 2-3. Longitudinal profile plot of Dripping Spring Wash

Table 2-1. Reach segment average slope

Reach Segment	Average Slope (%)
1	1.0
2	1.9
3	1.7
4	1.9
5	2.4
6	2.8
7	4.0

2.2.2 Discharge

As part of the DEIS Design study, KCB developed hydrology for Dripping Spring Wash downstream of the TSF for both the existing and proposed (with TSF) conditions. Table 2-2 lists the discharge estimates provided by KCB for the 2-year, 10-year, and 100-year recurrence interval storms.

Table 2-2. Dripping Spring Wash hydrology (KCB 2018)

Recurrence Interval (yr)	Natural Catchment		With TSF and Diversions	
	Peak Flow (cfS)	Total Volume (acre-ft)	Peak Flow (cfS)	Total Volume (acre-ft)
2	15,700	1,600	1,270	870
10	28,500	2,850	2,400	1,550
100	51,600	5,200	4,500	2,800

The reduction in peak discharges between the existing and proposed conditions is due to loss of catchment from the TSF and attenuation through the diversion structures.

2.2.3 Empirical Relationships

2.2.3.1 Lane Equations

Lane (1952) published empirical formulas to define the threshold slope for channel pattern, based on data from alluvial sand bed rivers. His equations leave an intermediate zone between the lines defined by the two slope equations where either pattern occurs. The Lane equations for channel pattern are:

$So > 0.010\ Qm^{-0.25}$ (Braided channels)

$So < 0.001\ Qm^{-0.25}$ (Meandering channels)

So = channel slope (ft/ft), and

Qm = mean annual discharge (cfs)

The mean annual discharge (Qm) for Dripping Spring Wash was estimated using the 2-year recurrence interval discharge as computed by KCB. The Qm values used in this analysis are 15,700 cfs for the existing condition and 1,270 cfs for the proposed TSF condition.

2.2.3.2 Leopold & Wolman Equations

The Leopold and Wolman equations (1957) were developed using data from rivers with coarse bed material (D50 > ¼ inch).

$So > 0.06\ Qmaf^{-0.44}$ (Braided channels)

$So < 0.06\ Qmaf^{-0.44}$ (Meandering channels)

So = channel slope (ft/ft)

Qmaf = mean annual flood (cfs)

The equations are based on bankfull discharge, which Leopold and Wolman determined to be equal to the mean annual flood. The mean annual flood has a recurrence interval of about 2.33 years (ADWR, 1985). The 2-year discharge was used in this analysis as an approximation of the mean annual flood.

2.2.3.3 Results

Application of the channel pattern equations to the study area results are shown in Table 2-3 and Table 2-4 considering both the existing conditions and proposed (TSF) conditions. Both field observations and aerial photograph interpretation suggest that the existing condition channel pattern of Dripping Spring Wash is primarily braided. Because the wash is predominantly a sand-bed dominated system, the Lane equation is probably the most appropriate. Braided systems are generally reflective of steeper slopes and higher sediment loads than meandering systems. Natural straight river systems are rare in alluvial environments, and if present, are usually reflective of human influence. The predicted vs. observed braided pattern for the existing condition suggests that Dripping Spring Wash is presently in equilibrium (stable). The results also suggest that the reduction in downstream discharge resulting from the proposed TSF will not have substantial downstream geomorphic impacts to Dripping Spring Wash.

Table 2-3. Lane equation channel pattern analysis results

EXISTING CONDITIONS				
Channel Segment	**Qm (cfs)**	**So (ft/ft)**	**Predicted Pattern**	**Observed Pattern**
Segment 1	15,700	0.010	BRAIDED	BRAIDED
Segment 2	15,700	0.019	BRAIDED	BRAIDED
Segment 3	15,700	0.017	BRAIDED	BRAIDED
Segment 4	15,700	0.019	BRAIDED	BRAIDED
Segment 5	15,700	0.024	BRAIDED	BRAIDED
Segment 6	15,700	0.028	BRAIDED	BRAIDED
Segment 7	15,700	0.040	BRAIDED	BRAIDED
PROPOSED (TSF) CONDITONS				
Channel Segment	**Qm (cfs)**	**So (ft/ft)**	**Predicted Pattern**	**Observed Pattern**
Segment 1	1,270	0.010	BRAIDED	BRAIDED
Segment 2	1,270	0.019	BRAIDED	BRAIDED
Segment 3	1,270	0.017	BRAIDED	BRAIDED
Segment 4	Skunk Camp TSF			
Segment 5				
Segment 6				
Segment 7	1,270	0.040	BRAIDED	BRAIDED

Table 2-4. Leopold & Wolman equation channel pattern analysis results

EXISTING CONDITIONS				
Channel Segment	**Qm (cfs)**	**So (ft/ft)**	**Predicted Pattern**	**Observed Pattern**
Segment 1	15,700	0.010	BRAIDED	BRAIDED
Segment 2	15,700	0.019	BRAIDED	BRAIDED
Segment 3	15,700	0.017	BRAIDED	BRAIDED
Segment 4	15,700	0.019	BRAIDED	BRAIDED
Segment 5	15,700	0.024	BRAIDED	BRAIDED
Segment 6	15,700	0.028	BRAIDED	BRAIDED
Segment 7	15,700	0.040	BRAIDED	BRAIDED
PROPOSED (TSF) CONDITIONS				
Channel Segment	**Qm (cfs)**	**So (ft/ft)**	**Predicted Pattern**	**Observed Pattern**
Segment 1	1,270	0.010	BRAIDED	BRAIDED
Segment 2	1,270	0.019	BRAIDED	BRAIDED
Segment 3	1,270	0.017	BRAIDED	BRAIDED
Segment 4	Skunk Camp TSF			
Segment 5				
Segment 6				
Segment 7	1,270	0.040	BRAIDED	BRAIDED

2.2.4 Aerial Photograph Analysis

Modern (2018) and historical photographs were collected and assessed to determine if Dripping Spring Wash has experienced any significant geomorphic changes within the period of record. Historical aerial photographs from 1953 were the earliest available for the study area. The 1953 photographs were semi-rectified using ArcGIS software tools and compared directly with modern orthophotography. The most significant changes observed was the lateral position of the low-flow channel. Overall channel pattern and general limits of the braided channel corridor were consistent. Lateral changes to the low-flow channel of an alluvial river over time is a natural response to flood events. Overall, the historical comparison indicates that Dripping Spring Wash has remained in a stable condition over the past 65 years. Figure 2-4 through Figure 2-8 show an aerial photograph comparison at several locations within the study area. The figures also confirm the braided channel pattern discussed previously.

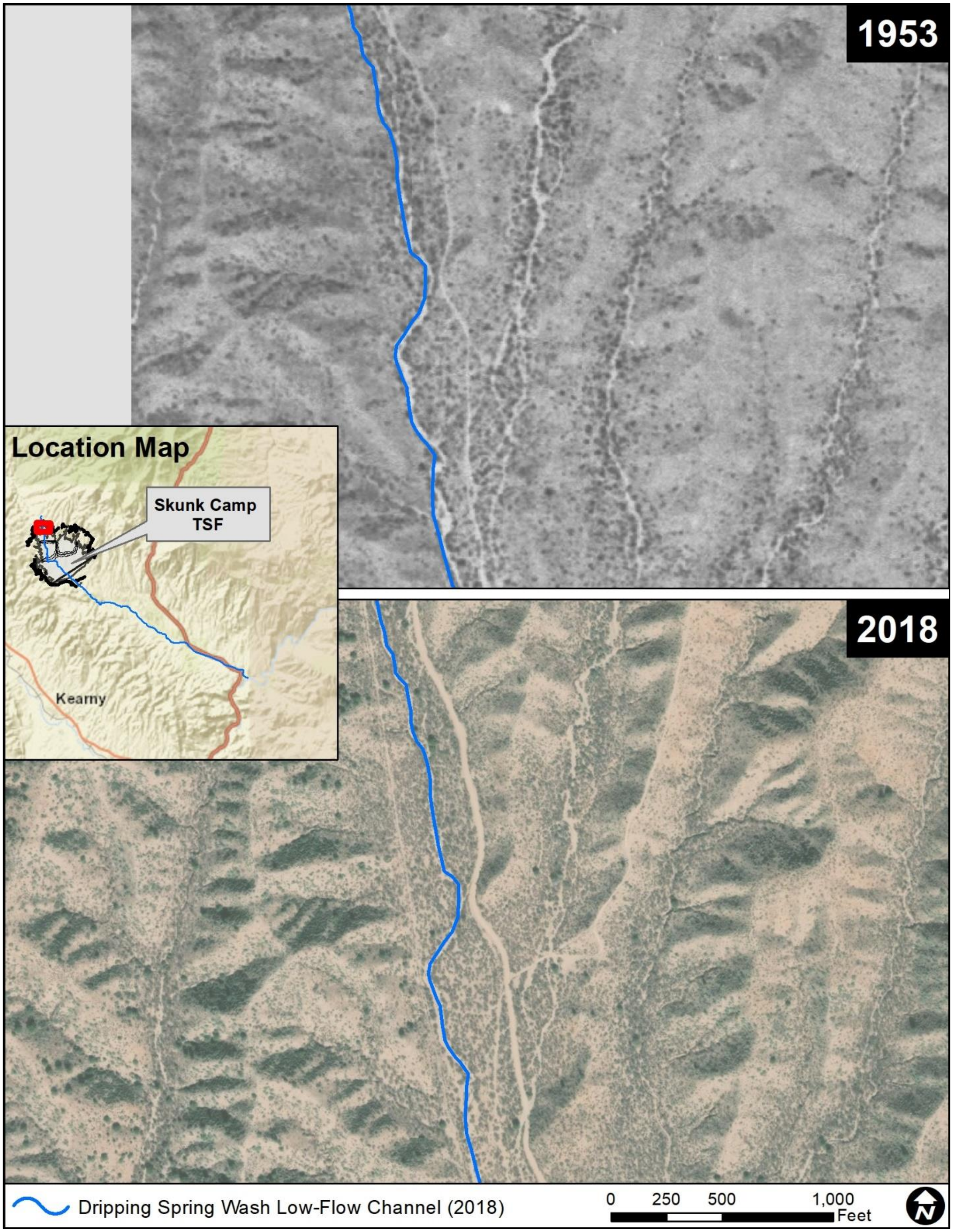


Figure 2-4. Aerial photograph comparison area 1

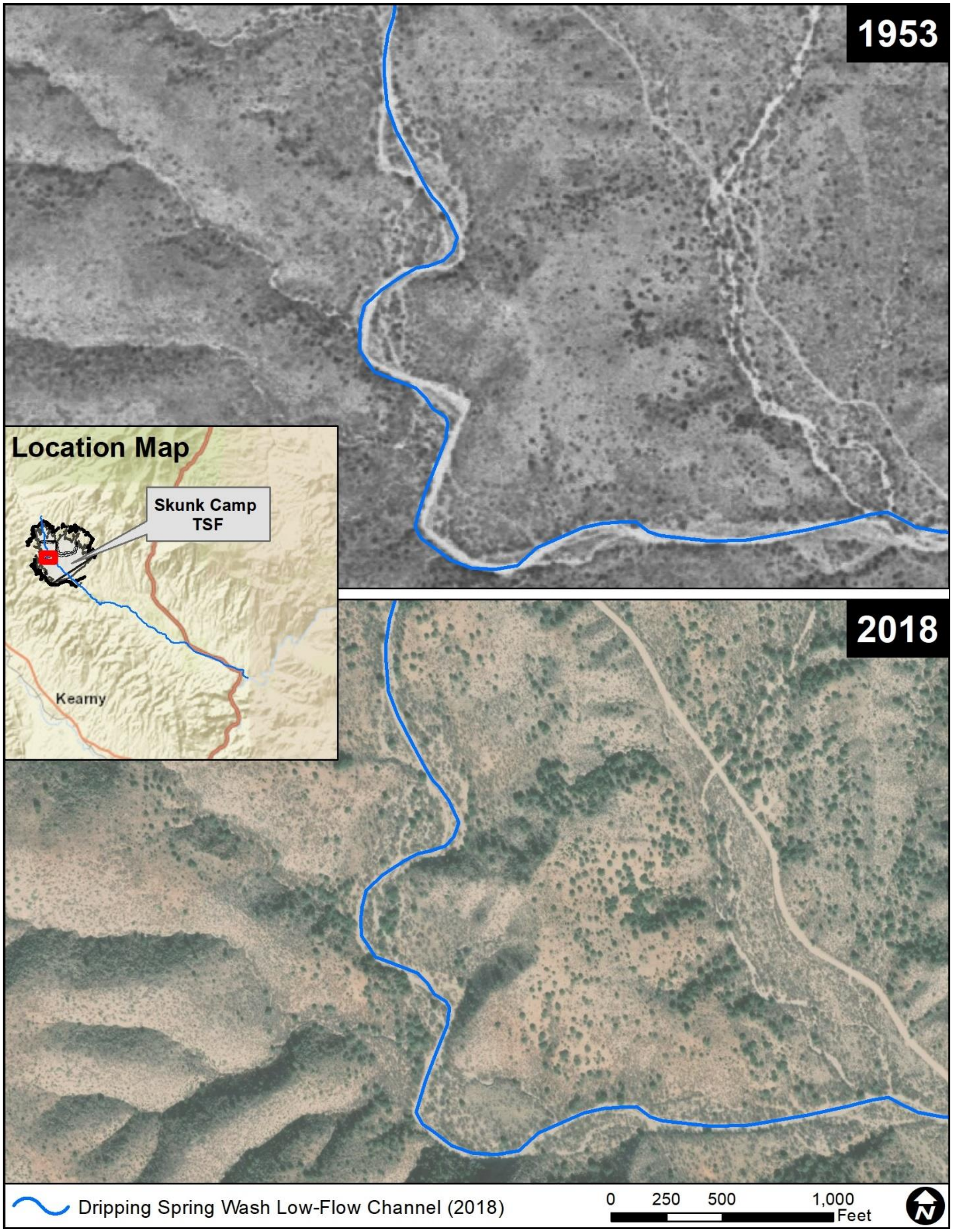


Figure 2-5. Aerial photograph comparison area 2

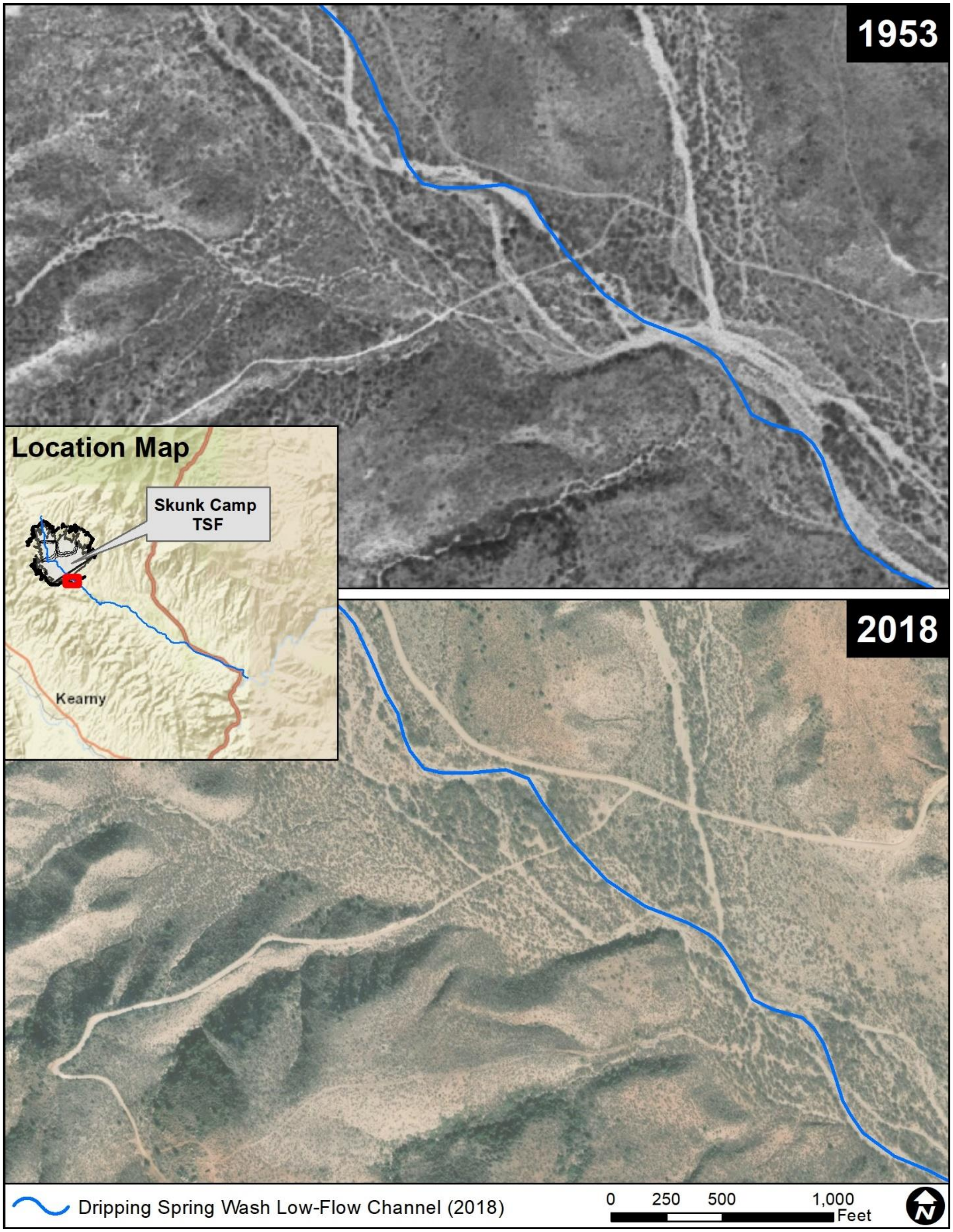


Figure 2-6. Aerial photograph comparison area 3

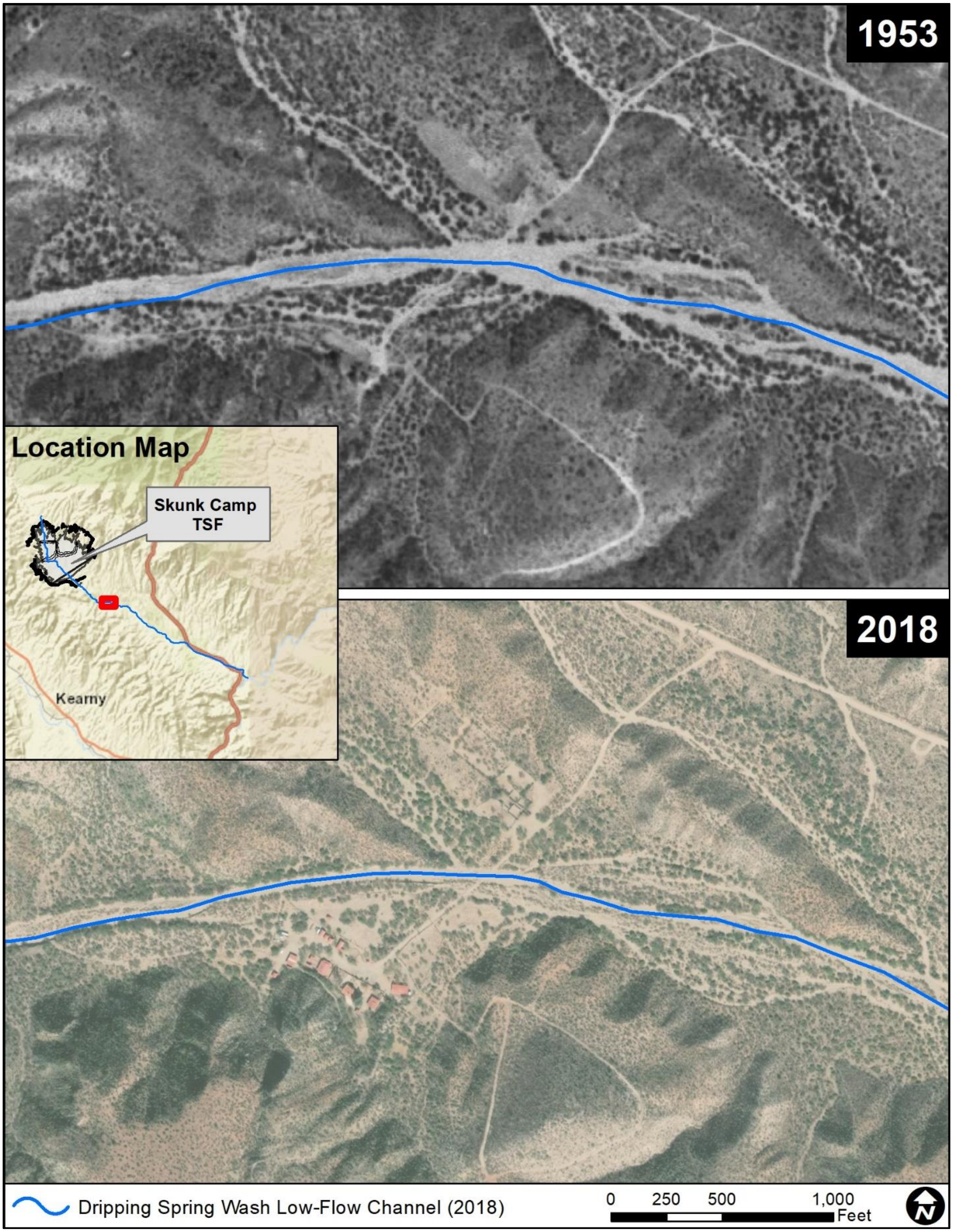


Figure 2-7. Aerial photograph comparison area 4

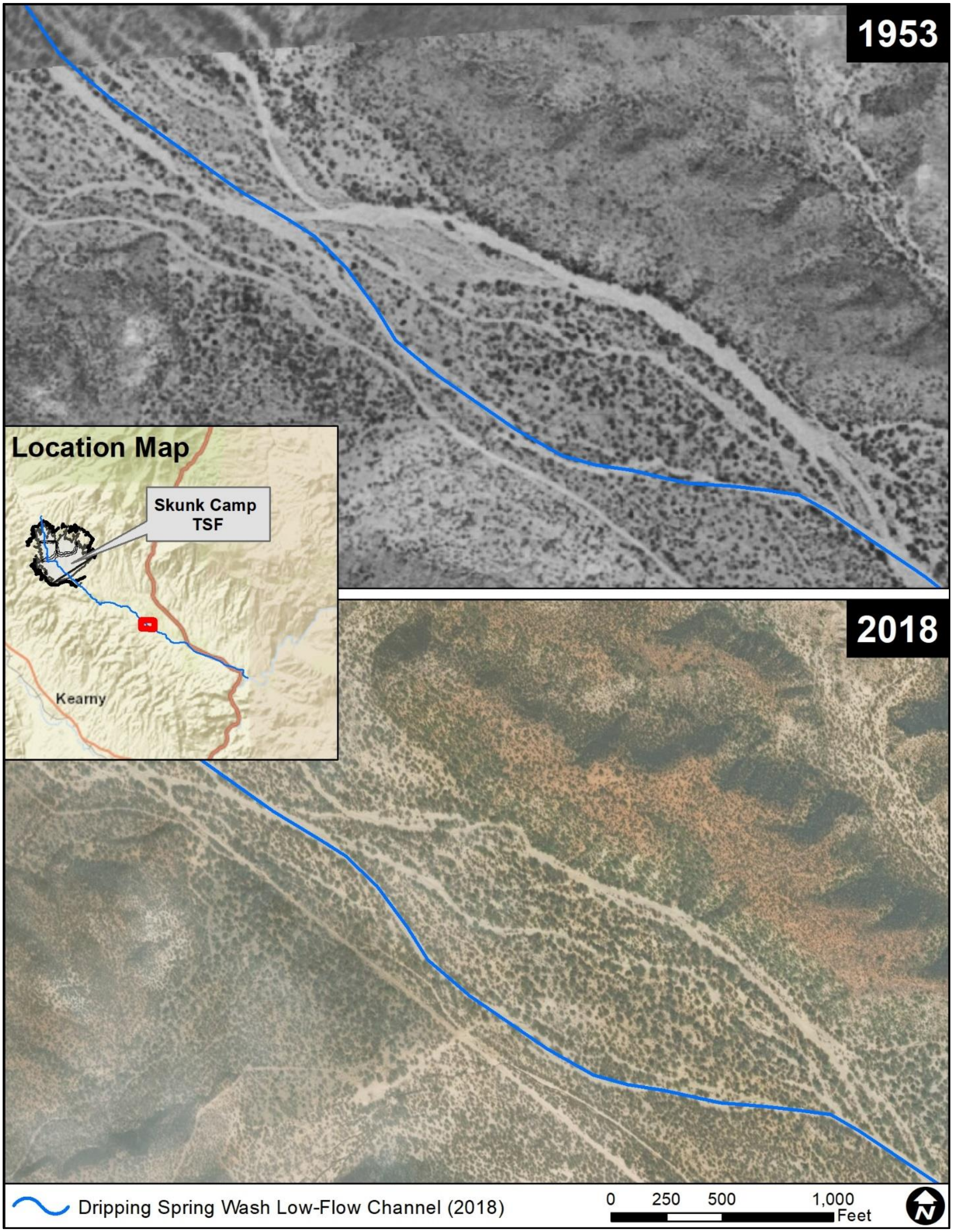


Figure 2-8. Aerial photograph comparison area 5

2.3 Field Investigation

A field investigation to the project area was conducted by JEF staff on April 8, 2020. The purpose of the investigation was to assess 1) the general geomorphic condition of the Dripping Spring Wash, and 2) observe the characteristics of the bedload sediment for Dripping Spring Wash and its major tributaries upstream of the Skunk Camp TSF.

2.3.1 Existing Geomorphic Condition

Dripping Spring Wash was observed at multiple locations both upstream and downstream of the proposed TSF. Field observations confirmed the aerial photograph interpretation and channel pattern desktop analyses that Dripping Spring Wash is predominately a braided system. Several key locations were visited to determine signs of channel instability (e.g. headcutting, channel incision, high rates of lateral migration, perched tributaries, etc.). No such evidence was observed during the field investigation. Figure 2-9 shows the location of the field sites visited along with field photographs of the Dripping Spring Wash low-flow channel. All field photographs are included in Appendix A.

2.3.2 Sediment

The availability of sediment for transport during flow events has an impact on the geomorphic character of alluvial river systems. Braided channels (like Dripping Spring Wash) are generally defined by steeper slopes and high sediment transport rates. The balance of slope and sediment keep a system in equilibrium, and a change of either input can result in a disequilibrium condition from which the system will attempt to recover. For example, if the sediment supply of a system is cutoff to either the main channel, its tributaries, or some combination of both, the natural response of the system will be to scour the channel bed and/or laterally erode the channel banks in an attempt to re-balance the energy in the system. Channel scour can cause adverse impacts to infrastructure such as road crossings and bridges. Rapid lateral erosion can threaten property and infrastructure located in the floodplain fringe.

The characteristics of the bed sediments in both Dripping Spring Wash and its major tributaries were observed and noted during the field investigation. The Dripping Spring Wash low-flow channel sediments are primarily medium and coarse sand and gravel. Some of the less-active channel braids have distribution cobbles indicating higher energy transport regimes during large flood events. Most of the tributaries are also characterized by sand and gravel bedload sediments. A few of the tributaries on the west side of Dripping Spring Wash are dominated by a cobble and boulder bed sediment regime. Figure 2-10 shows a few examples of the observed bed sediments in the system and identifies either Dripping Spring Wash (DSW) or tributary (TRB) source.

2.3.3 Summary

Dripping Spring Wash is an alluvial river system predominately characterized by a braided channel pattern and sand and gravel bedload sediment. Aerial photograph interpretation and field investigation indicates the wash is in a natural stable condition. The bedload sediment of the wash suggests high sediment transport rates during moderate and large flood events. The availability of sediment from both the main wash and its tributaries is one component that this is contributing to the overall stability of the system.

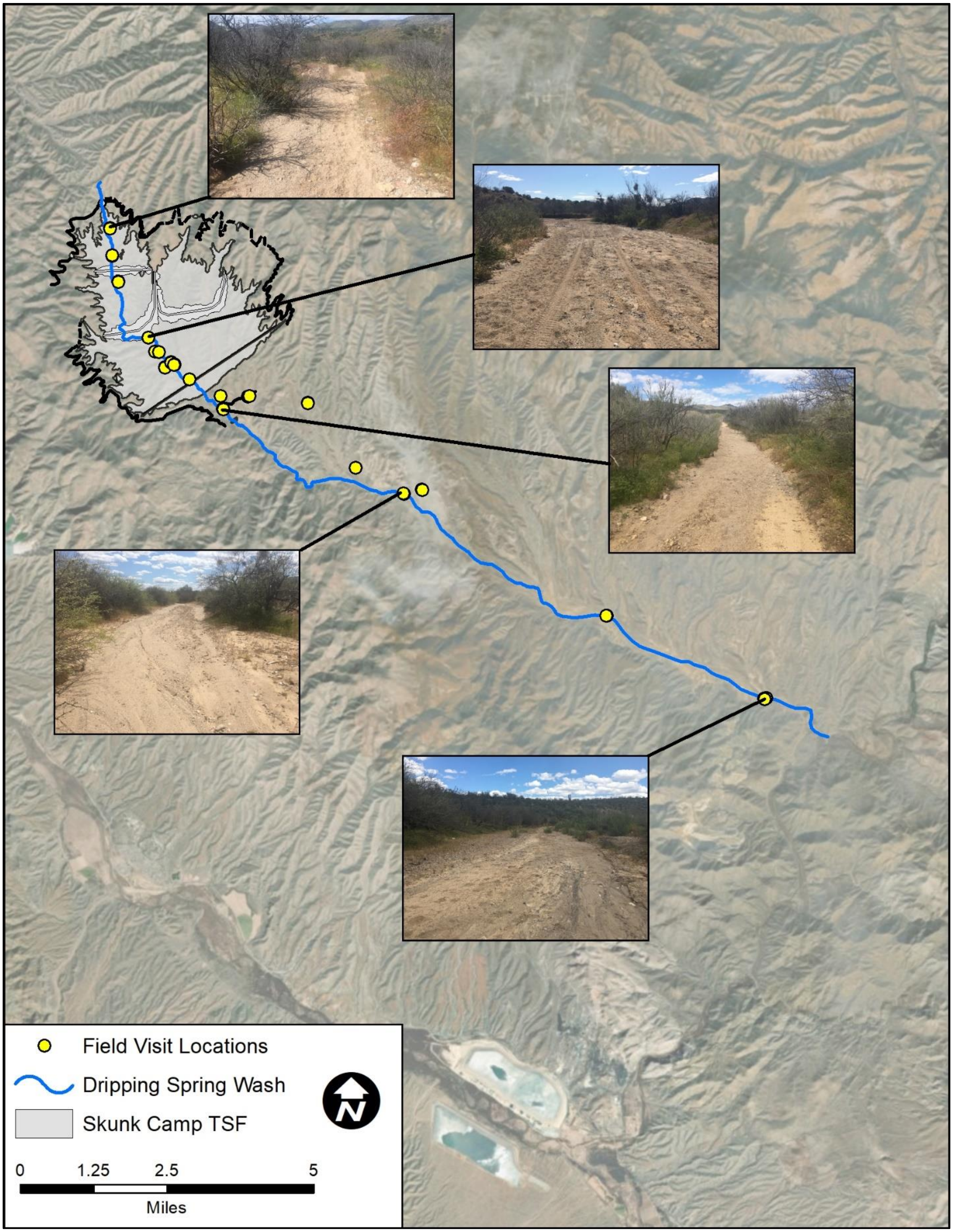


Figure 2-9. Field site locations and photographs

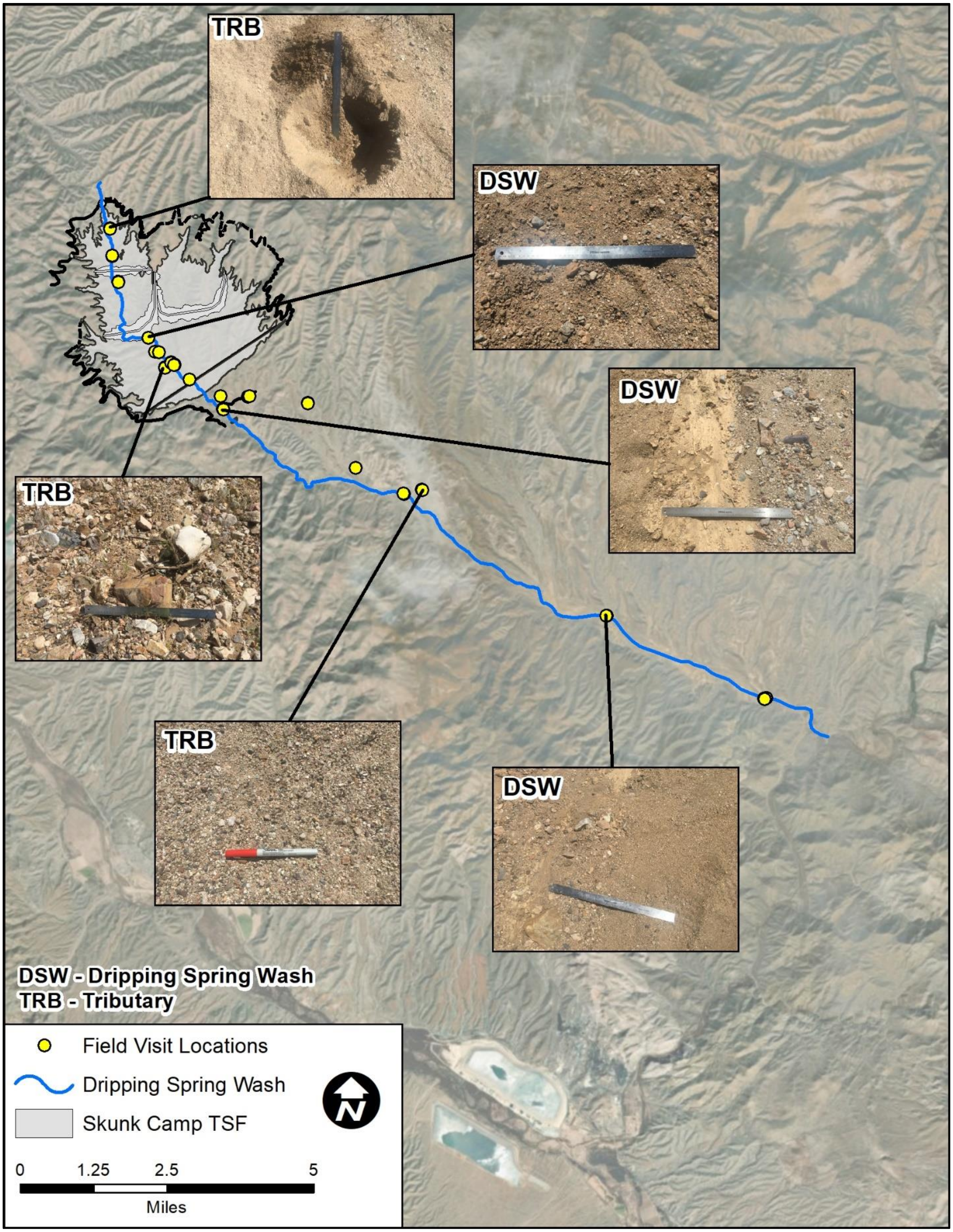


Figure 2-10. Observed bedload sediment

2.4 Potential Impacts of the TSF

The geomorphic assessment of Dripping Spring Wash indicates the overall system is presently in a natural equilibrium condition. The channel pattern analysis described in this report indicates the reduction in mean annual discharge from the proposed Skunk Camp TSF will not adversely impact the overall channel pattern downstream of the TSF.

The qualitative sediment analysis indicates Dripping Spring Wash is primarily a sand and gravel alluvial system that is subject to high rates of sediment transport during flood events. The system is presently in a natural balance of sediment supply, transport capacity, and slope. The proposed Skunk Tank TSF design includes multiple surface water diversion dam structures for many of the Dripping Spring Wash tributaries that drain into the TSF. The purpose of the dam structures is to trap and divert stormwater into the proposed TSF diversion channel and pipeline network, which then diverts the flow around the TSF and discharges back to Dripping Spring Wash downstream of the TSF (see Figure 1-2). The diversion dams will also trap and store tributary sediment. The release of “clearwater” flow downstream of the TSF will likely result in channel bed scour and/or bank erosion of Dripping Spring Wash that may propagate upstream and adversely impact the TSF main embankment. It is recommended that engineered erosion countermeasures be implemented in the TSF design to mitigate potential erosion.

The proposed operational span of the TSF is approximately 41 years, during which time the Dripping Spring Wash discharge immediately downstream of the TSF will be reduced as discussed in Section 2.2.2. The reduction in discharge will result in a reduction in the sediment transport capacity of Dripping Spring Wash, which will result in a reduction of sediment (bedload and suspended load) delivery to the Gila River.

The eventual closure of the TSF will be phased and includes the following objectives (highlight added) (KCB, 2020):

Closure Focus	Objectives
Physical (geotechnical stability, water management, erosion protection)	▪ Develop long-term landform that maintains stability and integrity of the TSF embankments. ▪ Minimize ponded water on the closed tailings surface. ▪ Safely route TSF surface runoff downstream of the TSF. ▪ Manage erosion of closed surfaces to acceptable levels consistent with established performance criteria.
Geochemical	▪ Protect reclaimed covered surfaces against wind and water erosion, to avoid exposure of tailings. ▪ Minimize the potential for acidification of the potentially acid generating (PAG) tailings and transport of seepage. ▪ Minimize long-term seepage from the TSF, by limiting net infiltration[1] into the TSF post-closure. ▪ Preserve groundwater and surface water quality downstream of the TSF, in accordance with regulatory requirements.
End land-use	▪ Construct a sustainable vegetated landform that is compatible with the natural landscape. ▪ Transition TSF to land uses that are consistent with surrounding areas (e.g. low-intensity livestock grazing and wildlife habitat).

Notes: 1. Net Infiltration: infiltration of precipitation that is not subsequently lost to evaporation or plant transpiration.

The closure strategy includes removal of the surface water diversion structures and pipeline network, and the establishment of a diversion channel and tailings surface channel network that will divert and transport offsite and onsite stormwater back to Dripping Spring Wash downstream of the TSF, restoring the sediment transport capacity and overall sediment delivery of Dripping Spring Wash to near pre-TSF conditions.

3 REFERENCES

Arizona Department of Water Resources (ADWR), 1985, Design Manual for Engineering Analysis of Fluvial Systems.

Banks, N.G. and M.H. Krieger, 1977, Geologic Map of the Hayden Quadrangle, Pinal and Gila Counties, Arizona. U.S. Geological Survey.

Cornwall, H.R. and M.H. Krieger, 1978, Geologic Map of the El Capital Mountain Quadrangle, Gila and Pinal Counties, Arizona. U.S. Geological Survey.

KCB, 2018, DEIS Design for Alternative 6 – Skunk Camp. Doc # CCC.03-81600-EX-REP-00006 – Rev. 1. Resolution Copper LLC.

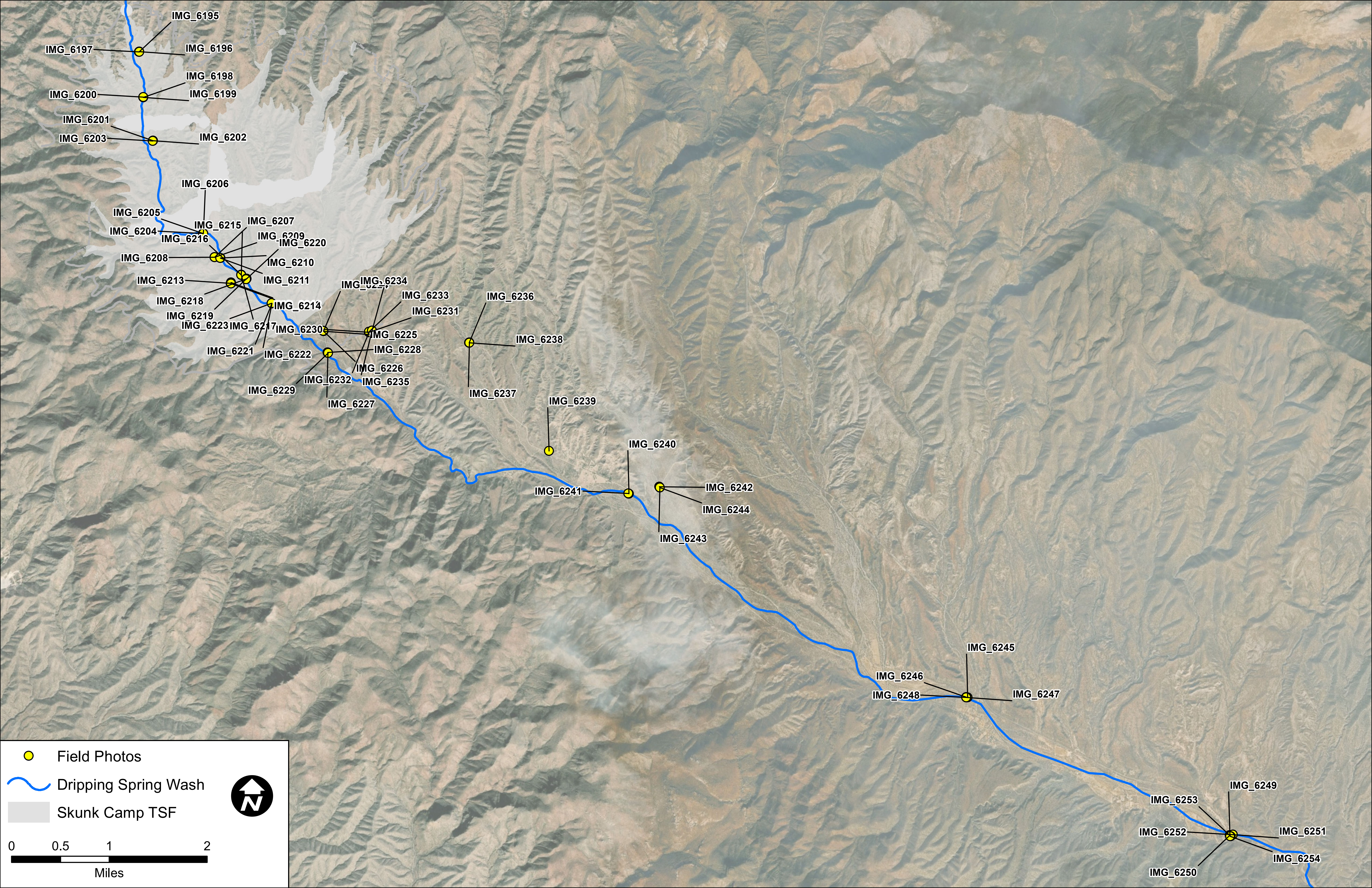
KCB, 2020, Skunk Camp Tailings Storage Facility Reclamation Plan. Resolution Copper LLC.

Lane, E.W., 1952, Progress Report on Studies in the Design of Stable Channels of the Bureau of Reclamation, HYD-352, Vol. 79.

Leopold, L.B., and Wolman, M.G., 1957, River Channel Patterns: Braided, Meandering, and Straight, USGS Professional Paper 282-B. Washington, D.C.

APPENDIX A

Field Photographs


IMG_6195
IMG_6197
IMG_6196
IMG_6198
IMG_6200
IMG_6199
IMG_6201
IMG_6203
IMG_6202
IMG_6206
IMG_6205
IMG_6204
IMG_6215
IMG_6207
IMG_6216
IMG_6209
IMG_6220
IMG_6208
IMG_6210
IMG_6213
IMG_6211
IMG_6218
IMG_6214
IMG_6219
IMG_6223
IMG_6217
IMG_6221
IMG_6222
IMG_6234
IMG_6233
IMG_6231
IMG_6230
IMG_6225
IMG_6228
IMG_6226
IMG_6235
IMG_6229
IMG_6232
IMG_6227
IMG_6236
IMG_6238
IMG_6237
IMG_6239
IMG_6240
IMG_6241
IMG_6242
IMG_6244
IMG_6243
IMG_6245
IMG_6246
IMG_6248
IMG_6247
IMG_6249
IMG_6253
IMG_6252
IMG_6251
IMG_6254
IMG_6250
Field Photos
Dripping Spring Wash
Skunk Camp TSF
N
0
0.5
1
2
Miles

IMG_6195

IMG_6196

IMG_6197

IMG_6198

IMG_6199

IMG_6200

IMG_6201

IMG_6202

IMG_6203

IMG_6204

IMG_6205

IMG_6206

IMG_6207

IMG_6208

IMG_6209

IMG_6210

IMG_6211

IMG_6212

IMG_6213

IMG_6214

IMG_6215

IMG_6216

IMG_6217

IMG_6218

IMG_6219

IMG_6220

IMG_6221

IMG_6222

IMG_6223

IMG_6224

IMG_6225

IMG_6226

IMG_6227

IMG_6228

IMG_6229

IMG_6230

IMG_6231

IMG_6232

IMG_6233

IMG_6234

IMG_6235

IMG_6236

IMG_6237

IMG_6238

IMG_6239

IMG_6240

IMG_6241

IMG_6242

IMG_6243

IMG_6244

IMG_6245

IMG_6246

IMG_6247

IMG_6248

IMG_6249

IMG_6250

IMG_6251

IMG_6252

IMG_6253

IMG_6254