RESOLUTION COPPER PROJECT EIS HYDROLOGIC MODEL RESULTS FOR DEIS ALTERNATIVES

PROJECT NO.: 1704-003 OCTOBER 30, 2018

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October 30, 2018
Project No.: 1704-003

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Dear Chris,

Re: Resolution Copper Project, Hydrologic Model Results for DEIS Alternatives

Please find attached our report that details a hydrologic analysis completed for the Draft Environmental Impact Statement (DEIS) alternatives that have been identified as part of the Resolution Copper Project EIS. We appreciate the opportunity to work on this interesting project.

Yours sincerely,

BGC ENGINEERING INC.
per:

Hamish Weatherly, M.Sc., CPG
Principal Hydrologist

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LIMITATIONS

1.0 INTRODUCTION

In support of the completion of the Resolution Copper Project Draft Environmental Impact Statement (DEIS), BGC Engineering, Inc. (BGC) is providing hydrology expertise to SWCA Environmental Consultants (SWCA) and the United States Department of Agriculture Tonto National Forest (TNF). The TNF is the lead Federal agency for the EIS, and SWCA is the TNF's third-party EIS contractor. The TNF, SWCA and their consultants, including BGC, comprise the EIS project team. This memorandum has been prepared to document hydrologic analyses completed for the DEIS alternatives

As described in the July 9, 2018 Process Memorandum to File (Evolution of Range of Alternatives Considered in Detail in DEIS), there are a total of six alternatives to be analyzed as part of the DEIS. As part of the alternatives assessment, several issue factors must be addressed, including:

> **6C-4. Quantitative assessment of change in volume, frequency, and magnitude of runoff for the project area.**

For this analysis, volume is assumed to reference monthly and annual runoff volumes, while magnitude refers to peak flows of various durations.

JE Fuller Inc., part of the Resolution Copper Mining LLC team (Applicant), have proposed that USGS regression equations (Paretti, Kennedy, Turney & Veilleux, 2014) be used to estimate peak instantaneous flows for various return periods and durations of 1 to 30 days (Kennedy, Paretti & Veilleux, 2014). These regressions would be used for all alternatives, allowing for quantification of potential changes in peak flow. However, such an analysis only addresses the magnitude (i.e., peak) of runoff. Volumetric changes in runoff are not addressed by such an approach. A hydrologic model, which could take various forms of complexity, is required to address runoff volume.

Montgomery & Associates (M&A; consultant to Applicant) have constructed a basin-wide water budget for Queen Creek (M&A, June 6, 2018). While a useful analysis, the M&A water budget was constructed with an annual timestep and does not quantify impacts to streamflow for the various alternatives. As a result, BGC was tasked with construction of a hydrologic model for the various affected watersheds to quantify potential streamflow impacts on a monthly basis. This report provides a discussion of the methodology employed by BGC, as well as model results.

2.0 DEIS ALTERNATIVES

2.1. Summary of Alternatives

A total of 6 alternatives have been identified for analysis as part of the DEIS. These alternatives are summarized in Table 2-1.

Table 2-1. Resolution Copper Project DEIS alternatives (June 29, 2018).

Location	TSF Facility Description	Final Range of Alternatives for Detailed Analysis	Report Reference
-	None	Alternative 1 – No Action	-
Near West	Slurry tailings, unlined, no Potentially Acid-Generating (PAG) cell, modified centerline dam	Alternative 2 – Near West – Modified Proposed Action – Wet	Klohn Crippen Berger (KCB) (2018, June 8)
	Slurry/thin lift, lined PAG cell, modified centerline dam	Alternative 3 – Near West – Modified Proposed Action – Dry	KCB (2018, June 8)
Silver King	Filtered tailings, lined PAG cell	Alternative 4 – Silver King Filtered	KCB (2018, June 4)
Peg Leg	Slurry tailings, lined PAG cell, other selective lining, true centerline dam	Alternative 5 – Peg Leg	Golder (2018, June 20)
Skunk Camp	Slurry tailings, lined PAG cell, true centerline dam	Alternative 6 – Skunk Camp	KCB (2018, August 8)

Detailed descriptions of the various alternatives can be referenced in the reports listed in Table 2-1.

2.2. Impacted Areas

This section provides a cursory summary of the alternatives as they relate to impacts to watershed area. An overview map of the alternative locations is provided in Drawing 01.

2.2.1. Subsidence Crater

The proposed block cave mining operation will result in the formation of a subsidence crater at the surface. This subsidence crater is estimated to cover an area of 2.70 sq.mi. within the Queen Creek and Devil's Canyon watersheds (Drawing 01). An additional watershed area of 0.78 sq.mi. will be located upgradient of the subsidence crater. Once fully formed, precipitation within the subsidence footprint is not expected to report as runoff to either Queen Creek or Devil's Canyon. Runoff from the upgradient area will also report to the subsidence crater.

2.2.2. West Plant Site

The West Plant Site covers an approximate area of 1.40 sq.mi. (Figure 2-1). Surface runoff from this area, which is assumed to be contact water, will be captured by collection ditches and ponds and used in process.

2.2.3. Alternative 2/3 – Near West

The Near West alternative is located in the lower watershed of Queen Creek, upstream of the Whitlow Ranch Dam (Figure 2-1). Alternatives 2 and 3 have a similar footprint, intersecting portions of Roblas Canyon, Bear Tank Canyon, and Potts Canyon (Figure 2-2). A number of seepage collection ponds are proposed around the perimeter of the Tailings Storage Facility (TSF) to collect contact water runoff from the facility. Fresh water diversion channels are also proposed above the facility to divert the upper watershed of Bear Tank Canyon into the adjacent watersheds of Roblas Canyon and Potts Canyon (Figure 2-2).

2.2.4. Alternative 4 – Silver King

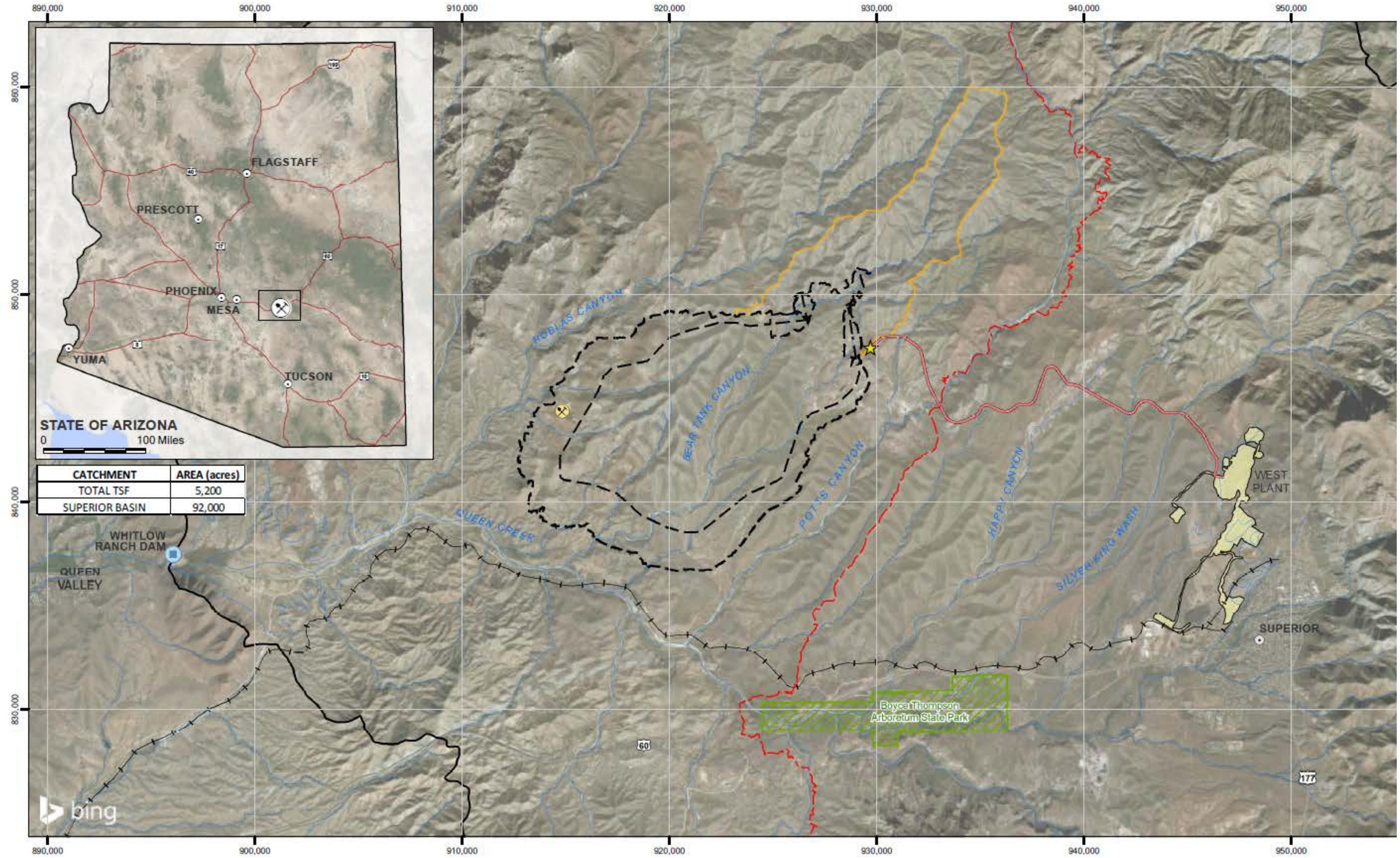
The Silver King TSF is located further up the Queen Creek valley to the north-northwest of Superior (Figure 2-3). The proposed footprint for Alternative 4 intersects mid to upper reaches of Potts Canyon, Happy Canyon, and Silver King Wash. Two fresh water diversion channels and dams are proposed upgradient of the facility to minimize impacts to streamflow. One of the diversion channels conveys surface runoff to a diversion dam on Reevis Rail Canyon, a tributary of Potts Canyon. The other diversion channel conveys surface runoff to a diversion dam on Comstack Wash, a tributary of Silver King Wash.

2.2.5. Alternative 5 – Peg Leg

The Peg Leg alternative is located to the south of the Queen Creek watershed in the Donnelley Wash basin (Drawing 01). The proposed TSF is located in mid reaches of Donnelley Wash and will also impact a smaller tributary (Unnamed Wash) to the immediate north of Donnelley Wash. Undisturbed, upper reaches of both watercourses will be diverted around the facility in either a north or south diversion channel (Figure 2-4). Both tributaries discharge into the Gila River.

2.2.6. Alternative 6 – Skunk Camp

The final alternative, Skunk Camp, is located to the east of the Town of Superior within the upper reaches of Dripping Spring Wash (Drawing 01). Dripping Spring Wash drains to the southeast, discharging into the Gila River. Fresh water diversion channels and dams are proposed on either side of the TSF, with one set of channels discharging into Dripping Spring Wash and the other set of channels diverting surface runoff into the upper reaches of Mineral Creek (Figure 2-5).



CATCHMENT	AREA (acres)
TOTAL TSF	5,200
SUPERIOR BASIN	92,000

Figure 2-1. Site location Alternatives 2 and 3 (after KCB, June 8, 2018).

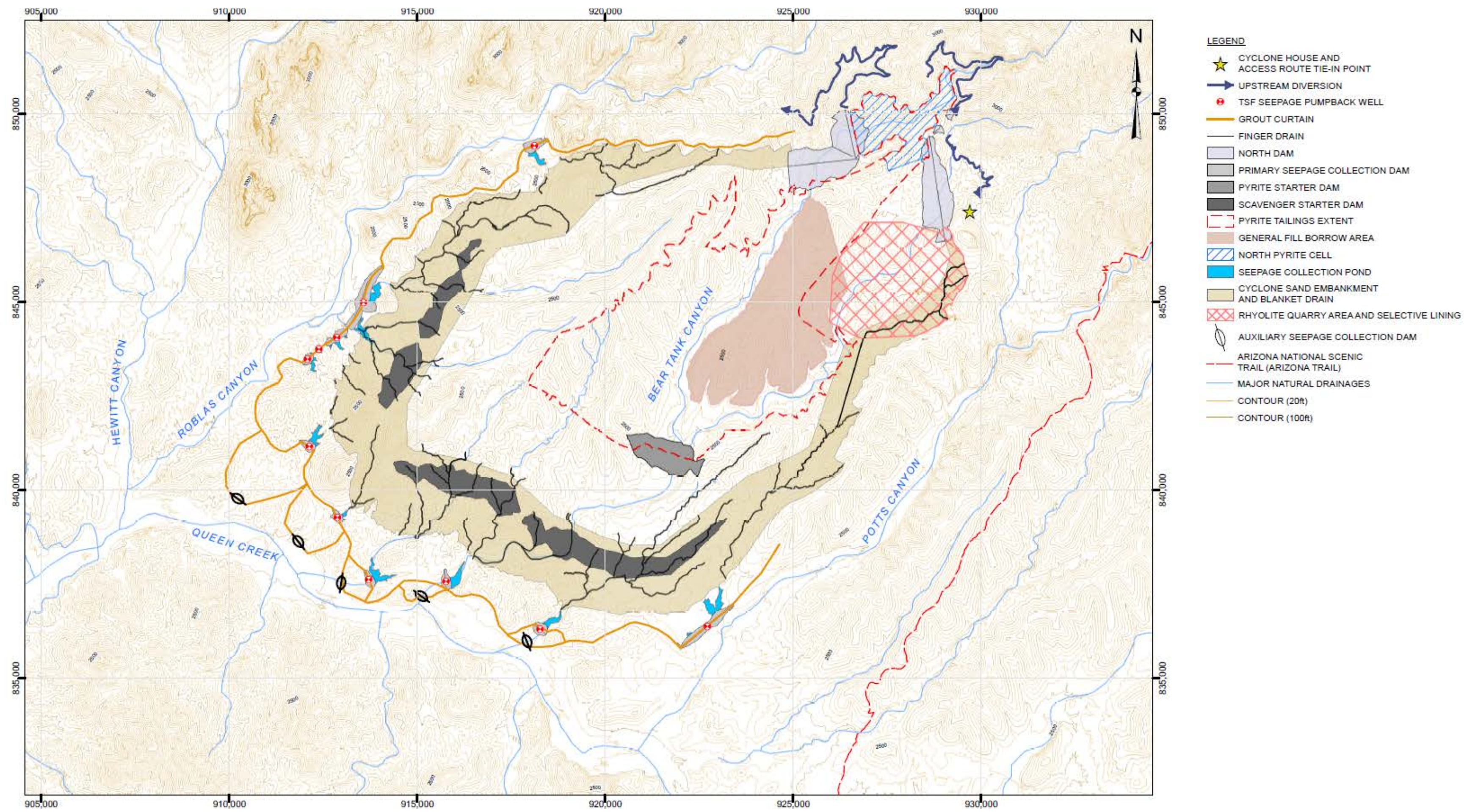


Figure 2-2. TSF layout and key features of Alternatives 2 and 3 (after KCB, June 8, 2018).

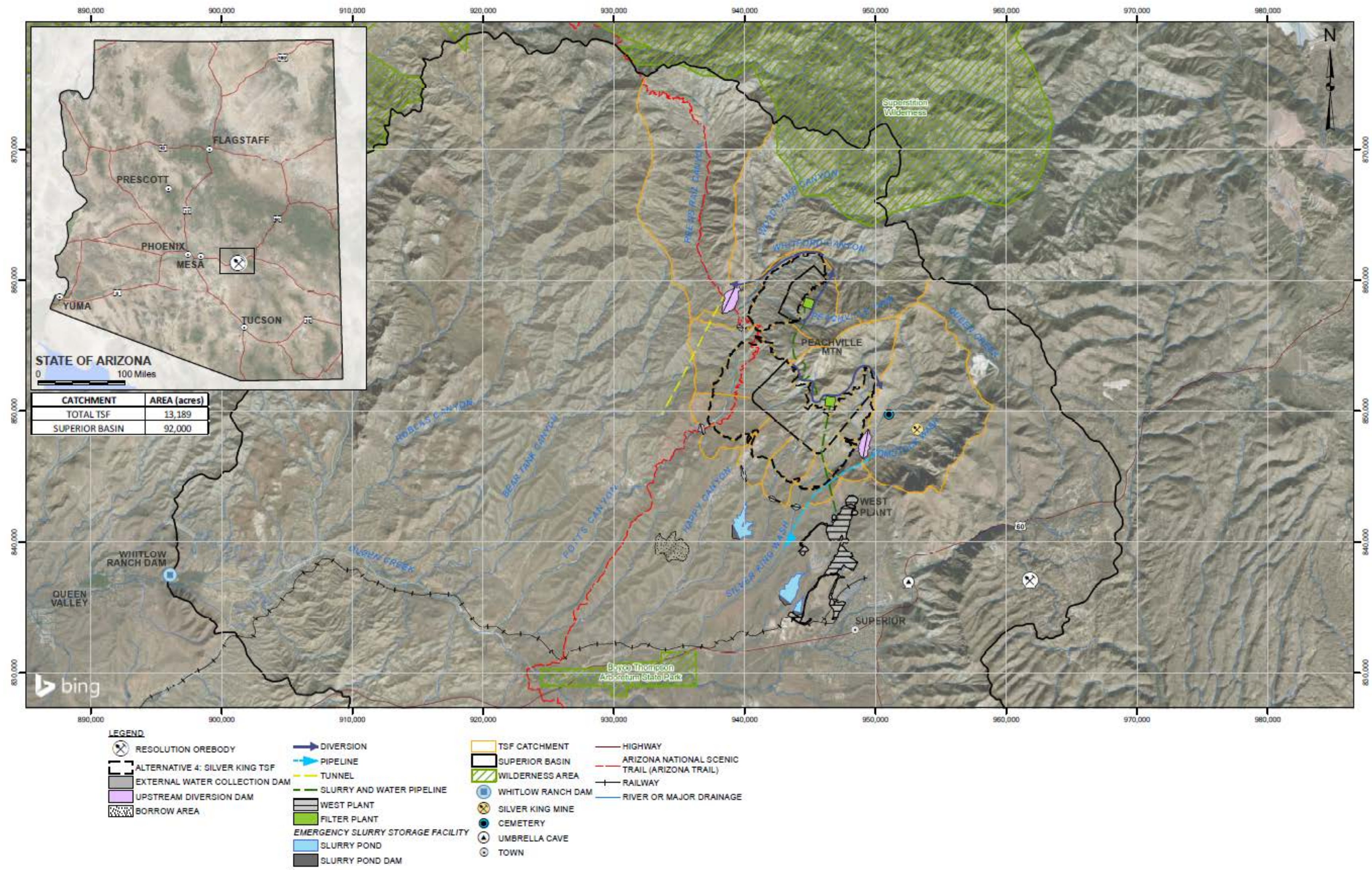


Figure 2-3. TSF layout and key features of Alternative 4 (after KCB, June 4, 2018).

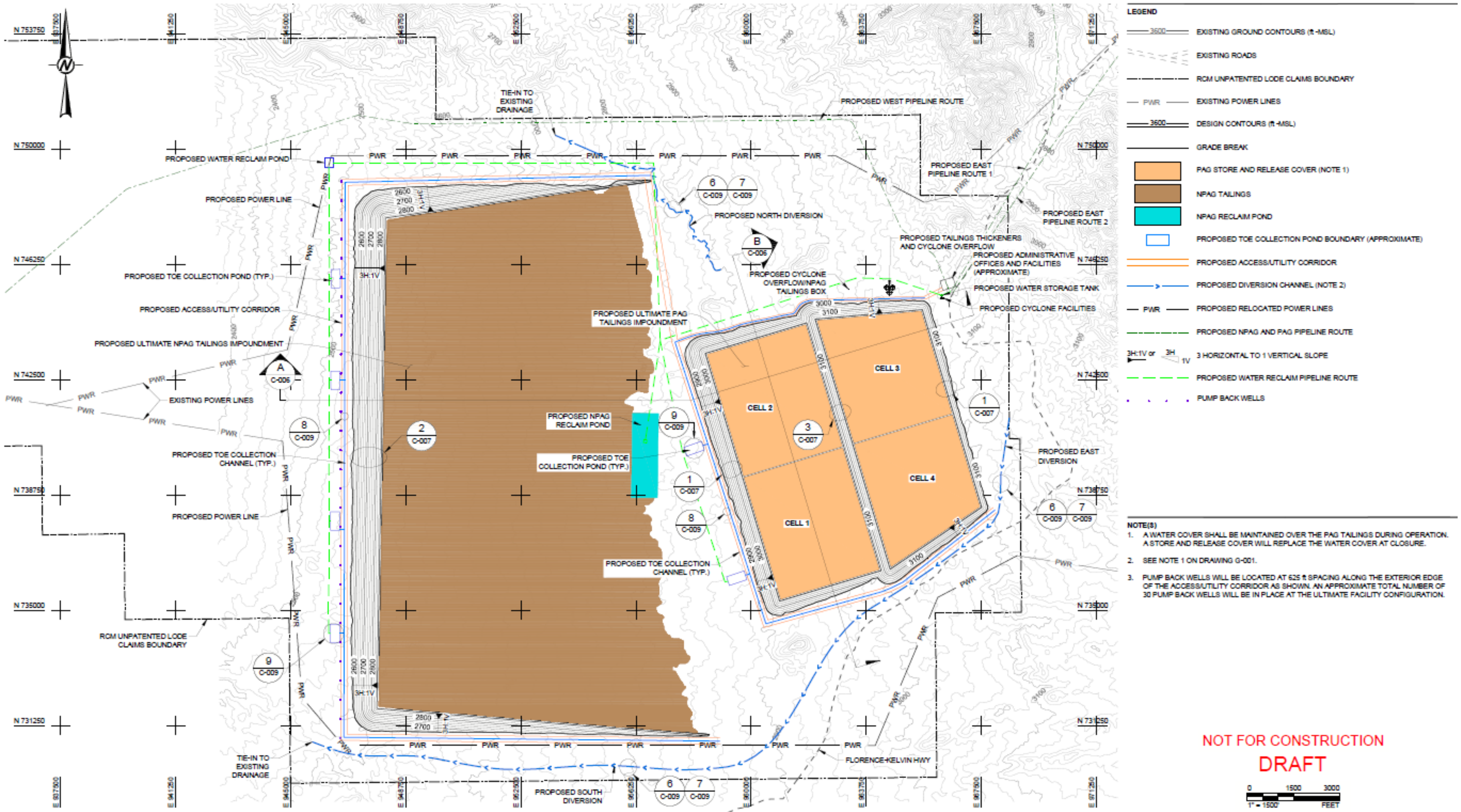


Figure 2-4. TSF layout and key features of Alternative 5 (after Golder, June 20, 2018).

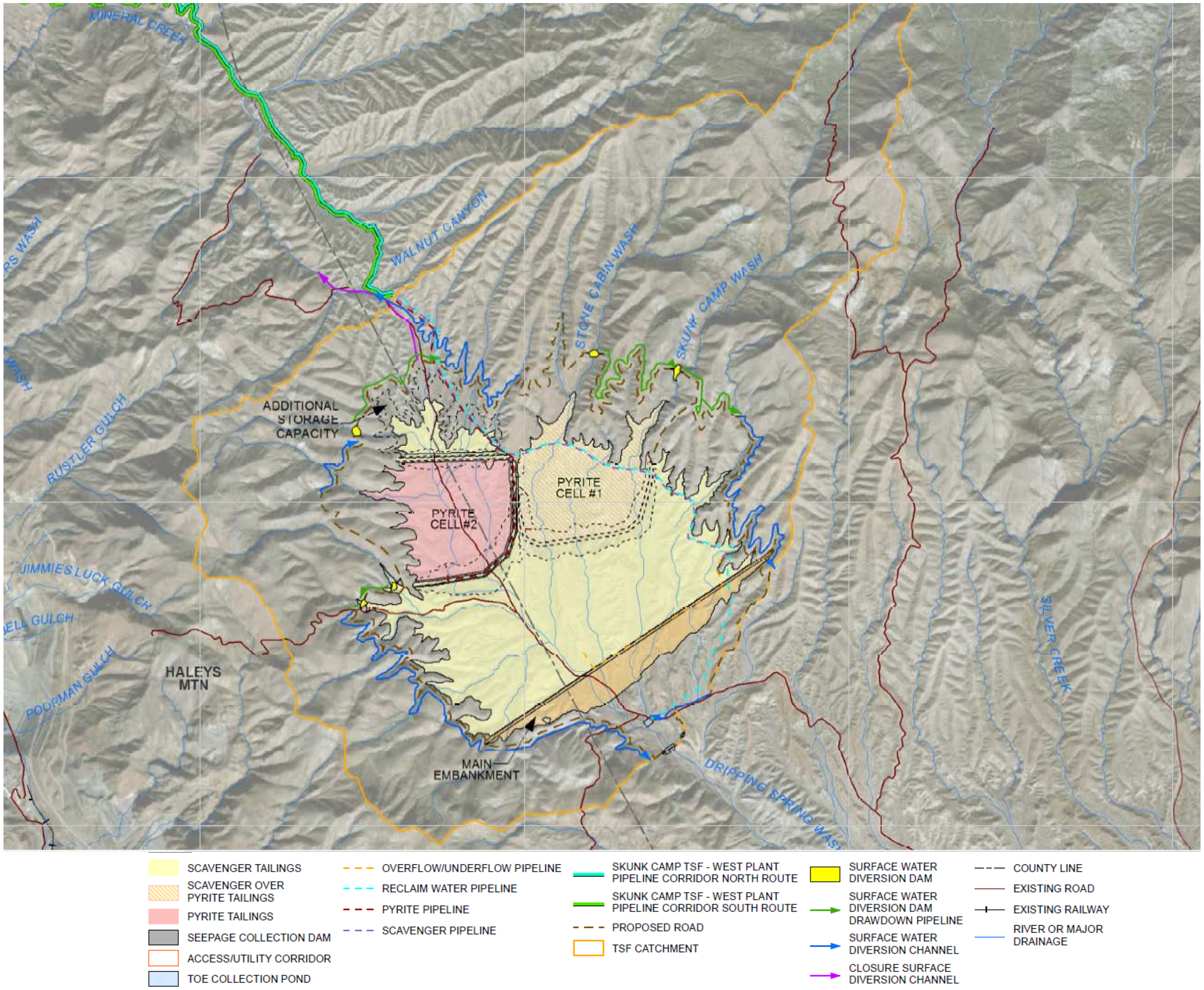


Figure 2-5. TSF layout and key features of Alternative 6 (after KCB, August 8, 2018).

2.3. Locations to Analyze Changes

Table 2-2 summarizes locations where BGC has analyzed streamflow changes. These locations were determined collaboratively by BGC, SWCA, and the United States Forest Service (USFS).

Table 2-2. Watershed locations to analyze changes in streamflow for the project EIS alternatives.

Location	Rationale	Alternatives
Devil's Canyon – Downstream of confluence with Hackberry Canyon, roughly DC-8.1C.	The watershed upstream of this location is likely impacted by the subsidence crater. Hackberry Canyon looks like it is unlikely to be affected by subsidence, but on the margin. This is also a point with a flow measurement history.	All
Devil's Canyon – Confluence with Mineral Creek	Farthest point downstream to be analyzed; edge of the analysis area.	All
Queen Creek – at Magma Avenue Bridge	The watershed upstream of this location is likely impacted by the subsidence crater. This is a good location to assess impacts, as the creek emerges from of a bedrock-confined valley.	All
Queen Creek – at Boyce Thompson Arboretum	The watershed upstream of this location is likely impacted by the subsidence crater, West Plant Site, and Silver King alternative, and potentially reflects a sensitive area.	All
Queen Creek – Upstream of Whitlow Ranch Dam	The watershed upstream of this location would be impacted by the Near West alternatives (2/3), Silver King (4), West Plant Site, and the subsidence crater.	All
Potts Canyon – confluence with Queen Creek	All three tributaries are impacted by the Silver King alternative (4).	Alt 4
Happy Canyon – confluence with Queen Creek		
Silver King Wash –confluence with Queen Creek		
Roblas Canyon – confluence with Queen Creek	Both tributaries are impacted by the Near West alternatives (2/3).	Alts 2/3
Bear Tank Canyon –confluence with Queen Creek		
Unnamed Wash – confluence with Gila River	Both tributaries are impacted by the Peg Leg alternative (5).	Alt 5
Donnelly Wash – confluence with Gila River		
Gila River at Donnelley Wash	The Gila River is impacted by the Peg Leg alternative (5).	Alt 5
Dripping Spring Wash – confluence with Gila River	This is the main watershed impacted by the Skunk Camp alternative (6).	Alt 6
Gila River at Drippings Spring Wash	The Gila River is impacted by the Skunk Camp alternative (6).	Alt 6

The total footprint of each of the alternatives is summarized in Table 2-3. These footprints reference the total watershed area where contact water will be collected (e.g., from the seepage dam to an upstream diversion channel or dam). As such, the footprints are slightly larger than the TSF dams alone.

Table 2-3. Disturbed footprint for each of the alternatives.

Alternative	Disturbance Footprint (sq.mi.)
Subsidence Crater – Queen Creek[1]	2.20
Subsidence Crater – Devil's Canyon[2]	1.28
West Plant Site	1.40
Near West – Alt 2/3	6.90
Silver King – Alt 4	6.32
Peg Leg – Alt 5	11.88
Skunk Camp – Alt 6	12.15

[1] The actual disturbance footprint is 1.76 sq.mi., but an additional 0.44 sq.mi. area upgradient of the subsidence zone would discharge to the disturbed area.

[2] The actual disturbance footprint is 0.94 sq.mi., but an additional 0.34 sq.mi. area upgradient of the subsidence zone would discharge to the disturbed area

A summary of existing and proposed condition watershed areas for each of these locations is provided in Table 2-4. Existing watershed areas are delineated on Drawing 01.

Table 2-4. Existing and proposed action watershed areas at analysis locations.

Location	Watershed Area (sq.mi.)			Alternative
	Existing	Proposed Action Footprint	% Disturbed	
Devil's Canyon – DC-8.1C	18.96	1.28	6.8%	all
Devil's Canyon at Mineral Creek	35.75	1.28	3.6%	all
Queen Creek – at Magma Avenue Bridge	10.37	2.20	21.2%	all
Queen Creek – at Boyce Thompson Arboretum	27.94	3.60	12.9%	2/3, 5, 6
	27.94	5.72+	20.5%	4
Queen Creek – Upstream of Whitlow Ranch Dam	142.73	10.50	7.4%	2/3
	142.73	9.92	7.0%	4
	142.73	3.60	2.5%	5, 6
Potts Canyon	18.09	4.20	23.2%	4
Happy Canyon	4.19	0.71	16.9%	4
Silver King Wash	6.69	0.21	3.1%	4
Roblas Canyon	10.16	1.30	12.8%	2/3
Bear Tank Canyon	4.91	4.91	100%	2/3
Donnelly Wash	59.91	10.76	18.0%	5
Unnamed Wash	7.11	1.11	15.6%	5
Gila River at Donnelley Wash*	18,011	11.88	0.1%	5
Dripping Spring Wash	117.0	12.15	10.4%	6
Gila River at Drippings Spring Wash^	12,866	12.15	0.1%	6

+ This modelling node is located upstream of the confluence with Potts Canyon, so the Alt 4 disturbance footprint only includes Happy Canyon and Silver King Wash plus the subsidence crater and West Plant Site.

* Watershed area as measured at USGS gage 09474000 – Gila River at Kelvin, AZ. This USGS gage is located ~ 15 miles upstream of the Donnelley Wash confluence.

^ Watershed area as measured at USGS gage 09469500 – Gila River below Coolidge Dam, AZ. This USGS gage is located ~ 20 miles upstream of the Dripping Spring Wash confluence.

3.0 HYDROLOGIC MODEL – SELECTION AND CALIBRATION

3.1. Model Selection

There are a large number of hydrologic models presently available for predicting streamflow from climatic inputs and land surface characteristics as evidenced by 72 models reviewed in Singh and Woolhiser (2002). These models are principally constructed on a daily or hourly basis, but can be used on an annual, monthly, or weekly basis. The degree of model complexity varies widely, but most have well in excess of 3 to 5 model parameters and many have more than 10 to 20 parameters. Most of these models are theoretical in that they are physically based (white-box models). Such models have been made possible by computer advances with the Stanford Watershed Model (SWM, now HSPF) (Crawford & Linsley, 1966) being the first attempt to model the entire hydrologic cycle.

Current models in popular use include:

- HSPF (Bicknell, Imhoff, Kittle, Donigan & Johansaon, 1993) and its extended water quality model are standards adopted by the Environmental Protection Agency (EPA).
- UBC watershed model (Quick, 1995) and Waterloo Flood Model (WATFLOOD) (Kouwen, Soulis, Pietroniro, Donald, & Harrington, 1993) are popular in Canada.
- Physically Based Runoff Production Model (TOPMODEL) (Beven & Kirby, 1979) and Systeme Hydrologique Europeen (SHE) (Abbot, Bathurst, Cunge, O'Connell, & Rasmussen, 1986) are standard models in Europe.
- The Precipitation-Runoff Modelling System, Version 4 (PRMS-IV) is commonly used in the US and was developed by the US Geological Survey (USGS) (Markstorm, Regan, Hay, Viger, Webb, Payn & LaFontaine, 2015).
- Hydrologic Simulation Model (HBV) (Bergstrom, 1995) is the standard model for flood forecasting in Scandinavian countries.

While these physically-based models can provide a high resolution of streamflow forecasting, they are generally data intensive and complicated. Bevin (1989) suggests that despite the large number of parameters normally included in watershed models, "it appears that 3 to 5 model parameters should be sufficient to reproduce most of the information in a hydrologic record." Jakeman and Hornberger (1993) and others have drawn similar conclusions.

In early 2018, BGC (January 15, 2018) recommended that the EIS team consider two potential modelling approaches: HSPF and a less complex, monthly hydrologic model.

<u>HSPF</u>

A Hydrologic Simulation Program – Fortran (HSPF) model was previously developed for the Queen Creek watershed by the Arizona Department of Environmental Quality (ADEQ, 2013). While the period of calibration was short (end of November 2007 to end of February 2008), there was good agreement between simulated and observed flows. Therefore, the proposed approach was to take the calibrated HSPF model and apply it to the EIS alternatives. Given the lack of additional high-quality streamflow data in the project area, additional model calibration was not proposed. However, the period of record for the model would be extended to include a multi-decadal rainfall dataset.

Monthly Hydrologic Model

A less complex monthly rainfall-runoff model was also proposed. Despite increased computing power and increasingly sophisticated physically-based models, there is an increasing use (and development) of monthly hydrologic models to address a range of hydrological problems (Xu & Singh, 1998). The inter-relation between rainfall, evapotranspiration (ET_o) and runoff on a monthly scale appears to be very close because of the mutual effects and continuous feedback of water movements in the soil-plant-atmosphere continuum (Xiong & Guo, 1999). Hence, if most of the rainfall can be converted into streamflow or water vapour within a month, then it is no longer necessary to distinguish between the runoff generating and routing processes. Monthly water balance models should therefore take a simpler form and use a smaller number of parameters than daily hydrologic models. Monthly models range in complexity, but most have 2 to 5 parameters that require calibration. Monthly hydrologic models can be classified as conceptual (grey-box models) where the equations consider the physical processes in a highly simplified manner. A black-box model is one that is purely empirical. Examples of monthly hydrologic models include: Vandewiele, Xu, and Win (1992); Maklouf and Michel (1994); Xiong and Guo (1999); and Zhang, Potter, Hickel, Zhang and Shao (2008). The last model was of particular interest, as it has been applied to arid areas.

During a meeting on April 11, 2018, Hamish Weatherly of BGC proposed to the EIS team that as a first approach the monthly Dynamic Water Balance Model (DWBM) (Zhang et al., 2008) be applied to the Project area, with streamflow calibration data provided by regional data collected by the United States Geological Survey (USGS) at Pinto Creek. Pinto Creek is located to the immediate north of the upper reaches of Queen Creek and flows to the north, discharging into Roosevelt Lake. The DWBM was considered a candidate model as it had previously been applied with success in Arizona (Hamel, Guswa, Sahl, & Zhang, 2016).

Required inputs to the DWBM are monthly rainfall and potential evaporation (ET_o); the model employs four calibration parameters. The model was calibrated using streamflow data from USGS gage *Pinto Creek Below Haunted Canyon Near Miami* (#09498501). Data are available for the period October 1995 to present at this station, although the USFS (Greg Olsen, pers. comm.) recommended that streamflow data past 2010 not be used for model calibration due to water management activities in the adjacent Carlotta Mine.

Preliminary modelling with the DWBM resulted in a relatively poor fit to the Pinto Creek streamflow data. BGC subsequently decided that a hydrologic model with a daily timestep was required for improved streamflow predictions. Because BGC had recent success with the Australian water balance model (AWBM) on another project, it was identified internally as a candidate model. The AWBM is a catchment water balance model that calculates runoff from rainfall at daily or hourly time increments (Boughton, 2004). The model was originally developed in the early 1990s (Boughton & Carroll, 1993) and is now one of the most widely used rainfall-runoff models in

Australia. The AWBM was preferred by BGC over HSPF in that it has far fewer calibration parameters.

Application of the AWBM to the Pinto Creek watershed resulted in very good calibration to the Pinto Creek USGS streamflow data. Initial model results were presented to the EIS team on June 19, 2018 and it was decided to adopt the AWBM for the EIS alternatives streamflow quantification.

The next section provides an overview of the AWBM, followed by a description of the calibration process.

3.2. Australian Water Balance Model – Description

In its simplest form, the AWBM consists of a store of water in the underlying soils of a catchment. The capacity of this storage unit, *C*, represents the storage capacity of the catchment and is expressed in units of depth (mm). The model assumes that all rainfall or snowmelt is abstracted and that no runoff occurs until the storage unit is filled, following which all rainfall/snowmelt becomes runoff. If the storage unit is empty at the start of the rainfall/snowmelt (i.e., zero antecedent wetness), then there is a lag between rainfall and the start of runoff (line *C* in Figure 3-1a). If there is antecedent moisture at the start of rainfall/snowmelt, then the abstraction is the amount of rainfall/snowmelt required to fill the storage capacity (illustrated by the deficit *D* in Figure 3-1a). When the catchment is fully saturated, i.e., *D* = 0, then all rainfall becomes runoff and the rainfall-runoff relation is the 45° line from the origin (Figure 3-1a).

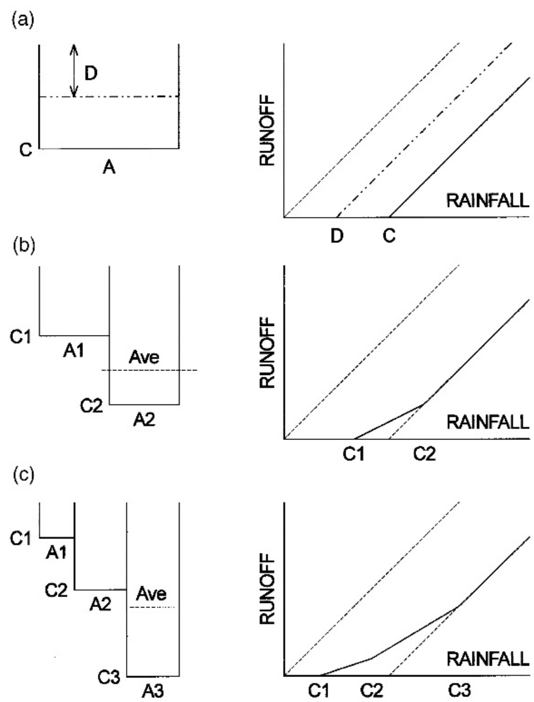


Figure 3-1. Relation of runoff to rainfall/snowmelt with variability in surface storage (after Broughton, 2004).

The AWBM allows for additional moisture stores to be defined for a watershed, recognizing that land cover is almost never uniform over a watershed. Figure 3-1b shows a catchment with two storage capacities, *C1* and *C2*, while Figure 3-1c shows one with three capacities – *C1*, *C2*, and *C3*. In the latter case, the three capacities cover partial areas *A1*, *A2*, and *A3*, respectively of the catchment. The partial areas are fractions of the catchment, where *A1* + *A2* + *A3* = 1. Runoff begins after an amount of rainfall/snowmelt sufficient to fill the smallest storage capacity *C1*. The rainfall-runoff relation becomes a 45º line after an amount equal to the largest capacity *C3*. If the 45º line is project backward, it intersects the x-axis at a value of the average surface storage capacity.

When constructing a hydrologic model, Broughton (2004) recommends the use of three surface stores instead of two or four. The author indicates that increasing the number of areas and surface storage capacities can result in better fits to streamflow data. However, the increase in the number of parameters complicates the calibration process and more parameters produce more interactions among parameters and less definition of each.

The model also allows for evaporation (E) losses from the moisture stores at a calibrated fraction of the defined potential evaporation (P).

The total excess runoff from the three surface stores becomes runoff and is divided between surface runoff and baseflow. The baseflow index (*BFI*) is the fraction of excess flow that becomes baseflow. The runoff components then report to either the surface attenuation store or the baseflow attenuation store (Figure 3-2).

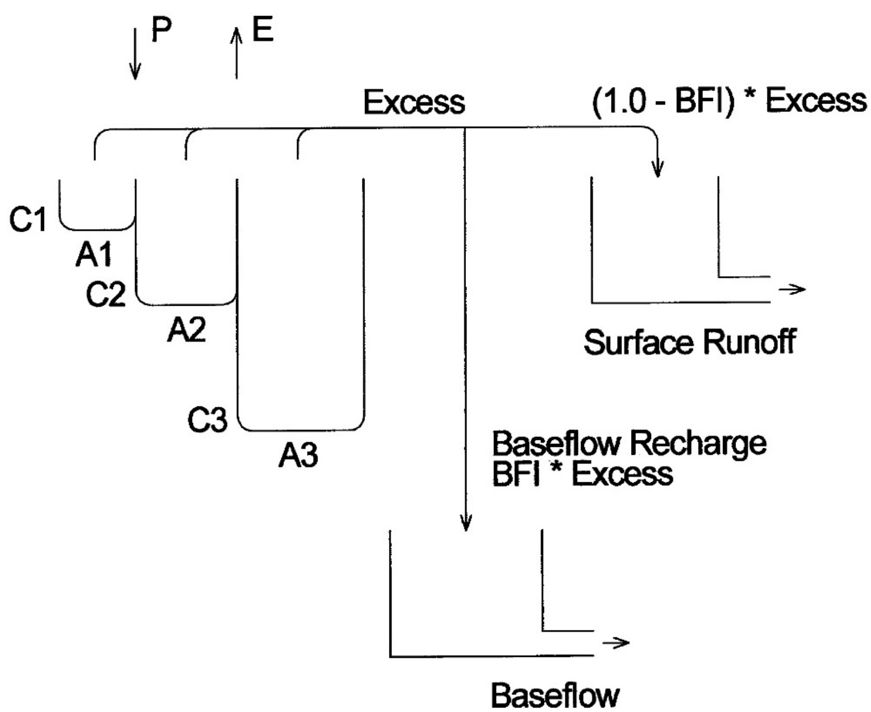


Figure 3-2. Structure of the AWBM (after Broughton 2004).

Discharge from the baseflow attenuation store is calculated as $BS * (1 - K_b)$ where BS is the amount of moisture in the store (mm) and K_b is the baseflow recession constant for the timestep of the calculations. In the AWBM, the fraction of the excess runoff transferred to the baseflow store occurs at the same time as the residual store is transferred to the surface attenuation store. This structure results in a hydrograph where the baseflow discharge is at a maximum at the end of surface runoff and recedes after (Figure 3-3).

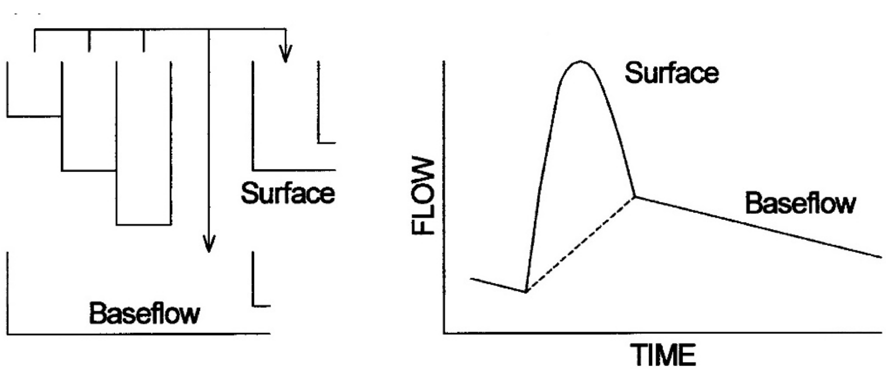


Figure 3-3. AWBM structure for baseflow recharge and resulting streamflow (after Broughton, 2004).

Discharge from the surface attenuation store is calculated as $SS * (1 - K_s)$ where SS is the amount of moisture in the store (mm) and K_s is the recession constant of surface runoff for the timestep of the calculations.

3.3. Model Calibration

3.3.1. Streamflow Data

As noted, the AWBM was calibrated to streamflow data from the USGS Pinto Creek (#09498501) gage. A drainage area of 37.4 sq.mi. reports to this gage (Drawing 01). Figure 3-4 presents the monthly runoff depth reported at this station for the period January 1996 to December 2010. A majority of runoff occurs during the winter (December to March) when evaporation rates are at a minimum. High rainfall also occurs during the summer monsoon season, but typically does not result in runoff. Figure 3-5 demonstrates this relation where some months can have up to 4 to 6 inches of rainfall with minimal runoff response.

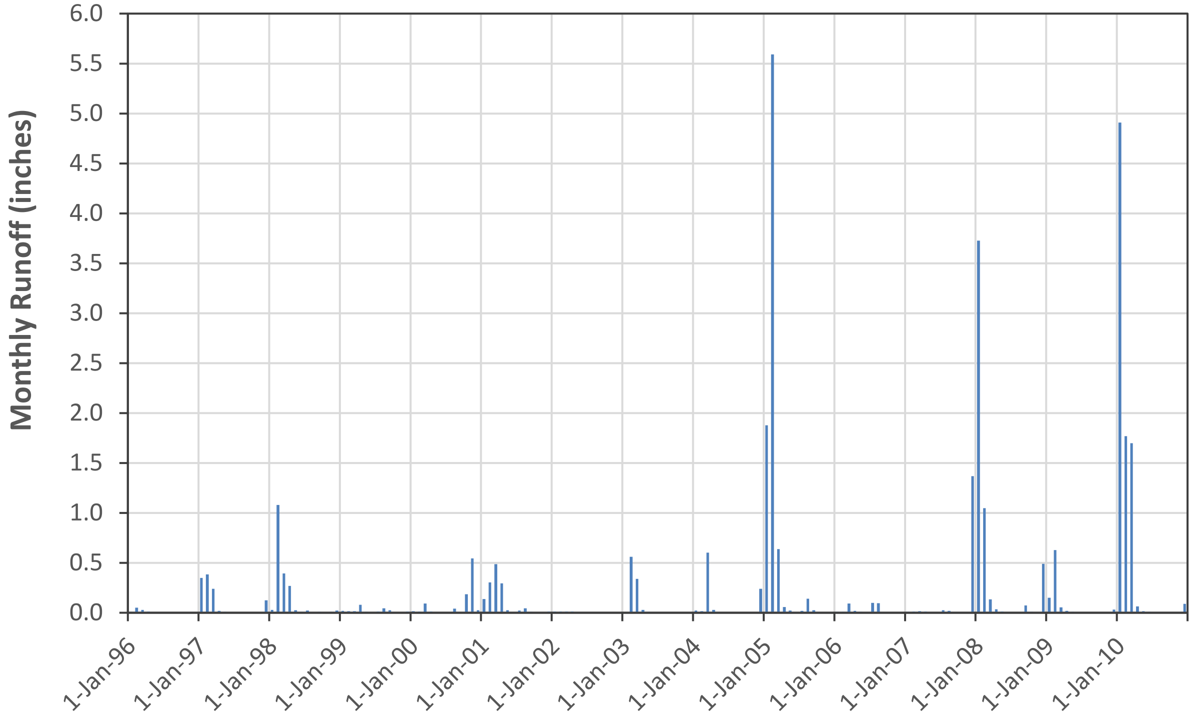


Figure 3-4. AWBM structure for baseflow recharge and resulting streamflow (after Broughton, 2004).

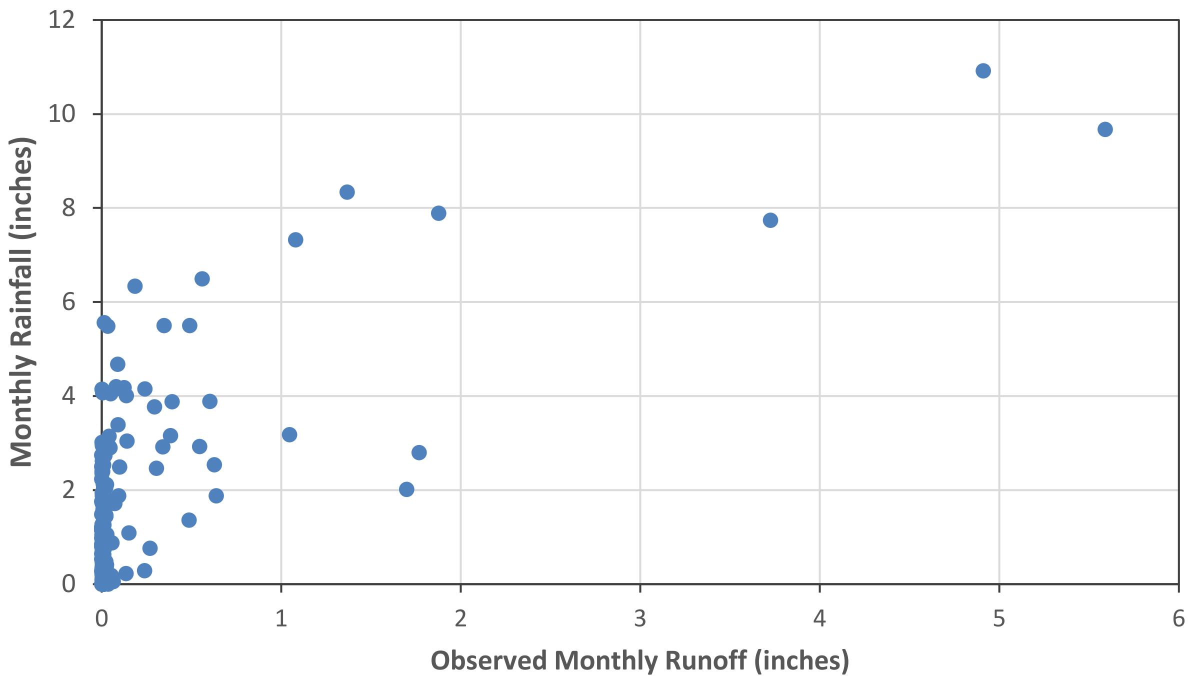


Figure 3-5. Observed monthly runoff at Pinto Creek gage versus monthly rainfall.

Annual runoff, rainfall, and ET_o at the Pinto Creek gage are summarized in Table 3-1 for the period 1996-2010. The data sources for rainfall and ET_o are described in the next section.

Table 3-1. Annual observed runoff, rainfall and potential evaporation at Pinto Creek USGS gage.

Year	Runoff (inches)	Rainfall (inches)	ET_o (inches)
1996	0.13	16.2	71.5
1997	1.13	19.8	69.1
1998	1.88	23.9	66.5
1999	0.24	15.1	71.0
2000	0.94	19.0	71.5
2001	1.35	21.5	69.0
2002	0.06	6.8	75.3
2003	0.95	20.0	72.8
2004	0.92	19.9	71.0
2005	8.39	25.8	70.0
2006	0.35	12.5	69.6
2007	1.48	20.6	72.1
2008	5.54	29.4	70.7
2009	0.89	16.7	72.3
2010	8.57	29.1	69.4
average	**2.19**	**19.7**	**70.8**

During the model calibration process, BGC also considered continuous streamflow data collected by the Resolution Copper Mining LLC team (Applicant). These data have predominantly been collected in the Devil's Canyon watershed at 6 locations, starting in 2004 and extending to present. Additional stations were installed in 2010 by the Applicant in Queen Creek (1 station) and Mineral Creek (two stations). Details of the surface water baseline data are provided in M&A (2013, May 16), M&A (2017, January 26), and JE Fuller (2017, January 31). BGC reviewed the available streamflow data and concluded that the data were not suitable for model calibration due to numerous gaps in the dataset and lack of rating curve validation at higher discharge – almost all of the manual streamflow data were gathered at discharges less than 1 cfs.

3.3.2. Climate Data

Climate data inputs to the AWBM were sourced from two datasets.

Rainfall

Daily rainfall data were sourced from PRISM (Parameter-elevation Regressions on Independent Slopes). PRISM was developed by Oregon State University's PRISM Climate Group starting back in the early 1990s (http://www.prism.oregonstate.edu/). The database uses records from available climate stations, including snow surveys, to estimate monthly precipitation and temperature on a 30 arc-second grid (roughly 2640 ft), covering the period from 1895 to present. PRISM has undergone nearly constant development since its inception. PRISM assumes that for a localized region, elevation is the most important factor in the distribution of climate variables. PRISM calculates a local climate-elevation relationship for each grid cell and uses nearby station data to populate the regression function. In addition to topographic facets, PRISM has station weighting functions that account for proximity to coastlines, the location of temperature inversions and cold air pools, and several measures of terrain complexity.

PRISM has been tested and verified throughout the United States and has been applied in numerous countries across the globe including Canada. Temperature and precipitation data are also available on a daily basis, starting January 1, 1981. Daily data are available on a 4-km by 4-km pixel. For application to the Resolution Copper Project, BGC downloaded daily data for the period 1981-2016 and interpolated the data to a finer grid (1-km by 1-km pixel).

Drawing 02 shows the spatial variation of average annual rainfall (PRISM) for the period 1980-2010 in the Project area. Average annual rainfall is lowest in the valley bottom of Queen Creek (13 inches in the vicinity of Whitlow Ranch Dam), increasing to as high as 26 inches in the upper reaches of the Queen Creek watershed. Average rainfall decreases again as one moves across the drainage divide into the Pinto Creek watershed.

As a secondary check, BGC also compared the PRISM estimates to rainfall data collected at the following climate stations (Drawing 02):

- Superior, AZ (USC00028348) – 1920 to 2006
- Miami, AZ (USC00025512) – 1920 to present
- Superior 2 ENE, AZ (USC00028349) – 1974 to 1996
- Pinal Ranch, AZ (USC00026561) – 1895 to 1973

Good correlation was observed between the data recorded at the above stations and the PRISM dataset, which is expected as the PRISM data are derived from such stations.

Evapotranspiration

Daily evapotranspiration data were obtained from gridMet[1], which is a dataset of daily high resolution (~ 4-km grid) surface meteorological data covering the contiguous US from 1979-yesterday (Abatzoglou, 2013). ET_o is a derived variable from the primary climate variables (temperature, shortwave radiation, wind velocity, humidity) and is calculated using the ASCE Penman-Monteith equation.

As with the PRISM data, BGC downloaded daily ET_o data for the period 1981-2016 and interpolated the data to a finer grid (1-km by 1-km pixel).

[1] http://www.climatologylab.org/gridmet.html

3.3.3. Calibration

Using the downloaded datasets, BGC calculated watershed-average daily values of rainfall and ET_o for the Pinto Creek USGS gage watershed. Daily values were obtained for the period 1996-2010 and input to the AWBM. Optimization of the calibration parameters was conducted on a monthly rather than daily basis, as the desired model output is on a monthly rather than daily time-step. Results of the calibration are presented in Figure 3-6.

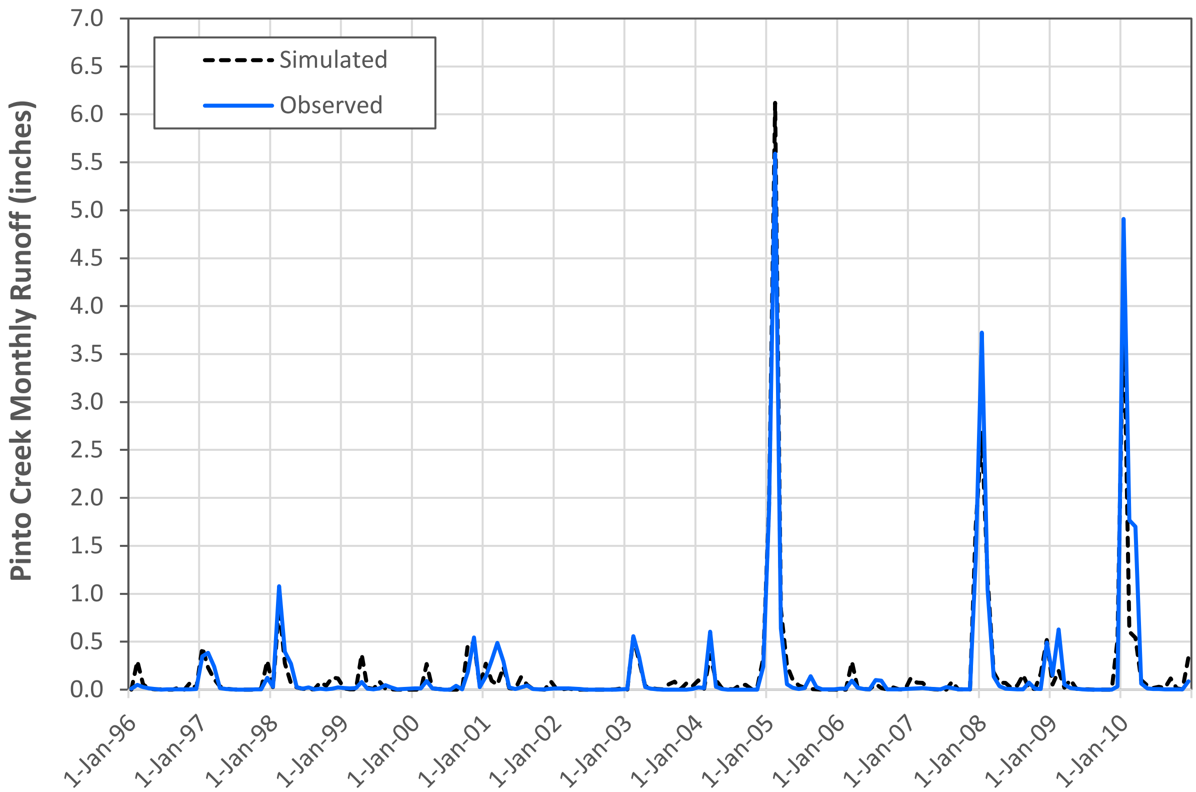


Figure 3-6. Simulated versus observed runoff at Pinto Creek USGS gage (#09498501).

Visually the simulated results are a very close match to the observed data. Three model goodness of fit criteria were calculated to quantify the accuracy of the model results:

- Nash-Sutcliffe Efficiency Index (NSE)
- RSR: ratio between mean quadratic error (RMSE) and standard deviation of observations ($STDEV_{obs}$)
- PBIAS: percentile bias.

$$NSE = \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{mean}\right)^2}\right]$$

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}}{\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{mean}\right)^2}}$$

$$PBIAS = \frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right) \cdot 100}{\sum_{i=1}^{n} Y_i^{obs}}$$

The goodness-of-fit values for the simulated monthly runoff depths are:

- NSE = 0.92
- RSR = 0.28
- PBIAS = 2.6%

These values fall within the very good accuracy criteria category, as per model evaluation guidelines recommended by Moriasi *et al.* (2007) (Table 3-2).

Table 3-2. General model performance ratings for a monthly time step (Moriasi et al., 2007).

Accuracy Criteria	NSE	RSR	PBIAS
Very Good	0.75 – 1.0	0.0 – 0.5	< |10%|
Good	0.65 - 0.75	0.5 – 0.6	|10%| - |15%|
Fair	0.5 – 0.65	0.6 – 0.7	|15%| - |25%|
Poor	< 0.5	> 0.7	> |25%|

The resulting AWBM calibration parameters are listed in Table 3-3.

Table 3-3. AWBM calibration parameters for Pinto Creek.

Parameter	Calibrated Value
A1	0.134
A2	0.433
C1 (mm)	12.7
C2 (mm)	144.3
C3 (mm)	276.5
BFI	0.827
K_{base}	0.176
K_{surf}	0.972

3.4. Model Application

Having calibrated the AWBM to Pinto Creek, the calibrated model was then applied to the various model nodes summarized in Table 2-2. Implicit in this statement is the assumption that the EIS watersheds (i.e., Queen Creek, Devil's Canyon, Dripping Spring and Donnelley Wash) are hydrologically similar to Pinto Creek. Put another way, all the watersheds are assumed to have a common hydrologic response unit (HRU). HRUs are typically based on the physical attributes of the watershed such as elevation, slope and aspect, vegetation type, soil type, and spatiotemporal climate patterns. Investigation of satellite imagery and available GIS layers (e.g., Ecological Response Units, Terrestrial Ecosystem Survey, NRCS data, Arizona soils data) suggests that this assumption is valid. The watersheds are generally characterized by thin soils over bedrock with sparse vegetation and have similar slope gradients. Exceptions are the valley bottom of Queen Creek where a thick sequence of alluvium exists and the average watershed gradient of Donnelley Wash. The impacts of the alluvial sequence are discussed further in model results. The significantly lower watershed gradient of Donnelley Wash compared to the other watersheds can't be reconciled, as there is no other gaging station in the general area that could be used as a streamflow analog.

Table 3-4. Study watershed characteristics.

Watershed	Min Elevation (ft)	Max Elevation (ft)	Mean Elevation (ft)	Average Slope (%)	Area (sq.mi.)
Pinto Creek	3,190	6,680	4,415	39	37
Devil's Canyon	2,240	5,610	4,240	36	36
Dripping Spring Wash	2,025	7,645	3,670	33	117
Queen Creek	2,135	5,610	3,225	31	143
Donnelley Wash	1,615	3,900	2,900	7	60

Assuming the study watersheds and Pinto Creek share a common HRU, then the calibrated AWBM can be applied to estimate average monthly streamflow at the model nodes. However, runoff depths would still vary between watersheds due to the highly variable spatial distribution of rainfall (i.e., Drawing 02). Accordingly, the following steps were applied to estimate average monthly streamflow at each of the model nodes:

1. Delineate the watershed boundary.
2. Calculate watershed-average daily values of rainfall (1981-2016) for the watershed using the interpolated 1-km grid PRISM data.
3. Calculate watershed-average daily values of ET_o (1981-2016) for the watershed using the interpolated 1-km pixel gridMet data.
4. Input the daily rainfall and ET_o data into the calibrated AWBM.
5. Estimate average monthly streamflow from the daily 1981-2016 output.

The above steps were then repeated for the area of the watershed that would be disturbed by the EIS alternative being evaluated. Subtraction of the two sets of values then yielded the potential impact to average monthly streamflow.

4.0 HYDROLOGIC MODEL RESULTS

AWBM results for the various modelling locations are summarized in this section. Model results are grouped by watershed.

4.1. Existing Conditions

For this analysis, Alternative 1 (No Action) assumes that existing conditions and ongoing trends are maintained. Watershed-average climatic conditions (rainfall and ET_o) for the period 1981-2016 are summarized in Table 4-1 for a number (7) of the analysis locations. Also summarized are average monthly runoff depths based on the AWBM simulations.

Average watershed-average annual rainfall varies from 16.6 inches (Donnelley Wash) to 23.1 inches (Devil's Canyon DC-8.1C). Average watershed-average annual potential evapotranspiration (ET_o) is less variable ranging from 67.7 inches to 77.4 inches. Simulated average monthly runoff depths range from a minimum at Donnelley Wash (0.83 inches) to a maximum at Devil's Canyon DC-8.1C (2.67 inches). This variability mimics the spatial distribution of rainfall.

Of note is that adjusted monthly runoff depths are also presented for the three Queen Creek locations.

- The adjusted monthly runoff depths for Queen Creek at Magma Avenue account for direct recharge to the existing mine workings from Queen Creek surface flows. M&A (June 6, 2018) have estimated this recharge at 240 AF/yr (0.33 cfs). This recharge is pumped out of the system as a result of mine dewatering activities and does not report back into the Queen Creek watershed.
- Queen Creek transitions from a steep bedrock streambed to an alluvial bedded, low gradient stream below the Town of Superior. As a result, there is an additional loss of water for downstream reaches of Queen Creek as the surface flows seep into the adjacent alluvium (ADEQ, 2013). This wetting of the alluvium represents a transmission loss and is assumed to be ultimately lost from the system as evapotranspiration. These transmission losses are significant, as indicated by Queen Creek streamflows monitored by the USGS (09478500 – *Queen Creek below Whitlow Dam near Superior*, AZ). Streamflow data are available from this station for the period October 2002 to present. Table 4-2 summarizes average monthly streamflow both measured by the USGS and simulated by BGC for the period 2003-2016. Measured flows are approximately 55% of simulated flows. Therefore, simulated flows presented in the following sections have been adjusted by a factor of 0.56 for Queen Creek at Boyce Thomson Arboretum and Queen Creek above Whitlow Ranch Dam.

Table 4-1. Watershed-average monthly precipitation and potential evapotranspiration, and simulated runoff depths for existing watersheds (1981-2016).

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total/Average
Precipitation (in.)													
Devil's Canyon DC-8.1C	3.1	2.6	2.6	0.9	0.4	0.2	2.3	2.9	1.9	1.3	1.8	3.1	**23.1**
Devil's Canyon at Mineral Creek	2.8	2.4	2.3	0.8	0.4	0.2	2.3	2.9	1.9	1.2	1.7	2.8	**21.7**
Queen Creek at Magma Avenue	3.0	2.6	2.4	0.9	0.4	0.2	2.3	3.0	2.0	1.3	1.7	3.0	**22.7**
Queen Creek at Boyce Thomson Arboretum	2.6	2.3	2.2	0.8	0.4	0.2	2.2	2.8	1.8	1.1	1.6	2.6	**20.5**
Queen Creek above Whitlow Ranch Dam	2.2	2.0	2.0	0.7	0.4	0.2	2.0	2.5	1.6	1.0	1.4	2.2	**18.2**
Donnelley Wash	2.0	1.9	1.6	0.6	0.3	0.2	1.9	2.7	1.4	1.0	1.2	1.7	**16.6**
Dripping Spring Wash	2.4	2.1	2.0	0.7	0.4	0.2	2.2	2.6	1.6	1.1	1.5	2.3	**19.3**
ET_o (in.)													
Devil's Canyon DC-8.1C	2.6	2.9	4.8	6.6	8.7	9.7	8.8	7.5	6.5	4.9	3.1	2.2	**68.4**
Devil's Canyon at Mineral Creek	2.5	2.8	4.8	6.6	8.6	9.6	8.8	7.5	6.4	4.8	3.0	2.1	**67.7**
Queen Creek at Magma Avenue	2.5	2.9	4.8	6.6	8.6	9.6	8.8	7.5	6.5	4.9	3.1	2.1	**67.9**
Queen Creek at Boyce Thomson Arboretum	2.5	2.9	4.8	6.6	8.7	9.7	8.9	7.7	6.6	4.9	3.1	2.1	**68.5**
Queen Creek above Whitlow Ranch Dam	2.4	2.9	4.8	6.7	8.8	9.8	9.1	7.9	6.7	4.9	3.0	2.0	**69.0**
Donnelley Wash	2.5	3.1	5.0	7.0	9.0	10.0	9.1	7.9	6.8	5.1	3.1	2.1	**70.7**
Dripping Spring Wash	3.1	3.4	5.5	7.5	9.7	10.8	9.7	8.3	7.3	5.7	3.7	2.7	**77.4**
Runoff Depth (in.)													
Devil's Canyon DC-8.1C	0.83	0.62	0.40	0.10	0.03	0.01	0.03	0.08	0.07	0.06	0.11	0.32	**2.67**
Devil's Canyon at Mineral Creek	0.65	0.50	0.31	0.07	0.02	0.01	0.04	0.09	0.08	0.06	0.10	0.26	**2.19**
Queen Creek at Magma Avenue	0.76	0.58	0.35	0.09	0.03	0.01	0.04	0.10	0.08	0.07	0.11	0.29	**2.50**
– adjusted	0.63	0.48	0.29	0.07	0.02	0.01	0.03	0.08	0.07	0.05	0.09	0.24	**2.06**
Queen Creek at Boyce Thomson Arboretum	0.53	0.41	0.25	0.06	0.02	0.01	0.03	0.08	0.06	0.05	0.09	0.22	**1.81**
– adjusted	0.27	0.20	0.13	0.03	0.01	0.00	0.02	0.04	0.03	0.03	0.04	0.11	**0.92**
Queen Creek above Whitlow Ranch Dam	0.36	0.28	0.18	0.04	0.01	0.00	0.02	0.05	0.05	0.04	0.07	0.16	**1.28**
– adjusted	0.19	0.15	0.10	0.02	0.01	0.00	0.01	0.03	0.03	0.02	0.04	0.09	**0.69**
Donnelley Wash	0.25	0.16	0.10	0.02	0.01	0.00	0.01	0.04	0.03	0.04	0.06	0.10	**0.83**
Dripping Spring Wash	0.43	0.28	0.17	0.04	0.01	0.00	0.01	0.04	0.03	0.05	0.08	0.16	**1.30**

Table 4-2. Observed and simulated average monthly runoff depth for Queen Creek at Whitlow Ranch Dam.

Month	Observed (inches)	Simulated (inches)
January	0.19	0.21
February	0.12	0.27
March	0.07	0.12
April	0.02	0.02
May	0.02	0.01
June	0.01	0.00
July	0.02	0.03
August	0.03	0.04
September	0.02	0.04
October	0.01	0.02
November	0.01	0.04
December	0.02	0.17
Average	**0.55**	**0.99**

4.2. Devil's Canyon – All Action Alternatives

All of the EIS action alternatives will impact Devil's Canyon at the two modelling nodes: DC-8.1C and the confluence with Mineral Creek. The impact to streamflow is a result of the subsidence zone encroaching into the Devil's Canyon watershed. Model results for these two locations are presented in Table 4-3.

Table 4-3. AWBM simulation results of average monthly streamflows for Devil's Canyon.

Month	DC-8.1C				Mineral Creek confluence			
	Existing (cfs)	Captured Flow (cfs)	Proposed Action (cfs)	% change	Existing (cfs)	Captured Flow (cfs)	Proposed Action (cfs)	% change
January	13.73	0.72	13.01	-5.3%	21.97	0.72	21.25	-3.3%
February	11.23	0.62	10.61	-5.6%	17.33	0.62	16.71	-3.6%
March	6.60	0.35	6.25	-5.3%	10.38	0.35	10.04	-3.4%
April	1.64	0.08	1.56	-5.1%	2.47	0.08	2.38	-3.4%
May	0.48	0.03	0.45	-5.4%	0.73	0.03	0.71	-3.5%
June	0.17	0.01	0.17	-5.3%	0.27	0.01	0.26	-3.4%
July	0.53	0.04	0.48	-8.2%	0.84	0.04	0.79	-5.2%
August	1.36	0.10	1.27	-7.2%	2.18	0.10	2.09	-4.5%
September	1.18	0.09	1.09	-7.5%	1.98	0.09	1.89	-4.5%
October	1.04	0.07	0.97	-6.5%	1.75	0.07	1.68	-3.9%
November	1.96	0.11	1.84	-5.9%	3.22	0.11	3.11	-3.6%
December	5.32	0.29	5.04	-5.4%	8.48	0.29	8.19	-3.4%
Average	**3.74**	**0.21**	**3.53**	**-5.6%**	**5.92**	**0.21**	**5.71**	**-3.5%**

Existing flows represent Alternative 1 – do nothing.

Proposed action flows represent Alternatives 2, 3, 4, 5 and 6.

4.3. Queen Creek – All Action Alternatives

Modelled average monthly streamflow for the Queen Creek locations are presented in this section. Simulated flows have been adjusted to account for direct recharge to the existing mine workings from surface flows and transmission losses to the alluvial bedded, low gradient stream below the Town of Superior (see Section 4.1).

4.3.1. Queen Creek at Magma Avenue

Queen Creek flows at Magma Avenue will be impacted by all action alternatives due to a portion of the watershed falling within the subsidence crater. Model results are shown in Table 4-4.

Table 4-4. AWBM simulation results of average monthly streamflows for Queen Creek at Magma Avenue.

Month	Existing (cfs)	Captured Flow (cfs)	Proposed Action (cfs)	% change
January	5.63	1.02	4.61	-18.2%
February	4.75	0.89	3.86	-18.6%
March	2.61	0.49	2.12	-18.8%
April	0.68	0.12	0.56	-17.8%
May	0.20	0.04	0.16	-18.4%
June	0.07	0.01	0.06	-18.5%
July	0.31	0.06	0.25	-20.2%
August	0.74	0.14	0.59	-19.6%
September	0.64	0.13	0.51	-19.7%
October	0.49	0.10	0.39	-19.5%
November	0.83	0.16	0.67	-19.4%
December	2.17	0.40	1.76	-18.6%
Average	**1.58**	**0.29**	**1.28**	**-18.6%**

Existing flows represent Alternative 1 – do nothing.

Proposed action flows represent Alternatives 2, 3, 4, 5 and 6.

4.3.2. Queen Creek at Boyce Thomson Arboretum

Queen Creek flows at Boyce Thomson Arboretum will be impacted by all action alternatives due to a portion of the watershed falling within the subsidence crater and the collection of contact water within the West Plant Site. Additional flow losses will also occur under Alternative 4, with flows in Happy Canyon and Silver King Wash being reduced. Model results are shown in Table 4-5.

4.3.3. Queen Creek above Whitlow Ranch Dam

Queen Creek flows above Whitlow Ranch Dam will be impacted by all action alternatives due to a portion of the watershed falling within the subsidence crater and the collection of contact water within the West Plant Site. Additional flow losses will also occur under Alternatives 2/3 and 4 with flow reductions in north tributaries. Model results are shown in Table 4-6.

4.3.4. Queen Creek Tributaries – Alternatives 2/3 and 4

As well as impacting flows in Queen Creek, Alternative 2/3 will impact flows in Roblas Canyon, Bear Tank Canyon, and Potts Canyon. Model results are presented in Table 4-7. All streamflow in Bear Tank Canyon will either be diverted into Potts Canyon or captured within the TSF footprint, resulting in a total loss of surficial runoff at the canyon's mouth. Runoff diverted into Potts Canyon results in a slight increase in streamflow for this watershed.

Alternative 4 will impact flows in Potts Cayon, Happy Canyon and Silver King Wash, as summarized in Table 4-8. While the TSF disturbance footprint within Silver King Wash is 0.21 sq.mi. (Table 2-4), portions of the Potts Canyon and Happy Canyon watersheds is diverted into Silver King Wash. As a result, the overall impact to streamflow in this wash is only 0.5% on average.

Table 4-5. AWBM simulation results of average monthly streamflows for Queen Creek at Boyce Thomson Arboretum.

Month	Alternative 2, 3,5 and 6				Alternative 4			
	Existing (cfs)	Captured Flow (cfs)	Proposed Action (cfs)	% change	Existing (cfs)	Captured Flow (cfs)	Proposed Action (cfs)	% change
January	6.54	0.88	5.66	-13.4%	6.54	1.30	5.24	-19.8%
February	5.50	0.75	4.75	-13.7%	5.50	1.10	4.40	-20.0%
March	3.07	0.41	2.66	-13.5%	3.07	0.61	2.46	-19.9%
April	0.81	0.10	0.71	-12.8%	0.81	0.15	0.66	-18.8%
May	0.24	0.03	0.20	-13.4%	0.24	0.05	0.19	-19.7%
June	0.08	0.01	0.07	-13.3%	0.08	0.02	0.07	-19.6%
July	0.38	0.05	0.32	-14.3%	0.38	0.08	0.30	-21.3%
August	0.98	0.13	0.84	-13.5%	0.98	0.20	0.77	-20.7%
September	0.81	0.11	0.70	-13.6%	0.81	0.17	0.64	-20.4%
October	0.63	0.08	0.54	-13.4%	0.63	0.13	0.50	-20.2%
November	1.12	0.15	0.97	-13.0%	1.12	0.23	0.89	-20.3%
December	2.68	0.35	2.33	-13.2%	2.68	0.53	2.15	-19.7%
Average	**1.89**	**0.25**	**1.63**	**-13.4%**	**1.89**	**0.38**	**1.51**	**-19.9%**

Existing flows represent Alternative 1 – do nothing.

Table 4-6. AWBM simulation results of average monthly streamflows for Queen Creek above Whitlow Ranch Dam.

Month	Alternative 2/3				Alternative 4				Alternatives 5 and 6			
	Existing (cfs)	Captured Flow (cfs)	Proposed Action (cfs)	% change	Existing (cfs)	Captured Flow (cfs)	Proposed Action (cfs)	% change	Existing (cfs)	Captured Flow (cfs)	Proposed Action (cfs)	% change
January	23.90	1.61	22.29	-6.8%	23.90	2.24	21.66	-9.4%	23.90	0.88	23.02	-3.7%
February	21.14	1.33	19.80	-6.3%	21.14	1.89	19.25	-8.9%	21.14	0.75	20.39	-3.6%
March	12.11	0.77	11.33	-6.4%	12.11	1.03	11.08	-8.5%	12.11	0.41	11.69	-3.4%
April	2.83	0.19	2.64	-6.7%	2.83	0.26	2.57	-9.3%	2.83	0.10	2.73	-3.7%
May	0.87	0.06	0.81	-6.4%	0.87	0.08	0.79	-9.1%	0.87	0.03	0.84	-3.6%
June	0.32	0.02	0.30	-6.5%	0.32	0.03	0.29	-8.9%	0.32	0.01	0.31	-3.5%
July	1.50	0.11	1.39	-7.3%	1.50	0.14	1.36	-9.0%	1.50	0.05	1.44	-3.6%
August	3.64	0.24	3.40	-6.7%	3.64	0.35	3.29	-9.6%	3.64	0.13	3.51	-3.6%
September	3.27	0.21	3.05	-6.5%	3.27	0.29	2.98	-8.8%	3.27	0.11	3.16	-3.4%
October	2.60	0.17	2.43	-6.4%	2.60	0.22	2.38	-8.4%	2.60	0.08	2.52	-3.2%
November	5.07	0.32	4.76	-6.2%	5.07	0.40	4.68	-7.9%	5.07	0.15	4.93	-2.9%
December	10.94	0.71	10.23	-6.5%	10.94	0.91	10.03	-8.4%	10.94	0.35	10.59	-3.2%
Average	**7.28**	**0.47**	**6.81**	**-6.5%**	**7.28**	**0.65**	**6.64**	**-8.9%**	**7.28**	**0.25**	**7.03**	**-3.5%**

Existing flows represent Alternative 1 – do nothing.

Table 4-7. AWBM simulation results of average monthly streamflows for Queen Creek Tributaries – Alternative 2/3.

Month	Roblas Canyon				Bear Tank Canyon				Potts Canyon			
	Existing (cfs)	TSF (cfs)	Proposed Action (cfs)	% change	Existing (cfs)	TSF (cfs)	Proposed Action (cfs)	% change	Existing (cfs)	Diverted (cfs)	Proposed Action (cfs)	% change
January	2.91	0.21	2.70	-7.1%	1.20	1.20	0.00	-100%	8.19	0.36	8.55	4.5%
February	2.38	0.16	2.22	-6.7%	0.96	0.96	0.00	-100%	6.81	0.30	7.11	4.4%
March	1.37	0.10	1.27	-7.6%	0.54	0.54	0.00	-100%	3.64	0.17	3.80	4.6%
April	0.32	0.03	0.30	-7.9%	0.13	0.13	0.00	-100%	1.01	0.04	1.05	3.9%
May	0.10	0.01	0.09	-7.4%	0.04	0.04	0.00	-100%	0.29	0.01	0.30	4.2%
June	0.04	0.00	0.03	-7.5%	0.01	0.01	0.00	-100%	0.10	0.00	0.11	4.3%
July	0.19	0.02	0.17	-9.5%	0.08	0.08	0.00	-100%	0.45	0.02	0.48	4.7%
August	0.40	0.03	0.37	-7.7%	0.17	0.17	0.00	-100%	1.19	0.05	1.24	4.5%
September	0.38	0.03	0.35	-8.3%	0.15	0.15	0.00	-100%	1.04	0.04	1.09	4.3%
October	0.29	0.02	0.26	-8.5%	0.12	0.12	0.00	-100%	0.78	0.03	0.81	4.4%
November	0.58	0.05	0.53	-8.7%	0.25	0.25	0.00	-100%	1.41	0.07	1.47	4.7%
December	1.25	0.11	1.14	-8.7%	0.52	0.52	0.00	-100%	3.34	0.14	3.48	4.3%
Average	**0.84**	**0.06**	**0.78**	**-7.5%**	**0.35**	**0.35**	**0.00**	**-100%**	**2.33**	**0.10**	**2.44**	**4.4%**

Existing flows represent Alternative 1 – do nothing.

Table 4-8. AWBM simulation results of average monthly streamflows for Queen Creek Tributaries – Alternative 4.

Month	Silver King Wash				Happy Canyon				Potts Canyon			
	Existing (cfs)	TSF (cfs)	Proposed Action (cfs)	% change	Existing (cfs)	TSF (cfs)	Proposed Action (cfs)	% change	Existing (cfs)	TSF (cfs)	Proposed Action (cfs)	% change
January	3.23	0.01	3.23	-0.2%	0.99	0.55	0.44	-55.3%	8.19	1.69	6.49	-20.7%
February	2.68	0.01	2.66	-0.6%	0.84	0.45	0.38	-54.1%	6.81	1.41	5.39	-20.7%
March	1.48	0.00	1.48	-0.3%	0.52	0.26	0.26	-50.6%	3.64	0.76	2.88	-20.8%
April	0.41	0.00	0.41	0.7%	0.11	0.07	0.05	-58.0%	1.01	0.20	0.82	-19.4%
May	0.12	0.00	0.12	0.0%	0.03	0.02	0.01	-57.1%	0.29	0.06	0.23	-20.3%
June	0.04	0.00	0.04	-0.1%	0.01	0.01	0.01	-53.8%	0.10	0.02	0.08	-20.4%
July	0.19	0.00	0.19	-0.8%	0.07	0.03	0.03	-51.5%	0.45	0.10	0.36	-21.8%
August	0.47	0.01	0.47	-1.4%	0.18	0.09	0.09	-49.9%	1.19	0.27	0.92	-22.6%
September	0.41	0.00	0.41	-0.5%	0.14	0.07	0.07	-51.4%	1.04	0.22	0.83	-21.0%
October	0.31	0.00	0.31	-0.9%	0.11	0.06	0.05	-50.1%	0.78	0.17	0.61	-21.4%
November	0.53	0.01	0.53	-1.6%	0.23	0.10	0.13	-45.1%	1.41	0.31	1.10	-21.9%
December	1.31	0.01	1.30	-0.7%	0.46	0.23	0.23	-49.7%	3.34	0.69	2.64	-20.8%
Average	**0.93**	**0.00**	**0.92**	**-0.5%**	**0.31**	**0.16**	**0.15**	**-52.5%**	**2.33**	**0.49**	**1.85**	**-20.9%**

Existing flows represent Alternative 1 – do nothing.

4.4. Donnelley Wash – Alternative 5

Streamflow at the mouth of Donnelley Wash and a smaller tributary to the immediate north will be impacted by the Alternative 5 TSF footprint. Model results are shown in Table 4-9.

Average monthly streamflows for the Gila River are based on USGS gage 09474000 – *Gila River at Kelvin, AZ*. Streamflow records for this gage extend as far back as 1911. Monthly values reported in Table 4-9 are averages for the 1981-2016 period. This USGS gage is located approximately 15 miles upstream of the Donnelley Wash confluence (Drawing 01) and has a reported drainage area of 18,011 sq.mi.

4.5. Dripping Spring Wash – Alternative 6

Streamflow at the mouth of Dripping Spring Wash will be impacted both by the Alternative 6 TSF footprint and the northern diversion channels, which divert water into the Mineral Creek watershed. Model results are shown in Table 4-10. Average monthly impacts to the Gila River are provided for two locations: at the confluence with Dripping Spring Wash and confluence with Donnelley Wash. Results for the latter assume that all of the surface runoff diverted into the Mineral Creek watershed eventually reports to the Gila River, although it is recognized that some of this runoff could be lost to evaporation or evapotranspiration before discharging to the Gila River.

Average monthly streamflows for the Gila River at Dripping Spring Wash are based on USGS gage 09469500 – *Gila River below Coolidge Dam, AZ*. Streamflow records for this gage extend as far back as 1899. Monthly values reported in Table 4-10 are averages for the 1981-2016 period. This USGS gage is located approximately 20 miles upstream of the Dripping Spring Wash confluence (Drawing 01) and has a reported drainage area of 12,866 sq.mi. In comparison, the drainage area of the Gila River at Dripping Spring Wash is estimated at 15,473 sq.mi. (JE Fuller, 2018).

Table 4-9. AWBM simulation results of average monthly streamflows for Donnelley Wash and Unnamed Wash – Alternative 5.

Month	Donnelley Wash at Mouth				Donnelley Wash Tributary at Mouth				Gila River at Donnelley Wash Confluence			
	Existing (cfs)	TSF (cfs)	Proposed Action (cfs)	% change	Existing (cfs)	TSF (cfs)	Proposed Action (cfs)	% change	Existing (cfs)	TSF (cfs)	Proposed Action (cfs)	% change
January	13.19	2.97	10.23	-22.5%	1.18	0.31	0.87	-26.1%	746	3.27	743.2	-0.4%
February	9.26	2.12	7.14	-22.9%	0.82	0.22	0.60	-26.7%	554	2.34	551.3	-0.4%
March	5.27	1.18	4.09	-22.3%	0.55	0.12	0.43	-22.0%	852	1.30	850.3	-0.2%
April	1.31	0.28	1.03	-21.0%	0.13	0.03	0.10	-22.5%	609	0.30	608.4	0.0%
May	0.34	0.08	0.25	-24.8%	0.03	0.01	0.02	-26.3%	536	0.09	536.1	0.0%
June	0.14	0.03	0.11	-22.7%	0.01	0.00	0.01	-24.1%	636	0.04	636.3	0.0%
July	0.66	0.10	0.55	-15.8%	0.05	0.01	0.04	-21.9%	744	0.11	743.9	0.0%
August	2.32	0.40	1.92	-17.2%	0.19	0.04	0.14	-22.3%	720	0.44	719.1	-0.1%
September	1.49	0.29	1.21	-19.3%	0.16	0.03	0.13	-18.9%	345	0.32	344.5	-0.1%
October	2.10	0.44	1.66	-20.9%	0.22	0.05	0.18	-20.5%	252	0.49	251.2	-0.2%
November	3.13	0.60	2.53	-19.3%	0.27	0.06	0.21	-23.0%	61	0.67	60.5	-1.1%
December	5.30	1.01	4.29	-19.1%	0.54	0.11	0.43	-19.6%	245	1.12	243.4	-0.5%
Average	**3.69**	**0.79**	**2.90**	**-21.3%**	**0.34**	**0.08**	**0.26**	**-23.7%**	**526**	**0.87**	**525.0**	**-0.2%**

Existing flows represent Alternative 1 – do nothing.

Table 4-10. AWBM simulation results of average monthly streamflows for Dripping Spring Wash – Alternative 6.

Month	Dripping Spring Wash at Mouth					Gila River at Dripping Spring Wash Confluence				Gila River at Donnelley Wash Confluence			
	Existing (cfs)	TSF (cfs)	Mineral Creek Diversion (cfs)	Proposed Action (cfs)	% change	Existing (cfs)	TSF / Diverted Flow (cfs)	Proposed Action (cfs)	% change	Existing (cfs)	TSF (cfs)	Proposed Action (cfs)	% change
January	43.66	5.57	3.03	35.06	-12.8%	436	8.6	427.9	-2.0%	746	5.6	740.9	-0.7%
February	31.65	4.26	2.31	25.08	-13.5%	384	6.6	377.5	-1.7%	554	4.3	549.4	-0.8%
March	16.89	2.30	1.25	13.34	-13.6%	701	3.6	697.7	-0.5%	852	2.3	849.3	-0.3%
April	4.12	0.55	0.30	3.27	-13.4%	562	0.9	561.1	-0.2%	609	0.6	608.1	-0.1%
May	1.11	0.16	0.08	0.87	-13.9%	536	0.2	535.8	0.0%	536	0.2	536.0	0.0%
June	0.46	0.06	0.03	0.36	-13.5%	642	0.1	642.0	0.0%	636	0.1	636.3	0.0%
July	1.44	0.18	0.10	1.16	-12.4%	687	0.3	686.4	0.0%	744	0.2	743.8	0.0%
August	3.84	0.48	0.26	3.10	-12.5%	602	0.7	601.3	-0.1%	720	0.5	719.1	-0.1%
September	3.27	0.41	0.22	2.63	-12.6%	288	0.6	287.7	-0.2%	345	0.4	344.4	-0.1%
October	4.63	0.49	0.27	3.87	-10.6%	153	0.8	152.7	-0.5%	252	0.5	251.2	-0.2%
November	7.92	0.96	0.52	6.44	-12.1%	33	1.5	32.0	-4.4%	61	1.0	60.2	-1.6%
December	16.17	2.08	1.13	12.96	-12.9%	179	3.2	175.5	-1.8%	245	2.1	242.5	-0.9%
Average	**11.18**	**1.45**	**0.79**	**8.94**	**-12.9%**	**435**	**2.2**	**432.5**	**-0.5%**	**526**	**1.4**	**524.4**	**-0.3%**

Existing flows represent Alternative 1 – do nothing.

5.0 SUMMARY

Table 5-1 summarizes estimated changes in annual average streamflow for the six alternatives.

Table 5-1. Estimated change in average annual streamflow for the six DEIS alternatives.

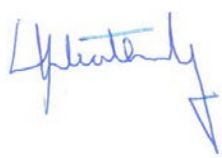
Location		Alternative					
		1	2	3	4	5	6
Queen Creek at Magma Avenue	cfs	1.58	1.28	1.28	1.28	1.28	1.28
	% change	**-**	**-19**	**-19**	**-19**	**-19**	**-19**
Queen Creek at Boyce Thomson Arboretum	cfs	1.89	1.63	1.63	1.51	1.63	1.63
	% change	**-**	**-13**	**-13**	**-20**	**-13**	**-13**
Queen Creek above Whitlow Ranch Dam	cfs	7.28	6.81	6.81	6.64	7.03	7.03
	% change	**-**	**-6.5**	**-6.5**	**-9**	**-3.5**	**-3.5**
Devil's Canyon at Mineral Creek	cfs	5.92	5.71	5.71	5.71	5.71	5.71
	% change	**-**	**-3.5**	**-3.5**	**-3.5**	**-3.5**	**-3.5**
Dripping Spring Wash	cfs	11.18	11.18	11.18	11.18	11.18	8.94
	% change	**-**	**0**	**0**	**0**	**0**	**-13**
Donnelley Wash	cfs	3.69	3.69	3.69	3.69	2.90	3.69
	% change	**-**	**0**	**0**	**0**	**-21**	**0**
Gila River at Donnelley Wash	cfs	526	526	526	526	525.0	524.4
	% change	**-**	**0**	**0**	**0**	**-0.2**	**-0.3**

6.0 CLOSURE

We trust the above satisfies your requirements at this time. Should you have any questions or comments, please do not hesitate to contact us.

Yours sincerely,

BGC ENGINEERING INC.
per:



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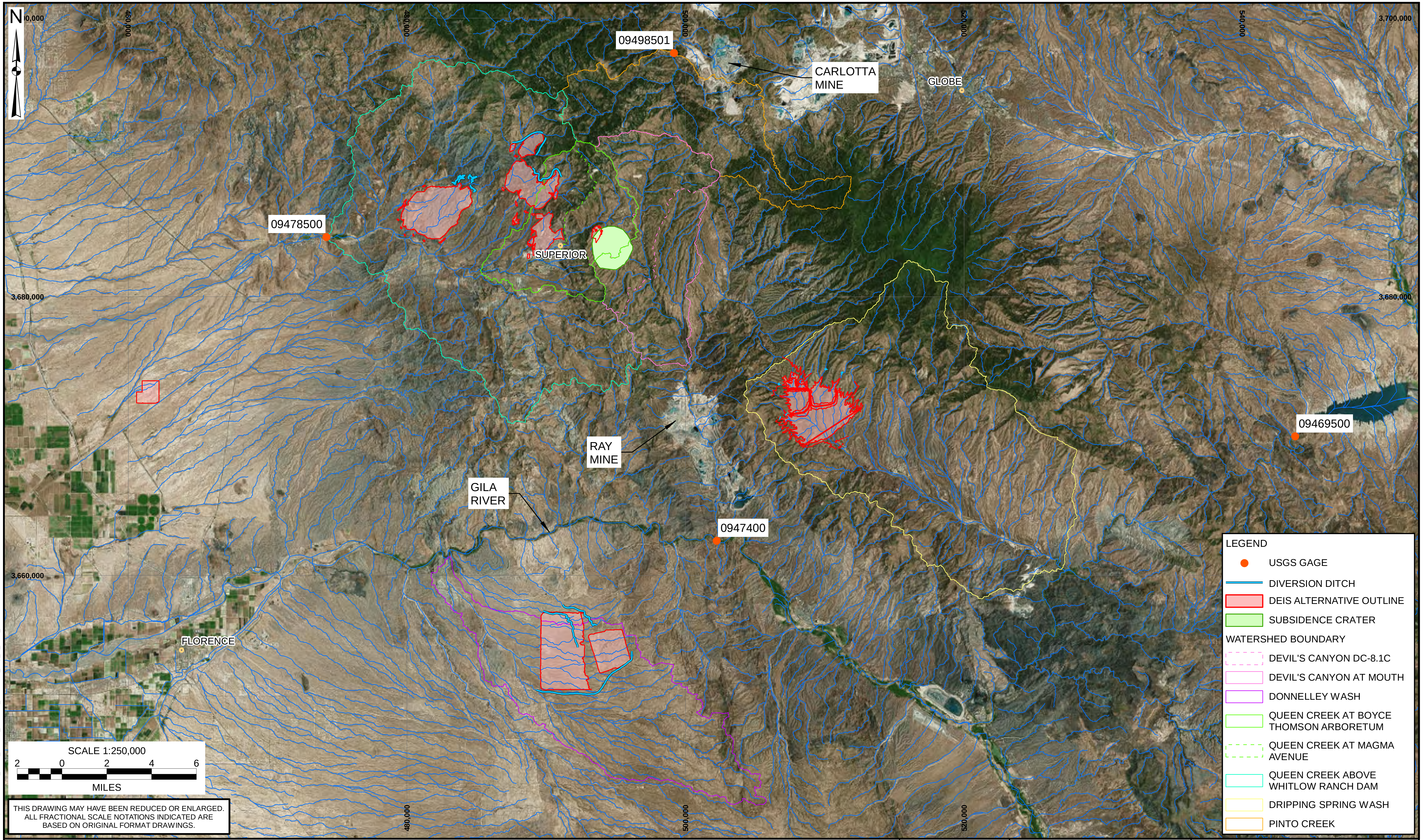
DRAWINGS



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PROJECT: RESOLUTION COPPER PROJECT EIS, WATER BALANCE MODEL FOR DEIS ALTERNATIVES

TITLE: WATERSHED MAP OF DEIS ALTERNATIVES

PROJECT No.:	DWG No:
1704005	01

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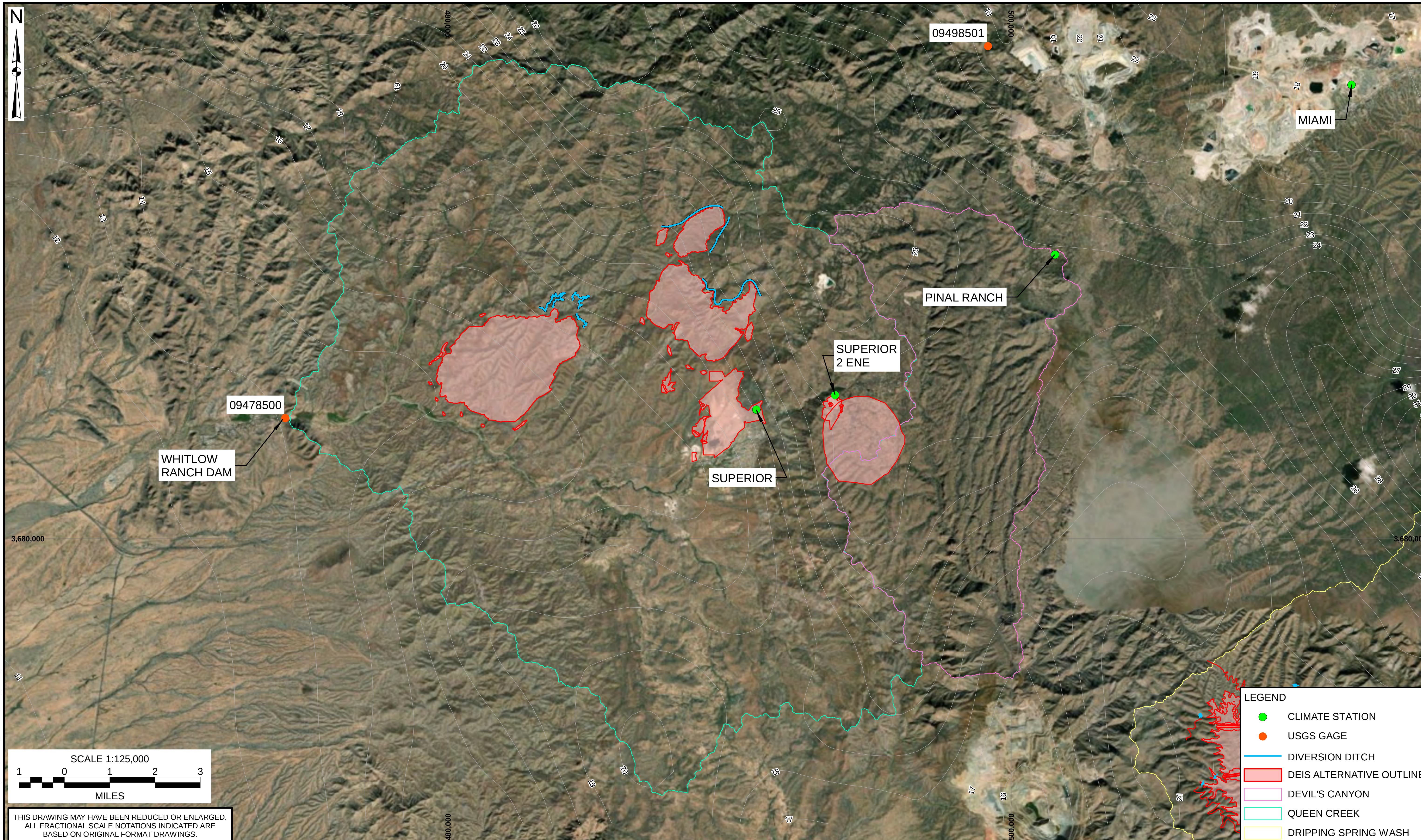

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RESOLUTION COPPER PROJECT, WATER BALANCE MODEL FOR EIS ALTERNATIVES", AND DATED OCTOBER 2018.
3. PROJECTION IS NAD 1927 UTM ZONE 12N.
4. PRECIPITATION DATA PROVIDED BY PRISM CLIMATE GROUP, OREGON STATE UNIVERSITY, DATED JUNE 13, 2018. CONTOUR INTERVAL IS 1 ".
5. IMAGERY PROVIDED BY ESRI WORLD IMAGERY, DATED JUNE 7, 2015.
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SCALE:	1:125,000
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DRAWN:	JVT
CHECKED:	HW
APPROVED:	RE

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
SWCA
ENVIRONMENTAL CONSULTANTS

PROJECT:
RESOLUTION COPPER PROJECT EIS,
WATER BALANCE MODEL FOR DEIS ALTERNATIVES

TITLE:
MEAN ANNUAL PRECIPITATION (PRISM), 1981 - 2010

PROJECT No.:	DWG No:
1704005	02

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