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System-wide Hydrologic Water Flow Budget

RESOLUTION COPPER, PINAL COUNTY, ARIZONA

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1 EXECUTIVE SUMMARY

This report presents a water budget for all watersheds and groundwater systems within the projected impact area for the panel-cave underground mining project proposed by Resolution Copper. The report was prepared by Montgomery & Associates on behalf of Resolution Copper.

The purpose of this study is to identify the principal natural and anthropogenic water budget components for four domains, the Queen Creek, Devils Canyon, and Upper Mineral Creek watersheds and associated groundwater systems, and the Deep Groundwater System, and to use available hydrologic and water use data to develop quantitative water budgets for the current conditions.

The following conclusions are based on compilation, review, and analysis of available data for each of the four water budget domains.

1.1 Queen Creek Domain

The Queen Creek water budget domain encompasses Queen Creek watershed and the near-surface groundwater systems that underlie it, the Apache Leap Tuff (ALT) aquifer to the east, and the Superior Basin Groundwater System to the west.

- Mean annual precipitation (118,500 acre-feet per year (AF/yr)) is the principal inflow of water to the Queen Creek domain. Imported water for municipal use (490 AF/yr) and predicted seepage from Tailings Pond 6 (180 AF/yr) comprise comparatively small secondary inflows to the domain.

- Mean annual outflows from the domain include surface evapotranspiration (-114,200 AF/yr), discharge at the basin outlet (-3,730 AF/yr), groundwater evapotranspiration (-1070 AF/yr), groundwater recharge to the Deep Groundwater System via infiltration to the mine workings along Queen Creek Canyon (-240 AF/yr), pumping from the Superior Basin groundwater system (-110 AF/yr), and vertical groundwater flux out of the ALT aquifer (-30 AF/yr).

- There is a net negative residual for the Queen Creek domain of -210 AF/yr. The residual is a calculated imbalance which may be related to errors in other estimated water budget components, or due to physical processes such as change in groundwater storage. Anthropogenic losses associated with groundwater pumping, groundwater flux out of the ALT aquifer, and recharge to the Deep Groundwater System associated with dewatering of the mine workings exceed anthropogenic inflows associated with seepage from Tailings Pond 6 and imported municipal water (some of which is lost to ET) by approximately 150 AF/yr, suggesting that anthropogenic fluxes may contribute to the negative residual in the Queen Creek water budget domain.

1.2 Deep Groundwater System Domain

The Deep Groundwater System domain is generally isolated from the Queen Creek and Devils Canyon watersheds that overlie it by the Whitetail Conglomerate, a regional aquitard, except for a small area in the vicinity of Queen Creek Canyon where geologic units from the Deep Groundwater System are exposed at the surface along the stream bed.

- Mean annual inflows include 240 AF/yr of recharge to the mine workings via infiltration along Queen Creek Canyon where the geologic units are exposed along the stream bed, and 580 AF/yr of vertical groundwater flux into the Deep Groundwater System.

- Annual outflow from the Deep Groundwater System for 2017 is approximately -1,360 AF/yr of groundwater pumping due to shaft dewatering.

- These fluxes produce a net negative residual of approximately -540 AF/yr, which represents water removed from storage in the Deep Groundwater System as a result of mine dewatering activities.

1.3 Devils Canyon Domain

The Devils Canyon water budget domain includes Devils Canyon watershed and the ALT aquifer that underlies it.

- The mean annual inflow of water to the Devils Canyon domain is 37,700 AF/yr of precipitation.

- The mean annual outflows of water from the system include surface evapotranspiration (-32,400 AF/yr), surface discharge at the confluence with Mineral Creek (-4,620 AF/yr), lateral groundwater flux from the Devils Canyon domain into the Upper Mineral Creek domain (-360 AF/yr), groundwater evapotranspiration (-340 AF/yr), and groundwater pumping (-30 AF/yr).

- The residual for the Devils Canyon water budget domain is negligible; this domain is approximately at equilibrium.

1.4 Upper Mineral Creek Domain

The Upper Mineral Creek water budget domain includes Upper Mineral Creek watershed and the groundwater system that underlies it.

- The mean annual inflows of water to the Upper Mineral Creek domain include 57,200 AF/yr of precipitation and 360 AF/yr of lateral groundwater flow from the Devils Canyon domain.

- The mean annual outflows of water from the system include surface evapotranspiration (-55,300 AF/yr), groundwater evapotranspiration (-1,390 AF/yr), and surface water runoff at the basin outlet (-860 AF/yr).

- The residual for the Upper Mineral Creek water budget domain is negligible; this domain is approximately at equilibrium.

2 INTRODUCTION

At the request of Resolution Copper (RC), Montgomery & Associates (M&A) has prepared this report describing the water budget for all watersheds and groundwater systems within and adjacent to the projected impact area for the block-cave mining project proposed by RC, as described in the General Plan of Operations (GPO) (RC, 2016). The water budget encompasses all of the upper Queen Creek, Devils Canyon, and Upper Mineral Creek watersheds (**Figure 1**), including both surface water and groundwater systems, which are divided into four water budget domains as shown in **Table 1**. The upper Queen Creek watershed is defined as the Queen Creek Watershed above Whitlow Ranch Dam. The Upper Mineral Creek Watershed is defined as the Mineral Creek Watershed above Big Box Dam. Data support the conceptualization that the Deep Groundwater System interacts hydraulically with the Queen Creek domain as described in **Section 2.5.2**; for the purposes of this water budget, the Deep Groundwater System domain is considered to be beneath the Queen Creek watershed east of the concentrator fault. No data describing the Deep Groundwater System is available outside this area.

Table 1. Water Budget Domains

Queen Creek Watershed	Devils Canyon Watershed	Upper Mineral Creek Watershed
Deep Groundwater System		

2.1 Objectives

The purpose of this study is to identify the principal natural and anthropogenic water budget components for the Queen Creek/Devils Canyon/Upper Mineral Creek watersheds and associated groundwater systems, and then use available hydrologic and water use data to develop a quantitative water budget for the current conditions. The intent of this report is to concisely describe the groundwater and surface water systems at a level of detail appropriate to support evaluation of potential impacts from the proposed panel-cave underground mine.

2.2 Background

Located within Arizona's "Copper Triangle," the study area (**Figure 1**) has a long history of mining activity. The Magma Mine property, presently controlled by RC, comprises former processing and waste rock disposal facilities north of Superior (West Plant Site), and a shaft complex east of Superior at the crest of the Apache Leap escarpment (East Plant Site). Although active mining and processing of mineralized ore has not occurred in the Magma Mine since 1996, substantial study, data collection, and modeling is being conducted by RC to support investigations for the proposed underground panel-cave mining operation southeast and immediately adjacent to the Magma Mine.

The target of the proposed underground panel-cave mining project, the Resolution orebody, is located southeast of the Town of Superior at depths ranging from 6,000 to 7,000 feet below land surface; elevation of the orebody ranges from 2,000 to 3,000 feet below mean sea level (msl). RC proposes to construct and operate an underground copper mine, operated using the panel-cave method, and associated facilities on a combination of private, federal, and state lands. A detailed description of the proposed project can be found in the GPO (RC, 2016).

In addition to the underground mine and facilities at the historical East Plant Site (EPS), infrastructure associated with the proposed mine would include new facilities at the West Plant Site (WPS), such as a concentrator, administrative facilities, a laboratory; a filter plant and loadout facility, and a Tailings Storage Facility (TSF) and associated tailings pipeline corridor, as described in the GPO (RC, 2016). Location for the proposed Near West TSF is shown on **Figure 1.**

2.3 Physiography

The study area, located in the Gila River basin, encompasses approximately 605 square miles and includes three primary watersheds: Queen Creek watershed, Devils Canyon watershed, and Upper Mineral Creek watershed (**Figure 1**). The terrain is characterized by steeply incised drainages. Most of the stream channels are ephemeral or intermittent; however, continuously saturated reaches have been identified in Queen Creek, Devils Canyon, and Upper Mineral Creek watersheds as shown on **Figure 1**. The climate, topography, and vegetation of the study area are described by M&A (2013a, 2013b, 2016b, 2017a).

Principal third-party water users in the study area include companies, utilities, and individuals requiring water supply for use in mining, ranching, potable water supply, stock, and irrigation for agriculture and for Boyce Thompson Arboretum (BTA). Most of these water users are located in Queen Creek watershed (for more information see M&A, 2013a, 2013b, 2016b and 2017a). No active mining operations are located in Devils Canyon or Upper Mineral Creek watersheds. However, it is worth noting that below the confluence with Devils Canyon Mineral Creek is dammed and diverted around the Asarco Ray open pit mine.

The Town of Superior, Arizona is the only municipality in the study area. According to the 2010 census, the current population of Superior is approximately 2,800. Water supply for the town is currently provided by the Arizona Water Company (AWC) via the Desert Wellfield, located about 16 miles west-southwest from Superior, outside the Queen Creek watershed. No water is currently provided by AWC from sources within the Queen Creek watershed. A number of private wells with ADWR "exempt" status are located near the town site; private wells are typically relatively shallow. Because of their exempt status, these wells generally produce relatively small quantities of groundwater and are limited to pumping less than 35 gallons per minute (M&A, 2013a).

The unincorporated town of Top of the World is located along Highway 60 at the northern end of the Devils Canyon watershed. According to the 2010 census, the population of Top of the World is approximately 230. Water supply to Top of the World is unregulated. Small wells classified as "exempt" supply water for domestic use and small-scale livestock watering. There are no population centers in the Upper Mineral Creek watershed.

2.4 Hydrogeologic Setting

The geology of the study area, located on the eastern edge of the Basin and Range physiographic province, is complex and consists of volcanic, metamorphic, and sedimentary units ranging in age from Precambrian to Quaternary (**Figure 2**). Detailed characterizations of the hydrogeologic units present in the study area have been described by M&A (2013d, 2017b, 2017c,) based on the work of Spencer and Richard (1995), Spencer and others (1998), Scarborough (1989), Peterson (1969), Ferguson and Trapp (2001), Ferguson and Skotnicki (1995), Richard and Spencer (1998), and Keith (1983). This report focuses on four principal hydrogeologic domains identified in the study area: the ALT, the Whitetail Conglomerate, the Deep System, and the Superior Basin. For more detailed descriptions of individual geologic units, see M&A (2013a, 2013c, 2013d, 2017c).

2.4.1 Apache Leap Tuff

The Apache Leap Tuff (Tal) is an early Miocene regional rock-stratigraphic marker unit of the Superstition Volcanic Field (Ferguson and Trapp, 2001). The Tal is non-welded to densely welded ash-flow tuff that has a widespread outcrop across most of Devils Canyon watershed and parts of Queen Creek and Mineral Creek watersheds (**Figure 2**). Unconsolidated alluvial deposits occur across the Apache Leap Tuff outcrop belt ranging from thin localized veneers to deposits that approach several tens of feet in thickness and encompass several hundred acres such as the alluvial deposits at Top of the World (**Figure 2**).

The ALT aquifer is a fractured-rock aquifer hosted in the Tal outcrop belt that extends throughout much of the Upper Queen Creek and Devils Canyon drainages, and a portion of the Mineral Creek drainage (**Figure 2**). The ALT aquifer is separated from the Deep Groundwater System by a thick sequence of older Tertiary basin-fill sediments (Whitetail Conglomerate), described below. Across much of the ALT aquifer water levels are relatively steady; however, in the area near active mine dewatering, water levels in the ALT aquifer appear to be in decline (M&A, 2016a).

2.4.2 Whitetail Conglomerate

The tertiary Whitetail Conglomerate (Tw) underlies the Tal and separates it from the Deep System. The Tw is a massive conglomerate with subangular to subrounded pebbles and cobbles in a poorly cemented reddish brown matrix. The thickness of the Tw is spatially variable due to regional faulting. The Tw acts as an aquitard between the ALT aquifer and the Deep System.

2.4.3 Deep Groundwater System

The Deep Groundwater System includes two principal groundwater domains that encompass a variety of geologic units (M&A 2013a, 2017c). These groundwater domains are defined by regional structural features. The first domain is located within the Resolution Graben, the approximate spatial extent of which is indicated on **Figure 2**. The Resolution Graben hosts the Resolution orebody; a series of regional faults offset the rocks within the graben from those units that are located outside the graben (M&A, 2013a, 2017c). Within the Resolution Graben, the Deep Groundwater System is hydraulically connected to existing mine workings and a clear hydraulic response to ongoing dewatering of the mine workings is observed between the elevations of -15 and -2,774 feet, msl (M&A 2016a).

The second deep groundwater domain includes the area outside the graben and east of the Concentrator Fault (M&A, 2013a, 2017c). Graben-bounding faults appear to impede hydraulic communication between the Deep Groundwater System outside the graben and the Deep Groundwater System inside the graben (M&A, 2013a, 2017c). Water levels are substantially higher outside the graben and limited response to dewatering of the existing mine workings has been observed to date (M&A, 2016a).

2.4.4 Superior Basin

The Superior Basin, which underlies most of Queen Creek watershed (**Figure 1**), is comprised of a large, east-tilting block bounded by two major north-northwest trending, normal faults that dip to the west: the Elephant Butte Fault and Concentrator Fault. These faults largely control the pattern of geologic units exposed at land surface and their distribution in the sub-surface. Both faults are regional in scale and have resulted in substantial displacement of rock units (Ferguson and Skotnicki, 1995).

The groundwater system west of the Concentrator Fault and throughout the Superior Basin is hosted in low-permeability Tertiary basin-fill deposits (Gila Conglomerate) and fractured Tertiary volcanic rocks (younger than Tal) (**Figure 2**). A detailed description of the structure and hydrogeologic units of the Superior Basin is provided in M&A 2017c.

2.5 Water Budget Domains

The study area (**Figure 1**) encompasses approximately 605 square miles and includes three primary watersheds: Upper Mineral Creek watershed, Devils Canyon watershed, and Queen Creek watershed. It also includes the groundwater systems underlying these watersheds, and the Deep Groundwater System, treated as its own separate domain, that primarily underlies the eastern portion of Queen Creek watershed. While a small portion of the Deep Groundwater System underlies Devils Canyon watershed, data suggest that the Deep Groundwater System interacts hydraulically solely with the Queen Creek domain as described below in **Section 2.5.2**. The four domains are summarized in **Table 1** and described in the following sections.

2.5.1 Queen Creek Domain

Queen Creek watershed encompasses approximately 143 square miles above the Whitlow Ranch Dam, a constriction point in the system where all water from the watershed eventually converges and drains. Land surface elevation in Queen Creek watershed ranges from 5,560 feet above mean sea level (amsl) at Kings Crown Peak 5 miles northeast of Superior to 2,056 feet amsl at the basin outlet at Whitlow Ranch Dam. Queen Creek watershed has a relatively long history of disturbance resulting from human activities in the area, including ranching, prospecting, and mining.

The outlet of the basin is at Whitlow Ranch Dam, a compacted earth-fill dam constructed in 1960 as a flood control structure (U.S. Army Corps of Engineers, 1975). The dam is located in a narrow canyon, where the alluvium is truncated and the bedrock geometry forces groundwater to the surface. This is conceptualized as the exit point for all groundwater and surface water in the Superior Basin (M&A, 2013a). Below Whitlow Ranch Dam, the Queen Creek alignment continues towards Phoenix on gentler terrain, before entering the Gila River; however, there are numerous flow impeding structures that prevent this flow from reaching the Gila River.

Queen Creek and its tributaries are largely ephemeral. An effluent dependent continuously saturated reach has been identified along Queen Creek from 9.7 to 10.8 miles upstream of Whitlow Ranch Dam, immediately downstream of the discharge point of the Superior Wastewater Treatment Plant (WWTP) (M&A, 2017a). Small intermittent and/or continuously saturated reaches have also been identified in Arnett Creek and Telegraph Canyon (M&A, 2013b), and in Whitford Canyon near No Name Spring based on ongoing field observations.

The upper portion of Queen Creek watershed is underlain by the ALT aquifer, separated from the Deep Groundwater System by the Tw aquitard (**Sections 2.4.1, 2.4.2, and 2.4.3**). The lower portion of the watershed is underlain by the Superior Basin Groundwater system (**Section 2.4.4**). Together, the surface water system of Queen Creek watershed, the ALT aquifer within the watershed boundary, and the Superior Basin groundwater system comprise the Queen Creek water budget domain.

2.5.2 Deep Groundwater System Domain

The Deep Groundwater System domain is comprised of the groundwater domains described in **Section 2.4.3**. The Deep Groundwater System is isolated from the ALT aquifer that overlies it by the Tw aquitard; however, along Queen Creek Canyon, rocks from the Deep Groundwater System are exposed along the stream bed.

Measured water levels in monitoring wells both within the Resolution Graben and in adjacent groundwater systems that are separated from the Resolution Graben by regional faults suggest that dewatering of the mine workings produces a predominantly vertical hydraulic gradient within the Graben that is not observed in adjacent groundwater systems. While drawdowns associated with mine and shaft dewatering have been measured outside of the graben, these drawdowns have been much smaller in magnitude than those within the graben (M&A, 2013a, 2017c).

2.5.3 Devils Canyon Domain

Devils Canyon watershed above the confluence with Mineral Creek encompasses approximately 36 square miles. Land surface elevation ranges from approximately 5,560 feet amsl at Kings Crown Peak in the northwestern portion of the basin to 2,200 feet amsl at the confluence with Mineral Creek. Devils Canyon watershed is characterized by steep topographical relief and large areas of exposed bedrock, resulting in rapid surface runoff following precipitation events.

Devils Canyon and its tributaries are largely ephemeral. Three continuously saturated reaches have been identified along Devils Canyon from 3.4 to 3.8 miles upstream, from 4.7 to 5.7 miles upstream, and from 6.6 to 6.8 miles upstream of the confluence with Mineral Creek (M&A, 2017a). Flow rates in the intermittently/ continuously saturated sections range from dry to 0.65 cubic feet per second (cfs) (M&A, 2017a). All tributaries to Devils Canyon are ephemeral. Although Devils Canyon is near to historical mine workings and the Town of Superior, compared to Queen Creek watershed it have been relatively unaffected by anthropogenic activity. However, surface water quality in Devils Canyon and its tributaries is classified as impaired by ADEQ, likely due to historical copper smelting in the region (M&A 2013b, 2016b).

Almost all of Devils Canyon watershed is underlain by Tal, and baseflow in most of the continuously saturated reaches of Devils Canyon is supported in part by discharge from the ALT aquifer (M&A, 2013b, 2016b). Together, surface water in the Devils Canyon watershed and the ALT aquifer make up the Devils Canyon water budget domain.

2.5.4 Upper Mineral Creek Watershed

Upper Mineral Creek watershed above the confluence with Devils Canyon encompasses approximately 55 square miles, and drains the southeastern portion of the study area. Land surface elevation ranges from approximately 7,850 feet amsl at Pinal Peak in the northeastern portion of the basin to 2,200 feet amsl at the confluence with Devils Canyon. Occurrence surveys have identified a continuously saturated reach from 1 – 4 miles upstream of the confluence with Devils Canyon along the main channel of Upper Mineral Creek; this area supports a lush riparian corridor (M&A, 2017a). Flow rates range from 0.06 to 0.13 cfs at the upstream monitoring location, and from 0.71 to 4.00 cfs at the downstream monitoring location (M&A, 2017a). The Upper Mineral Creek watershed is comparatively unpopulated and is relatively unaffected by anthropogenic activity.

The western portion of the Upper Mineral Creek watershed is underlain by Tal, and streamflow in the continuously saturated reach of Upper Mineral Creek is supported in part by discharge from the ALT aquifer (M&A, 2013b, 2016b). The eastern portion of the watershed is underlain by diverse geology. Groundwater within Upper Mineral Creek watershed is not differentiated by geology. Rather, a generalized Upper Mineral Creek groundwater system comprises the groundwater portion of the Upper Mineral Creek water budget domain.

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3 CONCEPTUAL FRAMEWORK

The regional water budget is comprised of three primary watersheds, or domains, each of which include both surface water and groundwater components. **Figure 3** shows a general conceptual diagram illustrating inflows, outflows, and primary internal fluxes. The conceptual framework of the water budget domains and components is described in the following sections. **Table 2** indicates which components are relevant to each of the four water budget domains.

3.1 Surface Hydrologic System

The surface water hydrologic system comprises water related processes that occur above the land surface, including precipitation, evapotranspiration (ET), and streamflow. The surface hydrologic system interacts with the groundwater hydrologic system via recharge, where water leaves the surface water system and enters the groundwater system, and via groundwater discharge, where water returns to the surface water system from the groundwater system as seepage from springs, seeps, and stream bed discharge (baseflow). Also included in the surface water hydrologic system are anthropogenic inflows, including discharge of imported water for municipal and industrial uses and treated discharge from the Superior WWTP. Each of these components is described in the following sections. Unless otherwise indicated, each component applies to all three watershed domains, but not to the Deep Groundwater System since this domain is not in direct hydraulic contact with surface hydrologic processes.

3.1.1 Precipitation

The primary inflow of water to the system is meteoric precipitation. Precipitation that falls on the land surface is subsequently partitioned into surface runoff, soil moisture, groundwater recharge, and surface ET. Shallow soil moisture is typically lost to surface ET on relatively short timescales.

3.1.2 Imported Water

An additional inflow of water to the Queen Creek domain comes as water imported from outside the domain for municipal and industrial supply to the Town of Superior. Water is imported from the Desert Wellfield, located to the west of the watershed. Following use, waste water is treated at the Superior WWTP and discharged to the Queen Creek channel downstream of the town.

3.1.3 Natural Recharge

Groundwater recharge is the process by which the groundwater system is replenished, typically through infiltration of precipitation or surface runoff. In the mountain and desert ecosystems of the Southwestern US, recharge has been studied extensively and remains one of the more difficult components of the hydrologic cycle to quantify (Hogan and others, 2004). Recharge typically occurs via two primary pathways: (1) channel recharge, also called focused recharge, that occurs as infiltration along stream channels following storm runoff events, and (2) direct or diffuse recharge which is the process by which precipitation across the landscape percolates through the unsaturated zone to directly recharge the aquifer below (Meixner and others, 2016). Recharge is a complex process and is affected by many factors including climate, topography, soil and geology, and vegetation. Because of the complexity of recharge processes and the large spatial extent over which recharge occurs, measuring recharge directly is generally not feasible. In place of direct measurement of recharge, recharge is often estimated via physical or empirical models and water balance analyses.

3.1.4 Streamflow, Baseflow, and Surface Runoff

Streamflow is surface water that flows along the land surface in stream channels. Streamflow can be partitioned into two components: baseflow and surface runoff.

Baseflow is the component of streamflow that is sustained in the absence of stormwater runoff. While baseflow can be supported by natural or human causes, it is typically sustained by groundwater discharge (Brutsaert, 2010; USGS, 2018, https://water.usgs.gov/edu/ dictionary.html#B). In addition to baseflow which typically occurs along stream channel bottoms, groundwater may also discharge to the surface via seeps and springs, which sometimes contribute to total streamflow, but may also be lost to evapotranspiration prior to reaching a stream channel.

Surface water runoff is the fraction of precipitation that flows across the land surface via a network of small channels and subsequently enters the stream channel where it makes up all or part of total stream flow (Brutsaert, 2010). Surface runoff following a precipitation event can also be attenuated in tinajas, pools, shallow bedrock fractures, and thin alluvial veneers from which the water is slowly released (M&A, 2017d). Retention of seasonal precipitation likely supports a variety of ecosystem functions, and may ultimately be allocated to evapotranspiration, surface runoff, and/or recharge (Woodhouse, 1997).

3.1.5 Surface Evapotranspiration

Evapotranspiration encompasses both evaporation and transpiration, and is the process by which water returns to the atmosphere from the land surface and from the shallow subsurface. In the semi-arid climate of central Arizona, the majority of precipitation that falls on the land surface rapidly returns to the atmosphere via direct evaporation and/or evapotranspiration. Desert ecosystems have high surface evapotranspiration rates relative to precipitation rates; most precipitation that falls on the land surface returns to the atmosphere via evaporation or transpiration.

3.2 Groundwater System

The groundwater system described in this water budget is comprised of all water related processes that occur in the subsurface below the water table, including the groundwater systems described in **Section 2.4**. Unless otherwise indicated, the following components apply to all four groundwater systems, the ALT aquifer (Queen Creek and Devils Canyon domains), the Superior Basin groundwater system (Queen Creek domain), the Upper Mineral Creek groundwater system (Upper Mineral Creek Domain), and the Deep Groundwater System (Deep Groundwater System domain).

3.2.1 GET

Evapotranspiration occurs across the landscape wherever vegetation or soil moisture are present. This is largely a vadose zone process; the majority of plants do not access groundwater from beneath the water table in the arid southwest (as described above in **Section 3.1.5**). However, along stream drainages and areas where groundwater is relatively close to the surface, trees and shrubs can draw water from below the water table, resulting in groundwater evapotranspiration (GET). GET is an outflow from the near-surface groundwater systems (the ALT aquifer, the Superior Basin groundwater system, and the Upper Mineral Creek groundwater system), but not for the Deep Groundwater System which is far below the reach of deep rooted vegetation.

3.2.2 Groundwater Pumping

Groundwater pumping includes withdrawals from wells for irrigation, domestic, and industrial uses, and mine shaft dewatering, all of which have the effect of removing groundwater from storage.

3.2.3 Groundwater Flow

Groundwater flow in the study area includes both lateral and vertical fluxes. Within a watershed, recharge rates are higher at the top of the watershed, where precipitation rates are highest. Groundwater then flows laterally following the dominant trend of the regional topography from highland to lowland, exiting at the lowest point of the watershed as groundwater underflow. Lateral groundwater flow can occur across watershed boundaries where water level gradients do not follow the regional topography. Along the boundary between the Devils Canyon and Upper Mineral Creek watersheds, water levels in the ALT aquifer suggest groundwater flows to the southeast (WSP, 2017), out of the Devils Canyon domain and into the Upper Mineral Creek domain. This conceptualization is supported by hydrochemistry analysis in Upper Mineral Creek which indicates that surface water flow in Upper Mineral Creek is supported by discharge from the ALT aquifer (M&A, 2016b).

Groundwater movement in the Deep Groundwater System is minimally or not at all impacted by watershed boundaries, recharge, or surface topography. Instead, this comparatively old groundwater system is believed to have been at equilibrium until dewatering associated with mining activity produced a cone of depression in the area surrounding the mine workings. This perturbation has resulted in groundwater movement in the Deep Groundwater System that is directed towards the cone of depression. Most of the dewatering response is observed in wells located within the Resolution Graben, and the faults that form this structural feature impede the flow of groundwater towards the mine workings.

3.2.4 Seepage

Current operations at the WPS in the Queen Creek domain include ongoing reclamation of historical mine processing facilities and disposal of mine related waste rock from ongoing development of underground workings and shafts on the EPS. Seepage from tailings ponds and other facilities at the WPS infiltrate to the water table (Golder, 2013). This component is relevant only to the Superior Basin groundwater system.

4 METHODS AND RESULTS

The following sections describe the general methods used to estimate fluxes of water for each of the four water budget domains. Generally, the same approach was used for all three watershed domains; however, in some cases different approaches were used due to data availability and/or the unique characteristics of each domain. Flow diagrams for each water budget domain are shown on **Figures 4, 5, and 6**, illustrating the reservoirs (stocks) and fluxes specific to each domain. Results are summarized in **Table 3**; values are rounded to the nearest ten.

4.1 Surface Hydrologic System

4.1.1 Precipitation

Representative annual precipitation was estimated from the Precipitation-Regression on Independent Slopes Model (PRISM) (PRISM Climate Group, 2018). The PRISM data set correlates well with precipitation records from the National Weather Service gage at Superior (M&A, 2013a, 2017c). For this analysis, the period 2003 through 2017 was used to compute average annual precipitation. The spatial distribution of average annual precipitation is shown on **Figure 7**.

Total precipitation was 118,500 AF/yr (15.6 inches) for Queen Creek watershed, 37,700 AF/yr (19.6 inches) for Devils Canyon watershed, and 57,200 AF/yr (19.5 inches) for Upper Mineral Creek watershed. Precipitation represents the largest inflow of water to the domain. Precipitation does not apply directly to the Deep Groundwater System domain.

4.1.2 Imported Water

The Town of Superior imports water for municipal supply from the Desert Wellfield, located to the west of the study area. Mean annual production from the Desert Wellfield, computed for the period 2003-2015, is approximately 490 AF/yr. Following use, municipal waste water is collected and treated at the Superior WWTP, which discharges treated water to the Queen Creek channel west of Superior. Between 1984 and 2010, an average of 170 AF/yr was discharged to the channel (M&A, 2013a). Of this, 50% is assumed to be lost to evapotranspiration (M&A, 2017c). The remaining 50% of discharge is assumed to enter the alluvial groundwater system.

The difference between the volume of water imported from the Desert Wellfield for municipal use and the volume discharged from the WWTP is approximately 320 AF/yr. There is no documentation for where this water goes after delivery to municipal water users. The remainder is presumably accounted for by leaks, measurement error, and outdoor uses such as landscaping and dust control. For the purposes of this water budget it is assumed that this water is lost to evapotranspiration. Some fraction may also be directed to septic tanks. No significant volumes of water are imported into the Deep Groundwater System, Upper Mineral Creek, or Devils Canyon domains.

4.1.3 Natural Recharge

Natural groundwater recharge derives from precipitation and associated surface runoff that infiltrates at the land surface and percolates downward to the aquifer. Research has been previously conducted by others to develop practical methods of quantifying recharge in the semi-arid and arid areas of the southwestern United States. **Equation 1** was developed by Anderson and others (1992) to quantify recharge in the Basin and Range province of south-central Arizona.

$$[1] \quad \log Q = -1.40 + 0.98 logP$$

Where Q is the recharge rate and P is annual precipitation in excess of 8 inches per year.

Average annual precipitation was estimated for each domain as described in **Section 4.1.1**. Representative recharge rates were estimated for each domain based on the equation above, resulting in 1,840 AF/yr for the Queen Creek watershed, 720 AF/yr for the Devils Canyon watershed, and 1,090 AF/yr for the Upper Mineral Creek watershed. When converted to percent of precipitation, estimated recharge ranges from 1.6% to 2.4% of mean annual precipitation (**Table 3**). These results are consistent with other regional aquifer recharge studies (Osterkamp, 1973; Freethey and Anderson, 1986; Hogan and others, 2004; Woodhouse, 1997).

In addition to diffuse and direct recharge, a portion of surface runoff in the Queen Creek watershed infiltrates to historical mine workings along Queen Creek Canyon where the geologic units of the Deep Groundwater System are exposed along the creek bed. Water that infiltrates via this pathway recharges the shallow portion of the Deep Groundwater System and flows into the mine workings, where water levels are maintained by pumping. The rate of infiltration to the Deep Groundwater System was estimated based on seasonal fluctuations in shaft dewatering rates required to maintain steady water levels in the mine workings. During the winter rainy season, dewatering rates increased by approximately 240 AF/yr, suggesting that roughly 240 AF/yr of precipitation-derived surface runoff infiltrates to the mine workings via this pathway. Recharge along Queen Creek Canyon represents a fraction of the total recharge to the Queen Creek domain, so the 240 AF/yr that infiltrates to the mine workings as recharge to the Deep Groundwater System domain represents an outflow of water from the Queen Creek Domain (**Table 3**).

4.1.4 Streamflow, Baseflow, and Surface Runoff

Streamflow is comprised of (1) surface runoff generated by precipitation that flows over the land surface without interacting with the groundwater system, and (2) baseflow, which is the portion of streamflow supported by groundwater discharge (Brutsaert, 2010). Streamflow that exits the watershed domain is defined as an outflow or loss to the system. Streamflow within the watershed is an internal flux. Methods for computing total streamflow, baseflow and surface runoff are described in the following three sections.

Streamflow

The basin outlet for the Queen Creek watershed is located at Whitlow Ranch Dam (**Figure 1**). Whitlow Ranch Dam is a compacted earth-fill dam constructed in 1960. It is located in a narrow bedrock canyon, and is the discharge point for all surface water leaving the Queen Creek watershed. The bedrock and dam structures force groundwater to the surface, where water pools in a surface impoundment. Water discharges from the impoundment into a diversion structure and exits the basin as surface water. Upstream from this surface impoundment, there is no baseflow component to Queen Creek streamflow. Because baseflow does not exist upstream from the dam, the total flow measured at the gage below the dam can be considered a measurement of runoff and underflow (i.e. water that would be leaving the basin as groundwater if the dam were not present).

Continuous streamflow data collected by the USGS from 2002 – 2016 was used to estimate representative streamflow, underflow, and runoff for Queen Creek. Mean annual streamflow below Whitlow Ranch Dam is approximately 3,730 AF/yr.

Within the Queen Creek watershed, most of Queen Creek is ephemeral and flows in response to precipitation events. However, a continuously saturated reach is located downstream of the WWTP, where treated water is discharged to the Queen Creek channel as described above in **Section 4.1.2**. Additional continuously or intermittently saturated reaches have been identified along Arnett Creek, a tributary of Queen Creek, upstream of the US 60 bridge, and in Telegraph Canyon upstream from the confluence with Arnett Creek (M&A, 2013b).

Streamflow at the basin outlets for the Upper Mineral Creek and Devils Canyon watersheds was estimated from discharge measured below Big Box Dam, located below the confluence of these two basins. The dam is constructed of concrete set into bedrock; upstream of the dam is a reservoir surrounded by perennial vegetation. Shortly downstream of Big Box Dam, Mineral Creek is routed through a tunnel to circumvent the Ray Mine pit; streamflow measured below the dam captures all surface water flow. Based on discharge data provided by ASARCO for 1997 - 2009 (**Appendix A**), mean annual discharge below the dam is approximately 5,500 AF. The discharge record from below Big Box Dam, comprised of monthly manual field observations, indicates that there are periods of zero discharge; low flows and high flows are not always captured, as noted in the field notes in **Appendix A**.

The 5,500 AF/yr discharged at Big Box Dam was apportioned to Devils Canyon and Upper Mineral Creek based on surface runoff estimated at Lower Mineral, the monitoring station nearest the basin outlet for Upper Mineral Creek watershed (**Figure 1**). Average surface runoff at Lower Mineral from 2003-2016 was estimated to be approximately 860 AF/yr. The remaining 4,620 AF/yr was attributed to surface flow from the Devils Canyon watershed. The large difference in basin outflow from these two watershed domains is consistent with a conceptual understanding of some fundamental differences between the two watersheds. Upper Mineral Creek watershed has more gradual topographic relief. Upstream of the continuously saturated reach in Upper Mineral Creek are extensive alluvial deposits that capture runoff and release it slowly, resulting in high baseflow and relatively low surface runoff. In contrast, Devils Canyon watershed has much more topographic relief and large areas of exposed bedrock, resulting in flashy storm runoff events, less storage in the alluvium, and a much higher proportion of surface runoff relative to baseflow.

Surface water flow within the watersheds is measured by a series of data sondes (**Table 4; Figure 1**). Only one data sonde, Upper Carbonate, is located within Queen Creek watershed. It is situated in Queen Creek Canyon in an ephemeral reach that typically experiences a rapid response to storm runoff due to large areas of exposed bedrock in the upstream contributing area (**Figure 1**). Mean annual streamflow at this site is 795 AF/yr (**Table 4**).

Six data sondes measure streamflow along the main channel of the Devils Canyon watershed (**Table 4; Figure 1**). In the upper basin, DC 13.5 C is located in an ephemeral reach. DC 10.9 C is located in a continuously saturated reach of the stream that is supported by discharge of modern waters from alluvium (M&A, 2013b, 2017a). Farther downstream, DC 8.8 C, DC 8.1 C, DC 7.1 C, and DC 5.5 C are located along continuously saturated reaches that are supported by discharge from the ALT aquifer (M&A, 2013b, 2017a). Mean annual streamflow at each sonde location is shown in **Table 4**. Streamflow is generally higher at the upstream data sondes than at the downstream data sondes; for example, at DC 13.5 C, mean annual streamflow is approximately 7,500 AF/yr, while at DC 5.5 C mean annual streamflow is 2,480 AF/yr (**Table 4**). This pattern is attributed to basin geometry, geology, and vegetation. The upper basin consists largely of exposed bedrock with very low retention of precipitation and few phreatophytes. The lower basin contains alluvial deposits and soils that attenuate runoff and release it slowly. Also in the lower basin, perennial vegetation diverts a fraction of stream water to evapotranspiration as described below in **Section 4.2.1**.

Two data sondes are located within the Upper Mineral Creek watershed, Upper Mineral and Lower Mineral (**Table 4; Figure 1**). Upper Mineral is located near the top of a continuously saturated reach, while Lower Mineral is located near the end of the same reach. Both are located in the lower portion of the watershed. Streamflow increases from approximately 850 AF/yr at Upper Mineral to approximately 2,250 AF/yr at Lower Mineral (**Table 4**); this gain in streamflow is due to increased baseflow as discussed in the following section.

Baseflow and Surface Runoff

Baseflow, which is streamflow supported by groundwater discharge (Brutsaert, 2010), was estimated for nine data sonde locations and one stream gage location shown on **Figure 1** using a delta filter method described in M&A, 2015. Surface water runoff was estimated based on the **Equation 2** (e.g. Brutsaert, 2010).

$$[2]\ Runoff = Total\ Streamflow - Baseflow$$

The only place along Queen Creek where groundwater contributes significantly to streamflow is at Whitlow Ranch Dam. As described in the streamflow section above, this quantity should be considered underflow rather than baseflow because it represents groundwater outflow from the water budget domain; however, the method is the same as that for used to estimate baseflow. Groundwater underflow rates for Queen Creek below Whitlow Ranch Dam were estimated using a Delta Filter analysis as described in M&A, 2015. An assessment of sixteen years of daily streamflow in Queen Creek below Whitlow Ranch Dam from 2003-2016 suggests a mean annual groundwater underflow rate of approximately 1,350 AF/yr. However, because the reservoir structure in front of the dam retains some runoff and delays its release, the Delta Filter underflow/baseflow separation analysis is considered to be an overrepresentation of the true amount of groundwater outflow. For this reason, the median groundwater underflow of 790 AF/yr identified from the Delta Filter analysis was deemed to be a more appropriate representation of groundwater underflow exiting the basin. Corresponding annual surface runoff for Queen Creek below Whitlow Ranch Dam, estimated using **Equation 2**, is approximately 2,930 AF/yr (**Table 3**).

At the Upper Carbonate data sonde in Queen Creek Canyon (**Figure 1**), baseflow represents a very small fraction of total streamflow and is not present throughout the year (**Table 4**), consistent with the understanding that this portion of Queen Creek is primarily supported by precipitation runoff.

Within Devils Canyon watershed, the proportion of total streamflow that is comprised of baseflow (or groundwater discharge) generally increases from upstream to downstream. Mean annual baseflow and surface runoff estimates for each sample location along with the ratio of baseflow to runoff are presented in **Table 4**. Monitor locations DC 13.5 and DC 10.9 have high streamflow rates composed primarily of recent storm runoff that is attenuated by alluvial deposits and discharges slowly over time; the ratio of baseflow to surface runoff is less than 0.05 (**Table 4**). These monitoring locations are located above the intersection of the ALT aquifer water table elevation and the canyon floor so groundwater discharge does not contribute to flow at these sites. Beginning upstream of DC 8.8 C and continuing past DC 5.5 C, baseflow is supported by discharge from the ALT aquifer (M&A, 2013b, 2016b, 2017a). The ratio of baseflow to surface runoff for these sites ranges from 0.05 to 0.14 (**Table 4**). Along the length of the canyon, water infiltrates where alluvial deposits are present and is forced to the surface by bedrock geometry where the canyon narrows. As Devils Canyon cuts deeper into the Tal on its path downstream, streamflow is both consumed by evapotranspiration and augmented by additional contributions to baseflow from the ALT aquifer. Continuous baseflow does not exit the watershed at big box dam as evidenced by periods of zero discharge from the dam (**Appendix A**). For the purposes of this study, and because of the limited data availability at Big Box Dam, it is assumed that no baseflow leaves the basin as streamflow.

Within the Upper Mineral Creek watershed, both data sondes indicate a significantly higher baseflow component relative to Devils Canyon watershed. At Upper Mineral, mean baseflow was 331 AF/yr, and mean surface runoff was 522 AF/yr; the ratio of baseflow to surface runoff was 0.63 (**Table 4**). At Lower Mineral mean baseflow was 1,386 AF/yr, mean surface runoff was 860 AF/yr, and the ratio of baseflow to runoff was 1.61 (**Table 4**), suggesting that the majority of streamflow in this reach is derived from groundwater discharge. The continuously saturated reach in this section of Upper Mineral Creek is supported in part by discharge from the ALT aquifer as well as by recent precipitation attenuated in alluvial deposits and side drainages (M&A, 2013b, 2016b, 2017a). Continuous baseflow does not exit the watershed at big box dam as evidenced by periods of zero discharge below Big Box Dam (**Appendix A**). For the purposes of this study, and because of the limited data availability at Big Box Dam, it is assumed that no baseflow leaves the basin as streamflow.

4.1.5 Surface Evapotranspiration

Surface evapotranspiration (SET) was estimated using **Equation 3** (e.g. Brutsaert, 2010).

$$[3]\ SET = Precipitation + Imported\ Water - Runoff - Recharge - \tfrac{1}{2}(WWTP\ Discharge)$$

Precipitation, imported water, recharge, and surface runoff were estimated as described above in **Sections 4.1.1, 4.1.2, 4.1.3, and 4.1.4**. WWTP discharge and Imported Water pertain only to the Queen Creek watershed. Discharge from the WWTP is described above in **Section 4.1.2**; 50% of WWTP discharge infiltrates to the alluvial aquifer and the remaining 50% is included in estimated SET for the Queen Creek domain.

SET comprises the largest volumetric outflow for each of surface domains; it does not apply to the Deep Groundwater System domain. Estimated SET for the Queen Creek domain was approximately -114,200 AF/yr; SET for the Devils Canyon domain was approximately -32,400 AF/yr; SET for the Upper Mineral Creek domain was approximately -55,300 AF/yr. Evapotranspiration losses make up 86% to 97% of total annual precipitation in this arid environment (**Table 3**), comparable with rates published for the Superior Basin (M&A, 2013a).

4.2 Groundwater Hydrologic System

4.2.1 GET

For groundwater evapotranspiration (GET) to occur, the water table must be accessible within the rooting depth of plants. In the arid southwest, this typically occurs only in stream channels, where topography approaches or reaches the elevation of the water table. When this occurs, plants are able to access water year-round, resulting in evapotranspiration even during the driest months of the year. GET was estimated using **Equation 4**.

$$[4]\ GET = Recharge - Groundwater\ Underflow - Groundwater\ Pumping - Groundwater\ Fluxes - Infiltration\ to\ Mine\ Workings$$

Estimated GET volumes for each domain are shown in **Table 3**. GET is approximately -1,070 AF/yr in the Queen Creek domain, -340 AF/yr in the Devils Canyon domain, and -1,390 AF/yr in the Upper Mineral Creek domain.

Groundwater seeps and springs have been cataloged within the study area (M&A and WestLand Resources, 2017). Some springs and seeps are associated with seasonal precipitation attenuated in surface veneers, while others are connected to local groundwater systems (e.g. M&A, 2010, 2013b, 2016b, 2017d). For the purposes of this study, discharge from seeps and springs was assumed to be consumed via evaporation and/or transpiration.

4.2.2 Groundwater Pumping

Groundwater pumping for each domain was estimated based on available pumping records; mean annual groundwater pumping volumes are summarized in **Table 5** below.

TABLE 5. GROUNDWATER WITHDRAWALS, 2017 (in acre-feet/year)

Point Source Groundwater Withdrawals	Queen Creek Watershed	Deep Groundwater System	Devils Canyon Watershed	Upper Mineral Creek Watershed
Irrigation	18			
Boyce-Thompson Arboretum	53			
Harborlite Well	17			
Exempt wells	17		33	
Shaft dewatering		1,360		
Total Withdrawal Volume	**105**	**1,360**	**33**	**0**

Within the Queen Creek watershed, groundwater withdrawals include groundwater pumping for mining, irrigation, and domestic uses (**Table 5**). Agricultural activity, while present, is neither intensive nor widespread; groundwater withdrawals for irrigation are shown in **Table 5**. Deep percolation of excess irrigation water, sometimes referred to as "return flow," is water that infiltrates beyond the root zoot of plants after being applied at the surface and percolating downward to the aquifer. Due to the small scale of agriculture, relatively large depth to water across most of the watershed, and relatively low pumping volumes, deep percolation was deemed negligible.

Groundwater withdrawals from the Deep Groundwater System associated with RC mine shaft de-watering activities were approximately -1,360 AF/yr as reported to ADWR for 2017.

Groundwater pumping in the Devils Canyon watershed is primarily focused around the unincorporated community of Top of the World in the northern portion of the watershed (**Figure 1**). There are no recorded estimates of pumping volumes from wells in the area around Top of the World. Groundwater pumping was estimated based on average self-supplied domestic per capita use for the state of Arizona of 125 gallons per day, or 0.14 acre-feet per person per year (Maupin and others, 2010). The population of Top of the World is roughly 230 based on the 2010 census, resulting in annual groundwater withdrawals of approximately -30 AF.

Groundwater pumping within Upper Mineral Creek watershed is minimal. There are several small windmills and livestock wells, none of which have documented pumping volumes. The cumulative groundwater withdrawals are assumed to be negligible.

4.2.3 Groundwater Flow

Lateral Groundwater Flow

Lateral groundwater flow, described conceptually in **Section 3.2.3**, occurs within the groundwater systems of the Queen Creek, Devils Canyon, and Upper Mineral Creek domains, as well as in the Deep Groundwater System Domain. Within the Deep Groundwater System Domain, lateral groundwater movement occurs as groundwater flows towards the cone of depression created by dewatering of the mine workings. Upon entering the mine workings it is pumped to the surface as described in **Section 3.2.2**.

Within the Queen Creek, Devils Canyon, and Upper Mineral Creek domains, lateral groundwater flow that exits the water budget domain at the stream discharge point is synonymous with groundwater underflow, described in **Section 4.1.4**. Due to the bedrock geometry and the construction of Whitlow Ranch Dam at the Queen Creek basin outlet, groundwater underflow out of the Queen Creek domain is assumed to be negligible. Similarly, underflow at Big Box Dam is assumed to be negligible because of the dam structure, which is built into low permeability bedrock. A small pond formed in the reservoir behind the dam and associated riparian vegetation is assumed to consume water that might otherwise report as underflow out of the Devils Canyon and Upper Mineral Creek domains. The interaction of lateral groundwater flow with surface water within each domain is synonymous with baseflow as described in **Section 4.1.4**.

Lateral groundwater flow also occurs along the watershed boundary between the Devils Canyon and Upper Mineral Creek domains where the water table gradient slopes to the southeast (WSP, 2017). Lateral groundwater flux from the Devils Canyon domain into the Upper Mineral Creek domain (Q_L) was estimated based on **Equation 5**, where K_h is the representative horizontal hydraulic conductivity, ∇H_h is the hydraulic gradient, and A is the saturated cross sectional area over which the flux occurs.

$$[5] \quad Q_L = K_h \ \nabla H_h \ A$$

The representative horizontal hydraulic conductivity, K_h , was estimated as the geometric mean of measured conductivities at the nearest ALT aquifer monitoring wells (HRES-11, HRES-17, and HRES-18 (WSP 2017, Table 2.1)). The hydraulic gradient, ∇H_h, was estimated based on the contoured water levels in the ALT aquifer (WSP, 2017, Figure 2.5). Because the direction of flow is not perpendicular to the watershed boundary, vector analysis was used to quantify the component of flow across the watershed boundary. The saturated cross sectional area was estimated. The lateral groundwater flux from the Devils Canyon domain into the Upper Mineral Creek domain is approximately 360 AF/yr. Lateral fluxes are considered negligible between the other water budget domains.

Vertical Groundwater Flow

Vertical groundwater flow in the vicinity of the proposed mine is larger as a result of mine dewatering (**Section 4.2.2**). Vertical groundwater fluxes were estimated for water flowing out of the ALT aquifer (conceptualized as part of the Queen Creek watershed domain) into the Tw, which acts as a regional aquitard, and for water flowing out of the Tw into the Deep System. These estimates were prepared for both inside the area directly overlying the graben, and outside the graben. Vertical groundwater flux (Q_v) was estimated based on **Equation 6**, where K_v is the representative vertical hydraulic conductivity, ∇H_v is the vertical hydraulic gradient, and A is the surface area over which the flux occurs.

$$[6] \quad Q_v = K_v \ \nabla H_v \ A$$

Vertical groundwater fluxes and associated parameters are summarized in **Table 6**. Vertical fluxes occur within the ALT aquifer in the Queen Creek watershed domain due to its location directly over the current mine workings. Vertical flux out of the ALT aquifer and into the Tw is estimated to be -30 AF/yr (**Table 6**), nearly all of which is focused within the area directly above the mine workings.

Total groundwater flow into the deep system from the Tw is estimated to be 580 AF/yr (**Table 6**). The mine dewatering rate reported in 2017 is approximately -1,360 AF/yr. Including 240 AF/yr of direct recharge to the mine workings from Queen Creek surface flows (**Section 4.1.3**), these results suggest that approximately -540 AF/yr is coming out of storage in the deep system. The difference between the flux out of the ALT and the flux into the deep system is a result of the transient head response to dewatering of Shaft No. 9 and No. 10.

Vertical groundwater fluxes are considered negligible in Devils Canyon and Upper Mineral Creek domains.

4.2.4 Seepage

Seepage from the tailings at the West Plant Site was estimated by Golder (2018) as approximately 180 AF/yr of seepage from Tailings Pond 6 (**Table 3**) and 130 AF/yr of enhanced recharge north of the Settling Ponds. These volumes are assumed to enter the Superior Basin groundwater system in the Queen Creek domain. There is no significant seepage from surface facilities to the Deep Groundwater System, Devils Canyon, or Upper Mineral Creek water budget domains.

4.3 Residual

The residual is estimated as the sum of inflows to each domain minus the sum of outflows as shown in **Equation 7**. The Residual for each domain is shown in **Table 3**.

$$[7]\ \ Residual = \sum Inflows - \sum Outflows$$

The residual is a calculated imbalance which may be related to errors in other estimated water budget components, or due to physical processes such as change in groundwater storage or climate variability. Because of how the residual is calculated, it is not possible to differentiate between changes in storage within the domain and possible errors in the estimated water budget components. Estimation of the total volume of groundwater in storage was not part of the scope of this study.

The residual for the Queen Creek domain is approximately -210 AF/yr (**Table 3**). Anthropogenic losses associated with groundwater pumping, groundwater flux out of the ALT aquifer, and recharge to the Deep Groundwater System associated with dewatering of the mine workings exceed anthropogenic inflows associated with seepage from Tailings Pond 6 and imported municipal water (some of which is lost to ET) by approximately 150 AF/yr, suggesting that anthropogenic fluxes may contribute to the negative residual in the Queen Creek water budget domain.

The residual in the Deep Groundwater System domain is -540 AF/yr (**Table 3**). The negative residual is attributed to dewatering of the mine workings which exceeds the rate at which water in the Deep Groundwater System is replenished.

The residual in the Devils Canyon domain is -40 AF/yr; this domain is assumed to be in equilibrium (**Table 3**).

The residual in the Upper Mineral Creek domain is 0 AF/yr; this domain is assumed to be in equilibrium (**Table 3**).

5 SUMMARY

Results of the water budget analysis for each domain are shown in **Table 3** and discussed in the following sections.

5.1 Queen Creek Domain

The annual water budget for the Queen Creek domain includes two inflow components, precipitation (118,500 AF/yr), imported water for municipal use (490 AF/yr), and Seepage from Tailings Pond 6 at WPS (180 AF/yr); outflows from the domain include surface evapotranspiration (-114,200 AF/yr), discharge at the basin outlet (-3,730 AF/yr), groundwater evapotranspiration (-1,070 AF/yr), groundwater pumping (-110 AF/yr), and vertical groundwater flux out of the ALT aquifer (-30 AF/yr), as shown in **Table 3**. The residual for the domain is approximately -210 AF/yr. Anthropogenic losses associated with groundwater pumping, groundwater flux out of the ALT aquifer, and recharge to the Deep Groundwater System associated with dewatering of the mine workings exceed anthropogenic inflows from Seepage from Tailing Pond 6 and Imported Municipal Water (some of which is lost to ET) by approximately 150 AF/yr, indicating that anthropogenic fluxes may contribute to the residual in the Queen Creek water budget domain.

5.2 Deep Groundwater System Domain

The water budget for the Deep Groundwater System, consists of 240 AF/yr of recharge to the mine workings, 580 AF/yr of vertical groundwater flux, and -1,360 AF/yr of groundwater pumping to maintain water levels in the mine workings (**Table 3**). This produces a residual of approximately -540 AF/yr, which represents water coming out of storage in the Deep Groundwater System as a result of the dewatering activities.

5.3 Devils Canyon Domain

The annual water budget of the Devils Canyon domain includes 37,700 AF/yr of precipitation as the sole inflow of water to the system; water leaves the system via surface evapotranspiration (-32,400 AF/yr), discharge at the basin outlet (-4,620 AF/yr), lateral groundwater flow into the Upper Mineral Creek domain (-360 AF/yr), groundwater evapotranspiration (-340 AF/yr), and groundwater pumping (-30 AF/yr), as shown in **Table 3**. The residual for the Devils Canyon water budget domain is -40 AF/yr, and the system is approximately at equilibrium.

5.4 Upper Mineral Creek Domain

The annual water budget of the Upper Mineral Creek domain includes 57,200 AF/yr of precipitation and 360 AF/yr of lateral groundwater flow as inflows to the system; outflows include surface evapotranspiration (-55,300 AF/yr), groundwater evapotranspiration (-1,390 AF/yr), and discharge at the basin outlet (-860 AF/yr) (**Table 3**). The residual is 0 AF/yr; the water budget of the Upper Mineral Creek domain is at equilibrium.

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TABLE 2. WATER BUDGET DOMAINS AND APPLICABLE COMPONENTS

	WATER BUDGET DOMAINS			
Component	**Queen Creek**	**Deep System**	**Devils Canyon**	**Upper Mineral Creek**
Mean Annual Precipitation	Inflow		Inflow	Inflow
Imported Water	Inflow			
WWTP Discharge	[1]Internal flux			
Seepage from WPS	[1]Internal flux			
Natural Groundwater Recharge	[1]Internal flux		[1]Internal flux	[1]Internal flux
[2]Recharge to Deep Groundwater System	Outflow	Inflow		
Baseflow	[1]Internal flux		[1]Internal flux	[1]Internal flux
[3]Discharge at Basin Outlet	Outflow		Outflow	Outflow
Groundwater Underflow	Outflow		Outflow	Outflow
Surface Water Runoff	Outflow		Outflow	Outflow
Groundwater Pumping	Outflow		Outflow	Outflow
Mine Shaft Dewatering		Outflow		
Groundwater Flux out of ALT Aquifer	Outflow			
Groundwater Flux into Deep System		Inflow		
Surface Evapotranspiration	Outflow		Outflow	Outflow
Groundwater Evapotranspiration	Outflow		Outflow	Outflow
RESIDUAL	Inflows - Outflows	Inflows - Outflows	Inflows - Outflows	Inflows - Outflows

[1] *Internal fluxes occur WITHIN the watershed domain and are not included in the residual calculation.*

[2] *Recharge to Deep Groundwater System* is a component of *Natural Groundwater Recharge* to the Queen Creek Domain.

[3] *Discharge at Basin Outlet* is the sum of *Groundwater Underflow* and *Surface Water Runoff* at the outlet of each watershed. Baseflow does not exit the outlet of any watershed.

WWTP = Wastewater Treatment Plant

WPS = West Plant Site

ALT = Apache Leap Tuff

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TABLE 3. WATER BUDGET RESULTS IN ACRE-FEET PER YEAR AND AS PERCENT OF TOTAL PRECIPITATION

Component	Queen Creek		Deep Groundwater System		Devils Canyon		Upper Mineral Creek	
	Acre-Feet per Year	Percent of Precipitation	Acre-Feet per Year	Percent of Precipitation	Acre-Feet per Year	Percent of Precipitation	Acre-Feet per Year	Percent of Precipitation
Mean Annual Precipitation	118500	100.0%	---	---	37700	100.0%	57200	100.0%
Imported Water	490	0.4%	---	---	---	---	---	---
Seepage from WPS Tailings Pond 6	180	0.2%	---		---	---	---	---
[1]WWTP Discharge	*170	0.1%	---	---	---	---	---	---
[1]Enhanced Recharge at WPS	*130	0.0%	---	---	---	---	---	---
[1]Natural Recharge	*1840	1.6%		---	*720	1.9%	*1090	2.4%
[2]Recharge to Deep Groundwater System	-240	-0.2%	240	---				
[1]Baseflow	*[3]U	---	---	---	*280	0.7%	*1390	2.4%
[4]Discharge at Basin Outlet	-3730	-3.1%	---	---	-4620	-12.2%	-860	-1.5%
[1]Groundwater Underflow	*-790	-0.7%	---	---	*0	0.0%	*0	0.0%
[1]Surface Water Runoff	*-2930	-2.5%	---	---	*-4620	-12.2%	*-860	-1.5%
Groundwater Pumping	-110	-0.1%	---	---	-30	-0.1%	Negligible	0.0%
Mine Shaft Dewatering	---	---	-1,360	---	---	---	---	---
Lateral Groundwater Flux	---	---	---		-360	-0.9%	360	0.6%
Vertical Groundwater Flux out of ALT Aquifer	-30	0.0%	---	---	---	---	---	---
Vertical Groundwater Flux into Deep System	---	---	580	---	---	---	---	---
Surface Evapotranspiration	-114200	-96.3%	---	---	-32400	-85.8%	-55300	-96.6%
Groundwater Evapotranspiration	-1070	-0.9%	---	---	-340	-0.9%	-1390	-2.4%
RESIDUAL	**-210**	**-0.2%**	**-540**	**---**	**-40**	**0.0%**	**0**	**0.1%**

NOTES:

Convention: Inflows and internal flows are positive; outflows are negative. Negative residual implies net loss of water.

[1] * Not included in residual calculation

[2] *Recharge to Deep Groundwater System* is comprised of a fraction of *Natural Recharge* to the Queen Creek Domain.

[3] U = Unknown – Insufficient data

[4] *Discharge at Basin Outlet* is the sum of *Groundwater Underflow* and *Surface Water Runoff* at the outlet of each watershed.

--- = Not applicable

WPS = West Plant Site

WWTP = Wastewater Treatment Plant

ALT = Apache Leap Tuff

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TABLE 4. MEAN ANNUAL STREAMFLOW, BASEFLOW, AND SURFACE RUNOFF (in acre-feet/year)

	Queen Creek Watershed	Devils Canyon Watershed						Upper Mineral Creek Watershed	
	Upper Carbonate	DC 13.5 C	DC 10.9 C	DC 8.8 C	DC 8.1 C	DC 7.1 C	DC 5.5 C	Upper Mineral	Lower Mineral
Mean Annual Streamflow	795	7,499	3,500	3,577	2,472	1,951	2,480	852	2,246
Mean Annual Baseflow	35	205	146	281	109	235	241	331	1,386
Mean Annual Runoff	760	7,295	3,354	3,297	2,363	1,716	2,239	522	860
Baseflow/Runoff Ratio	0.05	0.03	0.04	0.09	0.05	0.14	0.11	0.63	1.61

TABLE 6. ESTIMATED VERTICAL GROUNDWATER FLOW

	Out of ALT Aquifer				Into Deep System			
	K_v	∇H_v	A	Q_v	K_v	∇H_v	A	Q_v
	feet/day	feet/feet	square feet	acre-feet/year	feet/day	feet/feet	square feet	acre-feet/year
Inside Graben	6.11E-04	-0.09	85,773,000	30	2.60E-04	-1.71	85,773,000	320
Outside Graben	4.61E-04	-0.07	1,129,140,100	0	1.43E-04	-0.18	1,238,101,300	260
TOTAL			1,214,913,100	30			1,323,874,300	580

K_v = vertical hydraulic conductivity in feet per day
∇Hv = vertical hydraulic gradient in feet per foot
A = area in square feet
Q_v = vertical groundwater flux in acre-feet per year
ALT = Apache Leap Tuff

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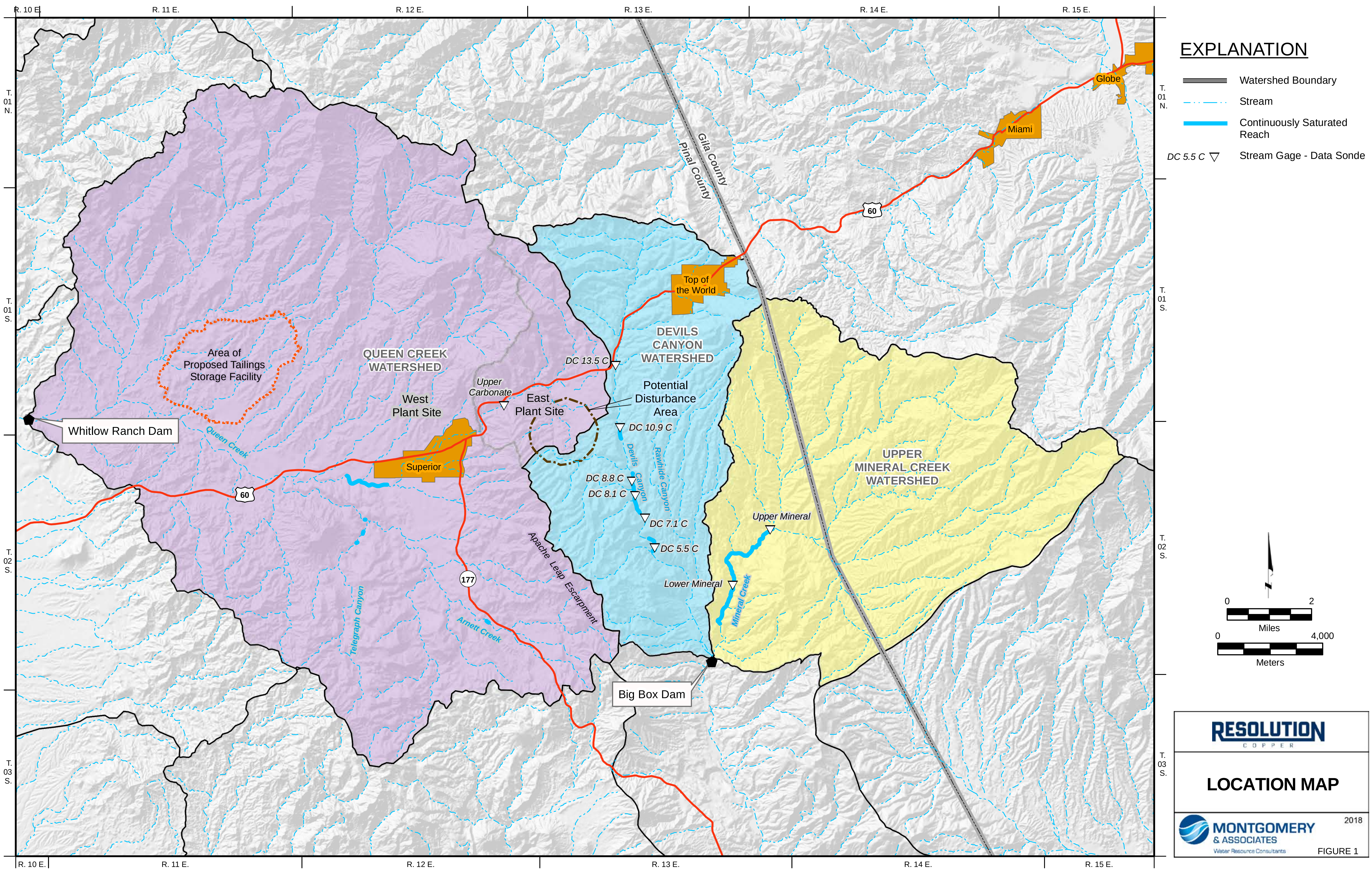

RESOLUTION COPPER

LOCATION MAP

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Water Resource Consultants

2018

FIGURE 1

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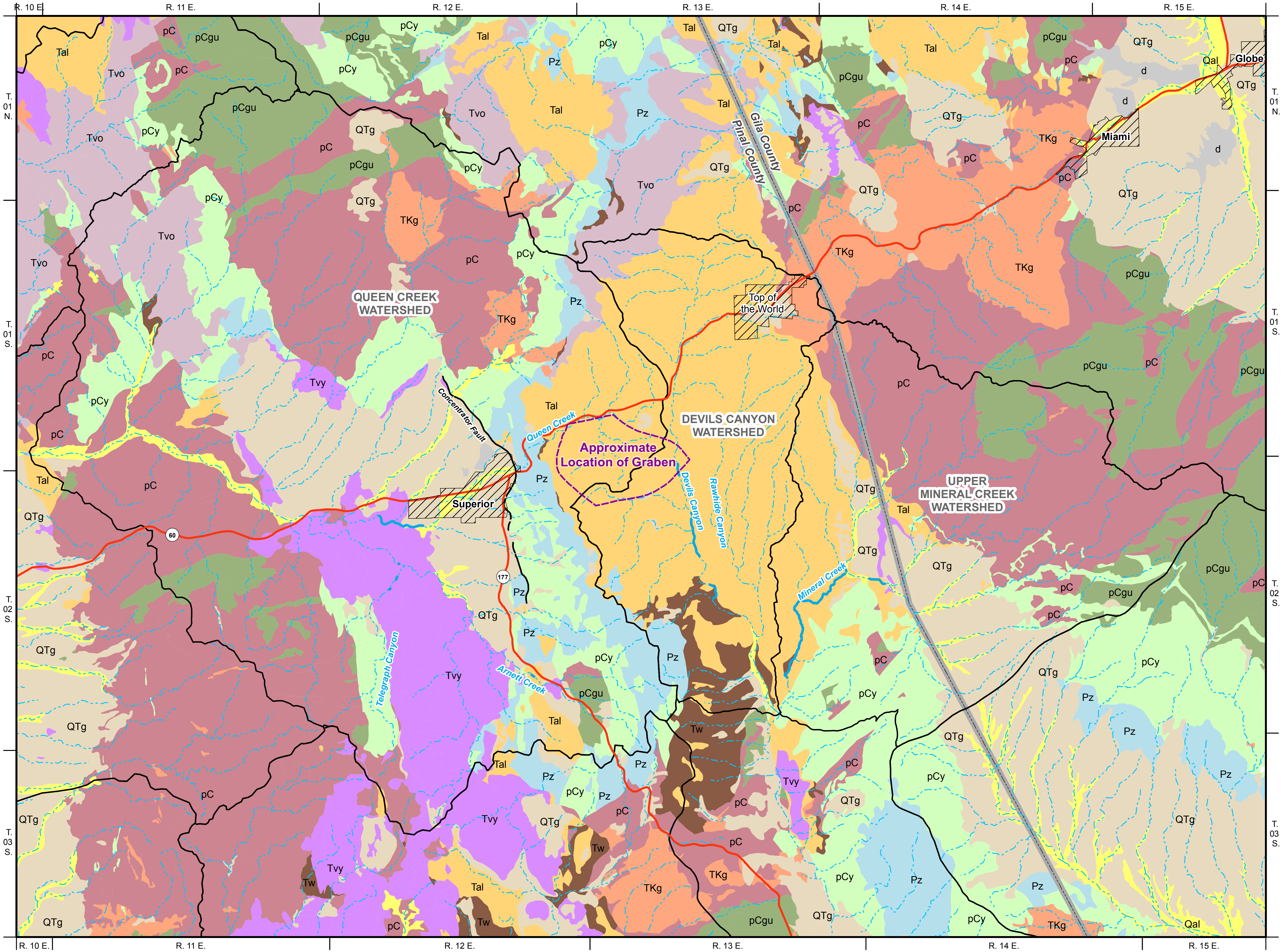

EXPLANATION

- Watershed Boundary
- Fault
- Stream
- Continuously Saturated Reach

GENERALIZED GEOLOGIC UNITS

- d — Disturbed Surficial Deposits
- Qal — Quaternary Alluvial Deposits and Surficial Deposits
- QTg — Quaternary and Tertiary Basin-Fill Deposits
- Tvy — Younger Tertiary Volcanic Rocks
- Tal — Tertiary Apache Leap Tuff
- Tvo — Older Tertiary Volcanic Rocks, Undifferentiated
- Tw — Tertiary Whitetail Conglomerate
- TKg — Cretaceous and Tertiary Intrusive Rocks
- Pz — Paleozoic Sedimentary Rocks, Undifferentiated
- pCy — Younger Precambrian Sedimentary and Intrusive Rocks, Undifferentiated
- pCgu — Undifferentiated Precambrian Intrusive Rocks
- pC — Older Precambrian Pinal Schist

0 2 Miles

0 4,000 Meters

RESOLUTION COPPER

GEOLOGY MAP

MONTGOMERY & ASSOCIATES
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FIGURE 2

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(Geology modified from Spencer and others, 1998; Peterson, 1969, and Spencer and Richard, 1995)

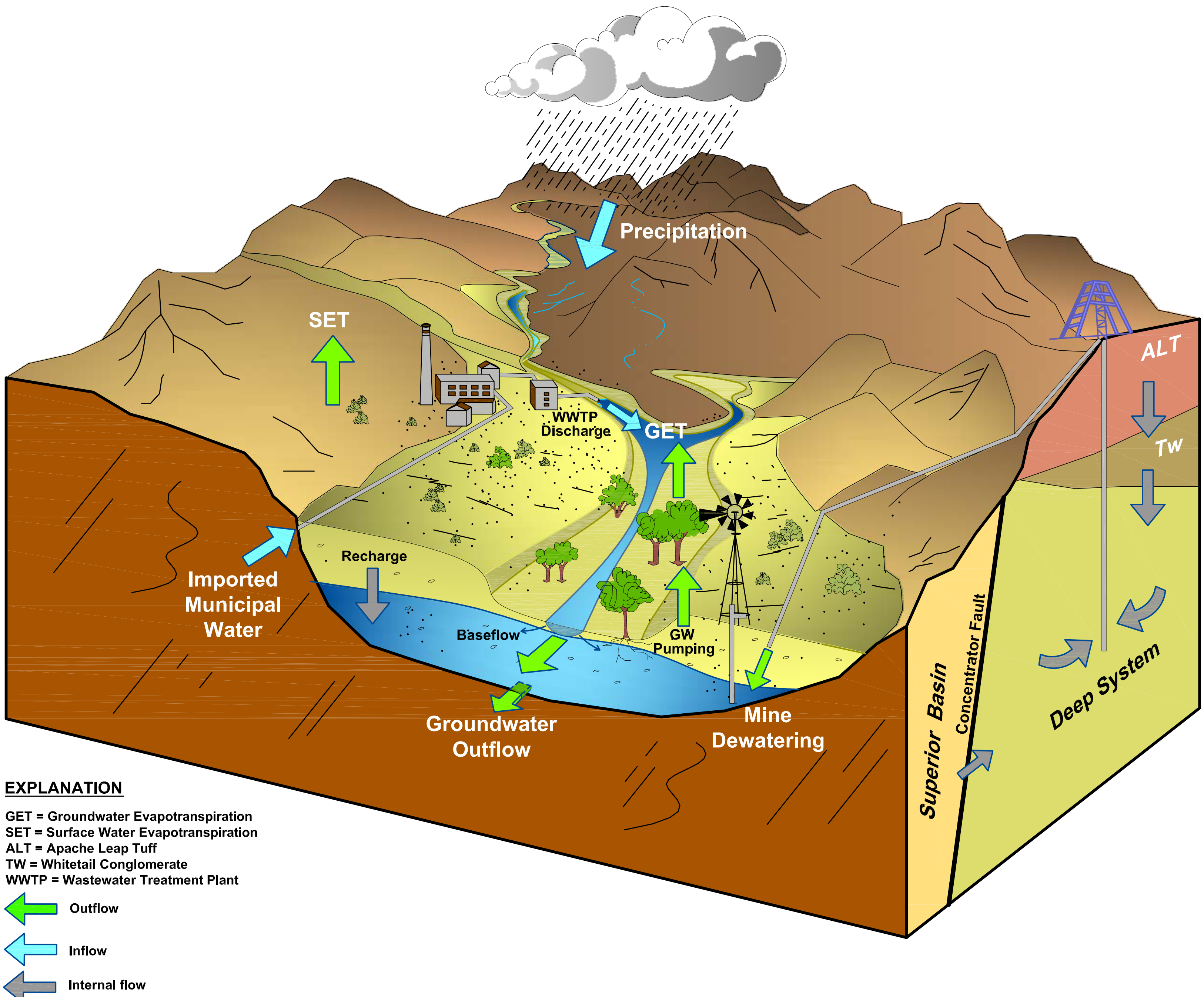

FIGURE 3. SCHEMATIC DIAGRAM OF WATER BUDGET COMPONENTS

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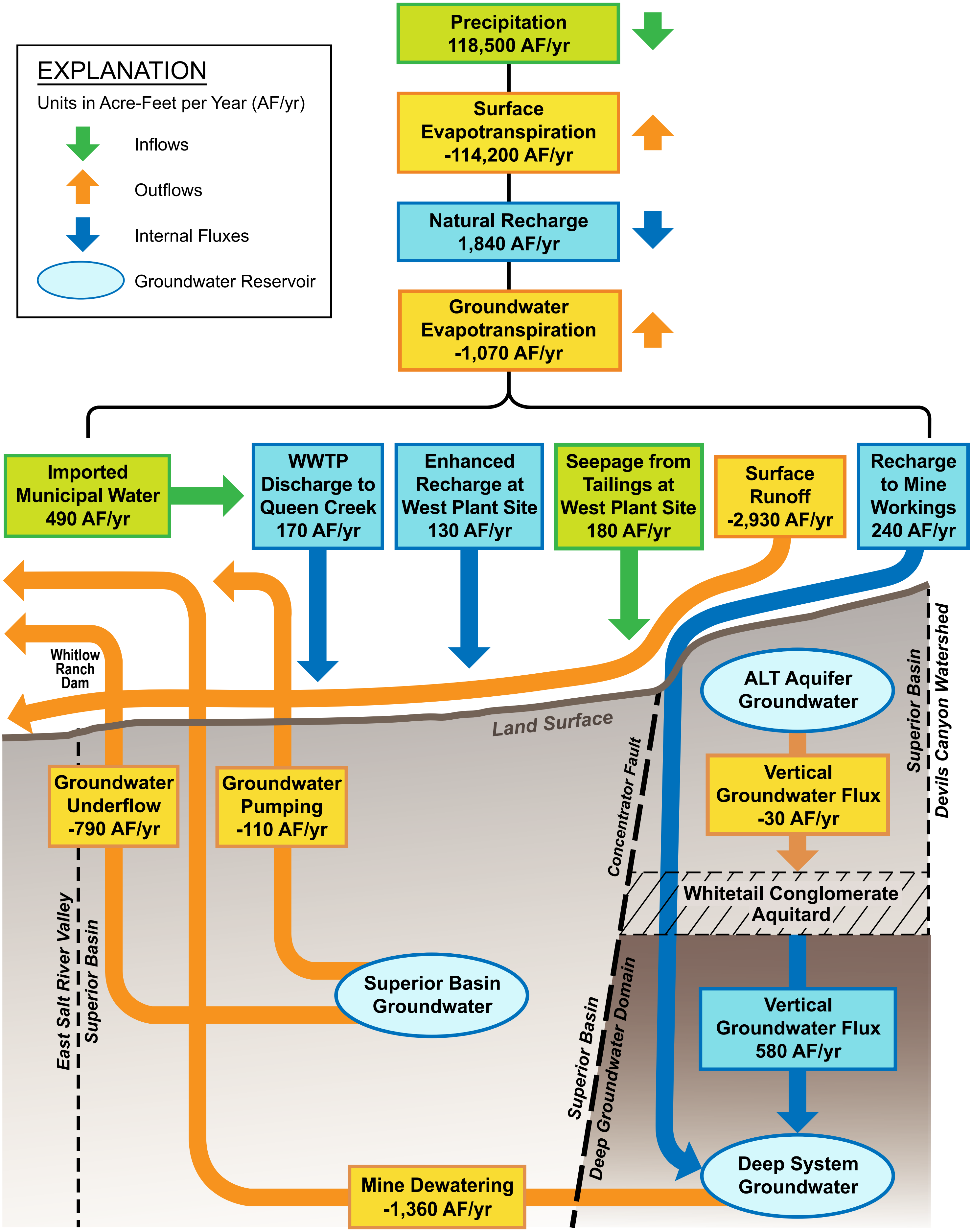

FIGURE 4. ANNUAL WATER BUDGET FOR QUEEN CREEK AND DEEP GROUNDWATER SYSTEM DOMAINS

GIS\605.1601\WaterBudget_QueenCreekWatershed.ai\01June2018

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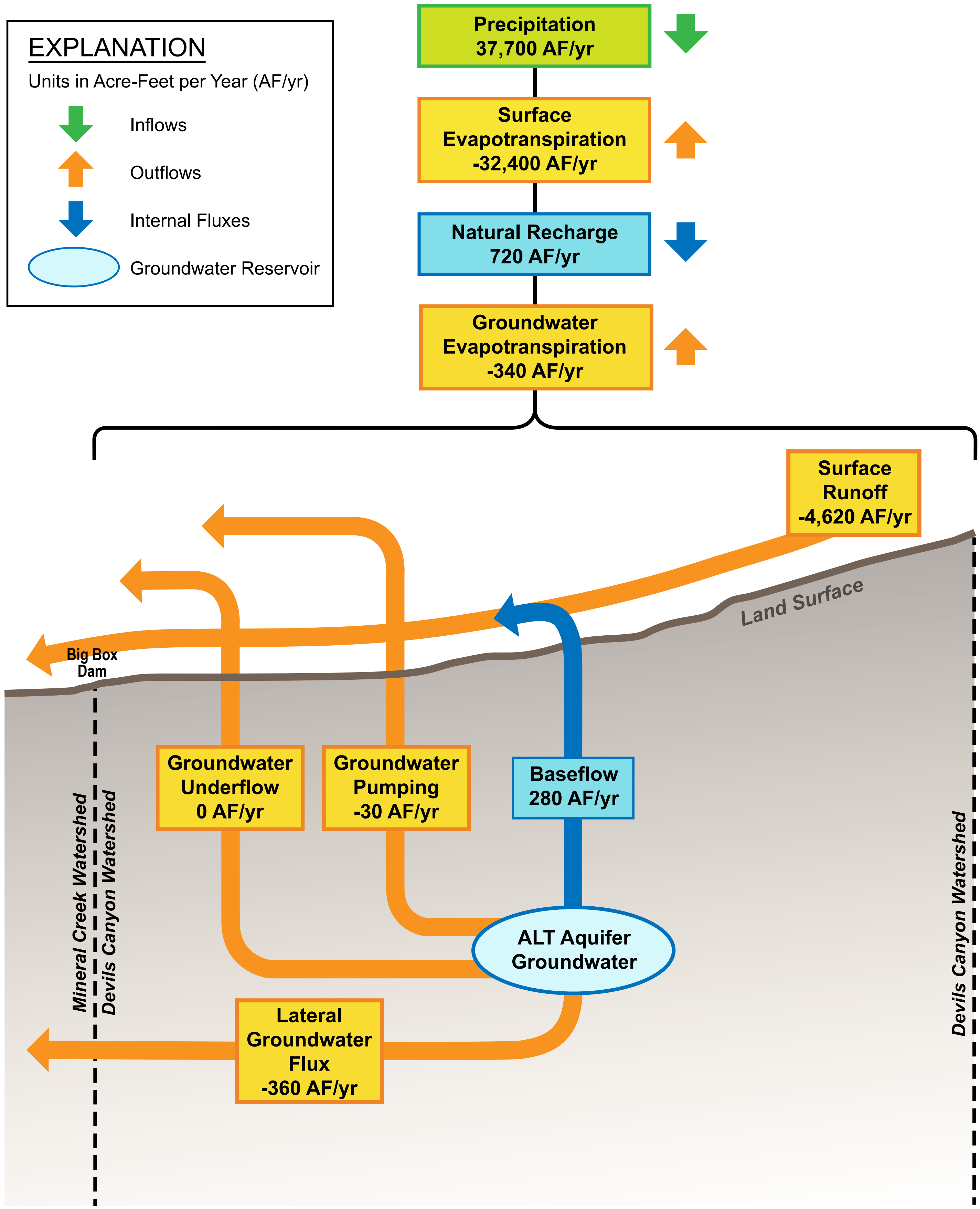

FIGURE 5. ANNUAL WATER BUDGET FOR DEVILS CANYON DOMAIN

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GIS\605.1601\WaterBudget_DevilsCanyon.ai\01June2018

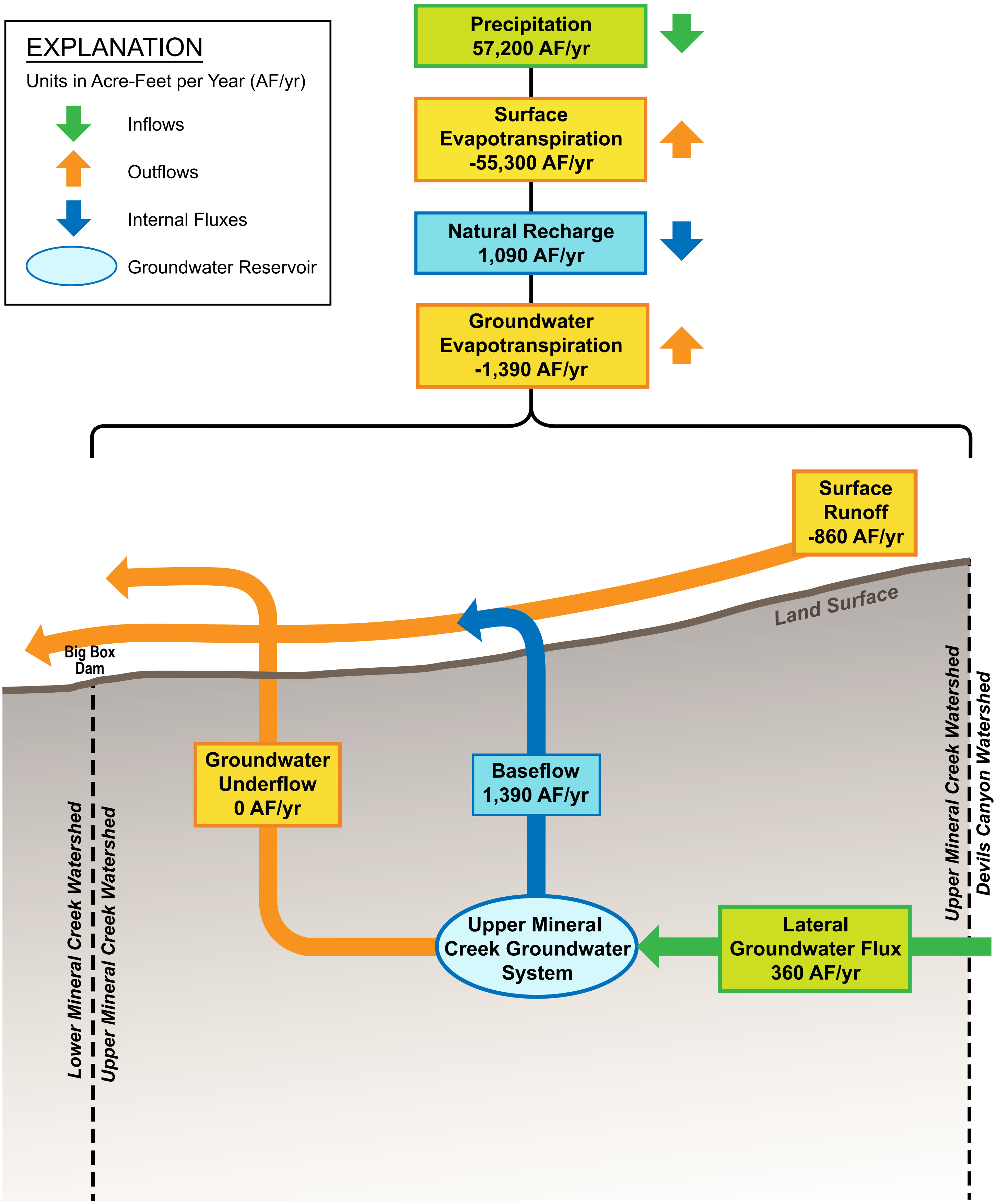

FIGURE 6. ANNUAL WATER BUDGET FOR UPPER MINERAL CREEK DOMAIN

GIS\605.1601\WaterBudget_Mineral Creek.ai\01June2018

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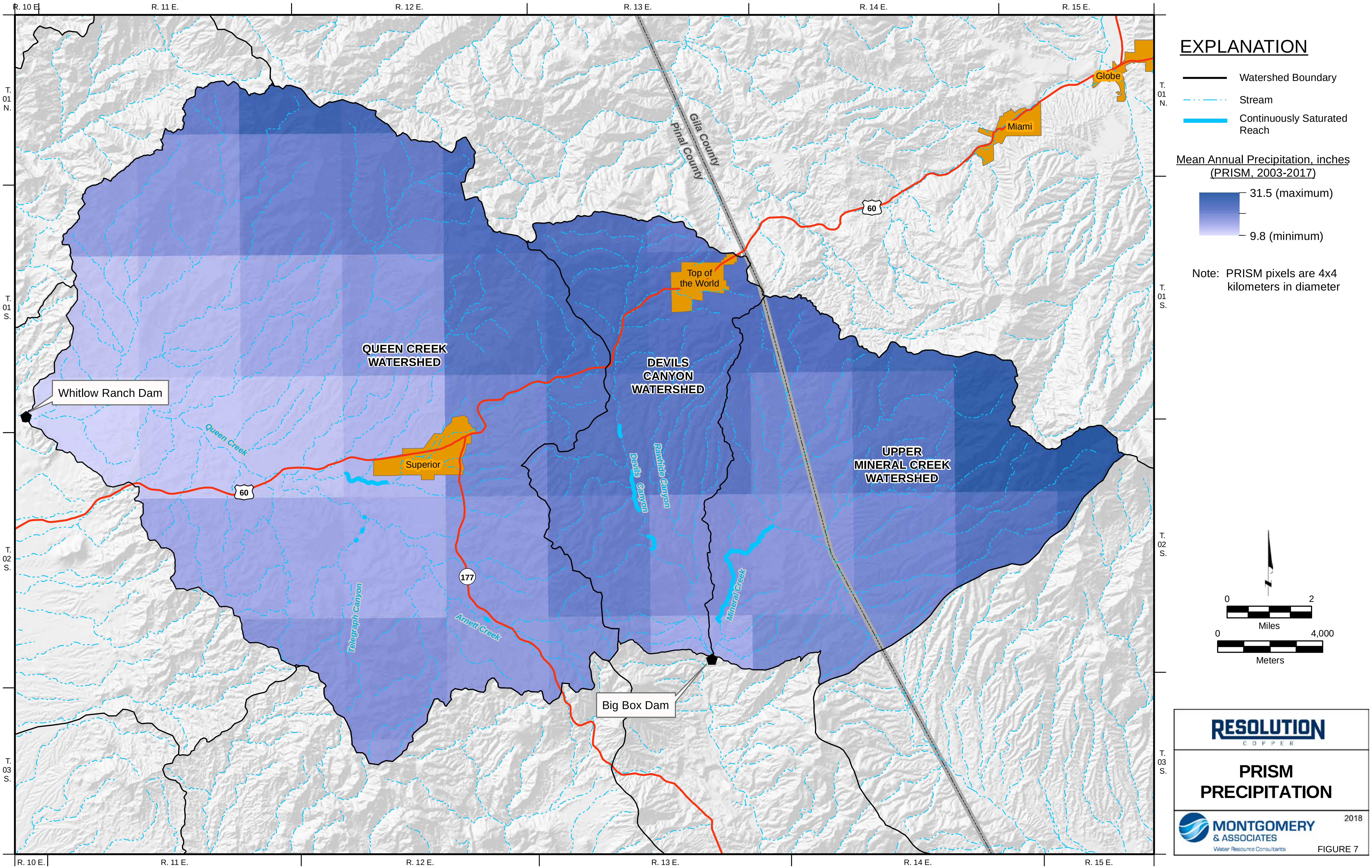

GIS-Tuc\Projects\605\605.1601\PRISM_Precip.mxd\31May2018

Reference: PRISM Climate Group, 2018

Appendix A

Discharge Measured below Big Box Dam, 1997 – 2009

TABLE A-1. DISCHARGE MEASURED BELOW BIG BOX DAM, 1997 – 2009
(in cubic feet per second)

Date	Discharge	Field Notes
10/14/1997	0.32974548	
11/10/1997	0.41886588	
12/12/1997	1.94950875	
1/13/1998	5.3249439	
2/13/1998		High Flow
3/12/1998	6.1270275	
4/14/1998	7.31901285	
5/28/1998	2.72931225	
6/12/1998	2.7404523	
7/14/1998	1.2922458	
8/14/1998	0.9803244	
9/14/1998	0.70182315	
10/15/1998	0.7352433	
11/13/1998	0.9803244	
12/15/1998	0.8243637	
1/14/1999	0.668403	
2/15/1999	1.0248846	
3/15/1999	1.1808453	
4/7/1999		High Flow
5/7/1999	1.114005	
6/9/1999	0.79094355	
7/15/1999		High Flow
8/3/1999	3.342015	
9/15/1999	0.7352433	
10/12/1999	0.1782408	
11/11/1999	0.3119214	
12/8/1999	0.3564816	
1/10/2000	0.6461229	
2/10/2000	1.1808453	
3/14/2000	3.6093762	
4/11/2000	1.3590861	
5/8/2000	1.28110575	
6/8/2000	0.4233219	
7/7/2000	0.32306145	
8/10/2000	0.25844916	
10/16/2000	1.56629103	
11/13/2000	17.48219187	
12/13/2000	9.381615388	
1/15/2001	5.172369775	
2/13/2001	6.386145063	
3/12/2001		Low Flow
4/13/2001	19.8240309	
5/14/2001		Low Flow
6/11/2001		No Flow
7/11/2001		No Flow
8/8/2001	25.55199953	

TABLE A-1. DISCHARGE MEASURED BELOW BIG BOX DAM, 1997 – 2009
(in cubic feet per second)

Date	Discharge	Field Notes
9/13/2001		No Flow
10/11/2001		No Flow
11/15/2001		No Flow
12/14/2001		No Flow
1/10/2002		No Flow
2/13/2002		No Flow
3/7/2002		No Flow
4/19/2002		No Flow
5/6/2002		No Flow
6/12/2002		No Flow
7/15/2002		No Flow
8/14/2002		No Flow
9/9/2002		No Flow
10/11/2002		No Flow
11/14/2002		No Flow
12/9/2002		No Flow
1/13/2003		No Flow
2/13/2003		No Flow
3/6/2003	89.51252976	
4/9/2003	5.55442893	
5/6/2003	1.69990479	
6/9/2003	0.6640361	
7/15/2003		No Flow
8/13/2003		No Flow
9/15/2003		No Flow
10/15/2003		No Flow
11/10/2003		No Flow
12/4/2003		No Flow
1/9/2004	1.225739702	
2/12/2004	6.792534087	
3/11/2004	124.1755083	
4/14/2004	12.69582482	
5/15/2004	4.67875416	
6/9/2004	0.253324737	
12/15/2004	0.604615074	
1/17/2005	7.494780559	
2/15/2005		High Flow
3/8/2005		High Flow
4/13/2005	2.936316659	
5/20/2005	1.327448358	
6/17/2005	1.012430024	
7/15/2005	0.596794759	
8/18/2005	0.58596663	
9/15/2005	0.58819464	
10/18/2005	0.930862578	
11/16/2005	0.293874519	

TABLE A-1. DISCHARGE MEASURED BELOW BIG BOX DAM, 1997 – 2009
(in cubic feet per second)

Date	Discharge	Field Notes
12/9/2005	0.440031975	
1/12/2006	0.300019371	
3/15/2006	0.677293729	
4/11/2006	0.677293729	
5/9/2006	0.53403448	
6/15/2006	0.065949096	
7/12/2006		DRY
9/9/2006	1.452083237	
10/10/2006	0.850054883	
11/15/2006	2.80506459	
12/5/2006	0.1826077	
1/23/2007	0.422519816	
2/13/2007	1.676577525	
3/15/2007	1.781360835	
4/16/2007	3.48237963	
5/18/2007	0.142236158	
6/26/2007		DRY
7/11/2007		DRY
8/3/2007		DRY
9/14/2007		DRY
10/5/2007		DRY
11/20/2007		DRY
12/17/2007	98.69750099	
1/14/2008	47.70307547	
2/14/2008	89.72499279	
3/6/2008	14.0809118	
4/8/2008	35.60230755	
5/14/2008	6.689911946	
6/10/2008	2.970182411	
7/16/2008	25.66839077	
8/13/2008	5.544380605	
9/9/2008	10.78067199	
10/7/2008	2.815981839	
11/11/2008	1.320095925	
12/10/2008	0.953365479	
1/12/2009	4.05052218	
2/17/2009	101.1204619	
3/12/2009	5.236269102	
4/15/2009	1.43929446	
5/6/2009	0.49907424	
6/8/2009	0.219993707	

Data provided by ASARCO; measurement method not known.

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Fax: 520.689.9304

June 13, 2018

Ms. Mary Rasmussen
US Forest Service
Supervisor's Office
2324 East McDowell Road
Phoenix, AZ 85006-2496

Subject: Response to Informational Request – Groundwater Working Group.

Dear Ms. Rasmussen,

As requested during groundwater working group meetings, please find attached the following reports:

- *System-wide Hydrologic Water Flow Budget*, Montgomery and Associates, June 2018
- *Fault Core Review and Guidance for Groundwater Flow Modeling*, Technical Memorandum by Wickham GeoGroup, LLC, December 2015

Sincerely,

Vicky Peacey,

Senior Manager, Environment, Permitting and Approvals; Resolution Copper Company, as Manager of Resolution Copper Mining, LLC

Cc: Ms. Mary Morissette; Senior Environmental Specialist; Resolution Copper Company

Attachments:

Montgomery and Associates, June 2018. *System-wide Hydrologic Water Flow budget*.

Technical Memorandum Wickham GeoGroup, December 2015. *Fault Core Review and Guidance for Groundwater Flow Modeling.*