APPENDIX A
DAVIDSON CANYON CONCEPTUAL MODEL
(TETRA TECH, 2010a)

TETRA TECH

Davidson Canyon Hydrogeologic Conceptual Model and Assessment of Spring Impacts

Rosemont Copper Project

A description of the hydrologic dynamics and key physical processes that are governing groundwater–surface water interactions in Davidson Canyon which includes a discussion on springs and their interface with the groundwater system.

July 2010

complex world CLEAR SOLUTIONS™

Davidson Canyon Hydrogeologic Conceptual Model and Assessment of Spring Impacts

Rosemont Copper Project

A description of the hydrologic dynamics and key physical processes that are governing groundwater–surface water interactions in Davidson Canyon which includes a discussion on springs and their interface with the groundwater system.

Prepared for:

ROSEMONT COPPER
Resourceful.

4500 Cherry Creek South Drive, Suite #1040
Denver, CO 80246
(303) 300-0138
Fax (303) 300-0135

Prepared by:

TETRA TECH

3031 West Ina Road
Tucson, AZ 85741
(520) 297-7723
Fax (520) 297-7724

Tetra Tech Project No. 114-320869

July 2010

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOGRAPHS

LIST OF APPENDICES

EXECUTIVE SUMMARY

Rosemont Copper Company (Rosemont) is planning the development of an open pit mining and mineral processing operation known as the Rosemont Copper Project (Project) on the east side of the Santa Rita Mountains, approximately 30 miles southeast of Tucson Arizona in Pima, County. As part of the mining operation, dewatering of the Open Pit will continue throughout the 20-25 years of operation and cease at closure.

When mining ceases and dewatering is discontinued, the pit will naturally refill with water from groundwater, surface-water, and precipitation contributions and a pit lake will form. Based on regional groundwater modeling performed by Montgomery & Associates (M&A), it is expected that the pit will remain a perpetual hydraulic sink at a stabilized, equilibrium condition due to the high evaporation rate of the Rosemont area. This implies that groundwater will perpetually flow into the Open Pit, although at a much lower rate than during the active dewatering process.

During operations, dewatering will create drawdown in the groundwater table. The propagation of the groundwater drawdown will preferentially follow the most permeable rocks and will likely not be uniform around the pit. Additionally, the drawdown will be the greatest around the pit and be less at greater distances away from the pit, such as in Davidson Canyon.

It is anticipated that the Rosemont Project will have some effect on Davison Canyon due to the changes in the surface and groundwater flow patterns at the Project site. It has been estimated that the area affected by the Project comprises about 16% of the entire Davidson Canyon watershed. Stormwater flow patterns will be altered in the Project area and will likely result in reduced downstream flows, which may decrease the riparian vegetation. Construction of flow-through drains and diversion channels are anticipated as part of the Project's tailings and waste rock facilities. These facilities are designed to pass stormwater from the up-gradient side of the facilities to the down-gradient side. In average annual conditions, it is estimated that most of the stormwater entering the flow-through drains will result in infiltration and ultimately recharge to the pit lake as opposed to passing through as downstream surface flows.

Both regional and local springs occur in the Davidson Canyon watershed. All observed springs have minor discharge, with flows less than one (1) gallon per minute being common. On a regional scale, these springs do not appear to be significant to the overall water balance. Only a few of the 20 or so springs observed in the upper reach of Davidson Canyon had observed perennial flow over the short monitoring duration. Rosemont, Questa, and Helvetia Springs may be supplied by the regional groundwater flow system. These springs could be impacted by changes to the regional groundwater flow system due to the Open Pit.

The regional groundwater table appears to be separated from the surface-water system within Davidson Canyon under normal conditions. Depth-to-water measurements indicate that the regional water table is 7 to 30 feet below the stream channel. Based on the low discharge rates and intermittent flows, most springs appear to be fed by shallow, perched water sources that are strongly influenced by seasonal precipitation variations, which would not be influenced by changes to the regional groundwater flow system. The "Reach 2" spring in the lower reach of Davidson Canyon appears to be supplied by stormwater runoff, not regional groundwater, so it is unlikely to be impacted by the Project.

Water-level declines in the lower reaches of Davidson Canyon (i.e., a distance of 9 to 14 miles) due to the Open Pit could occur if the cone of depression extends to this area. Due to these long distances, groundwater lowering associated with the Open Pit could take hundreds of years to materialize. Flow modeling by M&A indicated that the magnitude of potential impacts in Davidson Canyon would likely be on the order of one (1) to ten (10) feet. M&A data also demonstrate that natural fluctuations in groundwater range between four (4) and 25 feet in the

Davidson Canyon area (M&A, 2010). The complexity of the flow system, along with the numerous variables that could cause water-level declines, makes it technically challenging to reasonably predict the potential impacts due to the pit at the scale of these fluctuations. Wells located between the Open Pit and down-gradient edge of the proposed facilities are in place to allow monitoring of the pit dewatering and recovery. Down-gradient impacts due to the Open Pit, however, may be indiscernible from current conditions due to natural and man-induced regional water-table fluctuations.

Davidson Canyon is separated from the Project area, and therefore the Open Pit, by a series of northwest trending faults. Faults can have no discernable effect on groundwater flow or act as barriers or conduits for groundwater flow. Horizontal groundwater flow perpendicular to faults is commonly impeded and flow along the fault strike is commonly enhanced. Hydraulic testing in the pit area encountered flow boundaries, which are likely fault zones. The effect that these mapped and inferred faults have is not clear at this time, but they will likely impede propagation of drawdown towards Davidson Canyon. The northwest trending faults are generally perpendicular to northeasterly flow down Davidson Canyon with numerous springs occurring along these faults. These springs also imply that the faults most likely act as barriers to groundwater flow.

The long-term impacts to the water resources in Davidson Canyon and the larger Cienega Creek basin need to be considered in the context of long-term pit inflows. The reduction of water to the flow system cannot exceed the steady-state groundwater inflow to the pit. Pit-inflow estimates from the M&A groundwater flow model are over 300 gallons per minute (gpm) at the end of mining and decrease to about 120 gpm after 100 years. This reduction of water from the flow system would likely be distributed over the extent of the cone of depression.

Although not related to mining operations, there are other sources of potential impacts to the groundwater resources associated with Davidson Canyon. Current water users are likely tapping the regional groundwater system in the Davidson Canyon watershed to supply water to their homes, ranches, and small businesses. The Arizona Department of Water Resources (ADWR) well registry database indicates that there are over 300 wells (monitoring wells excluded) within the Davidson Canyon watershed. The actual pumping rates for these wells are not reported, although the reported pump capacities for some wells are substantial (e.g., greater than 100 gpm). Assuming the range of average discharge is from one (1) gpm to five (5) gpm, the cumulative withdrawal from these wells would be 300 gpm to 1,500 gpm. This range of groundwater withdrawal could be greater than the pumping expected due to dewatering the pit or from evaporative losses during the steady-state pit lake condition.

Based on the available geologic data, spring data, and well information showing existing water-table fluctuations, the anticipated downstream effects of pit dewatering and the post-mining pit lake may be indiscernible from the existing natural and man-induced regional effects. Groundwater monitoring will facilitate the detection of downstream effects and allow for adaptive management decisions related to mitigation during operations, closure, and post closure.

The conclusions of this investigation can be summarized as follows:

- The long-term, steady state impact of the terminal pit lake will be equal to the steady-state pit inflows. M&A (2009b) has estimated pit inflows to be approximately 120 gallons per minute 100 years after the end of mining.
- Groundwater users in Davidson Canyon could be collectively pumping more groundwater than will be consumed by the pit.
- Natural water-level fluctuations in Davidson Canyon are on the order of 4 to 25 feet, which will likely obscure drawdown impacts due to the pit.

- Down-gradient surface-water flows will be reduced due to the approximately 16 percent reduction in the watershed due to the Project facilities, which could result in a reduction of riparian vegetation.
- There are three potential regional springs, Rosemont, Questa, and Helvetia Springs, that could be impacted by changes to the regional groundwater flow system.
- The numerous local or perched springs will not be impacted unless their localized water catchment areas are directly disturbed by the Project operations.
- Faults acting as flow barriers may limit propagation of drawdown away from the Open Pit.
- The regional groundwater flow system is isolated from the surface-water system under typical, non-stormwater runoff conditions.

Regional groundwater flow models are currently being developed by Tetra Tech to simulate pre-mining steady-state conditions, active-mining conditions, and post-mining conditions. Following completion of these models, the simulated impacts to Davidson Canyon will be analyzed and the results of this analysis will be provided in an addendum to this report. However, the historically observed low spring flows and minor riparian vegetation within Davidson Canyon are insignificant on a regional scale. The incised stream channel, controlling geology, and localized conditions cannot be precisely represented with the regional scale model cells. This will limit the impacts analysis to relative changes in spring flows and/or water levels within the Canyon.

1.0 INTRODUCTION

Rosemont Copper Company (Rosemont) is planning the development of an open-pit mining and mineral processing operation known as the Rosemont Copper Project (Project) located in the northern Santa Rita Mountains. As part of the design and permitting process, Rosemont has undertaken detailed studies of the area resources. These resources include both surface water and groundwater and their interface.

The Project is located in the upper watershed of Davidson Canyon. Regional groundwater modeling performed by Montgomery & Associates (M&A) as detailed in *Groundwater Flow Modeling Conducted for Simulation of Proposed Rosemont Pit Dewatering and Post-Closure* (M&A, 2009b) indicates that there will be a post-mining pit lake that may affect groundwater elevations in Davidson Canyon, both during and after operations. In addition to the Open Pit, the configuration of the other Project facilities may also affect the volume of storm runoff shed to downstream drainages. An understanding of the physical processes controlling the surface water and groundwater systems is needed to evaluate the effect, if any, that the Project may have on the hydrologic conditions in Davidson Canyon.

1.1 Project Scope, Objectives, and Approach

The objective of this report is to determine possible impacts to Davidson Canyon (Figure 1) by the Rosemont operation. The scope of this analysis is limited to those portions of the operation that may directly impact the surface-water and groundwater hydrology of Davidson Canyon, and includes an analysis of the effect on spring flows, surface-water flows, and riparian areas.

This review also includes an analysis of what effect pit dewatering, surface-water diversions, and the alteration of groundwater recharge will have on flows in Davidson Canyon.

While modifications to surface-water drainages will occur in the main operations area, the primary focus of this evaluation is on the impacts to the groundwater system caused by groundwater drawdown from pit dewatering. Other studies have been completed to address the specific issues related to stormwater management in the main operations area.

The approach for evaluating potential impacts to Davidson Canyon from future Project operations is to integrate the existing body of knowledge into a conceptual model. Several sources of data are available for use in this evaluation.

The following in-depth hydrogeologic investigations involving baseline data collection, field testing, and modeling have been completed by M&A:

- *Results of Phase 2 Hydrogeologic Investigations and Monitoring Program, Rosemont Project, Pima County, Arizona* (M&A, 2009a);
- *Groundwater Flow Modeling Conducted for Simulation of Proposed Rosemont Pit Dewatering and Post-Closur*e (M&A, 2009b); and
- *Analysis of Long-Term, Multi-Well Aquifer Test – November 2008 through January 2009, Rosemont Project, Pima County, Arizona* (M&A, 2009c).

Geologic mapping has been completed by the Arizona Geological Survey (Ferguson and others, 2001).

The Pima Association of Governments (PAG) has completed several studies on Cienega Creek and Davidson Canyon including:

- *Contribution of Davidson Canyon to Baseflows in Cienega Creek* (PAG, 2003a);

- *Geologic Influence on the Hydrology of Lower Cienega Creek* (PAG, 2003b); and
- *Unique Waters Nomination – Davidson Canyon* (PAG, 2005).

Tetra Tech has completed the following reports to address baseline and post-mining hydrology, infiltration modeling, and fate and transport modeling:

- *Baseline Regulatory (100-Yr) Hydrology and Average-Annual Runoff, Rosemont Copper Project* (Tetra Tech, 2010a);
- *Infiltration, Seepage, Fate and Transport Modeling Report* (Tetra Tech, 2010b);
- *Post-Mining Regulatory (100-Yr) Hydrology and Average-Annual Runoff, Rosemont Copper Project* (Tetra Tech, 2010d); and
- *Rosemont Infiltration Analysis* (Tetra Tech, 2010e).

Field reconnaissance of Davidson Canyon has also been completed by Tetra Tech and Rosemont technical staff. In addition, there are numerous studies from published literature that provide a valuable understanding of the processes that are occurring in Davidson Canyon.

This body of knowledge has been integrated to create a conceptual model, which is a description of the hydrologic dynamics and key physical processes that are governing groundwater–surface water interactions in Davidson Canyon. The degree to which surface flows and spring flows are connected to the regional groundwater flow system will largely determine the potential impacts due to the proposed Rosemont operation. The conceptual model of these processes has been developed so that potential impacts can be inferred. Existing data are presented to support the interpretations used to build the conceptual model and to support the conclusions on potential impacts.

1.2 Report Organization

The conceptual model is first presented to provide an overview of the hydrologic system in Davidson Canyon. Secondly, those Project operations that may impact the water resources in Davidson Canyon are then briefly discussed. The range of potential impacts of these operations on the surface water and groundwater systems are then presented in a more generalized manner. Finally, specific impacts to individual water-resource features are discussed.

Details of the critical background information, data, and interpretations that support the conceptual model are provided in Section 7.0 (Data and Interpretations). Data from field investigations and previous studies are presented, interpreted, and applied to determine the likely impacts to Davidson Canyon.

1.3 Groundwater Flow Model Simulated Impacts

Regional groundwater flow models are currently being developed by Tetra Tech to simulate pre-mining steady-state conditions, active-mining conditions, and post-mining conditions. Following completion of these models, the simulated impacts to Davidson Canyon will be analyzed. However, the historically observed low spring flows and minor riparian vegetation within Davidson Canyon are insignificant on a regional scale. The incised stream channel, controlling geology, and localized conditions cannot be precisely represented with the regional scale model cells. This will limit the impacts analysis to relative changes in spring flows and/or water levels within the Canyon. The results of this analysis will be submitted as an Addendum to this report.

2.0 CONCEPTUAL MODEL

The Rosemont Copper Project site is located in the Santa Rita Mountains southeast of Tucson. Peaks in the Santa Rita Mountains are over 6,000 feet above mean sea level (amsl) and the topography drops into the Cienega Creek and Davidson Canyon watersheds to the east and northeast. The elevation at the confluence of Davidson Canyon and Cienega Creek is 3,325 feet amsl. The proposed Rosemont Open Pit and the other main Project facilities are located in the upper Davidson Canyon watershed (Figure 1). The western flank of the Empire Mountains also drains into Davidson Canyon.

The bedrock forming the Santa Rita Mountains consists of a metamorphic core flanked by a metamorphic shell of Paleozoic and Mesozoic-aged sedimentary rock including carbonates, shales, and limestones (Wardrop, 2005). These and similar rocks across the watershed are collectively termed bedrock. Permeability in the bedrock is primarily due to secondary fractures since the bulk rock is typically metamorphosed or highly consolidated with minimal porosity. This bedrock is typically covered by basin-fill deposits, recent alluvium, and unconsolidated deposits in the low lying surface-water drainage channels. These surficial deposits typically have higher storage and permeability with the capacity to transmit more water than the underlying bedrock.

The bedrock highs define the watershed boundary for Davidson Canyon (Figure 1). Due to the generally low permeability of the bedrock and the focusing of water toward the interior of the watershed, it is assumed that the groundwater sub-basin follows the watershed boundary. Although groundwater inflows to the sub-basin are not believed to be occurring in significant amounts, there could be inflows in the upper-most reaches where the divides are less pronounced. Groundwater observed in Davidson Canyon is predominately the result of recharge occurring within the watershed.

2.1 Recharge

Recharge is precipitation that infiltrates and reaches the groundwater water table. In semi-arid areas such as Davidson Canyon, recharge can occur in a number of ways and are identified by their occurrence in the watershed. Mountain top or high elevation recharge occurs when precipitation infiltrates through fractures in the bedrock. This recharge mechanism can be relatively limited due to the steep slopes, low permeability bedrock, and high percentage of runoff. The presence of nearly vertically dipping rock units in the pit area, however, suggests that there could be locally enhanced recharge due to higher vertical permeability. Precipitation in the higher mountain areas tends to runoff and collect in drainages where it then proceeds to flow down-gradient into areas that are more conducive to recharge. Run-on and precipitation on flatter slopes with higher permeability surficial deposits is more likely to create recharge. These conditions are commonly found at the slope breaks on mountain fronts and within surface-water drainages filled with unconsolidated materials. It is reasonable to assume that recharge in the Davidson Canyon watershed occurs in a similar manner as other basins with similar characteristics. The majority of recharge is therefore thought to occur at the base of the mountain front and within the surface-water drainages.

Available geochemical data indicates that some areas are recharged only in winter, while others are more strongly influenced by summer rains (see Section 7.6 for details). Wells and springs in the upper reaches of the watershed have isotopic values indicative of winter recharge. However, precipitation occurs year round. This suggests that summer rain is shed from higher elevations and recharges the groundwater system at lower elevations. Evapotranspiration in the summer months overwhelms water infiltrating into shallow soils, resulting in little diffuse recharge. Water samples from the Reach 2 Spring (Davidson Canyon #2 sample) in lower Davidson Canyon (Figure 1) have a geochemical signature that is strongly influenced by summer rain. This suggests that deeper, regional groundwater is not a significant source of water to the Reach 2 Spring.

Water infiltrating at higher elevations would tend to migrate downward and become recharge within the bedrock. Storm events can also create runoff and supply large amounts of water to the unconsolidated materials in the drainage bottoms. This water can saturate the channel material and infiltrate downward to supply recharge to the regional flow system. Water infiltrating into the drainage bottoms can also continue to flow laterally and down-gradient through the highly permeable channel material.

2.2 Groundwater Hydrology

In the regional flow system, groundwater levels vary from approximately 5,500 ft amsl to 2,600 ft amsl, which is a change of approximately 2,890 ft. This large water-level change results in steep gradients from the mountain top areas to the lower elevation riparian areas. The most pronounced gradients occur within the Davidson Canyon watershed.

The configuration and properties of the bedrock and surficial deposits leads to a groundwater system with two (2) primary flow components. The bedrock forms a deeper flow system with limited storage which flows primarily through fractures. The surficial deposits form spatially limited, shallow flow systems with greater storage (per unit area), with flows primarily through matrix materials. The degree to which these deep and shallow flows interact is largely dependent on the location within the system. Water levels east of the proposed Open Pit indicate that there are downward gradients, which indicates recharging conditions. There are, however, wells (e.g. PC-5 and PC-2) in the pit area that have upward gradients with water levels at or near the land surface. These wells are likely monitoring localized conditions within the complex geology that are not representative of the overall regional flow system.

In the upper reaches of the Davidson Canyon, the regional groundwater table is typically from 20 feet to over 100 feet below the ground surface (bgs). The shallowest depth-to-water (DTW) tends to occur in the alluvial drainages (RP-2 DTW = ~30 feet), while topographically higher wells, such as RP-4, has a DTW of approximately 181 feet. The observed DTW below the surface-water channels indicates that there is no persistent or direct connection between the surface-water flows and the regional groundwater. However, the downward gradients do indicate that recharge is occurring in the upper reaches of the watershed and through the stream channels.

2.3 Groundwater – Surface Water Interactions

Persistent and direct groundwater–surface water interactions occur when the groundwater table intersects the channel bottom or when there is a mechanism that causes deeper groundwater to flow to the surface (Figures 2 and 3). This results in groundwater discharging to the stream and an increase in the surface-water flows. These streams tend to have persistent base flows over distances of several hundred feet to miles. Base flows tend to be consistent since regional groundwater level fluctuations are small and less influenced by short-term or seasonal changes in precipitation and evapotranspiration. Precipitation events tend to increase stream flows by contributing more water to the groundwater base flow. Groundwater discharging to stream channels can occur anywhere, but in semi-arid environments such as Southern Arizona, it is most likely to occur in the major channels that drain the basins or in the lower reaches of stream drainages.

Cienega Creek is a potential example of a major drainage with groundwater inflows that contribute to sustaining surface flows. Within Davidson Canyon, the lower reaches [from the Reach 2 Spring to the confluence with Cienega Creek (Figure 4)], would be the most likely to receive groundwater inflows. These lower reaches occur in an area where the land surface is approaching the water table. There are limited data to determine the groundwater table in this area; however, the Pima County well shown on Figure 4 indicates that the water table is consistently seven (7) to 15 feet below the channel bottom (Figure 5). This would indicate that the regional groundwater table is disconnected from the Davidson Canyon stream channel in this area.

This shallow water table indicates that the groundwater is approaching the channel bottom as it nears Cienega Creek. Although groundwater would be expected to intersect the topographically lower Cienega Creek at the confluence with Davidson Canyon, there was no flow in this lower reach during Tetra Tech's site visit in January 2010. This indicates that the groundwater is either just below land surface or disconnected from Cienega Creek. The Reach 2 Spring (aka Davidson Canyon #2 sample) has an isotopic signature that is strongly influenced by summer precipitation. A winter recharge isotopic signature at the Reach 2 Spring would indicate that deeper, regional groundwater was dominant in this portion of the flow system. There is no evidence to suggest that regional groundwater is feeding the Reach 2 Spring or the stream channel under normal conditions. It is possible that heavy precipitation and runoff events could induce channel recharge, which would temporarily raise the regional groundwater levels until they intersect the stream channel.

2.4 Role of Faults and Dikes

The Santa Rita and Empire Mountains are separated by the Davidson Canyon fault zone, which consists of two (2) primary faults. The western fault trace is concealed by alluvium and the eastern fault is partially exposed in the northern piedmont of the Empire Mountains (Ferguson et al., 2001). The numerous faults that have been mapped in this area are illustrated on Figure 6. These faults are poorly understood (Ferguson et al., 2001) and their importance to groundwater flow is largely inferred. Water-level contours indicate that groundwater flow is focused toward the surface water drainage (M&A, 2009b) (Figure 7). The orientation of the Davidson Canyon fault zone is roughly parallel to groundwater flow and also suggests that there is the potential for enhanced flow. The width of an enhanced flow zone due to faulting cannot be determined based on available information. This is a significant issue since a highly permeable and extensive fault zone would act to drain groundwater from the Open Pit area and upper watershed. Significant, perennial groundwater discharge to the lower reaches of Davidson Canyon would be expected if the fault zone was transmitting significant volumes of groundwater. Such a fault zone, however, is unlikely since if it existed, this phenomenon would already be occurring under existing conditions. Therefore, there is limited evidence to suggest that Davidson Canyon is acting as a major groundwater drain.

Davidson Canyon is separated from the Project area, and therefore the Open Pit, by a series of northwest trending faults. Faults can have no discernable effect on groundwater flow or can act as barriers or conduits for groundwater flow. Horizontal groundwater flow perpendicular to faults is commonly impeded and flow along the fault strike is commonly enhanced. The effect that these mapped faults have on the propagation of drawdown towards Davidson Canyon is not clear at this time. However, these northwest trending faults are generally perpendicular to northeasterly flow down Davidson Canyon, which would imply that they most likely act as barriers to flow or at best have no discernable effect. The occurrence of springs along a fault indicates that the fault is acting as a barrier to horizontal groundwater flow and forcing the water to the surface. Of particular note are Mulberry Spring, Crucero Spring, Lower Mulberry Spring, Scholefield Spring, SC-2, MC-1, MC-2, Fig Tree Spring, Sycamore Spring, Questa Spring, and Helvetia Spring, all of which occur along northwest trending fault zones (Figure 8**)**.

Hydraulic testing near the Open Pit suggested that flow boundaries were encountered, which could be faults. In some cases, wells did not recover to their pre-pumping levels in the expected time period (e.g HC-1A, HC-5B, PZ-5) (M&A, 2009c). This indicates that the wells are not located in an infinite aquifer, but rather in a compartmentalized aquifer that is bounded by faults or other low permeability materials. These bounding faults or compartments would tend to limit the propagation of drawdown away from the Open Pit.

These lines of evidence imply that at least some of the numerous faults located between the Open Pit and Davidson Canyon act as barriers to groundwater flow. When considering potential impacts due to pit dewatering, assuming that these faults have no effect would result in the greatest propagation of groundwater drawdown in Davidson Canyon. Considering that the faults may act as flow barriers is a scenario that could be simulated in groundwater flow modeling efforts.

Numerous quartz porphyry dikes have formed in the Empire Mountains (Ferguson, C.A., 2009) and Mount Fagan areas (Ferguson et. al., 2001). Similar to faults, there is the potential that these dikes may create barriers to groundwater flow. One of the longest and most continuous dikes perpendicularly intersects Davidson Canyon downstream of the confluence with Barrel Canyon (Figure 6). Groundwater flow-model simulations can be used to test the dike’s influence on groundwater flow.

2.5 Local and Regional Springs

Springs occur when groundwater discharges at the ground surface. In the Davidson Canyon watershed, springs can receive water from shallow, local, or perched sources or from deeper, regional groundwater sources. The source of the discharging water is important because it will determine which springs are likely to be impacted due to Project operations. Local, or perched, springs are not hydraulically connected to the regional groundwater system under normal conditions (Figure 9). Characteristics of local springs include variable temperature, intermittent flow, and short residence time. These springs are fed by precipitation that infiltrates into the ground, flows a relatively short distance, and is discharged to the surface (Figure 9). Regional springs on the other hand tend to have perennial flow, consistent flow rates, and consistently warmer water temperatures. Flow paths and residence times for regional springs also tend to be longer than those of local springs. In general, water temperatures and chemistry from regional springs tend to reflect those observed in deep groundwater wells since the flow paths are deeper and the water may chemically equilibrate with the sub-surface rocks (Figures 2 and 3).

Both regional and local springs occur in the Davidson Canyon watershed. All observed springs have minor discharge with flows less than one (1) gallon per minute (gpm) being common. On a regional scale, these springs are not significant to the water balance. M&A reported spring flows and physical parameters for 20 springs in the upper reach of Davidson Canyon (M&A, 2009a). Helvetia Spring and Rosemont Spring (Figure 8) are the only springs with observed perennial flow over the short duration of monitoring. All other springs have been observed to be dry or wet, with no surface flow at the time of site visits. It would be more appropriate to call most of these sites “seeps” rather than springs. Based on the low discharge rates and intermittent flows, most springs appear to be fed by shallow water sources that are strongly influenced by seasonal precipitation variations.

Questa Spring is most likely fed by the deeper, regional groundwater flow system. This spring’s water chemistry is consistent with nearby well RP-9 and its carbon-14 data are representative of water that is possibly thousands of years old. Although very low flows and dry conditions have been reported at Questa Spring, these observations may not reflect field conditions. During a January 2010 site visit, Tetra Tech observed low or no-flow conditions at several springs, including the spring tank at Questa Spring. A short distance down-gradient from the Questa Spring tank, however, water was observed to be discharging at the surface. It is unknown if these surface discharges were measured and recorded during previous sampling events as spring flow.

3.0 RELEVANT MINING OPERATIONS

When compared to the other parts of the Rosemont operation, the proposed Open Pit will have the most significant impact on the groundwater flow system. The pit will require dewatering during the 20-25 years of active mining. When mining ceases and dewatering is discontinued, the pit will naturally refill with water. This refilling process will take many years to reach an equilibrium or steady-state condition. It is expected that the pit will remain a hydraulic sink at this long-term equilibrium condition. This means that groundwater will perpetually flow into the Open Pit, although at a much lower rate than during the dewatering process. Dewatering will create drawdown as would any discharging groundwater well. The propagation of drawdown will preferentially follow the most permeable rocks and will likely not be uniform around the pit.

As previously discussed, groundwater recharge on the steep mountain block areas, like those areas around the pit, is expected to account for a relatively minor portion of the total recharge compared to the lower reaches. The Open Pit and other operations facilities will also alter the drainages and thus the surface-water flow as well as the natural recharge processes in this portion of the mountain block. The pit will capture natural precipitation that falls within the surface expression and the groundwater capture zone will route recharging water to the pit. While this will be offset to some degree by the site water management features associated with the Rosemont Project, this condition will most likely result in an overall decrease in recharge to Davidson Canyon. On a regional scale, however, the capture zone of the pit accounts for a small percentage of the total Davidson Canyon watershed.

The drawdown due to pit dewatering and the ultimate hydraulic sink, including the decreased recharge, will potentially have different impacts. These impacts will vary spatially, with features closest to the pit likely to experience the greatest impact. For the following discussions, Reaches 1-4 in Davidson Canyon are considered the lower reaches. The headwater reach and the Barrel Canyon reach are considered the upper reaches (Figure 1).

Springs may be impacted if their water source is diminished due to Project operations. This most likely will occur in the upper reaches of Davidson Canyon. However, the water source for the springs is of paramount importance when assessing the potential for Project operations to cause impacts. Local springs that receive water from shallow flow paths will only be impacted if their water catchment areas are directly disturbed by the Project operations. Springs fed by deeper, regional groundwater are more likely to be impacted if the pit disrupts the regional flow system supplying water to them. In both cases, the likelihood of a spring being impacted increases with proximity to the Open Pit. This same situation will apply to groundwater wells.

Changes to the pre-mining stormwater runoff characteristics due to the Project facilities may alter the down-gradient stormwater flows. Riparian vegetation could be impacted if it is sensitive to small changes in stormwater flows or if it is dependent on the regional groundwater flow system. In either case, declining shallow groundwater levels may leave roots out of reach of their dry season water source, potentially resulting in die off or reduced density. These impacts are highly sensitive to specific conditions including plant type, natural water depth, and seasonal fluctuations.

Studies have been performed predicting the pit lake water quality. After 200 years of simulation, modeling indicated the pit lake water quality would resemble that of local groundwater (Tetra Tech, 2010c). Infiltration, Seepage, and Fate and Transport modeling has also been performed on the waste rock, dry stack tailings, and spent ore pile associated with the Heap Leach Facility (Tetra Tech, 2010b). The results of this analysis indicated that any potential seepage from these facilities would have measured constituents mostly below the Arizona Aquifer Water Quality

Standards (AWQS). Any stormwater and seepage in the vicinity of the Open Pit will likely be captured by the hydraulic sink (Figure 10).

4.0 OTHER GROUNDWATER STRESSES

Although not related to mining operations, there are other sources of impacts to the groundwater resources associated with Davidson Canyon. Current water users are likely tapping the regional groundwater system in the Davidson Canyon watershed to supply water to their homes, ranches, and small businesses. The Arizona Department of Water Resources (ADWR) well registry database indicates that there are over 300 wells (monitoring wells excluded) within the Davidson Canyon watershed (Figure 11). The actual pumping rates for these wells are not reported, although the reported pump capacities for some wells are substantial (e.g., greater than 100 gpm). The available data does not allow the individual or total withdrawals to be determined. Assuming the range of average discharge is from one (1) gpm to five (5) gpm, the cumulative withdrawal from these wells would be 300 gpm to 1500 gpm. This range of groundwater withdrawal is greater than the pumping expected due to dewatering the pit or from evaporative losses during the steady-state pit lake condition.

The majority of the ADWR registered wells are located much closer to sensitive riparian areas in the lower reaches of Davidson Canyon than the Open Pit. Although water withdrawals from these wells would have an impact on Davidson Canyon’s water resources, the degree of those impacts has not been quantified.

Natural climatic variations can also impact the groundwater resources and water users within Davidson Canyon. Less precipitation results in less recharge which, if persistent for long periods, will result in declining regional water levels. The shallow groundwater system appears to be very sensitive to drought, or below normal precipitation conditions. Therefore, many spring and surface flows can be rapidly affected by drought conditions. The “Unique Water Nomination for Davidson Canyon” application filed by Pima Association of Governments (PAG, 2005) acknowledged that drought conditions had decreased flows to the unnamed spring (referred to as the Reach 2 Spring in this report).

5.0 POTENTIAL IMPACTS

The long-term impacts to the water resources in Davidson Canyon and the larger Cienega Creek basin need to be evaluated in the context of long-term pit inflows. The reduction of water to the flow system cannot exceed the steady-state groundwater inflow to the pit. Pit-inflow estimates from the M&A groundwater flow model are over 300 gpm at the end of mining and decrease to about 120 gpm after 100 years (M&A, 2009b). This reduction of water from the flow system would likely be distributed over the groundwater flow system and not at a specific location.

5.1 Groundwater and Surface-Water Impacts

Water-level data and channel elevations indicate that the shallow groundwater system is disconnected from the deeper groundwater system. The lack of a persistent hydraulic connection between the shallow and deep systems is most pronounced in the upper portion of the watershed. It is expected that a seasonal connection of the shallow and deep flow systems may occur in the lower reaches (Figures 1 and 4 – Reaches 2, 3, and 4). This temporary connection would occur in response to prolonged precipitation and stormwater runoff events.

Recharge from surface-water flows can result in a temporary rising of water levels that would connect the shallow, local water in the stream channels with the deeper, regional groundwater. This process will naturally continue with or without influence of an open pit. A temporary seasonal connection and the lack of a persistent connection between the shallow and deep flow systems is relevant to potential impacts to the Reach 2 Spring, surface-water flows, and riparian vegetation. A lowered regional water table in Reaches 2, 3, and 4 (Figure 4) would be less likely to rise to the stream channel elevation due to recharge from stormwater runoff. These lower reaches also have riparian vegetation. Plants with deeper root systems may currently obtain water from the regional water table. Reductions in plant density would be expected if the regional water table was lowered beyond the root depths.

Water-level declines in the lower reaches of Davidson Canyon (i.e., 9 to 14 miles) due to the Open Pit will occur if the cone of depression extends to these distances. Groundwater lowering associated with the Open Pit could take hundreds of years to materialize in lower Davidson Canyon. Flow modeling by M&A indicated that the magnitude of potential impacts in Davidson Canyon would likely be on the order of one (1) to ten (10) feet (M&A, 2009b). M&A data also demonstrate that natural fluctuations in groundwater range between four (4) and 25 feet in the Davidson Canyon area (M&A, 2010).

It has been estimated that the surface area affected by the Project comprises about 16% of the entire Davidson Canyon watershed. Stormwater flow patterns will be altered in the Project area and will likely result in reduced flows to downstream receptors. Construction of flow-through drains and diversion channels are anticipated as part of the Project. These drains are designed to pass stormwater from the up-gradient side of the facilities to the down-gradient side. In average annual conditions, most of the stormwater entering these flow-through drains will result in infiltration and ultimately recharge as opposed to passing through as downstream surface flows. This focused recharge would supply water to the pit lake and reduce the down-gradient drawdown due to the Open Pit.

5.2 Water Quality

Down-gradient water-quality impacts due to the Project would not be expected to occur if the pit is maintained as a terminal hydraulic sink. This sink will provide tertiary containment for the operations and prevent groundwater in the operations areas from flowing down-gradient to wells, springs, and riparian areas (Figure 10). Groundwater flow modeling supports the creation of a terminal hydraulic sink (M&A, 2009). Groundwater inflow rates to the post-mining pit lake are expected to be relatively low.

5.3 Local and Regional Springs

Springs are the most likely groundwater resources to be impacted by the Project. Springs near the Open Pit will likely be impacted by the pit disturbance. The springs nearest the pit are McCleary, MC-1, MC-2, Fig Tree, Sycamore, Helvetia, Peligro Adit, Ruelas, SW, Locust, and Deering Spring (Figure 8). If the source areas that supply water to these springs are disturbed by the pit they will likely experience decreased or terminated flows. Long-term pit dewatering will reduce water levels in the low storage bedrock forming the crest of the Santa Rita Mountains. This may not alter the local flow system since it appears to be disconnected from the regional flow system. The rationale for suggesting potential reductions in discharge at these springs is based solely on their proximity to the pit.

Papago, Mulberry, Crucero, Lower Mulberry, Scholefield, SC-2, and Barrel Spring (Figure 8) may not be impacted by the Project. These springs appear to be fed by local recharge, are not connected to the deeper, regional flow system, and are probably of a sufficient distance from the pit.

Questa Spring (Figure 8) is likely fed by the regional flow system. Pit dewatering and alteration of the recharge mechanisms may or may not affect flows at this spring. Questa Spring is located over three (3) miles from the pit, and the hydraulic connection between the pit area and the spring is unclear. The proximity of Rosemont Spring to the pit and the pit depth make it likely that it will have reduced or terminated flows. The maximum measured discharge from the Rosemont Spring is about 0.79 gpm. Any change in the flow system supplying groundwater to this spring could easily terminate flow at this location.

Davidson Spring, Reach 2 Spring, and Escondido Spring are located in the lower reach of Davidson Canyon (Figure 8) at distances of nine (9) to 14 miles from the pit. Davidson Spring is likely fed by recharge from the Empire Mountains and is likely disconnected from the upper reaches of Davidson Canyon. No data are available to conclusively determine the source of water to Davidson Spring. Evidence suggests that the Reach 2 Spring and Escondido Spring are fed largely by summer recharge from surface-water flows and not by regional groundwater. The lack of a persistent hydraulic connection of the springs and surface flows to the regional groundwater flow system makes it unlikely that these springs and surface flows will be impacted by Project activities. Climatic variations and groundwater pumping will likely obscure any impacts due to the mining operation.

5.4 Other Impact Sources

The complexity of the flow system and the numerous variables that cause water-level declines on a regional scale make it technically challenging to predict impacts due only to the pit. Impacts from dewatering of the Open Pit may be indiscernible from the natural and man-induced regional water-table fluctuations. Changing weather and climate conditions, or other stresses, including groundwater pumping from within Davidson Canyon, in the Cienega Creek basin, and potentially in the Tucson basin, can impact water levels in Davidson Canyon. Wells between the Open Pit and down-gradient features need to be monitored to determine a cause and effect relationship.

6.0 BACKGROUND INFORMATION

6.1 Study Area Description

The study area for this Davidson Canyon Conceptual Model encompasses the entire Davidson Canyon watershed which includes the area from the Rosemont Copper Project Site in the Santa Rita Mountains to where Davidson Canyon discharges to Cienega Creek, north of I-10 (Figure 1). The watershed covers an approximate area of 32,920 acres (51 square miles). The upper portion of the watershed includes the sub-watersheds of McCleary Canyon, Wasp Canyon, and Barrel Canyon (Figure 1). Further northwards, Davison Canyon drains the western flank of the Empire Mountains through a series of small sub-drainages. The distance from the confluence of upper Davison Canyon with Barrel Canyon to the outlet of Davidson Canyon at Cienega Creek is approximately 14 miles.

The topography varies considerably within the Davison Canyon watershed from 6,000 feet amsl in the upper watershed to 3,325 feet amsl at the outlet to Cienega Creek (Figure 1). Average annual precipitation in the higher elevations of the watershed has been as high as 26 inches per year and precipitation in the topographically lower reaches near I-10 has been 16 inches. The average annual rainfall for the Project areas is about 18 inches (Tetra Tech, 2010a). Generally, surface water flows occur only in response to direct rainfall within the drainage basin. However, springs and seeps within Davidson Canyon sustain some short intermittent and reportedly perennial reaches in the lower reaches (PAG, 2005).

6.2 Outstanding Arizona Water Designation

Two (2) reaches of Davidson Canyon have been classified as Outstanding Arizona Water (OAW) resources by ADEQ under A.A.C. R18-11-112. The two (2) reaches, Reach 2 and Reach 4, are shown on Figure 4.

The Unique Water characteristics, as described in A.A.C. R-18-11-112 and presented in the nomination document (PAG, 2005), include:

- The surface water is a perennial water;
- The surface water is in a free-flowing condition;
- The surface water has good water quality; and
- The surface water meets one or both of the following conditions:
    - The surface water is of exceptional recreational or ecological significance because of its unique attributes; and
    - Threatened or endangered species are known to be associated with the surface water in this area. Therefore, maintaining the existing water quality and quantity is essential to the maintenance and propagation of threatened or endangered species.

Reaches 2 and 4 (Figure 4) were designated as OAW by ADEQ in a public notice dated December 3, 2008. The designations require ADEQ to protect the water quality of these two (2) reaches of Davidson Canyon using anti-degradation criteria.

7.0 DATA AND INTERPRETATIONS

Details of the data and interpretations that support the conceptual model are provided in this section. Data from field investigations and previous studies are presented, interpreted, and applied as needed to determine the likely impacts to Davidson Canyon.

7.1 Surface Water Hydrology

As a result of hydrologic variability along Davidson Canyon, there is a need to clarify the definitions for ephemeral, intermittent, and perennial streams. This report will adopt the definitions presented by the United States Environmental Protection Agency (U.S. E.P.A., 2008):

Ephemeral:	A stream or portion of a stream which flows briefly in direct response to precipitation, and whose channel is at all times above the groundwater reservoir.
Intermittent:	A stream where portions flow continuously only at certain times of the year. For example, when it receives water from a spring, ground-water source, or from a surface source such as melting snow (i.e., seasonal). At low flow there may be dry segments alternating with flowing segments.
Perennial:	A stream or portion of a stream that flows year-round, is considered a permanent stream, and for which baseflow is maintained by groundwater discharge to the streambed. Discharge to the streambed from groundwater would be due to the groundwater elevation adjacent to the stream typically being higher than the elevation of the streambed.

The perennial reach of Davidson Canyon as defined by PAG (2005) is located about 0.5 miles upstream from the Interstate 10 bridge crossing. This reach extends downstream from the Reach 2 Spring for a distance of about 0.8 miles. However, field observations suggest that most or all of this reach may technically be classified as intermittent based on the definition stated above. Reach 4 also falls under the intermittent classification. The lower sections of Reach 1 are largely ephemeral as is the rest of the study reach (Figure 1). The U.S. Geological Survey (USGS) operated a stream gage (Davidson Canyon Wash near Vail, AZ, USGS Gauging Station No. 09484590) from February, 1968 through Water Year 1981. The gage is located about 0.2 miles upstream from the Interstate 10 crossing approximately 1000 feet north of the "perennial" reach. The watershed area draining to this gauging station is about 50.5 square miles. A duration analysis of the available mean daily flow data (February, 1968 through September, 1975) indicates the channel at this location conveys flow about 23 percent of the time, or about 84 days per year, and the flow exceeds one (1) cubic foot per second (cfs) less than five (5) percent of the time (Figure 12).

Peak flow data collected during the period of record indicates the flood hydrology is characterized by sudden, brief, and dramatic flood events, where the rising and falling stream flows are steep, and the period of peak flow is short. Using the measured annual flood peaks, a flood-frequency curve was developed using the U.S. Army Corps of Engineers HEC-FFA computer program (USACE, 1992), which is based on the procedures outlined in U.S. Water Resources Council (USWRC) Bulletin 17B (USWRC, 1981), with a generalized skew coefficient of -0.2. The resulting frequency curve indicates that the 2-year peak flow is about 1,590 cfs, the 10-year peak flow is about 6,070 cfs, and the 100-year peak flow is about 13,900 cfs (Figure

13). Peak flows are thunderstorm driven, typically occurring during the monsoon season between late July and early September.

7.1.1 Channel Morphology

The morphology of Davidson Canyon and associated tributaries provide insights into the processes controlling streamflow and channel development, sediment transport, and groundwater recharge. These processes largely control where the ecologically valuable resources develop and dictate their form. The channel morphology has principally been developed from the field observations, grain size samples, and channel bed elevation data that was collected by Tetra Tech using a Trimble GeoXH. The elevation data was collected and post-processed using nearby base station data from Tucson. The post-processed data typically had a reported vertical accuracy of about 1.6 feet. The morphology of the channel, particularly in downstream reaches, is strongly coupled to the bedrock geology of the area and thus Section 7.2 should be considered in the context of the geologic interpretations. The observed morphologic and physical characteristics of the channel, such as the cross-sectional geometry, bedslope, planform, and sediment balance, suggest that the channel in Davidson Canyon is controlled by extreme flow events, since the low volume base flows likely do not transport significant quantities of sediment.

The channel bedslope of the mainstem headwater reach of Davidson Canyon flattens in the downstream direction, decreasing from about 3.7 percent in the reach between Questa Spring and Station 255+00 to about 1.9 percent in the reach between Station 255+00 and the confluence with Barrel Canyon (Figure 14). Similarly, the slope in Barrel Canyon flattens from about 4.3 percent upstream from Rosemont Spring to about 1.7 percent above its confluence with Davidson Canyon. Downstream from the confluence with Barrel Canyon, the channel bedslope is relatively constant at about 1.2 percent. In these lower gradient areas, alluvium fills in behind the bedrock outcrops within the channel. These trapped sand deposits allow for water storage, presumably with water perching on less permeable bedrock. Bedrock outcrops along the channel bed provide grade control (Photograph 1) and are shown as steps in the longitudinal profile (Figure 14). These features occur primarily upgradient of Reach 2. A conceptualization of the system is presented on Figure 15.

The headwater reaches of Davidson Canyon include the main reach and the Barrel Canyon reach. While these reaches have localized areas that are constricted by bedrock (Photograph 2), the channel geometry is typically wide and shallow, bounded by broad floodplains with moderate to dense grass, brush, and trees (Photographs 3 and 4). This channel geometry indicates significant sediment storage in the channel and overbanks. The sediment supply to the headwater reaches is primarily derived from incision of small tributary channels (Photograph 5) and toe erosion of alluvial terraces along the mainstem (Photograph 6), but erosion caused by overland sheet flow may also be a source of sediment.

It should be noted that the sediment deposition upstream from the bedrock steps (discussed above) does not indicate a system-wide sediment imbalance but instead suggests a portion of the bed material load is trapped in localized, low-gradient zones. Sediment deposition was also identified along transition zones where energy losses, associated with flow expansion, result in expansion bars (Photograph 7).

In the downstream reaches of Davidson Canyon (Figure 4 – Reaches 2, 3, and 4), the valley bottom is relatively wide in areas where the surficial geology is comprised of alluvium and is somewhat constricted through reaches that have historically incised through bedrock outcrops. The cross sectional shape similarly varies with the composition of the valley floor. Where the valley bottom is wide, the channel consists of a well-defined low-flow channel bounded by low-elevation floodplains that are moderately to densely vegetated with grasses and brush (Photograph 8). Reaches cut through bedrock typically have a poorly defined and irregular cross sectional shape with no identifiable floodplain (Photograph 9). Lateral migration in the downstream reaches appears to be limited to localized areas where coarse-grained sediment deposits deflect flow towards the toe of alluvial banks and terraces (Photograph 10).

Bed material throughout the reaches of Davidson Canyon is generally gravelly sand with some cobble- and boulder-sized clasts. Three (3) samples of the alluvial sediments within Davidson Canyon (Figure 1) were collected for particle size analysis (Appendix A). The samples were primarily well sorted sand with gravel and were collected from a depth of zero (0) to one (1) foot bgs. The Hazen Method was used to estimate the hydraulic conductivity of the alluvium in Davidson Canyon. Three (3) samples were also collected at these same locations from zero (0) to one (1) foot bgs within the channel. The Hazen approximation, as documented by Fetter (1994), is:

$$K = C(d_{10})^2$$

Where:

- K is hydraulic conductivity [cm/sec]
- d_{10} is the effective grain size [cm]
- C is a coefficient base for coarse well sorted sand (120)

Applying the Hazen approximation to the reported grain size distribution results in the following:

Table 1 Estimated Hydraulic Conductivity of Alluvium

Sample	d_{10} (cm)	Hydraulic Conductivity (cm/sec)	Hydraulic Conductivity (ft/day)
1	0.04	0.19	538
2	0.05	0.30	850
3	0.03	0.11	306

The permeability estimates are high and would likely result in high infiltrations rates when the surface water is present (high loses to the subsurface system).

Consistent with other ephemeral channels in the southwest, the presence of the relatively large bed material indicates the morphologic and physical characteristics of the channel (i.e., cross sectional geometry, bed slope, planform, and sediment balance) are controlled by extreme flow events, since the low volume base flows likely do not transport significant quantities of sediment. Evidence of channel down cutting was not observed during the field visit, and persistent longitudinal sediment deposits along the channel bed indicate that:

- The bed material load is significant; and
- The bed material sediment supply is either in equilibrium with or slightly exceeds the transport capacity.

Based on the geomorphic characteristics observed in the field, the following conclusions may be drawn:

- Base flows are low in magnitude and duration while high magnitude flood events are driven by monsoon thunderstorms;

- The sediment supply to the headwater reaches is somewhat greater than the transport capacity, resulting in sediment storage that occurs along the low-flow channel and along the low-elevation floodplain surface. The resulting sediment supply to the downstream reaches (Reaches 2, 3, and 4) appears to be in balance with the transport capacity;
- The physical and morphologic characteristics of Davidson Canyon are not significantly affected by base flows and are controlled by the thunderstorm-driven flood events; and
- Channel seepage between Reach 2 and Cienega Creek is likely significant due to the shallow alluvial aquifer north of I-10. Recharge would be due to monsoon driven surface flows.

7.2 Geology

Geologic data for the Davidson Canyon watershed is primarily available from existing geologic mapping (Ferguson et al., 2001) and from the hydrogeologic characterization work completed by M&A (M&A, 2009a). These data were supplemented with geologic observations made by Tetra Tech during the January 2010 field reconnaissance work. Understanding the geologic framework of the study area, and particularly the Davidson Canyon fault zone and the corresponding geologic controls on streamflow, are an essential component of conceptualizing the flow system. The geology ultimately controls spring flow and flow along the intermittent reaches, as well as the degree to which channels are connected to the broader hydrogeologic system that will be immediately affected by pit dewatering and pit lake formation.

The Santa Rita and Empire Mountains are separated by the Davidson Canyon fault zone. The western fault trace is concealed by alluvium and the eastern fault is partially exposed in the northern piedmont of the Empire Mountains (Ferguson et al., 2001). Neither of the mapped primary fault traces directly underlie the channel alluvium. These faults along Davidson Canyon, and around Davidson Springs, are poorly understood (Ferguson et al., 2001). The hydraulic properties of the Davidson Canyon fault zone have not been tested and the faults are inferred over much of their extent, making field observations of properties (e.g., aperture, open versus closed, degree of fine grained material, etc.) difficult. There may also be considerable lateral and vertical variability in the hydraulic properties of the fault zone. Water-level contours indicate that groundwater flow is focused toward the surface water drainage (M&A, 2009b). The orientation of the fault zone roughly parallel to the groundwater flow direction would also suggest that there is some potential for enhanced flow. The width of an enhanced flow zone due to the fault cannot be determined based on available information. This is a significant issue since a highly permeable and extensive fault zone would act to drain groundwater from the pit area and upper watershed. Such a fault zone, however, seems unlikely since this draining phenomenon would already be occurring under existing conditions. Therefore, there is no evidence to suggest that Davidson Canyon is acting as a major groundwater drain.

Davidson Canyon is separated from the pit by a series of northwest trending faults in the Upper Cretaceous Volcanics (Figure 6). The effect that these faults will have on the propagation of drawdown towards Davidson Canyon depends on the hydraulic properties of the faults. Faults can affect groundwater flow in two (2) ways: by juxtaposing units with different hydrologic properties; and 2) by exhibiting characteristics that are different from surrounding unfaulted rocks and can therefore act as barriers to flow and/or conduits for flow. If the fault zone cores are filled with gouge, they can act as barriers to flow (barrier faults). Alteration and mineral precipitation can also alter the hydraulic characteristics by occluding pore spaces and filling connected fractures. The degree to which faulting results in compartmentalization of the groundwater flow system near the pit remains uncertain. However, the occurrence of numerous springs along the northwest trending faults in the Upper Cretaceous Volcanic suggests that these faults are acting as barriers to groundwater flow. These faults are roughly perpendicular to groundwater flow and the barrier faults result in groundwater being forced to the surface.

Numerous quartz porphyry dikes have formed in the Empire Mountains (Ferguson, C.A., 2009) and Mount Fagan areas (Ferguson et. al., 2001). Some of these dikes appear to have been formed by intrusion into existing faults (Drewes, 1972). These dikes are younger than the surrounding bedrock and therefore cut through the older bedrock. There is the potential that these dikes may create barriers to groundwater flow. One of the longest and most continuous dikes perpendicularly intersects Davidson Canyon downstream of the confluence with Barrel Canyon (Figure 6). There has been no hydraulic testing of this dike to characterize its hydraulic properties and its influence on groundwater flow. The cross-cutting nature, width, and length of this dike, however, suggest that it may influence groundwater flow.

When considering potential impacts due to pit dewatering, assuming that these faults and dikes have no effect would result in the greatest propagation of drawdown in Davidson Canyon. However, the available evidence suggests that some of these faults and dikes likely act as barriers to flow, which would limit how drawdown would propagate north and northeast of the Rosemont Project site. Further analysis of the aquifer test data obtained by M&A may provide additional insights into the typical hydraulic characteristics of these faults (M&A, 2009a; 2009c).

7.2.1 Geologic Controls on Streamflow

Streamflow in Reach 2 originates at the Reach 2 Spring (Figures 1 and 4). It should be noted that during the January 2010 field reconnaissance, most portions of this “perennial” reach were dry. It has been suggested that streamflow is perennial or intermittent where the volume of channel alluvium is restricted by bedrock and groundwater is forced to the surface (PAG, 2005). In contrast, where the width or depth of the alluvium increases, streamflow becomes intermittent or ephemeral (PAG, 2005). The geology in the area of the Reach 2 Spring is comprised of steeply dipping Turney Ranch Formation of the Bisbee Group (Upper Cretaceous) (Figure 16). The medium-to thick bedded quartz sandstone is interbedded with thin- to medium-bedded, reddish colored silty mudstone and shale. The more resistant quartz sandstone beds periodically form fins that extend into the channel, which could potentially constrict subsurface flow and create upward vertical gradients or temporarily pond surface water. PAG (2005) noted seeing ponded water behind some of these fins (Photograph 11) during their field investigation, although none was observed by Tetra Tech (2010b).

The Davidson Canyon channel is very narrow (i.e., less than a 100 feet) in the vicinity of the Reach 2 Spring (Photograph 12 – just north of spring, note dry channel) and for a considerable distance upstream. The channel alluvium width is limited and the depth is unknown, but also probably limited. The Reach 2 spring may be connected to upstream alluvial material that stores stormwater that subsequently flows through the shallow subsurface and discharges at the spring. This spring is likely fed by local sources and would be susceptible to going dry during prolonged periods without precipitation and runoff. Persistent depth-to-water below the channel bottom (Figure 5; PAG, 2005) and isotope data (Figure 17), suggest that there is not a persistent supply of regional groundwater in this reach of Davidson Canyon. Continuous observation, measurement, and documentation of this spring would be necessary to confirm that it is truly perennial as stated by PAG (2005).

The resistant sandstone beds in the steeply dipping Turney Ranch Formation in the vicinity of the spring (Photograph 13) are exerting strong controls on the channel geometry. A sharp bend in the channel occurs in the channel just south of the spring, where the channel turns to follow bedding planes in the Turney Ranch Formation. The sharp turn, in combination with constriction of the alluvium, could be driving upwelling to the spring during wet periods. Example bedrock constrictions in Davidson Canyon are presented in Photographs 14 through 16. No water upwelling or wet spots were observed during the January 2010 site visit. These outcrops have bedding planes and fractures with open apertures (Photograph 17) that could transmit water.

Similar conditions exist at the outlet of Davidson Canyon to Cienega Creek, where bedrock outcrops (Photograph 18) are present and bedrock highs in the subsurface could create upwelling of any subsurface flow in the alluvium, resulting in discharge to Cienega Creek, as proposed by PAG (2003b). Additionally, bedrock outcrops and constricting of the channel north of Escondido Spring likely influences the seasonally sustained base flows. This reach was also dry during the January 2010 Tetra Tech site visit.

PAG (2003) suggested that based on their water quality study, water was not upwelling along the inferred western splay of the Davidson Canyon fault. This conclusion was supported further by the fact that the density of vegetation around faults did not indicate that more water was available to plants in the fault zones. If large quantities of water were being transmitted through Davidson Canyon, perennially observable discharge, as a result of the enhanced and/or channelized fracture flow, would be expected. Based on a review of the available information, no such outlet for flow within the Davidson Canyon fault zone has been identified.

7.3 Groundwater Hydrology

The groundwater hydrology is largely dependent on the underlying geology but is also affected by other hydrologic processes and stresses occurring within the watershed. Existing data are largely based on the hydrogeologic characterization work completed by M&A (M&A, 2009a, 2009b and 2009c). The manner in which potential impacts to Davidson Canyon will occur are governed by the hydrogeology of the groundwater flow system and the hydrologic stresses being exerted on that system. The hydraulic connection between the Open Pit and down-gradient bedrock and between alluvial aquifers and deeper bedrock aquifers is of critical importance in assessing potential impacts to both spring flows and streamflow sustained by alluvial aquifers.

Hydraulic testing near the Open Pit suggested that flow boundaries were encountered, which could be faults. In some cases, wells did not recover to their pre-pumping levels in the expected time period (e.g HC-1A, HC-5B, PZ-5) (M&A, 2009c). This indicates that the wells are not located in an infinite aquifer, but rather may be in a compartmentalized aquifer that is bounded by faults or other low permeability materials. These bounding faults or compartments would tend to limit the propagation of drawdown away from the Open Pit. It is difficult to identify specific faults that are responsible for creating these compartments and thus to justify the simulation of these features in groundwater flow models.

The formation of a perpetual pit lake represents a new discharge as a result of lake surface evaporation, creating a hydraulic sink. This new discharge will alter the flow system’s dynamic equilibrium in much the same manner as the existing pumping wells in the basin have already caused an upset to the equilibrium established over hundreds of years. A new dynamic equilibrium will be approached when there is no further loss from storage, which is achieved through an increase in recharge or a decrease in natural discharge (Sophocleous, 2002).

The cone of depression associated with the pit lake will expand with time as a function of the aquifer diffusivity (Transmissivity/Storativity). The large distances to surface flows in northern Davidson Canyon and moderate aquifer diffusivity means that reduced natural discharge (discharge to streams, phreatophyte water use, etc.) and/or induced recharge will likely take hundreds of years before the new dynamic equilibrium is established.

7.3.1 Alluvial Flow System

There are limited data associated with the alluvial aquifers developed along Davidson Canyon. A single well (Pima County Well; Figure 1) is screened within the alluvium in Reach 3. Alluvial aquifers are more substantially developed in the broad sections of Davidson Canyon such as Reaches 3 and 4. Even in these wider sections of alluvium, the deposits are spatially limited and have limited water storage capacity. For example, the variation in the water table is about 7 to 15 feet at the Pima County well (Figure 5). This variation means that under flowing conditions, the stream would lose water and result in recharge to the alluvial aquifer. Persistent stormwater flows that provide significant recharge could raise the water table enough to temporarily connect the channel with the alluvial flow system. There are no deep monitoring wells near the Pima County well and thus the hydraulic connection of the alluvial aquifer to the deeper bedrock flow system is not known.

The alluvial aquifers are expected to be unconfined at most locations. The exception would be where heterogeneities in the alluvium cause locally semi-confined conditions. The estimated hydraulic conductivities of the alluvium are very high (hundreds of feet per day) and flow occurs through the matrix of the porous media. In contrast, flow through the bedrock is most likely to be in discrete, interconnected fractures rather than in the matrix. The storativity of the alluvium is considerably higher than the bedrock and is approximately equivalent to the specific yield. A reasonable estimate of the specific yield of the gravelly sand alluvium ranges from 20% to 35% (Johnson, 1967).

Discharge from the alluvial aquifers in Davidson Canyon, namely the sediments in the lowest reach to Cienega Creek, was not confirmed. Tetra Tech did not have access to monitoring data in this area but there is evidence for shallow groundwater based on the increasing density of riparian vegetation. Furthermore, it would be expected that groundwater would intersect the topographically lower Cienega Creek at the confluence with Davidson Canyon. During Tetra Tech’s site visit in January 2010, there was no flow in this lower reach, which indicates that the groundwater is likely just below land surface or disconnected from Cienega Creek. It is likely that groundwater elevations through this reach vary on a similar scale to those observed at the Pima County well and groundwater discharge in this area at various times of the year seems likely.

Based on the field observations, there are likely small perched alluvial aquifers of limited spatial extent and thickness that form in sand filled sections of more erodible bedrock (i.e., mudstone and shales) in the lower section of Reach 1 and in Reach 2 (Figure 15). These limited aquifers appear to be important for spring flow and may provide groundwater storage for vegetation within and near the channel. For example, willows present in many of these areas suggest shallow groundwater.

7.3.2 Regional Bedrock Flow System

Regional groundwater flow in the vicinity of Davidson Canyon has been documented by M&A and illustrates converging flow towards Davidson Canyon and a horizontal hydraulic gradient that is to the north within the canyon (Figure 7) (M&A, 2009a). The hydraulic gradients suggest that groundwater likely discharges to Davidson Canyon or converges to and flows along the canyon northwards.

The ADWR well registry database indicates that there are over 300 wells (monitoring wells excluded) within the Davidson Canyon watershed (Figure 11). The actual pumping rates for these wells are not reported, although the reported pump capacities for some wells are substantial (e.g., greater than 100 gpm). As such, the total withdrawals are unknown. However, assuming a range of average discharge from one (1) gpm to five (5) gpm, the cumulative discharge would be 300 gpm to 1500 gpm.

The bedrock typically has low matrix permeability and much of the permeability in the bedrock system is likely secondary permeability as a result of interconnected fractures, faults, and bedding plane partings. Based on the low to moderate permeability determined from the pumping test data for the bedrock units distal to the pit location, the bedrock flow system may not be moving significant volumes of water (M&A, 2009a). Based on the multi-well pumping test (M&A, 2009c), the "aquifer block" (as defined by the RP-6 block), encompassing upper Davidson Canyon, was assigned a horizontal hydraulic conductivity of 0.5 feet/day (M&A, 2009a). This value is greater than surrounding "aquifer blocks" with similar lithology, such as the RP-3B "aquifer block" (which includes RP-7). This block separates the pit from Davidson Canyon and is comprised on non-fractured Mesozoic and younger blocks with a horizontal hydraulic conductivity estimated to be 0.002 feet/day (M&A, 2009c).

The vertical hydraulic conductivity is an important hydraulic parameter when assessing potential impacts to springs and surface flows as it affects the hydraulic connection between deeper bedrock layers with shallow saturated bedrock that could be interacting with the alluvial aquifers. Based on the geologic observations in the field, the vertical anisotropy of the bedrock outcrops in Davidson Canyon would likely be substantial. These considerations are further complicated by the steeply dipping nature of many of these units, which in places could make the vertical hydraulic conductivities greater than the horizontal. The reported storativity of these rocks is 7×10^{-4} (M&A, 2009c).

The cone of depression associated with the pit lake will expand with time as a function of the aquifer diffusivity [(hydraulic conductivity*aquifer thickness)/storativity]. The degree to which the drawdown will propagate within the saturated bedrock underlying the Davidson Canyon channel will depend on the degree of hydraulic connection to the bedrock adjacent to the pit. The aquifer testing completed by M&A did not suggest a strong connection between these "aquifer blocks" (M&A, 2009c).

Stream flow losses due to the pit drawdown cannot occur until the pit's cone of depression intersects the stream channel. Given the considerable distance to reaches where flows may be partially sustained by groundwater, there would be a considerable time lag between the onset of pit dewatering and any potential stream losses (i.e., hundreds of years). Furthermore, impacts to surface flows in Davidson Canyon are dependant not only on the hydraulic connection to the underlying aquifer but also on the connection to the upper-most portion of the Cienega Creek watershed. Changes in pumping, climate, and riparian evapotranspiration are also likely over this period. These changes may mitigate the pit impacts or make it difficult to distinguish the cause of the impacts.

7.4 Groundwater – Surface Water Interactions

The groundwater-surface water interactions in the Davidson Canyon watershed are largely driven by shallow alluvial flow systems. Groundwater–surface water interactions have been evaluated using hydraulic head and channel bed elevation data and by evaluating existing geochemical data. The channel bed is hydraulically disconnected over most, if not all of the study reach, from the regional water table (Figure 9). The areas with the most potential for groundwater-surface water interactions are in topographically low areas in lower Davidson Canyon (e.g., Reach 4) which are the areas furthest from the proposed Rosemont Project. The gain or loss of water to a stream from an aquifer is a function of the stream stage, groundwater elevation, and the permeability of the aquifer material. Changes to baseline conditions as a result of mining operations cannot occur unless the cone of depression reaches the aquifer in the vicinity of a stream that is hydraulically connected to groundwater.

For discussion purposes, the Davidson Canyon watershed is divided into reaches (Figures 1 and 4). Subtle hydrologic differences exist between each of the reaches. The distance of each reach from the Open Pit is also important since drawdown will decrease away from the pit. Potential impacts are therefore likely to vary by reach.

7.4.1 Upper Davidson and Barrel Canyons

The arroyos draining the upper sub-watersheds in the basin generally only flow in response to large precipitation events. Data in Barrel Canyon indicate that the channel bed elevation (4,538.5 feet amsl – as surveyed by Tetra Tech, see Section 2.3.1) and the shallow water table are separated by material that varies in its degree of saturation. Seepage from streambeds would have to move through a thick unsaturated zone [approximately 23 feet at RP-2a, based on a groundwater elevation of 4,515.3 feet amsl reported by M&A (M&A, 2009b)] until it reaches the water table. The RP-2 nest of piezometers indicates downward vertical hydraulic gradients (M&A, 2009a), which is indicative of downward flow and groundwater recharge. Infiltration and recharge along these channels with relatively thick unsaturated zones can be substantially higher than the hilly areas adjacent to the drainage (Anderholm, 1994; Birdsell et al, 2005). However, the stream channel-groundwater interactions can still be quite muted.

Data from wells 23dcc2 and RP-8 (Figure 14) also indicate that the groundwater elevations in these wells are below that of the channel. The groundwater elevation at wells 23dcc2 ranges from 4,363.8 feet amsl to 4,349.5 feet amsl, which is between five (5) and 20 feet below the channel elevation (4,369.3 feet amsl). Well 23dcc2 is reportedly 600 feet deep (M&A, 2009a). This well is not likely screened across the entire water table and thus there is some error associated with using these data to define the water table. The groundwater elevations at RP-8 (perforated from 102 feet bgs to 250 feet bgs) range from 4,283.9 feet amsl to 4,286.9 feet amsl (M&A, 2009a). These elevations are approximately 50 feet below the channel elevation of 4,333.8 feet amsl.

As a result of the absence of a permanent hydraulic connection between groundwater and surface water (when present), groundwater lowering would not be expected to alter surface flows resulting from stormwater runoff. It is possible that surface water drainages and springs could discharge regional groundwater by flow through fractures and faults in this area. However, there are no data or field observations to suggest that the bedrock fractures are supplying regional groundwater to the alluvium under non-stormwater runoff events.

7.4.2 Reaches 2 and 3

The groundwater-surface water interactions along the lower reaches of Davidson Canyon are likely highly variable in space and time, as is typical of intermittent drainages of the desert southwest. However, the reaches of Davidson Canyon with the greatest potential for interaction between groundwater and surface water are located along the narrow riparian zone of Reaches 2 and 4, and potentially Reach 3 (Figure 4). An important component of the conceptualization of these lower sections is the role of the geological and geomorphic constraints on the system. Based on Tetra Tech's January 2010 field investigation, it appears likely that the mostly bedrock-lined channel with limited alluvium near the Reach 2 Spring could drive upwelling (i.e., discharge to stream). The unconstrained reaches, with relatively more alluvium, results in downwelling (i.e., recharge to groundwater) during stormwater runoff events. There are no data or field observations to suggest that bedrock fractures are recharging the alluvium under non-runoff periods.

The geomorphic evidence for the Reach 2 Spring being supplied by a perched or local flow system (see Sections 7.1 and 7.2) is also supported by the available stable isotope data (Section 9.6). These data indicate that the source of the surface water sampled at the Reach 2 Spring is derived from summer precipitation. This shallow water then discharges when bedrock contact forces flow to the surface (Figure 15).

When present, surface flows likely create substantial seepage rates through Reach 3 of Davidson Canyon, as the channel is relatively wide through this reach. However, the monitoring data from the Pima County well indicates that shallow groundwater elevations have not been above the channel bed elevation (Figure 5). Given the infrequency of the monitoring events, it is possible that brief and periodic hydraulic connections between the shallow groundwater and surface water, resulting in recharge to groundwater, could occur in response to high surface flows.

7.4.3 Reach 4 – Escondido Spring to Cienega Creek Confluence

The channel bed elevation in the Escondido Spring area was measured to be approximately two (2) to three (3) feet below the broad floodplain. Groundwater data from the area are not available, but vegetation suggests that groundwater is shallow. The wider alluvial deposits may create a larger reservoir of groundwater storage than many other areas of Davidson Canyon. Escondido Spring was dry during the January 2010 site visit, and the channel was dry south of the confluence with Cienega Creek. It would appear that flow in Escondido spring results from recharging the alluvial aquifer in the area. This recharge can be from stormwater infiltrating into the channel, discharge from the bedrock and/or upwelling of groundwater associated with the bedrock constrictions (Photograph 16). The width of the channel alluvium is constrained in approximately the last 1,000 feet, before the confluence. Similar to Reach 2, stable isotope data suggests recharge from summer precipitation and source waters associated with a local flow system.

PAG (2003) estimated that discharge from Davidson Canyon accounted for between 8 to 24% of the flow to Cienega Creek from just upstream of the Davidson Canyon confluence and Marsh Station Road. The study estimates were based entirely on mixing of water chemistry from Davidson Canyon with upstream water from Cienega Creek to reproduce downstream Cienega Creek water quality. This study did not consider physical groundwater processes such as hydraulic gradients that would be necessary to drive water from Davidson Canyon into Cienega Creek. The study also did not consider other processes that could cause enrichment of delta O^{18}/O^{16} values or the potential for these processes to vary seasonally (e.g., open water evaporation, evapotranspiration). Regardless, some groundwater discharge to either lower Davidson Canyon or directly to Cienega Creek is probable and the magnitude likely varies seasonally. Peak flows in Cienega Creek may also create conditions were Cienega Creek loses water to the alluvial groundwater system.

7.5 Upper Davidson Canyon Springs

Springs are an important component of the hydrological system and are likely of significant ecological value. They can also offer an opportunity to improve the understanding of the hydrogeologic system when the underlying mechanisms for spring discharge are well understood. Data are available to characterize spring flow, spring water temperature, and water quality in upper Davidson Canyon as a result of the monitoring program initiated by the Rosemont Project and reported by M&A (M&A, 2009a). Additional data are available from the field observations completed by Tetra Tech during January 2010. A summary of basic flow data collected at the springs is presented in Table 2.

Table 2 Flow characteristics of selected springs near Davidson Canyon and the Rosemont Project Area

Spring Name	Source[1]	Temperature Range (˚C)	Flow Conditions[2]	Discharge (gpm)	
				Minimum	Maximum
Barrel Spring	Local	11	Intermittent	0.00	0.20
Crucero Spring	Local	8.3-17.6	Intermittent	0.00	0.61
Deering Spring	Local	10.4-22	Intermittent	0.00	1.00
Fig Tree Spring	Local	n/a	Intermittent seep	0.00	0.10
Helvetia Spring	Regional (?)	11.7-20.5	Perennial	0.18	1.59
Locust Spring	Local	n/a	Intermittent seep	0.00	0.00
Lower Mulberry Spring	Local	13.1-19.7	Intermittent seep	0.00	0.08
MC-1	Local	12.9-28.6	Intermittent	0.00	1.00
MC-2	Local	10.3-29.6	Intermittent	0.00	0.74
McCleary Dam	Local	10.6-26.3	Intermittent	0.03	10.00
Mulberry Spring	Local	16.1-23.3	Intermittent	0.00	0.08
Papago Spring	Local	9.8-25.2	Intermittent	0.00	1.70
Peligro Adit	Local	14-28	Intermittent	0.00	0.02
Questa Spring	Regional (?)	10.6-26.3	Intermittent	0.00	0.32
Rosemont Spring	Regional (?)	9.3-30.4	Perennial	0.00	0.79
Ruelas Spring	Local	n/a	Intermittent seep	0.00	0.00
SC-2	Local	9	Intermittent seep	0.00	0.00
Scholefield Spring	Local	10.6-18.8	Intermittent seep	0.00	0.00
SW	Local	n/a	Intermittent seep	0.00	0.00
Sycamore Spring	Local	11.7-23.6	Intermittent	0.00	1.00

[1] Local = water likely derived from shallow, localized source that is not consistently connected to the regional water table; Regional = water potentially derived from deeper, regional water table.
[2] Intermittent = visible flow observed on occasion; Intermittent seep = visible wet areas observed on occasion, but flow has not been observed; Perennial = flow has been observed on all site visits;

The spring discharges in Davidson Canyon range from dry to barely perceptible seepage (of which there are many) to discharges of up to one (1) gpm at MC-1 and MC-2. Higher flows have been recorded at McCleary Dam, but these flows are clearly impacted by the dam's physical restriction and likely represent stormwater flows that are not representative of groundwater conditions. Spring flow variability appears to depend largely on whether the spring is connected to the regional or local flow systems.

Springs evolve from a variety of mechanisms some of which are described by Fetter (1994) and presented below:

- Depression Spring: These springs form when the water table reaches the surface. Typically a change in topography creates a corresponding undulation in the water table configuration, which creates a local flow system with a spring formed at the local discharge zone.

- Contact Spring: Contact springs occur where a permeable unit overlies a unit of much lower permeability. The lithologic contact can be marked by a line of springs, which can be associated with the regional water table or a perched water table.
- Fault Spring: Faulting can create geologic conditions favorable to spring formation when a less permeable geologic unit is juxtaposed against a permeable one or when a fault zone has extensive gouge development. This creates a regional flow boundary that can force water to discharge near the fault. This is similar to the springs in lower Davidson Canyon where upwelling in the alluvium is thought be driven by bedrock on the down-gradient edge of small alluvial deposits.
- Fracture/Joint Springs: These springs occur from the existence of open or permeable joints or fractures in low permeability rock. Water movement through such rock is principally through these fractures and springs form where these fractures intersect the land surface at low elevations.

Without a detailed study, it is not always possible to determine the underlying mechanism for spring flow. However, knowledge of the type of spring is essential to evaluate whether the spring is likely to be affected by the Rosemont Project.

7.5.1 Local Springs

Often local springs, or perched-water springs, evolve as depression springs when the water table reaches the surface or as contact springs. Local springs are thought to have sources of water derived from local, shallow flow systems. These systems can be isolated from, or are only temporarily connected to, the deeper bedrock flow system (Figure 9). Local springs typically have relatively cold water temperatures. This occurs because the water's shallow nature and relatively short travel times do not allow it to be heated at depth by the natural hydrothermal gradient. In addition, due to the typically low discharge rates, water temperatures tend to be highly variable since the water rapidly equilibrates to the ambient air and surface soil/rock temperatures. Discharge rates and persistence of flow can also be used to identify local springs. Springs fed largely by stormwater infiltration will have peak flows following storm events and decreased or terminated flows during dryer conditions.

Local springs would be less likely to be affected by mine activities, unless they are in close proximity to the pit where the pit may alter the local flow system that is yielding water to the spring. The depth of the Open Pit will impact the deeper, regional flow system, but if this system is disconnected from the shallow, local system there would be no impact to the local springs.

Water temperature has been measured at all springs during routine site visits. These temperatures correlate well with air temperature, which suggests that the springs in Davidson Canyon are of a local, shallow origin. These data should be interpreted with caution, however, as it is unknown where the water temperatures were measured. Temperature measurements should be obtained at the spring orifice and not in a spring tank or after the water has flowed across the ground. Since the validity of the spring water temperatures cannot be verified, other data types are needed to confirm whether the springs are the result of local conditions.

Spring-flow estimates have also been obtained during the routine site visits. There is over two (2) years of data currently available. Observed non-flowing conditions during this relatively short-time period would indicate that the spring is fed by a local, shallow source of water. Conversely, perennial flow observed over this short time period would not conclusively indicate that the spring is perennial over the long-term.

7.5.1.1 Barrel Spring

Barrel Spring was found to be dry, although moist sands were present in the alluvium during Tetra Tech's January 2010 site visit. Barrel Spring has had non-flowing conditions observed on 18 out of 26 routine site visits from November 2008 through January 2010. Tetra Tech's field observations suggest that this spring is similar to the conceptual model presented on Figure 15. Spring flow is thought to come from surface flows infiltrating into the alluvium and creating local water storage upstream from a bedrock constriction that forces the water to the surface. Regional flow system changes due to the Open Pit are unlikely to affect this spring's flows.

7.5.1.2 Fault Springs along the Northwest Trending Faults

Mulberry Spring, Crucero Spring, Lower Mulberry Spring, Scholefield Spring, SC-2, MC-1, MC-2, Fig Tree Spring, Sycamore Spring, and Helvetia Spring all occur along northwest trending fault zones (Figure 8). The occurrence of springs along a fault indicates that the fault is acting as a barrier to groundwater flow and forcing the water to the surface. The high elevation of these springs and their variable water temperatures suggests that they are likely fed by stormwater infiltrating into a shallow system. Isotope data suggests that the water discharging at most of these springs is from winter precipitation, rather than from summer precipitation. These data are inconclusive for identifying whether the springs are fed by a local or regional source of water. The intermittent flow and low discharge rates suggests that the springs are fed by a local, shallow water source. This local water source could become connected to the regional flow system during high recharge periods if the regional water table rises and contributes to flow at these springs.

7.5.2 Regional Springs

Regional springs are springs that, based on the existing information, are interpreted to be connected to the regional bedrock flow system (Figures 2 and 3). These springs can occur along formational contacts but more often seem to be occurring as a result of faulting or jointing/fracturing. If regional springs are within the cone of depression created by the Rosemont Open Pit, lowering of the hydraulic head is likely to decrease or cease spring discharge.

Regional springs typically have consistent, warm water temperatures, consistent discharge rates, and perennial flow. This occurs largely due to the water's deep flow paths, relatively long travel times, and lack of connection to seasonal and annual precipitation variations. Water temperatures in deep wells and regional springs would be expected to be similar. Well PC-5, for example, is a 2,000 foot deep flowing well having a consistent water temperature of about 27° Celsius (C). No springs have had temperatures of this magnitude measured during the winter months when air temperatures are low. It is unclear, however, whether the temperature data were collected in such a way that they would be reliable for interpretation.

7.5.2.1 Questa Spring

Questa Spring is likely a contact spring related to the mapped and observed contact of the Quaternary-Tertiary gravels and the low permeability Pantano Formation. Specific electrical conductance data are elevated which suggests long residence times. The stable isotope data are reflective of winter precipitation. Carbon-14 data suggest that the discharging water could be thousands of years old. General chemistry data presented on Stiff diagrams indicates that the Questa Spring water is not similar to the other waters sampled in the pit area. The spring water is similar to the water in nearby well RP-9. These data suggest that Questa Spring is supplied by the regional groundwater system.

Routine site visits note that Questa Spring often flows at an estimated rate of less than 0.1 gpm and has been observed dry on several occasions. However, the flow in the drainage downstream of the Questa Spring orifice and tank was considerably higher (Photograph 19) during Tetra Tech's January 2010 site visit. It is suspected that the routine site visits do not reflect the spring's true discharge characteristics. Similarly, the spring temperature measurements appear to represent conditions in the spring tank. These measurements could be missing the diffuse discharge to the drainage down-gradient of the tank.

The diffuse discharge observed at Questa Spring leads to the suspicion that flows are greater than those recorded to date and perennial flow is possible. This is important to the determination of the spring's water source being local or regional. No-flow or dry conditions were observed in January 2010 at several other area springs that appear to be supplied by shallow, local groundwater. The location of Questa Spring at the top of the sub-watershed also limits the amount of flow that would be expected from stormwater infiltrating into the shallow alluvium. A local spring would have likely ceased to flow under these conditions as evidenced by the other springs observed during January 2010.

Based on these observations, it is likely that Questa Spring is supplied by the regional groundwater flow system. The available data and analyses do not allow a determination of whether Questa Spring is receiving recharge from, or is hydraulically connected to, the pit area specifically or to the Santa Rita Mountains in general. The groundwater level drawdown associated with the Open Pit will result in decreased heads in the basin fill deposits and deep bedrock, which means Questa Spring may be susceptible to decreased or ceased flows.

7.5.2.2 Rosemont Spring

Rosemont Spring is a fracture spring related to fractures in Cretaceous sedimentary rocks intersecting the surface (J. Cornoyer, oral communication, March 2010). The isotope data from Rosemont Spring indicate that it is significantly influenced by summer precipitation. The water temperature measurements at the spring indicate that water temperature is not strongly correlated to air temperature (R^2=0.6), but these data may not be reliable for interpretation.

Rosemont Spring is one of two (2) springs in the area that has been observed to be flowing on each routine site visit. This may indicate that the spring is supplied by a deeper, more consistent water source than the shallow alluvium, but the short period of record does not allow for a conclusive determination that the spring is perennial. Nearby well PC-5 is 2,000 feet deep, has a consistent water temperature of 27° C, and has been observed to flowing at many times during the year. The general chemistry at Rosemont Spring is similar to wells PC-5, HC-3B, and PC-4. It is possible that the Rosemont Spring is being supplied by the same water source that is being monitored by these wells, but this is not conclusive.

Based on the available data and observations, it is not possible to conclusively determine whether Rosemont Spring is a local or a regional spring. The spring's proximity to the pit, however, makes it highly susceptible to be terminated or to have reduced flows.

7.5.2.3 Helvetia Spring

Helvetia Spring is located on the western side of the Santa Rita Mountains and is not within the Davidson Canyon watershed. Flow has been observed at this spring on each of the monthly site visits between January 2009 and February 2010. Based on the simple criteria of perennial discharge, this spring could be considered "regional." However, the long-term persistence of discharge is unknown and a longer period of data collection is necessary to decrease the uncertainty of whether the source of water to Helvetia Spring is from local or regional sources.

7.5.2.4 Davidson Spring

Davidson Spring could not be visited due to the lack of property access. This spring is also not included in the routine spring site visits. However, based on its location along a known fault (Figures 6 and 8), it is likely a fault spring or a fracture spring. The spring's location on the flanks of the Empire Mountains suggests that its water source is likely associated with recharge along the Empire Mountains. If this is the case, it is possible that the spring would not be affected by drawdown associated with the Rosemont Project. However, there are no data available to determine if Davidson Spring is supplied by local sources or whether it is hydraulically connected to the regional groundwater system. The impact of the Open Pit on Davidson Spring is therefore indeterminable at this time.

7.6 Water Quality

Available water-quality data includes general chemistry, stable isotopes, radioactive isotopes (tritium and carbon-14), and the results of seepage modeling. These data are briefly discussed to provide insight into conditions within Davidson Canyon.

7.6.1 General Chemistry

Water-quality data are available for springs in both the upper watershed as part of the M&A studies (M&A, 2009a) and from surface water in lower Davidson Canyon from PAG (2003). The data suggests that when present, surface waters in Davidson Canyon are typically of reasonable quality with dissolved solids less than 500 mg/L (Table 3).

Table 3 Average Cation and Anion Chemistry for Lower Davidson Canyon Springs

Parameter	Reach 2	Reach 4 – ~1000 feet Upstream of Cienega Creek
Ca	89	96
Mg	22	23
Na	47	46
Cl	16	16
SO4	85	94
Alk as HCO3-	358	358
Laboratory Total Dissolved Solids	437	460

Source: Pima Association of Governments, 2003a.; All units are mg/L.

Stiff diagrams of the general chemistry have been prepared by M&A (Figure 18; M&A, 2009a). These diagrams facilitate visual observations that indicate similarities and differences in general water chemistry. There are several different types of water observed in the area, which could be due to groundwater compartmentalization or geologic rock variations, including varying degrees of alteration. The general water chemistry for a few springs is discussed since their similarity or differences with deeper groundwater provide an indication of whether they will be impacted by the Project.

Rosemont Spring chemistry is very similar to nearby wells PC-5, HC-3B, and PC-4 (Figure 18). This may indicate that Rosemont Spring is fed by water being monitored in these wells. However, the isotope data suggest that the spring water and well water are different (Section 7.6.3). Rosemont Spring's proximity to the pit suggests that it will be impacted, regardless of whether it is fed by shallow or deep groundwater.

Questa Spring and nearby well RP-9 have very similar chemistries that are dissimilar to water chemistries observed in other areas (Figure 18). This supports Questa Spring being fed by deeper, regional groundwater. These data alone, however, do not provide an indication of the origin or flow paths of these waters.

Springs MC-1 and MC-2 are located near each other, but their water chemistries are starkly different (Figure 18). MC-1 has very low concentrations of the major ions, whereas MC-2 has elevated concentrations of Ca and HCO_3 . MC-2 discharges from an area known to have highly altered rocks, but MC-1 discharges from unaltered rocks (J. Cornoyer, oral communication, March 2010). The MC-2 water is apparently obtaining the chemistry of these altered rocks even though the resident times are likely low (based on young Carbon 14 values – see Section 7.6.3). MC-1 and MC-2 do not have water chemistries that are similar to nearby wells. These springs are likely fed by shallow, local water sources. Any impacts would likely be due to their close proximity to the pit and not due to a connection with the regional groundwater system.

Deering Spring has a water chemistry that is dissimilar from the surrounding wells HC-1A, HC-1B, PC-4, HC-2A, HC-2B, and RP-5 (Figure 18). The spring has higher levels of Ca and HCO_3 that are not evident in the wells, which suggests that it is fed by a different source of water than the wells. If Deering Spring is impacted by the Project it will likely be due to its proximity to the pit and not due to a connection with the regional groundwater system.

7.6.2 Stable Isotopes

The available stable isotope data are useful for assessing the potential source of water to the Reach 2 Spring and more generally the manner in which groundwater recharge within Davidson Canyon occurs. Data for deuterium and oxygen-18 are presented in the M&A site characterization report (M&A, 2009a). Data from this report are associated with the numerous groundwater wells (shallow, intermediate, and deep) as well as springs and seeps. There are also data for these same constituents in the PAG (2003) report on Cienega Creek and Davidson Canyon. The data in the PAG (2003) report are associated with the lower reaches of Davidson Canyon, including the Reach 2 Spring and riparian areas in the Outstanding Arizona Waters designation. Stable isotope data for local precipitation are available (Wagner, 2006) for comparison to the groundwater and surface water in the area.

In contrast to precipitation, the isotopic signature of groundwater and surface water in the study area does not seem to vary seasonally. As a result, it is possible to distinguish between areas that are recharged in winter, and others that are recharged by waters originating as summer rains. Figure 17 is a standard graph of delta deuterium versus delta oxygen-18 for pit area wells and springs/seeps.

The groundwater proximal to the proposed Project area is recharged by winter precipitation. In Figure 17, groundwater samples are illustrated as squares, springs as triangles, and meteoric precipitation as over-sized symbols. The pit area wells in particular are strongly associated with recharge of winter precipitation. On the other hand, surface water from the Reach 2 Spring and Escondido Spring within Davidson Canyon are strongly influenced by summer precipitation. The difference between the pit area wells and Davidson Canyon samples suggests summer rain is rapidly shed from higher elevations to recharge at lower elevations. This supports the assertion that the Reach 2 Spring and Escondido Spring are primarily maintained by a local flow system rather than bedrock discharge from the regional flow system with recharging water from the mountain block.

7.6.3 Tritium and Carbon-14

Radioactive Tritium and Carbon-14 (^{14}C) isotope data have been obtained from several sites in the Project area (M&A, 2009a). These data can provide an indication of the relative age of water in wells and springs. The available ^{14}C data are not corrected, so they do not allow for an absolute age value to be determined, so this evaluation is a relative comparison.

Prior to the atmospheric testing of nuclear weapons in the late 1950s and early 1960s, levels of tritium in precipitation averaged 5 to 10 tritium units (TU). Tritium levels in precipitation rose dramatically after the first nuclear weapon detonations. Levels of tritium in precipitation peaked in 1963 at several thousand tritium units. The Nuclear Test Ban Treaty between the United States and the Soviet Union in 1963 ended almost all atmospheric testing of nuclear weapons and levels of tritium have been steadily declining. Nonetheless, current levels of tritium in precipitation over North America still average 10 to 30 TU.

General guidelines on interpreting these TU values are provided in Table 4. In the Project area, TU values range from less than 0.6 to 5.3. These low tritium values indicate that the groundwater at the Project site did not originate as recharge from the 1950’s through the 1970’s.

Table 4 General Guidelines on Interpreting TU Values.

Tritium Units (TU)	Approximate age
<0.8	Sub-modern (prior to 1950s)
0.8 - 4	Mix of sub-modern and modern
5 - 15	Modern (<5 to 10 years)
15 - 30	Some bomb tritium
>30	Recharge in the 1960's to 1970's
>50	Recharge in the 1960's

Source: (Sustainability of Semi-Arid Hydrology and Riparian Areas, 2010)

The youngest water, based on TU data, is from springs. MC-1 and Sycamore Spring have TU of 5.3 and 5.1, which indicates modern water (<5 to 10 years). Deering Spring, MC-2, and Rosemont Spring have TU of 3.6, 1.9, and 1.2. This indicates that these springs are a mix of modern and some sub-modern water (Table 4). Spring MC-2’s 1.9 TU is comparable to well RP-3A (1.7 TU), with a screen interval of 100-440 feet bgs. The youngest well water is from RP-6, which has a TU of 3.4 and a relatively shallow screen interval of 200-360 feet bgs. Several wells have TU values between 1.0 and 2.2, indicating that they likely have a mix of sub-modern and modern water.

Questa Spring has a low TU of <0.6 and is therefore sub-modern water. RP-8 and RP-9 are wells near Questa Spring and they have similar TU values of 0.6 and <1.0. Seven (7) wells have sub-modern water based on TU values.

Carbon 14 data are available as Fraction Modern Carbon ($F^{14}C$) values (M&A, 2009a). In general terms, as the percent of modern carbon decreases the water gets older. The ^{14}C data suggest that the water from the springs, with the exception of Questa Spring, are relatively young. Deering Spring, MC-1, MC-2, Sycamore Spring, and Rosemont Spring are relatively young waters with $F^{14}C$ values ranging from 0.83 to 1.05. These relatively young ages are consistent with a shallow, local water source. Questa Spring has a $F^{14}C$ of 0.31, which is much older than the other springs and similar to the deeper well samples. This is consistent with a deeper regional water source. Rosemont Spring has an intermediate, but relatively young $F^{14}C$ value of 0.83. This water is younger than Questa Spring, but may be older than the other analyzed springs listed above. Rosemont Spring's $F^{14}C$ are comparable with the upper well intervals that were analyzed (HC-1B, HC-5A, RP-3A, and RP-4A). Definitive interpretation and distinction between the higher $F^{14}C$ values (0.83 – 1.05) is not possible.

The ^{14}C data supports a deeper, regional groundwater source for Questa Spring. Rosemont Spring water's age cannot be distinguished from the three (3) other springs that are fed by shallow, local water sources. The source of Rosemont Spring water is largely indeterminate based on the radioactive isotopes.

7.6.4 Infiltration and Seepage Modeling

Infiltration, Seepage, and Fate and Transport modeling of the Waste Rock Storage Area and Heap Leach Facility was completed by Tetra Tech (Tetra Tech, 2010b) and seepage modeling of the Dry Stack Tailings Facility was completed by AMEC Earth and Environmental, Inc. (AMEC) (2009). Tetra Tech also completed fate and transport modeling of the Dry Stack Tailings Facility (Tetra Tech, 2010b).

The results of these studies and models using site-specific materials and designs for infiltration, seepage, and fate and transport modeling show that the Rosemont Waste Rock Storage Area, Heap Leach Facility, and the Dry Stack Tailings Facility will have little or no impact on the quality or quantity of water within the regional groundwater system. Furthermore, it is possible that most, if not all of the facilities will be captured by the hydraulic sink created by the pit lake. As a result, seepage reaching the groundwater table would be expected to migrate back towards the pit within the passive containment zone.

7.6.5 Pit Lake

Based on the predicted post-mining pit lake water balance, M&A predicted that a lake will form in the pit (M&A, 2010b). Modeling also indicated that the pit lake will be a hydraulic sink with the final pit lake surface elevation being lower than the surrounding heads on the east side of the pit. Water in the surrounding bedrock will be drawn towards the pit and will not be able to exit (M&A, 2009b).

In addition to the hydrogeological analysis performed by M&A (M&A, 2009b), the expected chemical conditions within the pit lake were analyzed by Tetra Tech. This analysis included geochemical testing of the non-ore rock expected to comprise the final pit walls, and a comparison of the results of that geochemical testing to local groundwater quality. Tetra Tech used M&A's pit filling data as an input to a geochemical pit lake predictive model. The geochemical model showed the quality of the pit lake water was only slightly changed from local groundwater after 200 years of simulation (Tetra Tech 2010c).

As long as the elevation of the pit lake surface is less than the water levels in the surrounding aquifer, a terminal pit lake condition will be sustained. Evapoconcentration of the pit lake water will continue as long as the terminal lake conditions persist. However, because these waters do not enter the aquifer, they cannot migrate towards Davidson Canyon. As a result, impairment of the water sources in Davidson Canyon as a result of the Rosemont pit lake is not anticipated.

7.7 Riparian Vegetation and Evapotranspiration

Research on riparian evapotranspiration (ET) rates suggests that riparian ET is a complicated parameter and rates may vary depending on numerous factors including, but not limited to, vegetation composition and density, groundwater depth, weather conditions, and season. There is significant spatial and temporal variability of ET measurements, making them difficult to quantify.

Riparian vegetation in the Davidson Canyon watershed has been mapped (Figure 19) as part of the Sonoran Desert Conservation Plan (Harris Environmental Group and others, 2000). The areas of the various plant subgroups are presented in Table 5. Additional mapping by WestLand Resources, Inc. (WestLand) in the Rosemont area was presented in a report titled *Onsite Riparian Habitat Assessment* (WestLand, 2010). This mapping shows a significant reduction in riparian areas from those presented in the Sonoran Desert Conservation Plan. Therefore, the riparian areas presented in Table 5 are likely overstated.

Table 5 Vegetation Type Areas

Vegetation Type	Vegetation Classification	Area
Madrean Evergreen Forest and Woodland	123.3	936.91
Scrub-Grassland (Semi-desert Grassland)	143.1	1,764.80
	143.163	25.26
Sonoran Desertscrub	154.1	7.25
	154.111	76.53
Interior Southwestern Riparian Deciduous Forest and Woodland	232.2	132.15
Sonoran Riparian Deciduous Forest and Woodland	224.52	641.40
	224.521	69.53
	224.523	2.76
	224.53	17.31
Sonoran Deciduous Riparian Scrub	234.712	84.36

Plant functional groups (PFGs) and plant cover density were estimated based on data derived from the existing groundwater flow model (M&A, 2009b). This information was used to estimate evapotranspiration rates for lower Davidson Canyon in the flow model. M&A estimated the riparian evapotranspiration to be 115 AF/yr, all of which was simulated as occurring north of I-10. Evapotranspiration rates for the upper reaches of Davison Canyon have not been determined.

Even though the vegetation upstream of Reach 2 (Figure 19) may not be tapping groundwater sources directly, they are likely to have some effect on the water balance of Davidson Canyon. The vegetation is expected to consume at least some of the water infiltrating along drainages, reducing the volume that ultimately recharges the water table.

7.7.1 Potential Effects of Groundwater Lowering on Riparian Vegetation

Studies along the Bill Williams River, located in western Arizona, have demonstrated that different riparian tree species react differently to declines in groundwater-level elevations. The riparian trees can also react differently depending on the regime in which they were established. For example, trees established in consistent, shallow groundwater depths (< 13 feet) respond differently than trees established in deeper groundwater associated with ephemeral reaches (Horton et al., 2001). Decreasing groundwater levels can reduce water availability and result in canopy dieback. The degree of stress and ultimately the degree of impact is often site dependent, although the Horton study (2001) determined a 9.8 feet depth-to-groundwater level as an important threshold for increasing plant stress. Shafroth et al. (2000) determined that the root distribution of woody riparian vegetation is related to groundwater-level history and a decline in water table relative to the condition under which roots develop can strand the plant's roots.

Determining impacts to the riparian zone depends on existing water levels and the speed at which the impacts occur. However, it would appear reasonable to assume that impacts that drop the depth to groundwater level beyond approximately ten (10) feet could create increased dieback and mortality (Horton et al., 2001) and beyond 13 feet could have significant canopy dieback and mortality. The distance from the Project site and the long periods over which the potential impacts would materialize (e.g., hundreds of years) are favorable for riparian vegetation if the impacts are within the range of natural fluctuations and therefore within the range of tolerated conditions.

7.8 The Role of Davidson Canyon on Recharge

The recharge dynamics associated with Davidson Canyon are important for understanding how drainage and tributaries are connected to and interact with the regional flow system. For example, if surface flows are reduced as a result of the Rosemont Project, there might be less recharge to the regional flow system. The available data are comprised of the hydraulic-head data that generally show hydraulically disconnected drainage systems [(see Section 7.4 (Groundwater-Surface Water Interactions)]. However, there has been considerable study on the role of localized recharge along ephemeral drainages in the southwestern United States.

Mountain front recharge in arid environments is a topic of intense research and is typically divided into two (2) components, a focused near surface component and a diffuse near surface component (Wilson and Guan, 2004). The diffuse component of recharge within the Davidson Canyon watershed is thought be quite small, given that the mean annual precipitation (P) is much less than the mean annual potential evapotranspiration (PET). Numerous studies have concluded that there is no diffuse recharge at many arid and semiarid sites worldwide where P is much less than the PET (Small, 2005). At smaller time intervals, P can exceed PET, as determined by the storm size and seasonality. A higher relative percentage of water infiltrates and becomes recharge when ET is low, since water can migrate past the root zone. Small (2005) found that the relative timing of P and PET maxima is critical and that recharge occurs when rainy seasons occur during winter (when evapotranspiration is lowest) instead of summer. This is consistent with stable isotope analyses which also suggested that diffuse recharge on the mountain block was controlled by winter precipitation. The soil type, geology and slope will also factor into the amount of diffuse recharge.

The low permeability of the bedrock, and the steep topography in much of the Davidson Canyon watershed, likely results in most of the precipitation being redistributed and focused to the ephemeral channels within the watershed. Flows in response to precipitation on the mountain block are also likely redistributed to the drainages in Davidson Canyon watershed. Focused flow on a dry channel with permeable alluvium typically result in rapid infiltration. Typically this starts to occur at the contact between the mountain block and the alluvial fan, where a change in slope and more permeable geologic media result in increased infiltration rates (Wilson and Guan, 2004).

Water infiltrating in the alluvium or during overbanking could potentially evaporate, be transpired by vegetation, infiltrate vertically beyond the root zone and recharge the water table, or migrate along perching layers. Canyons and drainages often develop preferentially along existing planes of weakness such as fractures or faults in the bedrock. If these features are more permeable than the surrounding rocks, recharge rates can be high in the drainage channels. Similarly, the Davidson Canyon fault zone may create an enhanced permeability in the bedrock in the vicinity of the drainage. If present, these could potentially create a more rapid pathway from the alluvium into the deeper bedrock flow system.

Goodrich et al. (2004) determined that ephemeral stream channel recharge was significant in some years, but negligible in others due to weak monsoons. This finding is largely consistent with the isotope data that suggest that channel infiltration primarily occurs in the summer as a result monsoon induced flows.

Stable-isotope data indicates that recharge in Davidson Canyon varies seasonally. Recharge on the mountain block is more likely to occur during the winter months, whereas recharge in the stream channels is more likely to occur during the summer monsoon season.

REFERENCES

AMEC Earth & Environmental, Inc. (2009). *Dry Stack Tailings Storage Facility, Final Design Report*. Prepared for Rosemont Copper Company. Report dated April 15, 2009.

Anderholm, S.K. (1994). *Ground-Water Recharge Near Santa Fe, North-Central New Mexico*. United States Geological Survey (USGS) Water Res. Invest. Rep. 94-4078, p. 68 pp.

Birdsell, K.H., Newman, B.D., Broxton, D.E., and Robinson, B.A. (2005). *Conceptual Models of Vadose-Zone Flow and Transport Beneath the Pajarito Plateau, Los Alamos, New Mexico*. Vadose Zone Journal. Volume 4. Pages 620-636. Dated 2005.

Cleverly, J.R., Dahm, C.N., Thibault, J.R., McDonnell, D.E., and J.E. Allred Coonrod (2006). Riparian ecohydrology: Regulation of water flux from the ground to the atmosphere in the Middle Rio Grande, New Mexico. Hydrological Processes, Vol. 20, p. 3207-3225.

Drewes, Harald (1972). Structural Geology of the Santa Rita Mountains, Southeast of Tucson, Arizona. U.S. Geological Survey Professional Paper 748. 35 p.

Ferguson, C.A. (2009). *Bedrock Geologic Map of the Northern Part of the Empire Ranch 7 ½' Quadrangle, Pima County, Arizona*: Arizona Geological Survey Open-File Report OFR-09-05, scale 1:24,000.

Ferguson, C.A., Youberg, A., Gilbert, W.G., Orr, T.R., Richard, S.M. and Spencer, J. (2001). *Geologic Map of the Mount Fagan 7.5' Quadrangle, Eastern Pima County, Arizona*. Arizona Geological Survey Digital Geologic Map 11. November 2001.

Fetter, C.W. (1994). *Applied Hydrogeology*. Prentice Hall, New Jersey. 691p.

Phillips, F.M., Hogan, J., and Scanlon, B.R. (2004) *Water Science and Application Series, Vol.9, American Geophysical Union, Washington, D.C.*, p. 77-99. American Geophysical Union, Washington, DC.

Goodrich, D.C., Williams, D.G., Unkrich, C.L., Hogan, J.F., Scott, R.L., Hultine, K.R., Pool, D., Coes, A.L., and Miller, S. (2004). *Comparison of Methods to Estimate Ephemeral Channel Recharge, Walnut Gulch, San Pedro River Basin, Arizona*. Groundwater Recharge in a Desert Environment: The Southwestern United States. Editor. J.F. Hogan.

Horton, J.L., Kolb, T.E., and Hart, S. (2001). *Physiological Response to Groundwater Depth Varies Among Species and with River Flow Regulation*. Ecological Applications, Vol. 11, p. 1046-1059.

Harris Environmental Group, URS Corporation and Ducan & Associates (2000). Riparian Vegetation Mapping and Classification, Sonoran Desert Conservation Plan – Final Report. Prepared for Pima County Government. December 2000.

Johnson, A.I. (1967). *Specific yield — Compilation of Specific Yields for Various Materials*. U.S. Geological Survey Water Supply Paper 1662-D. 74 p.

Levick, L., Fonseca, J., Goodrich, D., Hernandez, M., Semmens, D., Stromberg, J., Leidy, R., Scianni, M., Guertin, D. P., Tluczek, M., and Kepner, W. (2008). *The Ecological and*

Hydrological Significance of Ephemeral and Intermittent Streams in the Arid and Semi-arid American Southwest. U.S. Environmental Protection Agency and U.S. Department of Agriculture (USDA) Agriculture Research Service (ARS) Southwest Watershed Research Center. EPA/600/R-08/134, ARS/233046, 116 pp.

Montgomery & Associates, Inc. (M&A) (2009a). *Results of Phase 2 Hydrogeologic Investigations and Monitoring Program, Rosemont Project, Pima County, Arizona*. Prepared for Rosemont Copper Company. Report dated February 26, 2009.

M&A (2009b). *Groundwater Flow Modeling Conducted for Simulation of Proposed Rosemont Pit Dewatering and Post-Closure*. Prepared for Rosemont Copper Company. Report dated October 28, 2009.

M&A (2009c). *Analysis of Long-Term, Multi-Well Aquifer Test – November 2008 through January 2009, Rosemont Project, Pima County, Arizona*. Prepared for Rosemont Copper Company. Report dated October 28, 2009.

M&A (2010). *Comparison of Natural Fluctuation in Groundwater Level to Provisional Drawdown Projections, Rosemont Mine*. Prepared for Rosemont Copper Company. Technical Memorandum to Jamie Sturgess (Rosemont Copper Company). Technical Memorandum dated March 1, 2010.

Pima Association of Governments (PAG) (2003a). *Contribution of Davidson Canyon to Baseflows in Cienega Creek*. Dated November 2003.

PAG (2003b). *Geologic Influence on the Hydrology of Lower Cienega Creek*. Dated December 2003.

PAG (2005). *Unique Waters Nomination – Davidson Canyon*. Dated December 2005.

Shafroth, P.B., Stromberg, J., Patten, D.T., (2000). *Woody Riparian Vegetation Response to Different Alluvial Water Table Regimes*. Western North American Naturalist, Vol. 60, p. 66-76.

Sophocleous, M. (2002). *Interactions Between Groundwater and Surface Water: The State of the Science*. Hydrogeology Journal, vol. 10, pp. 52-67.

Sustainability of Semi-Arid Hydrology and Riparian Areas (SAHRA) (2010). SAHRA – Isotopes & Hydrology. http://www.sahra.arizona.edu/programs/isotopes/hydrogen.html#6. Site Visited April 1, 2010.

Tetra Tech, Zeller M.E., P.E., P.H. (2010a). *Baseline Regulatory (100-Yr) Hydrology and Average-Annual Runoff, Rosemont Copper Project*. Technical Memorandum to Kathy Arnold (Rosemont Copper Company). Technical Memorandum dated March 4, 2010.

Tetra Tech (2010b). *Infiltration, Seepage, Fate, and Transport Modeling Report*. Prepared for Rosemont Copper Company. Report dated February 2010.

Tetra Tech (2010c). *Geochemical Pit Lake Predictive Model*. Prepared for Rosemont Copper Company. Report dated February 2010.

Tetra Tech Zeller M.E., P.E., P.H. (2010d). *Post-Mining Regulatory (100-Yr) Hydrology and Average-Annual Runoff, Rosemont Copper Project*. Technical Memorandum to Kathy Arnold (Rosemont Copper Company). Technical Memorandum dated March 5, 2010.

Tetra Tech (2010e). Rosemont Infiltration Analysis. Technical Memorandum to Kathy Arnold (Rosemont Copper Company). Technical Memorandum dated April 5, 2010.

U.S. Army Corps of Engineers (1992). *HEC-FFA, Flood Frequency Analysis, User's Manual*. Hydrologic Engineering Center, Davis, California.

U.S. Environmental Protection Agency (2008). T*he Ecological and Hydrological Significance of Ephemeral and Intermittent Streams in the Arid and Semi-arid American Southwest*. EPA/600/R-08/134. November 2008.

U.S. Water Resources Council (1981). *Guidelines for Determining Flood Flow Frequency*. Bulletin No. 17B of the Hydrology Committee.

Wardrop (2005). *Technical Report on the Rosemont Property, Pima County, Arizona*. Prepared for Augusta Resource Corporation.

Wagner, J.D.M. (2006). Speleothem Record of Southern Arizona Climate Change. PhD dissertation, University of Arizona.

WestLand Resources Inc. (WestLand) (2010). *Onsite Riparian Habitat Assessment*. Prepared for Rosemont Copper Company. Report dated April 2010.

Wilson J. L., and Guan, H., (2004). *Mountain-Block Hydrology and Mountain-Front Recharge. Groundwater Recharge in a Desert Environment: The Southwestern United States*. edited by Small, E., 2005. Climate Controls on Diffuse Groundwater Recharge in Semiarid Environments of the Southwestern United States. Water Resources Research, Vol. 41, W04012.