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C. H. HUCKELBERRY
County Administrator

September 7, 2007

Jeanine Derby
Forest Supervisor
Coronado National Forest
300 West Congress
Tucson, Arizona 85701

Re: **Rosemont Mine – Hydrologic Studies Needed for the Environmental Impact Statement**

Dear Ms. Derby:

Augusta Resources Corporation proposes to construct the Rosemont Mine project in the northern Santa Rita Mountains. The area is a zone of mountain front recharge for the upper and lower Cienega basins. The mine's footprint would occupy some 4,415 acres of Coronado National Forest, state and private lands, and alter surface water flows to Davidson Wash, a tributary that provides a high-quality source of water to Cienega Creek and the Bar V Ranch managed by Pima County.

The attached report is a reconnaissance analysis of the hydrogeologic setting and water balance in the area. It provides the Forest Service with a basis for identifying additional studies which are needed in order to analyze, disclose and mitigate the potential impacts for the Environmental Impact Statement (EIS) under the National Environmental Policy Act (NEPA).

Previous work based on examination of 70 EISs for modern hard rock mines in the western United States found consistent underestimation of water quality impacts. In the Cienega groundwater basins where Rosemont is located, groundwater supply impacts to people and riparian ecosystems is also a concern. This report examines how the proposed open pit, which would cover about 700 acres and extend some 1,800 to 2,900 feet deep, could affect the amount and direction of groundwater flows. Dr. Tom Myers prepared the report under the direction of our staff. Dr. Myers is a Nevada-based hydrologist with experience in examining the hydrologic effects of open pit mining in bedrock settings.

Dr. Myers estimates that the proposed pit may intercept about 650 acre feet per year of flow to the Davidson Wash or approximately 0.8 cubic feet per second. This is approximately the same amount of flow that reaches the lower Cienega Creek from Davidson Canyon. The proposed project would also intercept substantial amounts of groundwater discharge flowing toward the upper Cienega Creek near and within the Las Cienegas National Conservation Area.

Depending on the exact depth to pre-mine water levels and where the measurement occurs, the pit could lower the regional water table by up to 1,500 feet. This would create a drawdown cone that would draw from the regional groundwater similar to pumping from a large diameter well. If the drawdown cone expands into the basin fill aquifer, groundwater would be drawn north toward the pit and reduce the flow to the upper Cienega Creek.

So far, the information Augusta has provided to the United States Forest Service about groundwater conditions is deficient for developing an EIS. Dr. Myers' report tells us that the impacts of the pit construction and dewatering geographically extend beyond the boundaries of what Augusta has examined to date. There are substantial uncertainties in recharge, runoff, evapotranspiration, and storage properties of the aquifer. The Forest Service must require Augusta to reduce these uncertainties through extensive field data collection in order to calibrate groundwater and surface water models and run sensitivity analyses. The results of the modeling would include estimates of recharge, evapotranspiration, and channel flow for a large area around project site, including the upper Cienega basin. The models should also take into account various mine construction features in order to estimate the effects of the proposed project on the flows. Such models would also provide the foundation for water quality impact analyses.

Only with this additional data and modeling can the Regional Forester adequately consider the project impacts. These data would help substantiate Augusta's stated position to avoid impacts to Cienega Creek water resources. These data are also needed in order for Augusta to demonstrate compliance with the Regional Forest policy on groundwater (attached).

Sincerely,

C.H. Huckelberry
County Administrator

CHH/jj
Attachment

c: The Honorable Congressman Raúl Grijalva
The Honorable Congresswoman Gabrielle Giffords
The Honorable Chairman and Members, Pima County Board of Supervisors
John Bernal, Deputy County Administrator for Public Works
Suzanne Shields, Regional Flood Control District Director
Thomas Helfrich, Water Resources Division Manager, Regional Flood Control District
Julia Fonseca, Environmental Planning Manager, Regional Flood Control District

Pima County Regional
FLOOD CONTROL
DISTRICT

MEMORANDUM

Director's Office
Regional Flood Control District

DATE: August 27, 2007

TO: C. H. Huckelberry
County Administrator

FROM: Suzanne Shields, P.E.
Director and Chief Engineer

SUBJECT: Rosemont Mine – Hydrologic Studies for the Environmental Impact Statement

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Augusta Resources Corporation proposes to construct the Rosemont Mine project in the northern Santa Rita Mountains, which would affect up to 4,415 acres of Coronado National Forest, state and private lands including the area of mountain front recharge for the upper and lower Cienega basins. In the Cienega groundwater basins where the Rosemont Mine is located, groundwater availability for riparian ecosystems is of critical concern.

The report was prepared by Dr. Tom Myers who is a Nevada-based hydrologist with experience in examining the hydrologic effects of open pit mining in bedrock settings. His report is a reconnaissance analysis of the hydrogeologic setting and overall water balance in the area. It provides a basis for identifying additional studies that are needed to fully analyze, disclose and mitigate the potential impacts of the Rosemont Mine as required for the Environmental Impact Statement (EIS) under the National Environmental Policy Act (NEPA).

The proposed mine would impact groundwater and surface water by dewatering pits, diverting or blocking surface runoff, decreasing natural recharge by covering areas with tailings and overburden, and the production well to withdraw water for use in the mining and refining process.

The proposed open pit, which would cover about 700 acres and extend some 1,800 to 2,900 feet deep, could lower the groundwater table by 1,500 feet affecting the volume and direction of groundwater flows in the Cienega Watershed. Dr. Myers estimates that the proposed pit may intercept about 650 af/y of flow to the Davidson Canyon or approximately 0.8 cfs, which is approximately the same amount of flow that reaches lower Cienega Creek from Davidson Canyon. The proposed project would also intercept substantial amounts of groundwater flowing toward the upper Cienega Creek near and within the Las Cienegas National Conservation Area.

Depending on the exact depth to pre-mine water levels and where the measurement occurs, the pit could lower the regional water table by up to 1,500 feet. This would create a drawdown cone that would draw in the regional groundwater similar to pumping from a large diameter well. This substantial drawdown may draw groundwater from a significant distance if the adjoining aquifers are hydraulically connected to the bedrock aquifer of the pit. Of special concern is the alluvial aquifer southeast of the site, which drains toward the upper Cienega Creek. If the drawdown cone expands into the alluvial aquifer, groundwater would be drawn north toward the pit (see Figure 12 of the report). This would reduce the flow to upper Cienega Creek by an uncertain amount, which would depend on the distance that the drawdown cone will extend to the south.

Prior to considering whether to construct this proposed mine, the U.S. Forest Service (USFS) should require the project proponent to collect a large amount of data and to complete numerous analyses. Only with this additional data can decision makers adequately consider the project. These data would help substantiate Augusta's stated position to avoid impacts to Cienega Creek water resources.

So far, the information Augusta has provided to the USFS about groundwater conditions is deficient for an EIS. Dr. Myers' report tells us that the impacts of the pit construction and dewatering will extend geographically beyond the boundaries of what Augusta has examined to date. He recommends that substantial data needs to be collected in order to evaluate the proposed mine. Without pump tests and other investigations, there are substantial uncertainties in recharge, runoff, evapotranspiration, and storage properties of the aquifer. Augusta should be required to reduce these uncertainties through field data collection in order to calibrate hydrologic and hydrogeologic models for existing conditions and run sensitivity analyses.

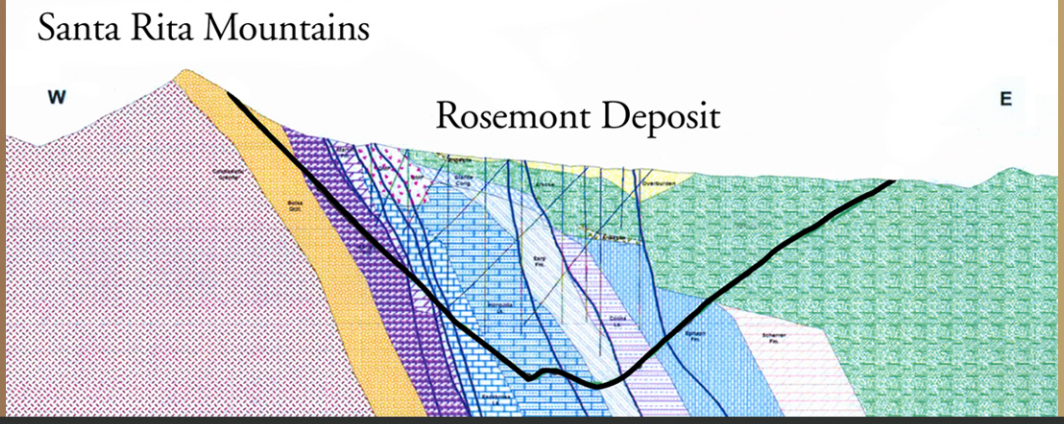
Augusta should provide a detailed groundwater model to simulate the drawdown cone and the amount of water to be drawn towards the pit. The groundwater model should extend far enough into the Cienega drainage that the model boundary does not influence or control the predicted flows. Pump tests sufficient to estimate transmissivity and storage coefficients for the aquifers must be completed throughout the model domain. This basic data is needed prior to completing the groundwater modeling of the project's impacts.

The results of the modeling would include estimates of recharge, evapotranspiration, and channel flow within and downstream of the project site. The models then should incorporate proposed mine and water use to estimate the effects of the proposed project on the flows. Such models would also provide the foundation for water quality impact analysis.

Dr. Myers will be developing a simple three dimensional groundwater model based on this Phase 1 report. Dr. Myers' Phase 2 model would in no way be a substitute for the detailed model analyses required for an EIS; however, it would provide Pima County and the USFS with a better tool to request more studies and better mitigation outcomes from Augusta Resources. Dr. Myers notes the need for a detailed surface water runoff model of the area. I will assign District staff to develop the appropriate scope of such an effort to ensure that the impacts of changes in transmission losses and overbank flood storage are understood.

SS/TJH/JF/tj
Attachments

c: John Bernal, Deputy County Administrator – Public Works
Nicole Fyffe, Executive Assistant – County Administrator's Office
Chris Cawein, Deputy Director – Regional Flood Control District
Thomas Helfrich, Manager – Water Resources Division
Julia Fonseca, Environmental Planning Manager – Water Resources Division



Hydrogeology of the

SANTA RITA ROSEMONT PROJECT SITE

PIMA COUNTY BOARD OF SUPERVISORS
Richard Elías, Chairman, District 5; Ann Day, District 1
Ramón Valadez, District 2; Sharon Bronson, District 3
Raymond J. Carroll, District 4

COUNTY ADMINISTRATOR
C.H. Huckelberry

Hydrogeology of the Santa Rita Rosemont Project Site Conceptual Flow Model and Water Balance

Prepared by:

Tom Myers PhD
Hydrologic Consultant
Reno NV

Prepared for:

Pima County Board of Supervisors

Under the auspices of:

Pima County Regional Flood Control District

August 8, 2007

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Executive Summary

The Augusta Resources Corporation proposes to construct the Rosemont Mine project in the northern Santa Rita Mountains. It would affect up to 4415 acres of Coronado National Forest, state and private land with an open pit, tailings disposal areas and waste rock. The proposed open pit would cover about 700 acres with ancillary facilities affecting an additional 250 acres and the tailings/waste rock and leach pad would cover 2895 acres. Full construction of the proposed pit would require 19 years. It may affect both ground and surface water by dewatering pits, diverting surface water, capturing runoff, covering areas with tailings which may decrease the recharge and contaminate the groundwater, and developing process water.

This report is a reconnaissance analysis of the conceptual flow and water balance in the area. The conceptual flow model for the area is based on topography, geology and precipitation and identifies the likely flow paths in the watershed and aquifer system. The water balance includes estimates of recharge to and groundwater flow from the area; there is no evapotranspiration (ET) discharge from the regional groundwater.

Recharge to the site is a combination of diffuse recharge to bedrock and recharge from the ephemeral channel deposits. Groundwater flows to the east-northeast through bedrock where it discharges from the site as underflow through the bedrock, the Willow Canyon formation. ET from riparian vegetation within the project area is from the perched, ephemeral aquifers in the channel deposits rather than from the regional aquifer

The total recharge to the project area watershed is about 650 af/y, or 1.5 in/y, based the similarity between the project area watershed and the upper Cienega Creek watershed. The probable uncertainty range is from 520 to 780 af/y. It does not account for a substantial amount of transmission loss from the ephemeral channels that transpires from riparian vegetation nor does it account for additional recharge that may occur from the ephemeral channels from runoff off of the site.

Groundwater flows in bedrock to the east-northeast through and from the site where it discharges as underflow. The primary bedrock formation is the Willow Canyon. If the recharge equals the discharge, the required hydraulic conductivity for discharge from the site is 0.3 ft/d. ET from riparian vegetation within the project area is not considered discharge from the project area groundwater because the channel deposit aquifers are considered perched.

The uncertainty inherent in these calculations includes that in the methodology for estimating recharge and in the estimate of the underflow cross-section. Additional uncertainty occurs in the conceptual model assuming there is no regional groundwater ET discharge.

The Rosemont Project pit would intersect and remove ephemeral tributary channels to Wasp Canyon. Based on the water balance, the proposed pit would intercept about 650 af/y of flow to the Davidson Canyon or approximately 0.8 cfs. This is

approximately the flow that reaches Cienega Creek from Davidson Canyon. The proposed project would intercept substantial amounts of groundwater discharge to the downstream basins.

The proposed pit would be from 1800 to 2900 feet deep. Depending on the exact depth to pre-mine water levels and where the measurement occurs, the pit would lower the regional water table by up to 1500 feet. This would create a drawdown cone which would draw from the regional groundwater similar to pumping from a large diameter well. This substantial drawdown may draw groundwater from a significant distance if the adjoining aquifers are hydraulically connected to the bedrock aquifer of the pit. Of special concern is the basin fill aquifer southeast of the site which drains toward Cienega Creek. If the drawdown cone expands into the basin fill aquifer, groundwater would be drawn north toward the pit. This would reduce the flow to Cienega Creek by an uncertain amount which would depend on the distance that the drawdown cone will extend to the south.

Prior to considering whether to construct this proposed mine, the Forest Service should require the project proponent to collect a large amount of data and to complete numerous analyses. Only with this additional data can decision makers adequately consider the project.

Recharge estimates should be improved using physically based modeling that balances precipitation, ET and soil moisture to determine recharge and runoff. The runoff from this modeling should be calibrated with observed runoff to determine if the time step used for long-term modeling adequately simulates storm runoff and to parameterize the model. Ephemeral channel flows and recharge should also be estimated using a routing model which takes the runoff and simulates the percolation, or transmission losses, to the alluvial aquifer. An estimate of how much of the percolation recharges the bedrock aquifer would require a detailed water balance of the alluvial aquifer. This would require accurate estimates or measurements of the ET from and storage properties of the aquifer. ET estimates include an assessment of the relative amount of ET supported by the alluvial aquifer and by direct rainfall. Storage properties include porosity or specific yield and estimates of the aquifer shape including thickness and width. Because the recharge occurs along a length of the channel, it is necessary to route the flow downstream. If the aquifer constricts, some groundwater may discharge back to the channel. The results of the modeling would include estimates of recharge, ET and channel flow within and downstream of the project site. The models should also incorporate the mine to estimate the effects of the proposed project on the flows.

A detailed groundwater model is necessary to simulate the drawdown cone and the amount of water to be drawn towards the pit. The groundwater model should extend far enough into the Cienega drainage that the model boundary does not influence or control the predicted flows. Pump tests sufficient to estimate transmissivity and storage coefficients for the aquifers must be completed throughout the model domain. This basic data is needed prior to completing the groundwater modeling of the project's impacts.

Introduction

The Augusta Resources Corporation proposes to construct the Rosemont Mine project in the northern Santa Rita Mountains (Figure 1). It would affect up to 4415 acres of Coronado National Forest, state and private land with an open pit, tailings disposal areas and waste rock (Westland 2007). The proposed open pit would cover about 700 acres with ancillary facilities affecting an additional 250 acres and the tailings/waste rock and leach pad would cover 2895 acres (Westland 2007, pages 9-11). Full construction of the proposed pit would require 19 years.

Large mining projects such as this can affect both ground and surface water by dewatering pits, diverting surface water, capturing runoff, covering areas with tailings which may decrease the recharge and contaminate the groundwater, and by developing process water. Even if the groundwater inflows are not substantial enough to require a large system of dewatering wells, inflows to the proposed pit would lower the water table in a fashion similar to pumping a larger diameter well. The largest effects would likely be on the groundwater and point of discharge from the groundwater – springs and seeps in the washes. Both of these discharges support critical riparian vegetation (Fonseca 2006).

The purpose of this report is to estimate the effects of constructing the mine site on the hydrology of the site and downstream watersheds in Davidson Canyon and Cienega Creek. It does this by considering the conceptual flow model and completing an steady state water balance for the site, both at a reconnaissance level. This report does not assess the hydrologic impacts of developing the process water which is expected to be about 5000 af/y.

The conceptual flow model for the area depends on the topography, geology, precipitation, recharge and discharge and identifies the likely flow paths in the watershed and aquifer system. The report discusses how the mine would affect the hydrology by intercepting groundwater flow. The conceptual model identifies the sources, such as recharge points (mountain block and ephemeral channels), and sinks of water, such as springs and riparian areas, in the basin.

The steady state water balance includes an estimate of recharge to and discharge from the system. Water balance at steady state means inflow equals outflow. Steady state means that average flow conditions predominate – that there are no substantial external stresses, such as pumping or climate change, occurring to the aquifer system that would change flow directions or water levels. In a dynamic system, as all arid region aquifers are, steady state is usually considered to be an average over a period of years to limit the effects of seasonal recharge and evapotranspiration changes.

A site visit was also completed. A trip report is attached in Appendix 1.

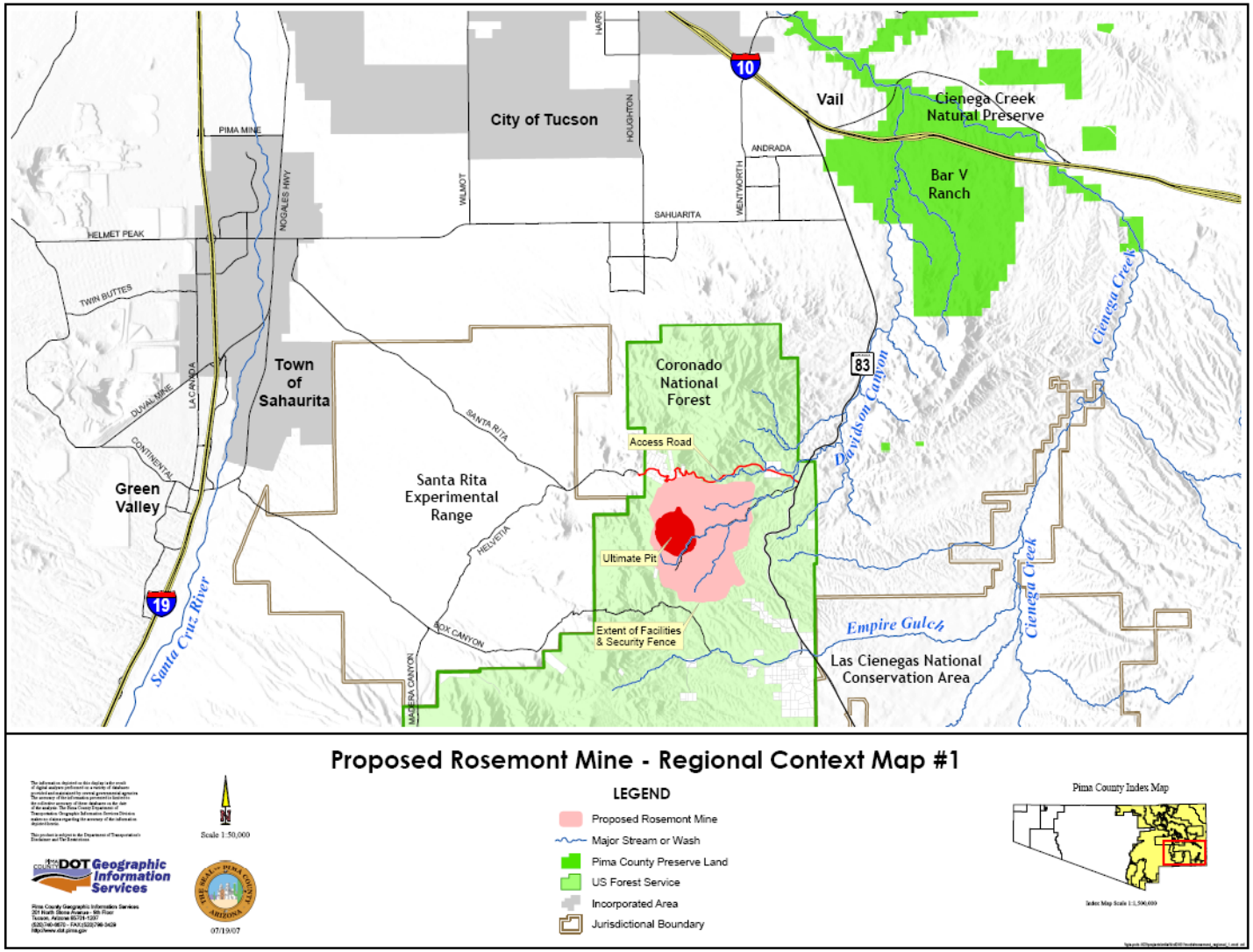

Figure 1: Regional site map for the Proposed Rosemont Mine.

Basic Hydrogeology at the Rosemont Project Area

Geologic Formations

The Santa Rita Mountains are part of the basin and range province that covers most of Arizona southwest of the Mogollon Rim. They are located 45 miles southeast of Tucson. The ridgeline consists of formations dipping steeply eastward consisting of a metamorphic core complex flanked by Paleozoic and Mesozoic-aged metamorphic carapaces of mostly sedimentary rock including carbonates, shales and limestone (Wardrop 2005).

The Rosemont Ranch area is within an east-facing mountain-block watershed (Anderson et al 1992) (Figure 2). The Mesozoic and Paleozoic sedimentary rocks, which predominate the bedrock geology of the area (Figure 3), are complexly fractured by northwest and northeast trending fractures (Harshbarger and Hargis 1976). In the thicker deposits near Wasp Canyon, which Johnson and Ferguson (2007) describe as Qo, older alluvium with "weakly consolidated gravel forming terraces and flat-topped interfluves". The deposits are incised between 4 and 12 meters and form cliffs and ledges. Ledges and cliffs form where there is not substantial saturation. Because of this geomorphology and the shallow thickness and narrow canyons, it is unlikely there is significant flow in these channels.

Harshbarger and Hargis (1976) indicate the watershed consists of three aquifers – bedrock, alluvium and basin fill. The bedrock is the primary regional aquifer.

The bedrock aquifer is fracture controlled and possibly confined. The predominant outcrop in the mine area is the Willow Canyon formation (Figure 3) which Harshbarger and Hargis describe as arkosic sandstone, conglomeratic sandstone, mudstone, and silt limestone. This formation ranges from 200 to about 1500 feet thick within the mine pit outline; east of the mine pit, the thickness increases to more than 3000 feet (WLR 2007). Under the Willow Canyon formation are various steeply east-dipping formations consisting of predominantly limestone. The few wells completed in this formation produce poorly, less than 30 gpm, but Hargis and Montgomery (1982) suggest that wells up to 100 gpm could be constructed. They report that well D-18-16-29cda, located near Rosemont Junction, was pump-tested in 1963 at 64 gpm and with 480 foot drawdown. The well depth is 508 feet, therefore the drawdown was a significant proportion of the well depth. The specific capacity equaled 0.13 gpm/ft.

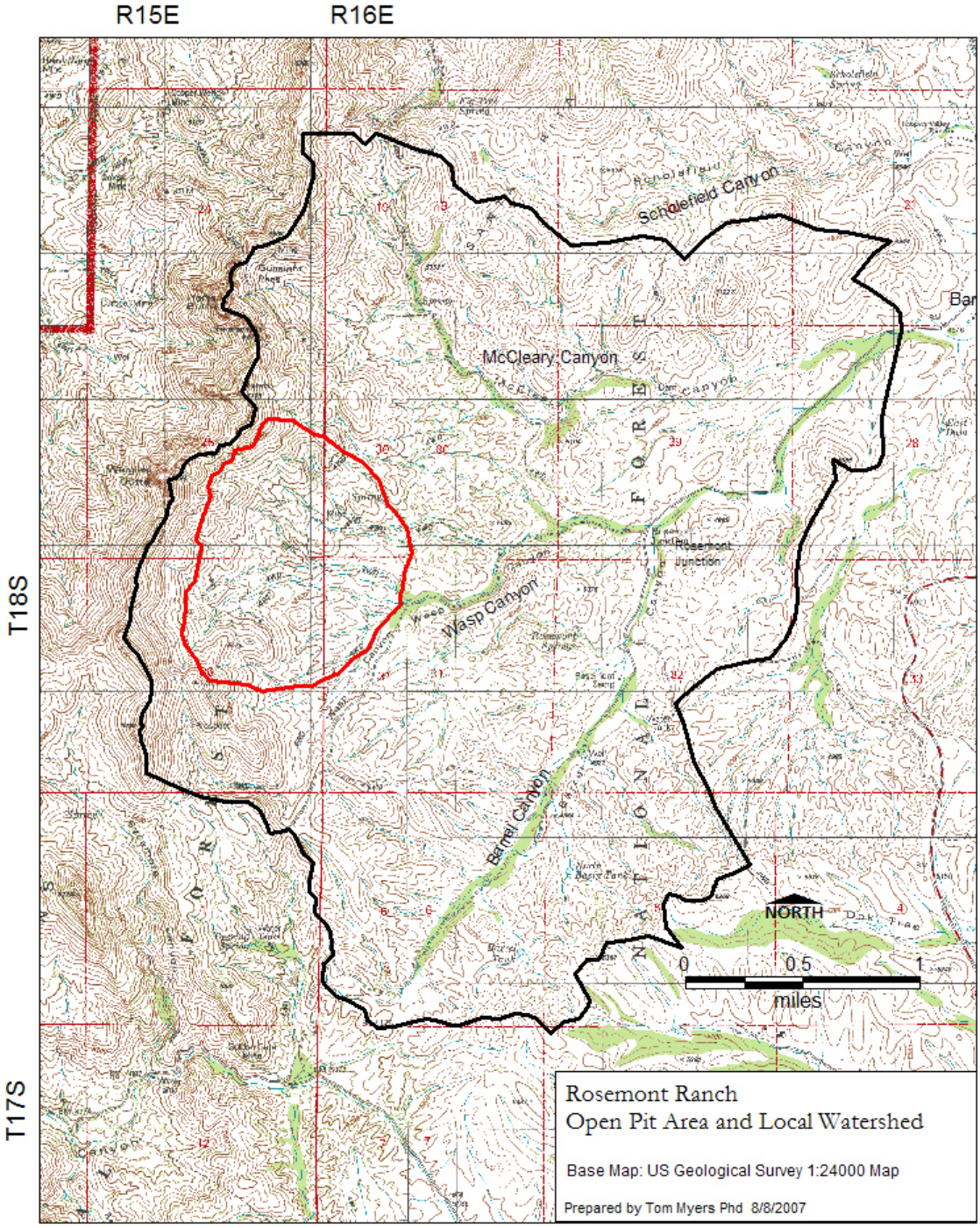

Figure 2: Location of proposed open pit and Barrel Canyon watershed potentially affected by the mine facilities based on July 2007 plan of operations (Westland 2007). Barrel Canyon is tributary to Davidson Canyon.

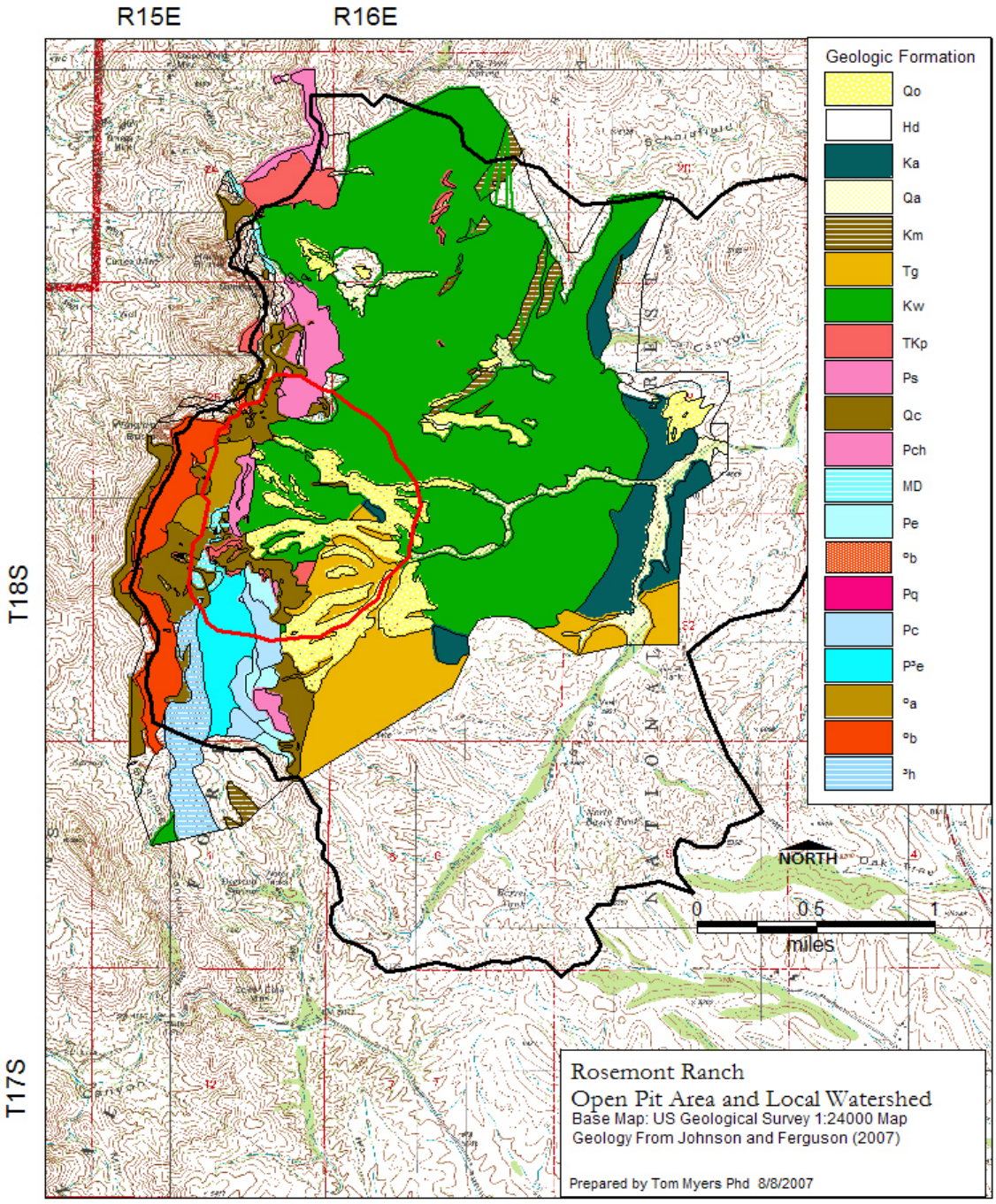

Figure 3: Geology near the proposed Rosemont project. The red outlined area is the proposed pit. Black outline is the Barrel Canyon watershed. See Johnson and Ferguson (2007) for a description of the geologic formations. The green area is the Willow Canyon formation (Kw).

The west side of the study area consists of Paleozoic rocks. Drillers encountered water at various levels within the borehole of two holes (Harshbarger and Hargis 1976, page 32). The water level fluctuated, primarily by rising, as the drilling encountered new fractures indicating the aquifer is fracture-controlled and confined. The description suggests that the fractures produce a moderate amount of water. None of the outcrops observed during a site visit however had substantial fracture systems which would transmit large amounts of water (Appendix 1).

If the percolating high elevation recharge follows the dip (does not cross the boundary among formations), it may flow deeply prior to discharging from the watershed. The upward vertical gradient observed in wells drilled into the bedrock may reflect this. The deep layers intersected by wells would have water that recharged into the formations upslope from the point of the well and therefore have higher head; the deeper the layer, the higher on the hillslope is the likely source. This recharge likely supports springs and baseflow further downstream off the study site. Discharge from the Rosemont project area includes this deep bedrock flow.

There may also be small alluvial aquifers in the ephemeral drainages such as Schofield Canyon or Wasp Canyon (Figure 2). While describing them as an aquifer, Harshbarger and Hargis (1976) indicate that water levels in wells that intersect the alluvium are at or below the bedrock interface; saturated water in the alluvium may be perched by the bedrock or by the clay and silt layers in the alluvium. The downstream portions of these channels have dense stands of mesquite and the upper reaches have willows and walnuts. These riparian plants require substantial water but not necessarily saturated conditions (Leenhouts et al 2005); perched aquifers may support them. Ephemeral channels are important for recharge, but the channel fill aquifers may be perched and ephemeral due to the infrequent runoff events, ET from riparian vegetation, and drainage to underlying bedrock.

There is also a basin fill aquifer in the southeast portion of the site (Harshbarger and Hargis 1976), but this is off the geology map (Johnson and Ferguson 2007) and may not currently be of consequence to the hydrology of the site. It is apparent however in the drainage of Cienega Creek (AZDWR, undated). This basin fill aquifer may be connected to aquifers in the project watershed and be affected by an open pit. This will be discussed in more detail below.

Climate

The nearest climate station is at the Santa Rita Experimental Station. The Western Climate Data Center provides climate data for two nearby sites (Table 1). The sites are about 7 miles southwest of the Rosemont project site on the west side of the Santa Rita Mountains. The elevation, 4300 feet msl, is representative of the project site. Precipitation varied from 19.73 for the Helvetia site to 22.18 in/y for the Santa Rita site (Table 1). Snowfall did occur at these sites, averaging 7.7 and 4 in/y for the earlier and later period, respectively.

Table 1: Temperature and Precipitation Averages for Climate Stations Near the Project Site

	Helvetia Santa Rita Range (023981)				Santa Rita Exp Range (027593)			
Month	Avg Max. Temp (F)	Avg Min. Temp (F)	Avg Prec(in.)	Avg Snow (in.)	Avg Max. Temp (F)	Avg Min. Temp (F)	Avg Prec (in.)	Avg Snow (in.)
Jan	57.9	35.9	1.58	3.2	60.3	37.7	1.63	0.9
Feb	61.1	38.2	1.72	2	63.2	39.2	1.46	0.8
Mar	66.4	42.4	1.14	0.6	67.9	42.8	1.48	1
Apr	74.8	49.4	0.52	0.1	75.4	48.4	0.69	0.2
May	82.9	56	0.28	0	83.7	56	0.24	0
Jun	92.1	64.4	0.67	0	92.9	64.9	0.62	0
Jul	91.3	67.6	4.05	0	91.6	67.3	4.87	0
Aug	87.9	65.8	4.15	0	88.3	65.7	4.32	0
Sep	86.5	63.4	2.19	0	86.4	63	2.16	0
Oct	78.3	54.5	0.68	0	79	55.3	1.64	0.1
Nov	67.8	43.6	1.22	0.2	67.7	43.8	1.15	0.1
Dec	60.5	38.3	1.52	1.5	60.3	38.3	1.95	0.9
Annual	75.6	51.6	19.73	7.7	76.4	51.9	22.18	4
Period of Record	6/1/1916 to 4/30/1950				5/1/1950 to 3/31/2006			
Lat	31 52				31 46			
Long	110 47				110 51			
Elev (ft msl)	4300				4300			

Source: Western Climate Data Center, http://www.wrcc.dri.edu/summary/Climsmaz.html

Surface Water Flow

There are no surface water gaging stations on the site, but three daily streamflow sites have operated or continue to operate on Davidson Canyon or Cienega Creek (Table 2). The period of record for these gages is short and for only two gages is the period coincident. A gage with a longer record, Pantano Wash near Vail, AZ (gage 09484600), has operated since 1988, but the gage elevation is much lower (3205 ft msl) and the drainage area is much larger (457 mi^2). The gaged area includes significantly lower elevation area and is not considered sufficiently representative of the project site to use for this study.

Table 2: Gaging Stations Used for this Study

Site	USGS #	Area (mi2)	Elev. (ft msl)	Period of Record for Daily Flows
Cienega Creek nr Pantano, AZ	09484560	289.0	3560	3/1/1968 – 9/30/1975
Cienega Creek nr Sonoita, AZ	09484550	*	4180	8/18/2001 – 6/21/2007
Davidson Canyon Wash nr. Vail AZ	09484590	50.5	3420	2/1/1968 – 9/30/1975
* - The area for this site is not reported.				

The Davidson Canyon near Vail gage had flow for most of the first year, 1968, but after that the site just flowed in response to storm events (Figure 4). Runoff occurred during the monsoon seasons of 1969, 70, 71, 72, 74 and 75. In contrast, only the late winter and early spring of 1971 produced significant non-monsoon runoff. Most of the runoff periods have at least two and several have four consecutive months with flow. However, except for 1968, most summer months have just a few days with flow. The hydrograph shows a rapid response to precipitation and little to no baseflow. Only 1968 and winter/spring 1971 had flow on many consecutive days that may reflect groundwater discharge from the area above the gage. Groundwater discharge to the channel, if it occurs, is primarily transpired by riparian vegetation.

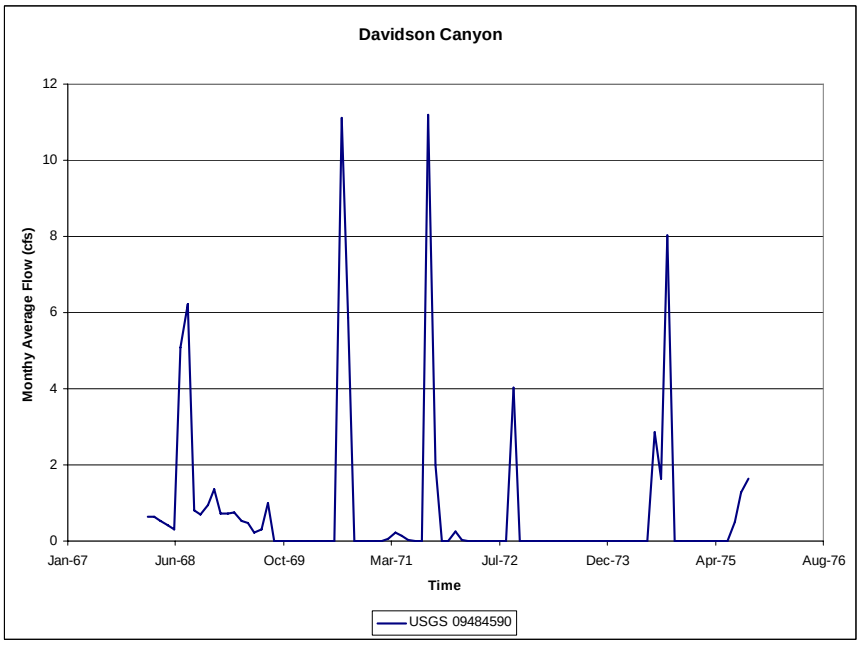

Figure 4: Monthly hydrograph for the Davidson Canyon near Vail AZ gage

The Cienega Creek near Pantano gage operated for a similar period as for the Davidson Canyon gage. Except for a lack of consistent flow in 1968, the flow at this gage is similar to that at the Davidson Canyon gage (Figure 5). This gage is downstream of Davidson Canyon so it likely experiences similar flow events. The lack of baseflow,

even when Davidson Canyon had baseflow, results from transmission losses, probably ET by riparian vegetation.

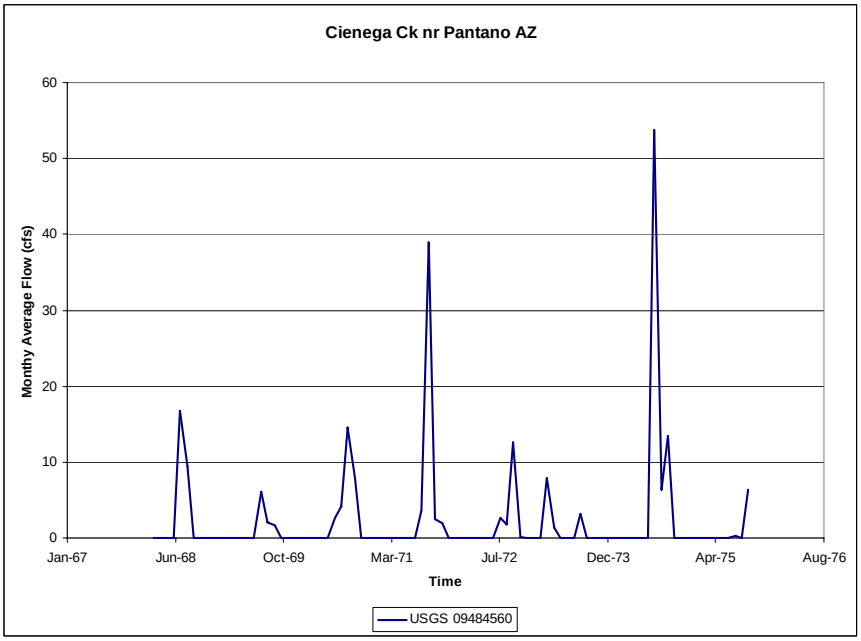

Figure 5: Monthly hydrograph for the Cienega Creek near Pantano AZ gaging station.

Upstream on Cienega Creek, at the gage "near Sonoita", the flow appears to be perennial although the period of record is from 2001 through 2006 so direct comparisons with the flow at the other gages are not possible (Figure 6). The lowest recorded flow between August 18, 2001, and June 21, 2007 has been 0.12 cfs. The mean flow is 1.4 cfs and the median is 0.68 cfs. The higher mean reflects the positive skew (skewness coefficient equals 13.4) caused by occasional high flow days in response to high precipitation. Recorded flows during August and September, 2006, showed a series of peaks followed by hydrograph recession to less than 1 cfs within a few days (Figure 7). This indicates the flow reverts to baseflow quickly, but is higher than during other parts of the year because the riparian vegetation would be utilizing the recent precipitation.

The flow regime reflects two controlling features. High flows occur in response to high precipitation events, but a perennial low baseflow depends on groundwater discharge. Cienega Creek is perennial for approximately nine miles between the confluence with Gardner Canyon and the Narrows, where the gage is constructed (Roudebush 1996). The Narrows is a relatively impervious bedrock outcrop which forces groundwater flow parallel to the channel to surface (Figure 8).

The lowest flow month is always June; from 2001 through 2006, the June flows were 0.33, 0.22, 0.26, 0.24, and 0.23 cfs, respectively. June is usually the end of a period during which there have been few major storm events and during which the evapotranspiration demands from riparian vegetation would be at their maximum. The flow would be all groundwater discharge.

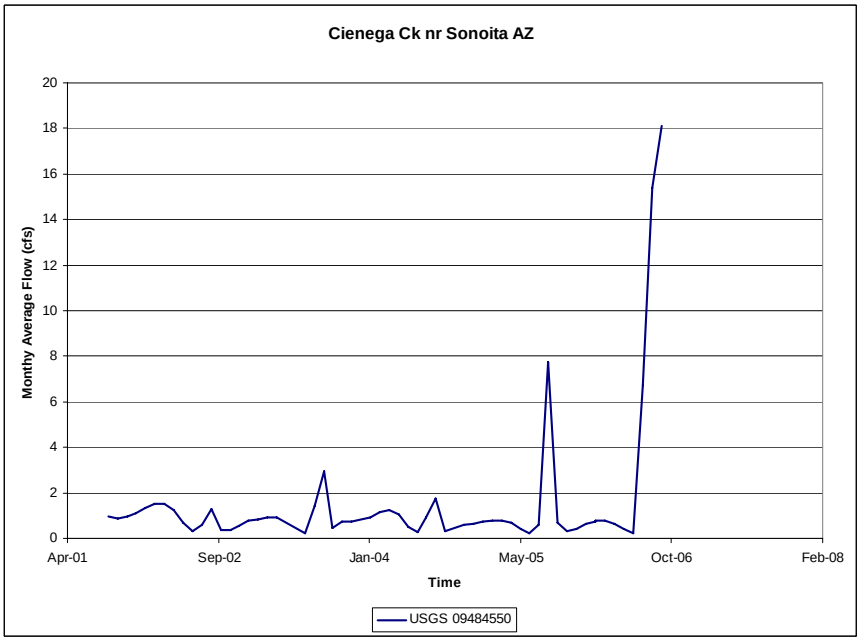

Figure 6: Monthly hydrograph at the Cienega Creek near Sonoita AZ gaging station.

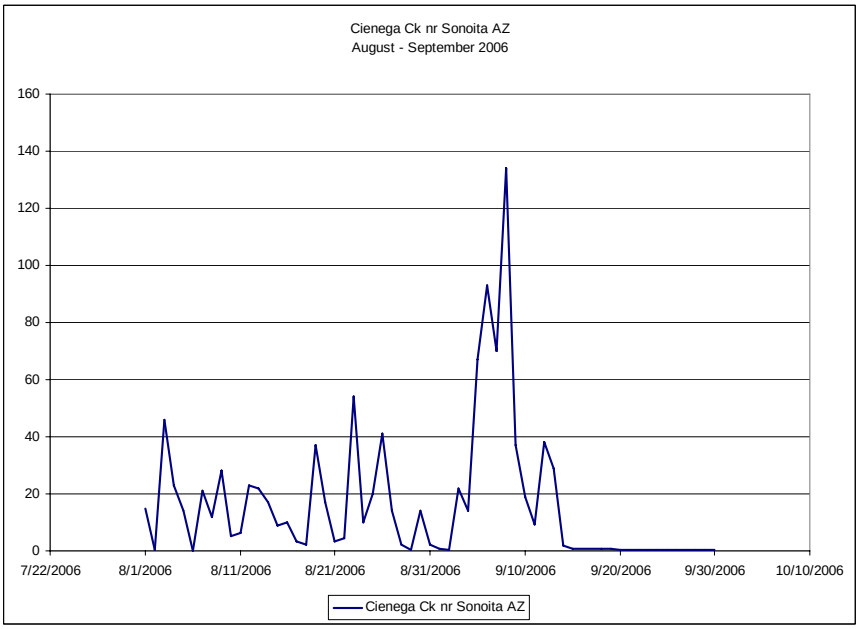

Figure 7: Daily hydrograph for the Cienega Creek near Sonoita AZ gaging station for August and September, 2006.

Figure 8: 09484550 Cienega Creek near Sonoita, AZ. From the web page of the Arizona US Geological Survey. Found at http://az.water.usgs.gov.DataReports/DR05/Basins/ SantaCruzBasin/photo_descriptions/pd09484550_a.html

Groundwater Levels

Data from Harshbarger and Hargis (1976) and Hargis and Montgomery (1982) were added to a GIS database. There were no additional wells or updated water level measurements available in the US Geological Survey web page (Appendix 1); the well level database on the Arizona Department of Water Resources web page was not accessible during this study period (July 31 and August 1, 2007). Because of the undeveloped nature of the basin it is unlikely that there is significant additional information available. Westland (2007) utilized the 1970s and 1980s well level data but also collected well data in house for some of the wells in the area.

The wells were digitized into a GIS system based on their listed quarter-quarter-quarter section location (Figure 9). The locations were partially verified by comparing the listed elevation with the elevation determined from the topographic map. At least one well, DH-1545, was incorrectly located in one of the reports. It was shown as D-19-16-6acd in Harshbarger and Hargis and D-19-16-5bbc in Hargis and Montgomery. The locations and elevations as reported by Hargis and Montgomery (1982) were used whenever there was a discrepancy.

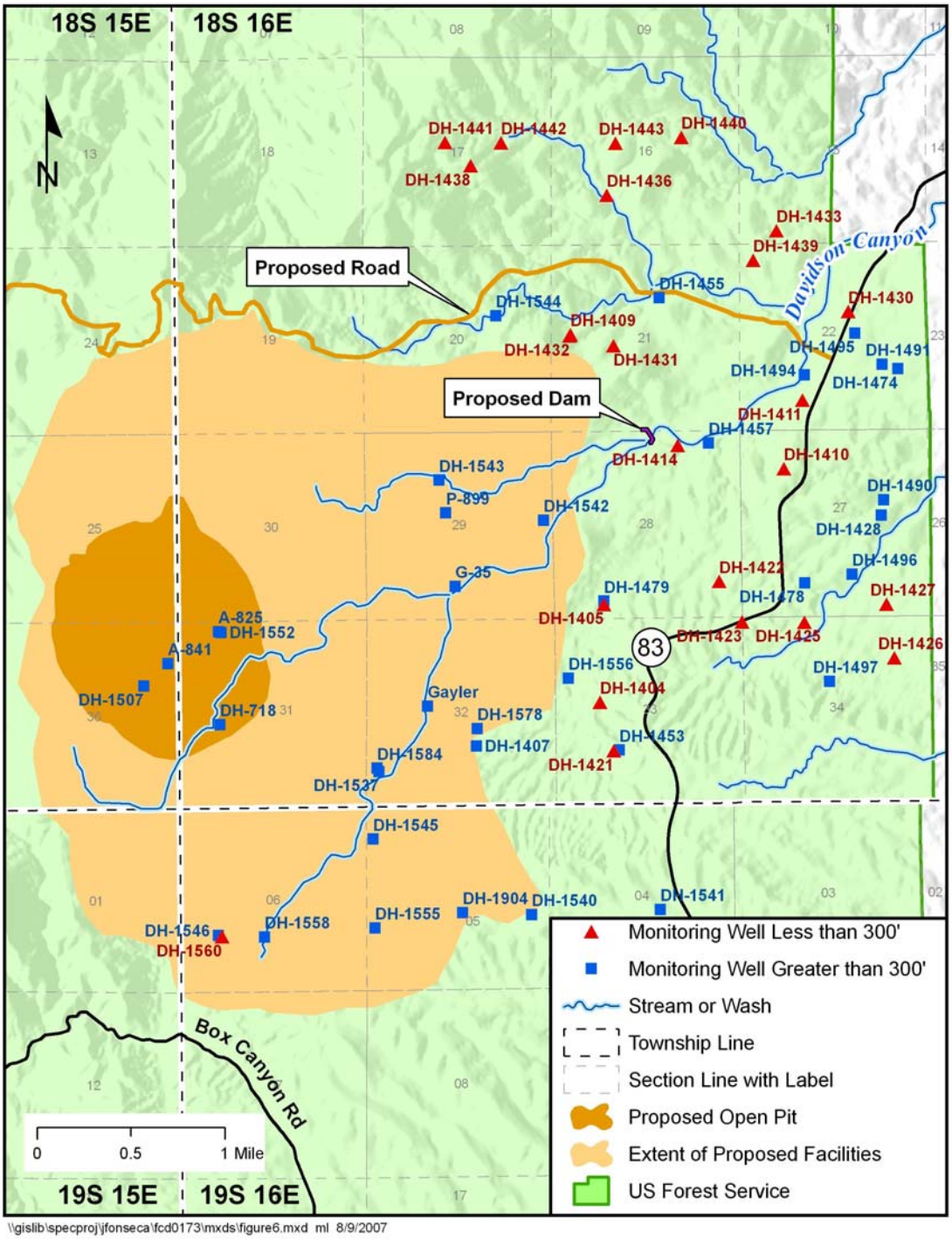

Figure 9: Location of groundwater monitoring wells at the Rosemont Ranch Project Area. See Figure 2 for site details and Figure 3 for geology.

Sixty wells were utilized for parts of the analysis, although the number available per year varied; there were 47, 51 and 53 for 1975, 1980 and 1982 respectively. Many of the wells are east of the project watershed. The well depth varied from less than 100 feet (60 feet at DH-1432) to 3475 feet at DH-1537. About 24 wells were less than 300 feet deep with the remainder distributed somewhat exponentially up to 3475 feet; eleven wells have depths greater than 1000 feet (Figure 10). Because of the variation in well depths and the potential vertical gradient, it is inappropriate to plot groundwater level contours using all of the wells. Well logs are not available, so it is not obvious which formation in which the wells are screened. However, the geology outcrop maps (Johnson and Ferguson 2007; WLR 2007) and cross-sections (WLR 2007) allow an interpretation of the water levels by formation type.

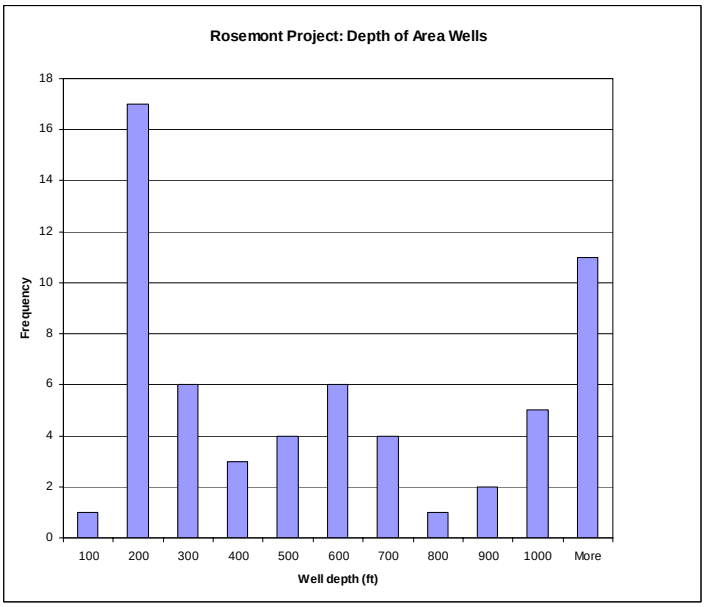

Figure 10: Frequency of well depths for the Rosemont Ranch project area.

Groundwater level contours were completed based on well depth for wells greater than or less than 300 feet. Segregation by depth was useful to identify vertical gradients in the flow and was necessary because of varying geologic formations. This level was chosen to separate shallow from deep wells because of the obvious cluster of wells with depth less than 300 feet and the wide distribution of depths to greater than 1000 feet for the wells greater than 300 feet deep. More segregation by depth is not feasible because there are too few wells.

Contouring was completed manually because the well distribution was not sufficiently regular for contouring routines which use areal correlation. Because there were more deep wells, more detail was possible for the deep wells. Also, there were no shallow wells as far west as a mile east of the proposed pit, so there were no contours for the shallow well set drawn near the pit. The deep contours resembled the topography, but the shallow contours in areas near the washes were above the ground level. They were redrawn to eliminate this impossibility and to better parallel the deep well contours.

The contours for both levels detail a flow system with flow to the east immediately east of the proposed pit and then northeast from the study area (Figure 11). The contours reflect equal pressure levels in the outcrop areas and slightly higher levels in the channels. This should be expected because of the recharge within the ephemeral channels. Within the pit area, observed groundwater levels vary from about 5050 to 5150 ft msl on the east half. There are no wells in the data base on the west side of the pit. These water levels reflect artesian pressure with water rising in the well from the zone which produces the water.

The groundwater divide along the south side of the study area coincides with a topographic divide separating Barrel Canyon from Oak Tree and Sycamore Canyons (Figure 11). This divide is also apparent on the Hargis and Montgomery (1976) and the Westland (2007, Figure 1-5) maps. Two wells, a shallow one, DH-1421, and a deep one, DH-1453, define the divide. Both were sampled in all three years and in each year there was about a 16 foot difference with the gradient being downward.

Westland (2007) indicated that based on their own sampling of water levels in some of the previously sampled wells, the water level has dropped since the 1970s due to drought.

Vertical Gradient

Vertical gradient may indicate vertical flow movements due to recharge zones or artesian pressures. The water levels are not sufficient to characterize vertical gradient across the site. The deepest drill hole, DH-1537, had numerous zones that produced water and appeared to have different pressures in each zone (Harshbarger and Hargis 1976); the pressure was greater at depth causing an apparent upward gradient. This well is in section 32 of T18SR16W about 2 miles east of the crest. The drill hole P-899 was noted to be a flowing well in 1980 and 1982 (no observations in 1975) (Hargis and Montgomery 1982). It is also about 2 miles east of the ridge crest. These two wells are located in an area where the Willow Canyon formation is very thick (WLR 2007), therefore it is likely both wells are completed in this formation. The apparent upward gradient indicates reflects the recharge occurring near the ridge crest because the observed pressure depends on the higher head resulting from the high elevation recharge.

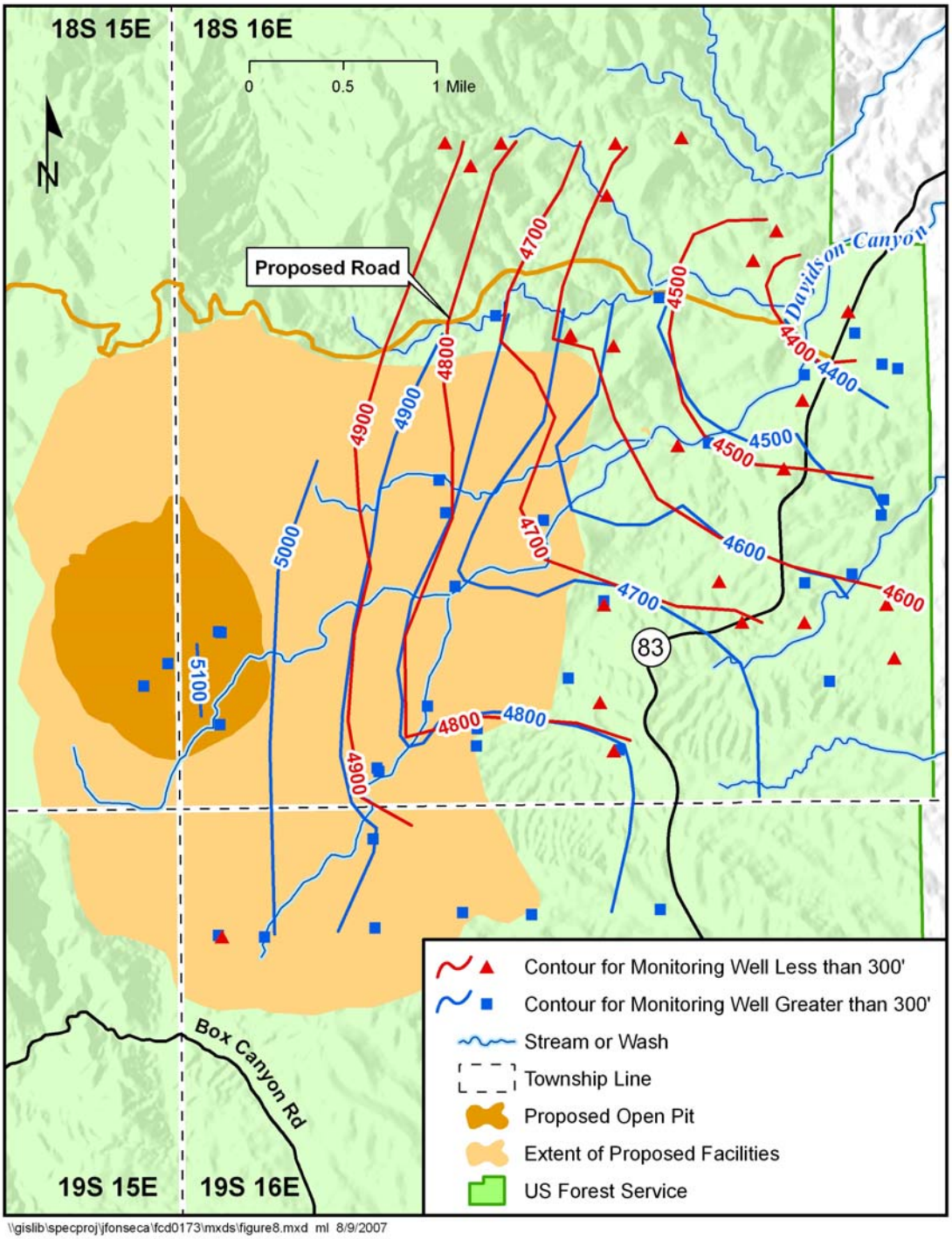

Figure 11: Groundwater level contours for project area for shallow (red; <300 ft) and deep (>blue; 300 ft) monitoring wells. Note the evidence for a groundwater divide extending from the northwest corner of Township 19 South, Range 16 East, across Highway 83 to the northeast.

Further east in section 22 of T18SR16W, there is evidence of an upward gradient in DH-1430 and DH-1495. However, drillholes DH-1411 and DH-1494, also in section 22, show a slight downward gradient. The shallower well, DH-1411, is constructed in an outcrop and could have a higher water level due to a localized diffuse recharge source. Further on the same outcrop, well DH-1410, has a water level about 100 feet higher which indicates further a localized source.

Near the west side of the proposed pit, the gradient appears to be nonexistent or slightly downward reflecting diffuse mountain block recharge. DH-1507 and A-841 show a 20 foot over 600 vertical foot downward gradient. These are in section 36 of T18S16W and are the best wells in the west half of the proposed pit available in the cited references.

The observed gradients reflect recharge in the higher mountains providing the head for lateral flow eastward from the project domain. There is an upward gradient in the east and some groundwater discharges as springs downgradient from the study site. The springs discussed by Harshbarger and Hargis (1976) were primarily higher in the mountains. The chemistry indicates that the springs are not discharging from the regional groundwater but rather are from local recharge and perched aquifers. These perched aquifers would be small because of the thinness of the soils and alluvium in the ephemeral channels at this point.

Conceptual Model of Flow at the Rosemont Ranch

The proposed Rosemont Ranch project lies in an upgradient subbasin of Davidson Canyon which is also a tributary of Cienega Creek. The project area includes the watershed above the confluence of Barrel Canyon and McCleary Canyon, an 8.131 square mile drainage (Figure 2). Most of the project area watershed would be disturbed by the mine. The Rosemont area, therefore, is a subset of the larger Cienega basin in which recharge occurs in the bounding mountains and from the ephemeral channels and discharges to springs, streams and other sinks in the stream that drains the watershed. Groundwater is ultimately tributary to the Santa Cruz basin.

Wilson and Guan (2004) break down mountain front recharge into its components including infiltration of streamflow, mostly ephemeral in the arid Southwest, infiltration of diffuse runoff from small watersheds with undefined channels and direct rainfall, and underflow from the adjacent mountain block through both fractures and porous media.

The underflow is from diffuse recharge which occurs near the location on which the precipitation falls. Flint et al (2004) developed a basin characterization model which determines diffuse recharge based on the water balance of the soil layer with ET discharge and percolation into the underlying geologic formation becoming recharge. High elevation springs emanating from bedrock depend on recharge into perched systems in the bedrock. Recharge may occur west of the topographic divide (Hargis and Harshbarger 1976, page 33), but geologic cross-sections (WLR 2007) do not reveal

stratigraphy which would be conducive to flow under the topographic divide. Therefore, the springs are probably from perched fractured bedrock aquifers or small colluvial aquifers.

Precipitation which does not recharge or discharge through ET becomes runoff which may eventually infiltrate through the bottom of streams. Ephemeral channels recharge groundwater at a rate equal to the transmission loss minus ET loss. In other words, the flow loss in a stream channel during a runoff event becomes recharge if subsequent transpiration by riparian vegetation does not cause it to be lost. For recharge to occur, initial runoff events may substantially fill the field capacity of the deposits and subsequent events may be able to percolate below the root zone to reach underlying bedrock (Osterkamp et al 1994). Percolation through channel deposits becomes recharge to the regional aquifer when it reaches the bedrock. At the nearby Walnut Gulch watershed, Goodrich et al (2003) found that from 20 to 50 percent of the total basin recharge could result from ephemeral channel recharge. They also noted that breaking down the stream transmission losses into ET loss from the riparian vegetation and recharge into the underlying regional aquifers is difficult. Osterkamp et al (1994) estimated for a more arid watershed, the Amargosa River near Shoshone CA, that about 90 percent of the basinwide recharge resulted from ephemeral stream channel loss.

Streamflow infiltration is often assumed to occur mostly at the mountain front, although Coes and Pool (2005) presented results indicating that ephemeral channel recharge may occur in the channel downstream from the mountain front.

The Rosemont Ranch project lies in the mountain block and slightly above the point of mountain front recharge, although recharge likely occurs in Wasp Canyon wherever alluvium lies over bedrock fractures. Substantial runoff exits the project area to recharge further downstream in Barrel Canyon or Davidson Canyon; this is mountain front recharge. The channel deposits form small ephemeral aquifers and primarily serve as a conduit for recharge to the regional bedrock aquifer. Groundwater levels at Rosemont were near the bedrock/alluvial interface during measurements during the 1970s and the alluvial thickness was on the order of tens of feet. This is similar to that reported at Walnut Gulch by Goodrich et al (2003). The recharge entering bedrock would be the difference between the amount of streamflow that infiltrates the channel bottom and that transpired by plants or which discharges back to the stream channel as a spring.

Discharge from the site occurs primarily as groundwater underflow. Riparian vegetation is not part of the discharge from the regional aquifer because it transpires water from the channel deposits, not the regional aquifer. This ET is an abstraction from the channel deposits and water that otherwise would become recharge to the bedrock aquifer as described above.

In summary, recharge to the site is a combination of diffuse recharge to bedrock and recharge from the ephemeral channel deposits. Groundwater flows to the east-northeast through bedrock where it discharges from the site as underflow through the bedrock, the Willow Canyon formation. ET from riparian vegetation within the project

area is from the perched, ephemeral aquifers in the channel deposits rather than from the regional aquifer.

Potential Effects of Rosemont Project

The Rosemont Project includes a 700 acre open pit extending from between 1800 and 2900 feet below ground surface and about 2700 acres of tailings and waste rock covering much of Barrel Canyon and Wasp Canyon above the confluence of Barrel Canyon and McCleary Canyon (Figure 2). The proposed pit would intersect and remove ephemeral tributary channels to Wasp Canyon. It would also intercept the flow in these channel deposits. Much of the ephemeral channel recharge would cease due to a lack of flow. Intercepting the surface water flow would affect mountain front recharge throughout Davidson Canyon downstream from the proposed project. Also, the channel may lie under tailings which would change the discharge along the ephemeral channels.

The diffuse bedrock recharge may also be lost from bedrock formations which flow into or are removed by the proposed pit. It would intercept underflow that otherwise would flow into Davidson Canyon. Precipitation into the proposed pit may recharge through the pit bottom, but this recharge would be much deeper than occurred prior its construction. This deeper discharge from the site could upset the current flow patterns.

The proposed pit would lower the regional aquifer water table by up to 2000 feet within the area of the pit. This would cause a drawdown cone in a manner analogous to that around a large diameter well with the gradient downward toward the pit from all directions. It would cause a discharge from the regional groundwater into the pit. Because of the pit depth, this drawdown cone will change the water table for a significant distance from the pit if the adjoining aquifers are hydraulically connected to the bedrock aquifer of the pit. Of special concern is the basin fill aquifer southeast of the site which in which groundwater flows toward Cienega Creek which is perennial above the narrows as discussed above. If the drawdown cone expands into the basin fill aquifer, groundwater would be drawn north toward the pit (see Figure 12). The amount of flow drawn toward the pit would depend on the extent of the drawdown cone which would depend on the conductivity in the basin fill. This would be a loss of flow to Cienega Creek but the amount is uncertain because the distance that the drawdown cone will extend to the south is uncertain.

Water Balance

At steady state, the water balance is inflow equals outflow without any change in groundwater storage. The only inflow is recharge from precipitation and the only outflow is underflow through the bedrock. Groundwater storage in large aquifers supports baseflow for long time periods whereas in small aquifers seasonal changes and inter-annual variability imposes variability on the baseflow and spring flow discharge. Nelson (2007) found that seasonal ET changes prevented the calibration of a steady state model of a larger watershed, the Santa Cruz. In a small watershed such as the Upper Cienega or the Barrel Canyon watershed of the project area, actual steady state may never

be realized. All estimates of baseflow discharge involve substantial assumptions and contain substantial variability and uncertainty.

Recharge to the Rosemont Project Watershed

Studies of nearby watersheds have found there is a high variability of basin recharge. PAGWP (2006) estimated recharge to Arivaca Basin equal to 945 af/y, or 2.3 in/y, using average annual rainfall of 17.83 inches in the logarithmic relationship derived by Anderson et al (1992). However, PAGWP (2006) tabulated estimated recharge by other researchers which illustrates the variability of recharge estimates ranging from 375 to 1400 af/y.

The Anderson et al (1992) method for estimating mountain-front recharge is not applicable at the Rosemont project area because the project area is within the mountain block. Mountain front recharge occurs where channels exit from the mountains and empty onto a broader valley and likely an alluvial fan. Even at the point where Barrel Canyon discharges into the next downstream valley, the equation would not apply because the area is too small and out of the range of data used by Anderson et al. Most specifically, Anderson et al's equation estimates mountain front recharge to a valley fill basin, not ephemeral channel recharge to a regional bedrock aquifer.

The Maxey-Eakin method (Maxey and Eakin 1949) is a popular method for estimating basin-wide recharge. It relates recharge efficiency to precipitation zones. This means that the volume of precipitation in a given zone is multiplied by the efficiency to estimate the volume of recharge for that zone. Summing the recharges for zones across a basin yields an estimate for the entire basin. It does not utilize geology. It was developed for entire Great Basin basins and, although it has been used to estimate recharge for smaller drainages, it is inappropriate to do so. It has also been determined to be accurate only when using precipitation estimates from the Hardman map which applies only to Nevada. It is not appropriate for use at the Rosemont project.

Recharge into the bedrock therefore will be estimated by analog with a nearby basin – Cienega Creek above the Narrows which is gaged with the Cienega Creek near Sonoita gage discusses above (Figure 12). Barrel Canyon is part of the Lower Cienega Creek watershed, below the narrows, and the hydrogeologic conditions are similar. Recharge to a basin equals discharge from the basin, therefore, by assuming that no groundwater passes the narrows, the recharge above the narrows can be estimated. By determining the recharge rate per area, the recharge for the Barrel Canyon watershed will be estimated by assuming a similar recharge rate per area.

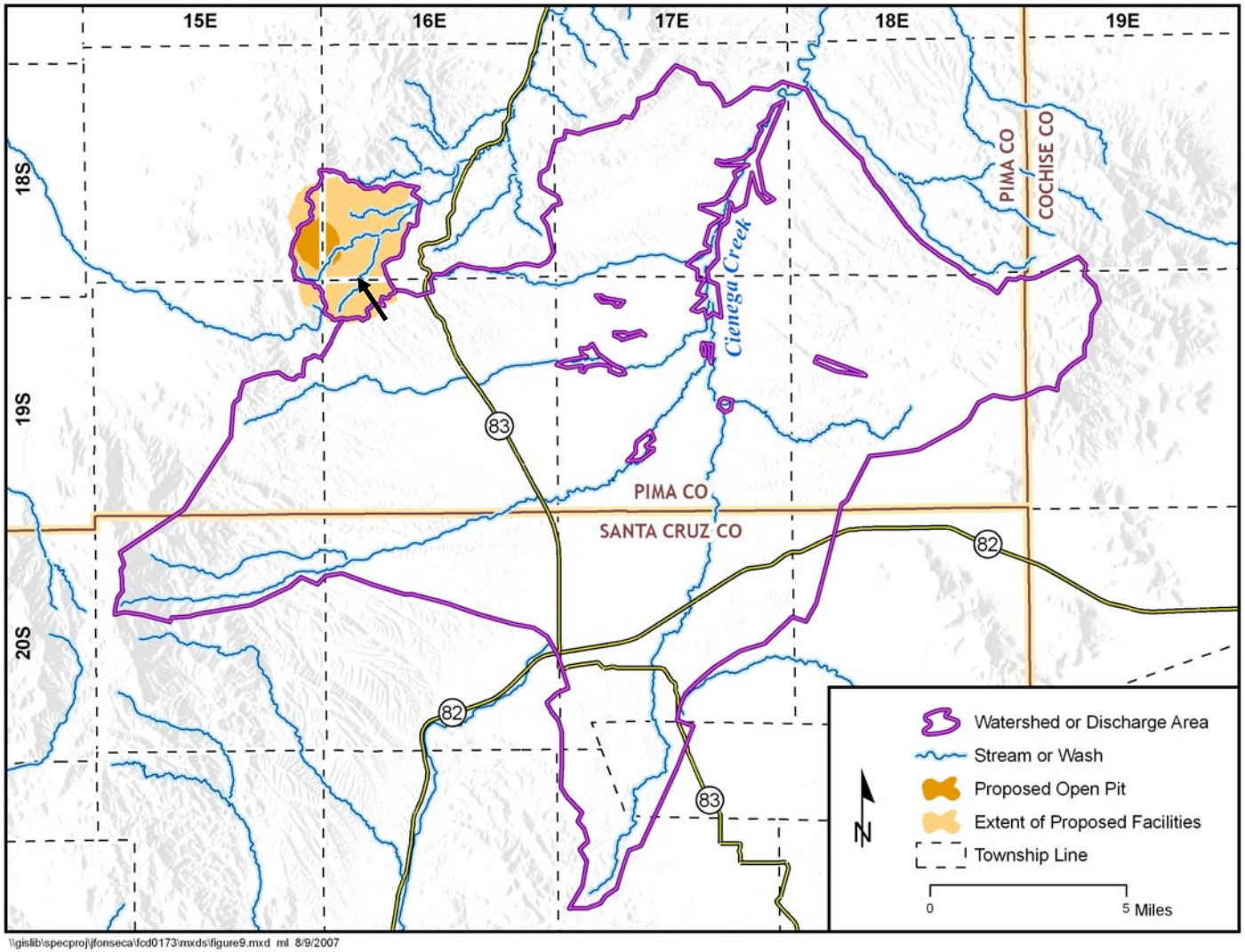

Figure 12 Map of Upper Cienega Creek and Barrel Canyon watersheds, with areas of groundwater discharge in the upper Cienega watershed. Pit dewatering may shift the flow of groundwater from the upper Cienega basin toward the pit, in the direction of the arrow.

This method assumes that the baseflow in the creek and the groundwater ET discharge is the total discharge from the basin and equals the recharge. This is the method used by others for estimating discharge from basins (Maxey and Eakin 1949, Welch and Bright 2007). During the lowest flow conditions of the year, the combined stream base flow and annual ET discharge equals the recharge.

The gaging station Cienega Creek near Sonoita has perennial flow with a median flow equal to about 0.7 cfs (Figures 6 and 7). The USGS does not publish the basin area above this gage. Therefore, using GIS systems, the basin was digitized to determine the area to be 136,000 acres which does not include the Sonoita Creek drainage, as ADWR (undated) suggests should be included, because Sonoita Creek drains west into the Santa Cruz River (Nelson 2007). About 18 square miles of the Santa Rita Mountains on the southwest boundary form the highest elevation portions of the basin. The Whetstone Mountains on the east drain mostly to the north of the gage; the south end is bounded by other small ranges such as the Canelo Hills and Mustang Mountains.

The USGS 1:100,000 scale map of the area shows extensive riparian vegetation near the creek above the Narrows (discharge areas on Figure 13). An aerial image shows this to be fairly dense and to consist at least partly of cottonwoods and mesquite (Figure 14). Digitizing within GIS indicates the ET discharge area along Cienega Creek to be about 1400 acres. Along the creek, it is likely the groundwater flow converges and flows to surface and the riparian vegetation. Other greenish areas, shown on the map, near ephemeral washes draining into Cienega Creek appear to be relatively sparsely vegetated, probably with mesquite; groundwater supporting these areas may be from local runoff and recharge into the ephemeral channels that has not yet reached the bedrock or the deeper basin fill. The steepness of the topographic slope that converges on Cienega Creek supports this interpretation; in basin fill, it is not likely that the regional water table parallels the surface and it is likely that local perched systems support the riparian vegetation.

Based on these observations, the surface water flow and ET from basin bottom riparian vegetation is assumed to be discharge from the regional aquifer system. The bedrock forming the Narrows is assumed to transmit very little groundwater so the flow and ET is the primary discharge.

The ET rate for discharge from riparian vegetation should be based on dense cottonwood/willow stands probably including substantial mesquite and shallow groundwater. Nelson (2007) estimated ET rates as 6.1 ft/y for dense cottonwood and mature cottonwood/willow zones, 3.66 ft/y for medium density cottonwood/willow, 1.83 for sparse density cottonwood/willow, 3.36 for high density mesquite, 2.02 for medium density mesquite, and 1.01 for low density mesquite. These estimates were used for the conceptual flow model for determining the water balance for a groundwater flow model of the Santa Cruz basin which is just west of the Santa Rita range (Nelson 2007).

Figure 13: Google earth view of Cienega Creek basin above the Narrows, showing areas of evapotranspiration (dark, in center, along streams).

Figure 14: Close-up google earth view of Cienega Creek above the Narrows, showing areas of evapotranspiration (dark, along watercourses).

Potential ET for cottonwoods along the Santa Cruz may be slightly higher than in the Cienega Creek drainage because the elevation is lower, therefore the high density ET rate may be slightly lower. Also, the exact distribution between cottonwoods and mesquite along Cienega Creek was not surveyed for this study. The method of digitizing the riparian vegetation also mostly likely led to an overestimate of the area. Thus, there are several sources of uncertainty in the ET estimate. For this reconnaissance analysis, the groundwater ET discharge rate equaled 4.0 ft/y for discharge from the regional groundwater. For 1400 acres, this indicates that approximately 5600 af/y discharges from riparian vegetation along Cienega Creek.

The lowest flow conditions in Cienega Creek occur during June. Flows in June reflect only groundwater discharge because during most years it has been several months since significant spring/winter storms; it is also prior to the summer monsoon period. The June baseflow is 0.25 cfs which will is estimated to be vegetation, there is an additional 0.25 cfs of discharge from the basin or approximately 200 af/y.

Summing the ET and flow, the total groundwater discharge from the upper Cienega Creek basin is 5800 af/y. This estimate methodology is the same as used to estimate discharge for the Maxey-Eakin recharge methodology (Avon and Durbin 1994). Over 136,000 acres, the discharge averages 0.5 in/y. However, it is likely that the mountain block and mountain front areas contribute the bulk of this recharge. This would reduce the contributory area to about 1/3 of the total area and the rate would be about 1.5 in/y which include diffuse recharge and recharge from the ephemeral channels. This is less than the PAGWP (2006) estimate for Arivaca basin for similar precipitation, but, even if their method was appropriate here, the Barrel Canyon watershed recharge is above the mountain front recharge zone.

The sources of uncertainty in the estimate include both the baseflow and the ET rate. Based on the values used by Nelson (2007), it is likely that the ET rate could have a plus or minus 1 in/y uncertainty. The baseflow could be higher, but because it is a small value compared to ET, it will be ignored here. A variability of 20 percent in the 1.5 in/y estimate would be reasonable.

Applying this to the Rosemont watershed area of 5200 acres, the total recharge is 650 af/y. The uncertainty of plus or minus 20 percent would cause the estimate to range from 520 to 770 af/y.

Evapotranspiration from the Rosemont Project Area

Groundwater evapotranspiration occurs primarily from the ephemeral channels. Water levels in the channel deposits are at or below the bedrock interface (Harshbarger and Hargis, 1976). This suggests that the ET discharging from riparian vegetation in Barrel Canyon does not emanate from the primary water table but from the water that ephemerally infiltrates the channel bottom. ET from the riparian vegetation decreases the

soil moisture in the channel deposits; this deficit must be filled by infiltrating surface water before percolation in the bedrock can begin. ET from the riparian vegetation is therefore part of the transmission loss that does not reach the bedrock groundwater (Goodrich et al 2003). Therefore, the estimated groundwater ET discharge is zero.

Underflow

The discharge from the site then will equal Darcy flow through the bedrock. To estimate that, it is necessary to estimate the effective conductivity. Because none of the properties of the formation are known, the conductivity was estimated assuming the discharge is 650 af/y, or 78,000 ft^3/d. Assuming the cross-section at the confluence of McCleary Wash and Barrel Canyon is 1 mile wide by 2000 feet thick (WLR 2007), and the gradient is 0.024 (Figure 11), the hydraulic conductivity would be 0.31 ft/d. Applying the uncertainty band estimated above, the hydraulic conductivity would vary from 0.25 to 0.37 ft/d. This is consistent with the conductivity values determined for sedimentary bedrock in the Santa Cruz model completed by Nelson (2007).

Discussion

The water balance estimated herein is that about 650 af/y of recharge enters the watershed including the Rosemont Project; the range is from 520 to 780 af/y. Because there is no ET discharge from the bedrock aquifer, the underflow is through the bedrock, the Willow Canyon formation. If the cross-section is assumed correctly, the hydraulic conductivity is 0.31 ft/d with variability from 0.25 to 0.37 ft/d.

The uncertainty inherent in this calculation includes that in the methodology for estimating recharge and in the estimate of the underflow cross-section. Additional uncertainty occurs in the conceptual model assuming there is no regional groundwater ET discharge.

Based on the water balance and the expected drawdown caused by the proposed pit, the pit would intercept essentially all of the groundwater discharge from the Barrel Canyon watershed or about 650 af/y of flow to the Davidson Canyon. This is approximately 0.8 cfs. This is about the same rate mentioned by PAGWP (1998) for flows from Davidson into Cienega Creek. It is therefore apparent that the proposed project would intercept substantial amounts of groundwater discharge to the downstream basins and cause significant changes.

A potentially larger impact would be the effect of the expanding drawdown cone. Because of the 1500 foot lowering of the water table, the proposed pit may intercept recharge to Cienega Creek from further south along the Santa Rita Mountains. The magnitude of the effect will depend on the extent of the drawdown cone, or zone of capture, to the southeast of the project site.

Recommendations

Prior to considering whether to construct this proposed mine, there is a lot of substantial data which needs to be collected and analyses to be completed. Only with this additional data can decision makers consider the project adequately. This section makes several recommendations for data collection and analysis which should be completed.

Recharge estimates should be improved using physically based modeling. Diffuse recharge could be estimated with a basin characterization model similar to Flint et al (2004) or TOPMODEL. These models balance precipitation and ET and store water as soil moisture. Infiltration that exceeds ET and cannot be stored as soil moisture becomes recharge if it does not exceed the saturated conductivity of the underlying bedrock. Excess water becomes runoff. It would be critical in this small watershed to use the correct time step, no more than daily. Flint et al (2004) had used a monthly time step. Climate data could be input using PRISM, but if a daily times step were needed it would be necessary to disaggregate monthly to daily data.

The runoff from this modeling should be calibrated with observed runoff to determine if the time step used for long-term modeling adequately simulates storm runoff.

Ephemeral channel flows and recharge along the length of the channel should also be estimated. This would require a routing model which takes the runoff calculated using methods of the previous two paragraphs and simulating the percolation, or transmission losses, to the alluvial aquifer. A detailed water balance of the alluvial aquifer should be completed to estimate how much of the percolation recharges the bedrock aquifer.

The alluvial aquifer water balance would require accurate estimates of the ET from and storage properties of the aquifer. ET estimates include an assessment of the relative amount of ET supported by the alluvial aquifer and by direct rainfall. Literature rates are acceptable but a detailed measurement of the ET area should be completed. Aquifer storage properties, including porosity or specific yield, and estimates of the aquifer shape including thickness and width are necessary for the water balance. Because the recharge occurs along a length of the channel, it is necessary to route the flow downstream. If the aquifer constricts, some groundwater may discharge back to the channel. The routing could be completed with the streamflow package of MODFLOW. The results of the modeling would include estimates of recharge to bedrock, ET and channel flow within and downstream of the project site.

The proposed mine would affect each of these flows. The models should be adjusted to incorporate the mine so that the effects of the project on the flows can be accurately determined.

It is necessary to collect detailed data to parameterize the models. This includes measurements of the alluvial aquifer porosity, synoptic analyses to determine the rate of seepage of surface flows, and detailed measurement of the ET from riparian vegetation. Piezometers should also be installed to monitor water level changes to determine whether the ET is from the alluvial aquifer or directly from precipitation. The modeling could be completed with estimated parameters, but the results would be much less precise and would have a higher uncertainty.

A major impact will be to groundwater flows in the bedrock. It may be reasonable to assume the pit will intercept almost all of the flow east-northeast from the project area. But the pit drawdown will expand north and south and draw additional groundwater toward the pit. The groundwater divide between Barrel Canyon and the Cienega Creek drainage would likely move southeastward. A detailed groundwater model is necessary to estimate the shape and extent of drawdown and the amount of water to be drawn towards the pit and its source.

The extent of the drawdown is unknown, therefore the groundwater model should extend far enough into the Cienega drainage that the model boundary does not influence or control the predicted flows. It should extend under Cienega Creek, which is a head-controlled flux boundary, to the bedrock in the Whetstone Mountains. On the south side, a line from Gardner Canyon to the south end of the Whetstone Mountains might be sufficient; a boundary along this line should be monitored to determine whether the project draws flow from further south. If it does, the boundary should be extended. It is not necessary to model the bedrock in the headwaters of Gardner Canyon. The ET discharge from riparian vegetation, discussed above, should be included in the model as a head-controlled flux boundary.

There is little knowledge of the hydrologic characteristics of the geologic formations of the area. It is necessary to complete pump tests to estimate transmissivity and storage coefficients for aquifers. This basic data is needed prior to completing the groundwater modeling of the project's impacts. This data is need from the Cienega drainage as well. New wells may be necessary for both pumping and monitoring. The new wells should be deep enough to adequately test and monitor the deep bedrock. The pit will be as deep as 2900 feet and it is necessary to understand the hydrogeology at that depth.

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Appendix 1

Field Trip to Rosemont Site
June 2, 2007

Attending: Tom Myers (author), Julia Fonseca, Neva Connolly, and Lainie Levick

This trip was for the author to obtain a better feeling for the terrain and geology of the study area with the other participants as tour guides. The trip started with a drive in from the northeast along Barrel Canyon. Barrel Canyon joins with Scholefield Canyon which drains into Davidson Canyon. The project concerns the County because the project area drains into Davidson Canyon (Photo 1). The project would also intercept surface flows and decrease recharge in the ephemeral channels.

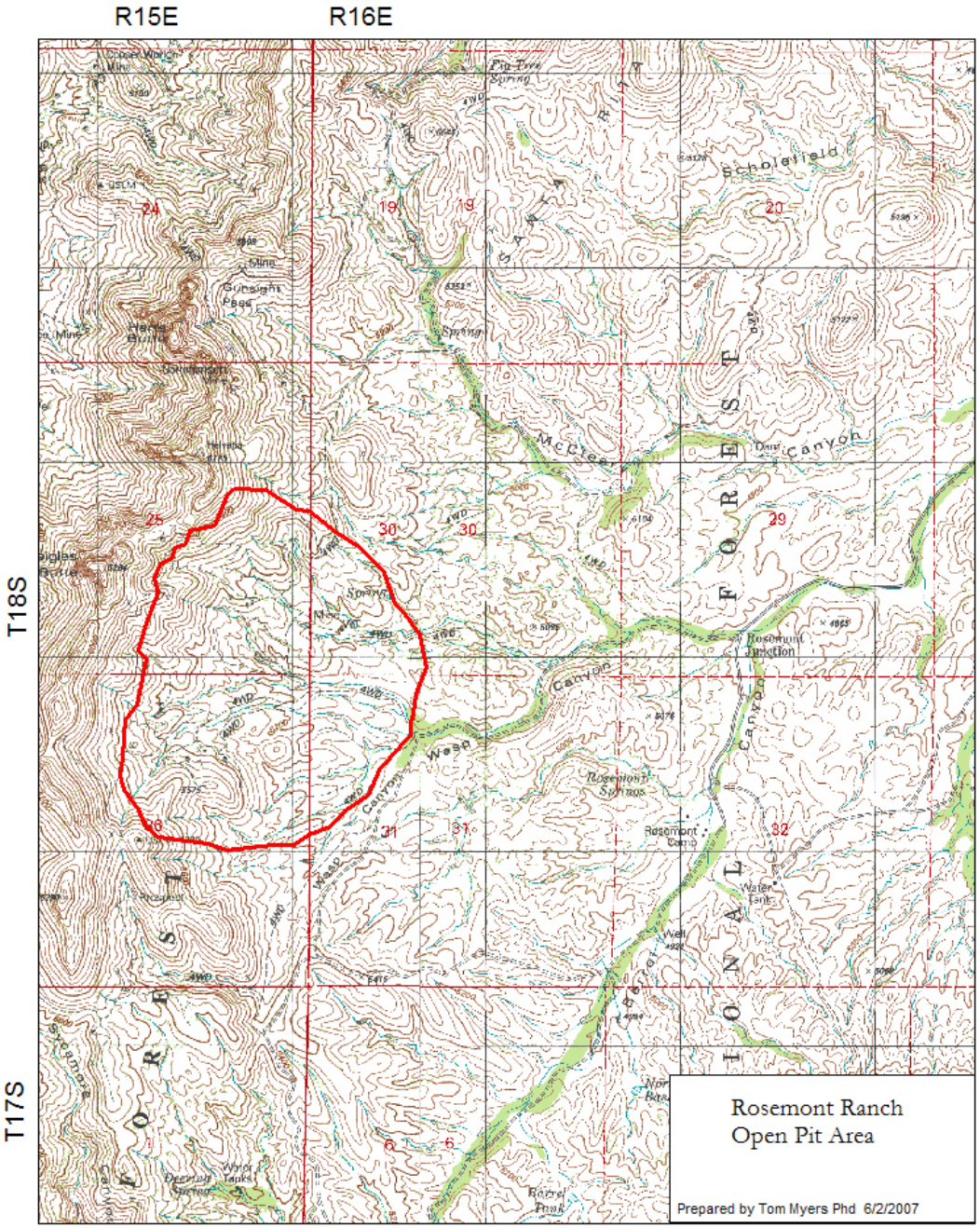
The vegetation in the drainages, particularly along Wasp Canyon, is mostly mesquite, walnut, and desert willow. The density is moderate and likely to cause substantial evapotranspiration (Photo 2). The 1:24000 scale maps appear to accurately portray the vegetation (Map 1). For estimating ET loss, the mapped green area is probably accurate. However, the vegetation appears drought-stressed (Photo 3) which indicates the ET rates are variable and depend on drought.

The alluvial aquifers are small, just a hundred feet at most wide and tens of feet deep, and therefore have a small storage capacity. Also, the alluvial aquifers appear to be limited to the main channels such as Wasp Canyon and Barrel Canyon; the smaller tributaries are almost V-shaped with very little alluvium for storing water. This observation was observed particularly in the channels draining into Wasp Canyon from the north (Map 1 and Photo 4).

On the terraces adjoining the channels, the soil cover is thin but present over much of the area. One photo showed about one foot of gravelly soil with little organic matter or silt. This overlays the bedrock outcrops. In my estimate, the soils would not hold significant amounts of meteoric waters; the trees observed over much of the site (Photo 2), especially on north facing slopes, probably have roots into fractures in the rock. The tree cover is thick enough however to have substantial interception so that small rainfall amounts may not fill the soil moisture.

There are various geologic outcrops in the area including obvious transitions among formations (Photo 5). None of the limestone or carbonate rock outcrops showed more than very narrow fractures (Photo 6). There are no obvious locations where substantial areal diffuse infiltration will recharge the groundwater. The relatively high water table and upward vertical gradient in deep bedrock wells observed by Hargis and Harshbarger indicates there is some recharge however. Runoff will reach the ephemeral channels where it will infiltrate and recharge.

None of the springs were found. Neither Lainie nor Julia have seen the springs shown on the USGS maps or reported by Hargis and Harshbarger. This could due to the drought conditions over the past years.



Map 1: Map of general topography near the proposed Rosemont pit area.

Photo 1: Northeast view from butte above Wasp Canyon.

Photo 2: View up Wasp Canyon into the south half of the proposed pit area.

Photo 3: Drought stressed tree in Wasp Canyon. There has been die-back at the tips of most tree but there is new growth nearer the trunk and main limbs.

Photo 4: Terraces and rolling hills in the proposed pit area. Also note the exploration roads.

Photo 5: Contact between two formations. Shows small transverse fractures but little evidence of large fractures which would transmit much water.

Photo 6: Detail of fractures.

Part 2. Managing Ground Water Resources

This section reviews the types of ground water issues that are important for all USDA Forest Service units, line officers, and staff to consider. Legal requirements and ground water-management strategies are discussed.

Federal Statutes

In addition to the Federal land management statutes cited in Forest Service Manual (FSM) 2501, the following Federal statutes provide pertinent direction to the Forest Service for its management of ground water resources in the National Forest System.

Safe Drinking Water Act of 1974, as amended. (42 U.S.C. §300f et seq). The intent of the SDWA is to ensure the safety of drinking-water supplies. Its authority is used to establish drinking-water standards and to protect surface- and ground water supplies from contamination.

Resource Conservation and Recovery Act of 1976, as amended. (42 U.S.C. §6901 et seq) The Resource Conservation and Recovery Act (RCRA) regulates the generation, transportation, treatment, storage and disposal of waste materials. It has very specific requirements for the protection and monitoring of ground water and surface water at operating facilities that may generate solid wastes or hazardous wastes.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended. (42 U.S.C. §6901 et seq). Also known as "Superfund", the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) regulates cleanup of existing environmental contamination at non-operating and abandoned sites (see also FSM 2160).

In addition, judicial doctrine and water-rights case law provide the legal interpretations of Federal and State statutes about usage and management of ground water (see FSM 2541.01 and Forest Service Handbook [FSH] 2509.16 for procedures to be followed for complying with Federal policy and State water-rights laws).

Overview of the National Ground Water Policy

The national ground water policy sets out the framework in which ground water resources are to be managed on NFS lands. The policy is designed to be located in two parts of the Forest Service Manual, FSM 2880, Geologic Resources, Hazards, and Services, and FSM 2543, Ground Water Resource Management. As of the publication date of this technical guide, FSM 2543 is in draft form and may change due to agency and public comment prior to finalization. Regional Foresters and Forest Supervisors are directed by the national ground water policy to perform the duties detailed below.

Land Management Planning

- Protection and sustainable development of ground water resources are appropriate components of land and resource management planning for NFS lands. Ground water inventories and monitoring data shall be integrated into the land and resource management process.
- When evaluating project alternatives or revising national forest plans, use the best available science, technology, models, information, and expertise to determine the location, extent, depths, amounts, flow paths, quality, and recharge and discharge areas of ground water resources and their hydrological connections with surface water.

Water Development

- Conduct appropriate National Environmental Policy Act (NEPA) analyses when evaluating applications for water wells or other activities that propose to test, study, monitor, modify, remediate, withdraw, or inject into ground water on NFS lands (see also FSH 2509).
- Always assume that hydrological connections exist between ground water and surface water in each watershed, unless it can be reasonably shown none exist in a local situation.
- Ensure that ground water that is needed to meet Forest Service and authorized purposes is used efficiently and, in water-scarce areas or time periods, frugally. Carefully evaluate alternative water sources, recognizing that the suitable and available ground water is often better than surface water for human consumption at administrative and public recreational sites.
- Prevent, if possible, or minimize the adverse impacts to streams, lakes, ponds, reservoirs, and other surface waters on NFS lands from ground water withdrawal.
- As applicable under State water-rights laws and adjudications, file water-use-permit applications and water-rights claims for beneficial uses of ground water by the Forest Service. Consult with the Office of General Counsel prior to filing (see also FSM 2541).
- Comply with wellhead protection (U.S. Environmental Protection Agency [EPA] 1994), sole-source aquifer, and underground injection control (UIC) requirements of Federal (40 Code of Federal Regulations [CFR] 144), State, and local agencies. Ensure that all public water systems (PWSs) on NFS lands that use ground water comply with EPA's ground water rules.
- Require all drinking-water systems that withdraw water from aquifers on NFS lands, and that are classified as community water systems (those that serve 25 year-round residents or have 15 or more service connections), to have flow meters installed and operating. Require wells on NFS lands that provide ground water that is later sold to consumers or used for industrial or commercial purposes to have flow meters installed and operating. Wells equipped with hand pumps are not required to have flow meters. Require injection wells with discharge pipes that are 4 inches inside diameter or larger to be metered.

Water Quality

- Identify the needs and opportunities for improving watersheds and improving ground water quality and quantity. Take appropriate steps to address the needs and take advantage of the opportunities.
- In areas where ground water on NFS land has become contaminated from human sources, evaluate the potential receptors, technical feasibility, costs, and likelihood of finding potentially responsible parties (PRPs), the risks of exacerbating the problem, and other relevant factors before making a decision to try to cleanup the ground water.
- Complete removal and/or remedial actions for ground water contamination at CERCLA/Superfund sites on NFS lands. Identify the PRPs and seek to have them perform the cleanup work, where possible, to minimize the cost of the cleanup to the Forest Service. At sites where the Forest Service is a PRP, the cleanup work should be aggressively performed in a timely manner to fulfill the agency's trustee responsibilities. Inform owners of non-federal property abutting NFS lands that overlie contaminated ground water of the existence of the contamination, the types of contaminants present, and the Forest Service plan for managing the contaminated ground water.

Ground Water-dependent Ecosystems

- Ecological processes and biodiversity of ground water-dependent ecosystems must be protected. Plan and implement appropriately to minimize adverse impacts on ground water-dependent ecosystems by (1) maintaining natural patterns of recharge and discharge, and minimizing disruption to ground water levels that are critical for ecosystems; (2) not polluting or causing significant changes in ground water quality; and (3) rehabilitating degraded ground water systems where possible.
- Manage ground water-dependent ecosystems to satisfy various legal mandates, including, but not limited to, those associated with floodplains, wetlands, water quality and quantity, dredge and fill material, endangered species, and cultural resources.
- Manage ground water-dependent ecosystems under the principles of multiple use and sustained yield, while emphasizing protection and improvement of soil, water, and vegetation, particularly because of effects upon aquatic and wildlife resources. Give preferential consideration to ground water-dependent resources when conflicts among land-use activities occur.
- Delineate and evaluate both ground water itself and ground water-dependent ecosystems before implementing any project activity with the potential to adversely affect those resources. Determine geographic boundaries of ground water-dependent ecosystems based on site-specific characteristics of water, geology, flora, and fauna.
- Establish maximum limits to which water levels can be drawn down at a specified distance from a ground water-dependent ecosystem in order to protect the character and function of that ecosystem.
- Establish a minimum distance from a connected river, stream, wetland, or other ground water-dependent ecosystem from which a ground water withdrawal may be sited.

Inventory and Monitoring

- Design inventory and monitoring programs to (1) gather enough information to develop management alternatives that will protect ground water resources, and (2) evaluate management concerns and issues expressed by the general public. Assign high priorities for survey, inventory, analysis, and monitoring to municipal water-supply aquifers, sensitive aquifers, unique ground water-dependent ecosystems, and high-value or intensively managed watersheds.
- Develop estimates of the usable quantity of ground water in aquifers while protecting important NFS resources and monitor to detect excessive water withdrawal.
- Define the present situation and detect spatial or temporal changes or trends in ground water quality or quantity and health of ground water-dependent ecosystems; detect impacts or changes over time and space, and quantify likely effects from human activities.

Data Management

- Establish guidelines and standards for the acquisition and reporting of ground water information to meet the specific needs of Forest Service programs. The storage of ground water data must conform to Forest Service Natural Resource Applications (FSNRA) standards and servicewide Geographic Information System (GIS) data standards. Storage will be in FSNRA databases upon availability.

Partnerships

- Close collaboration and partnership with other Federal Agencies and States/Tribes, regional and local governments and other organizations is essential in gathering and analyzing information about ground water resources for which the Forest Service has stewardship.

Ground Water Uses

Some 83.8 billion gallons per day of fresh ground water were pumped in the United States in 2000 (Hutson and others 2004). This total was about 8 percent of the estimated daily natural recharge to the Nation's ground water. Much of this water was being withdrawn in excess of the recharge capabilities of local aquifers ("overpumping"). Withdrawals significantly in excess of natural recharge are located predominantly in coastal areas of California, Texas, Louisiana, Florida, and New York, in the Southwest, and in the Central Plains. In the United States, management of ground water is primarily the responsibility of State and local governments. The authority and responsibility for overseeing the allocation and development of water resources typically resides with the State's department of natural resources or water resources or the State engineer's office. The authority and responsibility to prevent undue contamination of ground water typically resides with the State's health department or department of environmental quality or environmental management and with local government (e.g., health department, county commissioners, city council). In addition on most Federal lands some overlapping responsibilities for both ground water and quantity resides with the management agency.