Hydrologic Analysis of the Huachuca City, Arizona Wastewater Ponds

Prepared for

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1 Introduction

The Town of Huachuca City, AZ received FY 2003 and FY 2004 appropriations totaling $1,590,500 for an effluent recharge project. The proposed project includes construction of a new, lined wastewater holding pond at Huachuca City's existing wastewater treatment facility, consisting of unlined wastewater evaporation ponds, three lift stations, and approximately 40,000 feet of force main. The force main will transport the waste approximately eight miles south to Fort Huachuca's wastewater facility (Figure 1). The waste treated at Fort Huachuca's wastewater treatment facility will either be reused or recharged through the Fort's groundwater recharge facility. The US Environmental Protection Agency (USEPA) is funding the construction of the lined wastewater holding pond. All but the lined holding pond has already been built by the Fort.

In accordance with the National Environmental Policy Act (NEPA), USEPA Region IX issued a Draft Environmental Assessment (EA) in 2010 for the Town of Huachuca City. During the public comment period, EPA Region IX received substantive comments on the EA. Much of the public comment received centered on the potential hydrological connection between the existing wastewater evaporation ponds and nearby surface waters, and the potential impacts of eliminating any potential water recharge on the local populations of endangered Huachuca water umbel, a riparian plant species. While the Draft EA concluded that the project would not cause any significant impact on surface resources and endangered species, the analysis did not specifically address the potential for current wastewater disposal in unlined treatment ponds to support flows in the Babocomari and San Pedro rivers.

To address this concern, Tetra Tech reviewed existing materials, data, and reports to provide a hydrological analysis of the potential connection between the unlined ponds and the adjacent waterbodies. No additional data were collected; however, uncertainties in conclusions based on the existing data are identified.

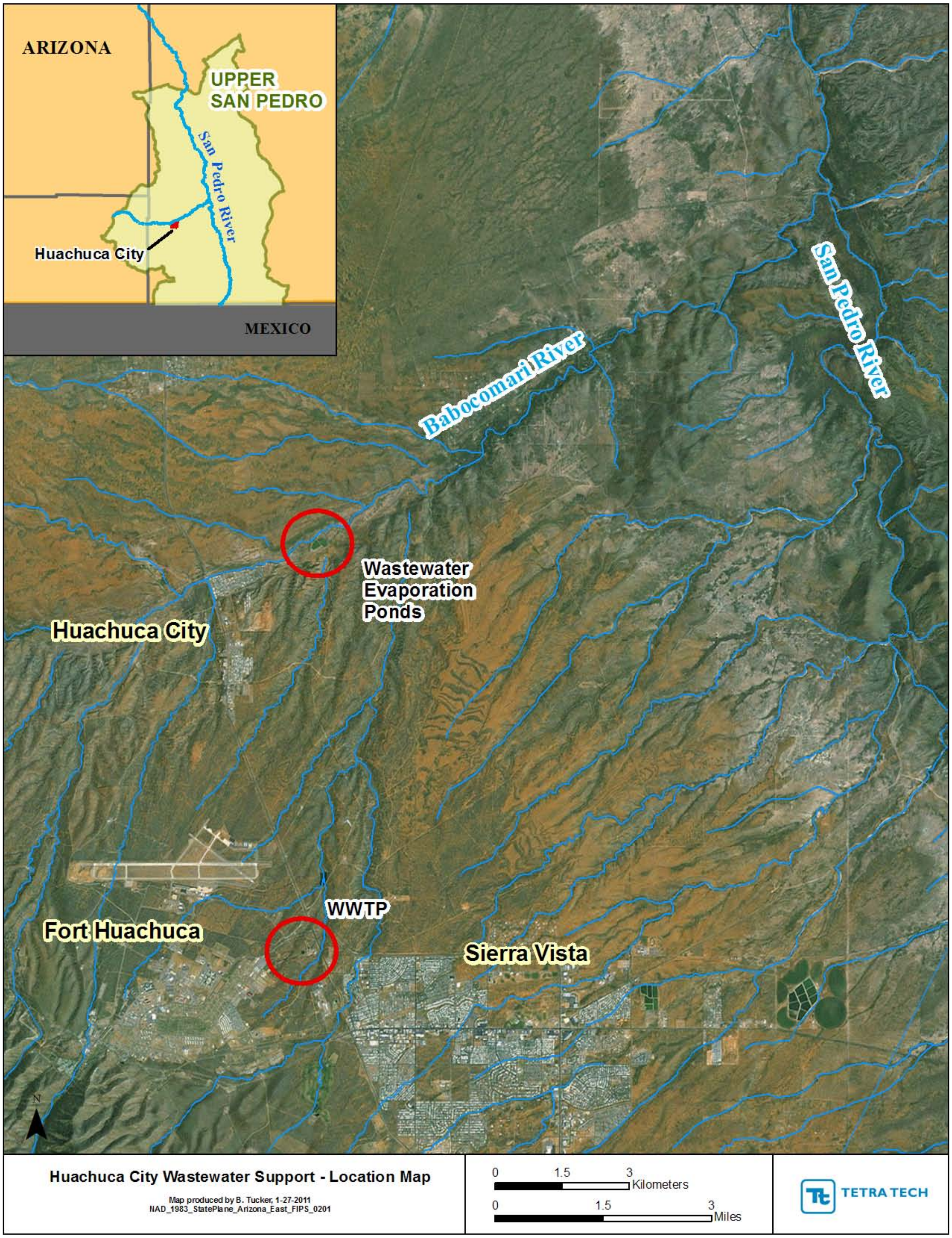

Figure 1. Location Map

2 Previous Findings

The 2002 estimated population of Huachuca City was less than 1,800 residents. Estimated per capita water use in 2002 was 124 gallons per capita per day and estimated effluent production was 150 acre-feet per year (AZDWR, 2005). Huachuca City is estimated to grown in population to 3,600 by 2050 generating 360,000 gpd (>400 acre-feet per year) of effluent (USEPA, 2010).

As described in the EA, the current facility for handling wastewater from Huachuca City consists of three unlined wastewater evaporation ponds and one abandoned lined pond all constructed in 1973. The ponds are located within the 100-year floodplain and approximately 1.5 meters up slope of the Babocomari River (Figure 2). The closest point from the West Pond to the Babocomari River over land is approximately 33 m. The furthest point (East Pond) is more than 350 m measured north to south. The proposed new, lined pond would be located on the existing facility site and include floodplain protection features.

Huachuca City received an Aquifer Protection Permit (No. P-100832) for the existing facility in 2002 from the Arizona Department of Environmental Quality. The permit authorizes the operation of sewage lagoons for treatment and disposal of domestic sewage. Monitoring of the wastewater effluent and groundwater are required. Diversion of flows from the existing facility to the Fort Huachuca WWTP is cited as a remedy to comply with flood protection requirements (i.e., the ponds are located in the 100-year floodplain). Groundwater monitoring required by the permit had shown no adverse effects prior to December 2002 according to an amendment to the permit.

Fort Huachuca implements a program to reduce the impacts of groundwater withdrawals through water conservation, recharge, and reuse. The program resulted in about 426 acre-feet of effluent recharged to the regional aquifer in 2005. Inclusion of Huachuca City effluent would substantially increase the amount recharged to the regional aquifer by the Fort.

The 2002 EA concluded the following regarding potential impacts of the project on water resources including floodplain resources, surface water, wetlands, and groundwater resources:

- Minor direct impact due to construction in the floodplain of the lined wastewater pond.
- Temporary minor impacts to dry wash crossing during construction of the force main.
- Elimination of surface water at the existing ponds.
- Loss of an estimated 0.4 acres of manmade wetlands.
- Direct beneficial impacts from minimizing the risk of groundwater contamination from the existing unlined ponds and an increase in recharge of effluent.
- With regard to threatened and endangered species, the EA found there to be indirect, beneficial impact resulting from an increase in artificial recharge to the aquifer, which contributes to baseflow of the San Pedro River and supports riparian vegetation.
- The EA concluded that the Huachuca water umbel (*Lilaeopsis schaffneriana recurva*) is not known to occur along the Babocomari River and is unlikely to occur around the sewage treatment ponds. It has been found along the nearby San Pedro River downstream of the site.

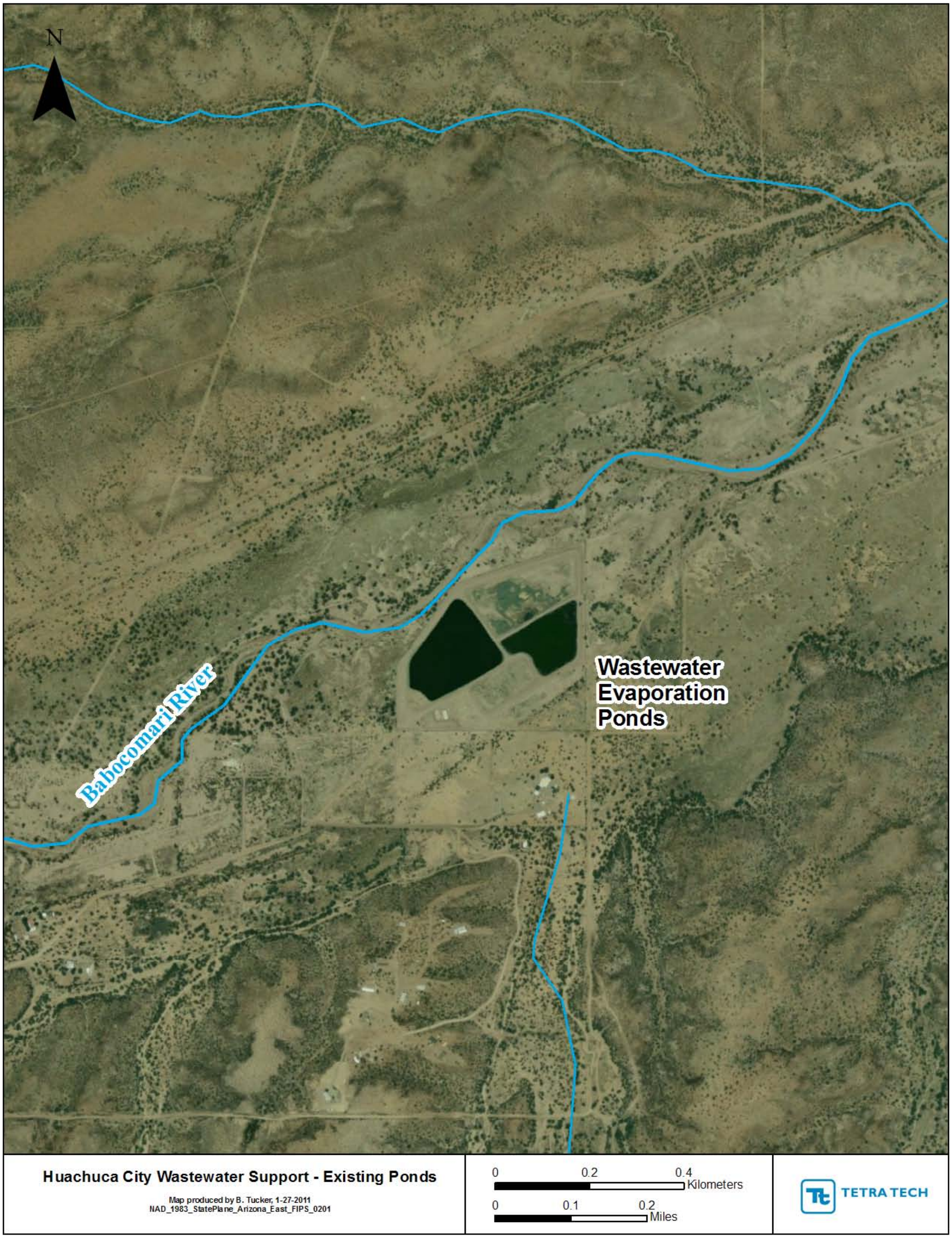

Figure 2. Aerial Image of Existing Wastewater Ponds

The Huachuca water umbel is a herbaceous, semi-aquatic perennial plant in the parsley family (USFWS, 2011). The United States Fish and Wildlife Service listed the species as endangered in 1997 and designated critical habitat in 1999. The Huachuca water umbel inhabits cienegas (marshy, spring areas) and associated vegetation within Sonoran desert scrub, grassland/oak woodland, and coniferous forests. It is found at elevations ranging from 4,000 to 6,500 feet and requires perennial water, gentle stream gradients, small to medium sized drainage areas and (apparently) mild winters. The potential threat to this species from alteration of ground and surface water flows, which may degrade or destroy wetland habitat, is of interest.

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3 Hydrogeological Setting

As described by Cook et al. (2009), the San Pedro River headwaters begin about 20 miles south of the US/Mexico international border. Once it crosses into the US, the river flows approximately 125 miles before its confluence with the Gila River in Winkleman, Arizona. It drains about 4,720 square miles in the US. The river is fed by two major tributaries, the Babocomari River and Aravaipa Creek.

The Babocomari River flows from the west and joins the San Pedro River south of Fairbank, Arizona. The main stem begins at an altitude of about 4,800 feet above sea level and descends for approximately 1,000 feet, draining an estimated 310 mi^2 (Figure 3). The river generally flows on Quaternary deposits over Tertiary basin fill sediments in the upper portion and late Tertiary/early Quaternary St. David Formation deposits in the lower reaches. Discontinuous bedrock channel sections are common in the 1-mile section upstream of the confluence with the San Pedro. The modern channel exists 3 to 20 feet below the historic floodplains due to downcutting.

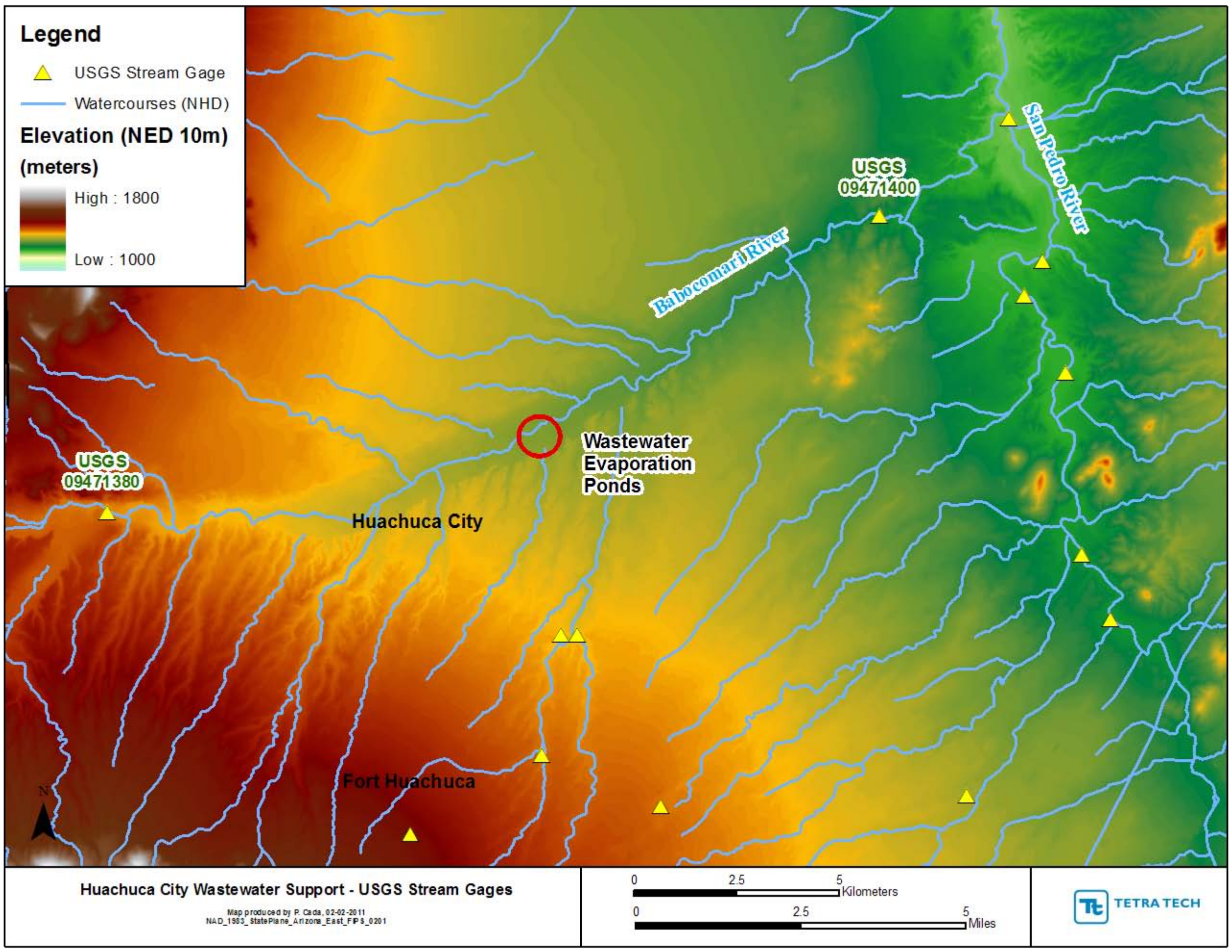

Figure 3. Elevation Map with USGS Stream Gages

The aquifer system in the upper San Pedro consists of alluvial fill of varying types: the Pantano Formation, upper and lower basin fill, and floodplain alluvium (Figure 4). The primary regional aquifer is the upper basin fill (closer to the surface) and lower basin fill, sedimentary rock (Tsy) layers of sand and gravel with interbedded silt and clay in some locations. These deposits are overlain by Holocene (or Quaternary) alluvium surrounding and underlying the San Pedro and Babocomari rivers. Groundwater in the aquifers along the Babocomari occurs at depths from less than 50 up to 200 feet below the surface (AZDWR, 2005).

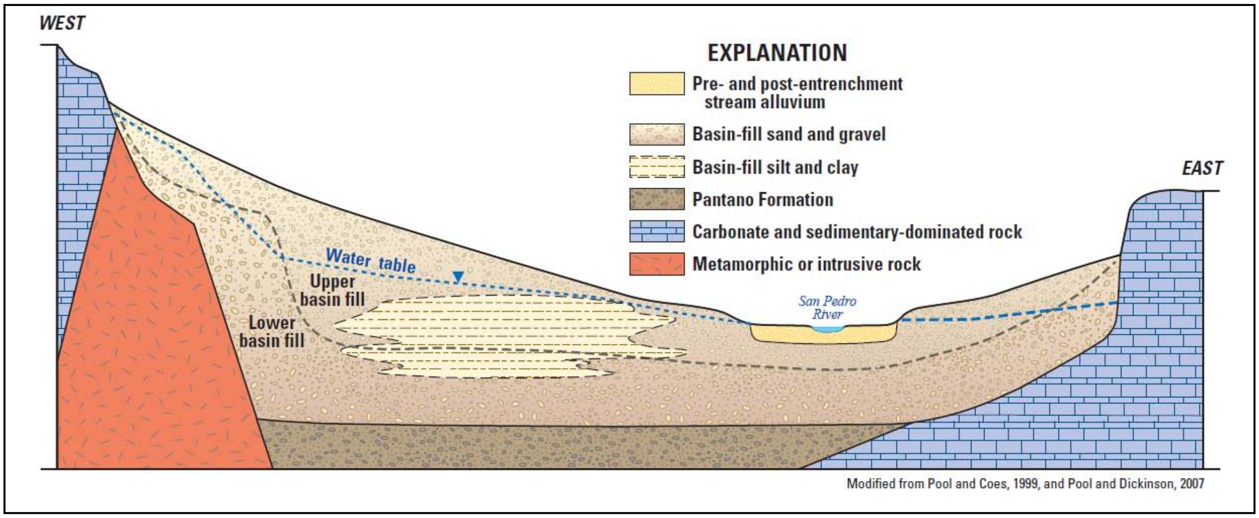

Figure 4. Generalized Cross Section (from Figure 2 in Thiros et al., 2010)

3.1 Recharge and Infiltration

Recharge to the groundwater aquifer system occurs via percolation of precipitation that is in excess of evaporation, vegetative use through evapotranspiration, and runoff to surface waters. Natural recharge is concentrated at high elevations and in and near stream channels underlain by permeable materials. Pool and Coes (1999) describe three natural sources of groundwater in the San Pedro River watershed: 1) water recharged within the Holocene alluvium near the river; 2) recharge to the regional aquifer in Mexico and east of the river along the Mule Mountains; and 3) recharge to the regional aquifer west of the river near the Huachuca Mountains. Recharge estimates for 2002 are 21,500 ac-ft/yr for Sierra Vista sub-area, an area that includes 950 mi^2 from the international border to near Fairbank (AZDWR, 2005). By comparison, groundwater demand was estimated to be 29,850 ac-ft/yr including 60 percent for agricultural, municipal, and industrial uses.

Artificial recharge programs are common in the region. Irrigation water and treated sewage effluent are infiltrated to supplement the aquifer storage. Total artificial and incidental recharge was estimated at 3,500 ac-ft/yr for the Sierra Vista sub-area (AZDWR, 2005). Contributing to this total, effluent was recharged at Fort Huachuca in 2001 at a rate of approximately 540 ac-ft/yr (Fort Huachuca, 2006).

Infiltration rates have been the subject of study by the USGS. Coes and Pool (2005) monitored infiltration fluxes through the basin floor in four boreholes within the Sierra Vista subwatershed. They found that infiltration fluxes down to several meters (i.e., below the depth typically affected by ET) ranged from about one to six centimeters (0.4 to 2.4 inches) per year. USGS also conducted a numerical groundwater flow modeling study in the Sierra Vista subbasin (Pool and Dickenson, 2006). By layer, average hydraulic conductivity for the lower and upper basin fill was 3.2 and 11.4 feet/day, respectively. Interbedded (i.e., with silt and clay layers) regions averaged 2.8 feet/day. Average vertical anisotropy, the ratio of horizontal to vertical conductivity, was 26.8 and 10.8. Interbedded regions had somewhat higher values.

3.2 Streamflow

Many sections of the San Pedro and Babocomari rivers are often dry or only slightly wet at the surface during much of the year. Perennial flows occur where the water table reaches the surface and regional and stream alluvial aquifers are hydraulically connected to the channel. This occurs primarily in areas where underlying impermeable strata force regional groundwater flow to the surface. Most of the base flow at Tombstone gage on the San Pedro River (downstream of the confluence with the Babocomari and also near Fairbank) is derived from regional groundwater (74±10 percent) with the remaining derived from summer storm runoff stored in the alluvial aquifer (Kennedy and Gungle, 2010).

In the Babocomari near Huachuca City there is no perennial flow, indicative of a poor connection between the river and underlying groundwater. This section of the river is also a losing reach with water table in the alluvial aquifer well below the land surface. For example average flow (4.81 cfs) upstream of Huachuca City at USGS gage 09471380 was higher than flow (2.44 cfs) downstream at USGS gage 09471400 (Figure 5). Figure 5 also shows periods where flow at the Upper Babocomari River gage is much higher than at the downstream gage. No significant withdrawals are known to occur between the two gages and the difference primarily represents infiltration into the alluvial aquifer.

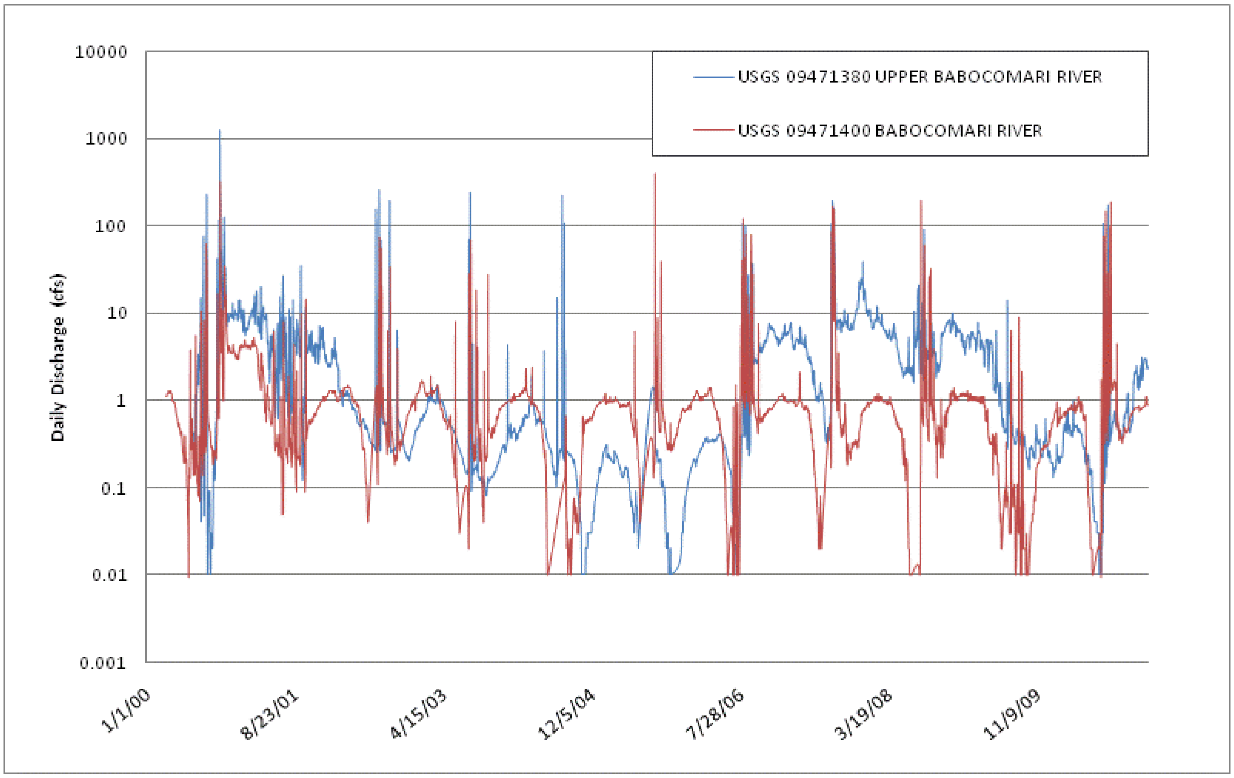

Figure 5. Stream Flow at Gage 09471380 (Upstream) and Gage 09471400

3.3 Site Geology and Soils

Mapping of the Holocene floodplain alluvium of the Babocomari by Cook et al. (2009) shows the latest Holocene and river terrace deposits (Qy2r) beneath and adjacent to the Huachuca City wastewater ponds (Figure 6). The materials consists of silt, clay, sand, and minor gravel deposits. Estimates of its thickness vary from about 40 to 150 feet (Pool and Coes, 1999; Goode and Maddock, 2000). Basin fill below the floodplain alluvium is dominated by sand and gravel material in the vicinity of the Huachuca City wastewater ponds with a saturated thickness between 980 to 1,300 ft (Pool and Dickenson, 2006). Depth to the Pantano Formation, the consolidated conglomerate, is approximately 1,200 ft (AZDWR, 2005).

Depth to groundwater in the vicinity of the Huchuaca City wastewater ponds is approximately 50 to 100 feet (AZDWR, 2005). Groundwater generally moves downgradient along the Babocomari river channel toward the San Pedro River.

Soils in the vicinity of the wastewater ponds are in the Riveroad and Ubik Map Unit based on the Natural Resources Conservation Service SSURGO data. The Riveroad unit is characterized by silt loam (0-21 in) to silty clay loam texture (21-60 in). Ubik is a loam/silty loam (0-16 in) to fine sandy loam (16-60 in). Percentage of clay for Riveroad and Ubik soils are 10-35 percent and 5-15 percent respectively. Saturated hydraulic conductivity is 1.4-4 µm/sec in the lower layer of Riveroad. Values are much higher for Ubik (14-42 µm/sec).

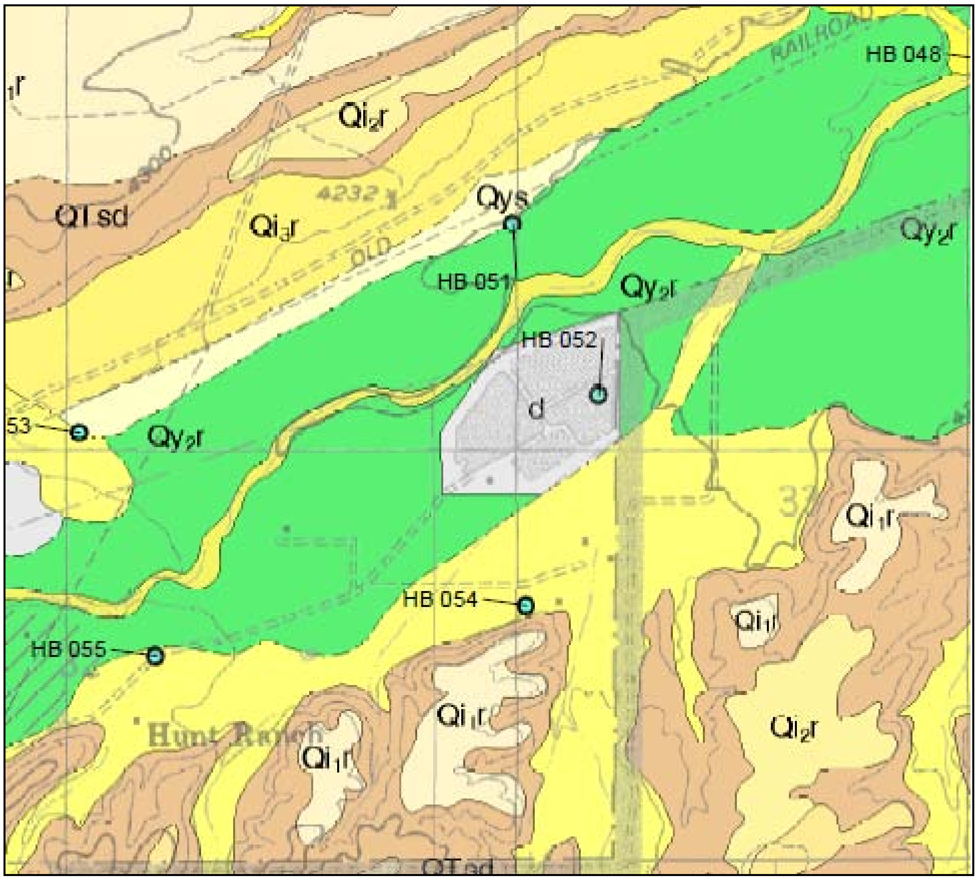

Figure 6. Holocene Alluvium Mapping at the Huachuca City Pond Site (from Cook et al., 2009)

4 Hydrologic Analysis

Huachuca City's wastewater ponds were designed for evaporation, but are unlined. Both Pool and Dickenson (2006) and Arizona Department of Water Resources (AZDWR, 2005) have previously suggested that little to no recharge occurs from the Huachuca City wastewater evaporation ponds. Indeed, the ponds have been in use for nearly 40 years without any sludge or sediment removal, and are expected to have developed a clogging layer due to sludge loading. Nonetheless, the existing ponds are a potential source of infiltration and local recharge. Several lines of evidence are presented to bound the problem and suggest the magnitude of local recharge and its potential significance to support of riparian vegetation in the Babocomari. These lines include calculation of a mass balance to estimate potential infiltration rates, a mathematical analysis to address the fate of any potential infiltrated water, and review of the type and extent of riparian vegetation, an indicator of hydraulic connectivity in this arid setting.

4.1 Mass Balance

An annual water mass balance can give an approximate indication of how much water is potentially available for infiltration given estimated inflows and outflows to the existing wastewater ponds.

The mass balance is evaluated on an annual basis using the following equation:

$$Inflow = Outflow \pm \Delta \text{Storage}$$

where *Inflow* includes precipitation, wastewater flow to the ponds, and surface runoff. *Outflow* consists of evaporation and infiltration.

Evaporation

Pan evaporation at Douglas weather station (SE of site) was 73.63 inches per year based on a 1948-2005 period of record (Western Regional Climate Center, 2011a). Application of a pan coefficient (0.72, NOAA 1982) to convert pan evaporation to free surface water evaporation results in 53 inches of evaporation. This is slightly higher than the 46 inches estimated for 2003 in the channel of the San Pedro River (Leenhouts, 2006).

Precipitation

Average annual precipitation measured at the Fort Huachuca (NCDC Coop Station # 023120) and Sierra Vista (NCDC Coop Station # 027880) stations was 14.4 inches per year (1971-1981) and 14.6 inches per year (1982-2005), respectively (Western Regional Climate Center, 2011b).

Wastewater Flow to the Ponds

According to AZDWR (2005), the estimated per capita water use in 2002 was 124 (gpcd) for Huachuca City. The estimated effluent production was 150 acre-feet in 2002. The surface area of the wastewater ponds was estimated from imagery: 6.19 ac and 3.66 ac for the West Pond and East Pond, respectively. Total surface area is 9.85 ac.

If the change in storage is assumed to be zero on an annual basis and there is no significant surface runoff to the ponds, the remaining components can be used to calculate the potential flow available for infiltration.

Rearranging the equation and converting evaporation and precipitation to acre-feet based on the cumulative pond surface area, using the average annual precipitation from Sierra Vista, the evaporation estimate from Leenhouts (2006), and the 2002 effluent inflow estimate, the mass balance is

$$Potential\_Infiltration = Inflow - Outflow \pm 0$$

$$Potential\_Infiltration = (11.98 + 150 + 0) - 37.76 - 0$$

= 124.19 ac-ft per year or 0.17 cfs

4.2 FATE OF INFILTRATED WATER

The large depth to groundwater and the evidently small rate of infiltration flow from the Huachuca ponds means that infiltration from the ponds represents a situation of steady infiltration into unsaturated soil. Mathematical descriptions of this situation are difficult, but have been studied in detail by a variety of authors. Philip (1968) derived an approach to describe infiltration from buried point sources or cylindrical cavities and showed that steady infiltration flows are the net effect of subtle interactions of gravity, capillarity, soil moisture content, and source geometry. Gravity is the dominant factor, but capillarity becomes increasingly important as the dimensionality of the source increases. The gravitational forces are always downward (*z* direction), while the capillary forces contain both a vertical and a lateral component.

Hydraulic conductivity in unsaturated soil (K(θ) or K(ψ)) is not a constant, but varies as a function of soil moisture content (θ) and the moisture potential (ψ). Philip's solutions depend on the approximation K(ψ) = $e^{\alpha\psi}$, as a result of which the relative strength of the capillary forces is an inverse function of α.

Wooding (1968) provided an initial analysis of steady infiltration from small, shallow circular "ponds," where the concept of small is appropriate to the scale of ring infiltrometers. He demonstrated that total flux into the soil results from a gravity term proportional to the pond's area and a capillary term proportional to the pond's circumference. The ratio of the gravity term to the capillary term is thus proportional to r/2 (where r is the radius of the pond) and the gravity term becomes increasingly dominant with pond size. He further demonstrated that as α increases above zero, the region of wetness beneath the pond contracts in width and elongates in the downward direction.

Weir (1986) derived a solution for the more intractable case of steady infiltration from large shallow ponds under somewhat restrictive assumptions of an isotropic, semi-infinite medium. Here "large" means that the radius of curvature is large relative to 2/α, which is the case for most real ponds. The resulting problem was solved by separation of the gravity and capillary portions of the flux. The analysis enabled Weir to conclude that surface flows induced by capillarity are restricted to a boundary layer of width 2/α, and confirmed the general findings of Wooding (1968) on the dependence of the lateral extent of wetness beneath the pond on α.

Finally, Waechter and Mandal (1993) solved the general case of infiltration from a hemispherical pond into unsaturated soil using a non-dimensional asymptotic analysis. This solves the general equation for flow based on Darcy's law under the unsaturated soil assumptions of Philip:

$$V^* = -K(\theta)\left[\nabla_*\psi - \hat{z}\right],$$

where K is hydraulic conductivity, θ is volumetric moisture content, ∇_* is the gradient operator relative to physical space coordinates (x,y,z), ψ is the moisture potential, and z is the unit vector in the z direction.

Once again, flow into unsaturated media beneath a pond is predominantly vertical, with spreading due to capillary effects. For a hemispherical pond, the dimensionless mean infiltration rate, $V_0(s)$ is shown to vary as $1 + 1.3909\ s^{-2/3}$, where the first term (1) represents the gravitational effect and the second term represents the capillary effect. In this representation s = ½ α *l*, where α is the parameter defined by Philip, as given above, and *l* is the characteristic length, equivalent to the radius of the pond.

Philip (1968) shows that α is typically about 0.01 cm^{-1} and ranges from 0.002 cm^{-1} for very fine textured material where capillarity is at its most import to about 0.05 cm^{-1} for coarse material. For a very small "pond" with radius *l* = 2 cm, s = α and the term showing the relative importance of capillary forces ranges from 10.25 (at s = 0.05) to 87.62 (at s = 0.002), showing the importance of capillarity. However, for larger ponds this is scaled down by the factor $l^{-2/3}$.

The two Huachuca ponds are adjacent to one another and have a total area of 9.85 acres. If these are approximated as a single semi-hemispherical pond the radius is 11,264.24 cm, resulting in a scaling term of 0.00199. Thus, at the dimensions of the Huachuca pond the strength of the capillary forces compared to downward gravitational forces would range from 0.0204 (for coarse media) to 0.174 (for very fine media). At the typical value of α cited by Philip, the ratio would be 0.060. This low ratio means that only a small amount of lateral spreading will occur relative to gravitational downward flow, even with the upper bound assumption that capillary forces act only in the lateral direction.

Accordingly, the zone of soil saturation beneath the ponds should be predominantly vertical, with only limited lateral flow. The low ratio of lateral to vertical flow means that any capillary flow toward the plan view location of the Babacomari River would occur only at depth and would contribute little or no moisture to the riparian vegetation of the river channel. Any infiltrated water would join the larger pool of regional groundwater and be subject to discharge a considerable distance downbasin.

4.3 Riparian Vegetation

Another line of evidence is provided by riparian vegetation. Review of aerial photography suggests little riparian vegetation along the Babocomari River in the vicinity of the wastewater ponds (Figure 1 and Figure 2). This extends approximately 4 and 2.5 miles upstream and downstream, respectively, with little difference between areas upstream and downstream of the evaporation ponds. Beyond this extent, vegetation cover is more dense suggesting a more sustained baseflow and hydraulic connection to alluvial and regional aquifers. Perennial reaches of the Babocomari and San Pedro rivers occur where this hydraulic connection occurs along with an upward gradient in flow to the channel and riparian region. Intermittent reaches tend to have groundwater at greater depths.

Leenhouts et al. (2005) conducted a study of the hydrologic requirements of and consumptive ground-water use by riparian vegetation along the San Pedro River. They characterize three major hydrologic reach types: perennial, intermittent-wet, and intermittent-dry. Perennial reaches tend to have Fremont Cottonwood or Gooding Willow trees, limited Tamarisk, and riverine marsh vegetation. At the other end of the spectrum, intermittent-dry reaches have predominantly lower growing, drought tolerant Tamarisk shrubs because the hydrologic environment cannot sustain other species. Near the confluence of the Babocomari and San Pedro, the reach is considered largely intermittent-wet.

The Babocomari adjacent to Hucachuca City is clearly in the intermittent-dry category. Lack of vegetation change in the vicinity of the ponds indicates that the ponds do not result in a significant supply of water to riparian vegetation in the area.

4.4 Conclusions

Several lines of evidence presented above suggest that only a small amount of recharge occurs from the existing wastewater ponds and the recharge that does occur has a low probability of contributing significant support for riparian vegetation in the vicinity of Huachuca City. These lines of evidence include a calculation of a water mass balance, a mathematical analysis of the fate of any potential infiltrated water, and a review of existing riparian vegetation. Together, these suggest that local recharge rates are low and will result in primarily vertical transport of water, with little influence on the surface channel and riparian vegetation of the Babocomari River in the vicinity of Huachuca City.

Any recharge that does occur at Huachuca City is likely to contribute to the regional aquifer storage and will emerge further down in the basin at and/or below the confluence with the San Pedro. Artificial recharge of this water at Fort Huachuca would be expected to have the same fate except a smaller fraction would be subject to evaporation, potentially resulting in a greater amount of total water recharge. As stated in the draft EA, this would result in a positive impact on Huachuca water umbel populations along the San Pedro River.

In sum, further analysis of the available evidence suggests that the conclusions regarding hydrology made in the 2010 EA are sound. Diversion of waste water from the existing Huachuca City evaporation ponds to recharge facilities on Fort Huachuca is unlikely to cause deleterious effects on vegetation and wildlife in the Babocomari riparian zone as the current ponds appear to provide little or no water supply to this zone. Instead, the small amount of infiltration that does occur appears to percolate vertically to the alluvial aquifer located approximately 50 feet below the river channel. Diverting the effluent to recharge on Fort Huachuca is also unlikely to have any net adverse impact on water balance in the San Pedro River. Indeed, it may serve to slightly increase groundwater transmission by reducing the evaporative losses that currently occur from the Huachuca City wastewater ponds.

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