ANNUAL MONITORING REPORT
2016

MARANA HIGH PLAINS EFFLUENT RECHARGE PROJECT

Underground Storage Facility Permit No. 71-563876.0007 (PCRFCD)
Water Storage Permit No. 73-563876.0200 (PCRWRD)

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1.0 INTRODUCTION

The Marana High Plains Effluent Recharge Project (MHPERP) is a constructed recharge project developed by the Pima County Regional Flood Control District (PCRFCD) in cooperation with the Bureau of Reclamation (BOR), Arizona Water Protection Fund (AWPF), Pima County Regional Water Reclamation Department (PCRWRD), and the Town of Marana. The project is located in Section 33 of Township 11 South, Range 11 East in the Avra Valley sub-basin of the Tucson Active Management Area (**Figure 1**). It is one component of a regional water resource, flood control, environmental protection and enhancement, and recreation program (the Northwest TAMA Replenishment Program) that is sponsored by more than a dozen local, state, and federal entities.

MHPERP is designed to recharge treated effluent into the local groundwater aquifer, while simultaneously creating wildlife habitat and public recreation opportunities associated with recharge facilities. The overall objectives for the project include the following:

- To recharge up to 600 acre-feet of water per year while maximizing infiltration rates in basins having side slopes vegetated with emergent plants and riparian trees;

- To provide trails, descriptive literature, and interpretive signs describing the project operations. Trails at the project site may eventually be linked to a longer river trail network that is scheduled to be built along the Santa Cruz River;

- To re-vegetate the area outside the recharge basins with plants that will improve wildlife habitat value and, once established, could survive if the recharge activities cease;

- To maintain wildlife, aquatic macroinvertebrates, and vegetative resources associated with an important effluent-dominated stream; and

- To monitor the biological effects that may result from establishing other habitat types that are now rare to the area (e.g., marsh, grassland), and increase the aerial extent of riparian vegetation.

The MHPERP facility is comprised of one settling basin (equalization basin) and four spreading basins (recharge cells), totaling 4.5 acres of recharge area (**Figure 2**). A comprehensive description of the MHPERP and the related monitoring plan was provided to the Arizona Department of Water Resources (ADWR) in support of the Constructed Underground Storage Facility (USF) Permit Application for the project filed in June 2007. In addition to the USF Permit (No. 71-563876.0008), the facility has an Aquifer Protection Permit (No. P-103195) from the Arizona Department of Environmental Quality (ADEQ) that authorizes the discharge of treated effluent into the aquifer.

The facility has been operating since February 2003, first as a pilot project and then as a constructed recharge project. In accordance with Sections 2 and 3 of the USF Permit (all versions), this is the fourteenth annual report for the MHPERP. This report includes all of the data that was collected during the 2016 Calendar Year.

2.0 PROJECT OPERATIONS

A modified USF Permit (71-563876.0007) was approved and signed by the ADWR Assistant Director, Ms. Sandra Fabritz-Whitney, on June 10, 2009. This permit authorizes PCRFCD to store effluent at MHPERP over a twenty-year term (through November 24, 2028) or until the Operation Prohibition Limits are met. Maximum annual storage at the facility is based on three constructed phases as follows:

Phase 1: 350 acre-feet per annum recharged within the equalization basin and the four recharge cells, as constructed in 2002;

Phase 2: 450 acre-feet per annum after construction of recharge enhancement trenches within Recharge Cells 1, 3 and 4, as constructed in 2009.

Phase 3: 600 acre-feet per annum after re-excavation of Recharge Cell 2, as constructed in 2010.

The facility operated per Phase 3 of the permit throughout the 2016 Calendar Year. A modified permit is in process to add a new delivery system (monitoring point), as described below. Contingency plans are in place within the current USF Permit to allow the District to perform enhancement functions as needed to maximize recharge at the facility.

2.1 Water Delivery

Water is delivered to the MHPERP via the "oxbow" channel, a remnant channel of the Santa Cruz River from when the riverbed was less incised and the channel meandered back and forth across the floodplain. A berm consisting of streambed materials is used to divert some of the effluent flowing down the main channel of the Santa Cruz River into the oxbow channel. The primary source of the effluent discharge is the Tres Rios Wastewater Reclamation Facility (formerly Ina Road Wastewater Treatment Plant), which is approximately 10 miles upstream of the diversion structure. Some effluent from the new Agua Nueva Wastewater Reclamation Facility (replaced the Roger Road Treatment Plant in 2014), approximately 15 miles upstream of the diversion structure, may mix with the effluent flows from the Tres Rios WRF during the winter months.

A constructed wet well collects the oxbow channel flows at the Northeast corner of the facility. Two non-clogging, submersible pumps convey effluent through an 8-inch line into an equalization basin, used to provide a more constant source of available effluent for recharge and help serve as a settling basin for removing particulate materials that could clog the recharge cells. A level sensor is installed in this basin to automatically turn the pumps on and off based on levels within the oxbow channel and the equalization basin. From the equalization basin, the effluent passes through a 16-inch isolation valve into the main distribution line, which feeds into each of the four recharge cells through motorized butterfly valves. Due to modifications of the basins over the last several years, the automatic level sensors in these basins are no longer needed to maintain water levels. The valves are closed manually (cranking the turn valve) by the facility operator when the cells are scheduled for a drying cycle.

A new effluent delivery system was constructed in November, 2016 to provide gravity flow into Recharge Cell 2. The new system consists of a pipeline between the wet well and the bottom of Recharge Cell 2, with a slide ditch gate used to control flows into the basin, and a flow meter (FM_{C2}) installed to measure the flows for reporting purposes. The gate opens and closes manually and the flow meter is connected to a solar panel, which saves on electric power use at the facility and also provides effluent deliveries to the project if electrical power is down. From Recharge Cell 2, effluent can be delivered to the other recharge cells through the main distribution line coming from the Equalization Basin.

Deliveries to MHPERP are based on the daily cycle of discharges from the treatment plants to the Santa Cruz River. Peaks in water levels at this site normally occur in the late morning and early evening hours. Deliveries to the facility are impacted by storm water events in the Santa Cruz River that damage and sometimes demolish the earthen structure used to divert flows into the oxbow channel. Malfunctioning pumps, faulty valve controls, and basin maintenance can also disrupt deliveries to the facility. Details of all the delivery interruptions for Calendar Year 2016 are provided in Section 6.0 (Facility Inspections and Maintenance) of this report.

2.2 Inflow Volumes

Water deliveries into the MHPERP facility are measured using 1) a Magnetflow® Mag Meter installed within the main line that runs from the pumps to the equalization basin (FMeq) and 2) an American Sigma 950 flow meter installed within the gravity-feed pipeline that runs between the wet well and Recharge Cell 2 (FM_{C2}). Upon review of documentation provided by PCRFCD, ADWR's Recharge Program determined that the facility could use the new delivery system (Monitor Point FM_{C2}) for storing water and recharge credit accrual on December 12, 2016.[1] Daily totals are read on-site by the facility operator, who compiles the data onto a daily log sheet. The daily log sheets are transmitted to PCRFCD staff on a weekly basis.

Appendix A contains the daily flow meter readings and volumes for Calendar Year 2016; note that there is a separate spreadsheet for meter readings at FM_{C2}, which officially started on December 12, 2016. Monthly, quarterly and annual volumes are provided at the bottom of the worksheets in both gallons and acre-feet. The total water volume delivered to MHPERP for Calendar Year 2016 was 627.2 acre-feet (AF), with a high of 100.22 AF in December and a low of 0.0 AF in August. Note that about 20 AF in December was delivered via the new gravity-feed pipeline (FM_{C2}). A total amount of 623.3 AF (after subtracting evaporation/evapotranspiration) was stored at the facility during the Calendar Year. This means that the maximum permitted amount of 600 AF was stored for the Pima County Regional Wastewater Reclamation Department, who has a Water Storage Permit (No. 73-563876.0200) for the facility.

2.3 Evaporation/Evapotranspiration

Appendix B displays the calculated monthly, quarterly and annual evaporation volumes for the recharge facility. These calculations are based on the Cooley Method (1970) using the "Maximum Curve", as approved by ADWR (also in **Appendix B**). Evaporation for each recharge cell is based on the percentage of open surface water that is not covered by vegetation. Daily and monthly wetted areas are provided in **Appendix C**.

Daily and monthly evapotranspiration volumes for the vegetated basins are provided in **Appendix D**. Evapotranspiration for each recharge cell was based on the percentage of vegetation within each basin, which was determined on a monthly basis during routine site inspections. The evapotranspiration volumes are calculated using the daily reference evapotranspiration values determined by the Arizona Meteorological

[1] ADWR approval was provided via an email from Tracey L. Carpenter, Hydrologist with the Water Planning and Permitting Division, dated December 12, 2016.

Network (AZMET) at their Tucson weather station (**Figure 3**).[2] AZMET determines reference evapotranspiration (ETo) using a modification to the Penman Equation developed for the California Irrigation Management Information System (CIMIS). An explanation of the procedures used in this computation is also provided in **Appendix D**. No multiplication factor was used in the calculation of reference evapotranspiration (ETo) for the MHPERP because there are no available crop coefficients for the native vegetation in this region.[3]

2.4 Recharge Volumes

The water quantity reporting summary is provided at the end of **Appendix A**. This summary includes the monthly net recharge volumes for the facility, which are the sum of the monthly volumes delivered to the recharge cells less the monthly evaporation and evapotranspiration losses. Quarterly sums and the annual sum are also provided on this worksheet. The net recharge (effluent stored) for the facility during the 2016 Calendar Year is 623.3 AF.

3.0 HYDROLOGIC MONITORING

Hydrologic monitoring of the facility includes measurement of on-site and off-site groundwater levels and direct observation of basin water levels. The on-site monitoring network consists of one monitor well and one piezometer, both measured monthly using a depth sounder (**Figure 4**). Off-site monitoring consists of quarterly water level measurements for one monitor well, SC-10.

3.1 Basin Water Levels

Water levels within the equalization basin are expected to fluctuate from one to five feet above the bottom elevation of 1,984 feet above mean sea level. Water depths in Recharge Cells 1 and 3 can fluctuate from 4 to 5 feet during the wet cycle, while water depths in Recharge Cell 2 can fluctuate from about 5 to 6 feet during the wet cycle.[4] Water depths in Recharge Cell 4 are expected to fluctuate from six to twenty inches during the wet cycles.[5] Water levels within the basins are maintained manually by the facility operator to maintain high infiltration rates, as determined by PCRFCD staff based on basin performance, and as needed to prevent overflows.

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[2] The Marana weather station has been out of service since December 14, 2011 so reference evapotranspiration values were collected from the Tucson weather station for Calendar Year 2016.

[3] The reference evapotranspiration (ET) values are determined for tall (8-15”), cool season grasses. Much of the vegetation in Recharge Cells 3 and 4 consists mostly of shrubs and grasses that are approximately 8-15” in height. Since no information is available for the species at MHPERP, it is assumed that ET losses at this facility are the same as those calculated at the AZMET station.

[4] Depths to the bottoms of these three basins have been significantly increased due to enhancement activities, but water levels primarily range from only one-half to two feet because of greater infiltration rates and shorter wetting cycles.

[5] Water depths are measured from a base elevation of 1982 feet above mean sea level. The bottom of the basin has been lowered approximately 8-10 inches by regular maintenance activities to remove vegetation and clogging soil layers.

3.2 Regional Groundwater Levels

In 2016, groundwater levels were measured for two monitoring wells, one on-site (HP-1) and one off-site (SC-10). Both wells were measured by PCRFCD personnel using either an electric sounder or contact meter. HP-1 was measured on a monthly basis and SC-10 was measured on a quarterly basis.

Appendix E contains the water level data and hydrographs for the on-site and off-site monitor wells. All of the monitor wells have alert levels of 30 feet below land surface (bls) and operation prohibition limits of 20 feet bls. Alert levels for the monitoring wells were not exceeded during the 2016 Calendar Year. Water levels in the on-site deep well (HP-1) fluctuated from 192.8 feet below land surface (bls) in January 2015 to a low of 201.8 feet bls in July 2016, and then up to 192.2 feet bls in December 2016. Water levels in the off-site monitor well (SC-10) dropped from 194.7 feet bls in March 2016 to 198.8 feet bls in June 2016, and then went up to 192.2 feet bls by December 2016.

3.3 Perched Groundwater Occurrence

Appendix E also contains the monitoring data and hydrograph for the one piezometer (HP-2) used to assess perched water conditions at the facility. This well was dry at its total depth of 80 feet bls during the entire 2016 Calendar Year. The alert level and operation prohibition limit for this well are set at 30 feet bls and 20 feet bls respectively.

4.0 INFILTRATION RATE ASSESSMENT

The average monthly, quarterly and annual infiltration rates for the entire facility during the 2016 Calendar Year are displayed in **Appendix F**. Infiltration rates were estimated using the "volumetric" method, which is simply the total daily inflow divided by the wetted acreage. Total wetted acreage for the facility is a summation of the wetted acreages for the individual recharge cells, described below.

Average monthly, quarterly and annual infiltration rates for each of the recharge cells are also displayed in **Appendix F**. The total wetted acreage used to calculate the infiltration rate within each recharge cell is determined using observations made by the daily operator combined with known topography of the recharge cell bottom. Rating curves, calculated using topography of the site, are used to estimate the percentage of wetted area in each recharge cell. The percent wetted area is then multiplied by the total basin acreage to calculate the wetted acreage.

Water levels within the equalization basin are determined visually by the facility operator using a staff gauge. The data is recorded onto daily logs and provided to PCRFCD on a monthly basis. Infiltration rates are then calculated using the same methods as for the recharge cells described above.

In 2016, monthly infiltration rates for the project ranged from 0.00 feet per day (August-no water delivered) to 4.85 feet per day (June). The average infiltration rate for the year was 3.34 feet/day, which is 0.72 feet/day higher than last year's average and is the highest annual infiltration rate ever recorded at this facility. Infiltration rates were greater than 2.8 feet/day in every month except January, February and August; note that deliveries in these months were very limited due to washouts of the diversion berm and maintenance activities. The exceptionally high monthly rates are most likely a function of numerous stoppages to effluent deliveries throughout the year, thus allowing the basins to dry, coupled with the deepening of the basins (exposure to coarser materials) in previous years and improved effluent quality.

Infiltration was the highest in Recharge Cell 1 (over 14 feet/day annual average), which was over-excavated in September 2013 to remove fine grained materials and expose coarser sands and gravels. Recharge Cells 2 and 3 also had high rates, 7.5 feet/day and 9.5 feet/day respectively, due to continued exposure of sands and gravels from modifications during previous years. Recharge Cell 4 still has the greatest depth to coarse sands and gravels, approximately 7.5 to 8 feet, which accounts for its lower average annual infiltration rate of about 2.9 feet per day in 2016, although this rate is significantly higher than in previous years. The equalization basin had the lowest annual average infiltration rate (0.1 feet/day), but this is primarily due to its function as a settling basin for fine deposits from effluent deliveries into the facility.

5.0 WATER QUALITY MONITORING

5.1 Water Quality Sampling Activities

The Aquifer Protection Permit (APP) requires water quality samples to be collected and analyzed on a monthly basis for nutrients (Nitrogen constituents) and total coliform (presence/absence); on a quarterly basin for total metals, fluoride and cyanide; and on a semiannual basis for Volatile and Semi-Volatile Organic Compounds (VOCs and SVOCs). Samples are collected from the source water inflow and from monitor well HP-1. Nitrogen forms are monitored more frequently because of the high nitrogen content in effluent water, and the potential for recharge to increase the nitrogen content in the local aquifer through leaching of nearby agricultural soils. Water quality sampling at the MHPERP also serves as a tool for studying nitrogen transformations in riparian and aquatic ecosystems, to determine if nitrogen levels can be reduced through the wetland recharge process.

5.2 Chemical Analyses Results

Table 1 summarizes the results from samples taken during the 2016 Calendar Year. Samples were taken at the oxbow channel (Diversion) and at the compliance well (HP-1). Sampling at the diversion was disrupted in January and August due to washout of the diversion berm by storm water runoff events and in February by reconstruction of the wet well area. There were no disruptions in sample collection from HP-1.

There were no exceedances of the discharge limits or aquifer quality limits in 2016 for the Diversion and HP-1. Therefore, there were no violations of the Aquifer Protection Permit (APP) during Calendar Year 2016.

6.0 FACILITY INSPECTIONS

Inspections of the facility equipment and functions are no longer a requirement of the Aquifer Protection Permit (APP) for this facility since June 2014. However, PCRFCD continues to inspection the facility on a regular basis to insure proper functioning of the equipment and that any problems are dealt with in a timely manner. The facility operator at MHPERP continues to perform inspections on a daily basis while collecting data for PCRFCD, transmitting any problems or required maintenance through the daily logs delivered on a weekly basis to PCRFCD. PCRFCD staff is contacted immediately for any alarms or serious problems concerning the facility equipment. PCRFCD performs monthly investigations of the facility to insure quality of the data collected and to note any general maintenance needs.

Table 2 lists the problems that occurred during the 2016 Calendar Year and the actions performed to resolve them. The main disruption to effluent deliveries to the facility was a combination of a storm water runoff event along the Santa Cruz River in early January and a breech in the headwall of the wet well in February. As a result, very little recharge was recorded over the first three months of the year. A second major disruption to effluent deliveries occurred in late July due to washout of the diversion berm from storm water runoff, with effluent deliveries halted until September 21. The summer monsoon period (July through mid-September) is typically the major disruption of effluent deliveries to the facility every year. A few, small storm water runoff events occurred during the rest of the year causing washout of the berm, but it was easily repaired and caused only temporary disruptions in effluent delivery (total of 17 days).

7.0 CONCLUSIONS

The calculated volume of water stored at MHPERP for Calendar Year 2016 was 623.3 AF. This is 1.8 AF less than last year's total of 625.1 AF, but is the second highest total since operations began in 2003. This is the third consecutive year that the facility has reached its permitted total of 600 AF. The facility operated under Phase 3 of the modified USF Permit No. 71-563876.0007 for the entire Calendar Year, which allowed the District to store a maximum of 600 AF per year.

Monitoring of operations has showed no continuing exceedences of water quality standards (Drinking Water Standards) at the project site. On-site and off-site monitoring showed no negative impacts to surrounding operations from a water level perspective.

A significant improvement in infiltration observed in Recharge Cell 4 allowed its contribution to the total amount of effluent stored at the facility to increase from about 30% in 2015 to just over 36% in 2016. Note that effluent is supplied to this basin as much as possible to support the riparian vegetation surrounding its edges. Recharge Cells 1 and 3 continue to perform at a high level, contributing 22.7% and 26.3% respectively to the total amount of effluent stored at the facility over Calendar Year 2016. Although a very respectable infiltration rate was maintained in Recharge Cell 2 for the year (7.5 ft/day average), this cell was not used nearly as much as in previous years - only 13.4% contribution to the 2016 total compared to 33.5% contribution to the 2015 total. No maintenance was performed on the equalization basin, which provided less than 2% to the total project volume.

Infiltration rates for the facility were very good during 2016, maintaining a rate of over 2.8 feet/day during normal operations. The average annual infiltration rate for the entire facility in 2016 was 3.34 feet/day, which is 0.72 feet/day greater than the previous annual high of 2.62 feet/day recorded in 2015. Recharge Cell 1 had the highest annual infiltration rate in 2016 (14.24 feet/day), while Recharge Cell 4 had the lowest (2.87 feet/day).[6] Excavation within Recharge Cells 1-3 and thus exposure of coarse sands and gravels over

[6] The equalization basin actually had the lowest infiltration rate recorded (0.1 feet/day), but this basin is primarily used for purposes other than recharge to the aquifer so it is not included in the comparison of infiltration rates.

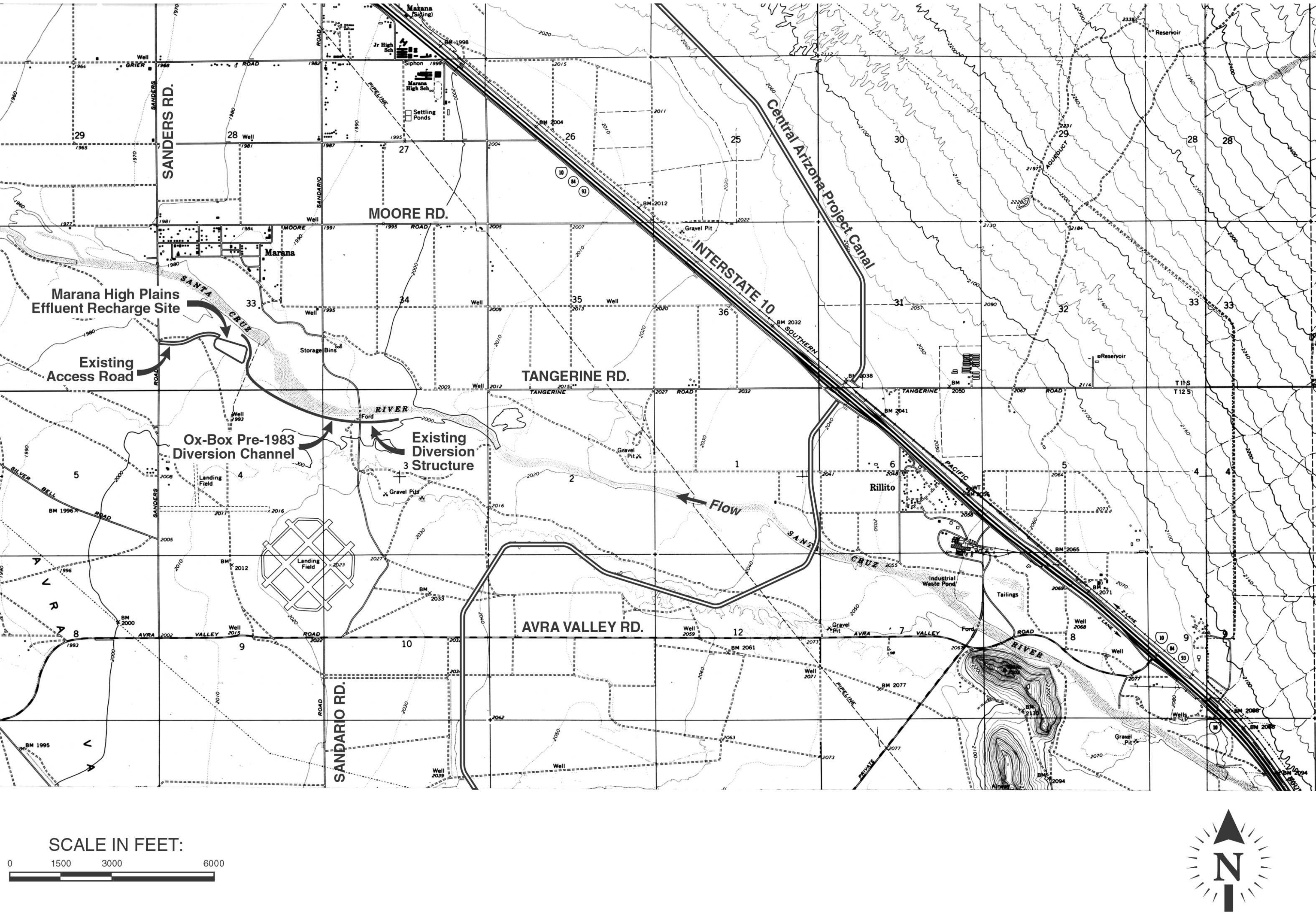
the last several years has significantly improved the overall infiltration rate for this facility. Higher quality effluent from the upstream treatment facilities has also significantly increased infiltration, as most notably shown by the greater overall infiltration rate within Recharge Cell 4, which has not been modified.

A total of 157 days (5.2 months) resulted in no effluent deliveries to the project. The majority of the down time (110 days or 70%) was due to washout of the diversion berm by storm water flows during the months of January and May through October. A total of 45 days were attributed to the breech and subsequent reconstruction of the wet well area, while the remaining 2 days of down time occurred at the end of the year when the facility was shut down after meeting its goal of 600 AF[7]. Greater exposure of sands and gravels in Recharge Basins 1-3 and a better quality effluent (lower turbidity and nutrients) delivered by the upstream treatment facilities has made the facility much more efficient; and the goal of 600 AF of recharge per annum more attainable. Addition of a new, gravity-feed distribution system into Recharge Cell 2 allows the project to operate without the use of electricity supplied by the local power company and independent of mechanical pumps that can break down or reduce in efficiency over time. Overall operating costs have been reduced.

[7] The facility met its goal of 600 AF prior to December 29 with the addition of the gravity-feed pipeline deliveries (FM_{C2}) on December 12. However, staff had not received the new permit, so deliveries from the pumps (FMeq) continued until the amount pumped reached a point where 600 AF net recharge was met.

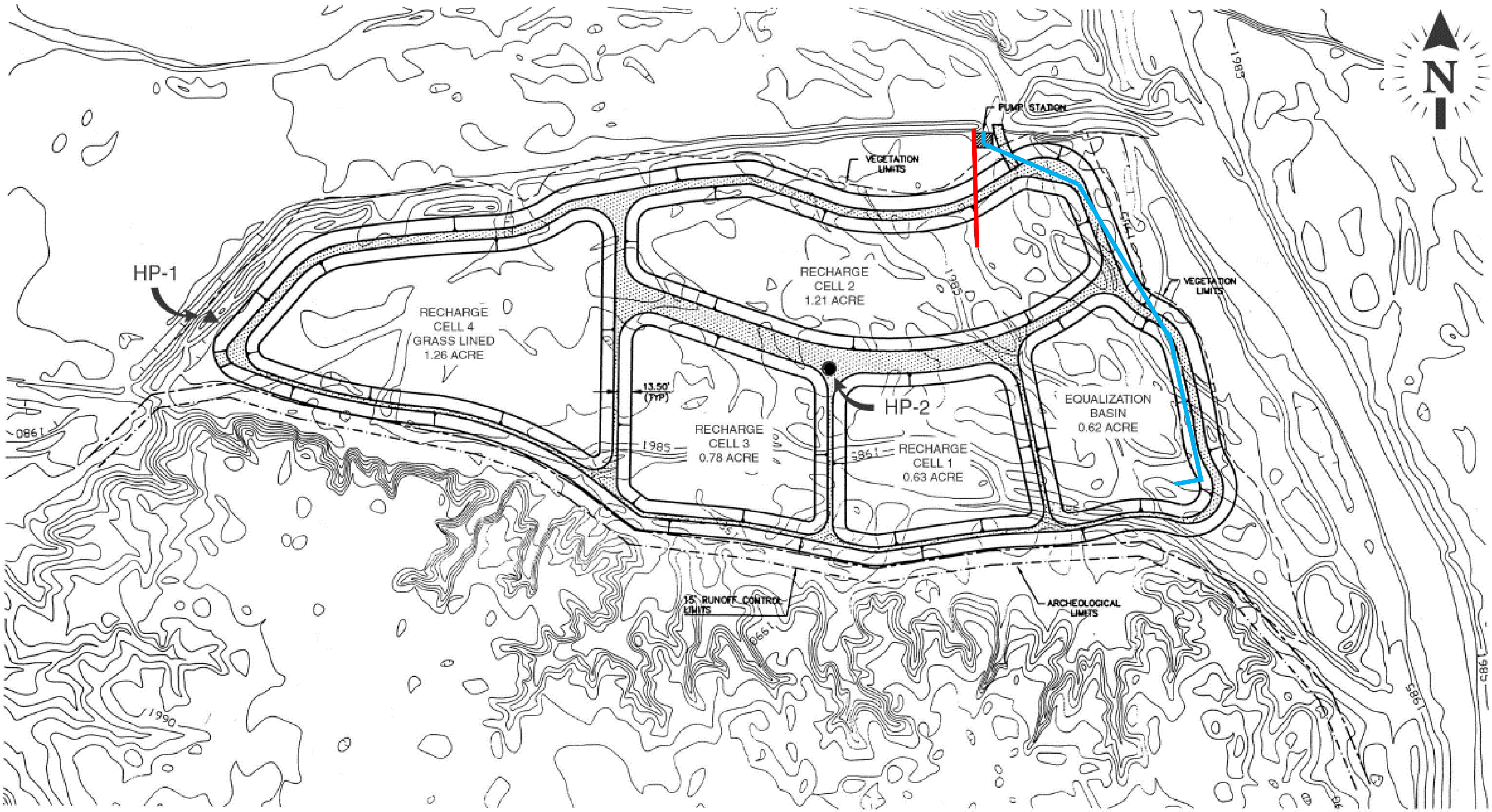
FIGURES

FIGURE 1
Location Map



Pima County Graphic Services db3483 7/02

FIGURE 2
Facility Map



SCALE IN FEET:

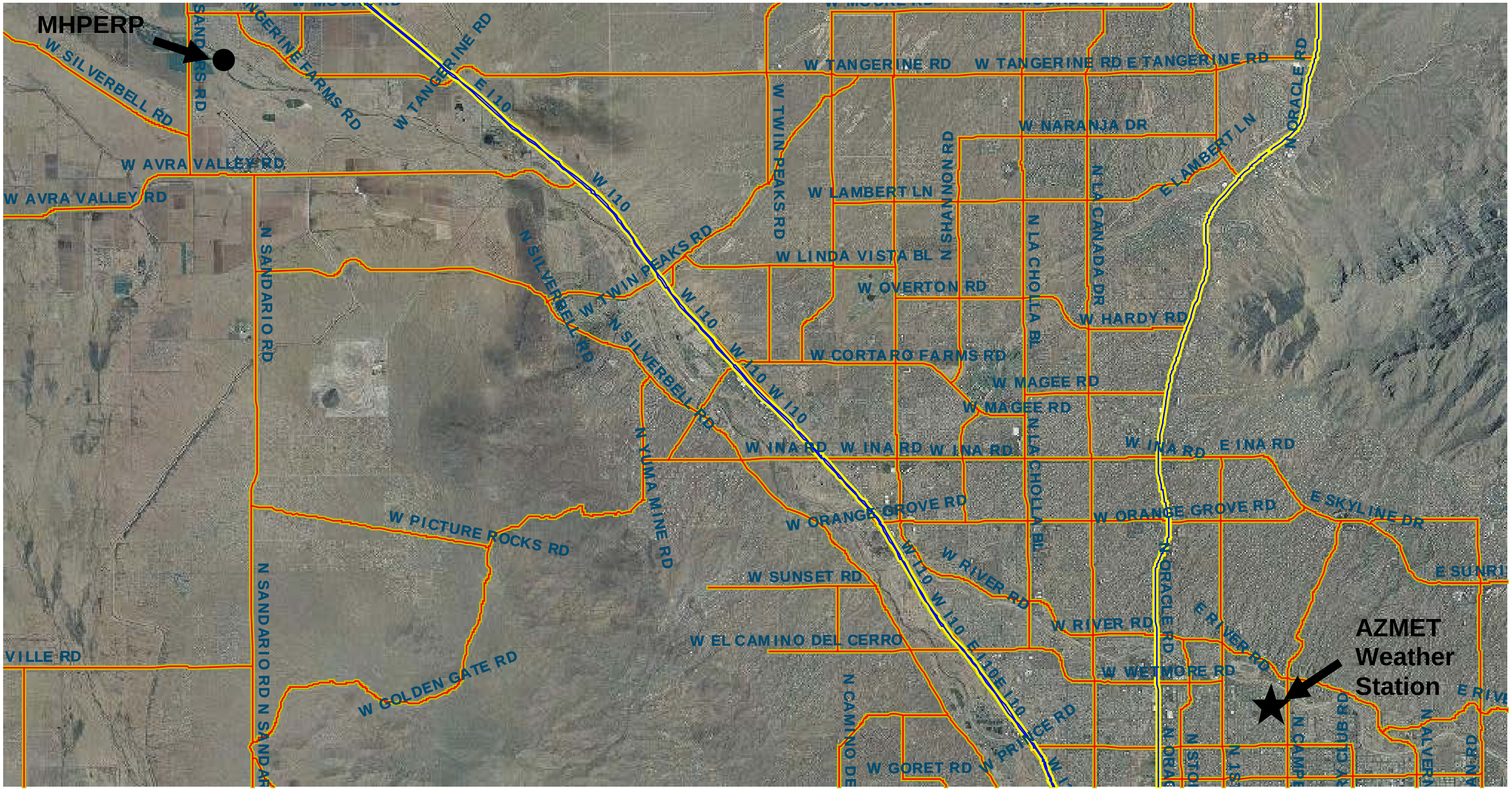
0 25 50 100

TOTAL RECHARGE AREA = 4.50 ACRES
ESTIMATED RECHARGE VOLUME = 600 ACRE-FT/YR

LEGEND

▲ MONITOR WELL
● PIEZOMETER
EXISTING CONVEYANCE (FMeq)
NEW CONVEYANCE (FM_{C2})

FIGURE 3
Tucson AZMET Weather Station
Location Map



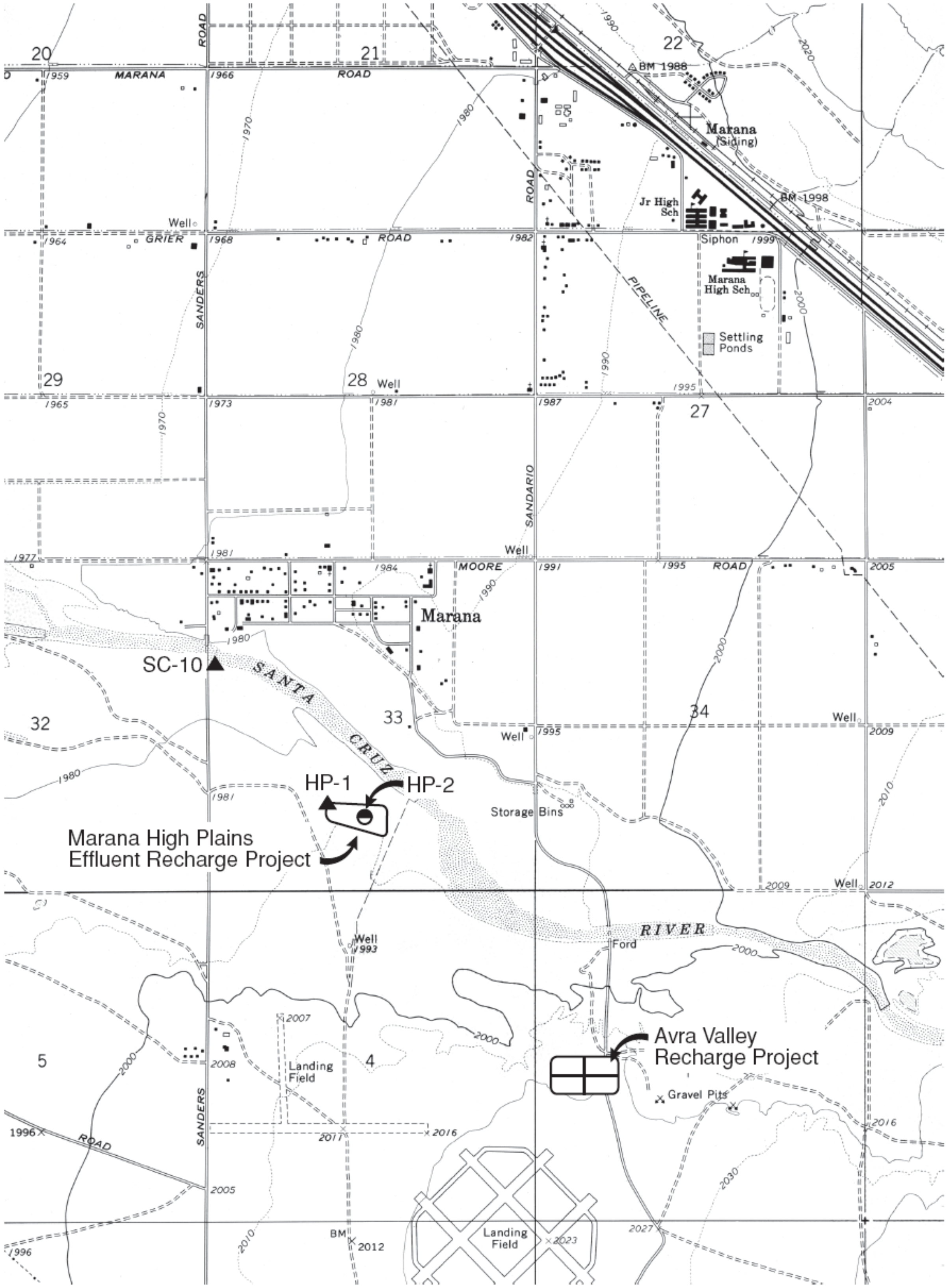
Date on line: Jan 1 1987 (Day of Year = 1)
Location: 1 km (p.6 miles) northwest of Intersection of Campbell Ave. & Roger Rd.
Elevation: 713 meters (2339 ft)
Coordinates: Latitude = 32º 16' 49" N; Longitude = 110º 56' 45" W
Cooperator: Campus Agricultural Center (CAC), College of Agri., Univ. of Arizona

N

Miles 1 2 4

SCALE

LEGEND
★ **Weather Station**



LEGEND

▲ MONITOR WELL

◓ PIEZOMETER

N

Miles .5 1 2

SCALE:

FIGURE 4
Marana High Plains
Effluent Recharge Project
Monitor Wells Location Map

TABLES

TABLE 1A
MARANA HIGH PLAINS EFFLUENT RECHARGE PROJECT
WATER QUALITY SUMMARY - SOURCE WATER DIVERSION
CALENDAR YEAR 2016

Constituent	Unit	Alert Level	Discharge Limit	Sample Date & Results											
				Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16
Nutrients															
Total Nitrogen[1]	mg/l	N/A	N/A	No Event	No Event	5.2	5.1	7.3	12.2	6.0	No Event	5.6	4.7	4.6	4.6
Nitrate-Nitrite as N	mg/l	N/A	N/A	No Event	No Event	3.5	3.0	2.5	4.5	3.8	No Event	3.6	3.1	2.7	2.8
Total Kjeldahl Nitrogen (TKN)	mg/l	N/A	N/A	No Event	No Event	1.7	2.1	4.8	7.7	2.2	No Event	2.0	1.6	1.9	1.8
Metals (Total)															
Free Cyanide	mg/l	0.16	0.2	No Event	No Event	< 0.05	No Event	< 0.05	No Event	No Event	No Event	< 0.05	No Event	No Event	< 0.05
Total Fluoride	mg/l	3.2	4	No Event	No Event	< 0.4	No Event	< 0.4	No Event	No Event	No Event	0.40	No Event	No Event	< 0.4
Arsenic	mg/l	0.04	0.05	No Event	No Event	0.0032	No Event	0.003	No Event	No Event	No Event	0.0039	No Event	No Event	0.0023
Barium	mg/l	1.6	2	No Event	No Event	0.053	No Event	0.05	No Event	No Event	No Event	0.79	No Event	No Event	0.039
Beryllium	mg/l	0.0032	0.004	No Event	No Event	< 0.001	No Event	< 0.001	No Event	No Event	No Event	< 0.001	No Event	No Event	< 0.001
Cadmium	mg/l	0.004	0.005	No Event	No Event	< 0.0001	No Event	< 0.0001	No Event	No Event	No Event	0.0001	No Event	No Event	< 0.0001
Chromium	mg/l	0.08	0.1	No Event	No Event	0.00065	No Event	0.0009	No Event	No Event	No Event	0.0018	No Event	No Event	0.0015
Lead	mg/l	0.04	0.05	No Event	No Event	0.00079	No Event	0.0014	No Event	No Event	No Event	0.0023	No Event	No Event	0.00095
Thallium	mg/l	0.0016	0.002	No Event	No Event	< 0.0001	No Event	< 0.0001	No Event	No Event	No Event	< 0.0001	No Event	No Event	< 0.0001
Nickel	mg/l	0.08	0.1	No Event	No Event	0.0022	No Event	0.0019	No Event	No Event	No Event	0.0025	No Event	No Event	0.0017
Antimony	mg/l	0.0048	0.006	No Event	No Event	< 0.0025	No Event	0.0047	No Event	No Event	No Event	< 0.001	No Event	No Event	< 0.001
Selenium	mg/l	0.04	0.05	No Event	No Event	0.00081	No Event	< 0.0005	No Event	No Event	No Event	0.00083	No Event	No Event	0.0005
Mercury	mg/l	0.0016	0.002	No Event	No Event	< 0.0002	No Event	< 0.0002	No Event	No Event	No Event	< 0.0002	No Event	No Event	<0.0002
Volatile Organic Compounds (VOCs)															
para-Dichlorobenzene	mg/l	0.06	0.075	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Dichloromethane	mg/l	0.004	0.005	No Event	No Event	No Event	< 0.003	No Event	No Event	No Event	No Event	No Event	< 0.003	No Event	No Event
o-Dichlorobenzene	mg/l	0.48	0.6	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Carbon tetrachloride	mg/l	0.004	0.005	No Event	No Event	No Event	< 0.003	No Event	No Event	No Event	No Event	No Event	< 0.003	No Event	No Event
Toluene	mg/l	0.8	1	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Benzene	mg/l	0.004	0.005	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Monochlorobenzene	mg/l	0.08	0.1	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Ethylbenzene	mg/l	0.56	0.7	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Tetrachloroethylene	mg/l	0.004	0.005	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
1,1-Dichloroethylene	mg/l	0.0056	0.007	No Event	No Event	No Event	< 0.005	No Event	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event
1,1,1-Trichloroethane	mg/l	0.16	0.2	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
1,1,2-Trichloroethane	mg/l	0.004	0.005	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
1,2-Dichloroethane	mg/l	0.004	0.005	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
1,2-Dichloropropane	mg/l	0.004	0.005	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
1,2,4-Trichlorobenzene	mg/l	0.056	0.07	No Event	No Event	No Event	< 0.005	No Event	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event
Vinyl Chloride	mg/l	0.0016	0.002	No Event	No Event	No Event	< 0.001	No Event	No Event	No Event	No Event	No Event	< 0.001	No Event	No Event
Trichloroethylene	mg/l	0.004	0.005	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Hexachlorobenzene	mg/l	0.0008	0.001	No Event	No Event	No Event	< 0.0008	No Event	No Event	No Event	No Event	No Event	< 0.0008	No Event	No Event
cis-1,2-Dichloroethylene	mg/l	0.05	0.07	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Styrene	mg/l	0.08	0.1	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Xylenes (Total)	mg/l	8	10	No Event	No Event	No Event	< 0.01	No Event	No Event	No Event	No Event	No Event	< 0.01	No Event	No Event
Trihalomethane (TTHM)	mg/l	0.08	0.1	No Event	No Event	No Event	< 0.004	No Event	No Event	No Event	No Event	No Event	< 0.004	No Event	No Event
trans-1,2-Dichloroethylene	mg/l	0.08	0.1	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Hexachlorocyclopentadiene	mg/l	0.04	0.05	No Event	No Event	No Event	< 0.005	No Event	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event

No Event = No sample taken (No flow, HP-1 pump not operating, or no testing required)
No Set Alert Levels per APP #103195
[1] Total Nitrogen = Nitrate-Nitrite as N + TKN (APP #103195)

TABLE 1B
MARANA HIGH PLAINS EFFLUENT RECHARGE PROJECT
WATER QUALITY SUMMARY - COMPLIANCE WELL HP-1
CALENDAR YEAR 2016

Constituent	Unit	Alert Level	Aquifer Quality Limit	Sample Date & Results											
				Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16
Nutrients															
Total Nitrogen[1]	mg/l	8	10	2.6	1.4	1.5	1.6	1.5	1.4	1.4	1.6	2.45	1.6	1.7	1.6
Nitrate-Nitrite as N	mg/l	8	10	2.6	1.4	1.5	1.6	1.5	1.4	1.4	1.6	1.6	1.6	1.7	1.6
Total Kjeldahl Nitrogen (TKN)	mg/l	N/A	N/A	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	0.85	< 0.5	< 0.5	< 0.5
Total Coliform (P-Present, A-Absent)	P/A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Metals (Total)															
Free Cyanide	mg/l	0.16	0.2	No Event	< 0.05	No Event	No Event	< 0.05	No Event	No Event	No Event	< 0.05	No Event	No Event	< 0.05
Total Fluoride	mg/l	3.2	4	No Event	< 0.4	No Event	No Event	< 0.4	No Event	No Event	No Event	< 0.4	No Event	No Event	< 0.04
Arsenic	mg/l	0.04	0.05	No Event	0.0014	No Event	No Event	0.0013	No Event	No Event	No Event	0.0018	No Event	No Event	0.0014
Barium	mg/l	1.6	2	No Event	0.1	No Event	No Event	0.099	No Event	No Event	No Event	0.084	No Event	No Event	0.096
Beryllium	mg/l	0.0032	0.004	No Event	< 0.001	No Event	No Event	< 0.001	No Event	No Event	No Event	< 0.001	No Event	No Event	< 0.001
Cadmium	mg/l	0.004	0.005	No Event	< 0.0001	No Event	No Event	< 0.0001	No Event	No Event	No Event	< 0.0001	No Event	No Event	< 0.0001
Chromium	mg/l	0.08	0.1	No Event	< 0.0005	No Event	No Event	< 0.0005	No Event	No Event	No Event	< 0.0005	No Event	No Event	< 0.0005
Lead	mg/l	0.04	0.05	No Event	< 0.0005	No Event	No Event	0.0011	No Event	No Event	No Event	< 0.0005	No Event	No Event	< 0.0005
Thallium	mg/l	0.0016	0.002	No Event	< 0.0001	No Event	No Event	< 0.0001	No Event	No Event	No Event	< 0.0001	No Event	No Event	< 0.0001
Nickel	mg/l	0.08	0.1	No Event	< 0.0005	No Event	No Event	0.00061	No Event	No Event	No Event	< 0.0005	No Event	No Event	< 0.0005
Antimony	mg/l	0.0048	0.006	No Event	< 0.0025	No Event	No Event	0.00013	No Event	No Event	No Event	< 0.001	No Event	No Event	< 0.001
Selenium	mg/l	0.04	0.05	No Event	0.0012	No Event	No Event	0.0001	No Event	No Event	No Event	0.0011	No Event	No Event	0.00098
Mercury	mg/l	0.0016	0.002	No Event	< 0.0002	No Event	No Event	< 0.0002	No Event	No Event	No Event	< 0.0002	No Event	No Event	< 0.0002
Volatile Organic Compounds (VOCs)															
para-Dichlorobenzene	mg/l	0.06	0.075	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Dichloromethane	mg/l	0.004	0.005	No Event	No Event	No Event	< 0.003	No Event	No Event	No Event	No Event	No Event	< 0.003	No Event	No Event
o-Dichlorobenzene	mg/l	0.48	0.6	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Carbon tetrachloride	mg/l	0.004	0.005	No Event	No Event	No Event	< 0.003	No Event	No Event	No Event	No Event	No Event	< 0.003	No Event	No Event
Toluene	mg/l	0.8	1	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Benzene	mg/l	0.004	0.005	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Monochlorobenzene	mg/l	0.08	0.1	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Ethylbenzene	mg/l	0.56	0.7	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Tetrachloroethylene	mg/l	0.004	0.005	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
1,1-Dichloroethylene	mg/l	0.0056	0.007	No Event	No Event	No Event	< 0.005	No Event	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event
1,1,1-Trichloroethane	mg/l	0.16	0.2	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
1,1,2-Trichloroethane	mg/l	0.004	0.005	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
1,2-Dichloroethane	mg/l	0.004	0.005	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
1,2-Dichloropropane	mg/l	0.004	0.005	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
1,2,4-Trichlorobenzene	mg/l	0.056	0.07	No Event	No Event	No Event	< 0.005	No Event	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event
Vinyl Chloride	mg/l	0.0016	0.002	No Event	No Event	No Event	< 0.001	No Event	No Event	No Event	No Event	No Event	< 0.001	No Event	No Event
Trichloroethylene	mg/l	0.004	0.005	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Hexachlorobenzene	mg/l	0.0008	0.001	No Event	No Event	No Event	< 0.0008	No Event	No Event	No Event	No Event	No Event	< 0.00085	No Event	No Event
cis-1,2-Dichloroethylene	mg/l	0.05	0.07	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Styrene	mg/l	0.08	0.1	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Xylenes (Total)	mg/l	8	10	No Event	No Event	No Event	< 0.01	No Event	No Event	No Event	No Event	No Event	< 0.01	No Event	No Event
Trihalomethane (TTHM)	mg/l	0.08	0.1	No Event	No Event	No Event	< 0.004	No Event	No Event	No Event	No Event	No Event	< 0.004	No Event	No Event
trans-1,2-Dichloroethylene	mg/l	0.08	0.1	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Hexachlorocyclopentadiene	mg/l	0.04	0.05	No Event	No Event	No Event	< 0.005	No Event	No Event	No Event	No Event	No Event	< 0.0053	No Event	No Event

No Event = No sample taken (No flow, HP-1 pump not operating, or no test required)
1 Total Nitrogen = Nitrate-Nitrite as N + TKN (APP #103195)

TABLE 2
MARANA HIGH PLAINS EFFLUENT RECHARGE PROJECT
FACILITY INSPECTIONS: PROBLEMS AND RELATED SOLUTIONS
CALENDAR YEAR 2016

Date	Problem	Solution
January 5, 2016	No flow in the oxbow channel	Diversion berm washed out due to storm water runoff during the afternoon. Berm was repaired on February 7, 2016 and recharge operations were restarted on February 9, 2016.
February 11, 2016	Headwall to the outlet culverts in wet well area was breeched due to undermining effluent base flows through corroded pipes.	Wet well area was reconstructed: outlet pipes were replaced, a new concrete headwall was created along with a concrete bottom floor; the diversion berm was breeched to allow for construction, which was completed on March 21, 2016. The diversion berm was repaired on March 28th and effluent deliveries to the project were restarted on March 29th.
June 7, 2016	Compliance well is not supplying any water to collect samples for water quality testing	The pump and discharge pipes were pulled and inspected on June 21, 2016. A fairly large hole was observed at the connection with the pump, so the pipe was replaced and the pump set back in the well. The well produced water again and samples were collected on June 22, 2016 for APP compliance testing.
June 11, 2016	Pumps are not pumping due to malfunctioning starter switches	The starter switches were bypassed to allow for continued water deliveries until they could be replaced. The starter switches were replaced by June 25, 2016.
June 27, 2016	No water in the oxbow channel due to washout of the diversion berm	The diversion berm was repaired and effluent deliveries to the facility were restarted on July 6, 2016.
July 27, 2016	Significant vegetative growth along the maintenance road is beginning to limit access into the facility.	Landscape maintenance was performed in September to clear vegetation from the roadway and around all of the electrical structures, compliance well and rain gauge.
July 28, 2016	No flow in the oxbow channel	Diversion berm was washed out by significant storm water runoff on July 27, 2015. The diversion berm was repaired and facility operations were restarted on September 21, 2016.
September 28, 2016	No flow in the oxbow channel	Diversion berm was washed out by significant storm water runoff on September 27, 2016. The diversion berm was repaired and facility operations were restarted on October 5, 2016.

APPENDIX A

Daily Flow Volumes &
Water Quantity Summary

USF DAILY FLOWMETER READINGS AND VOLUMES

Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Meter ID: Fm-eq
Year: 2016

	January		February		March		April		May		June	
	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons
	75311217		79492200		81254500		82014388		112525000		139388354	
Day 1	76300878	989661	79492200	0	81254500	0	83078653	1064265	113509100	984100	**140412438**	1024084
2	77294038	993160	79492200	0	81254500	0	84122180	1043527	114483500	974400	141443163	1030725
3	78242267	948229	79492200	0	81254500	0	85165184	1043004	115469860	986360	142476868	1033705
4	79189178	946911	79492200	0	81254500	0	86215000	1049816	116464440	994580	143469283	992415
5	79492200	303022	79492200	0	81254500	0	87263327	1048327	117461761	997321	144461382	992099
6	79492200	0	79492200	0	81254500	0	88322250	1058923	118427662	965901	145520308	1058926
7	79492200	0	79492200	0	81254500	0	89377620	1055370	119427900	1000238	146562008	1041700
8	79492200	0	79492200	0	81254500	0	90409535	1031915	120407250	979350	147511808	949800
9	79492200	0	80195800	703600	81254500	0	91439028	1029493	121386240	978990	148504708	992900
10	79492200	0	80960875	765075	81254500	0	92468555	1029527	122372140	985900	149494768	990060
11	79492200	0	81254500	293625	81254500	0	93503300	1034745	123355800	983660	149665288	170520
12	79492200	0	81254500	0	81254500	0	94550790	1047490	124306860	951060	149665288	0
13	79492200	0	81254500	0	81254500	0	95582340	1031550	125295600	988740	149665288	0
14	79492200	0	81254500	0	81254500	0	96618140	1035800	126277960	982360	149665288	0
15	79492200	0	81254500	0	81254500	0	97605880	987740	127260780	982820	150309608	644320
16	79492200	0	81254500	0	81254500	0	98623430	1017550	128237940	977160	151307948	998340
17	79492200	0	81254500	0	81254500	0	99641100	1017670	129237080	999140	152292976	985028
18	79492200	0	81254500	0	81254500	0	100608300	967200	130219340	982260	153281242	988266
19	79492200	0	81254500	0	81254500	0	101615220	1006920	131206940	987600	154269588	988346
20	79492200	0	81254500	0	81254500	0	102608890	993670	132196150	989210	155260927	991339
21	79492200	0	81254500	0	81254500	0	103615260	1006370	133189650	993500	156258198	997271
22	79492200	0	81254500	0	81254500	0	104649760	1034500	134182880	993230	157238025	979827
23	79492200	0	81254500	0	81254500	0	105614225	964465	135194610	1011730	158227127	989102
24	79492200	0	81254500	0	81254500	0	106578690	964465	136177944	983334	159211498	984371
25	79492200	0	81254500	0	81254500	0	107565890	987200	136723500	545556	160090225	878727
26	79492200	0	81254500	0	81254500	0	108557979	992089	136723500	0	160962760	872535
27	79492200	0	81254500	0	81254500	0	109557520	999541	136723500	0	161392588	429828
28	79492200	0	81254500	0	81254500	0	110548525	991005	136723500	0	161392588	0
29	79492200	0	81254500		81254500	0	111540525	992000	137395166	671666	161392588	0
30	79492200	0			81257400	2900	112525000	984475	138348350	953184	161392588	0
31	79492200	0			82014388	756988			139388354	1040004		
	Total (gal)	**4180983**	**Total (gal)**	**1762300**	**Total (gal)**	**759888**	**Total (gal)**	**30510612**	**Total (gal)**	**26863354**	**Total (gal)**	**22004234**
	Total (ac-ft)	**12.83**	**Total (ac-ft)**	**5.41**	**Total (ac-ft)**	**2.33**	**Total (ac-ft)**	**93.63**	**Total (ac-ft)**	**82.44**	**Total (ac-ft)**	**67.53**

1st Qtr Total (gal) =	**6703171**
1st Qtr Total (ac-ft) =	**20.57**

2nd Qtr Total (gal) =	**79378200**
2nd Qtr Total (ac-ft) =	**243.60**

USF DAILY FLOWMETER READINGS AND VOLUMES

Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Meter ID: Fm-eq
Year: 2016

	July		August		September		October		November		December	
	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons
	161407500		183167200		183167200		190855600		217431805		247055469	
Day 1	161407500	0	183167200	0	183167200	0	190855600	0	218476523	1044717.5	248000069	944600
2	161407500	0	183167200	0	183167200	0	190855600	0	219521190	1044667.5	248945669	945600.2
3	161407500	0	183167200	0	183167200	0	190855600	0	220508540	987350	249884269	938600
4	161407500	0	183167200	0	183167200	0	190855600	0	221511340	1002800	250823369	939100.2
5	161407500	0	183167200	0	183167200	0	191624420	768820	222499870	988530	251741469	918100
6	162197347	789847	183167200	0	183167200	0	192673050	1048630	223488440	988570	252688920	947450.8
7	163245747	1048400	183167200	0	183167200	0	193758200	1085150	224479240	990800	253623460	934540
8	164286050	1040303	183167200	0	183167200	0	194792570	1034370	225468075	988835	254565269	941808.8
9	165302780	1016730	183167200	0	183167200	0	195827060	1034490	226439550	971475	255509740	944471.2
10	166319510	1016730	183167200	0	183167200	0	196854730	1027670	227426170	986620	256440740	931000
11	167361045	1041535	183167200	0	183167200	0	197881200	1026470	228418020	991850	257372200	931460
12	168393780	1032735	183167200	0	183167200	0	198945560	1064360	229395150	977130	258284678	912478.2
13	169411067	1017287	183167200	0	183167200	0	199952620	1007060	230372180	977030	259188870	904191.8
14	170426540	1015473	183167200	0	183167200	0	200991140	1038520	231361280	989100	260105040	916170
15	171445520	1018980	183167200	0	183167200	0	202032995	1041855	232347950	986670	261030447	925407.2
16	172463780	1018260	183167200	0	183167200	0	203074790	1041795	233327700	979750	261927930	897482.8
17	173482400	1018620	183167200	0	183167200	0	204103780	1028990	234241890	914190	262789830	861900
18	174478840	996440	183167200	0	183167200	0	205131570	1027790	235134937	893046.7	263652020	862190
19	175471100	992260	183167200	0	183167200	0	206164360	1032790	236169100	1034163.3	264516880	864860
20	176477300	1006200	183167200	0	183167200	0	207185850	1021490	237202490	1033390.4	265382720	865840
21	177452700	975400	183167200	0	183764970	597770	208199650	1013800	238263100	1060609.6	266253945	871225
22	178470710	1018010	183167200	0	184820820	1055850	209230580	1030930	239305630	1042530	267117345	863400
23	179476475	1005765	183167200	0	185898220	1077400	210261330	1030750	240371160	1065530	267971940	854595
24	180482200	1005725	183167200	0	186939425	1041205	211267700	1006370	241353715	982555	268852028	880088
25	181494320	1012120	183167200	0	187980660	1041235	212283950	1016250	242322167	968452	269730748	878719.4
26	182483440	989120	183167200	0	189057680	1077020	213312140	1028190	243277094	954927.4	270660860	930112.6
27	183167200	683760	183167200	0	190074870	1017190	214332158	1020018	244232340	955245.6	271582211	921351.2
28	183167200	0	183167200	0	190855600	780730	215030100	697942	245193770	961430	272509100	926888.8
29	183167200	0	183167200	0	190855600	0	215605700	575600	246117030	923260	273173000	663900
30	183167200	0	183167200	0	190855600	0	216452770	847070	247055469	938438.8	273173000	0
31	183167200	0	183167200	0			217431805	979035			273173000	0
	Total (gal)	**21759700**	**Total (gal)**	**0**	**Total (gal)**	**7688400**	**Total (gal)**	**26576205**	**Total (gal)**	**29623663.8**	**Total (gal)**	**26117531.2**
	Total (ac-ft)	**66.78**	**Total (ac-ft)**	**0.00**	**Total (ac-ft)**	**23.59**	**Total (ac-ft)**	**81.56**	**Total (ac-ft)**	**90.91**	**Total (ac-ft)**	**80.15**

3rd Qtr Total (gal) =	**29448100**
3rd Qtr Total (ac-ft) =	**90.37**

4th Qtr Total (gal) =	**82317400**
4th Qtr Total (ac-ft) =	**252.62**
Annual Total Del. Vol for FM-eq (ac-ft) =	**607.17**

USF DAILY FLOWMETER READINGS AND VOLUMES

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0008

Meter ID: Fm-C2

Year: 2016

	January		February		March		April		May		June	
	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons
Day 1		0		0		0		0		0		0
2		0		0		0		0		0		0
3		0		0		0		0		0		0
4		0		0		0		0		0		0
5		0		0		0		0		0		0
6		0		0		0		0		0		0
7		0		0		0		0		0		0
8		0		0		0		0		0		0
9		0		0		0		0		0		0
10		0		0		0		0		0		0
11		0		0		0		0		0		0
12		0		0		0		0		0		0
13		0		0		0		0		0		0
14		0		0		0		0		0		0
15		0		0		0		0		0		0
16		0		0		0		0		0		0
17		0		0		0		0		0		0
18		0		0		0		0		0		0
19		0		0		0		0		0		0
20		0		0		0		0		0		0
21		0		0		0		0		0		0
22		0		0		0		0		0		0
23		0		0		0		0		0		0
24		0		0		0		0		0		0
25		0		0		0		0		0		0
26		0		0		0		0		0		0
27		0		0		0		0		0		0
28		0		0		0		0		0		0
29		0				0		0		0		0
30		0				0		0		0		0
31		0				0				0		
	Total (gal)	**0**	**Total (gal)**	**0**	**Total (gal)**	**0**	**Total (gal)**	**0**	**Total (gal)**	**0**	**Total (gal)**	**0**
	Total (ac-ft)	**0.00**	**Total (ac-ft)**	**0.00**	**Total (ac-ft)**	**0.00**	**Total (ac-ft)**	**0.00**	**Total (ac-ft)**	**0.00**	**Total (ac-ft)**	**0.00**

1st Qtr Total (gal) =	**0**
1st Qtr Total (ac-ft) =	**0.00**

2nd Qtr Total (gal) =	**0**
2nd Qtr Total (ac-ft) =	**0.00**

USF DAILY FLOWMETER READINGS AND VOLUMES

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0008

Meter ID: Fm-C2

Year: 2016

	July		August		September		October		November		December	
	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons
Day 1		0		0		0		0		0		0
2		0		0		0		0		0		0
3		0		0		0		0		0		0
4		0		0		0		0		0		0
5		0		0		0		0		0		0
6		0		0		0		0		0		0
7		0		0		0		0		0		0
8		0		0		0		0		0		0
9		0		0		0		0		0		0
10		0		0		0		0		0		0
11		0		0		0		0		0		0
12		0		0		0		0		0	945000	945000
13		0		0		0		0		0	1948000	1003000
14		0		0		0		0		0	2871000	923000
15		0		0		0		0		0	3787000	916000
16		0		0		0		0		0	4733000	946000
17		0		0		0		0		0	5392000	659000
18		0		0		0		0		0	5940000	548000
19		0		0		0		0		0	6408000	468000
20		0		0		0		0		0	6539000	131000
21		0		0		0		0		0	6539000	0
22		0		0		0		0		0	6539000	0
23		0		0		0		0		0	6539000	0
24		0		0		0		0		0	6539000	0
25		0		0		0		0		0	6539000	0
26		0		0		0		0		0	6539000	0
27		0		0		0		0		0	6539000	0
28		0		0		0		0		0	6539000	0
29		0		0		0		0		0	6539000	0
30		0		0		0		0		0	6539000	0
31		0		0				0			6539000	0
	Total (gal)	**0**	**Total (gal)**	**0**	**Total (gal)**	**0**	**Total (gal)**	**0**	**Total (gal)**	**0**	**Total (gal)**	**6539000**
	Total (ac-ft)	**0.00**	**Total (ac-ft)**	**0.00**	**Total (ac-ft)**	**0.00**	**Total (ac-ft)**	**0.00**	**Total (ac-ft)**	**0.00**	**Total (ac-ft)**	**20.07**

3rd Qtr Total (gal) =	**0**
3rd Qtr Total (ac-ft) =	**0.00**
4th Qtr Total (gal) =	**6539000**
4th Qtr Total (ac-ft) =	**20.07**
Annual Total Del. Vol for FM-eq (ac-ft) =	**20.07**

USF WATER QUANTITY REPORTING SUMMARY
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2016

	FM-eq Delivered Volumes (ac-ft)	FM-C2 Delivered Volumes (ac-ft)	Evaporation Losses (ac-ft)	Evapotranspiration Losses (ac-ft)	Net Recharge Volumes (ac-ft)	Quarterly Net Recharge Totals (ac-ft)
January	12.8	0.0	0.1	0.0	12.7	
February	5.4	0.0	0.1	0.0	5.3	
March	2.3	0.0	0.0	0.0	2.3	20.4
April	93.6	0.0	0.5	0.0	93.1	
May	82.4	0.0	0.8	0.1	81.5	
June	67.5	0.0	0.4	0.0	67.1	241.7
July	66.8	0.0	0.5	0.0	66.2	
August	0.0	0.0	0.0	0.0	0.0	
September	23.6	0.0	0.1	0.0	23.4	89.7
October	81.6	0.0	0.4	0.1	81.1	
November	90.9	0.0	0.3	0.0	90.6	
December	80.2	20.1	0.2	0.0	100.0	271.6

Annual Totals =	**607.2**	**20.1**	**3.6**	**0.4**	**623.3**

APPENDIX B

Evaporation Calculations & Cooley Method Description

USF EVAPORATION CALCULATIONS

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0008

Year: 2016

Basin ID	January Wetted Acres	Evap (AF)	February Wetted Acres	Evap (AF)	March Wetted Acres	Evap (AF)	April Wetted Acres	Evap (AF)	May Wetted Acres	Evap (AF)	June Wetted Acres	Evap (AF)
Equal. Basin	6	0.1	4	0.1	0	0.0	11	0.3	12	0.3	10	0.3
Cell 1	0	0.0	0	0.0	0	0.0	3	0.1	1	0.0	1	0.0
Cell 2	0	0.0	0	0.0	0	0.0	0	0.0	3	0.1	2	0.1
Cell 3	0	0.0	0	0.0	0	0.0	5	0.1	1	0.0	1	0.0
Cell 4	5	0.0	2	0.0	0	0.0	4	0.1	12	0.3	0	0.0
	12	**0.1**	**6**	**0.1**	**1**	**0.0**	**24**	**0.5**	**28**	**0.8**	**14**	**0.4**

1st Quarter Total Evap (AF) **=**	**0.2**
2nd Quarter Total Evap (AF) **=**	**1.7**

Cooley Adj. Fac	**0.95**

USF EVAPORATION CALCULATIONS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2016

Basin ID	July Wetted Acres	Evap (AF)	August Wetted Acres	Evap (AF)	September Wetted Acres	Evap (AF)	October Wetted Acres	Evap (AF)	November Wetted Acres	Evap (AF)	December Wetted Acres	Evap (AF)
Equal. Basin	10	0.3	0	0.0	3	0.1	9	0.2	10	0.1	11	0.1
Cell 1	1	0.0	0	0.0	0	0.0	0	0.0	1	0.0	4	0.0
Cell 2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	6	0.0
Cell 3	1	0.0	0	0.0	0	0.0	0	0.0	4	0.1	5	0.0
Cell 4	5	0.2	0	0.0	3	0.1	15	0.3	9	0.1	4	0.0
	17	**0.5**	**0**	**0.0**	**6**	**0.1**	**24**	**0.4**	**24**	**0.3**	**29**	**0.2**

3rd Quarter Total Evap (AF) **=**	**0.7**

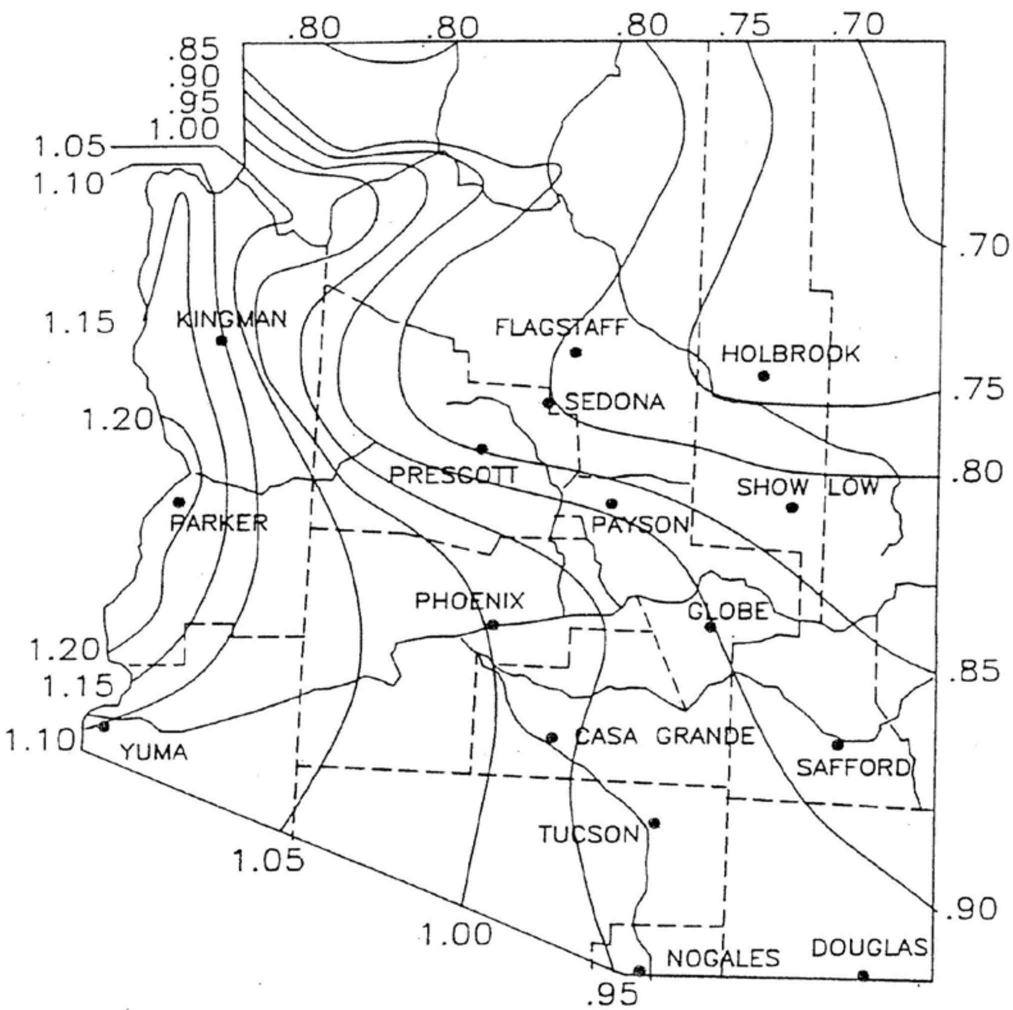
4th Quarter Total Evap (AF) **=**	**1.0**
Annual Total Evap (AF) **=**	**3.6**

COOLEY EVAPORATION INFORMATION

Cooley Monthly Maximum Evaporation Rates
from Cooley, 1970

Month	Maximum Evap Rate (inches)	Maximum Evap Rate (feet/day)	
January	3.6	0.009677	0.3
February	4.5	0.013393	0.375
March	6.5	0.017473	0.541667
April	8.4	0.023333	0.7
May	10.9	0.029301	0.908333
June	11.4	0.031667	0.95
July	11.8	0.031720	0.983333
August	10.5	0.028226	0.875
September	8.7	0.024167	0.725
October	7.0	0.018817	0.583333
November	4.8	0.013333	0.4
December	3.1	0.008333	0.258333

Cooley Evaporation Adjustment Factors for Arizona
from Cooley, 1970



ARIZONA DEPARTMENT OF WATER RESOURCES
HYDROLOGY DIVISION

TECHNICAL BULLETIN

Justification for using the Cooley Method Maximum Curve as the standard method for calculating evaporation losses at open-air underground storage facilities.

The Hydrology Division recommends using the Cooley Method with the Maximum Curve when calculating evaporative losses for spreading basins. This recommendation was derived for the following reasons:

- The Cooley Method is very consistent, in that, the daily evaporation rates and adjustment factors are fixed and do not change over time. This allows for a very simplified calculation method that is identical from year to year.
- The Cooley method is easy to use and can be adopted by a wide range of permittees and facilities. Especially as it relates to the collecting, reporting, and reviewing of the data and calculations. This has proven to be a benefit for new facility operators and changes in personnel at the Department. This is an important factor to consider when taking into account a duration of twenty years or longer for some facilities.
- The consistency of the Cooley Method makes it easy for the Department to review and verify calculation parameters when reviewing a new application and/or determining long term storage credits.
- The Cooley Method can be used without the Department demanding extraneous monitoring cost. The information required such as, wet/dry status of the basin(s) and the volume of water discharged are currently required in the USF permit for credit calculations and infiltration calculations.
- The Cooley Method unlike other empirical methods was designed specifically for Arizona.
- Other methods of determining evaporation can be very accurate, however, they are relatively expensive, requiring intensive measurements and calculation efforts to obtain evaporation values. In Hydrology's experience the difference between these methods and Cooley is negligible. This is especially true given the relatively small ratio of evaporation to the total amount of water recharged.
- The daily evaporation rates and adjustment factors, determined by Cooley, are used by the Arizona Department of Environmental Quality (ADEQ Engineering Bulletin No. 12). Thus having consistency between state agencies.

Justification for Using the Maximum Curve of the Cooley Method

- Using the maximum evaporation rate calculates evaporative loss less than the Class A pan evaporation data and greater than the normal evaporation curve. This produces a value that assures that all losses have been accounted for when calculating annual storage credits but is not over conservative.

- Class A pan data was one of the three sources used in preparing the Cooley Method. The corrections used in Class A pan calculations were calibrated to open water surfaces, considerably deeper than the average spreading basin. These deep open water bodies contain cooler water upwelling toward the surface causing a decrease in the evaporation rate. The spreading basins used in current recharge operations typically contain very shallow water (2 to 3 feet) that heats up fairly rapidly, thus increasing evaporative losses. Therefore, using the evaporation values calibrated for open water conditions would underestimate the evaporative losses in a spreading basin. The maximum evaporation rate more accurately estimates the evaporative losses for the conditions present at shallow recharge basins.

- Evaporation caused by the "wicking effect" may continue during dry cycles even when the basin does not contain standing water. The "wicking effect" process consists of water moving upward toward the surface due to the drying and heating of the ground above. This factor is not taken into account when using the normal values of evaporation, but is compensated for when using the maximum evaporation rate in calculations.

Attachments:

Evaporation from Open Water Surfaces in Arizona, K.R. Cooley, 1970

EVAPORATION FROM OPEN WATER SURFACES IN ARIZONA

Keith R. Cooley
Research Hydrologist
U. S. Water Convservation Laboratory, Soil and Water Conservation Research Division, Agricultural Research Service, U. S. Department of Agriculture.

Most people know that a considerable amount of water is lost by evaporation from open water surfaces in Arizona. However, they are amazed that, from a stock tank containing water 7 feet deep, the loss to evaporation in a year's time could be as much as 6 feet, leaving only one foot for livestock. On the other hand, declines in water level of 3 or 4 inches per day from fish ponds and swimming pools cannot be due entirely to evaporation.

Using the method outlined in this folder, the home owner, farmer, rancher, contractor, or consultant can estimate the amount of evaporation expected from an open, unfrozen water surface during any part of the year and for any location in Arizona. Results will generally be within 10 percent of actual evaporation on an annual basis.

How to Estimate Evaporation

Estimation of evaporation consists of three steps.

1. Select the average daily or average monthly evaporation for the period in question from Figure 1. For daily evaporation, choose one of the three curves, depending on whether you want maximum, normal, or minimum expected evaporation.

Values of average normal evaporation are shown in the bar graph as inches per month.

Use the curve representing normal evaporation for an estimate of expected evaporation under average conditions. However, for extremely hot windy periods, or cool cloudy periods, the curves representing maximum and minimum evaporation, respectively, will give a better estimate. The curves of maximum and minimum evaporation may also be of value when considering the possible range of seepage losses from water storage facilities.

2. Determine an adjustment factor from Figure 2 for the location in question. Read from the map the factor nearest the location in which you are interested.

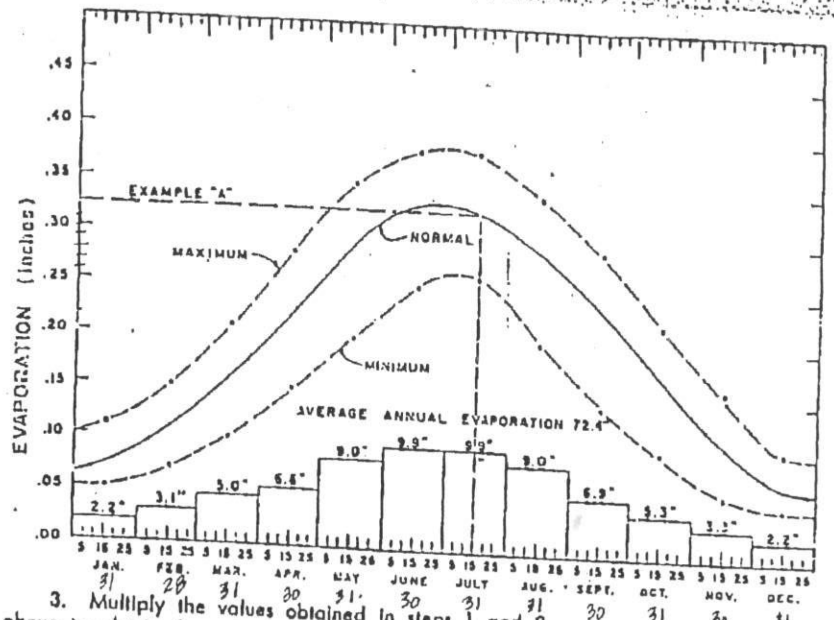


FIGURE 1. Maximum, Normal, and Minimum Daily Evaporation and Average Monthly Evaporation From Open Water Surfaces (Adjustment Factor = 1.00).

3. Multiply the values obtained in steps 1 and 2 above to obtain the estimated evaporation for the time and location in question.

For facilities with exposed walls, such as above-ground stock tanks and exposed-wall swimming pools, multiply the value obtained in step 3 above by 1.25, which is an average coefficient for the entire state for all types of exposed-wall structures.

Examples:

A. Wanted: Average daily normal evaporation from from a swimming pool in Tucson during July.
   Step 1. From Figure 1, average evaporation for July = 0.32 inches/day.
   Step 2. From Figure 2, adjustment factor = 0.95.
   Step 3. Multiply values obtained in steps 1 and 2 above: 0.32 x 0.95 = 0.3 inches/day = average daily evaporation during July in Tucson.

B. Wanted: Average normal evaporation from a fish pond in Phoenix during May and June.
   Step 1. From Figure 1, average evaporation for May and June = 9.0 and 9.9 inches, respectively.
   Step 2. Adjustment factor from Figure 2 for Phoenix = 1.0.

(See over)

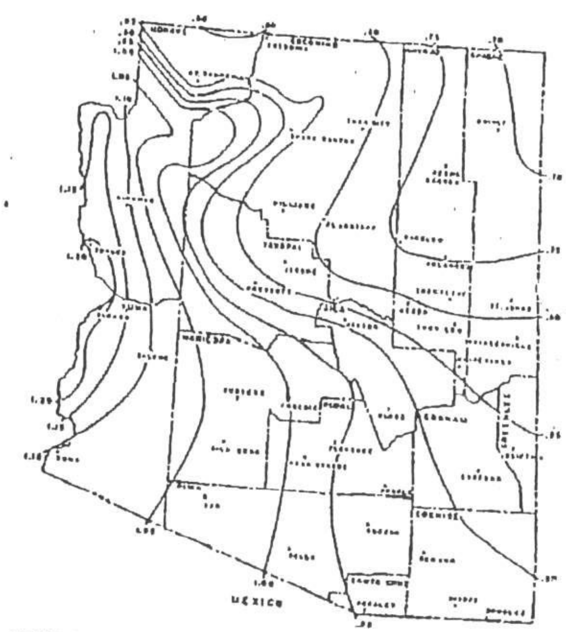


FIGURE 2. Evaporation Adjustment Factors for Arizona

Step 3. Multiply values obtained in steps 1 and 2 above: (9.0 x 1.0) + (9.9 x 1.0) = 18.9 or approximately 19 inches = total average evaporation for May and June.

C. Wanted: Maximum evaporation to be expected from a stock pond near Snowflake during May, June, and July.

Step 1. From the curve of maximum values in Figure 1, values for May, June, and July are: 0.35, 0.38, and 0.38 inches/day, respectively.

Step 2. From Figure 2, adjustment factor for Snowflake = 0.80.

Step 3. Multiply values obtained in steps 1 and 2 above times the number of days in each month:

May: 0.35 x 31 x 0.8 =	8.7
June: 0.38 x 30 x 0.8 =	9.1
July: 0.38 x 31 x 0.8 =	9.4
Total:	27.2 Inches

Maximum evaporation expected from a stock pond near Snowflake during May, June, and July is approximately 27 inches.

D. Wanted: Average normal evaporation from an exposed-wall swimming pool near Yuma during June.

Step 1. From Figure 1, average evaporation for June is 9.9 inches.

Step 2. From Figure 2, adjustment factor for Yuma = 1.10.

Step 3. Multiply values obtained in steps 1 and 2 above:
9.9 x 1.10 = 10.9 inches.

Step 4. Multiply by the coefficient for exposed-wall storage facilities, 1.25:
10.9 x 1.25 = 13.6 inches = average evaporation from an exposed-wall swimming pool at Yuma during June.

Acknowledgement

Data used in preparing this paper were obtained from three sources: (1) records of evaporation from sunken insulated evaporation pans at the U. S. Water Conservation Laboratory near Phoenix, Arizona, for the years 1966-1968, (2) records of evaporation from a Class A evaporation pan at the University of Arizona Mesa Experiment Farm for the years 1917-1967, and (3) evaporation maps of the United States based on 1946-1955 data.

Special acknowledgement is made to Mr. Paul C. Kangieser, U. S. Weather Bureau Climatologist, for supplying records of evaporation recorded at the Mesa Experiment Farm.

This publication is issued by the Cooperative Extension Service and the Agricultural Experiment Station of The University of Arizona. See your local County Extension Agent for additional information.

EVAPORATION FROM OPEN WATER SURFACES IN ARIZONA

FOLDER 159

Agricultural Experiment Station

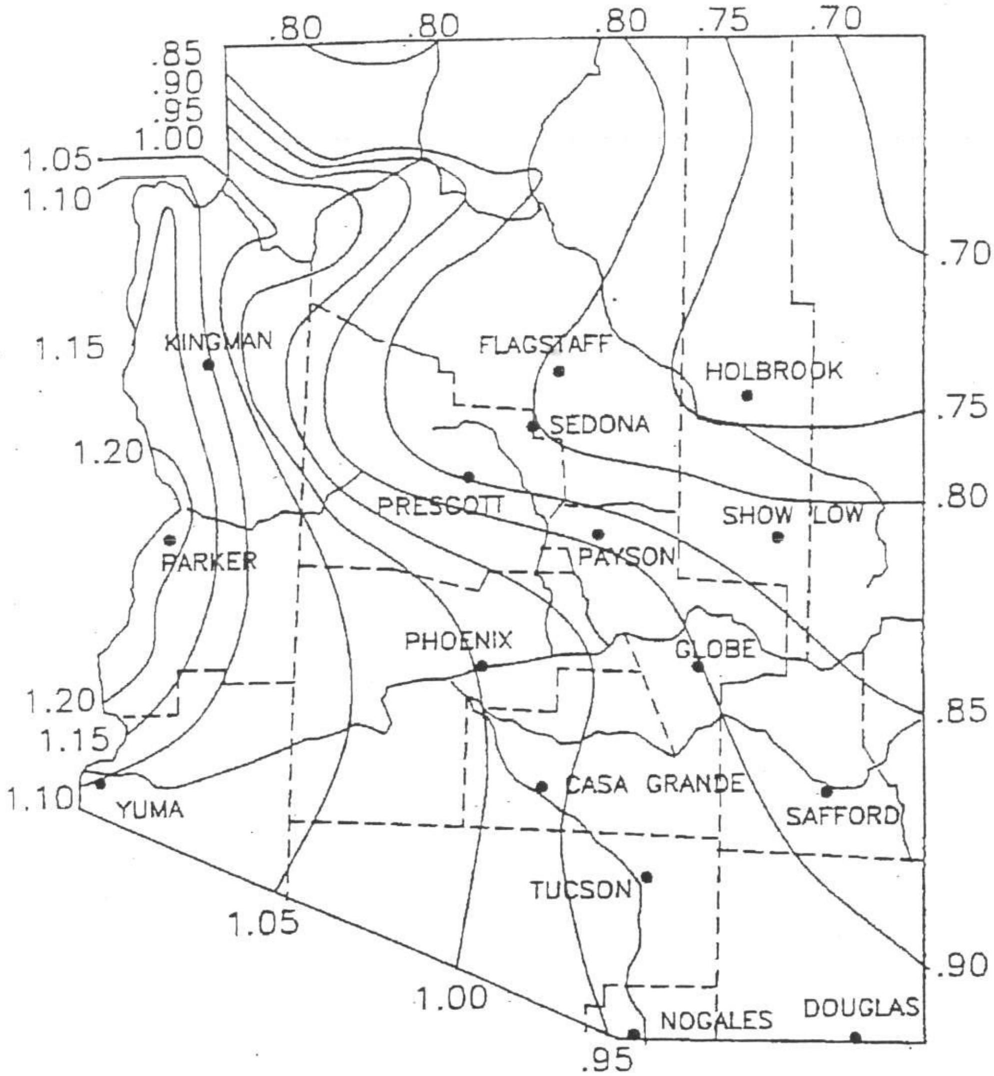
And

Cooperative Extension Service

The University of Arizona

Issued in furtherance of cooperative extension work in agriculture and home economics, Acts of May 8 and June 30, 1914, in cooperation with the U. S. Department of Agriculture. George E. Hull, Director of Extension Service, The University of Arizona College of Agriculture, Tucson,

FIGURE 10. EVAPORATION ADJUSTMENT FACTORS FOR ARIZONA



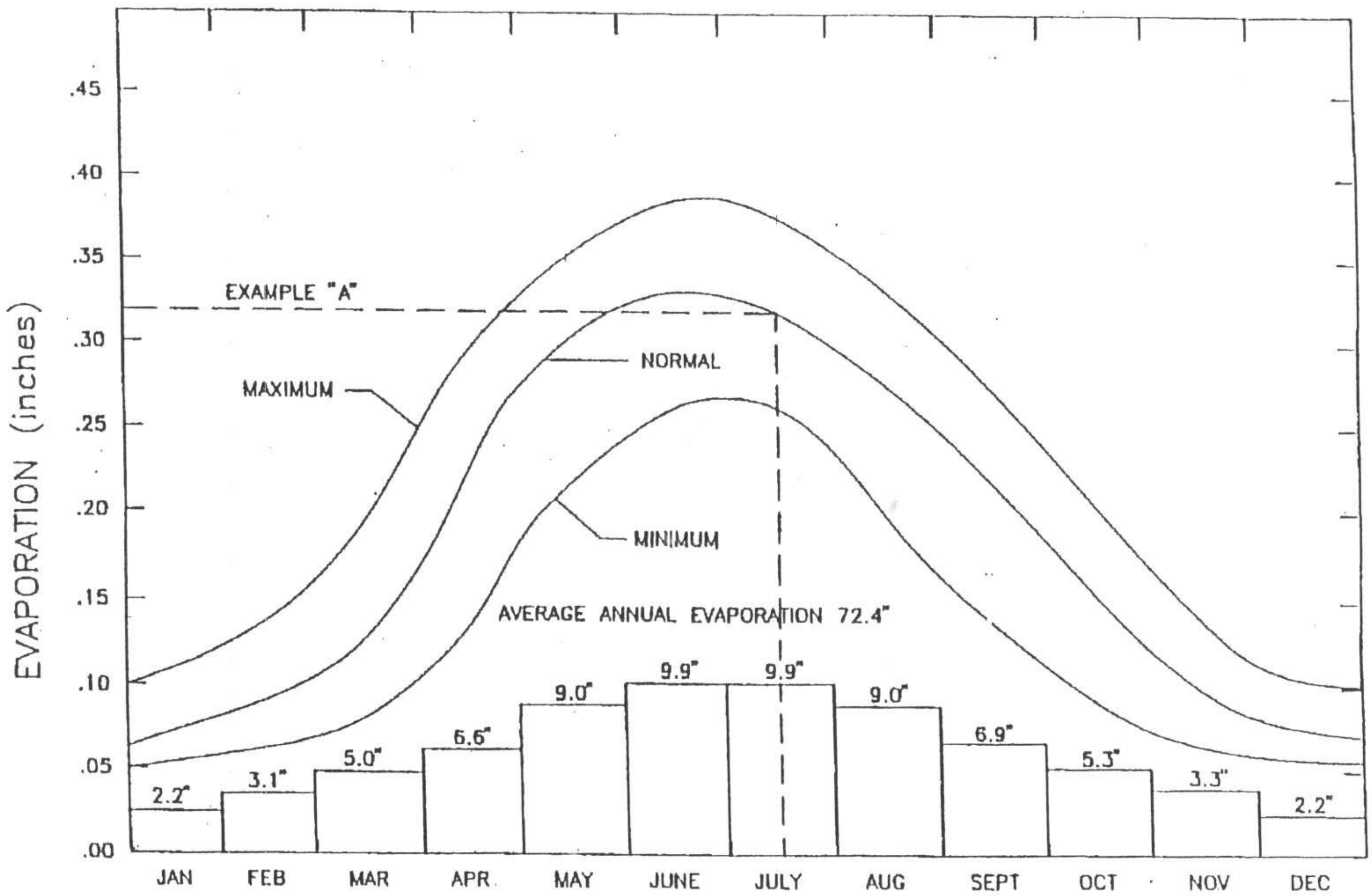


FIGURE 9. MAXIMUM, NORMAL AND MINIMUM DAILY EVAPORATION AND AVERAGE MONTHLY EVAPORATION FROM OPEN WATER SURFACES (Adjustment Factor = 1.00)

TABLE 3.2 MONTHLY MAXIMUM, NORMAL, AND MINIMUM OPEN WATER EVAPORATION AMOUNTS FOR ARIZONA (UNADJUSTED).

	EVAPORATION (IN)		
MONTH	MAXIMUM	NORMAL	MINIMUM
Jan (31 days)	3.6	2.2	1.6
Feb (28)	4.5	3.1	2.3
Mar (31)	6.5	5.0	3.1
April (30)	8.4	6.6	4.5
May (31)	10.9	9.0	6.2
June (30)	11.4	9.9	7.5
July (31)	11.8	9.9	8.1
August (31)	10.5	9.0	6.0
Sept (30)	8.7	6.9	4.1
Oct (31)	7.0	5.3	2.8
Nov (30)	4.8	3.3	1.8
Dec (31)	3.1	2.2	1.6
TOTAL	91.2 (7.6 ft.)	72.4 (6.0 ft.)	49.6 (4.1 ft.)

From: Cooley, 1970

APPENDIX C
Daily Wetted Acreages

USF DAILY WETTED ACREAGES
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2016

January

Date	**Equal. Basin** Wetted Area (acres)*	**Recharge Cell 1** Wetted Area (acres)*	**Recharge Cell 2** Wetted Area (acres)*	**Recharge Cell 3** Wetted Area (acres)*	**Recharge Cell 4** Wetted Area (acres)*
1	0.372	0	0	0	0.819
2	0.372	0	0	0	0.819
3	0.372	0	0.0605	0	0.819
4	0.372	0	0.121	0	0.819
5	0.372	0	0.0908	0	0.819
6	0.3565	0	0	0	0.63
7	0.341	0	0	0	0.315
8	0.3255	0	0	0	0.1575
9	0.31	0	0	0	0.063
10	0.2914	0	0	0	0
11	0.279	0	0	0	0
12	0.2604	0	0	0	0
13	0.248	0	0	0	0
14	0.2294	0	0	0	0
15	0.217	0	0	0	0
16	0.1984	0	0	0	0
17	0.186	0	0	0	0
18	0.1674	0	0	0	0
19	0.155	0	0	0	0
20	0.1364	0	0	0	0
21	0.124	0	0	0	0
22	0.1054	0	0	0	0
23	0.093	0	0	0	0
24	0.0744	0	0	0	0
25	0.062	0	0	0	0
26	0.434	0	0	0	0
27	0.031	0	0	0	0
28	0.0124	0	0	0	0
29	0	0	0	0	0
30	0	0	0	0	0
31	0	0	0	0	0
Total Wetted Acres	**6.4976**	**0**	**0.2723**	**0**	**5.2605**

February

Date	**Equal. Basin** Wetted Area (acres)*	**Recharge Cell 1** Wetted Area (acres)*	**Recharge Cell 2** Wetted Area (acres)*	**Recharge Cell 3** Wetted Area (acres)*	**Recharge Cell 4** Wetted Area (acres)*
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0.341	0	0	0	0.252
10	0.372	0	0	0	0.378
11	0.3565	0	0	0	0.63
12	0.341	0	0	0	0.378
13	0.341	0	0	0	0.252
14	0.341	0	0	0	0.126
15	0.31	0	0	0	0
16	0.2914	0	0	0	0
17	0.279	0	0	0	0
18	0.248	0	0	0	0
19	0.2294	0	0	0	0
20	0.186	0	0	0	0
21	0.155	0	0	0	0
22	0.124	0	0	0	0
23	0.093	0	0	0	0
24	0.062	0	0	0	0
25	0	0	0	0	0
26	0	0	0	0	0
27	0	0	0	0	0
28	0	0	0	0	0
29	0	0	0	0	0
Total Wetted Acres	**4.0703**	**0**	**0**	**0**	**2.016**

* Only include wetted non-vegetated area. All vegetated area must be inputted on the evapotranspiration calculation sheet.

USF DAILY WETTED ACREAGES
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2016

March

Date	Equal. Basin Wetted Area (acres)*	Recharge Cell 1 Wetted Area (acres)*	Recharge Cell 2 Wetted Area (acres)*	Recharge Cell 3 Wetted Area (acres)*	Recharge Cell 4 Wetted Area (acres)*
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	0	0	0
16	0	0	0	0	0
17	0	0	0	0	0
18	0	0	0	0	0
19	0	0	0	0	0
20	0	0	0	0	0
21	0	0	0	0	0
22	0	0	0	0	0
23	0	0	0	0	0
24	0	0	0	0	0
25	0	0	0	0	0
26	0	0	0	0	0
27	0	0	0	0	0
28	0	0	0	0	0
29	0	0	0	0	0
30	0.062	0	0	0	0
31	0.372	0	0	0	0.378
Total Wetted Acres	**0.434**	**0**	**0**	**0**	**0.378**

April

Date	Equal. Basin Wetted Area (acres)*	Recharge Cell 1 Wetted Area (acres)*	Recharge Cell 2 Wetted Area (acres)*	Recharge Cell 3 Wetted Area (acres)*	Recharge Cell 4 Wetted Area (acres)*
1	0.372	0	0	0	0.63
2	0.372	0	0	0	0.819
3	0.403	0	0	0	0.819
4	0.403	0.0063	0	0.0059	0.819
5	0.372	0.0063	0	0.0078	0.819
6	0.372	0.0315	0	0.039	0.378
7	0.372	0.0315	0	0.039	0.126
8	0.372	0.0315	0	0.039	0.0252
9	0.403	0.0945	0	0.117	0.0126
10	0.403	0.1062	0	0.1599	0
11	0.372	0.1178	0	0.2028	0
12	0.372	0.126	0	0.2418	0
13	0.372	0.126	0	0.2418	0
14	0.372	0.126	0	0.2418	0
15	0.372	0.1323	0	0.2496	0
16	0.372	0.1323	0	0.2808	0
17	0.372	0.1355	0	0.2847	0
18	0.372	0.1386	0	0.2886	0
19	0.372	0.1449	0	0.2886	0
20	0.403	0.1512	0	0.3042	0
21	0.403	0.1323	0	0.195	0
22	0.372	0.1512	0	0.2106	0
23	0.403	0.1575	0	0.2184	0
24	0.403	0.1606	0	0.2223	0
25	0.403	0.1638	0	0.2262	0
26	0.372	0.1701	0	0.234	0
27	0.372	0.1701	0	0.234	0
28	0.372	0.1701	0	0.234	0
29	0.372	0.1701	0	0.234	0
30	0.372	0.1701	0	0.234	0
Total Wetted Acres	**11.439**	**3.2543**	**0**	**5.2748**	**4.4478**

* Only include wetted non-vegetated area. All vegetated area must be inputted on the evapotranspiration calculation sheet.

USF DAILY WETTED ACREAGES
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2016

May

Date	Equal. Basin Wetted Area (acres)*	Recharge Cell 1 Wetted Area (acres)*	Recharge Cell 2 Wetted Area (acres)*	Recharge Cell 3 Wetted Area (acres)*	Recharge Cell 4 Wetted Area (acres)*
1	0.372	0.189	0	0.2574	0
2	0.403	0.189	0	0.2574	0
3	0.372	0.189	0	0.2574	0.252
4	0.372	0	0	0	0.504
5	0.372	0	0	0	0.819
6	0.372	0	0	0	0.819
7	0.372	0	0	0	0.819
8	0.372	0	0	0	0.819
9	0.372	0	0	0	0.819
10	0.372	0	0	0	0.819
11	0.372	0	0	0	0.819
12	0.403	0	0	0	0.819
13	0.403	0	0	0	0.819
14	0.372	0	0	0	0.819
15	0.372	0	0	0	0.819
16	0.372	0	0.00605	0	0.819
17	0.372	0	0.121	0	0.315
18	0.372	0	0.242	0	0.252
19	0.372	0	0.3025	0	0.126
20	0.372	0	0.3146	0	0.126
21	0.372	0	0.3267	0	0.126
22	0.372	0	0.3328	0	0
23	0.372	0	0.3388	0	0
24	0.372	0	0.363	0	0
25	0.372	0	0.363	0	0
26	0.372	0	0.242	0	0
27	0.31	0	0.0121	0	0
28	0.31	0	0	0	0
29	0.372	0	0	0	0
30	0.372	0	0.1815	0	0
31	0.372	0	0.242	0	0
Total Wetted Acres	**11.501**	**0.567**	**3.38805**	**0.7722**	**11.529**

June

Date	Equal. Basin Wetted Area (acres)*	Recharge Cell 1 Wetted Area (acres)*	Recharge Cell 2 Wetted Area (acres)*	Recharge Cell 3 Wetted Area (acres)*	Recharge Cell 4 Wetted Area (acres)*
1	0.341	0	0.2904	0	0
2	0.341	0	0.3146	0	0
3	0.341	0	0.3267	0	0
4	0.341	0	0.3388	0	0
5	0.341	0	0.3448	0	0
6	0.341	0.0063	0.3509	0.0117	0
7	0.341	0.0126	0.1815	0.0234	0
8	0.341	0.0189	0.0363	0.0234	0
9	0.341	0.0315	0	0.039	0
10	0.341	0.0315	0	0.0546	0
11	0.341	0.0378	0	0.0624	0
12	0.341	0.0063	0	0.0117	0
13	0.341	0	0	0	0
14	0.341	0	0	0	0
15	0.341	0.0063	0	0.0117	0
16	0.341	0.0189	0	0.0234	0
17	0.341	0.0189	0	0.0312	0
18	0.341	0.0189	0	0.039	0
19	0.341	0.0252	0	0.039	0
20	0.341	0.0378	0	0.0468	0
21	0.341	0.0378	0	0.0468	0
22	0.341	0.0378	0	0.0468	0
23	0.3844	0.0378	0	0.0468	0
24	0.3844	0.0378	0	0.0468	0
25	0.3844	0.0441	0	0.0468	0
26	0.341	0.04725	0	0.0507	0
27	0.3224	0.0504	0	0.0546	0
28	0.31	0.0284	0	0.0312	0
29	0.31	0.0063	0	0.0078	0
30	0.31	0	0	0	0
Total Wetted Acres	**10.2486**	**0.59855**	**2.184**	**0.7956**	**0**

* Only include wetted non-vegetated area. All vegetated area must be inputted on the evapotranspiration calculation sheet.

USF DAILY WETTED ACREAGES
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2016

July

Date	Equal. Basin Wetted Area (acres)*	Recharge Cell 1 Wetted Area (acres)*	Recharge Cell 2 Wetted Area (acres)*	Recharge Cell 3 Wetted Area (acres)*	Recharge Cell 4 Wetted Area (acres)*
1	0.248	0	0	0	0
2	0.248	0	0	0	0
3	0.248	0	0	0	0
4	0.248	0	0	0	0
5	0.248	0	0	0	0
6	0.31	0.0063	0	0.0078	0
7	0.3224	0.0693	0	0.0858	0
8	0.341	0.0756	0	0.0858	0
9	0.3224	0.0945	0	0.0858	0
10	0.3224	0.0472	0	0.0936	0
11	0.3224	0.126	0	0.0936	0
12	0.3224	0.1134	0	0.0936	0
13	0.3224	0.126	0	0.0936	0
14	0.3224	0.126	0	0.0936	0
15	0.3224	0.0315	0	0.156	0
16	0.3224	0	0	0.156	0
17	0.3224	0	0	0.156	0
18	0.3224	0	0	0.078	0.189
19	0.3224	0	0	0	0.378
20	0.3224	0	0	0	0.63
21	0.3224	0	0	0	0.819
22	0.3224	0	0	0	0.819
23	0.3224	0	0	0	0.63
24	0.3224	0	0	0	0.567
25	0.3224	0	0	0	0.504
26	0.3224	0	0	0	0.252
27	0.3224	0	0	0	0.189
28	0.3224	0	0	0	0.063
29	0.3162	0	0	0	0.0315
30	0.31	0	0	0	0.0126
31	0.31	0	0	0	0
Total Wetted Acres	**9.5976**	**0.8158**	**0**	**1.2792**	**5.0841**

August

Date	Equal. Basin Wetted Area (acres)*	Recharge Cell 1 Wetted Area (acres)*	Recharge Cell 2 Wetted Area (acres)*	Recharge Cell 3 Wetted Area (acres)*	Recharge Cell 4 Wetted Area (acres)*
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	0	0	0
16	0	0	0	0	0
17	0	0	0	0	0
18	0	0	0	0	0
19	0	0	0	0	0
20	0	0	0	0	0
21	0	0	0	0	0
22	0	0	0	0	0
23	0	0	0	0	0
24	0	0	0	0	0
25	0	0	0	0	0
26	0	0	0	0	0
27	0	0	0	0	0
28	0	0	0	0	0
29	0	0	0	0	0
30	0	0	0	0	0
31	0	0	0	0	0
Total Wetted Acres	**0**	**0**	**0**	**0**	**0**

* Only include wetted non-vegetated area. All vegetated area must be inputted on the evapotranspiration calculation sheet.

USF DAILY WETTED ACREAGES
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2016

September

Date	**Equal. Basin** Wetted Area (acres)*	**Recharge Cell 1** Wetted Area (acres)*	**Recharge Cell 2** Wetted Area (acres)*	**Recharge Cell 3** Wetted Area (acres)*	**Recharge Cell 4** Wetted Area (acres)*
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	0	0	0
16	0	0	0	0	0
17	0	0	0	0	0
18	0	0	0	0	0
19	0	0	0	0	0
20	0	0	0	0	0
21	0.3162	0	0	0	0.0126
22	0.341	0	0	0	0.0252
23	0.341	0	0	0	0.252
24	0.341	0	0	0	0.378
25	0.341	0	0	0	0.504
26	0.341	0	0	0	0.63
27	0.341	0	0	0	0.63
28	0.3844	0	0	0	0.504
29	0.31	0	0	0	0.252
30	0.248	0	0	0	0
Total Wetted Acres	**3.3046**	**0**	**0**	**0**	**3.1878**

October

Date	**Equal. Basin** Wetted Area (acres)*	**Recharge Cell 1** Wetted Area (acres)*	**Recharge Cell 2** Wetted Area (acres)*	**Recharge Cell 3** Wetted Area (acres)*	**Recharge Cell 4** Wetted Area (acres)*
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0.31	0	0	0	0.063
6	0.341	0	0	0	0.126
7	0.341	0	0	0	0.504
8	0.341	0	0	0	0.567
9	0.341	0	0	0	0.63
10	0.341	0	0	0	0.63
11	0.3844	0	0	0	0.63
12	0.341	0	0	0	0.63
13	0.341	0	0	0	0.63
14	0.341	0	0	0	0.63
15	0.341	0	0	0	0.63
16	0.341	0	0	0	0.63
17	0.341	0	0	0	0.63
18	0.341	0	0	0	0.63
19	0.341	0	0	0	0.63
20	0.341	0	0	0	0.63
21	0.341	0	0	0	0.63
22	0.341	0	0	0	0.504
23	0.341	0	0	0	0.63
24	0.341	0	0	0	0.504
25	0.341	0	0	0	0.63
26	0.341	0	0	0	0.63
27	0.341	0	0	0	0.63
28	0.341	0	0	0	0.504
29	0.341	0	0	0	0.504
30	0.341	0	0	0	0.504
31	0.341	0	0	0	0.63
Total Wetted Acres	**9.2194**	**0**	**0**	**0**	**15.12**

* Only include wetted non-vegetated area. All vegetated area must be inputted on the evapotranspiration calculation sheet.

USF DAILY WETTED ACREAGES
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2016

November

Date	Equal. Basin Wetted Area (acres)*	Recharge Cell 1 Wetted Area (acres)*	Recharge Cell 2 Wetted Area (acres)*	Recharge Cell 3 Wetted Area (acres)*	Recharge Cell 4 Wetted Area (acres)*
1	0.341	0	0	0	0.63
2	0.341	0	0	0	0.63
3	0.341	0	0	0	0.819
4	0.341	0	0	0	0.819
5	0.341	0	0	0	0.819
6	0.341	0	0	0	0.819
7	0.341	0	0	0.039	0.63
8	0.341	0	0	0.078	0.252
9	0.341	0	0	0.195	0.063
10	0.341	0	0	0.2028	0
11	0.341	0	0	0.2106	0
12	0.341	0	0	0.234	0
13	0.341	0	0	0.2535	0
14	0.341	0	0	0.273	0
15	0.341	0	0	0.2808	0
16	0.341	0	0	0.2964	0
17	0.341	0	0	0.312	0
18	0.341	0	0	0.312	0
19	0.341	0	0	0.312	0
20	0.341	0	0	0.3432	0
21	0.341	0	0	0.3744	0
22	0.341	0	0	0.39	0.063
23	0.341	0	0	0.078	0.63
24	0.341	0	0	0	0.819
25	0.341	0.0315	0	0	0.819
26	0.341	0.0504	0	0	0.819
27	0.341	0.063	0	0	0.504
28	0.341	0.1575	0	0	0
29	0.341	0.2205	0	0	0
30	0.341	0.315	0	0	0
Total Wetted Acres	**10.23**	**0.8379**	**0**	**4.1847**	**9.135**

December

Date	Equal. Basin Wetted Area (acres)*	Recharge Cell 1 Wetted Area (acres)*	Recharge Cell 2 Wetted Area (acres)*	Recharge Cell 3 Wetted Area (acres)*	Recharge Cell 4 Wetted Area (acres)*
1	0.341	0.315	0	0	0
2	0.341	0.315	0	0	0
3	0.341	0.315	0	0	0
4	0.341	0.315	0	0	0
5	0.341	0.315	0	0	0
6	0.341	0.315	0	0	0
7	0.341	0.315	0	0	0
8	0.341	0.315	0	0	0
9	0.341	0.315	0	0	0
10	0.341	0.315	0	0	0
11	0.341	0.315	0	0	0
12	0.341	0.1953	0.484	0	0.126
13	0.3844	0.0315	0.5445	0	0.63
14	0.3844	0	0.5445	0	0.63
15	0.341	0	0.5445	0	0.63
16	0.341	0	0.5445	0.039	0.819
17	0.341	0	0.5445	0.078	0.819
18	0.341	0	0.5445	0.117	0.63
19	0.341	0	0.5445	0.156	0.126
20	0.341	0	0.5445	0.2184	0
21	0.341	0	0.5445	0.273	0
22	0.341	0	0.484	0.39	0
23	0.341	0	0	0.273	0
24	0.341	0	0	0.39	0
25	0.341	0	0	0.39	0
26	0.341	0	0	0.663	0
27	0.341	0	0	0.663	0
28	0.341	0.0441	0	0.663	0
29	0.341	0.0945	0	0.312	0
30	0.31	0.0063	0	0.078	0
31	0.31	0	0	0.0078	0
Total Wetted Acres	**10.5958**	**3.8367**	**5.8685**	**4.7112**	**4.41**

* Only include wetted non-vegetated area. All vegetated area must be inputted on the evapotranspiration calculation sheet.

APPENDIX D

Evapotranspiration Calculations & AZMET Method Description

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2016

	January			February			March		
Date	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)
1	0.4158	0.08	0.002772	0	0.08	0	**0**	0.19	0
2	0.441	0.11	0.0040425	0	0.11	0	**0**	0.2	0
3	0.4158	0.12	0.004158	0	0.11	0	**0**	0.19	0
4	0.3402	0.03	0.0008505	0	0.11	0	**0**	0.21	0
5	0.2142	0.05	0.0008925	0	0.11	0	**0**	0.2	0
6	0.189	0.07	0.0011025	0	0.13	0	**0**	0.17	0
7	0	0	0	0	0.11	0	**0**	0.15	0
8	0	0.02	0	0	0.17	0	**0**	0.14	0
9	0	0.07	0	0	0.15	0	**0**	0.21	0
10	0	0.03	0	0	0.15	0	**0**	0.19	0
11	0	0.08	0	0.189	0.16	0.00252	**0**	0.19	0
12	0	0.09	0	0	0.17	0	**0**	0.22	0
13	0	0.09	0	0	0.18	0	**0**	0.22	0
14	0	0.1	0	0	0.18	0	**0**	0.22	0
15	0	0.05	0	0	0.17	0	**0**	0.22	0
16	0	0.08	0	0	0.17	0	**0**	0.23	0
17	0	0.1	0	0	0.19	0	**0**	0.24	0
18	0	0.07	0	0	0.14	0	**0**	0.24	0
19	0	0.11	0	0	0.12	0	**0**	0.25	0
20	0	0.11	0	0	0.19	0	**0**	0.23	0
21	0	0.11	0	0	0.2	0	**0**	0.25	0
22	0	0.11	0	0	0.2	0	**0**	0.3	0
23	0	0.11	0	0	0.2	0	**0**	0.27	0
24	0	0.12	0	0	0.2	0	**0**	0.23	0
25	0	0.09	0	0	0.17	0	**0**	0.26	0
26	0	0.11	0	0	0.19	0	**0**	0.28	0
27	0	0.13	0	0	0.2	0	**0**	0.25	0
28	0	0.11	0	0	0.19	0	**0**	0.26	0
29	0	0.13	0	0	0.2	0	0	0.17	0
30	0	0.15	0				**0**	0.17	0
31	0	0.18	0				**0**	0.17	0
Monthly Evapo-transpiration			**0.013818**			**0.00252**			**0**

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2016

	April			May			June		
Date	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)
1	0.189	0.24	0.00378	0	0.22	0	0.0372	0.35	0.001085
2	0.4032	0.25	0.0084	0	0.28	0	0.0372	0.38	0.001178
3	0.441	0.26	0.009555	0	0.29	0	0.0372	0.4	0.00124
4	0.4472	0.26	0.009689333	0	0.37	0	0.0372	0.38	0.001178
5	0.2772	0.27	0.006237	0.2772	0.34	0.007854	0.0372	0.37	0.001147
6	0	0.25	0	0.4158	0.32	0.011088	0.0372	0.37	0.001147
7	0	0.13	0	0.4158	0.26	0.009009	0.0372	0.37	0.001147
8	0	0.15	0	0.441	0.26	0.009555	0.0372	0.35	0.001085
9	0.0062	0.24	0.000124	0.441	0.28	0.01029	0.0372	0.35	0.001085
10	0	0.08	0	0.441	0.28	0.01029	0.0372	0.28	0.000868
11	0	0.21	0	0.441	0.29	0.0106575	0.0372	0.24	0.000744
12	0	0.22	0	0.4094	0.3	0.010235	0.0372	0.34	0.001054
13	0	0.24	0	0.3464	0.28	0.008082667	0.0372	0.35	0.001085
14	0	0.28	0	0.4032	0.25	0.0084	0.0372	0.35	0.001085
15	0	0.33	0	0.4158	0.37	0.0128205	0.0372	0.37	0.001147
16	0	0.28	0	0.441	0.34	0.012495	0.0372	0.36	0.001116
17	0	0.26	0	0	0.31	0	0.0372	0.36	0.001116
18	0	0.3	0	0	0.24	0	0.0372	0.41	0.001271
19	0	0.29	0	0	0.28	0	0.0372	0.4	0.00124
20	0	0.3	0	0	0.33	0	0.0372	0.37	0.001147
21	0	0.3	0	0	0.31	0	0.0372	0.33	0.001023
22	0	0.3	0	0	0.35	0	0.0372	0.37	0.001147
23	0	0.33	0	0	0.32	0	0.0372	0.11	0.000341
24	0	0.28	0	0	0.34	0	0.0372	0.29	0.000899
25	0.0062	0.32	0.000165333	0	0.35	0	0.0372	0.23	0.000713
26	0	0.28	0	0	0.31	0	0.0372	0.2	0.00062
27	0	0.25	0	0	0.3	0	0	0.23	0
28	0	0.31	0	0	0.33	0	0	0.21	0
29	0	0.22	0	0	0.34	0	0	0.19	0
30	0	0.21	0	0	0.34	0	0	0.09	0
31				0	0.34	0			
Monthly Evapo-transpiration			**0.037950667**			**0.120776667**			**0.026908**

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2016

	July			August			September		
Date	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)
1	0	0.16	0	0	0.2	0	0	0.26	0
2	0	0.28	0	0	0.09	0	0	0.2	0
3	0	0.31	0	0	0.15	0	0	0.24	0
4	0	0.29	0	0	0.16	0	0	0.29	0
5	0	0.33	0	0	0.22	0	0	0.3	0
6	0	0.3	0	0	0.27	0	0	0.17	0
7	0	0.32	0	0	0.26	0	0	0.05	0
8	0.0372	0.33	0.001023	0	0.29	0	0	0.22	0
9	0.0372	0.34	0.001054	0	0.1	0	0	0.24	0
10	0.0372	0.35	0.001085	0	0.23	0	0	0.23	0
11	0.0372	0.35	0.001085	0	0.24	0	0	0.26	0
12	0.0372	0.35	0.001085	0	0.28	0	0	0.14	0
13	0.0372	0.34	0.001054	0	0.28	0	0	0.21	0
14	0.0372	0.36	0.001116	0	0.28	0	0	0.2	0
15	0.0372	0.35	0.001085	0	0.28	0	0	0.22	0
16	0.0372	0.35	0.001085	0	0.29	0	0	0.23	0
17	0.0372	0.24	0.000744	0	0.27	0	0	0.23	0
18	0.0372	0.28	0.000868	0	0.28	0	0	0.25	0
19	0.0372	0.25	0.000775	0	0.27	0	0	0.22	0
20	0.2262	0.21	0.0039585	0	0.29	0	0	0.15	0
21	0.3144	0.27	0.007074	0	0.2	0	0	0.21	0
22	0.2514	0.34	0.007123	0	0.24	0	0.0372	0.23	0.000713
23	0.2262	0.36	0.006786	0	0.26	0	0.0372	0.13	0.000403
24	0.0372	0.34	0.001054	0	0.28	0	0.0372	0.22	0.000682
25	0.0372	0.31	0.000961	0	0.26	0	0.0372	0.22	0.000682
26	0.0372	0.33	0.001023	0	0.23	0	0.2262	0.18	0.003393
27	0.0372	0.31	0.000961	0	0.26	0	0.2262	0.19	0.0035815
28	0	0.28	0	0	0.27	0	0.0372	0.13	0.000403
29	0	0.28	0	0	0.26	0	0	0.16	0
30	0	0.26	0	0	0.29	0	0	0.16	0
31	0	0.23	0	0	0.28	0			
Monthly Evapo-transpiration			**0.0409995**			**0**			**0.0098575**

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2016

	October			November			December		
Date	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)
1	0	0.19	0	0.2262	0.16	0.003016	0.0372	0.1	0.00031
2	0	0.11	0	0.2262	0.15	0.0028275	0.0372	0.1	0.00031
3	0	0.24	0	0.2514	0.15	0.0031425	0.0372	0.11	0.000341
4	0	0.2	0	0.2514	0.12	0.002514	0.0372	0.1	0.00031
5	0	0.2	0	0.3144	0.13	0.003406	0.0372	0.11	0.000341
6	0.0372	0.17	0.000527	0.3144	0.13	0.003406	0.0372	0.09	0.000279
7	0.0372	0.23	0.000713	0.2262	0.14	0.002639	0.0372	0.07	0.000217
8	0.0372	0.23	0.000713	0.0372	0.25	0.000775	0.0372	0.09	0.000279
9	0.2262	0.19	0.0035815	0.0372	0.27	0.000837	0.0372	0.09	0.000279
10	0.2262	0.21	0.0039585	0.0372	0.2	0.00062	0.0372	0.1	0.00031
11	0.2262	0.21	0.0039585	0.0372	0.16	0.000496	0.0372	0.09	0.000279
12	0.2262	0.19	0.0035815	0.0372	0.19	0.000589	0.0372	0.1	0.00031
13	0.2262	0.2	0.00377	0.0372	0.13	0.000403	0.2448	0.08	0.001632
14	0.2262	0.19	0.0035815	0.0372	0.14	0.000434	0.2324	0.09	0.001743
15	0.2262	0.2	0.00377	0.0372	0.15	0.000465	0.2262	0.1	0.001885
16	0.2262	0.2	0.00377	0.0372	0.11	0.000341	0.4782	0.09	0.0035865
17	0.2262	0.21	0.0039585	0.0372	0.17	0.000527	0.3144	0.09	0.002358
18	0.2262	0.2	0.00377	0.0372	0.13	0.000403	0.2262	0.07	0.0013195
19	0.2262	0.19	0.0035815	0.0372	0.17	0.000527	0.0372	0.07	0.000217
20	0.2262	0.24	0.004524	0.0372	0.11	0.000341	0.0372	0.07	0.000217
21	0.2262	0.21	0.0039585	0.0372	0.09	0.000279	0.0372	0.02	0.000062
22	0.0372	0.17	0.000527	0.0762	0.1	0.000635	0.0372	0.06	0.000186
23	0.2262	0.17	0.0032045	0.2262	0.12	0.002262	0.0372	0.07	0.000217
24	0.0372	0.13	0.000403	0.453	0.12	0.00453	0.0762	0.09	0.0005715
25	0.2262	0.15	0.0028275	0.4782	0.14	0.005579	0.0762	0.04	0.000254
26	0.2262	0.16	0.003016	0.3144	0.09	0.002358	0.1152	0.07	0.000672
27	0.2262	0.18	0.003393	0.0372	0.12	0.000372	0.1152	0.08	0.000768
28	0.0372	0.15	0.000465	0.0372	0.09	0.000279	0.1152	0.05	0.00048
29	0.0372	0.16	0.000496	0.0372	0.12	0.000372	0.0372	0.04	0.000124
30	0.0372	0.16	0.000496	0.0372	0.09	0.000279	0	0.07	0
31	0.2262	0.17	0.0032045				0	0.01	0
Monthly Evapo-transpiration			**0.0697495**			**0.044654**			**0.0198575**

STANDARDIZED REFERENCE EVAPOTRANSPIRATION

A NEW PROCEDURE FOR ESTIMATING REFERENCE EVAPOTRANSPIRATION IN ARIZONA

Introduction

The Arizona Meteorological Network (AZMET) has provided daily values of reference evapotranspiration (ETo) for a number of southern Arizona locations for more than 15 years. ETo is a computed meteorological parameter that provides an estimate of environmental evaporative demand and serves as a critical input variable for most scientifically based irrigation scheduling systems. ETo is also used to estimate evaporation from water bodies and evapotranspiration (ET) from rain-fed ecosystems.

While there is general agreement among agronomists, irrigation engineers and meteorologists that ETo is a useful environmental parameter, there has been less agreement on how to compute ETo. And all too often the computational procedure for ETo varies from region to region and sometimes within a region. Use of multiple ETo computation procedures within a region can generate biases in ETo that result from the computation process, not any true differences in environmental evaporative demand. Figure 1 provides graphic evidence of this computational bias by presenting the total ETo for Tucson in 1996 as computed using the published ETo procedures for the public weather networks operating in Arizona (Brown, 1998), California (Snyder and Pruitt, 1985), and New Mexico (Sammis, 1996). It is important to note that the same meteorological data were used to generate the ETo data in Figure 1; only the computational procedures differed. These results provide clear evidence that lack of a standardized computational procedure for ETo can lead to confusion and perhaps serious mistakes when one is involved in activities such as irrigation scheduling, estimating consumptive use of vegetation, water rights litigation (especially across state lines), and development of crop coefficients (adjustment factors that convert ETo to crop ET).

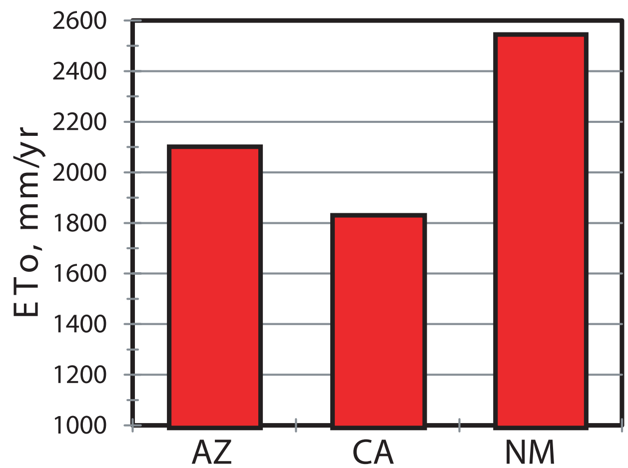


Figure 1. Reference ET (ETo) for Tucson for calendar year 1996 as computed using the published procedures for the public weather networks in Arizona, California, and New Mexico.

Over the past decade, scientists have recognized the problems and frustrations associated with non-standardized ETo computation and have formed national and international committees to address this issue. The American Society of Civil Engineers (ASCE) developed

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a special Task Committee (TC) in 1999 to develop a standardized procedure for computing ETo. The ASCE TC has issued its recommendations (Walter et al., 2004) which are to be published in 2005. AZMET participated in the ASCE TC and began generating ETo values using this ASCE Standardized ETo procedure in 2003. The purpose of this report is to first review the computation procedure recommended by the ASCE TC; second, provide specifics on the computation procedure AZMET will employ; and third, summarize how the new standardized ETo procedure and the original AZMET ETo (ETоa) procedure compare across months and locations.

Standardized Reference Evapotranspiration Definition

The ASCE TC defined reference evapotranspiration as "the ET rate from a uniform surface of dense actively growing vegetation having specified height and surface resistance (to transfer of water vapor), not short of soil water, and representing an expanse of at least 100 m of the same or similar vegetation." This definition leaves open the option of having more than one reference surface (differing height and surface resistance) and reflects the view of the TC that standardized computation procedures were necessary for two reference surfaces: 1) a short crop similar to clipped grass and 2) a tall crop similar to full-cover alfalfa. The recommended abbreviations for ETo computed for the short and tall crops using the standardized procedures are ETos and ETrs, respectively (see Table 1 for list of ET abbreviations used in this report).

The need to have procedures for two reference surfaces reflects the history of ET research in the U.S. Two crops — cool-season grass and alfalfa — have been used as reference surfaces for ET estimation for several decades. The TC recommendations allow users with a strong preference for one reference surface or another to continue using their preferred surface. An important reason for recommending two surfaces pertains to crop coefficients (Kcs) — the adjustment factors used to convert ETo to estimates of ET for a specific type of vegetation. Kcs will differ for the two reference surfaces since alfalfa typically uses more water than grass when both are grown under reference conditions. Over the past 30+ years, Kcs have been developed for use with ETo computed for both grass and alfalfa reference surfaces. The TC recommendation to allow for two reference surfaces allows local users to continue using the Kcs and reference surface they are most comfortable with.

ABBREVIATION	EXPLANATION
ET	Evapotranspiration
ETc	Evapotranspiration of a particular crop or vegetation type
ETo	Reference Evapotranspiration in general
ETos	Standardized Reference Evapotranspiration for Short Reference Crop
ETrs	Standardized Reference Evapotranspiration for Tall Reference Crop
ETsz	Standardized Reference Evapotranspiration in general
ETоa	Reference Evapotranspiration as computed by AZMET in past years

Table 1. Abbreviations related to evapotranspiration that are contained in this report.

Standardized Reference ET Equation

Generalized Form of Standardized Equation

The ASCE TC standardized procedure for computing reference evapotranspiration is based on the Penman-Monteith Equation and more specifically on simplifying the version of the Penman Monteith Equation recommended by ASCE (Jensen et al., 1990). The recommended general computation procedure is provided below:

$$ETsz = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{C_n}{T + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + C_d u_2)} \quad (1)$$

Where:

ETsz = standardized reference crop evapotranspiration (mm d^{-1} or mm h^{-1})

Δ = slope of the saturation vapor pressure-temperature curve (kPa $^{o}C^{-1}$)

R_n = Calculated net radiation at the crop surface (MJ m^{-2} d^{-1} or MJ m^{-2} h^{-1})

G = Soil heat flux density at the soil surface (MJ m^{-2} d^{-1} or MJ m^{-2} h^{-1})

γ = psychrometer constant (kPa $^oC^{-1}$)

C_n = numerator constant that changes with reference type and calculation time step

T = mean daily air temperature measured at 1.5 to 2.5 m above ground level (^oC)

U_2 = mean daily wind speed wind speed measured at 2 m above ground level (m s^{-1})

e_s = saturation vapor pressure measured at 1.5 to 2.5 m above ground level (kPa)

e_a = mean actual vapor pressure measured at 1.5 to 2.5 m above ground level (kPa)

C_d = denominator constant that changes with reference type and calculation time step

Equation 1 represents a generalized equation that can, with appropriate use of constants, handle different reference surfaces; different computational time steps; and slight variation in the measurement height of certain meteorological measurements. Note that standardized reference ET when described in this generalized form is given the abbreviation ETsz.

Standardized Equation To Be Used By AZMET

AZMET will utilize the standardized procedure for a short reference crop computed using a daily computational time step. The appropriate equation for this version of the standardized procedure is provided below:

$$ETos = \frac{0.408\Delta R_n + \gamma \dfrac{900}{T+273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (2)$$

Where:

ETos = standardized reference crop evapotranspiration for a short crop in mm d^{-1}

Δ = slope of the saturation vapor pressure-temperature curve (kPa $^oC^{-1}$)

R_n = Calculated net radiation at the crop surface in MJ m^{-2} d^{-1}

γ = psychrometer constant (kPa $^oC^{-1}$)

T = mean daily air temperature measured at 1.5 m above ground level (^oC)

u_2 = mean daily wind speed measured at 2 m above ground level (m s^{-1})

e_s = saturation vapor pressure measured at 1.5 m above ground level (kPa)

e_a = mean actual vapor pressure measured at 1.5 m above ground level (kPa)

A comparison of Eqs. 1 and 2 reveal some significant differences. One notable difference is the change in abbreviation for reference ET. The ASCE task force recommended using the abbreviation ETos for short crop standardized reference ET. Another important difference among the two equations is that the numerator and denominator constants in Eq. 1 are set equal to 900 and 0.34, respectively which represent the appropriate constants for the short reference crop and daily computational time step. Finally, one will notice that Eq. 2 no longer contains the soil heat flux variable (G in Eq. 1). Soil heat flux is typically very small over a period of 24 hours (heat that flows into soil in day is lost back to the surface at night) and thus is set equal to zero in the standardized equation when the daily computation time step is used.

The reason AZMET chose to use reference ET computed for a short reference crop is to provide continuity with past AZMET ETo data. AZMET has used a 0.08-0.15 m tall cool season grass as its ET reference surface since the inception of the network in 1987.

The time step for ETsz computation was another factor addressed by the ASCE TC. Time step refers to the time interval over which the ETsz computation is made. The TC recommended standardized procedures for two computational time steps — hourly and daily. The daily computational time step has been used for many decades, in part because most older meteorological data sets consisted of daily summaries. The advent of automated weather stations in the late 1970s led to an increase in the number of hourly data sets that could be used to compute ETo. Past research suggests the ETo computation is more accurate when the computation time step is hourly as opposed to daily or longer (Tanner and Pelton, 1960, Van Bavel, 1966), particularly in regions where meteorological conditions vary in an asymmetric manner each day (e.g., coastal locations with fog or sea breeze; certain mountain areas subject to sudden changes in wind or cloudiness each day). One of the objectives of the TC was to recommend a standardized procedure where the computational time step did not greatly impact the resulting ETsz value. The TC did conduct an evaluation of the impact of time step on the resulting ETsz value (Itenfisu et al., 2000). The evaluation found that ETsz computed using the hourly and daily time step was generally within 2% across a large number of locations (including Arizona).

AZMET chose to use the daily time step computation model for the following reasons: 1) meteorological conditions in Arizona do not generally exhibit serious asymmetric tendencies over the course of a day; 2) daily

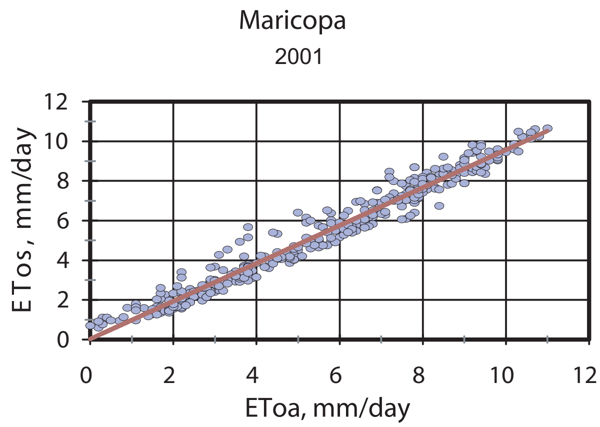

Figure 2. Reference evapotranspiration as computed using the ASCE standardized procedure (ETos) versus reference evapotranspiration computed using procedure employed by AZMET. The line represents the least squares regression line (ETos = 0.03 + 0.95 x ETo a; $r^2 = 0.96$).

meteorological data are easier to estimate than hourly data when data are missing due to instrument failure or station maintenance; and 3) AZMET questions the accuracy of nighttime net radiation (R_n)estimates required to estimate ETos on an hourly timescale.

Data Required To Compute ETos

Both meteorological and non-meteorological data are required for the computation of ETos. The required meteorological data include: 1) daily solar radiation (MJ m^{-2} d^{-1}), 2) mean daily vapor pressure (kPa), 3) mean daily wind speed (m s^{-1}), and 4) maximum and minimum air temperature for the day (^oC). All of the required meteorological data are collected by AZMET weather stations. Required non-meteorological data consist of elevation above sea level and latitude for the locations providing the meteorological data (AZMET weather station locations).

The meteorological data required for computation of ETos must be converted into the specific variables required in Eq. 2. Multiple procedures are available for making these required conversions. The ASCE TC reviewed many of the recommended conversion procedures and made recommendations on the best procedures to use based on the kind and quality of available meteorological data. The specific procedures and/or equations employed by AZMET to generate these required variables are presented in the Appendix to this report

Comparison of Standardized Reference ET with Original AZMET ETo

A logical question for users of ETo data would be how does the new standardized procedure (ETos) compare with the original AZMET ETo (ETo a) data. To answer this question, AZMET computed daily ETos for the period 1 January 1998 through 31 December 2001 (4 years), then compared the monthly, seasonal, and annual totals of ETos against similar totals of ETo a for locations presently served by AZMET weather stations.

ETos and ETo a were highly correlated across all locations served by AZMET. The data presented in Figure 2 are representative of the general relationship between ETos and ETo a. While ETos and ETo a are highly correlated, values of ETos generally run lower than ETo a. This lower bias of ETos is clearly evident in Tables 2 and 3 that present monthly, seasonal, and annual totals of ETos and ETo a for all locations presently served by AZMET weather stations. Also included in Tables 2 and 3 are ratios of ETos to ETo a for the various time scales.

Annual totals of ETos were 3-17% lower than similar totals of ETo a depending on location (Table 3). The lowest ratios of ETos to ETo a occur where wind flow is generally low (e.g., Waddell, Phoenix Encanto, and Phoenix Greenway). The highest ratios occur at locations exhibiting fairly high wind speeds (e.g., Marana, Parker).

The monthly and seasonal ratios presented in Tables 2 and 3 reveal that the lower bias of ETos (relative to ETo a) is not constant over time. Higher ratios typically occur during windy months and months with higher dew point temperatures (e.g., summer monsoon months). Lower ratios commonly occur when dew point and wind flow are low.

Converting Past ETo a to ETos

Long time users of AZMET data may have databases and spreadsheets that contain values of ETo a generated in past years. Users interested in converting ETo a data into reliable estimates of ETos may use the ratios presented in Tables 2 & 3. The simple conversion process uses the following equation:

$$ETos = Ratio * ETo a \qquad (3)$$

Table 2. Mean monthly values of reference evapotranspiration for all AZMET station sites for the period 1998-2001 computed using the ASCE standardized (ETos) and original AZMET (EToa) computation procedures. Monthly ratios of ETos to EToa are provided in columns labeled "Ratio."

LOCATION	JANUARY			FEBRUARY			MARCH			APRIL			MAY			JUNE		
	ETos (mm)	EToa (mm)	Ratio	ETos (mm)	EToa (mm)	Ratio	ETos (mm)	EToa (mm)	Ratio	ETos (mm)	EToa (mm)	Ratio	ETos (mm)	EToa (mm)	Ratio	ETos (mm)	EToa (mm)	Ratio
Aguila	72.6	80.5	0.90	77.8	90.1	0.86	125.4	147.2	0.85	171.1	198.5	0.86	241.6	273.0	0.89	261.4	289.3	0.90
Buckeye	74.3	83.8	0.89	84.7	96.1	0.88	134.0	151.7	0.88	180.2	207.0	0.87	240.5	270.0	0.89	251.0	276.2	0.91
Bonita	69.8	79.0	0.88	82.8	94.2	0.88	126.3	146.6	0.86	167.5	197.2	0.85	222.8	256.6	0.87	228.1	247.6	0.92
Coolidge	73.5	78.4	0.94	82.2	90.4	0.91	124.6	140.4	0.89	174.5	197.5	0.88	247.4	269.4	0.92	253.7	271.7	0.93
Eloy	69.4	77.1	0.90	81.1	91.3	0.89	125.7	146.0	0.86	173.5	204.2	0.85	241.6	274.7	0.88	254.0	277.5	0.92
Harquahala	65.7	76.6	0.86	73.9	87.7	0.84	124.5	148.0	0.84	166.8	198.2	0.84	220.9	253.1	0.87	246.7	272.4	0.91
Litchfield Pk.	66.8	75.7	0.88	77.5	88.4	0.88	126.1	144.3	0.87	173.5	202.5	0.86	238.7	270.1	0.88	263.1	287.7	0.91
Maricopa	63.3	72.5	0.87	80.0	89.7	0.89	126.0	143.6	0.88	175.0	199.1	0.88	244.0	267.5	0.91	261.3	280.4	0.93
Marana	90.2	89.5	1.01	98.9	102.2	0.97	144.9	157.5	0.92	184.2	206.2	0.89	251.8	274.1	0.92	264.6	277.3	0.95
Mohave Val.	80.7	87.0	0.93	87.3	94.6	0.92	145.8	164.6	0.89	191.8	214.9	0.89	257.8	278.6	0.93	257.4	275.2	0.94
Paloma	72.9	79.6	0.92	84.8	94.9	0.89	131.1	149.5	0.88	173.5	200.0	0.87	234.4	259.8	0.90	255.8	276.2	0.93
Parker	72.5	78.4	0.93	80.9	90.1	0.90	134.7	153.2	0.88	192.1	211.4	0.91	263.8	280.9	0.94	281.5	288.9	0.97
Phoenix Encanto	54.5	65.6	0.83	67.5	80.7	0.84	111.8	133.6	0.84	153.6	185.3	0.83	209.9	247.0	0.85	228.2	262.3	0.87
Phoenix Greenway	51.1	69.8	0.73	65.4	83.5	0.78	108.6	134.3	0.81	149.7	182.8	0.82	205.3	245.3	0.84	226.0	261.4	0.86
Queen Ck.	61.7	66.0	0.93	74.8	81.9	0.91	117.9	131.0	0.90	159.9	182.3	0.88	214.9	240.3	0.89	227.0	249.1	0.91
Roll	64.5	80.5	0.80	76.9	92.4	0.83	128.4	153.6	0.84	174.8	204.8	0.85	222.5	251.6	0.88	234.2	258.4	0.91
Safford	74.8	80.8	0.93	92.4	100.8	0.92	139.4	156.8	0.89	187.0	211.8	0.88	250.8	274.1	0.92	252.7	264.5	0.96
Tucson	68.6	80.8	0.85	82.4	94.6	0.87	128.0	151.2	0.85	166.3	196.0	0.85	224.3	258.1	0.87	235.4	258.3	0.91
Waddell	54.0	76.2	0.71	67.3	86.2	0.78	111.4	136.8	0.81	156.1	192.3	0.81	217.8	262.6	0.83	236.4	276.2	0.86
Yuma Mesa	69.7	85.2	0.82	80.2	95.8	0.84	129.4	155.0	0.83	168.7	199.6	0.85	217.6	247.7	0.88	238.8	261.8	0.91
Yuma N. Gila	71.6	84.2	0.85	80.2	94.3	0.85	127.5	151.3	0.84	170.2	199.0	0.86	211.8	239.7	0.88	229.0	251.2	0.91
Yuma Valley	83.9	94.5	0.89	90.5	103.3	0.88	135.1	158.7	0.85	181.3	207.9	0.87	230.5	254.1	0.91	259.3	278.5	0.93

Table 2 continued. Mean monthly values of reference evapotranspiration for all AZMET station sites for the period 1998-2001 computed using the ASCE standardized (ETos) and original AZMET (EToa) computation procedures. Monthly ratios of ETos to EToa are provided in columns labeled "Ratio."

LOCATION	JULY			AUGUST			SEPTEMBER			OCTOBER			NOVEMBER			DECEMBER		
	ETos (mm)	EToa (mm)	Ratio	ETos (mm)	EToa (mm)	Ratio	ETos (mm)	EToa (mm)	Ratio	ETos (mm)	EToa (mm)	Ratio	ETos (mm)	EToa (mm)	Ratio	ETos (mm)	EToa (mm)	Ratio
Aguila	249.1	259.6	0.96	218.3	222.3	0.98	184.0	199.0	0.92	138.3	153.7	0.90	90.5	100.6	0.90	75.5	82.3	0.92
Buckeye	236.8	245.5	0.96	225.3	226.9	0.99	188.6	200.6	0.94	137.9	153.6	0.90	86.3	97.8	0.88	70.9	79.3	0.89
Bonita	192.3	194.1	0.99	179.3	185.2	0.97	166.7	180.4	0.92	125.9	140.8	0.89	82.3	94.2	0.87	66.3	77.1	0.86
Coolidge	217.7	219.4	0.99	198.3	200.8	0.99	166.0	172.9	0.96	128.0	138.5	0.92	83.5	89.2	0.94	71.9	75.4	0.95
Eloy	236.1	237.6	0.99	219.0	221.7	0.99	177.3	192.1	0.92	130.3	147.1	0.89	78.5	93.6	0.84	65.3	73.0	0.89
Harquahala	249.6	260.8	0.96	231.2	234.9	0.98	182.7	199.1	0.92	127.6	148.5	0.86	77.7	93.4	0.83	68.6	78.6	0.87
Litchfield Pk.	246.8	257.5	0.96	219.2	228.3	0.96	172.5	192.0	0.90	121.4	138.1	0.88	74.7	86.8	0.86	60.9	69.0	0.88
Maricopa	247.6	249.7	0.99	223.6	225.1	0.99	182.8	192.9	0.95	128.1	141.9	0.90	73.6	84.4	0.87	58.9	66.1	0.89
Marana	220.2	216.1	1.02	209.6	204.4	1.03	193.4	194.1	1.00	152.9	155.2	0.99	107.9	107.5	1.00	82.6	83.7	0.99
Mohave Val.	233.5	244.3	0.96	211.0	217.2	0.97	169.0	184.8	0.91	131.0	144.1	0.91	89.0	97.6	0.91	91.8	99.8	0.92
Paloma	241.4	247.8	0.97	213.4	213.9	1.00	174.4	183.4	0.95	129.5	142.7	0.91	81.4	90.8	0.90	69.4	72.9	0.95
Parker	276.1	275.7	1.00	224.0	224.4	1.00	194.2	202.2	0.96	144.8	156.7	0.92	88.4	97.7	0.90	75.3	82.2	0.92
Phoenix Encato	223.8	243.3	0.92	207.0	222.7	0.93	161.3	185.7	0.87	108.7	131.2	0.83	63.3	79.8	0.79	49.9	61.7	0.81
Phoenix Greenway	221.2	240.3	0.92	206.2	222.1	0.93	158.1	185.7	0.85	106.8	137.0	0.78	60.3	85.6	0.70	47.0	66.4	0.71
Queen Ck.	219.7	222.5	0.99	205.8	207.9	0.99	169.2	179.5	0.94	117.9	131.1	0.90	72.5	82.2	0.88	57.3	63.2	0.91
Roll	234.1	246.0	0.95	222.2	230.5	0.96	180.8	193.5	0.93	129.9	143.3	0.91	74.8	84.3	0.89	63.8	77.5	0.82
Safford	205.5	203.4	1.01	178.2	177.7	1.00	161.8	170.0	0.95	125.7	136.0	0.92	80.3	88.5	0.91	68.9	72.4	0.95
Tucson	201.1	205.2	0.98	192.1	197.9	0.97	168.8	183.8	0.92	123.6	143.1	0.86	77.6	92.0	0.84	64.1	77.3	0.83
Waddell	225.6	250.7	0.90	199.0	220.2	0.90	156.2	188.8	0.83	107.5	140.2	0.77	61.9	88.8	0.70	48.8	71.0	0.69
Yuma Mesa	241.0	252.4	0.95	217.6	224.6	0.97	174.9	191.3	0.91	129.3	150.2	0.86	83.4	98.5	0.85	75.1	90.5	0.83
Yuma N. Gila	249.3	254.1	0.98	233.6	233.6	1.00	182.9	193.5	0.95	133.6	148.3	0.90	82.7	92.8	0.89	74.6	85.5	0.87
Yuma Valley	266.8	276.3	0.97	240.2	241.8	0.99	203.7	212.8	0.96	148.8	162.9	0.91	96.1	104.1	0.92	89.0	97.9	0.91

Table 3. Seasonal and annual means of reference evapotranspiration for all active AZMET monitoring sites for the period 1998-2001 as computed using the ASCE standardized (ETos) and original AZMET (EToa) procedures. Ratios of ETos to EToa are provided in columns labeled “Ratio.”

LOCATION	WINTER (Dec. - Feb.)			SPRING (Mar. - May)			SUMMER (Jun. - Aug.)			FALL (Sep. - Nov.)			ANNUAL		
	ETos (mm)	EToa (mm)	Ratio	ETos (mm)	EToa (mm)	Ratio	ETos (mm)	EToa (mm)	Ratio	ETos (mm)	EToa (mm)	Ratio	ETos (mm)	EToa (mm)	Ratio
Aguila	225.9	252.9	0.89	538.1	618.7	0.87	728.8	771.2	0.94	412.8	453.3	0.91	1905.7	2095.9	0.91
Buckeye	229.9	259.2	0.89	554.7	628.7	0.88	713.1	748.6	0.95	412.8	452.0	0.91	1910.5	2088.2	0.91
Bonita	218.9	250.3	0.87	516.6	600.4	0.86	599.7	626.9	0.96	374.9	415.4	0.90	1710.2	1892.9	0.90
Coolidge	227.6	244.2	0.93	546.5	607.3	0.90	669.7	691.9	0.97	377.5	400.6	0.94	1821.3	1944.0	0.94
Eloy	215.8	241.4	0.89	540.8	626.4	0.86	709.1	735.3	0.96	386.1	432.8	0.89	1851.9	2035.7	0.91
Harquahala	208.2	242.9	0.86	512.2	599.3	0.85	727.5	768.1	0.95	388.0	441.0	0.88	1835.9	2051.2	0.90
Litchfield Pk.	205.2	233.1	0.88	538.3	616.9	0.87	729.1	773.5	0.94	368.6	416.9	0.88	1841.3	2040.4	0.90
Maricopa	202.2	228.3	0.89	545.0	610.2	0.89	732.5	755.2	0.97	384.5	419.2	0.92	1864.2	2012.8	0.93
Marana	271.7	275.4	0.99	580.9	637.8	0.91	694.4	697.8	1.00	454.2	456.8	0.99	2001.2	2067.6	0.97
Mohave Val.	259.8	281.4	0.92	595.4	658.1	0.90	701.9	736.7	0.95	389.0	426.5	0.91	1946.2	2102.4	0.93
Paloma	227.1	247.4	0.92	539.0	609.3	0.88	710.6	737.9	0.96	385.3	416.9	0.92	1862.0	2011.3	0.93
Parker	228.7	250.7	0.91	590.6	645.5	0.91	781.6	789.0	0.99	427.4	456.6	0.94	2028.4	2141.6	0.95
Phoenix Encanto	171.9	208.0	0.83	475.3	565.9	0.84	659.0	728.3	0.90	333.3	396.7	0.84	1639.6	1898.7	0.86
Phoenix Greenway	163.5	219.7	0.74	463.6	562.4	0.82	653.4	723.8	0.90	325.2	408.3	0.80	1605.6	1914.1	0.84
Queen Ck.	193.8	211.1	0.92	492.7	553.6	0.89	652.5	679.5	0.96	359.6	392.8	0.92	1698.5	1836.7	0.92
Roll	205.2	250.4	0.82	525.7	610.0	0.86	690.5	734.9	0.94	385.5	421.1	0.92	1806.9	2016.3	0.90
Safford	236.1	254.0	0.93	577.2	642.7	0.90	636.4	645.6	0.99	367.8	394.5	0.93	1817.6	1936.6	0.94
Tucson	215.1	252.7	0.85	518.6	605.3	0.86	628.6	661.4	0.95	370.0	418.9	0.88	1732.2	1938.2	0.89
Waddell	170.1	233.4	0.73	485.3	591.7	0.82	661.0	747.1	0.88	325.6	417.8	0.78	1642.0	1989.7	0.83
Yuma Mesa	225.0	271.5	0.83	515.7	602.3	0.86	697.4	738.8	0.94	387.6	440.0	0.88	1825.7	2052.4	0.89
Yuma N. Gila	226.4	264.0	0.86	509.5	590.0	0.86	711.9	738.9	0.96	399.2	434.6	0.92	1847.0	2027.4	0.91
Yuma Valley	263.4	295.7	0.89	546.9	620.7	0.88	766.3	796.6	0.96	448.6	479.8	0.93	2025.2	2192.5	0.92

where **Ratio** represents the appropriate annual, seasonal or monthly ratio from Tables 2 and 3. Annual ratios should be used only to adjust annual totals of ETоa. Monthly ratios provide the best means of converting short term data sets (e.g., daily, weekly or monthly totals of ETоa). *Users wishing to obtain actual computed values of ETos for past years should contact AZMET. As part of the move to adopt ETos, AZMET will generate ETos for its entire database which extends back to 1987 at some locations.*

Crop Coefficients and ETos

Crop coefficients (Kcs) are used to convert ETo data into estimates of crop evapotranspiration (ETc). The simple conversion procedure is as follows:

$$ETc = Kc * ETo \quad (4)$$

It is important to note that Kcs need to be matched to the ETo procedure in order to obtain reliable estimates of ETc from Eq. 4. To help clarify this point, suppose one has a turf Kc of 0.75 that is appropriate for use with AZMET ETo (ETоa). To obtain an estimate of turf water use in Tucson for May one would multiply the Kc (0.75) times the May ETоa value for Tucson (258.1 mm from Table 2):

$$ETc = Kc * ETоa$$

$$ETc = 0.75 * 258.1 \text{ mm}$$

$$ETc = 193.6 \text{ mm } (7.62'')$$

If, however, this same Kc is erroneously applied to values of ETos, the same May turf water use estimate in Tucson would be:

$$ETc = Kc * ETos$$

$$ETc = 0.75 * 224.3 \text{ mm}$$

$$ETc = 168.2 \text{ mm } (6.62'')$$

or 25.4 mm (1.0") less than the correct value. It is clear from this example that failure to match Kcs with ETo procedure can lead to significant errors when estimating water use from vegetation.

Very few Kcs have been validated for use with ETos in Arizona with the notable exception of turfgrass (Brown and Kopec, 2000). While a number of research studies are presently underway (University of Arizona and USDA-ARS) that should provide validated Kcs for a number of Arizona crops in the near future, individuals interested in applying Kcs to ETos must either use published Kcs developed in another location, or adjust existing AZMET Kcs. A good place to locate Kcs for use with ETos is the publication entitled *Crop Evapotranspiration: Guidelines for computing crop water requirements* which is listed in the Reference section of this report.

Adjusting AZMET Kcs is a simple process that requires the use of the ratio data in Tables 2 and 3:

$$Kc_{os} = Kc_{az} / Ratio \quad (5)$$

where Kc_{os} and Kc_{az} are the crop coefficient values appropriate for use with ETos and ETоa, respectively; and **Ratio** is the ratio of ETos to ETоa provided in Tables 2 and 3. In the previous example pertaining to turfgrass water use for Tucson in May, one would correct the Kc_{az} value of 0.75 by dividing by the May ratio presented in Table 2 (0.87):

$$Kc_{os} = 0.75 / 0.87 = 0.86$$

Seasonal ratios of ETos to ETоa are provided in Table 3 to assist with adjusting Kc_{az} for row crops. For example, AZMET has recommended using a Kc of 1.12 for full cover cotton when using ETоa. The process of adjusting this Kc for use with ETos at Maricopa would proceed as follows:

$$Kc_{os} = 1.12 / 0.97 = 1.15$$

The value of 0.97 is the summer ratio for Maricopa (see Table 3).

On a practical note it is important to recognize that existing Kc_{az} values will require only minor adjustments (if any) when used during the summer months. Larger adjustments will be required in winter where the ratios of ETos to ETоa are generally much less than 1.0.

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Appendix

The procedures and equations used to compute the variables presented in Equation 2 are described in this Appendix. The variables are presented in the order they are encountered in Eq. 2.

Δ: Slope of Saturation Vapor Pressure vs. Temperature Relationship

The slope of the saturation vapor pressure versus temperature relationship, Δ (kPa $^oC^{-1}$), is computed using:

$$\Delta = 2503 \exp((17.27T)/(T + 237.3))/(T + 237.3)^2 \qquad (A1)$$

where T is the mean temperature for the day (^{o}C).

Rn: Net Radiation

Net radiation is the net amount of radiant energy available at the surface for evaporating water. Rn includes both short and long wave radiation and is computed using:

$$Rn = Rns - Rnl \qquad (A2)$$

where Rns = net shortwave radiation (MJ m^{-2} d^{-1}) defined as positive in the downward direction (toward earth) and Rnl = net longwave radiation (MJ m^{-2} d^{-1}) defined as positive in the upward direction (toward sky).

Net shortwave radiation (Rns) is computed as the difference between incoming and reflected shortwave radiation:

$$Rns = Rs - \alpha Rs = (1 - \alpha)Rs \qquad (A3)$$

where α = albedo or canopy reflection coefficient which is fixed at 0.23 and Rs = incoming solar radiation (MJ m^{-2} d^{-1}).

Net longwave radiation (Rnl) is the difference between upward longwave radiation (Rlu) and downward longwave radiation from the sky (Rld):

$$Rnl = Rlu - Rld \qquad (A4)$$

The daily value of Rnl is computed using:

$$Rnl=\sigma[(T_K^4max+T_K^4min)/2]*(0.34-0.14\sqrt{ea})[1.35(Rs/Rso) - 0.35] \qquad (A5)$$

where Rnl is net long-wave radiation in MJ m^{-2} d^{-1}, σ is the Stefan-Boltzman constant [= 4.901 x 10^{-9} MJ K^{-4} m^{-2} d^{-1}], T_K^4max is the maximum absolute temperature for the day (K), T_K^4min is the minimum absolute temperatures for the day (K), ea is the actual vapor pressure (kPa), Rs is solar radiation (MJ m^{-2} d^{-1}), and Rso is calculated clear-sky solar radiation (MJ m^{-2} d^{-1}). The ratio Rs/Rso indicates the relative level of cloudiness must be limited to $0.3 < Rs/Rso < 1.0$. Rs/Rso values <0.30 are set = 0.30; Rs/Rso values > 1.0 are set = 1.0.

Clear sky solar radiation (Rso) is computed using:

$$Rso = (0.75 + 2 * 10^{-5} z)Ra \qquad (A6)$$

where z is the elevation above sea level (m) and Ra is extraterrestrial radiation (MJ m^{-2} d^{-1}).

Extraterrestrial radiation is computed from earth-sun geometry using:

$$Ra = (24/\pi)Gsc\ dr * [\omega s \sin(\varphi) \sin(\delta) + \cos(\varphi) \cos(\delta) \sin(\omega s)] \qquad (A7)$$

where Gsc is the solar constant [= 4.92 MJ m^{-2} h^{-1}], dr is relative distance factor (between the earth and sun), ωs is sunset hour angle (radians), φ is the latitude (radians), and δ solar declination (radians).

The relative distance factor is computed using:

$$dr = 1 + 0.033\cos(2\pi J/365) \qquad (A8)$$

where J is the day of the year (1 = 1 January; 365 = 31 December).

The solar declination angle is computed using:

$$\delta = 0.409\sin((2\pi J/365) - 1.39) \qquad (A9)$$

The sunset angle is computed using:

$$\omega s = \arccos[-\tan(\varphi) \tan(\delta)] \qquad (A10)$$

γ: Psychrometer Constant

The psychrometer constant, γ (kPa $^{o}C^{-1}$), is computed using:

$$\gamma = 0.000665\ P \qquad (A11)$$

where P is the atmospheric pressure at the weather station site. Atmospheric pressure (kPa) is computed from the elevation of the weather station site:

$$P = 101.3\ ((293 - 0.0065\ z)\ /\ 293)^{5.26} \qquad (A12)$$

where z is the elevation of the weather station above mean sea level (m).

T: Mean Air Temperature

Mean air temperature (^{o}C) is calculated as the mean of the daily maximum and daily minimum air temperature:

$$T = (Tmax + Tmin)/2 \qquad (A13)$$

where Tmax and Tmin are the maximum and minimum air temperatures (°C) as obtained from the weather station data logger.

u_2:Wind Speed

The standardized equation requires the mean daily wind speed measured at 2 m above ground level (agl). Because AZMET measures wind speed at 3 m agl, wind speed is adjusted to an equivalent value at 2 m agl using the following:

$$u_2 = u_3 (4.87/\ln(67.8\ zw - 5.42) \qquad \text{(A14)}$$

where u_3 is the wind speed measured at 3 m agl and zw is the height of the wind speed measurement (3 m).

e_s: Saturation Vapor Pressure

Saturation vapor pressure is computed using:

$$es = (es(Tmax) + es(Tmin)) / 2 \qquad \text{(A15)}$$

where es(Tmax) and es(Tmin) are the saturation vapor pressures (kPa) computed using the maximum and minimum air temperatures, respectively. Saturation vapor pressure is computed using the following:

$$es = 0.6108 \exp((17.27Tex) / (Tex + 237.3)) \qquad \text{(A16)}$$

where Tex is either Tmax or Tmin (°C) .

ea: Actual Vapor Pressure

The mean actual vapor pressure for the day is computed by the weather station datalogger using simultaneous measurements of relative humidity (RH; %) and air temperature (Ta; °C) using:

$$ea = (RH/100) [0.6108 \exp((17.27Ta)/(Ta + 237.3))] \qquad \text{(A17)}$$

Values of ea are computed by the datalogger every 10 s and averaged for the day.

APPENDIX E

Water Level Measurements

USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2016

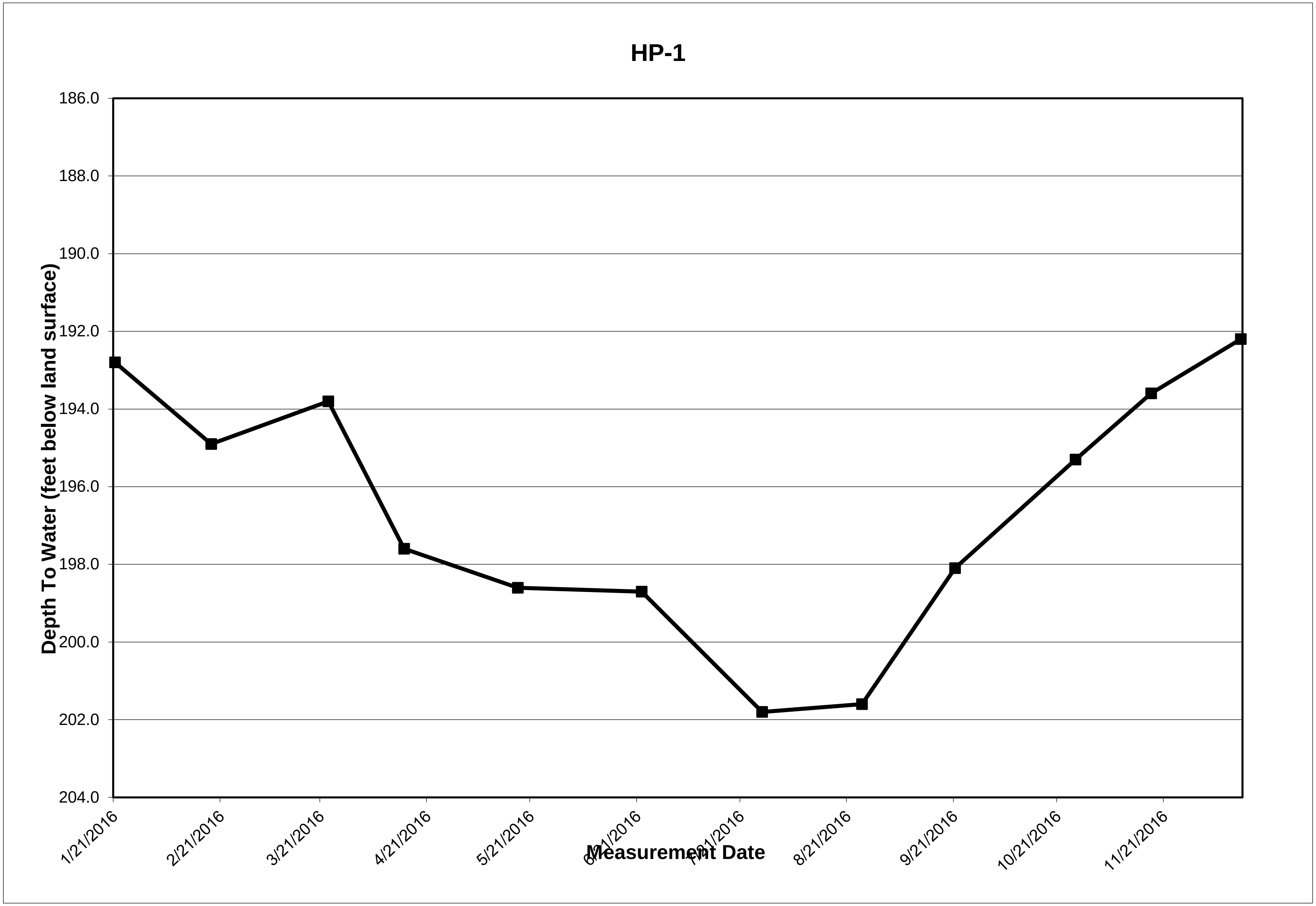
Monitor Point ID	**HP-1**
ADWR Registration Number	55-574110
Cadastral Location	D(11-11)33cad
Measuring Point Elevation (feet amsl)	1985.17
Measuring Point Description	top of port
Measuring Point Height (ft)	
Land Surface Elevation at Wellhead (feet amsl)	1985.17
Permit Alert Level (feet bls)	30
Permit OPL (feet bls)	20

Measurement Date	**DTW (feet below MP)**	**DTW (feet bls)**	**Elevation (feet amsl)**	**Exceedance Status**
1/21/2016	192.8	192.8	1792.4	
2/18/2016	194.9	194.9	1790.3	
3/23/2016	193.8	193.8	1791.4	
4/14/2016	197.6	197.6	1787.6	
5/17/2016	198.6	198.6	1786.6	
6/22/2016	198.7	198.7	1786.5	
7/27/2016	201.8	201.8	1783.4	
8/25/2016	201.6	201.6	1783.6	
9/21/2016	198.1	198.1	1787.1	
10/26/2016	195.3	195.3	1789.9	
11/17/2016	193.6	193.6	1791.6	
12/13/2016	192.2	192.2	1793.0	

* If well is dry, type the word **dry** in the DTW (feet below MP) column.

amsl - above mean sea level; DTW - depth to water; bls - below land surface; MP - measuring point

USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2016



USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2016

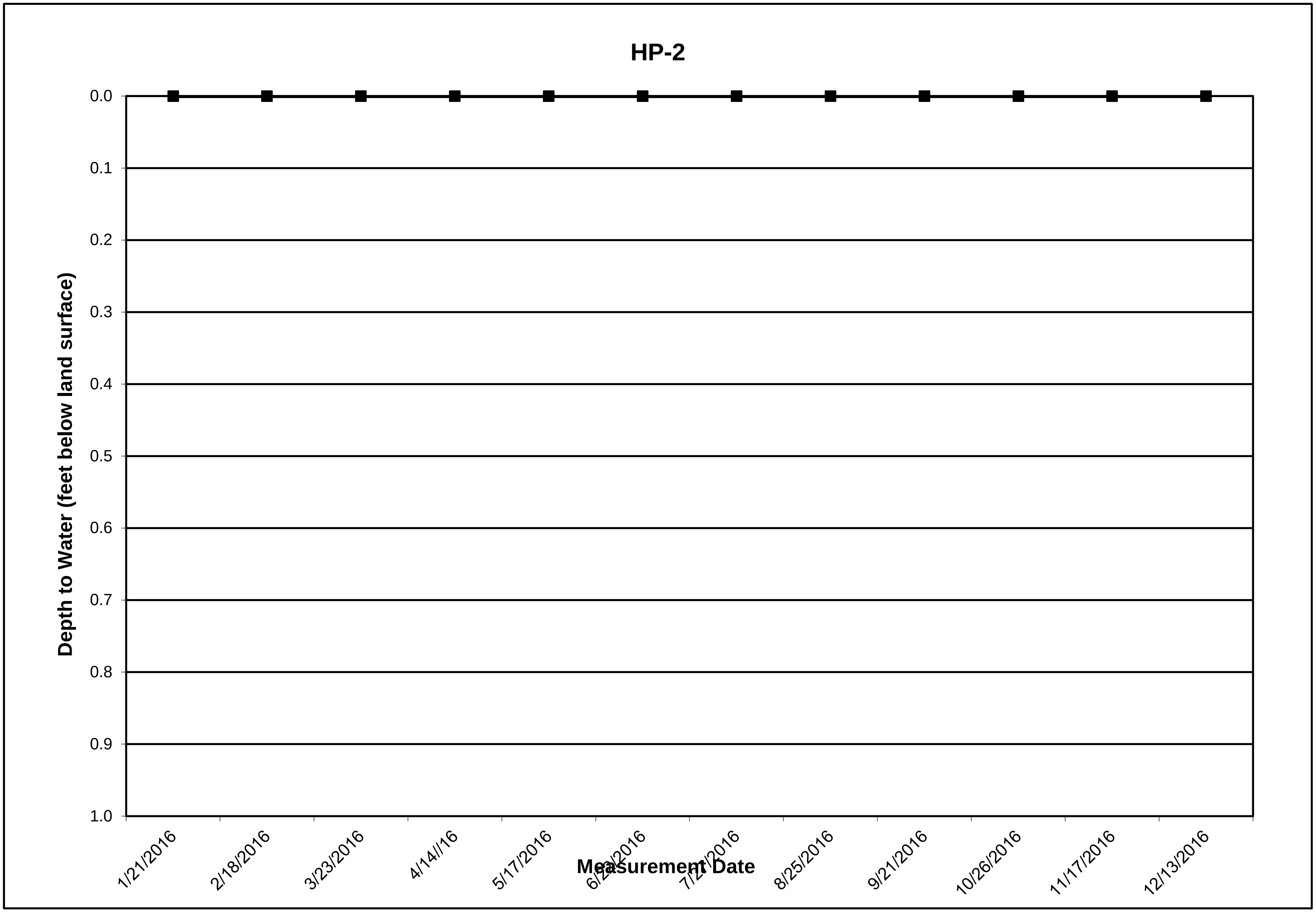
Monitor Point ID	HP-2
ADWR Registration Number	55-593607
Cadastral Location	D(11-11)33cad
Measuring Point Elevation (feet amsl)	1986.75
Measuring Point Description	top of port
Measuring Point Height (ft)	
Land Surface Elevation at Wellhead (feet amsl)	1986.75
Permit Alert Level (feet bls)	30
Permit OPL (feet bls)	20

Measurement Date	**DTW (feet below MP)**	**DTW (feet bls)**	**Elevation (feet amsl)**	**Exceedance Status**
1/21/2016	dry			
2/18/2016	dry			
3/23/2016	dry			
4/14//16	dry			
5/17/2016	dry			
6/22/2016	dry			
7/27/2016	dry			
8/25/2016	dry			
9/21/2016	dry			
10/26/2016	dry			
11/17/2016	dry			
12/13/2016	dry			

* If well is dry, type the word **dry** in the DTW (feet below MP) column.

amsl - above mean sea level; DTW - depth to water; bls - below land surface; MP - measuring point

USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2016



USF WATER LEVEL MEASUREMENTS

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0008

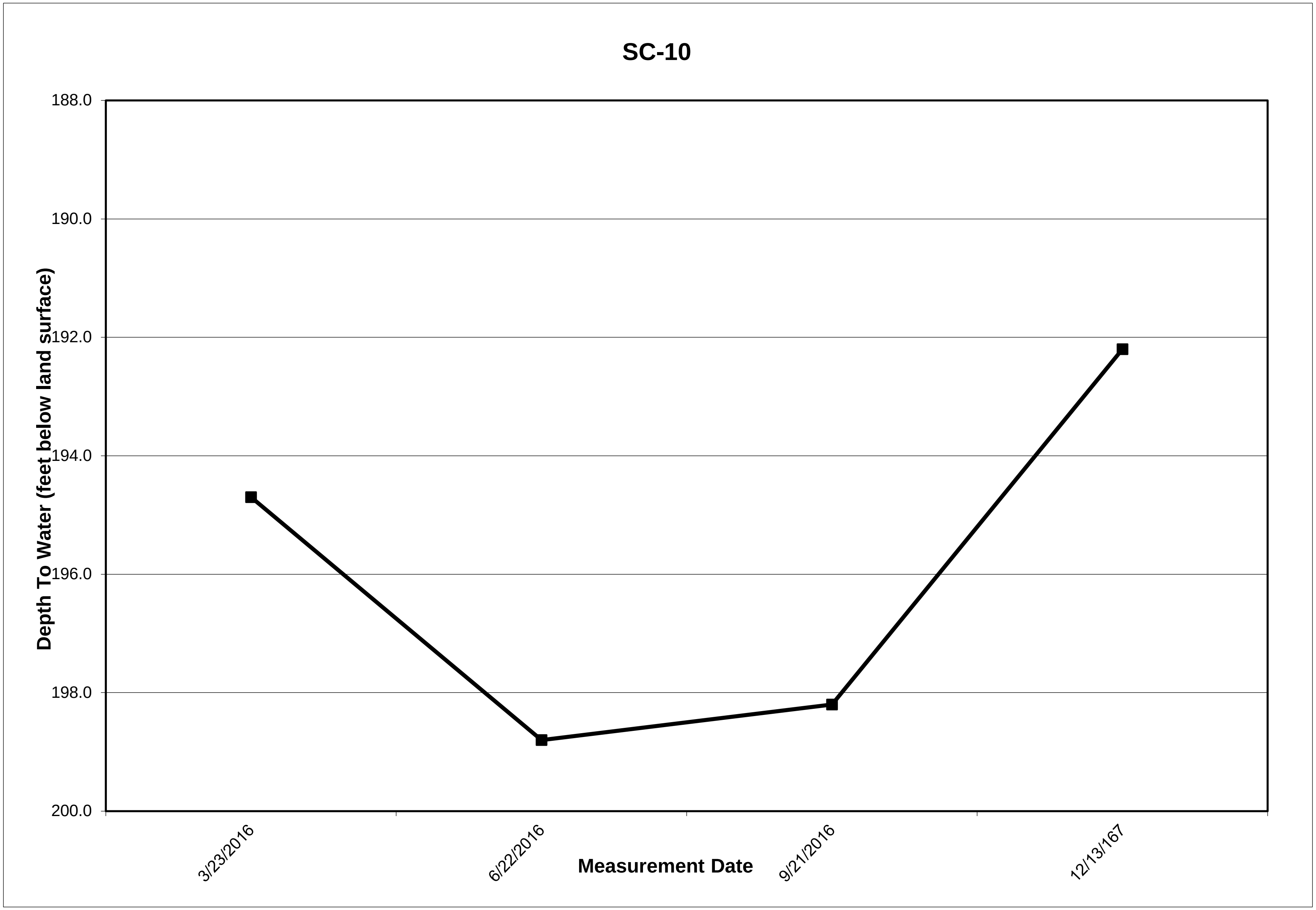
Year: 2016

Monitor Point ID	SC-10			
ADWR Registration Number	55-520129			
Cadastral Location	D(11-11)33bcb			
Measuring Point Elevation (feet amsl)	1978.36			
Measuring Point Description	top of port			
Measuring Point Height (ft)				
Land Surface Elevation at Wellhead (feet amsl)	1978.36			
Permit Alert Level (feet bls)	30			
Permit OPL (feet bls)	20			
Measurement Date	**DTW (feet below MP)**	**DTW (feet bls)**	**Elevation (feet amsl)**	**Exceedance Status**
3/23/2016	194.7	194.7	1790.5	
6/22/2016	198.8	198.8	1786.4	
9/21/2016	198.2	198.2	1787.0	
12/13/167	192.2	192.2	1793.0	

* If well is dry, type the word **dry** in the DTW (feet below MP) column.

amsl - above mean sea level; DTW - depth to water; bls - below land surface; MP - measuring point

USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2016



APPENDIX F

Infiltration Rate Data &
Calculations

INFILTRATION RATE DATA AND CALCULATIONS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2016

	Net Recharge Volumes (ac-ft)	**Total Wetted Acreages** (ac-days)	**Infiltration Rate** (ft/day)	**Quarterly Average Infiltration Rate** (ft/day)
January	12.7	12.0	1.06	
February	5.3	6.1	0.88	
March	2.3	0.8	2.86	1.08
April	93.1	24.4	3.81	
May	81.5	27.8	2.94	
June	67.1	13.8	4.85	3.66
July	66.2	16.8	3.95	
August	0.0	0.0		
September	23.4	6.5	3.61	3.85
October	81.1	24.3	3.33	
November	90.6	24.4	3.71	
December	100.0	29.4	3.40	3.48

Totals	**623.3**	**186.3**	**3.34**

CELL 1: INFILTRATION RATE DATA AND CALCULATIONS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2016

	Net Recharge Volumes (ac-ft)	Total Wetted Acreages (ac-days)	Infiltration Rate (ft/day)	Quarterly Average Infiltration Rate (ft/day)
January	0.0	0.0		
February	0.0	0.0		
March	0.0	0.0		
April	41.1	3.3	12.65	
May	3.3	0.6	5.77	
June	25.4	0.6	42.32	15.79
July	19.4	0.8	23.60	
August	0.0	0.0		
September	0.0	0.0		23.60
October	0.0	0.0		
November	16.5	0.8	19.62	
December	35.7	3.8	9.29	11.15
Totals	**141.3**	**9.9**	**14.24**	

CELL 2: INFILTRATION RATE DATA AND CALCULATIONS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2016

	Net Recharge Volumes (ac-ft)	Total Wetted Acreages (ac-days)	Infiltration Rate (ft/day)	Quarterly Average Infiltration Rate (ft/day)
January	5.8	0.3	21.37	
February	0.0	0.0		
March	0.0	0.0		21.37
April	0.0	0.0		
May	41.7	3.4	12.29	
June	16.3	2.2	7.45	10.40
July	0.0	0.0		
August	0.0	0.0		
September	0.0	0.0		
October	0.0	0.0		
November	0.0	0.0		
December	20.0	5.3	3.77	3.77
Totals	**83.7**	**11.2**	**7.50**	

CELL 3: INFILTRATION RATE DATA AND CALCULATIONS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2016

	Net Recharge Volumes (ac-ft)	**Total Wetted Acreages** (ac-days)	**Infiltration Rate** (ft/day)	**Quarterly Average Infiltration Rate** (ft/day)
January	0.0	0.0		
February	0.0	0.0		
March	0.0	0.0		
April	41.4	5.2	7.97	
May	3.3	0.8	4.27	
June	25.4	0.8	31.80	10.37
July	15.7	1.3	12.27	
August	0.0	0.0		
September	0.0	0.0		12.27
October	0.0	0.0		
November	46.3	4.2	10.96	
December	32.1	5.0	6.39	8.48

Totals	**164.1**	**17.3**	**9.50**

CELL 4: INFILTRATION RATE DATA AND CALCULATIONS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2016

	Net Recharge Volumes (ac-ft)	**Total Wetted Acreages** (ac-days)	**Infiltration Rate** (ft/day)	**Quarterly Average Infiltration Rate** (ft/day)
January	6.9	7.3	0.94	
February	5.3	2.2	2.39	
March	2.3	0.4	6.03	1.46
April	10.0	6.2	1.61	
May	32.1	16.4	1.96	
June	0.0	0.0		1.86
July	28.5	6.0	4.79	
August	0.0	0.0		
September	22.3	3.6	6.25	5.34
October	79.5	18.5	4.29	
November	27.1	12.0	2.25	
December	11.1	5.9	1.89	3.23

Totals	**225.1**	**78.4**	**2.87**

EQUALIZATION BASIN: INFILTRATION RATE DATA AND CALCULATIONS

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0007

Year: 2016

	Net Recharge Volumes (ac-ft)	Total Wetted Acreages (ac-days)	Infiltration Rate (ft/day)	Quarterly Average Infiltration Rate (ft/day)
January	0.1	6.5	0.01	
February	0.0	4.1	0.01	
March	0.0	0.4		0.01
April	0.6	11.5	0.05	
May	1.2	11.5	0.10	
June	0.0	11.2	0.00	0.05
July	2.7	10.3	0.26	
August	0.0	0.0		
September	1.1	3.6	0.31	0.27
October	1.6	10.2	0.15	
November	0.7	11.4	0.07	
December	1.1	11.7	0.09	0.10

Totals	**9.1**	**92.3**	**0.10**