ANNUAL MONITORING REPORT
2015

MARANA HIGH PLAINS EFFLUENT RECHARGE PROJECT

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

Prepared by

David Scalero, Principal Hydrologist
Pima County Regional Flood Control District
Water Resources Division
201 N. Stone Avenue, 7th Floor
Tucson, Arizona 85701

for

Arizona Department of Water Resources
3550 N. Central Avenue
Phoenix, Arizona 85012

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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. 71-563876.0007), 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 thirteenth annual report for the MHPERP. This report includes all of the data that was collected during the 2015 Calendar Year.

2.0 PROJECT OPERATIONS

A modified USF Permit was approved and signed by the ADWR Assistant Director, Ms. Sandra Fabritz-Whitney, on November 24, 2008. 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 was operated per Phase 3 of the permit throughout the 2015 Calendar Year. 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 located 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), which is located 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 and two non-clogging, submersible pumps convey the effluent through an 8-inch line into an equalization basin. The equalization basin is used to provide a more constant source of available effluent for recharge and to 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.

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 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 2015 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 a Magnetflow® Mag Meter installed within the main line that runs from the pumps to the equalization basin (FMeq). The 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 2015. 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 2015 was 629.9 acre-feet (AF). Water volumes delivered for recharge by month are as follows: January – 76.53 AF, February – 32.46 AF, March – 57.26 AF, April – 57.59 AF, May – 68.25 AF, June – 83.57 AF, July – 6.93 AF, August – 0.0 AF, September – 2.36 AF, October – 58.21 AF, November – 92.9 AF, and December – 93.85 AF. A total amount of 625.1 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 (formerly Pima County Wastewater Management), 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 was 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 Network (AZMET) at their Tucson weather station (**Figure 3**).[1] 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.[2]

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[1] 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 2014.

[2] 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.

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 2015 Calendar Year is 625.1 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.[3] Water depths in Recharge Cell 4 are expected to fluctuate from six to twenty inches during the wet cycles.[4] 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.

3.2 Regional Groundwater Levels

In 2015, 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 2015 Calendar Year. Water levels in the on-site deep well (HP-1) fluctuated from 191.1 feet below land surface (bls) in January 2015 to a low of 197.6 feet bls in April 2015, and then up to 194.8 feet bls in December 2015. Water levels in the off-site monitor well (SC-10) dropped from 194.7 feet bls in January 2015 to 196.3 feet bls in September 2014, and then went up to 194.1 feet bls by December 2015.

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[3] 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.

[4] 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.

3.3 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 2015 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 2015 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, which is 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 2015, monthly infiltration rates for the project ranged from 0.00 feet per day (August-no water delivered) to 5.08 feet per day (September). The average infiltration rate for the year was 2.62 feet/day, which is 0.76 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 feet/day from January through June, which was exceptional compared to previous years. Very little recharge occurred from July through September, so infiltration was either very low because no water was delivered to the Recharge Cells or very high because the little amount of water delivered had infiltrated into the ground quickly. Significant increases in infiltration were observed after October 2015, which is most likely due to the combination of basin maintenance in September and a ten-day drying period in October.

Infiltration was the highest in Recharge Cell 1 (over 18 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, 7.12 feet/day and 7.86 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 1.7 feet per day in 2015. 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 2015 Calendar Year. Samples were taken at the oxbow channel (Diversion) and at the compliance well (HP-1). Sampling at the diversion was disrupted in August due to washout of the diversion berm by storm water runoff events. No samples were collected from HP-1 in April due to no water production as a result of damaged discharge pipes.

There were no exceedances of the aquifer quality limits in 2015 for the Diversion, but there was one exceedance of Total Coliform in HP-1 from a sample collected in September. After disinfection of the well and associated equipment with chlorine bleach, repeated weekly measurements in October reported no continuing exceedances. Therefore, there were no violations of the Aquifer Protection Permit (APP) during Calendar Year 2015.

6.0 FACILITY INSPECTIONS

Inspections of the facility equipment and functions are no longer a requirement of the APP since June 2014. However, PCRFCD continues to inspections 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 2015 Calendar Year and the actions performed to resolve them. The main disruption of effluent deliveries to the facility was due to storm water runoff events along the Santa Cruz River during the summer monsoon period, which is typical for every year. The three month period from July through most of September was used to allow the recharge cells to dry and for maintenance activities such as the excavation and removal of vegetation and fine grained soil materials from the cell bottoms. 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 29 days).

7.0 CONCLUSIONS

The calculated volume of water stored at MHPERP for Calendar Year 2015 was 625.1 AF. This is just under 19 AF more than last year's total of 606.2 AF, and is just the second year that the facility has reached its permitted total of 600 AF since operations began in 2003. 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 at the project site. Total Coliform was detected in the compliance well (HP-1) during one sampling event in September, but PCRFCD quickly dealt with the problem and further testing showed no presence of this analyte. On-site and off-site monitoring showed no negative impacts to surrounding operations from a water level perspective.

Recharge Cell 2 continues to perform at a high level, having contributed 33% of the total amount of effluent stored at the facility over Calendar Year 2015. However, this amount is about 12% less than last year's contribution, which can be attributed to the improvements made to Recharge Cells 1 and 3 over the last two years and a significant improvement in infiltration observed within Recharge Cell 4. Recharge Cell 1 contributed about 16.7 % of the total amount of effluent stored at the facility in 2015, which is down almost 10% from 2014. Recharge Cell 3 contributed about 17.4% of the total amount of effluent, which is down 3.5% from last year. Recharge Cell 4 contributed 30.4% to the total recharge amount, which is significantly higher than the 7% contributed last year. This basin showed great improvement in infiltration due to maintenance work performed in September to break up clogging layers and expose more sands and gravels through deep ripping. No maintenance was performed on the equalization basin, which provided less than 2% to the total project volume.

Infiltration rates for the facility were good during 2015, maintaining a constant rate of over 2 feet/day during normal operations. The average annual infiltration rate for the entire facility in 2015 was 2.62 feet/day, which is 0.76 feet/day greater than the previous annual high of 1.86 feet/day that was recorded in 2014. Recharge Cell 1 had the highest annual infiltration rate in 2015 (18.05 feet/day), while Recharge Cell 4 had the lowest (1.70 feet/day).[5] Excavation within Recharge Cells 1-3 and thus exposure of coarse sands and gravels over the last several years has significantly helped 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 116 days (3.8 months) resulted in no effluent deliveries to the project. Almost all of the down time (112 days) was due to washout of the diversion berm by storm water flows during the months of January, July, August, September, and October. The remaining 4 days of down time were attributed to a breakout in the oxbow channel near the wet well, most likely the result of burrowing animal activities. Greater exposure of sands and gravels in Recharge Basins 1-3 and a greater quality effluent 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.

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[5] 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.

FIGURES

FIGURE 1
Location Map

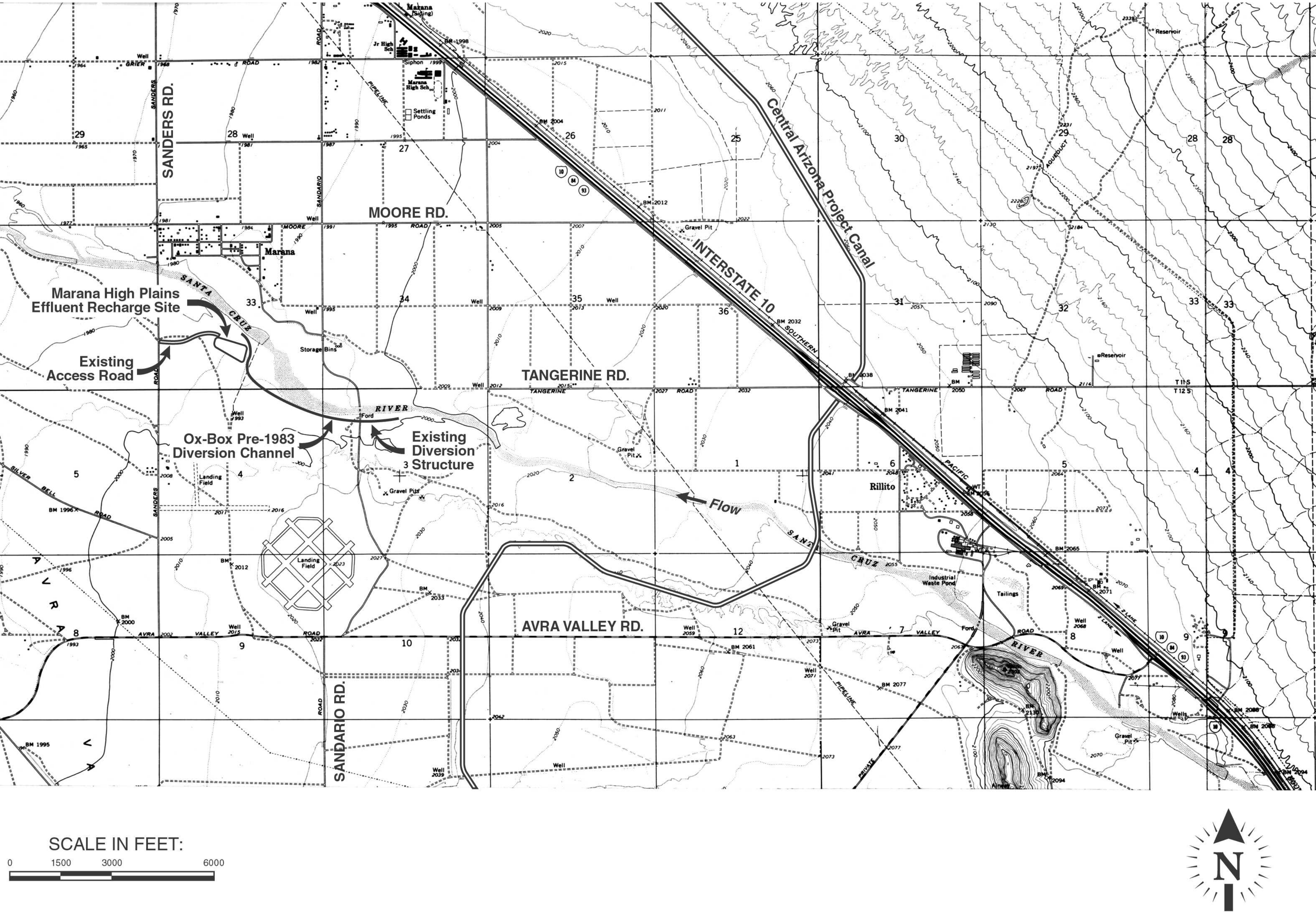
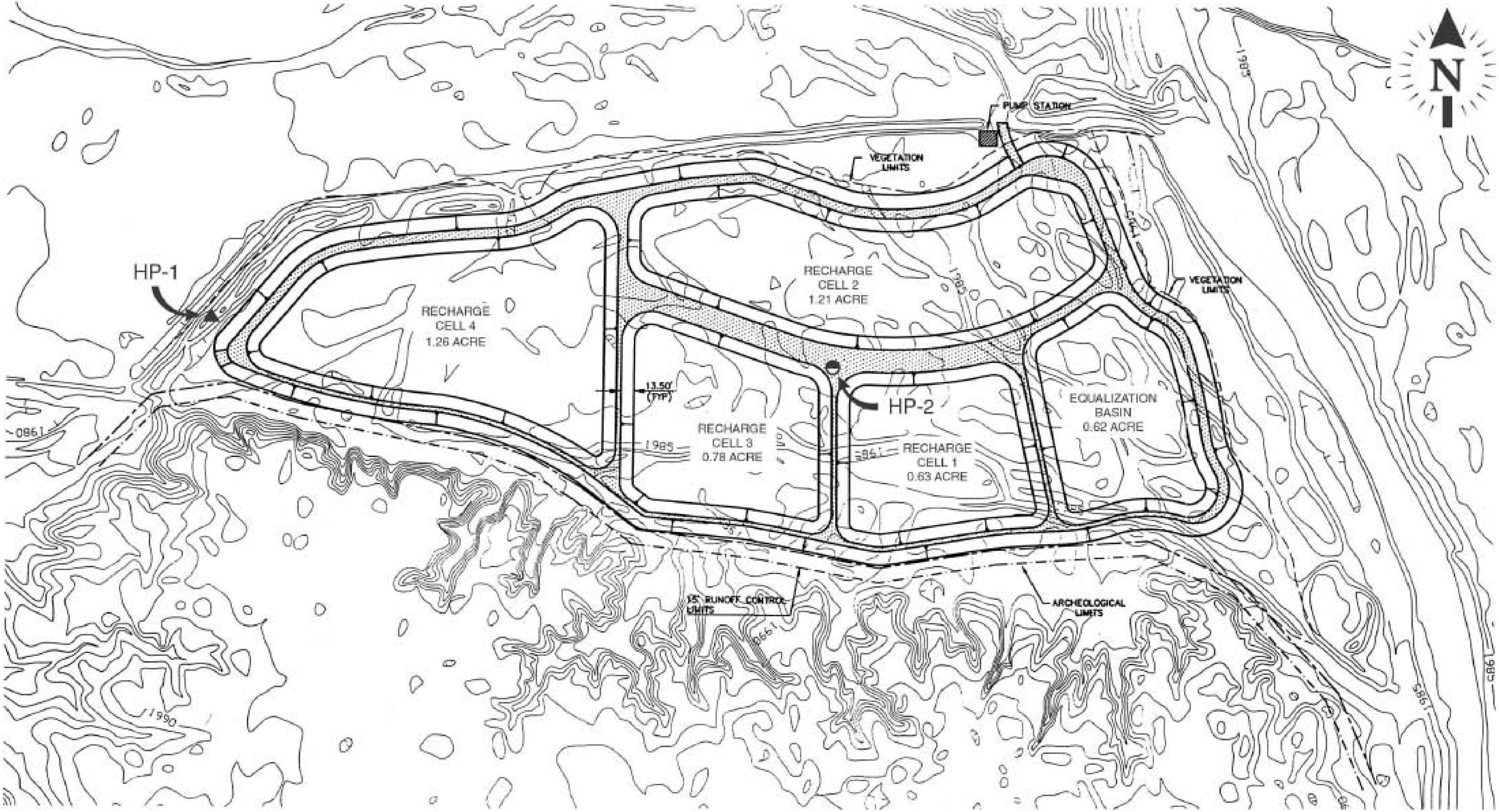


FIGURE 2
Facility Map



SCALE IN FEET:

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

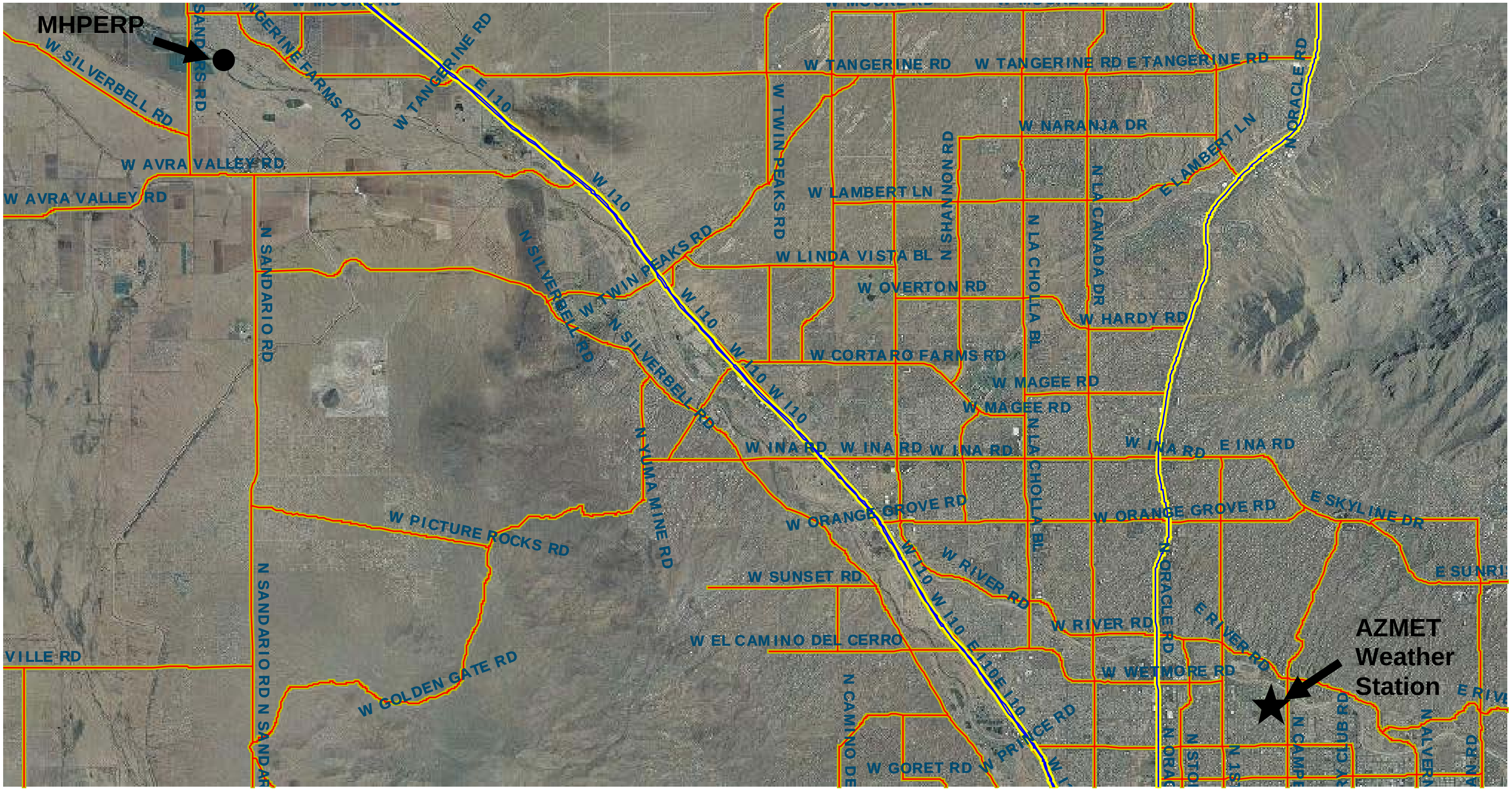
LEGEND

▲ MONITOR WELL

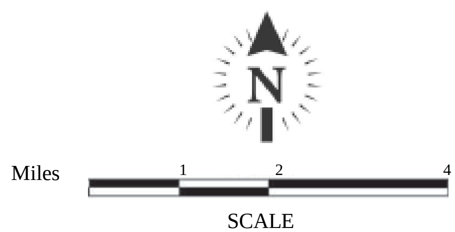
◓ PIEZOMETER

Pima County Graphic Services ds3483 7/02

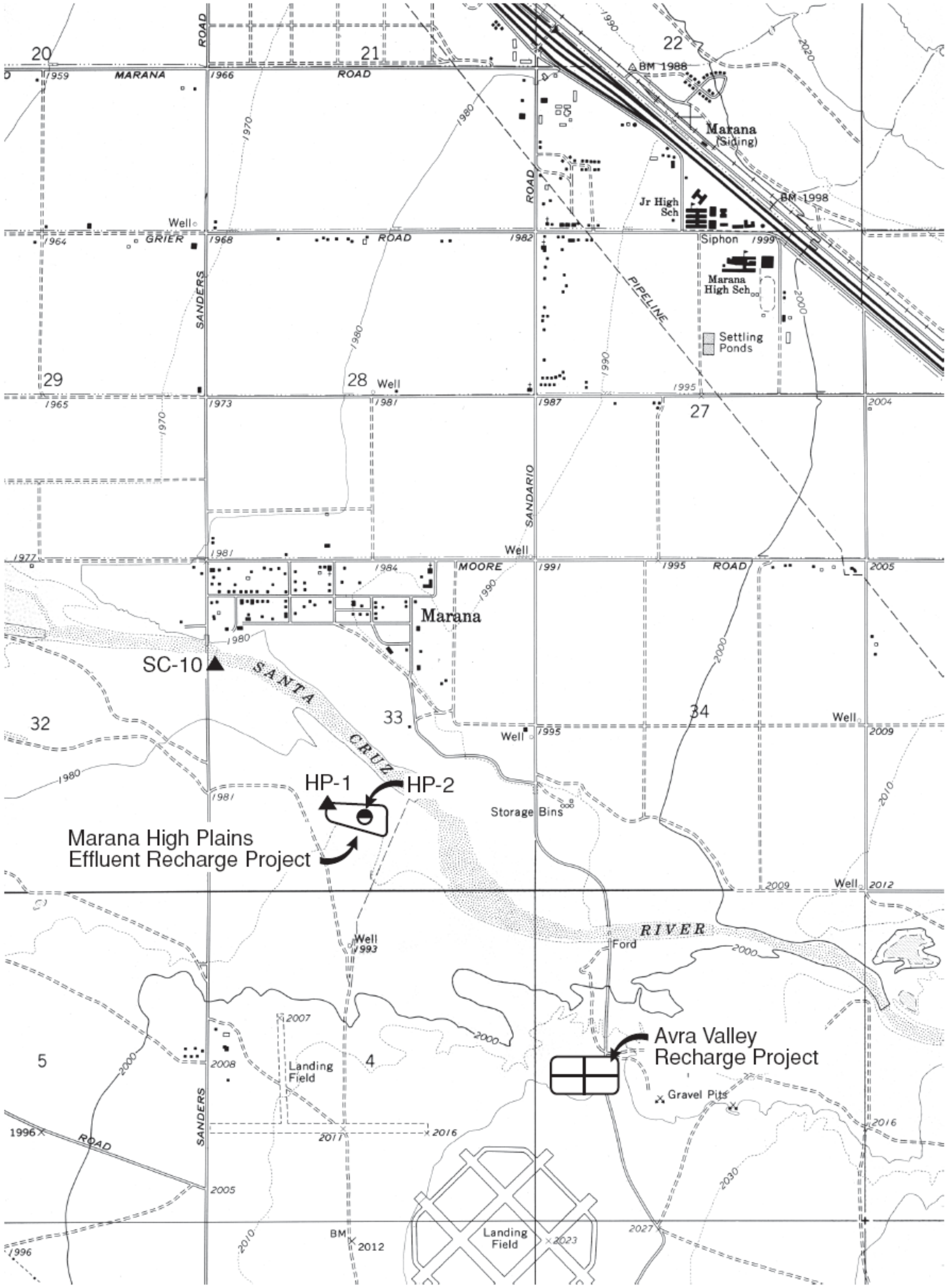
FIGURE 3
Tucson AZMET Weather Station
Location Map



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



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 2015

Constituent	Unit	Discharge Limit	Sample Date & Results											
			Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15
Nutrients														
Total Nitrogen[1]	mg/l	N/A	5.1	5.4	5.6	5.90	1.50	2.90	3.4	No Event	6.4	3.9	4.0	4.8
Nitrate-Nitrite as N	mg/l	N/A	4.2	3.8	3.9	4.1	1.5	1.9	2.0	No Event	4.6	2.5	2.3	2.4
Total Kjeldahl Nitrogen (TKN)	mg/l	N/A	0.9	1.6	1.7	1.8	< 0.5	1.0	1.4	No Event	1.8	1.4	1.7	2.4
Metals (Total)														
Free Cyanide	mg/l	0.2	< 0.05	No Event	No Event	< 0.05	No Event	No Event	No Event	No Event	< 0.05	No Event	No Event	< 0.05
Total Fluoride	mg/l	4	< 0.4	No Event	No Event	0.53	No Event	No Event	No Event	No Event	< 0.4	No Event	No Event	0.43
Arsenic	mg/l	0.05	0.0036	No Event	No Event	0.0049	No Event	No Event	No Event	No Event	0.0051	No Event	No Event	0.003
Barium	mg/l	2	0.048	No Event	No Event	0.11	No Event	No Event	No Event	No Event	0.1	No Event	No Event	0.063
Beryllium	mg/l	0.004	< 0.001	No Event	No Event	< 0.001	No Event	No Event	No Event	No Event	< 0.001	No Event	No Event	< 0.001
Cadmium	mg/l	0.005	< 0.001	No Event	No Event	< 0.001	No Event	No Event	No Event	No Event	< 0.001	No Event	No Event	< 0.0001
Chromium	mg/l	0.1	< 0.002	No Event	No Event	0.0051	No Event	No Event	No Event	No Event	0.0028	No Event	No Event	0.0011
Lead	mg/l	0.05	0.0012	No Event	No Event	0.0076	No Event	No Event	No Event	No Event	0.0038	No Event	No Event	0.0014
Thallium	mg/l	0.002	< 0.001	No Event	No Event	< 0.001	No Event	No Event	No Event	No Event	< 0.001	No Event	No Event	< 0.0001
Nickel	mg/l	0.1	0.0028	No Event	No Event	0.0094	No Event	No Event	No Event	No Event	0.0049	No Event	No Event	0.002
Antimony	mg/l	0.006	< 0.003	No Event	No Event	< 0.003	No Event	No Event	No Event	No Event	< 0.003	No Event	No Event	< 0.0025
Selenium	mg/l	0.05	< 0.002	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	0.00086
Mercury	mg/l	0.002	< 0.0002	No Event	No Event	< 0.0002	No Event	No Event	No Event	No Event	< 0.0002	No Event	No Event	< 0.0002
Volatile Organic Compounds (VOCs)														
para-Dichlorobenzene	mg/l	0.075	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Dichloromethane	mg/l	0.005	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event	No Event	No Event	< 0.003	No Event	No Event
o-Dichlorobenzene	mg/l	0.6	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Carbon tetrachloride	mg/l	0.005	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event	No Event	No Event	< 0.003	No Event	No Event
Toluene	mg/l	1	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Benzene	mg/l	0.005	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Monochlorobenzene	mg/l	0.1	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Ethylbenzene	mg/l	0.7	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Tetrachloroethylene	mg/l	0.005	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
1,1-Dichloroethylene	mg/l	0.007	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event
1,1,1-Trichloroethane	mg/l	0.2	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
1,1,2-Trichloroethane	mg/l	0.005	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
1,2-Dichloroethane	mg/l	0.005	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
1,2-Dichloropropane	mg/l	0.005	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
1,2,4-Trichlorobenzene	mg/l	0.07	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event
Vinyl Chloride	mg/l	0.002	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event	No Event	No Event	< 0.001	No Event	No Event
Trichloroethylene	mg/l	0.005	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Hexachlorobenzene	mg/l	0.001	No Event	No Event	No Event	No Event	< 0.0008	No Event	No Event	No Event	No Event	< 0.00083	No Event	No Event
cis--1,2-Dichloroethylene	mg/l	0.07	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Styrene	mg/l	0.1	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Xylenes (Total)	mg/l	10	No Event	No Event	No Event	No Event	<0.010	No Event	No Event	No Event	No Event	< 0.01	No Event	No Event
Trihalomethane (TTHM)	mg/l	0.1	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event	No Event	No Event	< 0.004	No Event	No Event
trans-1,2-Dichloroethylene	mg/l	0.1	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Hexachlorocyclopentadiene	mg/l	0.05	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event	No Event	No Event	< 0.0052	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 2015

Constituent	Unit	Aquifer Quality Limit	Sample Date & Results											
			Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15
Nutrients														
Total Nitrogen[1]	mg/l	10	1.5	1.5	1.9	No Event	1.6	1.5	1.5	1.4	2.2	1.4	1.3	1.3
Nitrate-Nitrite as N	mg/l	10	1.5	1.5	1.9	No Event	1.6	1.5	1.5	1.4	1.6	1.4	1.3	1.3
Total Kjeldahl Nitrogen (TKN)	mg/l	N/A	< 0.2	< 0.5	< 0.5	No Event	< 0.5	< 0.5	< 0.5	< 0.5	0.6	< 0.5	< 0.5	< 0.5
Total Coliform (P-Present, A-Absent)	P/A	A	A	A	A	No Event	A	A	A	A	P	A	A	A
Metals (Total)														
Free Cyanide	mg/l	0.2	< 0.05	No Event	No Event	No Event	< 0.05	No Event	No Event	No Event	< 0.05	No Event	No Event	< 0.05
Total Fluoride	mg/l	4	< 0.4	No Event	No Event	No Event	< 0.4	No Event	No Event	No Event	< 0.4	No Event	No Event	< 0.4
Arsenic	mg/l	0.05	< 0.003	No Event	No Event	No Event	< 0.003	No Event	No Event	No Event	< 0.003	No Event	No Event	0.0013
Barium	mg/l	2	0.096	No Event	No Event	No Event	0.1	No Event	No Event	No Event	0.11	No Event	No Event	0.087
Beryllium	mg/l	0.004	< 0.001	No Event	No Event	No Event	< 0.001	No Event	No Event	No Event	< 0.001	No Event	No Event	< 0.001
Cadmium	mg/l	0.005	< 0.001	No Event	No Event	No Event	< 0.001	No Event	No Event	No Event	< 0.001	No Event	No Event	< 0.0001
Chromium	mg/l	0.1	< 0.002	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	< 0.002	No Event	No Event	< 0.0005
Lead	mg/l	0.05	< 0.001	No Event	No Event	No Event	< 0.001	No Event	No Event	No Event	< 0.001	No Event	No Event	< 0.0005
Thallium	mg/l	0.002	< 0.001	No Event	No Event	No Event	< 0.001	No Event	No Event	No Event	< 0.001	No Event	No Event	< 0.0001
Nickel	mg/l	0.1	0.0027	No Event	No Event	No Event	0.0037	No Event	No Event	No Event	0.0033	No Event	No Event	< 0.0005
Antimony	mg/l	0.006	< 0.003	No Event	No Event	No Event	< 0.003	No Event	No Event	No Event	< 0.003	No Event	No Event	< 0.0025
Selenium	mg/l	0.05	< 0.002	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	< 0.002	No Event	No Event	0.0013
Mercury	mg/l	0.002	< 0.0002	No Event	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	0.075	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Dichloromethane	mg/l	0.005	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event	No Event	No Event	< 0.003	No Event	No Event
o-Dichlorobenzene	mg/l	0.6	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Carbon tetrachloride	mg/l	0.005	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event	No Event	No Event	< 0.003	No Event	No Event
Toluene	mg/l	1	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Benzene	mg/l	0.005	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Monochlorobenzene	mg/l	0.1	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Ethylbenzene	mg/l	0.7	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Tetrachloroethylene	mg/l	0.005	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
1,1-Dichloroethylene	mg/l	0.007	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event
1,1,1-Trichloroethane	mg/l	0.2	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
1,1,2-Trichloroethane	mg/l	0.005	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
1,2-Dichloroethane	mg/l	0.005	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
1,2-Dichloropropane	mg/l	0.005	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
1,2,4-Trichlorobenzene	mg/l	0.07	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event
Vinyl Chloride	mg/l	0.002	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event	No Event	No Event	< 0.001	No Event	No Event
Trichloroethylene	mg/l	0.005	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Hexachlorobenzene	mg/l	0.001	No Event	No Event	No Event	No Event	< 0.0008	No Event	No Event	No Event	No Event	< 0.00081	No Event	No Event
cis--1,2-Dichloroethylene	mg/l	0.07	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Styrene	mg/l	0.1	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Xylenes (Total)	mg/l	10	No Event	No Event	No Event	No Event	< 0.010	No Event	No Event	No Event	No Event	< 0.01	No Event	No Event
Trihalomethane (TTHM)	mg/l	0.1	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event	No Event	No Event	< 0.004	No Event	No Event
trans-1,2-Dichloroethylene	mg/l	0.1	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event	No Event	No Event	< 0.002	No Event	No Event
Hexachlorocyclopentadiene	mg/l	0.05	No Event	No Event	No Event	No Event	< 0.005	No Event	No Event	No Event	No Event	< 0.0051	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 2015

Date	Problem	Solution
February 6, 2015	No water in the oxbow channel	Diversion berm was washed out by storm water runoff on January 31, 2015. Berm was repaired on February 13, 2015 and recharge operations were restarted on February 14, 2015.
April 27, 2015	Compliance Well HP-1 is not producing any water. No samples could be obtained for water quality testing this month.	Discharge pipes and well pump were removed and inspected on May 12, 2015. A significant hole was located on the discharge pipe connected to the pump, most likely due to corrosion. The corroded discharge pipe was replaced with a new pipe, along with other new pipes as needed. The pump and discharge pipes were lowered back into the well and the pump was tested; pump rate was approximately 10 gallons per minute. Water samples were collected for compliance testing in May.
July 15, 2015	No water in the oxbow channel	Diversion berm was washed out by storm water runoff on July 1, 2015. Facility operations were shut down for the summer monsoon season.
July 15, 2015	Maintenance roads throughout the facility are congested with shrubs and tree branches, making access very difficult.	Landscape maintenance was performed in late July to clear vegetation from the roadway and around all of the electrical structures, compliance well and rain gauge.
September 23, 2015	Still no water in the oxbow channel due to continual washout of the diversion berm	Diversion berm was repaired on September 29, 2015 after it was determined that significant rainfall events were subsiding. Effluent diversion to the facility began on September 30, 2015.
October 22, 2015	No flow in the oxbow channel	Diversion berm was washed out by significant storm water runoff on October 17, 2015. The diversion berm was repaired and facility operations were restarted on October 26, 2015.
October 28, 2015	Significant vegetative growth along the maintenance road is beginning to limit access into the facility.	Landscape maintenance was scheduled and performed in late December to clear shrubs from the roadway and to prune back tree limbs to provide clear access to all of the facility equipment and recharge basins.

APPENDIX A

Daily Flow Volumes &
Water Quantity Summary

USF DAILY FLOWMETER READINGS AND VOLUMES

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0007

Meter ID: Fm-eq

Year: 2015

	January		February		March		April		May		June	
	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons
	57254024		82190608		92767184		111426555		130190760		152429288	
Day 1	58109064	855040	82190608	0	93524140	756956	112239144	812589	130261200	70440	153107616	678328
2	58911256	802192	82190608	0	94362934	838794	113024644	785500	130786283	525083	153819308	711692
3	59720696	809440	82190608	0	95203544	840610	113775120	750476	131459560	673277	154669816	850508
4	60573608	852912	82190608	0	95968578	765034	114481520	706400	132225895	766335	155427335	757519
5	61401912	828304	82190608	0	96402110	433532	115203710	722190	132992625	766730	156265336	838001
6	62235860	833948	82190608	0	97065490	663380	115970003	766293	133749205	756580	157101688	836352
7	63068956	833096	82190608	0	97721902	656412	116749390	779387	134491205	742000	157917130	815442
8	63920800	851844	82190608	0	98290352	568450	117491067	741677	135217264	726059	158748960	831830
9	64752352	831552	82190608	0	98953992	663640	118254054	762987	135927064	709800	159586588	837628
10	65583092	830740	82190608	0	99448000	494008	119007324	753270	136643087	716023	160436471	849883
11	66409396	826304	82190608	0	99934272	486272	119704524	697200	137401567	758480	161425751	989280
12	67249497	840101	82190608	0	100404192	469920	120355435	650911	138131016	729449	162399191	973440
13	68076424	826927	82190608	0	100850101	445909	121079160	723725	138885616	754600	163368311	969120
14	68913616	837192	82354762	164154	101279262	429161	121788382	709222	139437632	552016	164338871	970560
15	69773692	860076	82934150	579388	101630552	351290	122472736	684354	140293256	855624	165310871	972000
16	70589548	815856	83675600	741450	101943752	313200	123168350	695614	141099076	805820	166278551	967680
17	71444148	854600	84228970	553370	102494608	550856	123844012	675662	141906762	807686	167230391	951840
18	72280280	836132	84972444	743474	103020692	526084	124510192	666180	142730342	823580	168232631	1002240
19	73081644	801364	85704334	731890	103584992	564300	125066092	555900	143578392	848050	169217591	984960
20	73902256	820612	86536492	832158	104132192	547200	125758192	692100	144406190	827798	170225591	1008000
21	74745188	842932	87323152	786660	104582256	450064	126436876	678684	145218754	812564	171234311	1008720
22	75592824	847636	88091716	768564	105027444	445188	127124467	687591	146026851	808097	172243751	1009440
23	76424996	832172	88853356	761640	105847672	820228	127815504	691037	146794151	767300	173217191	973440
24	77251636	826640	89590504	737148	106600998	753326	128549424	733920	147554430	760279	174181991	964800
25	78074600	822964	90386942	796438	107261656	660658	129370092	820668	148283484	729054	175148231	966240
26	78914980	840380	91213679	826737	107968900	707244	130190760	820668	149074808	791324	176094203	945972
27	79741350	826370	92037644	823965	108674568	705668	130190760	0	149786016	711208	176985939	891736
28	80584892	843542	92767184	729540	109246463	571895	130190760	0	150518942	732926	177907106	921167
29	81412624	827732			109817774	571311	130190760	0	151181974	663032	178805886	898780
30	82190608	777984			110647480	829706	130190760	0	151823224	641250	179660468	854582
31	82190608	0			111426555	779075			152429288	606064		
	Total (gal)	**24936584**	**Total (gal)**	**10576576**	**Total (gal)**	**18659371**	**Total (gal)**	**18764205**	**Total (gal)**	**22238528**	**Total (gal)**	**27231180**
	Total (ac-ft)	**76.53**	**Total (ac-ft)**	**32.46**	**Total (ac-ft)**	**57.26**	**Total (ac-ft)**	**57.59**	**Total (ac-ft)**	**68.25**	**Total (ac-ft)**	**83.57**

1st Qtr Total (gal) =	**54172531**
1st Qtr Total (ac-ft) =	**166.25**

2nd Qtr Total (gal) =	**68233913**
2nd Qtr Total (ac-ft) =	**209.40**

USF DAILY FLOWMETER READINGS AND VOLUMES

Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Meter ID: Fm-eq
Year: 2015

	July		August		September		October		November		December	
	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons
	5246913		13773561		13773561		14540061		14459970		44731640	
Day 1	5501973	255060	13773561	0	13773561	0	15580398	1040337	15492720	1032750	45731155	999515
2	5501973	0	13773561	0	13773561	0	16619426.4	1039028.4	16522840	1030120	46736580	1005425
3	5501973	0	13773561	0	13773561	0	17665434	1046007.6	17547280	1024440	47740410	1003830
4	5501973	0	13773561	0	13773561	0	18714495	1049061	18577050	1029770	48749160	1008750
5	5501973	0	13773561	0	13773561	0	19779555	1065060	19597030	1019980	49740300	991140
6	5501973	0	13773561	0	13773561	0	20578168	798613	20629480	1032450	50731540	991240
7	5501973	0	13773561	0	13773561	0	20578168	0	21628470	998990	51742877	1011337
8	5501973	0	13773561	0	13773561	0	20578168	0	22627070	998600	52706220	963343
9	5501973	0	13773561	0	13773561	0	20578168	0	23661159	1034089	53685950	979730
10	5501973	0	13773561	0	13773561	0	20971048	392880	24659575	998416	54671580	985630
11	5501973	0	13773561	0	13773561	0	22028058	1057010	25643363	983788	55655000	983420
12	5501973	0	13773561	0	13773561	0	23092315	1064257	26632059	988696	56646100	991100
13	5501973	0	13773561	0	13773561	0	24130618	1038303	27642110	1010051	57637200	991100
14	5501973	0	13773561	0	13773561	0	25173543	1042925	28641690	999580	58641960	1004760
15	5501973	0	13773561	0	13773561	0	26228893	1055350	29641170	999480	59610340	968380
16	5501973	0	13773561	0	13773561	0	27257268	1028375	30661020	1019850	60602392	992052
17	5501973	0	13773561	0	13773561	0	27900768	643500	31672420	1011400	61598270	995878
18	5501973	0	13773561	0	13773561	0	27900768	0	32690560	1018140	62564037	965767
19	5501973	0	13773561	0	13773561	0	27900768	0	33703860	1013300	63544080	980043
20	5501973	0	13773561	0	13773561	0	27900768	0	34707540	1003680	64524563	980483
21	5501973	0	13773561	0	13773561	0	27900768	0	35705775	998235	65497963	973400
22	5501973	0	13773561	0	13773561	0	27900768	0	36704100	998325	66486464	988501
23	5501973	0	13773561	0	13773561	0	27900768	0	37714833	1010733	67464863	978399
24	5501973	0	13773561	0	13773561	0	27900768	0	38701800	986967	68448107	983244
25	5501973	0	13773561	0	13773561	0	27900768	0	39716800	1015000	69431540	983433
26	5501973	0	13773561	0	13773561	0	28298736	397968	40731800	1015000	70409905	978365
27	6259277	757304	13773561	0	13773561	0	29344698	1045962	41734780	1002980	71388300	978395
28	7258814	999537	13773561	0	13773561	0	30395804	1051106	42728788	994008	72372563	984263
29	7505684	246870	13773561	0	13773561	0	31433420	1037616	43726442	997654	73352962	980399
30	7505684	0	13773561	0	14541141	767580	32471456	1038036	44731640	1005198	74335343	982381
31	7505684	0	13773561	0			33508538	1037082			75311217	975874
	Total (gal)	**2258771**	**Total (gal)**	**0**	**Total (gal)**	**767580**	**Total (gal)**	**18968477**	**Total (gal)**	**30271670**	**Total (gal)**	**30579577**
	Total (ac-ft)	**6.93**	**Total (ac-ft)**	**0.00**	**Total (ac-ft)**	**2.36**	**Total (ac-ft)**	**58.21**	**Total (ac-ft)**	**92.90**	**Total (ac-ft)**	**93.85**

3rd Qtr Total (gal) =	**3026351**
3rd Qtr Total (ac-ft) =	**9.29**

4th Qtr Total (gal) =	**79819724**
4th Qtr Total (ac-ft) =	**244.96**
Annual Total Del. Vol for FM-eq (ac-ft) =	**629.90**

USF WATER QUANTITY REPORTING SUMMARY

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0007

Year: 2015

	FM-eq Delivered Volumes (ac-ft)	Evaporation Losses (ac-ft)	Evapotranspiration Losses (ac-ft)	Net Recharge Volumes (ac-ft)	Quarterly Net Recharge Totals (ac-ft)
January	76.5	0.3	0.0	76.2	
February	32.5	0.2	0.0	32.2	
March	57.3	0.4	0.0	56.8	165.3
April	57.6	0.6	0.1	56.9	
May	68.2	0.8	0.1	67.4	
June	83.6	0.9	0.1	82.6	206.9
July	6.9	0.3	0.0	6.7	
August	0.0	0.0	0.0	0.0	
September	2.4	0.0	0.0	2.3	9.0
October	58.2	0.4	0.0	57.8	
November	92.9	0.3	0.0	92.6	
December	93.8	0.2	0.0	93.6	244.0

Annual Totals =	**629.9**	**4.4**	**0.4**	**625.1**

APPENDIX B

Evaporation Calculations & Cooley Method Description

USF EVAPORATION CALCULATIONS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2015

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	12	0.1	6	0.1	11	0.2	12	0.3	12	0.3	13	0.4
Cell 1	1	0.0	0	0.0	0	0.0	1	0.0	1	0.0	0	0.0
Cell 2	5	0.0	3	0.0	4	0.1	2	0.0	0	0.0	8	0.3
Cell 3	3	0.0	0	0.0	1	0.0	1	0.0	5	0.1	1	0.0
Cell 4	13	0.1	7	0.1	8	0.1	11	0.2	10	0.3	9	0.3
	33	**0.3**	**15**	**0.2**	**25**	**0.4**	**27**	**0.6**	**28**	**0.8**	**31**	**0.9**

1st Quarter Total Evap (AF) **=**	**0.9**
2nd Quarter Total Evap (AF) **=**	**2.3**

Cooley Adj. Fac	**0.95**

USF EVAPORATION CALCULATIONS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2015

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	7	0.2	0	0.0	0	0.0	11	0.2	11	0.1	12	0.1
Cell 1	0	0.0	0	0.0	0	0.0	0	0.0	1	0.0	1	0.0
Cell 2	1	0.0	0	0.0	0	0.0	2	0.0	0	0.0	4	0.0
Cell 3	0	0.0	0	0.0	0	0.0	0	0.0	2	0.0	2	0.0
Cell 4	0	0.0	0	0.0	0	0.0	11	0.2	8	0.1	7	0.1
	8	**0.3**	**0**	**0.0**	**0**	**0.0**	**24**	**0.4**	**23**	**0.3**	**25**	**0.2**

3rd Quarter Total Evap (AF) **=**	**0.3**

4th Quarter Total Evap (AF) **=**	**0.9**
Annual Total Evap (AF) **=**	**4.4**

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.

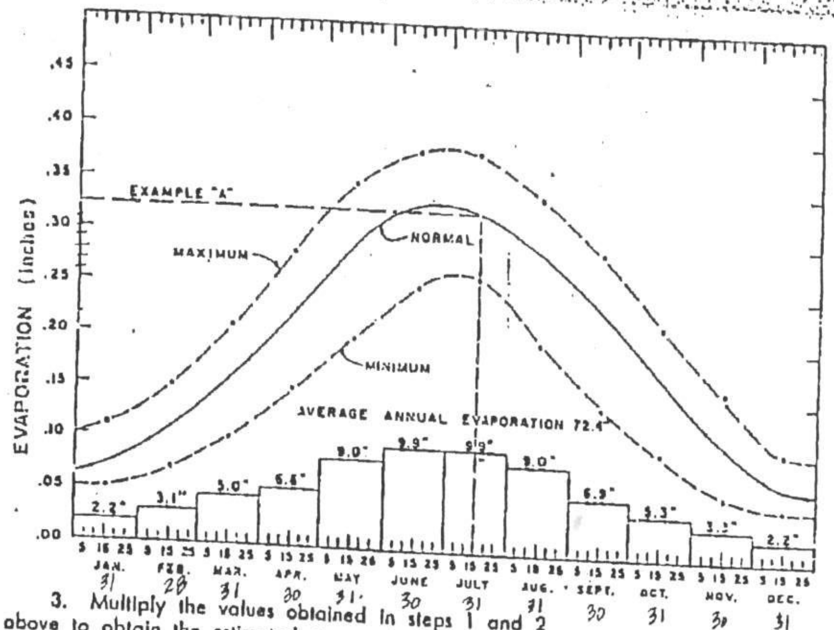


FIGURE 1. Maximum, Normal, and Minimum Daily Evaporation and Average Monthly Evaporation From Open Water Surfaces (Adjustment Factor = 1.00).

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)

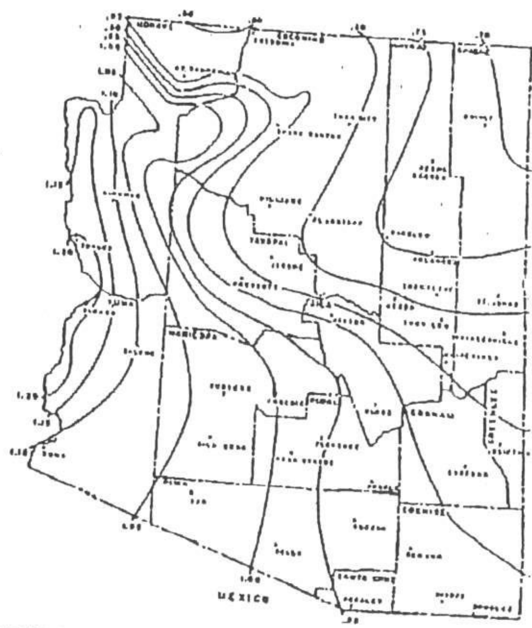


FIGURE 2. Evaporation Adjustment Factors for Arizona

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.

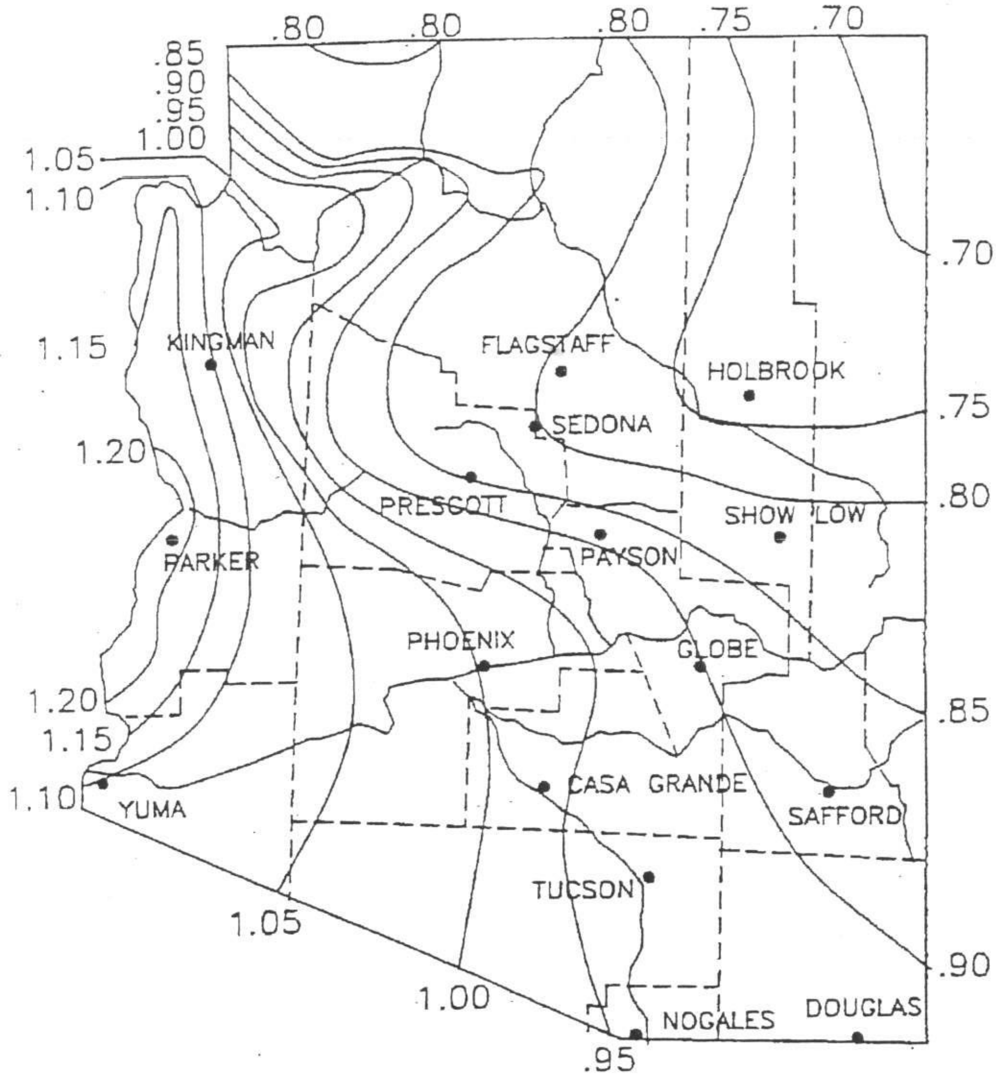
EVAPORATION FROM OPEN WATER SURFACES IN ARIZONA

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



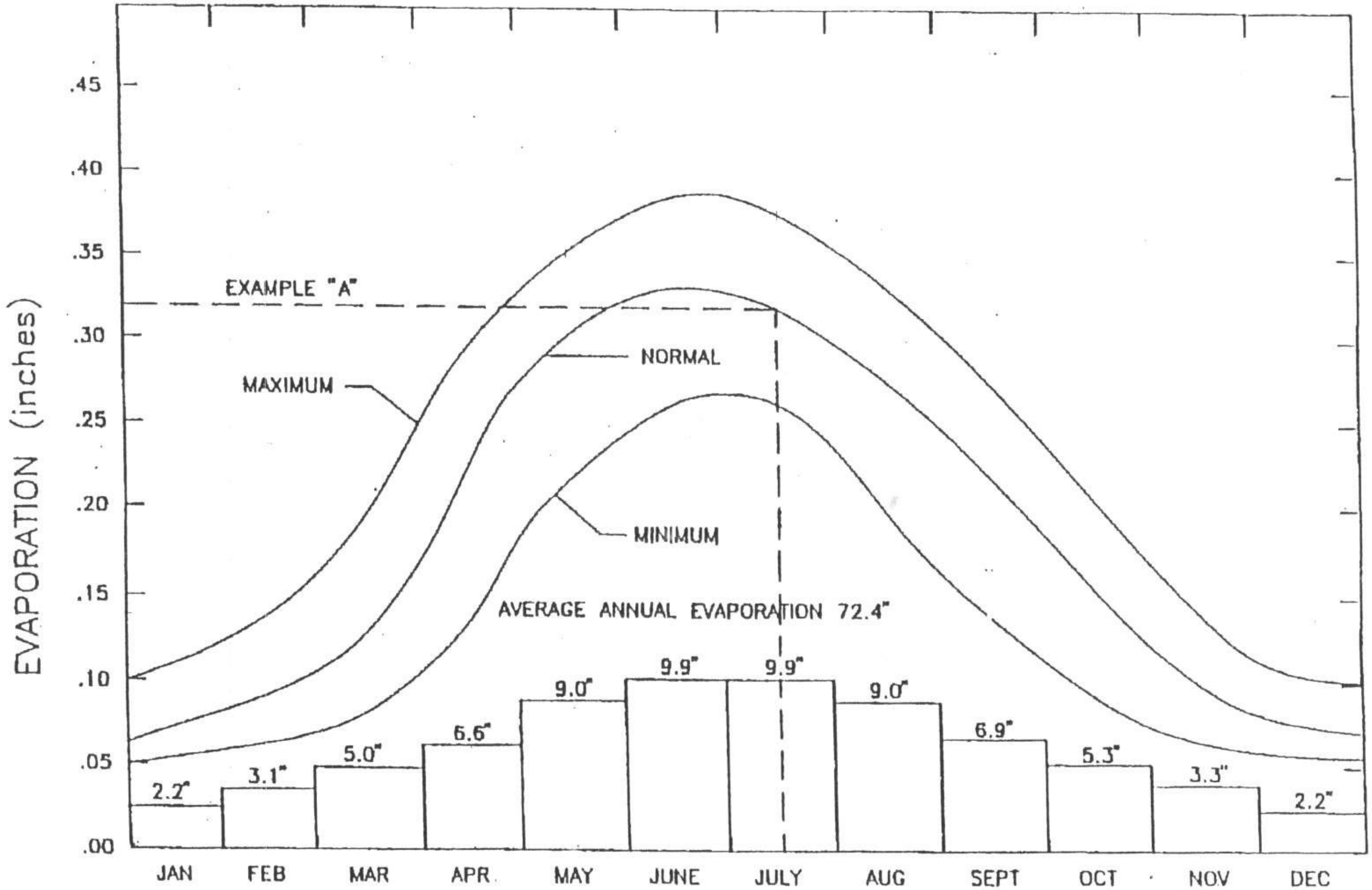


FIGURE 9. MAXIMUM, NORMAL AND MINIMUM DAILY EVAPORATION AND AVERAGE MONTHLY EVAPORATION FROM OPEN WATER SURFACES (Adjustment Factor = 1.00)

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. 71-563876.0007
Year: 2015

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	0.3720	0.0000	0.1452	0.0000	0.4410
2	0.3720	0.0000	0.2178	0.0000	0.6300
3	0.3720	0.0000	0.2420	0.0000	0.8190
4	0.3720	0.0000	0.2178	0.0000	0.8190
5	0.3720	0.0000	0.2420	0.0000	0.8190
6	0.3720	0.0000	0.2722	0.0000	0.8190
7	0.3720	0.0000	0.3025	0.0000	0.8190
8	0.3720	0.0000	0.3025	0.0000	0.8190
9	0.3720	0.0000	0.3025	0.0000	0.8190
10	0.3720	0.0000	0.3025	0.0000	0.8190
11	0.3720	0.0000	0.3146	0.0000	0.8190
12	0.3720	0.0000	0.3146	0.0000	0.8190
13	0.3720	0.0000	0.3267	0.0000	0.8190
14	0.3720	0.0000	0.3267	0.0000	0.8190
15	0.3720	0.0126	0.3388	0.0156	0.8190
16	0.3720	0.0315	0.0363	0.0390	0.5040
17	0.3720	0.0315	0.0000	0.0468	0.2520
18	0.3720	0.0315	0.0000	0.0624	0.1260
19	0.3720	0.0378	0.0000	0.0780	0.0000
20	0.3720	0.0441	0.0000	0.1170	0.0000
21	0.3720	0.0630	0.0000	0.1560	0.0000
22	0.3720	0.0756	0.0000	0.1950	0.0000
23	0.3720	0.0882	0.0000	0.2184	0.0000
24	0.3720	0.1134	0.0000	0.2340	0.0000
25	0.3720	0.1134	0.0000	0.2652	0.0000
26	0.3720	0.0819	0.0000	0.2730	0.0000
27	0.3720	0.0819	0.0000	0.2808	0.0000
28	0.3720	0.0819	0.0121	0.3120	,063
29	0.3720	0.0315	0.0484	0.1170	0.1260
30	0.3720	0.0126	0.1694	0.0780	0.2520
31	0.3720	0.0000	0.0847	0.0390	0.1260
Total Wetted Acres	**11.532**	**0.9324**	**4.5193**	**2.5272**	**13.104**

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	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.0000	0.0000	0.0000	0.0000	0.0000
4	0.0000	0.0000	0.0000	0.0000	0.0000
5	0.0000	0.0000	0.0000	0.0000	0.0000
6	0.0000	0.0000	0.0000	0.0000	0.0000
7	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000	0.0000	0.0000
9	0.0000	0.0000	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000	0.0000	0.0000
11	0.0000	0.0000	0.0000	0.0000	0.0000
12	0.0000	0.0000	0.0000	0.0000	0.0000
13	0.0000	0.0000	0.0000	0.0000	0.0000
14	0.3410	0.0000	0.0030	0.0000	0.0016
15	0.3720	0.0000	0.0061	0.0000	0.0032
16	0.3720	0.0000	0.0121	0.0000	0.1260
17	0.3720	0.0000	0.0605	0.0000	0.1512
18	0.3720	0.0000	0.0726	0.0000	0.2520
19	0.3720	0.0000	0.1210	0.0000	0.3780
20	0.3720	0.0000	0.1452	0.0000	0.3906
21	0.3720	0.0000	0.1936	0.0000	0.6300
22	0.3720	0.0000	0.2178	0.0000	0.6300
23	0.3720	0.0000	0.2541	0.0000	0.6300
24	0.3720	0.0000	0.2904	0.0000	0.6300
25	0.4340	0.0000	0.3146	0.0000	0.8190
26	0.4340	0.0000	0.3267	0.0000	0.8190
27	0.3720	0.0000	0.3388	0.0000	0.8190
28	0.3720	0.0000	0.3509	0.0000	0.8190
29					
Total Wetted Acres	**5.673**	**0**	**2.7074**	**0**	**7.0986**

* 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. 71-563876.0007
Year: 2015

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	0.3720	0.0000	0.3146	0.0000	0.8190
2	0.3720	0.0000	0.3146	0.0000	0.8190
3	0.3720	0.0000	0.3388	0.0000	0.8190
4	0.3720	0.0000	0.3388	0.0000	0.8190
5	0.3720	0.0000	0.3630	0.0000	0.8190
6	0.3720	0.0000	0.1452	0.0000	0.6300
7	0.3720	0.0000	0.2420	0.0000	0.6300
8	0.3720	0.0000	0.1331	0.0000	0.4410
9	0.3720	0.0000	0.2178	0.0000	0.4914
10	0.3720	0.0000	0.3025	0.0000	0.5418
11	0.3565	0.0000	0.1815	0.0000	0.3780
12	0.3410	0.0000	0.1815	0.0000	0.3150
13	0.3720	0.0000	0.1815	0.0000	0.3024
14	0.3410	0.0000	0.1452	0.0000	0.2520
15	0.3410	0.0000	0.1210	0.0000	0.2268
16	0.3410	0.0063	0.0605	0.0156	0.0378
17	0.3720	0.0126	0.0484	0.0234	0.0126
18	0.3720	0.0126	0.0484	0.0234	0.0000
19	0.3720	0.0189	0.0484	0.0234	0.0000
20	0.4340	0.0252	0.0242	0.0234	0.0000
21	0.3720	0.0189	0.0000	0.0390	0.0000
22	0.3410	0.0189	0.0000	0.0312	0.0000
23	0.3720	0.0189	0.0000	0.0234	0.0000
24	0.3720	0.0378	0.0000	0.0624	0.0000
25	0.3565	0.0378	0.0000	0.0546	0.0000
26	0.3720	0.0378	0.0000	0.0546	0.0000
27	0.3720	0.0441	0.0000	0.0624	0.0000
28	0.3720	0.0441	0.0000	0.0624	0.0000
29	0.3720	0.0441	0.0000	0.0624	0.0000
30	0.3720	0.0378	0.0000	0.0546	0.0000
31	0.3720	0.0504	0.0000	0.0780	0.0000
Total Wetted Acres	**11.408**	**0.4662**	**3.751**	**0.6942**	**8.3538**

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	0.3720	0.0504	0.0000	0.0780	0.0000
2	0.3720	0.0504	0.0000	0.0780	0.0000
3	0.3720	0.0630	0.0000	0.0780	0.0000
4	0.4340	0.0630	0.0000	0.0858	0.0000
5	0.4340	0.0693	0.0000	0.0936	0.0000
6	0.4340	0.0819	0.0000	0.1170	0.0000
7	0.4340	0.0819	0.0000	0.1170	0.0000
8	0.3720	0.0819	0.0000	0.1170	0.0000
9	0.4340	0.0882	0.0000	0.1170	0.0000
10	0.3720	0.0882	0.0000	0.1170	0.0000
11	0.3720	0.0882	0.0000	0.1170	0.0000
12	0.3720	0.0945	0.0000	0.1326	0.0000
13	0.3720	0.0945	0.0605	0.1326	0.0252
14	0.3720	0.0504	0.1210	0.0702	0.0504
15	0.3720	0.0000	0.1815	0.0078	0.1890
16	0.3720	0.0000	0.2420	0.0000	0.2268
17	0.3720	0.0000	0.2420	0.0000	0.3024
18	0.4340	0.0000	0.2420	0.0000	0.4410
19	0.3720	0.0000	0.0605	0.0000	0.8190
20	0.3720	0.0000	0.0605	0.0000	0.8190
21	0.3720	0.0000	0.6050	0.0000	0.8190
22	0.4340	0.0000	0.0847	0.0000	0.8190
23	0.3720	0.0000	0.0847	0.0000	0.8190
24	0.3720	0.0000	0.0242	0.0000	0.8190
25	0.3720	0.0000	0.0242	0.0000	0.8190
26	0.3720	0.0000	0.0121	0.0000	0.8190
27	0.3720	0.0000	0.0000	0.0000	0.8190
28	0.3720	0.0000	0.0000	0.0000	0.8190
29	0.3565	0.0000	0.0000	0.0000	0.6300
30	0.3410	0.0000	0.0000	0.0000	0.5040
Total Wetted Acres	**11.5475**	**1.0458**	**2.0449**	**1.4586**	**10.5588**

* 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. 71-563876.0007
Year: 2015

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	0.3565	0.0000	0.0000	0.0000	0.0000
2	0.3720	0.0000	0.0061	0.0000	0.0252
3	0.4340	0.0000	0.0121	0.0000	0.5670
4	0.4340	0.0000	0.0121	0.0000	0.8190
5	0.4340	0.0000	0.0121	0.0000	0.8190
6	0.4340	0.0000	0.0121	0.0000	0.8190
7	0.3720	0.0000	0.0121	0.0000	0.8190
8	0.3720	0.0000	0.0121	0.0000	0.8190
9	0.3720	0.0000	0.0121	0.0000	0.8190
10	0.3720	0.0000	0.0121	0.0000	0.8190
11	0.3720	0.0000	0.0121	0.0000	0.8190
12	0.3720	0.0000	0.0121	0.0000	0.8190
13	0.3720	0.0126	0.0000	0.0780	0.8190
14	0.3720	0.0063	0.0000	0.0156	0.6300
15	0.3720	0.0126	0.0000	0.0390	0.5670
16	0.3720	0.0189	0.0000	0.0780	0.0630
17	0.3720	0.0189	0.0000	0.1170	0.0252
18	0.3720	0.0252	0.0000	0.1560	0.0000
19	0.3720	0.0252	0.0000	0.1872	0.0000
20	0.3720	0.0315	0.0000	0.2184	0.0000
21	0.3720	0.0315	0.0000	0.2730	0.0000
22	0.3720	0.0315	0.0000	0.2886	0.0000
23	0.3720	0.0315	0.0000	0.3510	0.0000
24	0.3720	0.0630	0.0000	0.3510	0.0000
25	0.3720	0.0945	0.0000	0.3510	0.0000
26	0.3720	0.0945	0.0000	0.3510	0.0000
27	0.3720	0.1071	0.0000	0.3276	0.0000
28	0.3720	0.1071	0.0000	0.3276	0.0000
29	0.3720	0.1071	0.0000	0.3666	0.0000
30	0.3720	0.1008	0.0000	0.3510	0.0000
31	0.3720	0.0945	0.0000	0.3510	0.0000
Total Wetted Acres	**11.7645**	**1.0143**	**0.12705**	**4.5786**	**10.0674**

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	0.3720	0.0945	0.0000	0.3510	0.0000
2	0.3720	0.0630	0.0000	0.1950	0.1890
3	0.4340	0.0126	0.0000	0.1209	0.3780
4	0.4340	0.0000	0.0000	0.0468	0.8190
5	0.4340	0.0000	0.0121	0.0000	0.8190
6	0.4340	0.0000	0.0605	0.0000	0.8190
7	0.4340	0.0000	0.1210	0.0000	0.8190
8	0.4340	0.0000	0.1210	0.0000	0.8190
9	0.4340	0.0000	0.1452	0.0000	0.8190
10	0.4340	0.0000	0.1634	0.0000	0.8190
11	0.4340	0.0000	0.1815	0.0000	0.8190
12	0.4340	0.0000	0.2178	0.0000	0.8190
13	0.4340	0.0000	0.2904	0.0000	0.6300
14	0.4340	0.0000	0.3146	0.0000	0.5040
15	0.4340	0.0000	0.3388	0.0000	0.0000
16	0.4340	0.0000	0.3388	0.0000	0.0000
17	0.4340	0.0000	0.3509	0.0000	0.0000
18	0.3720	0.0000	0.3630	0.0000	0.0000
19	0.4340	0.0000	0.3630	0.0000	0.0000
20	0.3720	0.0000	0.3630	0.0000	0.0000
21	0.3720	0.0000	0.3932	0.0000	0.0000
22	0.3720	0.0000	0.4235	0.0000	0.0000
23	0.4340	0.0000	0.4356	0.0000	0.0000
24	0.4340	0.0000	0.4598	0.0000	0.0000
25	0.4340	0.0000	0.4840	0.0000	0.0000
26	0.4092	0.0000	0.4840	0.0000	0.0000
27	0.4340	0.0000	0.4840	0.0000	0.0000
28	0.4340	0.0000	0.4840	0.0000	0.0000
29	0.4340	0.0000	0.4840	0.0000	0.0000
30	0.4092	0.0000	0.4840	0.0000	0.0000
Total Wetted Acres	**12.5984**	**0.1701**	**8.3611**	**0.7137**	**9.072**

* 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. 71-563876.0007
Year: 2015

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	0.4092	0	0.5324	0	0
2	0.4092	0	0.3025	0	0
3	0.434	0	0.121	0	0
4	0.434	0	0.0605	0	0
5	0.372	0	0	0	0
6	0.3565	0	0	0	0
7	0.341	0	0	0	0
8	0.342	0	0	0	0
9	0.341	0	0	0	0
10	0.31	0	0	0	0
11	0.31	0	0	0	0
12	0.279	0	0	0	0
13	0.279	0	0	0	0
14	0.248	0	0	0	0
15	0.248	0	0	0	0
16	0.124	0	0	0	0
17	0.124	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	0.341	0	0.121	0	0
28	0.372	0	0.0605	0	0
29	0.372	0	0.0424	0	0
30	0.341	0	0.0242	0	0
31	0.31	0	0	0	0
Total Wetted Acres	**7.0969**	**0**	**1.2645**	**0**	**0**

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. 71-563876.0007
Year: 2015

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	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	0.341	0	0.121	0	0
Total Wetted Acres	**0.341**	**0**	**0.121**	**0**	**0**

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	0.3720	0.0000	0.2420	0.0000	0.0000
2	0.3720	0.0000	0.2541	0.0000	0.0000
3	0.3720	0.0000	0.2541	0.0000	0.0000
4	0.3720	0.0000	0.2662	0.0000	0.0000
5	0.3720	0.0000	0.2904	0.0000	0.0000
6	0.3565	0.0000	0.3146	0.0000	0.0000
7	0.3420	0.0000	0.2904	0.0000	0.0000
8	0.3255	0.0000	0.0000	0.0000	0.0000
9	0.3255	0.0000	0.0000	0.0000	0.0000
10	0.3410	0.0000	0.0000	0.0000	0.0252
11	0.3720	0.0000	0.0000	0.0000	0.1260
12	0.3720	0.0000	0.0000	0.0000	0.5040
13	0.3720	0.0000	0.0000	0.0000	0.8190
14	0.3720	0.0000	0.0000	0.0000	0.8190
15	0.3720	0.0000	0.0000	0.0000	0.8190
16	0.3720	0.0000	0.0000	0.0000	0.8190
17	0.3720	0.0000	0.0000	0.0000	0.8190
18	0.3410	0.0000	0.0000	0.0000	0.8190
19	0.3410	0.0000	0.0000	0.0000	0.8190
20	0.3410	0.0000	0.0000	0.0000	0.6300
21	0.3410	0.0000	0.0000	0.0000	0.2520
22	0.3255	0.0000	0.0000	0.0000	0.0000
23	0.3255	0.0000	0.0000	0.0000	0.0000
24	0.3255	0.0000	0.0000	0.0000	0.0000
25	0.3255	0.0000	0.0000	0.0000	0.0000
26	0.3410	0.0000	0.0000	0.0000	0.0000
27	0.3720	0.0000	0.0000	0.0000	0.4410
28	0.3720	0.0000	0.0000	0.0000	0.6300
29	0.3720	0.0000	0.0000	0.0000	0.6300
30	0.3720	0.0000	0.0000	0.0000	0.8190
31	0.3720	0.0000	0.0000	0.0000	0.8190
Total Wetted Acres	**11.0215**	**0**	**1.9118**	**0**	**10.6092**

* 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. 71-563876.0007
Year: 2015

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	0.372	0	0	0	0.819
2	0.372	0	0	0	0.819
3	0.372	0	0	0	0.819
4	0.341	0	0	0	0.819
5	0.372	0	0	0	0.63
6	0.372	0	0	0	0.63
7	0.372	0	0	0	0.63
8	0.372	0	0	0	0.63
9	0.372	0	0	0	0.63
10	0.372	0	0	0	0.63
11	0.372	0	0	0	0.63
12	0.372	0.0032	0	0.0078	0.63
13	0.372	0.0063	0	0.0156	0
14	0.372	0.0063	0	0.0156	0
15	0.372	0.0756	0	0.0936	0
16	0.372	0.0756	0	0.1014	0
17	0.372	0.0819	0	0.1014	0
18	0.372	0.0819	0	0.1014	0
19	0.372	0.0819	0	0.1014	0
20	0.372	0.0819	0	0.1014	0
21	0.372	0.0819	0	0.1014	0
22	0.372	0.0819	0	0.1014	0
23	0.372	0.0819	0	0.1014	0
24	0.372	0.0819	0	0.117	0
25	0.372	0.0819	0	0.117	0
26	0.372	0.0882	0	0.117	0
27	0.372	0.0882	0	0.117	0
28	0.372	0.0945	0	0.1482	0
29	0.372	0.0945	0	0.156	0
30	0.372	0.0945	0	0.1638	0
Total Wetted Acres	**11.129**	**1.364**	**0**	**1.8798**	**8.316**

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	0.3720	0.1008	0.0000	0.1950	0.0000
2	0.3720	0.1071	0.0000	0.2106	0.0000
3	0.3720	0.1134	0.0000	0.2808	0.0000
4	0.3720	0.1134	0.0000	0.2886	0.0000
5	0.3720	0.1197	0.0000	0.3120	0.0000
6	0.3720	0.1228	0.0000	0.3432	0.0000
7	0.3720	0.1260	0.0605	0.3744	0.0000
8	0.3720	0.0000	0.1815	0.0234	0.0000
9	0.3720	0.0000	0.2057	0.0000	0.0000
10	0.3720	0.0000	0.2178	0.0000	0.0000
11	0.3720	0.0000	0.2299	0.0000	0.0000
12	0.3720	0.0000	0.2420	0.0000	0.0000
13	0.3720	0.0000	0.3388	0.0000	0.0000
14	0.3720	0.0000	0.3388	0.0000	0.0000
15	0.3720	0.0000	0.3388	0.0000	0.0000
16	0.3720	0.0000	0.3509	0.0000	0.0000
17	0.3720	0.0000	0.3509	0.0000	0.0000
18	0.3720	0.0000	0.3509	0.0000	0.0000
19	0.3720	0.0000	0.3630	0.0000	0.0000
20	0.3720	0.0000	0.1936	0.0000	0.0000
21	0.3720	0.0000	0.1573	0.0000	0.0630
22	0.3720	0.0000	0.1210	0.0000	0.1260
23	0.3720	0.0000	0.0242	0.0000	0.3150
24	0.3720	0.0000	0.0000	0.0000	0.6300
25	0.3720	0.0000	0.0000	0.0000	0.8190
26	0.3720	0.0000	0.0000	0.0000	0.8190
27	0.3720	0.0000	0.0000	0.0000	0.8190
28	0.3720	0.0000	0.0000	0.0000	0.8190
29	0.3720	0.0000	0.0000	0.0000	0.8190
30	0.3720	0.0000	0.0000	0.0000	0.8190
31	0.3720	0.0000	0.0000	0.0000	0.8190
Total Wetted Acres	**11.532**	**0.8032**	**4.0656**	**2.028**	**6.867**

* 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. 71-563876.0007
Year: 2015

	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	0.0000	0.05	0	0.0000	0.05	0	0.2142	0.15	0.0026775
2	0.1890	0.03	0.0004725	0.0000	0.11	0	0.2142	0.06	0.001071
3	0.2142	0.06	0.001071	0.0000	0.11	0	0.2142	0.13	0.0023205
4	0.2142	0.07	0.0012495	0.0000	0.12	0	0.2142	0.15	0.0026775
5	0.2142	0.09	0.0016065	0.0000	0.12	0	0.2142	0.19	0.0033915
6	0.2142	0.09	0.0016065	0.0000	0.13	0	0.1890	0.28	0.00441
7	0.2142	0.13	0.0023205	0.0000	0.14	0	0.1890	0.18	0.002835
8	0.2142	0.02	0.000357	0.0000	0.14	0	0.0000	0.19	0
9	0.2142	0.08	0.001428	0.0000	0.14	0	0.0000	0.2	0
10	0.2142	0.09	0.0016065	0.0000	0.15	0	0.0000	0.2	0
11	0.2142	0.07	0.0012495	0.0000	0.16	0	0.0000	0.16	0
12	0.2142	0.05	0.0008925	0.0000	0.23	0	0.0000	0.11	0
13	0.2142	0.06	0.001071	0.0000	0.17	0	0.0000	0.15	0
14	0.2142	0.03	0.0005355	0.0000	0.1	0	0.0000	0.27	0
15	0.2142	0.1	0.001785	0.0000	0.07	0	0.0000	0.31	0
16	0.0000	0.13	0	0.0000	0.12	0	0.0000	0.23	0
17	0.0000	0.09	0	0.0000	0.14	0	0.0000	0.15	0
18	0.0000	0.11	0	0.0000	0.13	0	0.0000	0.05	0
19	0.0000	0.11	0	0.0000	0.15	0	0.0000	0.07	0
20	0.0000	0.11	0	0.0000	0.08	0	0.0000	0.17	0
21	0.0000	0.12	0	0.1890	0.14	0.002205	0.0000	0.2	0
22	0.0000	0.13	0	0.1890	0.15	0.0023625	0.0000	0.19	0
23	0.0000	0.11	0	0.1890	0.15	0.0023625	0.0000	0.21	0
24	0.0000	0.13	0	0.1890	0.09	0.0014175	0.0000	0.23	0
25	0.0000	0.07	0	0.2142	0.14	0.002499	0.0000	0.21	0
26	0.0000	0.04	0	0.2142	0.17	0.0030345	0.0000	0.22	0
27	0.0000	0.09	0	0.2142	0.18	0.003213	0.0000	0.24	0
28	0.0000	0.1	0	2.1420	0.11	0.019635	0.0000	0.24	0
29	0.0000	0.02	0			0	0.0000	0.2	0
30	0.0000	0	0				0.0000	0.22	0
31	0.0000	0	0				0.0000	0.25	0
Monthly Evapo-transpiration			**0.0172515**			**0.036729**			**0.019383**

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2015

	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	0.0000	0.28	0	0.0000	0.31	0	0.0000	0.39	0
2	0.0000	0.29	0	0.0000	0.29	0	0.0000	0.37	0
3	0.0000	0.2	0	0.0000	0.28	0	0.0000	0.38	0
4	0.0000	0.21	0	0.2142	0.22	0.003927	0.2204	0.19	0.003489667
5	0.0000	0.24	0	0.3464	0.24	0.006928	0.4094	0.19	0.006482167
6	0.0000	0.27	0	0.4032	0.31	0.010416	0.4220	0.37	0.013011667
7	0.0000	0.28	0	0.4032	0.24	0.008064	0.4220	0.35	0.012308333
8	0.0000	0.28	0	0.4158	0.31	0.0107415	0.4220	0.22	0.007736667
9	0.0000	0.24	0	0.4158	0.28	0.009702	0.4094	0.17	0.005799833
10	0.0000	0.26	0	0.4158	0.29	0.0100485	0.3464	0.27	0.007794
11	0.0000	0.27	0	0.4158	0.27	0.0093555	0.3212	0.31	0.008297667
12	0.0000	0.07	0	0.4158	0.16	0.005544	0.2204	0.34	0.006244667
13	0.0000	0.24	0	0.2142	0.26	0.004641	0.1952	0.35	0.005693333
14	0.0000	0.26	0	0.1890	0.28	0.00441	0.0062	0.35	0.000180833
15	0.0000	0.32	0	0.0000	0.15	0	0.0062	0.36	0.000186
16	0.0000	0.28	0	0.0000	0.22	0	0.0062	0.37	0.000191167
17	0.0000	0.28	0	0.0000	0.28	0	0.0062	0.39	0.0002015
18	0.0000	0.3	0	0.0000	0.27	0	0.0000	0.39	0
19	0.2772	0.29	0.006699	0.0000	0.29	0	0.0062	0.38	0.000196333
20	0.2772	0.27	0.006237	0.0000	0.3	0	0.0000	0.38	0
21	0.3402	0.29	0.0082215	0.0000	0.26	0	0.0000	0.37	0
22	0.3464	0.28	0.008082667	0.0000	0.33	0	0.0000	0.35	0
23	0.4032	0.28	0.009408	0.0000	0.29	0	0.0062	0.37	0.000191167
24	0.4032	0.16	0.005376	0.0000	0.3	0	0.0062	0.27	0.0001395
25	0.4185	0.26	0.0090675	0.0000	0.3	0	0.0062	0.31	0.000160167
26	0.4185	0.19	0.00662625	0.0000	0.32	0	0.1116	0.32	0.002976
27	0.4410	0.24	0.00882	0.0000	0.39	0	0.0062	0.27	0.0001395
28	0.4032	0.36	0.012096	0.0000	0.34	0	0.0062	0.23	0.000118833
29	0.1890	0.35	0.0055125	0.0000	0.34	0	0.0062	0.24	0.000124
30	0.0000	0.3	0	0.0000	0.35	0	0.0310	0.22	0.000568333
31				0.0000	0.35	0			
Monthly Evapo-transpiration			**0.086146417**			**0.0837775**			**0.082231333**

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2015

	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	0.031	0.19	0.000490833	0.0000	0.21	0	0	0.21	0
2	0.031	0.27	0.0006975	0.0000	0.27	0	0	0.17	0
3	0.0062	0.24	0.000124	0.0000	0.29	0	0	0.09	0
4	0	0.15	0	0.0000	0.29	0	0	0.09	0
5	0	0.08	0	0.0000	0.31	0	0	0.05	0
6	0	0.24	0	0.0000	0.1	0	0	0.21	0
7	0	0.23	0	0.0000	0.18	0	0	0.21	0
8	0	0.28	0	0.0000	0.2	0	0	0.08	0
9	0	1.9	0	0.0000	0.22	0	0	0.1	0
10	0	0.23	0	0.0000	0.19	0	0	0.02	0
11	0	0.27	0	0.0000	0.17	0	0	0.19	0
12	0	0.22	0	0.0000	0.17	0	0	0.23	0
13	0	0.24	0	0.0000	0.25	0	0	0.18	0
14	0	0.24	0	0.0000	0.26	0	0	0.17	0
15	0	0.22	0	0.0000	0.27	0	0	0.17	0
16	0	0.28	0	0.0000	0.31	0	0	0.19	0
17	0	0.18	0	0.0000	0.3	0	0	0.2	0
18	0	0.13	0	0.0000	0.3	0	0	0.23	0
19	0	0.26	0	0.0000	0.28	0	0	0.2	0
20	0	0.28	0	0.0000	0.21	0	0	0.23	0
21	0	0.28	0	0.0000	0.26	0	0	0.02	0
22	0	0.25	0	0.0000	0.23	0	0	0.11	0
23	0	0.13	0	0.0000	0.24	0	0	0.17	0
24	0	0.28	0	0.0000	0.25	0	0	0.19	0
25	0	0.26	0	0.0000	0.12	0	0	0.35	0
26	0	0.28	0	0.0000	0.2	0	0	0.28	0
27	0	0.24	0	0.0000	0.25	0	0	0.24	0
28	0	0.23	0	0.0000	0.24	0	0	0.23	0
29	0	0.17	0	0.0000	0.27	0	0	0.22	0
30	0	0.24	0	0.0000	0.23	0	0	0.23	0
31	0	0.19	0	0.0000	0.22	0			
Monthly Evapo-transpiration			**0.001312333**			**0**			**0**

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2015

	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	0.0000	0.23	0	0.3402	0.13	0.0036855	0.0000	0.1	0
2	0.0000	0.23	0	0.3402	0.14	0.003969	0.0000	0.11	0
3	0.0000	0.24	0	0.2142	0.17	0.0030345	0.0000	0.12	0
4	0.0000	0.22	0	0.2772	0.08	0.001848	0.0000	0.11	0
5	0.0000	0.16	0	0.189	0.13	0.0020475	0.0000	0.11	0
6	0.0000	0.13	0	0.189	0.13	0.0020475	0.0000	0.12	0
7	0.0000	0.14	0	0.189	0.13	0.0020475	0.0000	0.09	0
8	0.0000	0.18	0	0.189	0.14	0.002205	0.0000	0.1	0
9	0.0000	0.28	0	0.189	0.13	0.0020475	0.0000	0.09	0
10	0.0000	0.18	0	0.189	0.11	0.0017325	0.0000	0.1	0
11	0.0000	0.19	0	0.189	0.12	0.00189	0.0000	0.1	0
12	0.0000	0.13	0	0.189	0.12	0.00189	0.0000	0.02	0
13	0.2142	0.2	0.00357	0	0.13	0	0.0000	0.07	0
14	0.4032	0.18	0.006048	0	0.12	0	0.0000	0	0
15	0.4410	0.06	0.002205	0	0.04	0	0.0000	0.07	0
16	0.2142	0.14	0.002499	0	0.08	0	0.0000	0.07	0
17	0.2142	0.14	0.002499	0	0.11	0	0.0000	0.06	0
18	0.4158	0.13	0.0045045	0	0.09	0	0.0000	0.08	0
19	0.2142	0.15	0.0026775	0	0.12	0	0.0000	0.04	0
20	0.1890	0.14	0.002205	0	0.12	0	0.0000	0.08	0
21	0.0000	0.09	0	0	0.11	0	0.0000	0.08	0
22	0.0000	0.14	0	0	0.12	0	0.0000	0.01	0
23	0.0000	0.15	0	0	0.13	0	0.0000	0.06	0
24	0.0000	0.2	0	0	0.11	0	0.1890	0.06	0.000945
25	0.0000	0.17	0	0	0.07	0	0.2142	0.1	0.001785
26	0.0000	0.13	0	0	0.11	0	0.2772	0.12	0.002772
27	0.0000	0.15	0	0	0.1	0	0.3402	0.07	0.0019845
28	0.1890	0.1	0.001575	0	0.1	0	0.4032	0.07	0.002352
29	0.1890	0.12	0.00189	0	0.1	0	0.4158	0.06	0.002079
30	0.2142	0.06	0.001071	0	0.08	0	0.4158	0.07	0.0024255
31	0.2772	0.13	0.003003				0.4410	0.08	0.00294
Monthly Evapo-transpiration			**0.033747**			**0.0284445**			**0.017283**

THE UNIVERSITY OF ARIZONA®
Cooperative Extension

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).

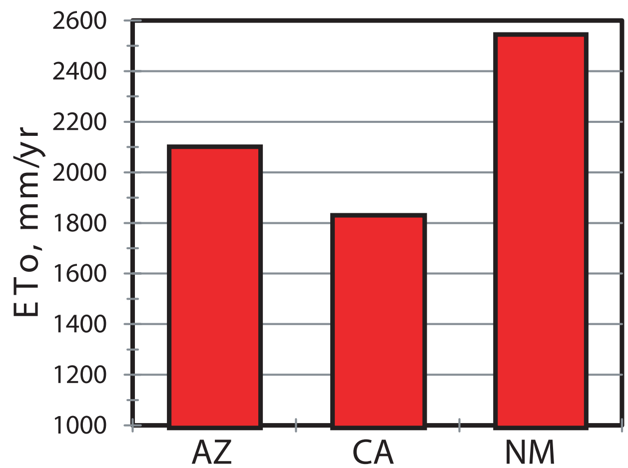


Figure 1. Reference ET (ETo) for Tucson for calendar year 1996 as computed using the published procedures for the public weather networks in Arizona, California, and New Mexico.

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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COLLEGE OF AGRICULTURE AND LIFE SCIENCES
TUCSON, ARIZONA 85721

PAUL W. BROWN
Extension Specialist, Biometeorology

This information has been reviewed by university faculty.

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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 (EToa) 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
ETοa	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 $^oC^{-1}$)

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:

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

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

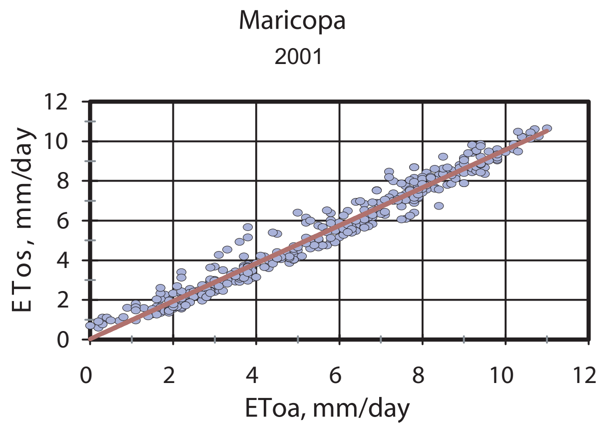

Figure 2. Reference evapotranspiration as computed using the ASCE standardized procedure (ETos) versus reference evapotranspiration computed using procedure employed by AZMET. The line represents the least squares regression line (ETos = 0.03 + 0.95 x EToa; r^2 = 0.96).

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 (°C). 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 (EToa) 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 EToa for locations presently served by AZMET weather stations.

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

Annual totals of ETos were 3-17% lower than similar totals of EToa depending on location (Table 3). The lowest ratios of ETos to EToa 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 EToa) 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 EToa to ETos

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

$$ETos = Ratio * EToa \quad (3)$$

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 (ETоa) computation procedures. Monthly ratios of ETos to ETоa are provided in columns labeled "Ratio."

LOCATION	JANUARY			FEBRUARY			MARCH			APRIL			MAY			JUNE		
	ETos (mm)	ETоa (mm)	Ratio	ETos (mm)	ETоa (mm)	Ratio	ETos (mm)	ETоa (mm)	Ratio	ETos (mm)	ETоa (mm)	Ratio	ETos (mm)	ETоa (mm)	Ratio	ETos (mm)	ETоa (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 (ETo a) computation procedures. Monthly ratios of ETos to ETo a are provided in columns labeled “Ratio.”

LOCATION	JULY			AUGUST			SEPTEMBER			OCTOBER			NOVEMBER			DECEMBER		
	ETos (mm)	ETo a (mm)	Ratio	ETos (mm)	ETo a (mm)	Ratio	ETos (mm)	ETo a (mm)	Ratio	ETos (mm)	ETo a (mm)	Ratio	ETos (mm)	ETo a (mm)	Ratio	ETos (mm)	ETo a (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 ETos. Monthly ratios provide the best means of converting short term data sets (e.g., daily, weekly or monthly totals of ETos). *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:

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

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 (ETos). To obtain an estimate of turf water use in Tucson for May one would multiply the Kc (0.75) times the May ETos value for Tucson (258.1 mm from Table 2):

$$ETc = Kc * ETos$$

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

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

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:

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

where Kc_{os} and Kc_{az} are the crop coefficient values appropriate for use with ETos and ETos, respectively; and **Ratio** is the ratio of ETos to ETos 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 ETos 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 ETos. 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 ETos 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:

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

where T is the mean temperature for the day (^oC).

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:

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

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:

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

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):

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

The daily value of Rnl is computed using:

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

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:

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

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:

$$es = (es(Tmax) + es(Tmin)) \;/\; 2 \qquad (A15)$$

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:

$$es = 0.6108 \exp((17.27Tex) \;/\; (Tex + 237.3)) \qquad (A16)$$

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:

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

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

APPENDIX E

Water Level Measurements

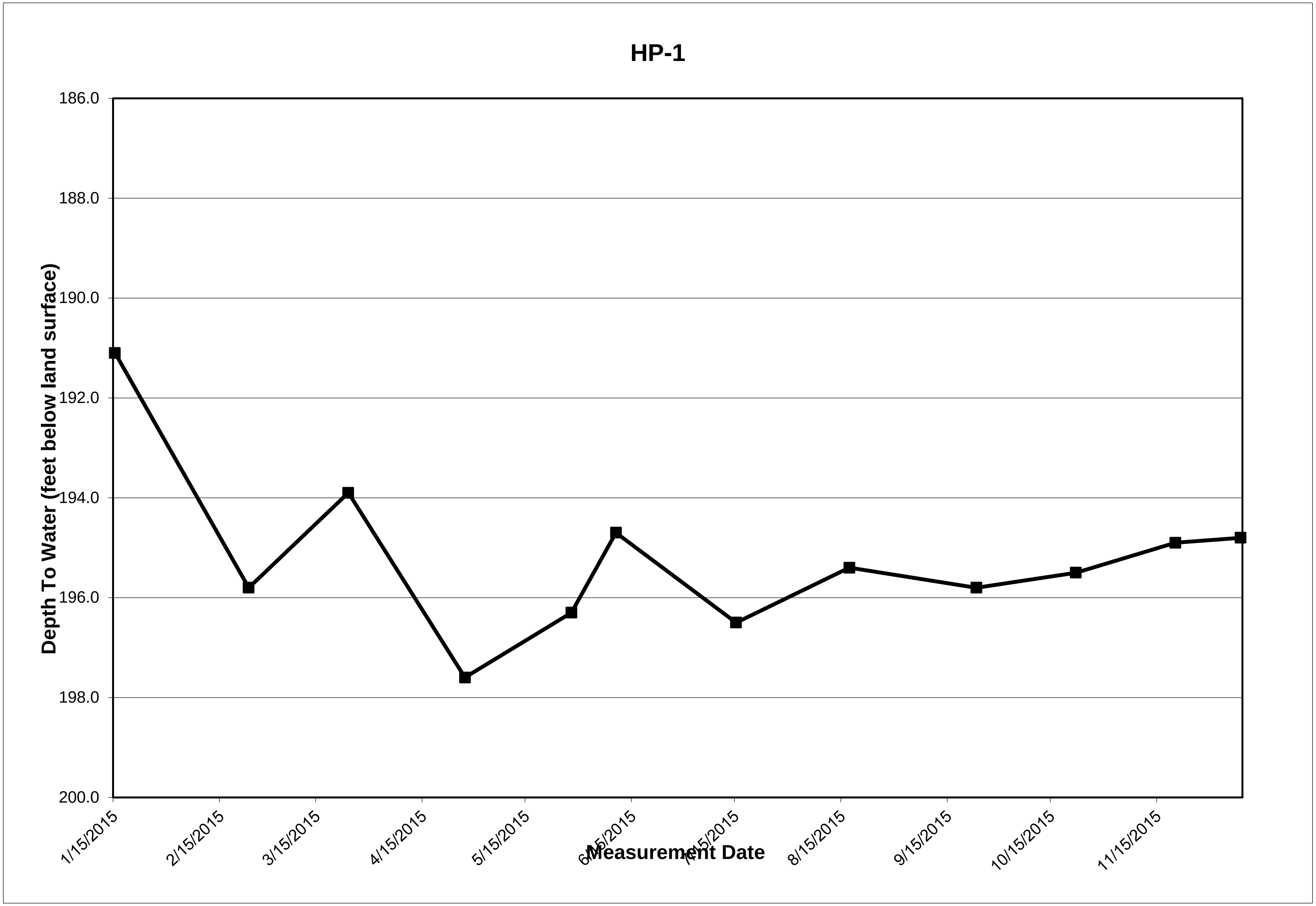
USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2015

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**
1/15/2015	191.1	191.1	1794.1	
2/23/2015	195.8	195.8	1789.4	
3/24/2015	193.9	193.9	1791.3	
4/27/2015	197.6	197.6	1787.6	
5/28/2015	196.3	196.3	1788.9	
6/10/2015	194.7	194.7	1790.5	
7/15/2015	196.5	196.5	1788.7	
8/17/2015	195.4	195.4	1789.8	
9/23/2015	195.8	195.8	1789.4	
10/22/2015	195.5	195.5	1789.7	
11/20/2015	194.9	194.9	1790.3	
12/9/2015	194.8	194.8	1790.4	

* 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. 71-563876.0007
Year: 2015



USF WATER LEVEL MEASUREMENTS

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0007

Year: 2015

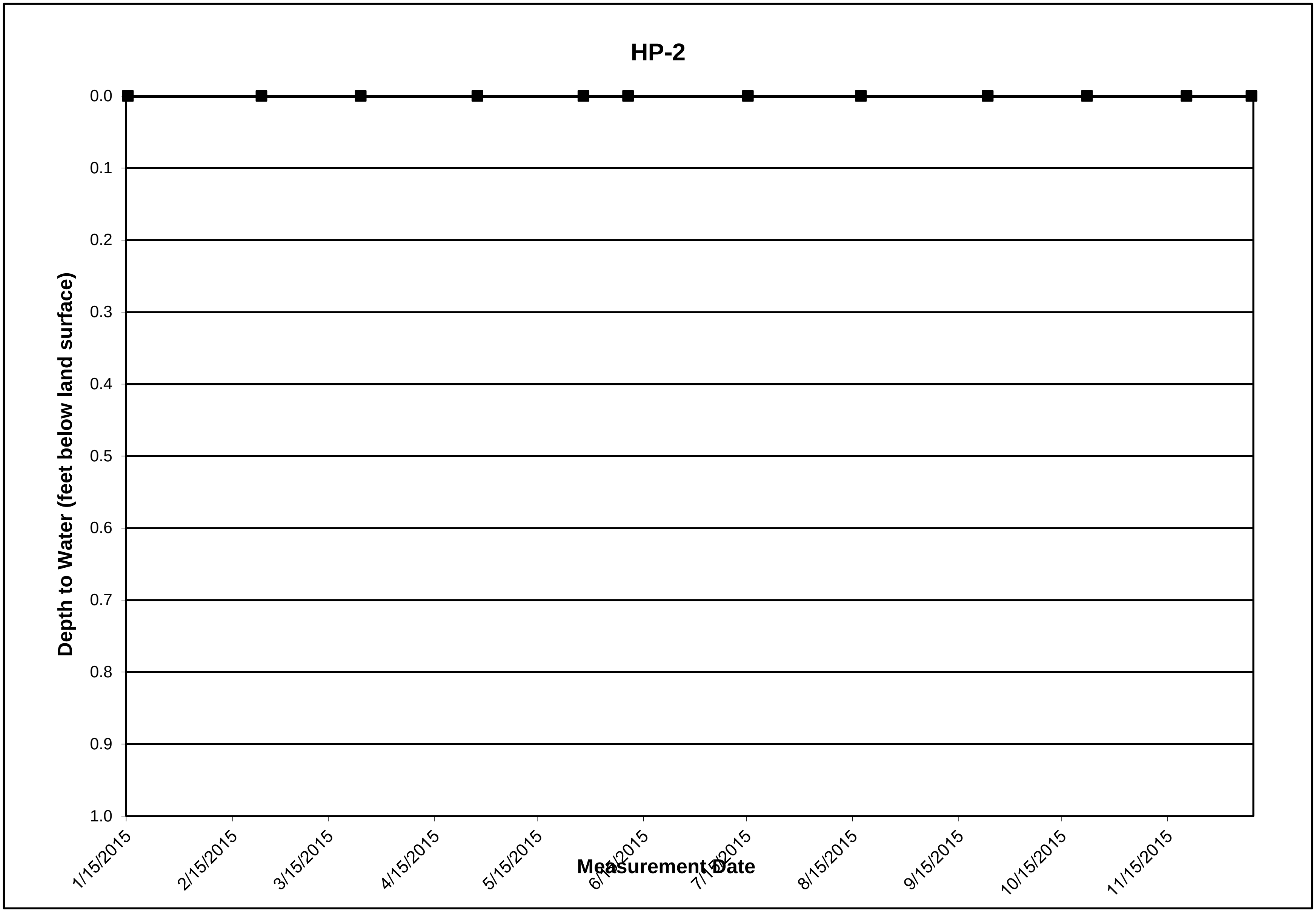
Monitor Point ID	HP-2
ADWR Registration Number	55-593607
Cadastral Location	D(11-11)33cad
Measuring Point Elevation (feet amsl)	1986.75
Measuring Point Description	top of port
Measuring Point Height (ft)	
Land Surface Elevation at Wellhead (feet amsl)	1986.75
Permit Alert Level (feet bls)	30
Permit OPL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

Measurement Date	DTW (feet below MP)	DTW (feet bls)	Elevation (feet amsl)	Exceedance Status
1/15/2015	dry			
2/23/2015	dry			
3/24/2015	dry			
4/27/2015	dry			
5/28/2015	dry			
6/10/2015	dry			
7/15/2015	dry			
8/17/2015	dry			
9/23/2015	dry			
10/22/2015	dry			
11/20/2015	dry			
12/9/2015	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. 71-563876.0007
Year: 2015



USF WATER LEVEL MEASUREMENTS

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0007

Year: 2015

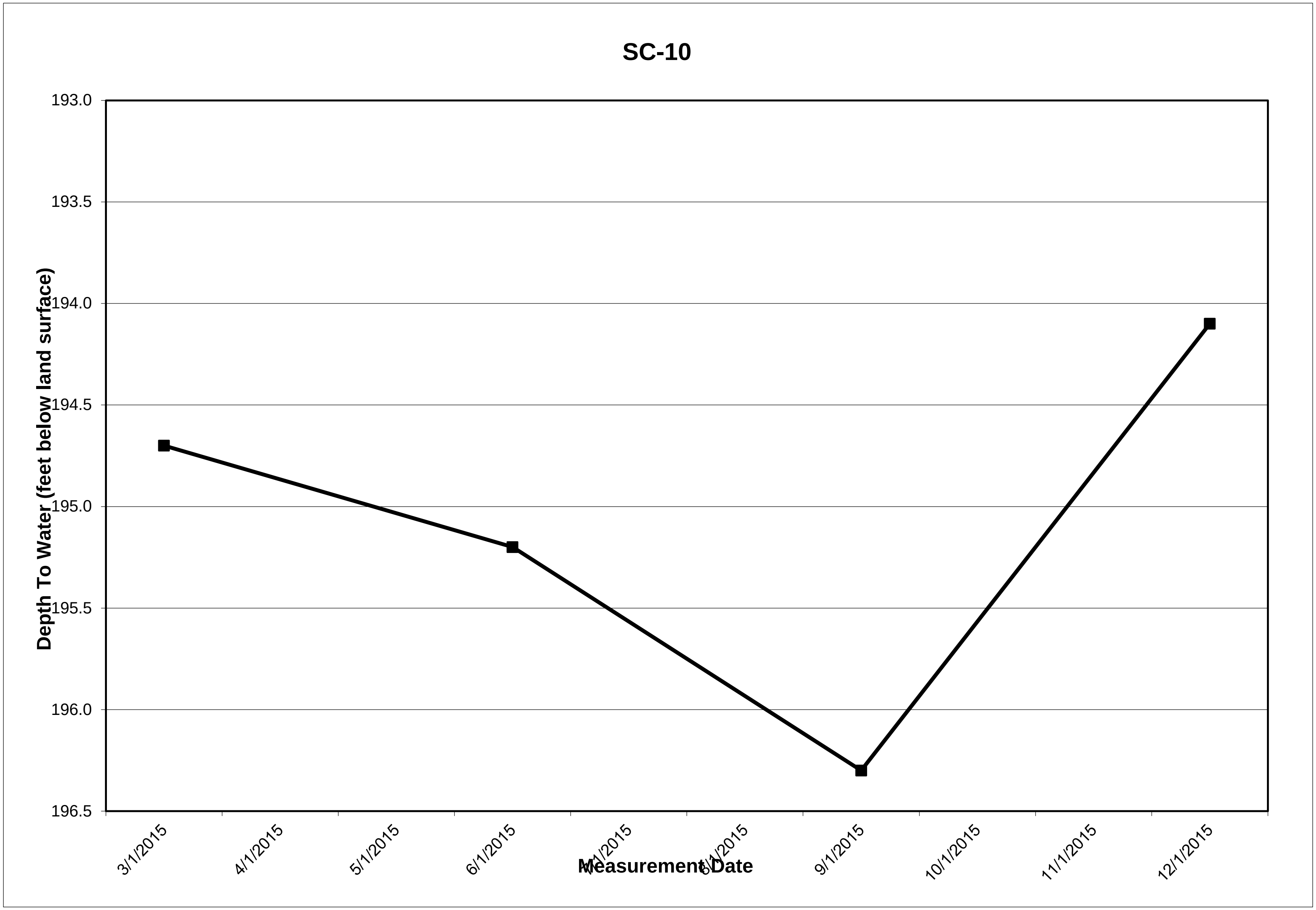
Monitor Point ID	SC-10
ADWR Registration Number	55-520129
Cadastral Location	D(11-11)33bcb
Measuring Point Elevation (feet amsl)	1978.36
Measuring Point Description	top of port
Measuring Point Height (ft)	
Land Surface Elevation at Wellhead (feet amsl)	1978.36
Permit Alert Level (feet bls)	30
Permit OPL (feet bls)	20

Measurement Date	DTW (feet below MP)	DTW (feet bls)	Elevation (feet amsl)	Exceedance Status
3/24/2015	194.7	194.7	1790.5	
6/10/2015	195.2	195.2	1790.0	
9/30/2015	196.3	196.3	1788.9	
12/9/2015	194.1	194.1	1791.1	

* 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. 71-563876.0007
Year: 2015



APPENDIX F

Infiltration Rate Data &
Calculations

INFILTRATION RATE DATA AND CALCULATIONS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2015

	Net Recharge Volumes (ac-ft)	**Total Wetted Acreages** (ac-days)	**Infiltration Rate** (ft/day)	**Quarterly Average Infiltration Rate** (ft/day)
January	76.2	32.6	2.34	
February	32.2	15.5	2.08	
March	56.8	24.7	2.30	2.27
April	56.9	26.7	2.13	
May	67.4	27.6	2.45	
June	82.6	30.9	2.67	2.43
July	6.7	8.4	0.80	
August	0.0	0.0		
September	2.3	0.5	5.08	1.02
October	57.8	23.5	2.45	
November	92.6	22.7	4.08	
December	93.6	25.3	3.70	3.41

Totals	**625.1**	**238.2**	**2.62**

CELL 1: INFILTRATION RATE DATA AND CALCULATIONS

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0007

Year: 2015

	Net Recharge Volumes (ac-ft)	Total Wetted Acreages (ac-days)	Infiltration Rate (ft/day)	Quarterly Average Infiltration Rate (ft/day)
January	16.5	0.9	17.75	
February	0.0	0.0		
March	14.6	0.5	31.15	22.25
April	13.9	1.1	13.28	
May	20.0	1.0	19.81	
June	1.4	0.2	8.06	15.84
July	0.0	0.0		
August	0.0	0.0		
September	0.0	0.0		
October	0.0	0.0		
November	28.5	1.4	20.99	
December	9.5	0.8	11.86	17.61
Totals	**104.5**	**5.8**	**18.05**	

CELL 2: INFILTRATION RATE DATA AND CALCULATIONS

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0007

Year: 2015

	Net Recharge Volumes (ac-ft)	Total Wetted Acreages (ac-days)	Infiltration Rate (ft/day)	Quarterly Average Infiltration Rate (ft/day)
January	21.6	4.5	4.78	
February	15.7	2.7	5.77	
March	13.5	3.8	3.59	4.62
April	15.0	2.0	7.34	
May	10.4	0.1	79.85	
June	66.7	9.1	7.36	8.20
July	6.5	1.3	5.16	
August	0.0	0.0		
September	1.5	0.1	12.33	5.78
October	16.8	1.9	8.77	
November	0.0	0.0		
December	41.9	3.9	10.67	10.05
Totals	**209.4**	**29.4**	**7.12**	

CELL 3: INFILTRATION RATE DATA AND CALCULATIONS

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0007

Year: 2015

	Net Recharge Volumes (ac-ft)	**Total Wetted Acreages** (ac-days)	**Infiltration Rate** (ft/day)	**Quarterly Average Infiltration Rate** (ft/day)
January	16.5	2.5	6.52	
February	0.0	0.0		
March	14.6	0.7	21.22	9.67
April	13.9	1.5	9.54	
May	24.2	4.6	5.28	
June	1.6	0.7	2.30	5.89
July	0.0	0.0		
August	0.0	0.0		
September	0.0	0.0		
October	0.0	0.0		
November	28.6	1.9	15.20	
December	9.6	2.0	4.71	9.76
Totals	**109.0**	**13.9**	**7.86**	

CELL 4: INFILTRATION RATE DATA AND CALCULATIONS

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0007

Year: 2015

	Net Recharge Volumes (ac-ft)	**Total Wetted Acreages** (ac-days)	**Infiltration Rate** (ft/day)	**Quarterly Average Infiltration Rate** (ft/day)
January	20.7	16.1	1.29	
February	15.6	10.6	1.46	
March	11.7	9.8	1.19	1.31
April	14.0	14.5	0.96	
May	12.0	13.9	0.86	
June	12.2	12.4	0.98	0.94
July	0.0	0.0		
August	0.0	0.0		
September	0.0	0.0		
October	37.7	13.8	2.74	
November	34.7	11.0	3.16	
December	31.9	9.6	3.33	3.04
Totals	**190.3**	**111.6**	**1.70**	

EQUALIZATION BASIN: INFILTRATION RATE DATA AND CALCULATIONS

Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2015

	Net Recharge Volumes (ac-ft)	Total Wetted Acreages (ac-days)	Infiltration Rate (ft/day)	Quarterly Average Infiltration Rate (ft/day)
January	0.9	11.5	0.08	
February	1.0	5.7	0.18	
March	0.9	11.4		0.10
April	0.1	11.6	0.01	
May	0.8	11.8	0.07	
June	0.7	12.9	0.06	0.05
July	0.2	7.2	0.03	
August	0.0	0.0		
September	0.9	0.3	2.53	0.14
October	3.3	11.0	0.30	
November	0.7	11.1	0.06	
December	0.8	11.5	0.07	0.14

Totals	**10.3**	**106.0**	**0.10**