ANNUAL MONITORING REPORT
2019

MARANA HIGH PLAINS EFFLUENT RECHARGE PROJECT

Underground Storage Facility Permit No. 71-563876.0008 (PCRFCD)
Water Storage Permit No. 73-563876.0200 (PCRWRD)

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1.0 INTRODUCTION

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

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

- To recharge up to 600 acre-feet of water per year while maximizing infiltration rates in basins having side slopes vegetated with emergent plants and riparian trees;
- To provide trails, descriptive literature, and interpretive signs describing the project operations. Trails at the project site may eventually be linked to a longer river trail network that is scheduled to be built along the Santa Cruz River;
- To re-vegetate the area outside the recharge basins with plants that will improve wildlife habitat value and, once established, could survive if the recharge activities cease;
- To maintain wildlife, aquatic macroinvertebrates, and vegetative resources associated with an important effluent-dominated stream; and
- To monitor the biological effects that may result from establishing other habitat types that are now rare to the area (e.g., marsh, grassland), and increase the aerial extent of riparian vegetation.

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

The facility has been operating since February 2003, first as a pilot project and then as a constructed recharge project. In accordance with Sections 2 and 3 of the USF Permit (all versions), this is the seventeenth annual report for MHPERP. This report includes all of the data that was collected during the 2019 Calendar Year.

2.0 PROJECT OPERATIONS

A modified USF Permit (71-563876.0008) was approved and signed by the ADWR Deputy Assistant Director, Gerry L. Walker, on March 24, 2017. This permit authorizes PCRFCD to store effluent at MHPERP over a twenty-year term (through November 24, 2028) or until the Operation Prohibition Limits are met. Maximum annual storage at the facility is based on three constructed phases as follows:

Phase 1: 350 acre-feet per annum recharged within the equalization basin and the four recharge cells, as constructed in 2002,
Phase 2: 450 acre-feet per annum after construction of recharge enhancement trenches within Recharge Cells 1, 3 and 4, as constructed in 2009,
Phase 3: 600 acre-feet per annum after re-excavation of Recharge Cell 2, as constructed in 2010.

The facility operated per Phase 3 of the permit throughout the 2019 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 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, which is approximately 10 miles upstream of the diversion structure. Some effluent from the new Agua Nueva Wastewater Reclamation Facility, approximately 15 miles upstream of the diversion structure, may mix with the effluent flows from the Tres Rios WRF during the winter months.

A constructed wet well collects the oxbow channel flows at the Northeast corner of the facility. Two non-clogging, submersible pumps convey effluent through an 8-inch line into an equalization basin, used to provide a more constant source of available effluent for recharge and help serve as a settling basin for removing particulate materials that could clog the recharge cells. Level sensors automatically turn the pumps on and off due to water 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.

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

Deliveries to MHPERP are based on the daily cycle of discharges from the treatment plants to the Santa Cruz River. Peaks in water levels at this site normally occur in the late morning and early evening hours. Deliveries to the facility are impacted by storm water events in the Santa Cruz River that damage and sometimes demolish the earthen structure used to divert flows into the oxbow channel. Malfunctioning pumps, faulty valve controls, and basin maintenance can also disrupt deliveries to the facility. Details of all the delivery interruptions for Calendar Year 2019 are provided in Section 6.0 (Facility Inspections and Maintenance) of this report.

2.2 Inflow Volumes

Water deliveries into MHPERP are measured using 1) a Magnetflow® Mag Meter installed within the main line that runs from the pumps to the equalization basin (FMeq) and 2) an American Sigma 950 flow meter installed within the gravity-feed pipeline that runs between the wet well and Recharge Cell 2 (FM_{C2}). The facility has been utilizing the new delivery system (Monitor Point FM_{C2}) for storing water and recharge credit accrual since approval was granted by ADWR's Recharge Program on December 12, 2016.[1] The facility's operator reads daily totals from both meters and then compiles the data onto a daily log sheet. The daily log sheets are transmitted to PCRFCD staff on a biweekly basis.

Appendix A contains the daily flow meter readings and volumes for Calendar Year 2019; note that there is a separate spreadsheet for meter readings at FM_{C2}. 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 2019 was 595.5 acre-feet (AF), with a high of 94.8 AF in June and a low of 0.0 AF in October. A total of 357.4 AF (60%) was delivered via the pumps into the equalization basin (FMeq) and 238.1 AF (40%) was delivered via the gravity-feed pipeline into Cell 2 (FM_{C2}).

2.3 Evaporation/Evapotranspiration

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

Daily and monthly evapotranspiration volumes for the vegetated basins are provided in **Appendix D**. Evapotranspiration for each recharge cell is based on the percentage of vegetation within each basin, which is 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**).[2] AZMET determines reference evapotranspiration (ETo) using a modification to the Penman Equation developed for the California

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

[2] The Marana weather station continued to be out of service since the 2017 Calendar Year.

Irrigation Management Information System (CIMIS). An explanation of the procedures used in this computation is also provided in **Appendix D**. No multiplication factor was used in the calculation of reference evapotranspiration (ETo) for the MHPERP because there are no available crop coefficients for the native vegetation in this region.[3]

2.4 Recharge Volumes

The water quantity 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 2019 Calendar Year is 587.1 AF. This means that the facility stored 587.1 AF for the Pima County Regional Wastewater Reclamation Department, who has a Water Storage Permit (No. 73-563876.0200) for the facility.

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 when in operation. 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 7 to 8 feet during the wet cycle.[4] Water depths in Recharge Cell 4 are expected to fluctuate from six to twenty inches during the wet cycles.[5] Water levels within the basins are maintained manually by the facility operator to maintain high infiltration rates, as determined by PCRFCD staff based on basin performance and as needed to prevent overflows.

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

[4] Depths to the bottoms of these three basins have been significantly increased due to enhancement activities. Water levels may primarily range from only two to three feet in Cells 1 & 3 because of greater infiltration rates and shorter wetting cycles.

[5] Water depths are measured from a base elevation of 1982 feet above mean sea level. The bottom of the basin has been lowered approximately 8-10 inches since operations commenced in 2003 due to maintenance activities.

3.2 Regional Groundwater Levels

In 2019, 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 an electric sounder. 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 2019 Calendar Year. Water levels in the on-site deep well (HP-1) decreased from 188.0 feet below land surface (bls) in January 2019 to 189.7 feet bls in February 2019, its lowest point for the year. Levels fluctuated a little thereafter, but generally trended upward to a high of 182.8 feet bls in November. The water level slightly dipped from November to December, down to 183.2 feet bls at the end of the year. Water levels in the off-site monitor well (SC-10) also dropped from January to February, 184.5 feet bls to 186.2 feet bls, but then trended upward to a high of 181.8 feet bls by December.

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 2019 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

Appendix F contains the average monthly, quarterly and annual infiltration rates for the entire facility during the 2019 Calendar Year. Infiltration rates are 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 recharge cells in operation, as described below.

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.

In 2019, monthly infiltration rates for the project ranged from a high of 6.05 feet per day (feet/day) in January to a low of 0.00 feet/day in October, when no effluent was delivered. The average infiltration rate for the year was 2.21 feet/day, which is 0.5 feet/day higher than last year’s rate of 1.69 feet/day. Infiltration rates were greater than one foot/day in every month that had consistent daily deliveries to the facility. The moderately high infiltration rates are primarily a product of continued exposure to coarser materials from basin deepening in previous years and improved effluent quality from the upstream treatment plants.

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 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 2019 Calendar Year. Samples were taken at the oxbow channel (Diversion) and at the compliance well (HP-1). There were no disruptions to sampling along the oxbow channel, but samples were not collected at HP-1 in January due to malfunctioning pump equipment.

There were no exceedances of the discharge limits or aquifer quality limits for the Diversion and HP-1. Therefore, there were no violations of the Aquifer Protection Permit (APP) during Calendar Year 2019.

6.0 FACILITY INSPECTIONS

Inspections of the facility equipment and functions are no longer a requirement of the Aquifer Protection Permit (APP) for this facility since June 2014. However, PCRFCD continues to inspect 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 biweekly 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 2019 Calendar Year and the actions performed to resolve them. The compliance well was repaired (well pump and discharge pipes replaced) in February, which allowed for samples to be collected for water quality testing. Several disruptions of flow occurred throughout the year due to washouts of the earthen diversion berm: 1) eleven days in January, 2) thirty-eight days from mid-February to late-March, 3) thirty-one days from mid-July to mid-August, 4) forty-two days from late-September to early November, and 5) twenty-seven days from mid-November to mid-December. Note that the majority of time during each disruption was to allow storm flows to subside, allow equipment into the area, and have the earthen materials be stable enough to contain flow. Maintenance was conducted in the bottoms of Recharge Cells 1-3 in October to maintain higher infiltration rates.

7.0 CONCLUSIONS

The calculated volume of water stored at MHPERP for Calendar Year 2019 was 587.1 AF. This is the first year that the facility was not able to reach its permitted maximum of 600 AF, after five consecutive years of over 600 AF recharged per year. The facility operated under Phase 3 of the modified USF Permit No. 71-563876.0008 for the entire Calendar Year, which allows the Pima County Regional Wastewater Reclamation District to store a maximum of 600 AF for the year.

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

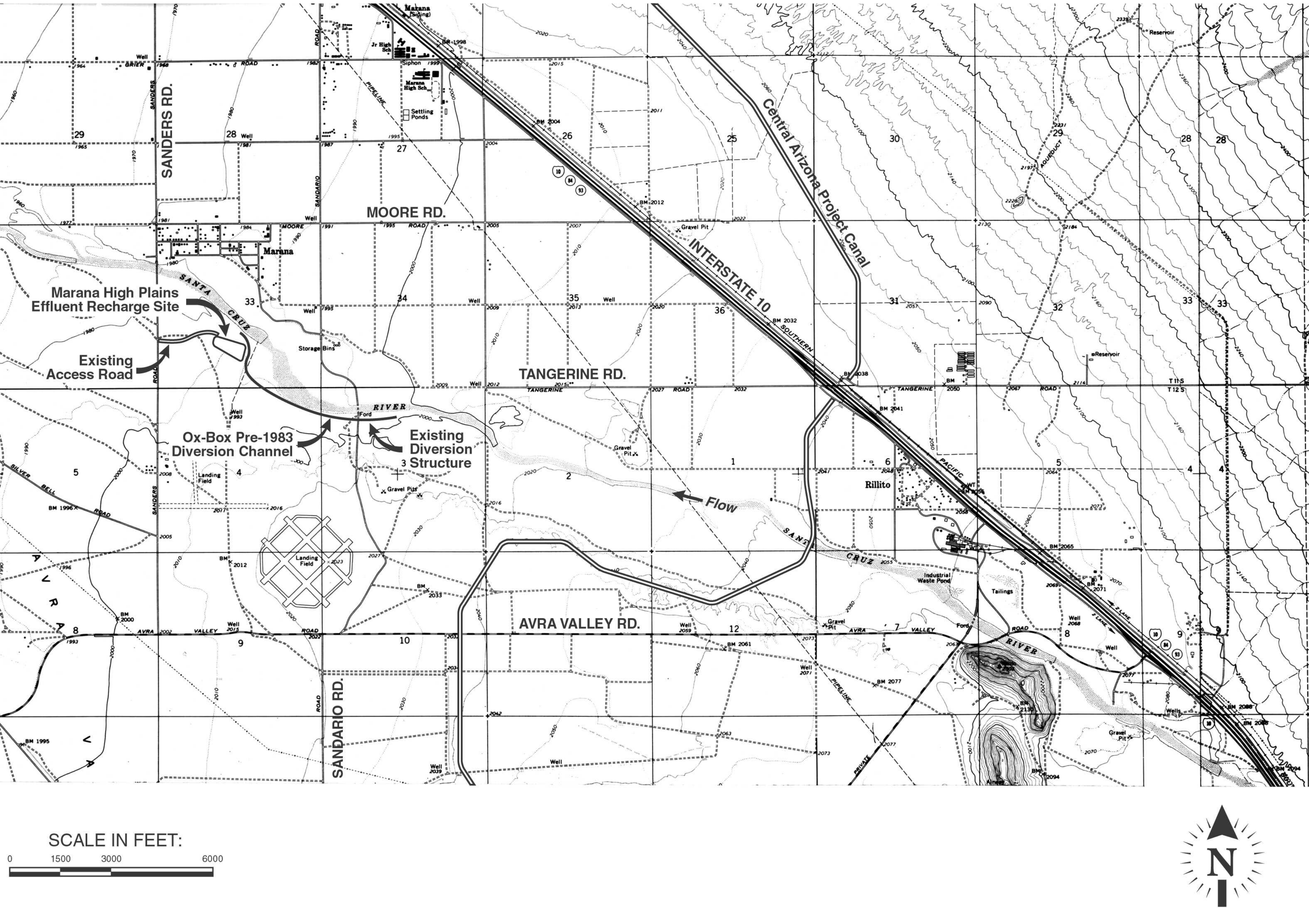
Infiltration at the facility was relatively good during 2019, maintaining monthly rates over one foot/day during normal operations. The average annual infiltration rate for the entire facility in 2019 was 2.21 feet/day, which was 0.5 feet/day higher than last year. Deepening of the basins and improved quality of effluent from the upstream treatment facilities has significantly increased infiltration at this facility over the last several years. Significant down times may have also allowed for greater infiltration rates due to more frequent drying of the basins.

There was a total of 149 days when no effluent was delivered to the project during facility operations. All down time was due to washout of the earthen diversion berm by storm flow events in early January, mid-February, mid-July, late-September and mid-November. This means that the facility only operated for about 60 percent of the year, thus the main reason why the maximum permitted amount of 600 AF was not quite reached. Facility operations continued through December 31.

Greater exposure of sands and gravels in Recharge Basins 1-3 and a better quality effluent (lower turbidity and nutrients) delivered by the upstream treatment facilities continues to make the facility more efficient; and the goal of 600 AF of recharge per annum more attainable. The gravity-feed distribution system to Recharge Cell 2 allows the project to operate with very little use of electricity supplied by the local power company and independent of mechanical pumps that can break down or reduce in efficiency over time.

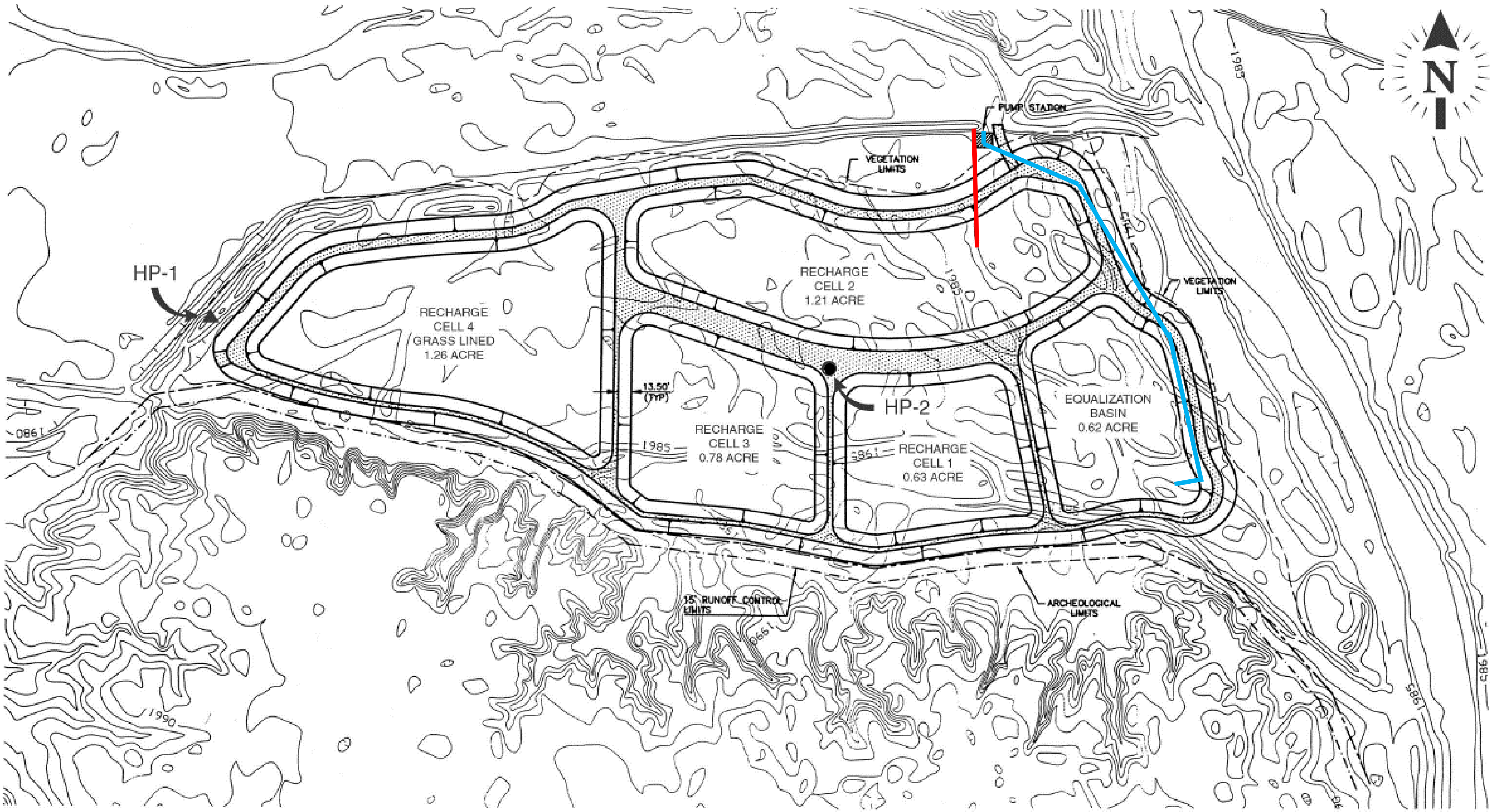
FIGURES

FIGURE 1
Location Map



Pima County Graphic Services db3483 7/02

FIGURE 2
Facility Map



SCALE IN FEET:

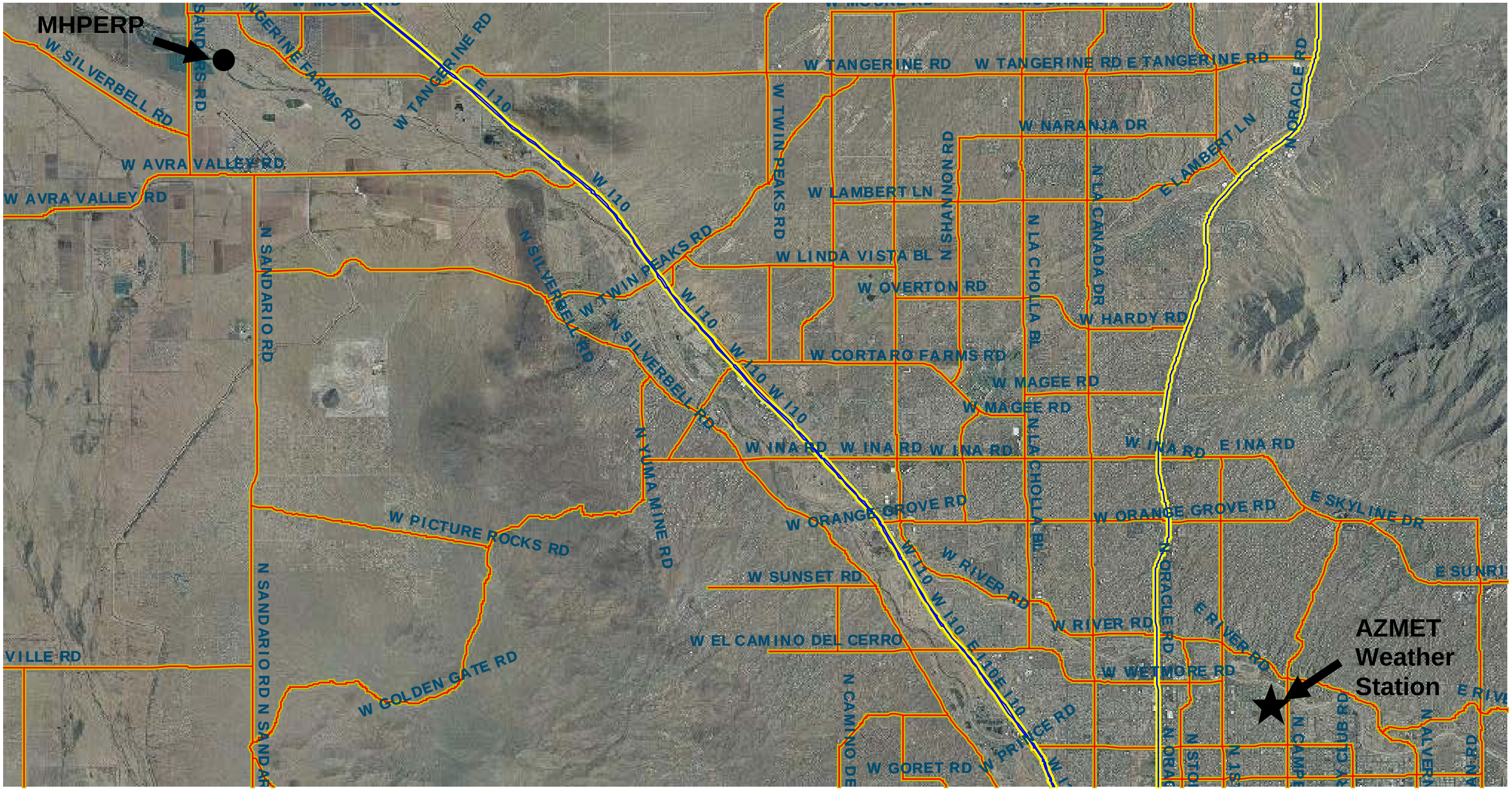
0 25 50 100

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

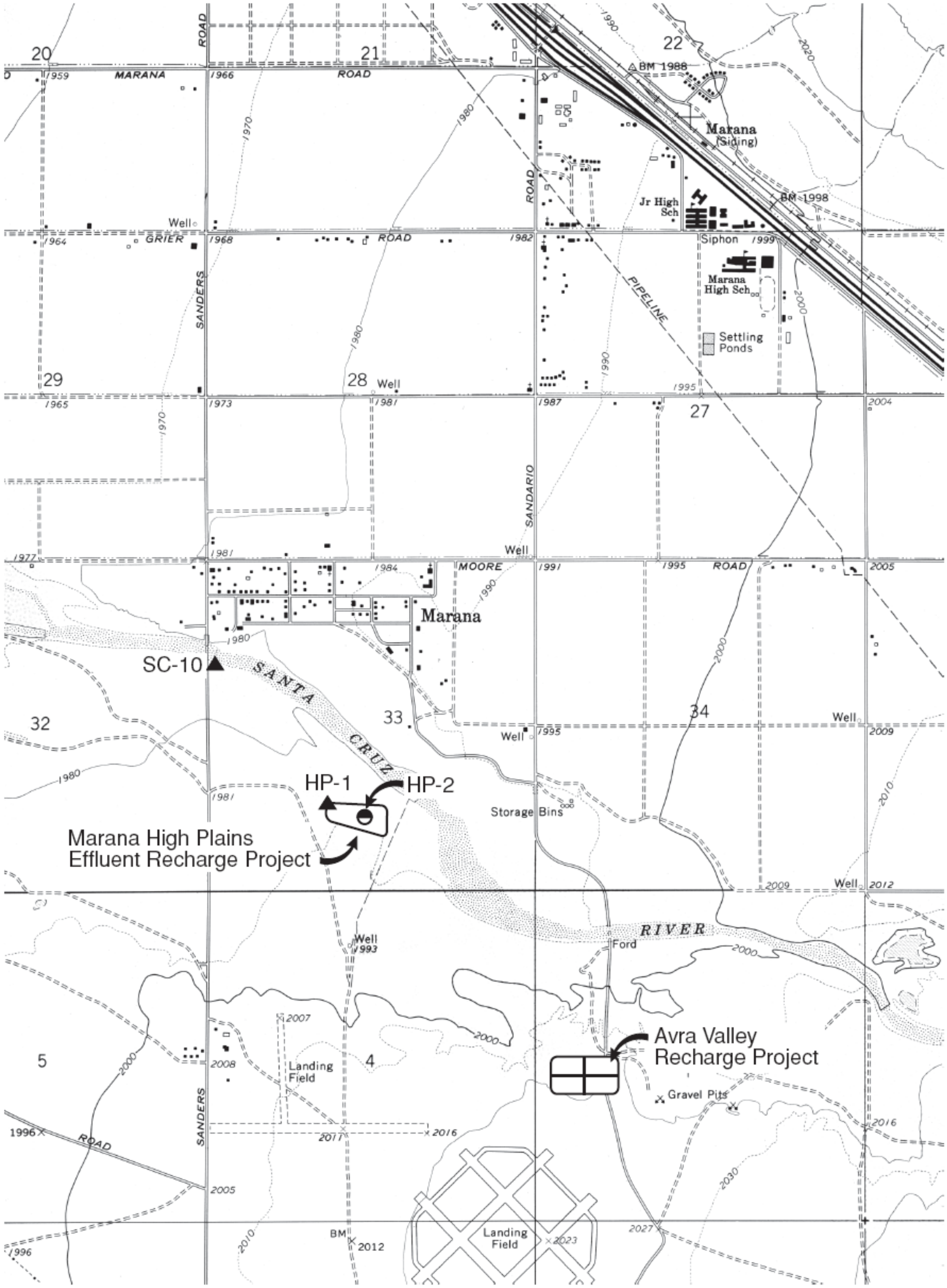
LEGEND

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

FIGURE 3
Tucson AZMET Weather Station
Location Map



Date on line: Jan 1 1987 (Day of Year = 1) **Location:** 1 km (p.6 miles) northwest of Intersection of Campbell Ave. & Roger Rd. **Elevation:** 713 meters (2339 ft) **Coordinates:** Latitude = 32º 16' 49" N; Longitude = 110º 56' 45" W **Cooperator:** Campus Agricultural Center (CAC), College of Agri., Univ. of Arizona	N Miles 1 2 4 SCALE	**LEGEND** ★ **Weather Station**



LEGEND

▲ MONITOR WELL

◓ PIEZOMETER

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

Pima County Graphic Services mhperpFig4 db 3-10

TABLES

TABLE 1A
MARANA HIGH PLAINS EFFLUENT RECHARGE PROJECT
WATER QUALITY SUMMARY - SOURCE WATER DIVERSION
CALENDAR YEAR 2019

Constituent	Unit	Alert Limit	Discharge Limit	Sample Date & Results											
				Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19
Nutrients															
Total Nitrogen[1]	mg/l	N/A	N/A	7.65	3.03	9.94	6.93	8.13	6.99	5.79	6.71	6.83	6.13	7.22	8.34
Nitrate-Nitrite as N	mg/l	N/A	N/A	5.50	1.54	8.30	5.32	6.52	5.44	4.59	5.19	5.32	4.86	5.33	6.50
Total Kjeldahl Nitrogen (TKN)	mg/l	N/A	N/A	2.15	1.49	1.64	1.61	1.61	1.55	1.20	1.52	1.51	1.27	1.89	1.84
Metals (Total)															
Free Cyanide	mg/l	0.16	0.2	No Event	<0.010	No Event	No Event	<0.010	No Event	No Event	No Event	<0.010	No Event	<0.010	No Event
Total Fluoride	mg/l	3.2	4	No Event	0.25	No Event	No Event	0.49	No Event	No Event	No Event	0.42	No Event	0.39	No Event
Arsenic	mg/l	0.04	0.05	No Event	0.0023	No Event	No Event	0.0031	No Event	No Event	No Event	0.0025	No Event	0.0017	No Event
Barium	mg/l	1.6	2	No Event	0.073	No Event	No Event	0.061	No Event	No Event	No Event	0.064	No Event	0.045	No Event
Beryllium	mg/l	0.0032	0.004	No Event	<0.0020	No Event	No Event	<0.0020	No Event	No Event	No Event	<0.0020	No Event	<0.0020	No Event
Cadmium	mg/l	0.004	0.005	No Event	0.0001	No Event	No Event	<0.0001	No Event	No Event	No Event	<0.001	No Event	0.0001	No Event
Chromium	mg/l	0.08	0.1	No Event	<0.0050	No Event	No Event	<0.0050	No Event	No Event	No Event	<0.0050	No Event	<0.0050	No Event
Lead	mg/l	0.04	0.05	No Event	0.0067	No Event	No Event	0.0036	No Event	No Event	No Event	0.0019	No Event	0.002	No Event
Thallium	mg/l	0.0016	0.002	No Event	<0.0005	No Event	No Event	<0.0005	No Event	No Event	No Event	<0.0005	No Event	<0.0005	No Event
Nickel	mg/l	0.08	0.1	No Event	<0.020	No Event	No Event	<0.020	No Event	No Event	No Event	<0.020	No Event	<0.020	No Event
Antimony	mg/l	0.0048	0.006	No Event	0.0005	No Event	No Event	0.0005	No Event	No Event	No Event	0.0007	No Event	0.0006	No Event
Selenium	mg/l	0.04	0.05	No Event	<0.0020	No Event	No Event	<0.0020	No Event	No Event	No Event	<0.0020	No Event	<0.0020	No Event
Mercury	mg/l	0.0016	0.002	No Event	<0.0002	No Event	No Event	<0.0002	No Event	No Event	No Event	<0.0002	No Event	<0.0002	No Event
Volatile Organic Compounds (VOCs)															
para-Dichlorobenzene	mg/l	0.06	0.075	No Event	No Event	No Event	<0.00032	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Dichloromethane	mg/l	0.004	0.005	No Event	No Event	No Event	<0.004	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
o-Dichlorobenzene	mg/l	0.48	0.6	No Event	No Event	No Event	<0.00047	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Carbon tetrachloride	mg/l	0.004	0.005	No Event	No Event	No Event	<0.004	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Toluene	mg/l	0.8	1	No Event	No Event	No Event	<0.004	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Benzene	mg/l	0.004	0.005	No Event	No Event	No Event	<0.004	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Monochlorobenzene	mg/l	0.08	0.1	No Event	No Event	No Event	<0.004	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Ethylbenzene	mg/l	0.56	0.7	No Event	No Event	No Event	<0.004	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Tetrachloroethylene	mg/l	0.004	0.005	No Event	No Event	No Event	<0.004	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
1,1-Dichloroethylene	mg/l	0.0056	0.007	No Event	No Event	No Event	<0.004	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
1,1,1-Trichloroethane	mg/l	0.16	0.2	No Event	No Event	No Event	<0.004	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
1,1,2-Trichloroethane	mg/l	0.004	0.005	No Event	No Event	No Event	<0.004	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
1,2-Dichloroethane	mg/l	0.004	0.005	No Event	No Event	No Event	<0.004	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
1,2-Dichloropropane	mg/l	0.004	0.005	No Event	No Event	No Event	<0.004	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
1,2,4-Trichlorobenzene	mg/l	0.056	0.07	No Event	No Event	No Event	<0.00053	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Vinyl Chloride	mg/l	0.0016	0.002	No Event	No Event	No Event	<0.0010	No Event	No Event	No Event	No Event	No Event	<0.0005	No Event	No Event
Trichloroethylene	mg/l	0.004	0.005	No Event	No Event	No Event	<0.004	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Hexachlorobenzene	mg/l	0.0008	0.001	No Event	No Event	No Event	<0.0003	No Event	No Event	No Event	No Event	No Event	<0.01	No Event	No Event
cis-1,2-Dichloroethylene	mg/l	0.05	0.07	No Event	No Event	No Event	<0.004	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Styrene	mg/l	0.08	0.1	No Event	No Event	No Event	<0.004	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Xylenes (Total)	mg/l	8	10	No Event	No Event	No Event	<0.012	No Event	No Event	No Event	No Event	No Event	<0.006	No Event	No Event
Trihalomethane (TTHM)	mg/l	0.08	0.1	No Event	No Event	No Event	<0.004	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
trans-1,2-Dichloroethylene	mg/l	0.08	0.1	No Event	No Event	No Event	<0.004	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Hexachlorocyclopentadiene	mg/l	0.04	0.05	No Event	No Event	No Event	<0.00052	No Event	No Event	No Event	No Event	No Event	<0.01	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 2019

Constituent	Unit	Alert Level	Aquifer Quality Limit	Sample Date & Results											
				Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19
Nutrients															
Total Nitrogen[1]	mg/l	8	10	No Event	1.10	1.68	1.49	1.44	1.60	1.61	1.58	1.54	1.41	1.45	1.34
Nitrate-Nitrite as N	mg/l	8	10	No Event	1.10	1.68	1.49	1.44	1.60	1.61	1.58	1.54	1.41	1.45	1.34
Total Kjeldahl Nitrogen (TKN)	mg/l	N/A	N/A	No Event	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Total Coliform (P-Present, A-Absent)	P/A	A	A	No Event	A	A	A	A	A	A	A	A	A	A	A
Metals (Total)															
Free Cyanide	mg/l	0.16	0.2	No Event	<0.010	No Event	No Event	<0.010	No Event	No Event	No Event	<0.010	No Event	<0.010	No Event
Total Fluoride	mg/l	3.2	4	No Event	0.31	No Event	No Event	0.31	No Event	No Event	No Event	0.28	No Event	0.33	No Event
Arsenic	mg/l	0.04	0.05	No Event	<0.0050	No Event	No Event	<0.0010	No Event	No Event	No Event	<0.0010	No Event	<0.0010	No Event
Barium	mg/l	1.6	2	No Event	0.065	No Event	No Event	0.083	No Event	No Event	No Event	0.083	No Event	0.073	No Event
Beryllium	mg/l	0.0032	0.004	No Event	<0.0020	No Event	No Event	<0.0020	No Event	No Event	No Event	<0.0020	No Event	<0.0020	No Event
Cadmium	mg/l	0.004	0.005	No Event	<0.0005	No Event	No Event	<0.0001	No Event	No Event	No Event	<0.0001	No Event	<0.0001	No Event
Chromium	mg/l	0.08	0.1	No Event	<0.0050	No Event	No Event	<0.0050	No Event	No Event	No Event	<0.0050	No Event	<0.0050	No Event
Lead	mg/l	0.04	0.05	No Event	<0.0050	No Event	No Event	<0.0010	No Event	No Event	No Event	<0.0010	No Event	<0.0010	No Event
Thallium	mg/l	0.0016	0.002	No Event	<0.0025	No Event	No Event	<0.0005	No Event	No Event	No Event	<0.0005	No Event	<0.0005	No Event
Nickel	mg/l	0.08	0.1	No Event	<0.020	No Event	No Event	<0.020	No Event	No Event	No Event	<0.020	No Event	<0.020	No Event
Antimony	mg/l	0.0048	0.006	No Event	<0.0025	No Event	No Event	<0.0005	No Event	No Event	No Event	<0.0005	No Event	<0.0005	No Event
Selenium	mg/l	0.04	0.05	No Event	<0.010	No Event	No Event	<0.0020	No Event	No Event	No Event	<0.0020	No Event	<0.0020	No Event
Mercury	mg/l	0.0016	0.002	No Event	<0.0002	No Event	No Event	<0.0002	No Event	No Event	No Event	<0.0002	No Event	<0.0002	No Event
Volatile Organic Compounds (VOCs)															
para-Dichlorobenzene	mg/l	0.06	0.075	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Dichloromethane	mg/l	0.004	0.005	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
o-Dichlorobenzene	mg/l	0.48	0.6	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Carbon tetrachloride	mg/l	0.004	0.005	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Toluene	mg/l	0.8	1	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Benzene	mg/l	0.004	0.005	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Monochlorobenzene	mg/l	0.08	0.1	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Ethylbenzene	mg/l	0.56	0.7	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Tetrachloroethylene	mg/l	0.004	0.005	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
1,1-Dichloroethylene	mg/l	0.0056	0.007	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
1,1,1-Trichloroethane	mg/l	0.16	0.2	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
1,1,2-Trichloroethane	mg/l	0.004	0.005	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
1,2-Dichloroethane	mg/l	0.004	0.005	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
1,2-Dichloropropane	mg/l	0.004	0.005	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
1,2,4-Trichlorobenzene	mg/l	0.056	0.07	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Vinyl Chloride	mg/l	0.0016	0.002	No Event	No Event	No Event	<0.0005	No Event	No Event	No Event	No Event	No Event	<0.0005	No Event	No Event
Trichloroethylene	mg/l	0.004	0.005	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Hexachlorobenzene	mg/l	0.0008	0.001	No Event	No Event	No Event	<0.0003	No Event	No Event	No Event	No Event	No Event	<0.01	No Event	No Event
cis-1,2-Dichloroethylene	mg/l	0.05	0.07	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Styrene	mg/l	0.08	0.1	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Xylenes (Total)	mg/l	8	10	No Event	No Event	No Event	<0.006	No Event	No Event	No Event	No Event	No Event	<0.0006	No Event	No Event
Trihalomethane (TTHM)	mg/l	0.08	0.1	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
trans-1,2-Dichloroethylene	mg/l	0.08	0.1	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Hexachlorocyclopentadiene	mg/l	0.04	0.05	No Event	No Event	No Event	<0.00052	No Event	No Event	No Event	No Event	No Event	<0.01	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 2019

Date	Problem	Solution
January 7, 2019	No flow in the oxbow channel – diversion berm washed out in the evening of January 6.	Diversion berm was repaired after storm flows settled and building materials were dry enough - deliveries were restarted on January 18
January 29, 2019	Pump within compliance well continues to be inoperable, thus affecting water sample collection.	Pump and discharge pipes were replaced and well was operable by February 20, 2019.
February 20, 2019	No flow in oxbow channel – diversion berm washed out in the evening of February 15.	Berm was repaired by March 25 and recharge operations were restarted on March 26.
July 14, 2019	No flow in the oxbow channel – diversion berm washed out in the afternoon of July 13.	Diversion berm was repaired after storm flows settled and building materials were dry enough - deliveries were restarted on August 14.
September 23, 2019	No flow in the oxbow channel – diversion berm washed out in the afternoon of September 22.	Diversion berm was repaired after storm flows settled and building materials were dry enough - deliveries were restarted on November 4.
October 1, 2019	Water level in Recharge Cell 2 is not reducing by very much over time below the 30% full mark.	Maintenance of the cell bottom was conducted to help increase infiltration; maintenance was also conducted in Recharge Cells 1 and 3 to help maintain higher infiltration rates.
November 20, 2019	No flow in the oxbow channel – diversion berm washed out in the afternoon of November 19.	Diversion berm was repaired after storm flows settled and building materials were dry enough - deliveries were restarted on December 17.

APPENDIX A

Daily Flow Volumes &
Water Quantity Summary

USF DAILY FLOWMETER READINGS AND VOLUMES

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0008

Meter ID: Fm-eq

Year: 2019

	January		February		March		April		May		June	
	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons
	149044900		149044900		149044900		149044900		49273300		50103600	
Day 1	149044900	0	149044900	0	149044900	0	149044900	0	49273300	0	**51179200**	1075600
2	149044900	0	149044900	0	149044900	0	149044900	0	49273300	0	52093000	913800
3	149044900	0	149044900	0	149044900	0	149044900	0	49273300	0	53114900	1021900
4	149044900	0	149044900	0	149044900	0	149044900	0	49273300	0	54117800	1002900
5	149044900	0	149044900	0	149044900	0	149044900	0	49273300	0	54996700	878900
6	149044900	0	149044900	0	149044900	0	149044900	0	49273300	0	55820500	823800
7	149044900	0	149044900	0	149044900	0	149044900	0	49273300	0	56775300	954800
8	149044900	0	149044900	0	149044900	0	149044900	0	49273300	0	57768400	993100
9	149044900	0	149044900	0	149044900	0	149044900	0	49273300	0	58862100	1093700
10	149044900	0	149044900	0	149044900	0	149044900	0	49273300	0	59994500	1132400
11	149044900	0	149044900	0	149044900	0	149044900	0	49273300	0	61060800	1066300
12	149044900	0	149044900	0	149044900	0	149044900	0	49273300	0	62159400	1098600
13	149044900	0	149044900	0	149044900	0	149044900	0	49273300	0	63226500	1067100
14	149044900	0	149044900	0	149044900	0	149044900	0	49273300	0	64172300	945800
15	149044900	0	149044900	0	149044900	0	149044900	0	49273300	0	65350700	1178400
16	149044900	0	149044900	0	149044900	0	149044900	0	49273300	0	66490900	1140200
17	149044900	0	149044900	0	149044900	0	149273300	228400	49273300	0	67696400	1205500
18	149044900	0	149044900	0	149044900	0	149273300	0	49273300	0	68824100	1127700
19	149044900	0	149044900	0	149044900	0	149273300	0	49273300	0	69711200	887100
20	149044900	0	149044900	0	149044900	0	149273300	0	49441100	167800	71059800	1348600
21	149044900	0	149044900	0	149044900	0	149273300	0	49441100	0	71936700	876900
22	149044900	0	149044900	0	149044900	0	149273300	0	49441100	0	73077400	1140700
23	149044900	0	149044900	0	149044900	0	149273300	0	49441100	0	74218100	1140700
24	149044900	0	149044900	0	149044900	0	149273300	0	49441100	0	75318200	1100100
25	149044900	0	149044900	0	149044900	0	149273300	0	49441100	0	76421400	1103200
26	149044900	0	149044900	0	149044900	0	149273300	0	49441100	0	77526300	1104900
27	149044900	0	149044900	0	149044900	0	149273300	0	49441100	0	78596400	1070100
28	149044900	0	149044900	0	149044900	0	149273300	0	49441100	0	79661500	1065100
29	149044900	0			149044900	0	149273300	0	49529800	88700	80325400	663900
30	149044900	0			149044900	0	149273300	0	49529800	0	80999300	673900
31	149044900	0			149044900	0			50103600	573800		
	Total (gal)	**0**	**Total (gal)**	**0**	**Total (gal)**	**0**	**Total (gal)**	**228400**	**Total (gal)**	**830300**	**Total (gal)**	**30895700**
	Total (ac-ft)	**0.00**	**Total (ac-ft)**	**0.00**	**Total (ac-ft)**	**0.00**	**Total (ac-ft)**	**0.70**	**Total (ac-ft)**	**2.55**	**Total (ac-ft)**	**94.82**

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

2nd Qtr Total (gal) =	**31954400**
2nd Qtr Total (ac-ft) =	**98.06**

USF DAILY FLOWMETER READINGS AND VOLUMES

Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Meter ID: Fm-eq
Year: 2019

	July		August		September		October		November		December	
	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons
	80999300		94012800		111892500		134390100		134390100		150360200	
Day 1	82117400	1118100	94012800	0	112922700	1030200	134390100	0	134390100	0	150360200	0
2	83256000	1138600	94012800	0	113956600	1033900	134390100	0	134390100	0	150360200	0
3	84395600	1139600	94012800	0	114869600	913000	134390100	0	134390100	0	150360200	0
4	85595500	1199900	94012800	0	115875700	1006100	134390100	0	135090300	700200	150360200	0
5	86719400	1123900	94012800	0	117082700	1207000	134390100	0	136030000	939700	150360200	0
6	87624400	905000	94012800	0	118110600	1027900	134390100	0	137460800	1430800	150360200	0
7	88586700	962300	94012800	0	119189600	1079000	134390100	0	138566400	1105600	150360200	0
8	89503300	916600	94012800	0	120226900	1037300	134390100	0	139635800	1069400	150360200	0
9	90478100	974800	94012800	0	121747100	1520200	134390100	0	140659700	1023900	150360200	0
10	91452100	974000	94012800	0	122717400	970300	134390100	0	141675200	1015500	150360200	0
11	92442500	990400	94012800	0	123334900	617500	134390100	0	142692300	1017100	150360200	0
12	93351800	909300	94012800	0	124360200	1025300	134390100	0	143661800	969500	150360200	0
13	94012800	661000	94012800	0	125416500	1056300	134390100	0	144647500	985700	150360200	0
14	94012800	0	94801200	788400	126496300	1079800	134390100	0	145667000	1019500	150360200	0
15	94012800	0	95850000	1048800	127546000	1049700	134390100	0	146678000	1011000	150360200	0
16	94012800	0	96788800	938800	128584800	1038800	134390100	0	147716000	1038000	150360200	0
17	94012800	0	97778700	989900	129613500	1028700	134390100	0	148691500	975500	151047600	687400
18	94012800	0	98769100	990400	130631800	1018300	134390100	0	149642400	950900	152315500	1267900
19	94012800	0	99850100	1081000	131631100	999300	134390100	0	150360200	717800	153517100	1201600
20	94012800	0	100703300	853200	132620100	989000	134390100	0	150360200	0	154794000	1276900
21	94012800	0	101790300	1087000	133609100	989000	134390100	0	150360200	0	155797500	1003500
22	94012800	0	102829800	1039500	134390100	781000	134390100	0	150360200	0	156769300	971800
23	94012800	0	103945700	1115900	134390100	0	134390100	0	150360200	0	157705900	936600
24	94012800	0	104974700	1029000	134390100	0	134390100	0	150360200	0	158784900	1079000
25	94012800	0	106004900	1030200	134390100	0	134390100	0	150360200	0	159645600	860700
26	94012800	0	106821000	816100	134390100	0	134390100	0	150360200	0	160527100	881500
27	94012800	0	107829300	1008300	134390100	0	134390100	0	150360200	0	161383000	855900
28	94012800	0	108843500	1014200	134390100	0	134390100	0	150360200	0	162423600	1040600
29	94012800	0	109732900	889400	134390100	0	134390100	0	150360200	0	163412300	988700
30	94012800	0	110870500	1137600	134390100	0	134390100	0	150360200	0	164401400	989100
31	94012800	0	111892500	1022000			134390100	0			165491400	1090000
	Total (gal)	**13013500**	**Total (gal)**	**17879700**	**Total (gal)**	**22497600**	**Total (gal)**	**0**	**Total (gal)**	**15970100**	**Total (gal)**	**15131200**
	Total (ac-ft)	**39.94**	**Total (ac-ft)**	**54.87**	**Total (ac-ft)**	**69.04**	**Total (ac-ft)**	**0.00**	**Total (ac-ft)**	**49.01**	**Total (ac-ft)**	**46.44**

3rd Qtr Total (gal) =	**53390800**
3rd Qtr Total (ac-ft) =	**163.85**

4th Qtr Total (gal) =	**31101300**
4th Qtr Total (ac-ft) =	**95.45**
Annual Total Del. Vol for FM-eq (ac-ft) =	**357.36**

USF DAILY FLOWMETER READINGS AND VOLUMES

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0008

Meter ID: Fm-C2

Year: 2019

	January		February		March		April		May		June	
	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons
	0		16527000		0		8238000		36337000		0	
Day 1	0	0	17705500	1178500	0	0	10119000	1881000	36829000	492000	**0**	0
2	48000	48000	18713900	1008400	0	0	11601000	1482000	37362000	533000	0	0
3	170000	122000	19712900	999000	0	0	13255000	1654000	37845000	483000	0	0
4	298000	128000	20246900	534000	0	0	14915000	1660000	38246000	401000	0	0
5	462000	164000	20747200	500300	0	0	16462000	1547000	38748000	502000	0	0
6	923000	461000	21021200	274000	0	0	17748000	1286000	39340000	592000	0	0
7	923000	0	21099400	78200	0	0	18898000	1150000	39809000	469000	0	0
8	923000	0	21212400	113000	0	0	19809000	911000	40300000	491000	0	0
9	923000	0	21360000	147600	0	0	21021000	1212000	40769000	469000	0	0
10	923000	0	21792000	432000	0	0	22125000	1104000	41242000	473000	0	0
11	923000	0	22435000	643000	0	0	23124000	999000	41697000	455000	0	0
12	923000	0	23793000	1358000	0	0	24088000	964000	42336000	639000	0	0
13	923000	0	25306000	1513000	0	0	24981000	893000	42860000	524000	0	0
14	923000	0	26860000	1554000	0	0	25833000	852000	43341000	481000	0	0
15	923000	0	27825000	965000	0	0	26775000	942000	43881000	540000	0	0
16	923000	0	27825000	0	0	0	27622000	847000	44397000	516000	0	0
17	923000	0	27825000	0	0	0	28325000	703000	44738000	341000	0	0
18	1267000	344000	27825000	0	0	0	29061000	736000	45178000	440000	0	0
19	1267000	0	27825000	0	0	0	29695000	634000	45624000	446000	0	0
20	1572000	305000	27825000	0	0	0	30398000	703000	46023000	399000	0	0
21	2055000	483000	27825000	0	0	0	31134000	736000	46542000	519000	0	0
22	3070000	1015000	27825000	0	0	0	31865000	731000	47149000	607000	0	0
23	4416000	1346000	27825000	0	0	0	32520000	655000	47708000	559000	0	0
24	5629000	1213000	27825000	0	0	0	33157000	637000	48258000	550000	0	0
25	6898000	1269000	27825000	0	0	0	33713000	556000	48802000	544000	0	0
26	8098000	1200000	27825000	0	42000	42000	34274000	561000	49344000	542000	0	0
27	9275000	1177000	27825000	0	721000	679000	34720000	446000	49870000	526000	0	0
28	10583000	1308000	27825000	0	2630000	1909000	35212000	492000	50539000	669000	0	0
29	11904000	1321000			4638000	2008000	35824000	612000	51067000	528000	0	0
30	12909000	1005000			6462000	1824000	36337000	513000	51608000	541000	0	0
31	14333000	1424000			8238000	1776000			51948000	340000		
	Total (gal)	**14333000**	**Total (gal)**	**11298000**	**Total (gal)**	**8238000**	**Total (gal)**	**28099000**	**Total (gal)**	**15611000**	**Total (gal)**	**0**
	Total (ac-ft)	**43.99**	**Total (ac-ft)**	**34.67**	**Total (ac-ft)**	**25.28**	**Total (ac-ft)**	**86.23**	**Total (ac-ft)**	**47.91**	**Total (ac-ft)**	**0.00**

1st Qtr Total (gal) =	**33869000**
1st Qtr Total (ac-ft) =	**103.94**

2nd Qtr Total (gal) =	**43710000**
2nd Qtr Total (ac-ft) =	**134.14**

USF DAILY FLOWMETER READINGS AND VOLUMES

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0008

Meter ID: Fm-C2

Year: 2019

	July		August		September		October		November		December	
	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons
	0		0		0		0		0		0	
Day 1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0			0	0			0	0
	Total (gal)	**0**	**Total (gal)**	**0**	**Total (gal)**	**0**	**Total (gal)**	**0**	**Total (gal)**	**0**	**Total (gal)**	**0**
	Total (ac-ft)	**0.00**	**Total (ac-ft)**	**0.00**	**Total (ac-ft)**	**0.00**	**Total (ac-ft)**	**0.00**	**Total (ac-ft)**	**0.00**	**Total (ac-ft)**	**0.00**

3rd Qtr Total (gal) =	**0**
3rd Qtr Total (ac-ft) =	**0.00**
4th Qtr Total (gal) =	**0**
4th Qtr Total (ac-ft) =	**0.00**
Annual Total Del. Vol for FM-eq (ac-ft) =	**238.08**

USF WATER QUANTITY REPORTING SUMMARY
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2019

	FM-eq Delivered Volumes (ac-ft)	FM-C2 Delivered Volumes (ac-ft)	Evaporation Losses (ac-ft)	Evapotranspiration Losses (ac-ft)	Net Recharge Volumes (ac-ft)	Quarterly Net Recharge Totals (ac-ft)
January	0.0	44.0	0.1	0.0	43.9	
February	0.0	34.7	0.2	0.0	34.5	
March	0.0	25.3	0.2	0.0	25.1	103.5
April	0.7	86.2	1.0	0.1	85.9	
May	2.5	47.9	1.4	0.4	48.7	
June	94.8	0.0	1.2	0.6	93.0	227.6
July	39.9	0.0	0.7	0.4	38.9	
August	54.9	0.0	0.6	0.1	54.2	
September	69.0	0.0	0.7	0.4	68.0	161.0
October	0.0	0.0	0.1	0.0	-0.1	
November	49.0	0.0	0.2	0.1	48.8	
December	46.4	0.0	0.1	0.0	46.3	95.0
Annual Totals =	**357.4**	**238.1**	**6.2**	**2.1**	**587.1**	

APPENDIX B

Evaporation Calculations & Cooley Method Description

USF EVAPORATION CALCULATIONS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2019

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	0	0.0	0	0.0	0	0.0	1	0.0	0	0.0	10	0.3
Cell 1	0	0.0	0	0.0	0	0.0	0	0.0	1	0.0	2	0.1
Cell 2	7	0.1	13	0.2	11	0.2	35	0.8	38	1.0	21	0.6
Cell 3	0	0.0	0	0.0	0	0.0	8	0.2	10	0.3	7	0.2
Cell 4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	7	**0.1**	**13**	**0.2**	**11**	**0.2**	**44**	**1.0**	**49**	**1.4**	**40**	**1.2**

1st Quarter Total Evap (AF) **=**	**0.4**
2nd Quarter Total Evap (AF) **=**	**3.5**

Cooley Adj. Fac	**0.95**

USF EVAPORATION CALCULATIONS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2019

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	6	0.2	6	0.2	8	0.2	0	0.0	7	0.1	5	0.0
Cell 1	1	0.0	0	0.0	1	0.0	0	0.0	0	0.0	1	0.0
Cell 2	13	0.4	9	0.2	7	0.2	6	0.1	2	0.0	1	0.0
Cell 3	4	0.1	6	0.2	14	0.3	0	0.0	3	0.0	3	0.0
Cell 4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	23	**0.7**	**21**	**0.6**	**29**	**0.7**	**6**	**0.1**	**12**	**0.2**	**10**	**0.1**

3rd Quarter Total Evap (AF) **=**	**1.9**

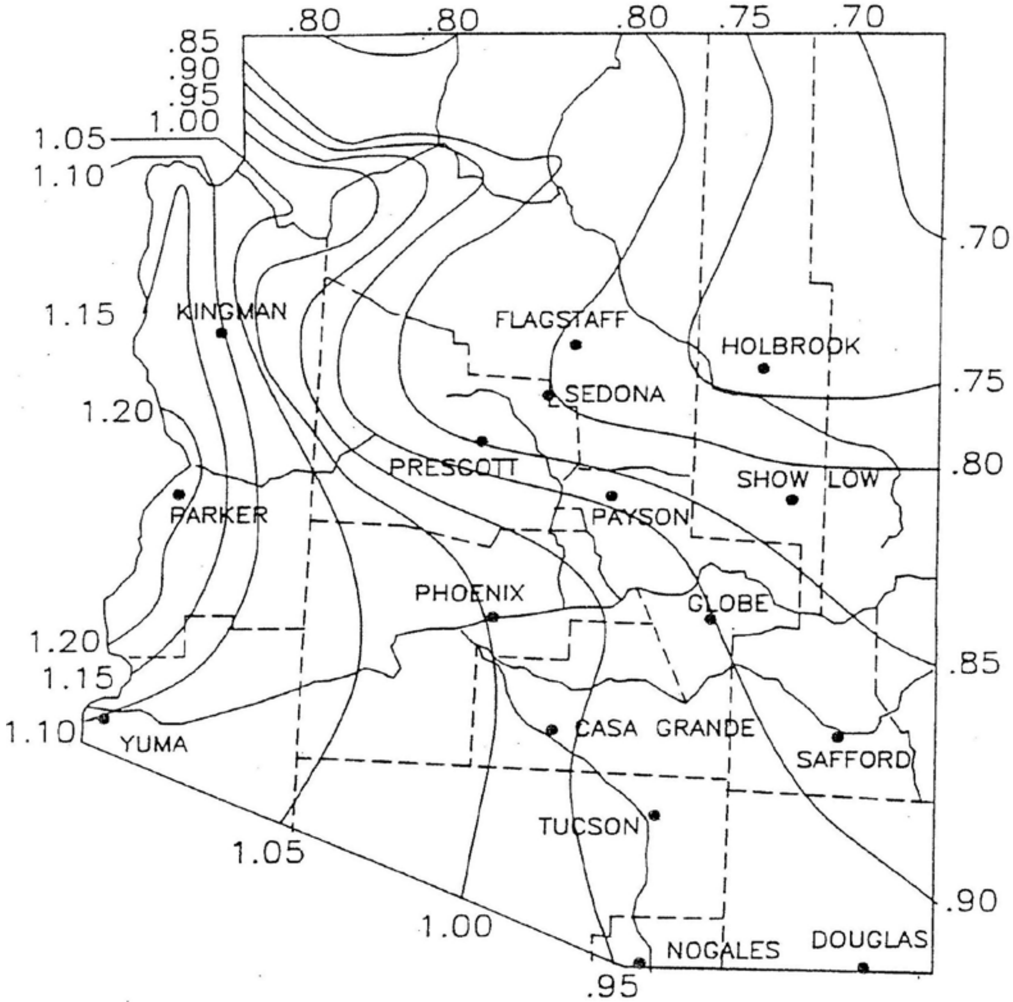
4th Quarter Total Evap (AF) **=**	**0.3**
Annual Total Evap (AF) **=**	**6.2**

COOLEY EVAPORATION INFORMATION

Cooley Monthly Maximum Evaporation Rates
from Cooley, 1970

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

Cooley Evaporation Adjustment Factors for Arizona
from Cooley, 1970



ARIZONA DEPARTMENT OF WATER RESOURCES
HYDROLOGY DIVISION

TECHNICAL BULLETIN

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

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

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

Justification for Using the Maximum Curve of the Cooley Method

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

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

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

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

EVAPORATION FROM OPEN WATER SURFACES IN ARIZONA

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

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

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

How to Estimate Evaporation

Estimation of evaporation consists of three steps.

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

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

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

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

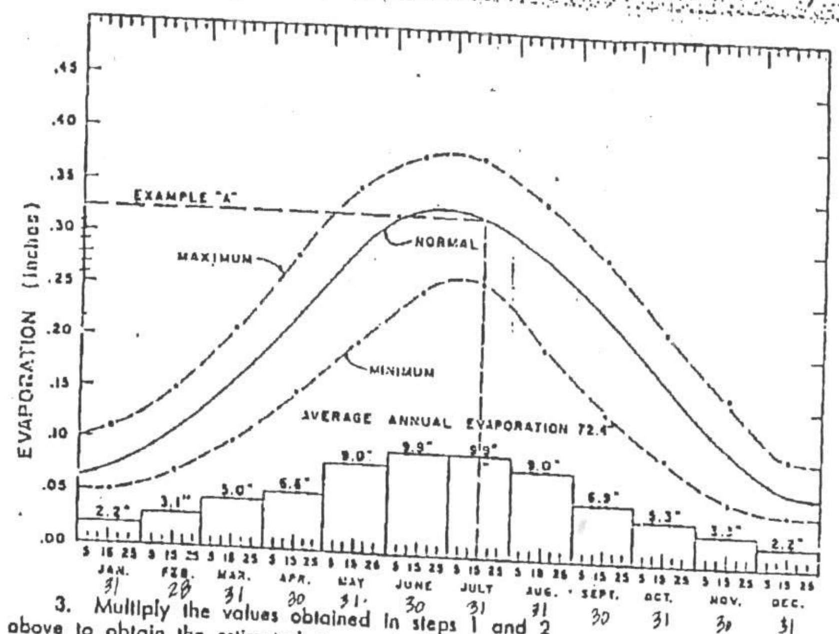


FIGURE 1. Maximum, Normal, and Minimum Daily Evaporation and Average Monthly Evaporation From Open Water Surfaces (Adjustment Factor = 1.00).

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

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

Examples:

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

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

(See over)

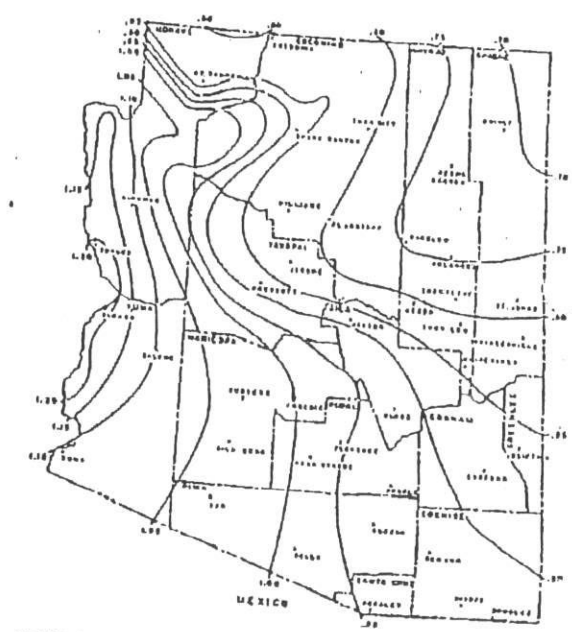


FIGURE 2. Evaporation Adjustment Factors for Arizona

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

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

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

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

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

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

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

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

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

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

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

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

Acknowledgement

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

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

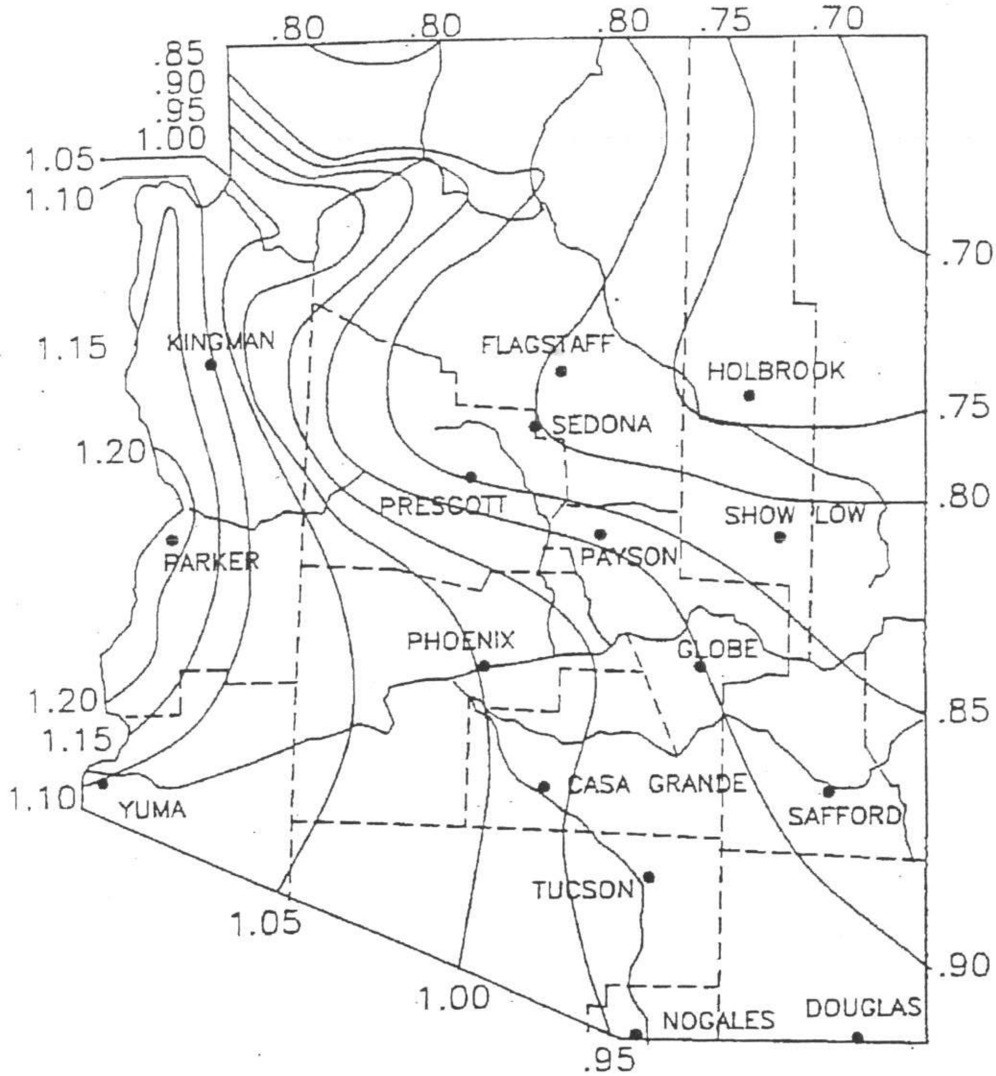
EVAPORATION FROM OPEN WATER SURFACES IN ARIZONA

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



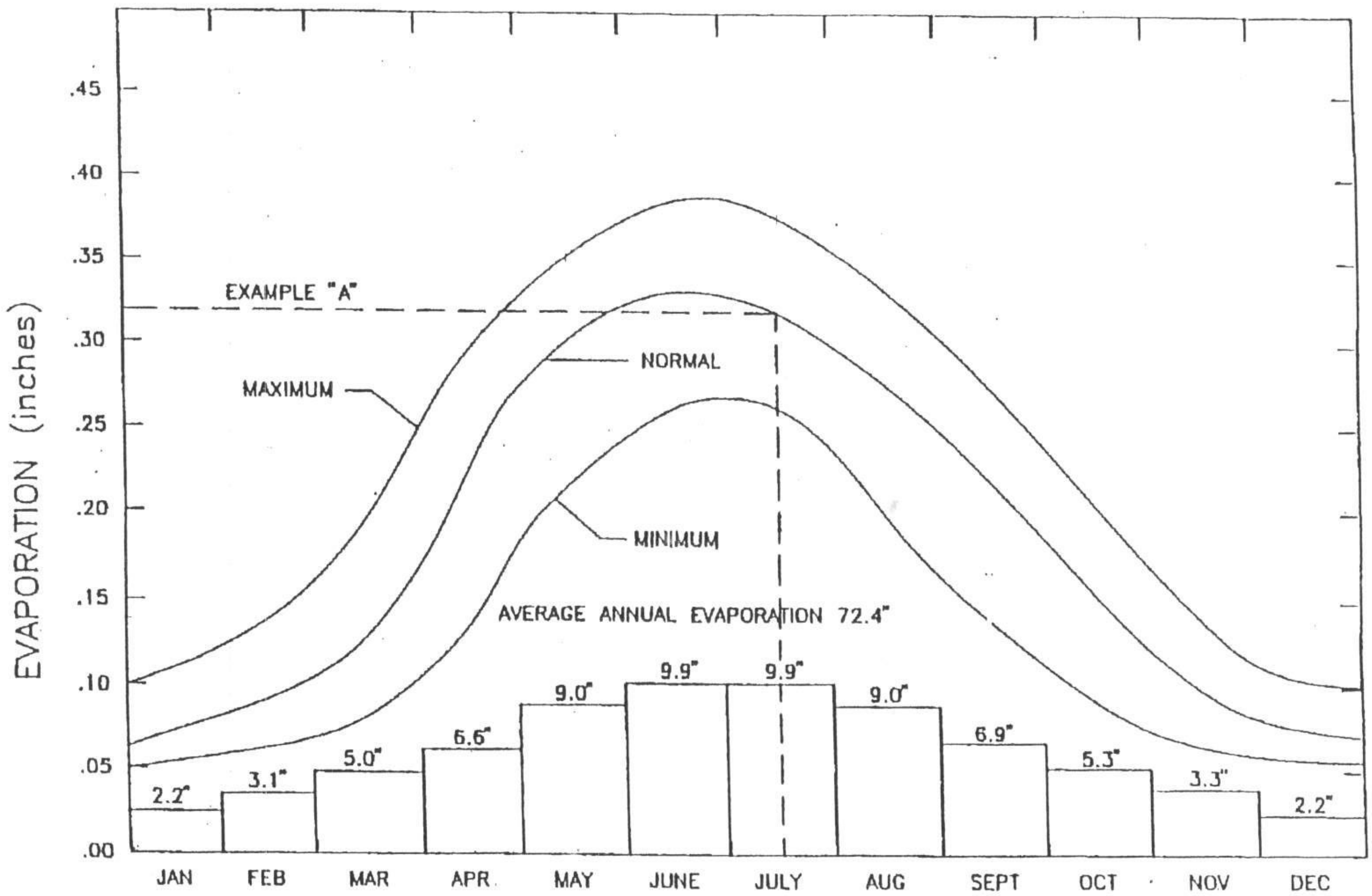


FIGURE 9. MAXIMUM, NORMAL AND MINIMUM DAILY EVAPORATION AND AVERAGE MONTHLY EVAPORATION FROM OPEN WATER SURFACES (Adjustment Factor = 1.00)

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

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

From: Cooley, 1970

APPENDIX C

Daily Wetted Acreages

USF DAILY WETTED ACREAGES
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2019

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	0	0.0605	0	0
2	0	0	0.0605	0	0
3	0	0	0.0968	0	0
4	0	0	0.0968	0	0
5	0	0	0.1815	0	0
6	0	0	0.1996	0	0
7	0	0	0.2178	0	0
8	0	0	0.1452	0	0
9	0	0	0.0968	0	0
10	0	0	0.0605	0	0
11	0	0	0.0605	0	0
12	0	0	0.0605	0	0
13	0	0	0.0605	0	0
14	0	0	0.0605	0	0
15	0	0	0.0605	0	0
16	0	0	0.0605	0	0
17	0	0	0.0605	0	0
18	0	0	0.121	0	0
19	0	0	0.1815	0	0
20	0	0	0.121	0	0
21	0	0	0.3025	0	0
22	0	0	0.4235	0	0
23	0	0	0.4356	0	0
24	0	0	0.4477	0	0
25	0	0	0.4598	0	0
26	0	0	0.4719	0	0
27	0	0	0.484	0	0
28	0	0	0.4961	0	0
29	0	0	0.5082	0	0
30	0	0	0.5566	0	0
31	0	0	0.605	0	0
Total Wetted Acres	**0**	**0**	**7.2539**	**0**	**0**

February

Date	Equal. Basin Wetted Area (acres)*	Recharge Cell 1 Wetted Area (acres)*	Recharge Cell 2 Wetted Area (acres)*	Recharge Cell 3 Wetted Area (acres)*	Recharge Cell 4 Wetted Area (acres)*
1	0	0	0.484	0	0
2	0	0	0.4598	0	0
3	0	0	0.5022	0	0
4	0	0	0.5445	0	0
5	0	0	0.363	0	0
6	0	0	0.3025	0	0
7	0	0	0.363	0	0
8	0	0	0.4235	0	0
9	0	0	0.363	0	0
10	0	0	0.363	0	0
11	0	0	0.4235	0	0
12	0	0	0.4538	0	0
13	0	0	0.484	0	0
14	0	0	0.5445	0	0
15	0	0	0.5445	0	0
16	0	0	0.605	0.0078	0
17	0	0	0.5445	0	0
18	0	0	0.484	0	0
19	0	0	0.484	0	0
20	0	0	0.484	0	0
21	0	0	0.4719	0	0
22	0	0	0.4598	0	0
23	0	0	0.4477	0	0
24	0	0	0.4356	0	0
25	0	0	0.4235	0	0
26	0	0	0.4235	0	0
27	0	0	0.4235	0	0
28	0	0	0.4235	0	0
29					
Total Wetted Acres	**0**	**0**	**12.7293**	**0.0078**	**0**

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

USF DAILY WETTED ACREAGES
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2019

March

Date	Equal. Basin Wetted Area (acres)*	Recharge Cell 1 Wetted Area (acres)*	Recharge Cell 2 Wetted Area (acres)*	Recharge Cell 3 Wetted Area (acres)*	Recharge Cell 4 Wetted Area (acres)*
1	0	0	0.4114	0	0
2	0	0	0.4114	0	0
3	0	0	0.3993	0	0
4	0	0	0.3993	0	0
5	0	0	0.3872	0	0
6	0	0	0.3872	0	0
7	0	0	0.3751	0	0
8	0	0	0.3751	0	0
9	0	0	0.363	0	0
10	0	0	0.363	0	0
11	0	0	0.3509	0	0
12	0	0	0.3388	0	0
13	0	0	0.3267	0	0
14	0	0	0.3146	0	0
15	0	0	0.3025	0	0
16	0	0	0.2904	0	0
17	0	0	0.2783	0	0
18	0	0	0.2662	0	0
19	0	0	0.2541	0	0
20	0	0	0.242	0	0
21	0	0	0.2299	0	0
22	0	0	0.2178	0	0
23	0	0	0.2057	0	0
24	0	0	0.1936	0	0
25	0	0	0.1815	0	0
26	0	0	0.1815	0	0
27	0	0	0.5445	0	0
28	0	0	0.5566	0	0
29	0	0	0.5687	0	0
30	0	0	0.5808	0	0
31	0	0	0.5929	0	0
Total Wetted Acres	**0**	**0**	**10.89**	**0**	**0**

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	0	0.605	0	0
2	0	0	0.605	0.0078	0
3	0	0	1.0648	0.0156	0
4	0	0	1.21	0.0398	0
5	0	0	1.21	0.078	0
6	0	0	1.21	0.117	0
7	0	0	1.21	0.156	0
8	0	0	1.21	0.1716	0
9	0	0	1.21	0.195	0
10	0	0	1.21	0.2306	0
11	0	0	1.21	0.2662	0
12	0	0	1.21	0.2843	0
13	0	0	1.21	0.3025	0
14	0	0	1.21	0.312	0
15	0	0	1.21	0.312	0
16	0	0	1.21	0.39	0
17	0.31	0	1.21	0.39	0
18	0.248	0	1.21	0.39	0
19	0	0	1.21	0.39	0
20	0	0	1.21	0.39	0
21	0	0	1.21	0.39	0
22	0	0	1.21	0.39	0
23	0	0	1.21	0.39	0
24	0	0	1.21	0.39	0
25	0	0	1.21	0.39	0
26	0	0	1.21	0.39	0
27	0	0	1.21	0.39	0
28	0	0	1.21	0.39	0
29	0	0	1.21	0.39	0
30	0	0	1.21	0.39	0
Total Wetted Acres	**0.558**	**0**	**34.9448**	**8.3384**	**0**

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

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Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2019

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	0	1.21	0.39	0
2	0	0	1.21	0.39	0
3	0	0	1.21	0.39	0
4	0	0	1.21	0.39	0
5	0	0	1.21	0.39	0
6	0	0	1.21	0.39	0
7	0	0	1.21	0.39	0
8	0	0	1.21	0.39	0
9	0	0	1.21	0.39	0
10	0	0	1.21	0.39	0
11	0	0	1.21	0.39	0
12	0	0	1.21	0.39	0
13	0	0	1.21	0.39	0
14	0	0	1.21	0.39	0
15	0	0	1.21	0.39	0
16	0	0	1.21	0.39	0
17	0	0	1.21	0.39	0
18	0	0	1.21	0.39	0
19	0	0	1.21	0.39	0
20	0.31	0.0063	1.21	0.39	0
21	0.155	0.0126	1.21	0.351	0
22	0	0.0315	1.21	0.312	0
23	0	0.0472	1.21	0.273	0
24	0	0.063	1.21	0.234	0
25	0	0.0788	1.21	0.195	0
26	0	0.0945	1.21	0.156	0
27	0	0.1102	1.21	0.117	0
28	0	0.126	1.21	0.078	0
29	0	0.126	1.21	0.039	0
30	0	0.126	1.21	0.039	0
31	0	0.126	1.21	0.039	0
Total Wetted Acres	**0.465**	**0.9481**	**37.51**	**9.633**	**0**

June

Date	Equal. Basin Wetted Area (acres)*	Recharge Cell 1 Wetted Area (acres)*	Recharge Cell 2 Wetted Area (acres)*	Recharge Cell 3 Wetted Area (acres)*	Recharge Cell 4 Wetted Area (acres)*
1	0.341	0.063	1.21	0.234	0
2	0.341	0.063	1.1737	0.234	0
3	0.341	0.063	1.1737	0.234	0
4	0.341	0.063	1.1374	0.234	0
5	0.341	0.063	1.1132	0.234	0
6	0.341	0.063	1.089	0.234	0
7	0.341	0.063	1.0648	0.234	0
8	0.341	0.063	1.0285	0.234	0
9	0.341	0.063	0.605	0.234	0
10	0.341	0.063	0.605	0.234	0
11	0.341	0.063	0.605	0.2418	0
12	0.341	0.063	0.5929	0.2418	0
13	0.341	0.063	0.5929	0.2418	0
14	0.341	0.063	0.5808	0.2418	0
15	0.341	0.063	0.5808	0.2496	0
16	0.341	0.063	0.5687	0.2496	0
17	0.341	0.063	0.5687	0.2496	0
18	0.341	0.063	0.5566	0.2496	0
19	0.341	0.063	0.5566	0.2574	0
20	0.341	0.063	0.5445	0.2574	0
21	0.341	0.063	0.5445	0.2574	0
22	0.341	0.063	0.5324	0.2574	0
23	0.341	0.063	0.5324	0.234	0
24	0.341	0.063	0.5203	0.234	0
25	0.341	0.063	0.5203	0.234	0
26	0.341	0.063	0.5082	0.234	0
27	0.341	0.063	0.5082	0.2262	0
28	0.341	0.063	0.4961	0.2262	0
29	0.341	0.063	0.4961	0.2262	0
30	0.341	0.063	0.484	0.234	0
Total Wetted Acres	**10.23**	**1.89**	**21.0903**	**7.1838**	**0**

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

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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	0.3410	0.0630	0.4840	0.2340	0.0000
2	0.3410	0.0630	0.4840	0.2340	0.0000
3	0.3410	0.0630	0.4840	0.2340	0.0000
4	0.3410	0.0630	0.4719	0.2340	0.0000
5	0.3410	0.0630	0.4719	0.2340	0.0000
6	0.3410	0.0630	0.4598	0.2340	0.0000
7	0.3410	0.0630	0.4598	0.2340	0.0000
8	0.3410	0.0630	0.4477	0.2340	0.0000
9	0.3410	0.0630	0.4477	0.2340	0.0000
10	0.3410	0.0630	0.4235	0.2340	0.0000
11	0.3410	0.0630	0.4235	0.2340	0.0000
12	0.3410	0.0630	0.4114	0.2340	0.0000
13	0.3410	0.0630	0.4114	0.2340	0.0000
14	0.3410	0.0472	0.3993	0.2340	0.0000
15	0.3100	0.0315	0.3993	0.2340	0.0000
16	0.2480	0.0315	0.3872	0.2340	0.0000
17	0.1240	0.0000	0.3872	0.1170	0.0000
18	0.0620	0.0000	0.3751	0.0390	0.0000
19	0.0000	0.0000	0.3751	0.0390	0.0000
20	0.0000	0.0000	0.3630	0.0078	0.0000
21	0.0000	0.0000	0.3630	0.0000	0.0000
22	0.0000	0.0000	0.3630	0.0000	0.0000
23	0.0000	0.0000	0.3630	0.0000	0.0000
24	0.0000	0.0000	0.3630	0.0000	0.0000
25	0.0000	0.0000	0.3630	0.0000	0.0000
26	0.0000	0.0000	0.3630	0.0000	0.0000
27	0.0000	0.0000	0.3630	0.0000	0.0000
28	0.0000	0.0000	0.3630	0.0000	0.0000
29	0.0000	0.0000	0.3630	0.0000	0.0000
30	0.0000	0.0000	0.3630	0.0000	0.0000
31	0.0000	0.0000	0.3630	0.0000	0.0000
Total Wetted Acres	**5.518**	**0.9292**	**12.5598**	**3.9468**	**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	0.363	0.39	0
2	0	0	0.363	0.39	0
3	0	0	0.363	0.39	0
4	0	0	0.363	0.312	0
5	0	0	0.363	0.312	0
6	0	0	0.363	0.312	0
7	0	0	0.363	0.2836	0
8	0	0	0.363	0.234	0
9	0	0	0.363	0.195	0
10	0	0	0.363	0.1014	0
11	0	0	0.363	0.078	0
12	0	0	0.363	0.0702	0
13	0	0	0.363	0.0624	0
14	0.31	0	0.242	0	0
15	0.341	0.0063	0.242	0.0312	0
16	0.341	0.0063	0.242	0.039	0
17	0.341	0.0063	0.242	0.0546	0
18	0.341	0.0126	0.242	0.0741	0
19	0.341	0.0252	0.242	0.0936	0
20	0.341	0.0252	0.242	0.0936	0
21	0.341	0.0252	0.242	0.117	0
22	0.341	0.0252	0.242	0.1326	0
23	0.341	0.0252	0.242	0.1716	0
24	0.341	0.0252	0.242	0.195	0
25	0.341	0.0252	0.242	0.2145	0
26	0.341	0.0252	0.242	0.234	0
27	0.341	0.0252	0.242	0.234	0
28	0.341	0.0315	0.242	0.234	0
29	0.341	0.0315	0.242	0.234	0
30	0.341	0.0315	0.242	0.273	0
31	0.341	0.0315	0.242	0.273	0
Total Wetted Acres	**6.107**	**0.3843**	**9.075**	**5.8294**	**0**

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

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Year: 2019

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	0.341	0.0378	0.2178	0.2964	0
2	0.341	0.0378	0.2178	0.2964	0
3	0.341	0.0378	0.2178	0.3276	0
4	0.341	0.0378	0.2178	0.351	0
5	0.341	0.0378	0.2178	0.3744	0
6	0.341	0.0378	0.2178	0.3744	0
7	0.341	0.0378	0.2178	0.3744	0
8	0.341	0.0441	0.2178	0.39	0
9	0.341	0.0441	0.2178	0.39	0
10	0.341	0.0441	0.2178	0.39	0
11	0.341	0.0441	0.2178	0.39	0
12	0.341	0.0441	0.2178	0.663	0
13	0.341	0.0567	0.2178	0.663	0
14	0.341	0.0567	0.2178	0.663	0
15	0.341	0.0567	0.2178	0.663	0
16	0.341	0.0567	0.2178	0.663	0
17	0.341	0.0567	0.2178	0.6006	0
18	0.341	0.063	0.2178	0.6006	0
19	0.341	0.063	0.2178	0.6006	0
20	0.341	0.063	0.2178	0.6006	0
21	0.341	0.063	0.2178	0.6006	0
22	0.3224	0.063	0.2178	0.6006	0
23	0.31	0.0126	0.2178	0.6006	0
24	0	0	0.2178	0.663	0
25	0	0	0.2178	0.39	0
26	0	0	0.2178	0.39	0
27	0	0	0.2178	0.312	0
28	0	0	0.2178	0.234	0
29	0	0	0.2178	0.156	0
30	0	0	0.2178	0.117	0
Total Wetted Acres	**7.7934**	**1.0962**	**6.534**	**13.7358**	**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	0	0.2178	0.078	0
2	0	0	0.2178	0.039	0
3	0	0	0.2178	0.0156	0
4	0	0	0.2178	0.0078	0
5	0	0	0.2178	0	0
6	0	0	0.2178	0	0
7	0	0	0.2178	0	0
8	0	0	0.2178	0	0
9	0	0	0.2178	0	0
10	0	0	0.2178	0	0
11	0	0	0.2178	0	0
12	0	0	0.2178	0	0
13	0	0	0.2178	0	0
14	0	0	0.2178	0	0
15	0	0	0.2178	0	0
16	0	0	0.2178	0	0
17	0	0	0.2178	0	0
18	0	0	0.2178	0	0
19	0	0	0.2178	0	0
20	0	0	0.2178	0	0
21	0	0	0.2178	0	0
22	0	0	0.2178	0	0
23	0	0	0.2178	0	0
24	0	0	0.2178	0	0
25	0	0	0.121	0	0
26	0	0	0.121	0	0
27	0	0	0.0605	0	0
28	0	0	0.0605	0	0
29	0	0	0.0605	0	0
30	0	0	0.0605	0	0
31	0	0	0.0605	0	0
Total Wetted Acres	**0**	**0**	**5.7717**	**0.1404**	**0**

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

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Year: 2019

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	0	0.0605	0	0
2	0	0	0.0605	0	0
3	0	0	0.0605	0	0
4	0.31	0.0063	0.0605	0.0156	0
5	0.341	0.0126	0.0605	0.039	0
6	0.341	0.0126	0.0605	0.0624	0
7	0.341	0.0126	0.0605	0.0936	0
8	0.341	0.0189	0.0605	0.117	0
9	0.341	0.0189	0.0605	0.1404	0
10	0.341	0.0189	0.0605	0.1647	0
11	0.341	0.0189	0.0605	0.189	0
12	0.341	0.0252	0.0605	0.189	0
13	0.341	0.0252	0.0605	0.189	0
14	0.341	0.0252	0.0605	0.273	0
15	0.341	0.0252	0.0605	0.273	0
16	0.341	0.0315	0.0605	0.273	0
17	0.341	0.0315	0.0605	0.312	0
18	0.341	0.0315	0.0605	0.312	0
19	0.3224	0.0099	0.0605	0.195	0
20	0.31	0.0063	0.0605	0.039	0
21	0.31	0	0.0605	0.0156	0
22	0.31	0	0.0605	0.0078	0
23	0.248	0	0.0605	0	0
24	0.217	0	0.0605	0	0
25	0.186	0	0.0605	0	0
26	0.155	0	0.0605	0	0
27	0.124	0	0.0605	0	0
28	0.093	0	0.0605	0	0
29	0.062	0	0.0605	0	0
30	0.031	0	0.0605	0	0
Total Wetted Acres	**7.4524**	**0.3312**	**1.815**	**2.9001**	**0**

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	0	0.0605	0	0
2	0	0	0.0605	0	0
3	0	0	0.0605	0	0
4	0	0	0.0605	0	0
5	0	0	0.0605	0	0
6	0	0	0.0605	0	0
7	0	0	0.0605	0	0
8	0	0	0.0605	0	0
9	0	0	0.0605	0	0
10	0	0	0.0605	0	0
11	0	0	0.0605	0	0
12	0	0	0.0484	0	0
13	0	0	0.0484	0	0
14	0	0	0.0484	0	0
15	0	0	0.0484	0	0
16	0	0	0.0363	0	0
17	0.3224	0.0158	0.0363	0.0585	0
18	0.341	0.0315	0.0363	0.117	0
19	0.341	0.0315	0.0363	0.1404	0
20	0.341	0.0315	0.0363	0.156	0
21	0.341	0.0315	0.0363	0.195	0
22	0.341	0.0315	0.0363	0.2145	0
23	0.341	0.063	0.0363	0.234	0
24	0.341	0.063	0.0363	0.234	0
25	0.341	0.063	0.0363	0.234	0
26	0.341	0.063	0.0363	0.234	0
27	0.341	0.0945	0.0363	0.234	0
28	0.341	0.0945	0.0363	0.234	0
29	0.341	0.0945	0.0363	0.234	0
30	0.341	0.0945	0.0363	0.234	0
31	0.341	0.0945	0.0363	0.234	0
Total Wetted Acres	**5.0964**	**0.8978**	**1.4399**	**2.9874**	**0**

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

APPENDIX D

Evapotranspiration Calculations & AZMET Method Description

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2019

	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	0.07	0	0	0.12	0	**0**	0.15	0
2	0	0.03	0	0	0.1	0	**0**	0.19	0
3	0	0.07	0	0	0.02	0	**0**	0.2	0
4	0	0.09	0	0	0.06	0	**0**	0.2	0
5	0	0.07	0	0	0.08	0	**0**	0.19	0
6	0	0.01	0	0	0.08	0	**0**	0.18	0
7	0	0.08	0	0	0.11	0	**0**	0.18	0
8	0	0.09	0	0	0.13	0	**0**	0.14	0
9	0	0.04	0	0	0.06	0	**0**	0.21	0
10	0	0.02	0	0	0.09	0	**0**	0.09	0
11	0	0.09	0	0	0.13	0	**0**	0.15	0
12	0	0.11	0	0	0.14	0	**0**	0.18	0
13	0	0.05	0	0	0.09	0	**0**	0.2	0
14	0	0.06	0	0	0.04	0	**0**	0.18	0
15	0	0.04	0	0	0.08	0	**0**	0.19	0
16	0	0.08	0	0	0.13	0	**0**	0.2	0
17	0	0.1	0	0	0.11	0	**0**	0.21	0
18	0	0.11	0	0	0.05	0	**0**	0.15	0
19	0	0.11	0	0	0.11	0	**0**	0.2	0
20	0	0.12	0	0	0.12	0	**0**	0.22	0
21	0	0.14	0	0	0.04	0	**0**	0.22	0
22	0	0.12	0	0	0	0	**0**	0.23	0
23	0	0.11	0	0	0.11	0	**0**	0.26	0
24	0	0.11	0	0	0.13	0	**0**	0.13	0
25	0	0.13	0	0	0.14	0	**0**	0.21	0
26	0	0.12	0	0	0.16	0	**0**	0.22	0
27	0	0.13	0	0	0.12	0	**0**	0.22	0
28	0	0.11	0	0	0.17	0	**0**	0.25	0
29	0	0.09	0			0	0	0.26	0
30	0	0.11	0				**0**	0.27	0
31	0	0.11	0				**0**	0.25	0
Monthly Evapo-transpiration			**0**			**0**			**0**

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2019

Date	April			May			June		
	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)
1	0	0.24	0	0.2532	0.29	0.006119	0.6192	0.35	0.01806
2	0	0.28	0	0.2658	0.25	0.0055375	0.6192	0.33	0.017028
3	0	0.26	0	0.2784	0.3	0.00696	0.6318	0.35	0.0184275
4	0	0.22	0	0.291	0.31	0.0075175	0.6318	0.34	0.017901
5	0	0.22	0	0.3099	0.31	0.00800575	0.6444	0.35	0.018795
6	0	0.23	0	0.3288	0.26	0.007124	0.6444	0.35	0.018795
7	0	0.27	0	0.3414	0.24	0.006828	0.657	0.34	0.018615
8	0	0.28	0	0.354	0.26	0.00767	0.657	0.36	0.01971
9	0	0.3	0	0.3792	0.22	0.006952	0.6696	0.31	0.017298
10	0	0.33	0	0.3846	0.24	0.007692	0.6822	0.33	0.0187605
11	0	0.26	0	0.3899	0.27	0.00877275	0.6822	0.35	0.0198975
12	0	0.14	0	0.417	0.17	0.0059075	0.6948	0.36	0.020844
13	0	0.24	0	0.4296	0.26	0.009308	0.7026	0.37	0.0216635
14	0	0.25	0	0.4422	0.27	0.0099495	0.7026	0.41	0.0240055
15	0	0.27	0	0.4674	0.31	0.0120745	0.7026	0.36	0.021078
16	0.039	0.19	0.0006175	0.48	0.3	0.012	0.7026	0.35	0.0204925
17	0.039	0.22	0.000715	0.4989	0.31	0.01288825	0.723	0.35	0.0210875
18	0.0516	0.26	0.001118	0.5178	0.28	0.012082	0.723	0.36	0.02169
19	0.0642	0.3	0.001605	0.5304	0.17	0.007514	0.723	0.35	0.0210875
20	0.102	0.34	0.00289	0.543	0.21	0.0095025	0.723	0.37	0.0222925
21	0.1902	0.31	0.0049135	0.582	0.3	0.01455	0.7434	0.39	0.0241605
22	0.228	0.26	0.00494	0.621	0.33	0.0170775	0.7434	0.38	0.023541
23	0.2532	0.23	0.004853	0.66	0.25	0.01375	0.759	0.35	0.0221375
24	0.2721	0.27	0.00612225	0.699	0.31	0.0180575	0.7668	0.35	0.022365
25	0.291	0.29	0.0070325	0.738	0.32	0.01968	0.7872	0.36	0.023616
26	0.2721	0.32	0.007256	0.777	0.35	0.0226625	0.795	0.35	0.0231875
27	0.2532	0.32	0.006752	0.816	0.33	0.02244	0.8028	0.36	0.024084
28	0.228	0.31	0.00589	0.855	0.27	0.0192375	0.8106	0.33	0.0222915
29	0.2343	0.18	0.0035145	1.049	0.32	0.027973333	0.8232	0.32	0.021952
30	0.2406	0.27	0.0054135	1.049	0.32	0.027973333	0.8232	0.37	0.025382
31				1.049	0.33	0.0288475			
Monthly Evapo-transpiration			**0.06363275**			**0.402653917**			**0.6302455**

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2019

	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	0.8232	0.37	0.025382	0.189	0.28	0.00441	0.516	0.25	0.01075
2	0.8232	0.37	0.025382	0	0.2	0	0.5664	0.24	0.011328
3	0.8232	0.38	0.026068	0	0.24	0	0.6042	0.27	0.0135945
4	0.8232	0.37	0.025382	0	0.31	0	0.6042	0.29	0.0146015
5	0.8232	0.34	0.023324	0	0.3	0	0.6042	0.26	0.013091
6	0.8232	0.24	0.016464	0	0.24	0	0.6042	0.26	0.013091
7	0.8232	0.27	0.018522	0	0.31	0	0.6042	0.27	0.0135945
8	0.8232	0.37	0.025382	0	0.25	0	0.6432	0.24	0.012864
9	0.8232	0.35	0.02401	0	0.19	0	0.6432	0.23	0.012328
10	0.8232	0.37	0.025382	0	0.09	0	0.6432	0.23	0.012328
11	0.8232	0.38	0.026068	0	0.25	0	0.8952	0.21	0.015666
12	0.8232	0.25	0.01715	0	0.29	0	0.9342	0.27	0.0210195
13	0.8232	0.29	0.019894	0	0.33	0	0.9342	0.25	0.0194625
14	0.8232	0.35	0.02401	0	0.31	0	0.9342	0.28	0.021798
15	0.7860	0.29	0.018995	0.1002	0.33	0.0027555	0.9342	0.21	0.0163485
16	0.7860	0.28	0.01834	0.1002	0.32	0.002672	0.9342	0.14	0.010899
17	0.3930	0.26	0.008515	0.1254	0.29	0.0030305	0.9576	0.23	0.018354
18	0.1650	0.31	0.0042625	0.1569	0.29	0.00379175	0.9576	0.24	0.019152
19	0.0630	0.35	0.0018375	0.1884	0.31	0.004867	0.9576	0.25	0.01995
20	0.0000	0.37	0	0.1884	0.32	0.005024	0.9576	0.27	0.021546
21	0.0000	0.36	0	0.2262	0.33	0.0062205	0.9576	0.22	0.017556
22	0.0000	0.25	0	0.2514	0.31	0.0064945	0.9204	0.22	0.016874
23	0.0000	0.2	0	0.3144	0.29	0.007598	0.9204	0.19	0.014573
24	0.0000	0.27	0	0.3522	0.27	0.0079245	0.708	0.07	0.00413
25	0.0000	0.28	0	0.3837	0.29	0.00927275	0.669	0.13	0.0072475
26	0.0000	0.34	0	0.4152	0.31	0.010726	0.504	0.19	0.00798
27	0.0000	0.33	0	0.4152	0.3	0.01038	0.504	0.16	0.00672
28	0.0000	0.35	0	0.4152	0.25	0.00865	0.441	0.2	0.00735
29	0.0000	0.29	0	0.4152	0.28	0.009688	0.252	0.23	0.00483
30	0.0000	0.26	0	0.4782	0.26	0.010361	0.189	0.23	0.0036225
31	0.0000	0.18	0	0.4782	0.29	0.0115565			
Monthly Evapo-transpiration			**0.37437**			**0.1254225**			**0.402649**

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2019

Date	October			November			December		
	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	0.126	0.22	0.00231	0	0.17	0	0	0.09	0
2	0.063	0.2	0.00105	0	0.16	0	0	0.09	0
3	0.0252	0.2	0.00042	0	0.15	0	0	0.07	0
4	0.0126	0.2	0.00021	0.126	0.16	0.00168	0	0.11	0
5	0	0.21	0	0.2892	0.15	0.003615	0	0.1	0
6	0	0.22	0	0.3522	0.13	0.0038155	0	0.08	0
7	0	0.22	0	0.4152	0.13	0.004498	0	0.07	0
8	0	0.22	0	0.4404	0.11	0.004037	0	0.02	0
9	0	0.22	0	0.4782	0.12	0.004782	0	0.01	0
10	0	0.24	0	0.4782	0.11	0.0043835	0	0.08	0
11	0	0.19	0	0.4782	0.1	0.003985	0	0.07	0
12	0	0.21	0	0.4782	0.17	0.0067745	0	0.08	0
13	0	0.2	0	0.4782	0.14	0.005579	0	0.09	0
14	0	0.18	0	0.4782	0.13	0.0051805	0	0.1	0
15	0	0.19	0	0.4782	0.11	0.0043835	0	0.11	0
16	0	0.25	0	0.4782	0.14	0.005579	0	0.09	0
17	0	0.22	0	0.5412	0.13	0.005863	0.1575	0.15	0.00196875
18	0	0.19	0	0.5412	0.15	0.006765	0.3522	0.18	0.005283
19	0	0.19	0	0.315	0.04	0.00105	0.4152	0.11	0.003806
20	0	0.21	0	0	0.05	0	0.4404	0.1	0.00367
21	0	0.2	0	0.126	0.04	0.00042	0.516	0.1	0.0043
22	0	0.19	0	0.063	0.09	0.0004725	0.5286	0.08	0.003524
23	0	0.19	0	0	0.08	0	0.5412	0.04	0.001804
24	0	0.22	0	0	0.09	0	0.5412	0.04	0.001804
25	0	0.29	0	0	0.06	0	0.5412	0.06	0.002706
26	0	0.19	0	0	0.11	0	0.5412	0.1	0.00451
27	0	0.23	0	0	0.04	0	0.5412	0.02	0.000902
28	0	0.2	0	0	0.06	0	0.5412	0.07	0.003157
29	0	0.19	0	0	0.03	0	0.5412	0.06	0.002706
30	0	0.14	0	0	0.08	0	0.5412	0.04	0.001804
31	0	0.18	0				0.5412	0.07	0.003157
Monthly Evapo-transpiration			**0.00399**			**0.072863**			**0.04510175**

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).

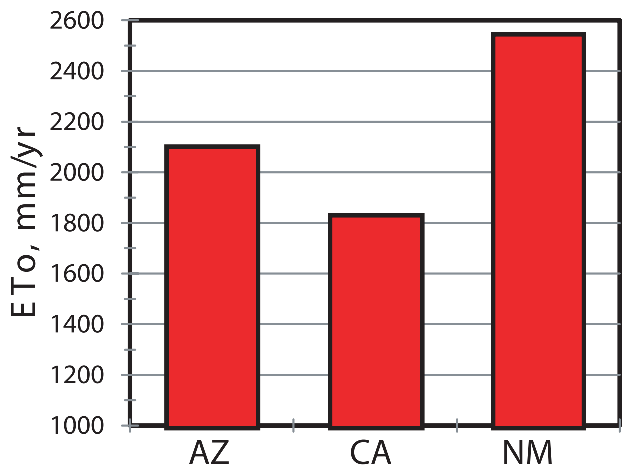

Figure 1. Reference ET (ETo) for Tucson for calendar year 1996 as computed using the published procedures for the public weather networks in Arizona, California, and New Mexico.

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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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 (ETo*a*) 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
ETo*a*	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

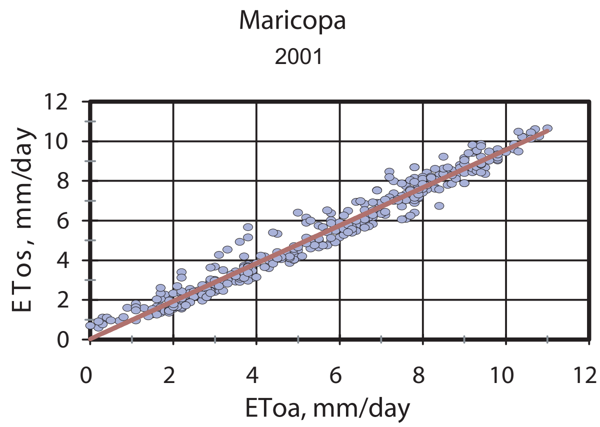

Figure 2. Reference evapotranspiration as computed using the ASCE standardized procedure (ETos) versus reference evapotranspiration computed using procedure employed by AZMET. The line represents the least squares regression line (ETos = 0.03 + 0.95 x EToa; r^2 = 0.96).

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 (^oC). All of the required meteorological data are collected by AZMET weather stations. Required non-meteorological data consist of elevation above sea level and latitude for the locations providing the meteorological data (AZMET weather station locations).

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

Comparison of Standardized Reference ET with Original AZMET ETo

A logical question for users of ETo data would be how does the new standardized procedure (ETos) compare with the original AZMET ETo (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 (ETоa) computation procedures. Monthly ratios of ETos to ETоa are provided in columns labeled “Ratio.”

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

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

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

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

Crop Coefficients and ETos

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

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

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

$$ETc = Kc * ETоa$$

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

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

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

$$ETc = Kc * ETos$$

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

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

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

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

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

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

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

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

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

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

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

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

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Appendix

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

Δ: Slope of Saturation Vapor Pressure vs. Temperature Relationship

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

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

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

Rn: Net Radiation

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

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

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

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

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

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

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

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

The daily value of Rnl is computed using:

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

where Rnl is net long-wave radiation in $MJ\ m^{-2}\ d^{-1}$, σ is the Stefan-Boltzman constant [= $4.901 \times 10^{-9}\ MJ\ K^{-4}\ m^{-2}\ d^{-1}$], $T_K{}^4max$ 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 $^oC^{-1}$), 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 (^oC) 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

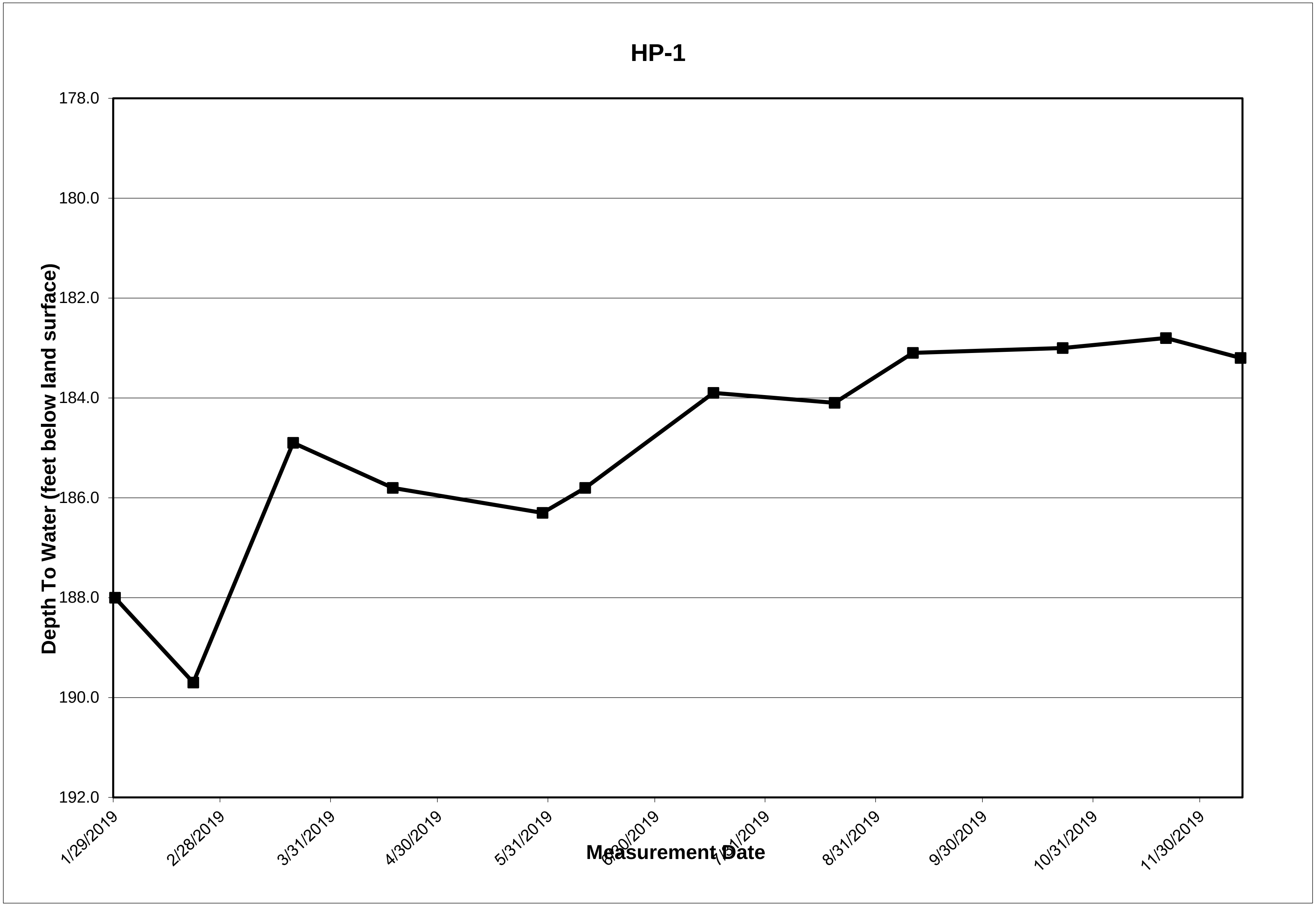
USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2019

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**
1/29/2019	188.0	188.0	1797.2	
2/20/2019	189.7	189.7	1795.5	
3/20/2019	184.9	184.9	1800.3	
4/17/2019	185.8	185.8	1799.4	
5/29/2019	186.3	186.3	1798.9	
6/10/2019	185.8	185.8	1799.4	
7/16/2019	183.9	183.9	1801.3	
8/19/2019	184.1	184.1	1801.1	
9/10/2019	183.1	183.1	1802.1	
10/22/2019	183.0	183.0	1802.2	
11/20/2019	182.8	182.8	1802.4	
12/11/2019	183.2	183.2	1802.0	

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

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

USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2019



USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2019

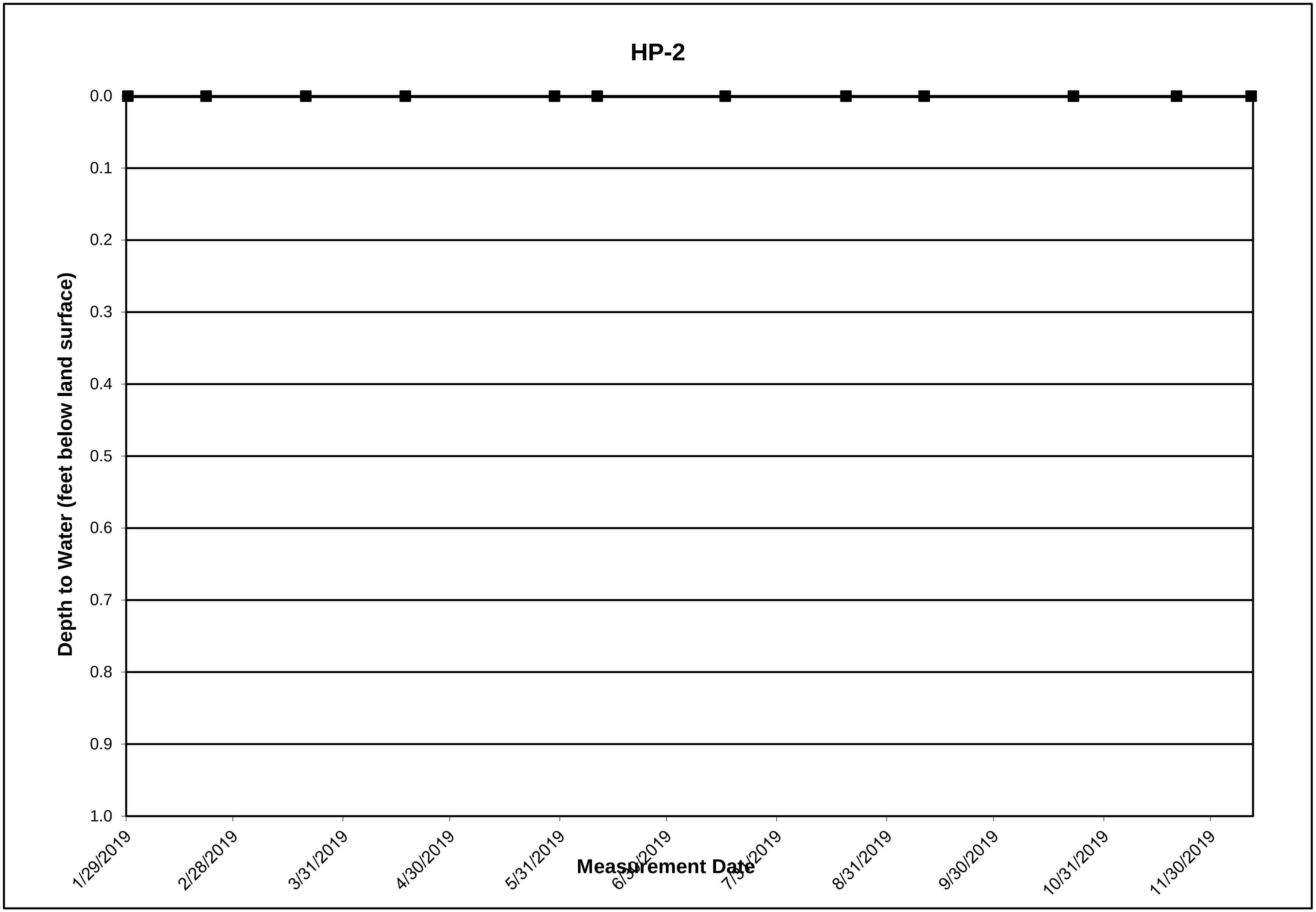
Monitor Point ID	HP-2
ADWR Registration Number	55-593607
Cadastral Location	D(11-11)33cad
Measuring Point Elevation (feet amsl)	1986.75
Measuring Point Description	top of port
Measuring Point Height (ft)	
Land Surface Elevation at Wellhead (feet amsl)	1986.75
Permit Alert Level (feet bls)	30
Permit OPL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

Measurement Date	DTW (feet below MP)	DTW (feet bls)	Elevation (feet amsl)	Exceedance Status
1/29/2019	dry			
2/20/2019	dry			
3/20/2019	dry			
4/17/2019	dry			
5/29/2019	dry			
6/10/2019	dry			
7/16/2019	dry			
8/19/2019	dry			
9/10/2019	dry			
10/22/2019	dry			
11/20/2019	dry			
12/11/2019	dry			

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

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

USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2019



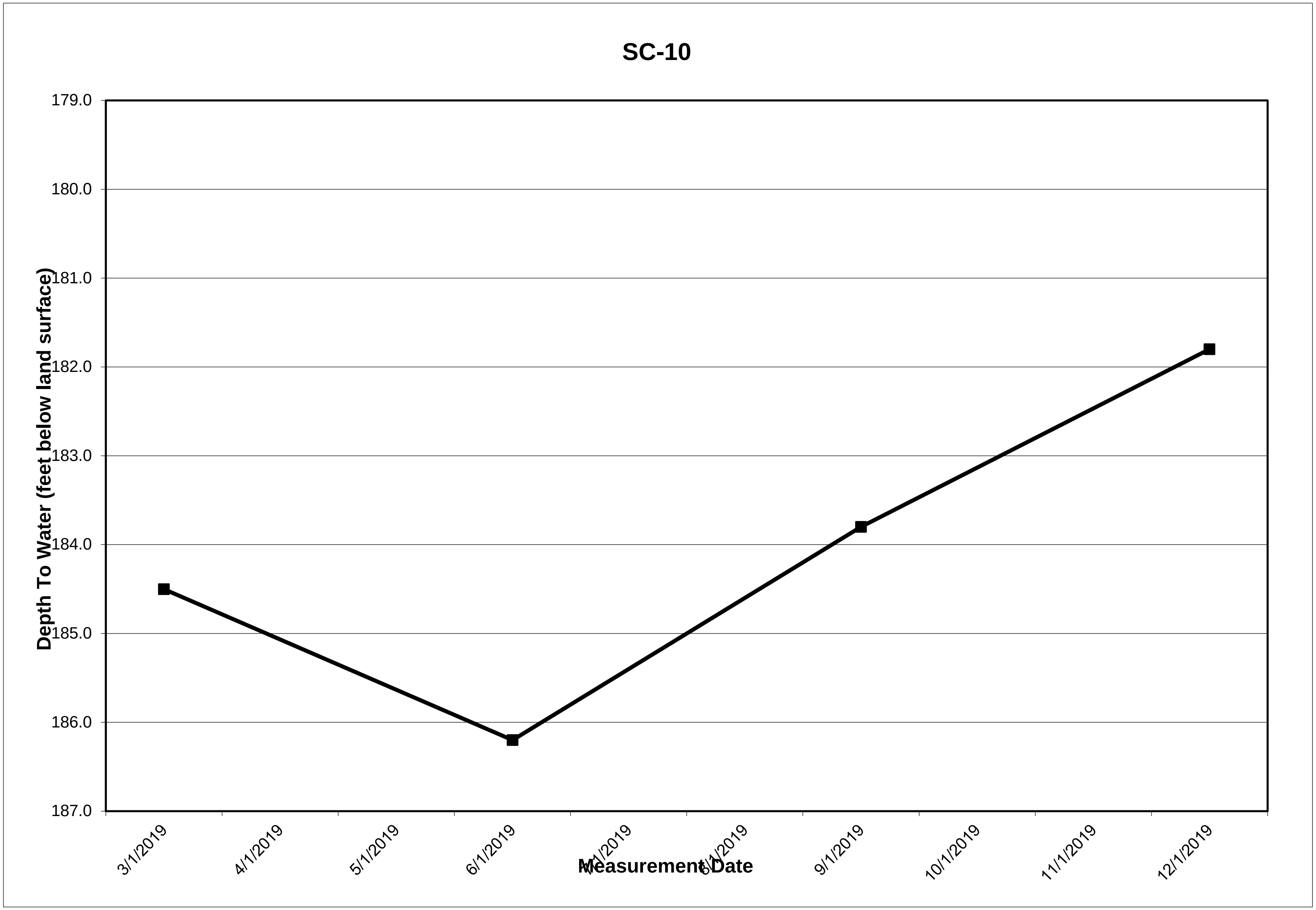
USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2019

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**
3/20/2019	184.5	184.5	1800.7	
6/10/2019	186.2	186.2	1799.0	
9/10/2019	183.8	183.8	1801.4	
12/11/2019	181.8	181.8	1803.4	

* 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. 71-563876.0008
Year: 2019



APPENDIX F

Infiltration Rate Data & Calculations

INFILTRATION RATE DATA AND CALCULATIONS

Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2019

	Net Recharge Volumes (ac-ft)	**Total Wetted Acreages** (ac-days)	**Infiltration Rate** (ft/day)	**Quarterly Average Infiltration Rate** (ft/day)
January	43.9	7.3	6.05	
February	34.5	12.7	2.71	
March	25.1	10.9	2.30	3.35
April	85.9	43.8	1.96	
May	48.7	48.6	1.00	
June	93.0	40.4	2.30	1.71
July	38.9	23.0	1.69	
August	54.2	21.4	2.53	
September	68.0	29.2	2.33	2.19
October	-0.1	5.9		
November	48.8	12.5	3.90	
December	46.3	10.4	4.44	3.29

Totals	**587.1**	**266.0**	**2.21**