ANNUAL MONITORING REPORT
2018

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 sixteenth annual report for MHPERP. This report includes all of the data that was collected during the 2018 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 2018 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 2018 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}). Upon review of documentation provided by PCRFCD, ADWR's Recharge Program determined that the facility could use the new delivery system (Monitor Point FM_{C2}) for storing water and recharge credit accrual on December 12, 2016.[1] The facility's operator reads daily totals on-site and then compiles the data onto a daily log sheet. The daily log sheets are transmitted to PCRFCD staff on a weekly basis.

Appendix A contains the daily flow meter readings and volumes for Calendar Year 2018; 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 2018 was 637.5 acre-feet (AF), with a high of 154.8 AF in March and a low of 0.0 AF from August through December, after the maximum of 600 acre-feet was surpassed. A total of 226.9 AF (35.6%) was delivered via the pumps into the equalization basin (FMeq) and 410.6 AF (64.4%) 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

[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 through the 2017 Calendar Year.

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

2.4 Recharge Volumes

The water quantity 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 2018 Calendar Year is 627.7 AF. This means that the maximum permitted amount of 600 AF was stored for the Pima County Regional Wastewater Reclamation Department, who has a Water Storage Permit (No. 73-563876.0200) for the facility.

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 2018, 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 2018 Calendar Year. Water levels in the on-site deep well (HP-1) fluctuated from 189.0 feet below land surface (bls) in January 2018 to a low of 193.8 feet bls in July 2018, and then up to 186.6 feet bls by December 2018. Water levels in the off-site monitor well (SC-10) dropped from 188.0 feet bls in March 2018 to 192.5 feet bls in September 2018, and then went up to 185.9 feet bls by December 2018.

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 2018 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 2018 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 2018, monthly infiltration rates for the project ranged from 0.00 feet per day in August through December (no water delivered) to 3.88 feet per day in March. The average infiltration rate for the year was 1.69 feet/day, which is just slightly above last year's rate of 1.63 feet/day. Infiltration rates were greater than one foot/day in every month that had consistent daily deliveries to the facility (July being the exception). The moderately high infiltration rates are primarily a product of the deepening of the basins (exposure to coarser materials) 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 2018 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 December 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 2018.

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 weekly basis to PCRFCD. PCRFCD staff is contacted immediately for any alarms or serious problems concerning the facility equipment. PCRFCD performs monthly investigations of the facility to insure quality of the data collected and to note any general maintenance needs.

Table 2 lists the problems that occurred during the 2018 Calendar Year and the actions performed to resolve them. A very brief disruption of effluent deliveries to the facility occurred in July, when storm water along the Santa Cruz River washed out the earthen diversion berm. The berm was quickly repaired and recharge resumed until the end of the month, when total deliveries exceeded 600 AF. Subsequent storm runoff events damaged the berm, but repairs were not made until the end of the year in preparation for recharge deliveries in 2019. The summer monsoon period (July through mid-September) is typically the major disruption of effluent deliveries to the facility every year. The facility was only down for a total of 4 days due to washouts of the berm and the activities to repair it. Note that the gravity-feed pipeline into Cell 2 was closed for 31 days from February to March to make minor repairs.

7.0 CONCLUSIONS

The calculated volume of water stored at MHPERP for Calendar Year 2018 was 627.7 AF. This is the fifth consecutive year that the facility has reached at least 600 AF. The facility operated under Phase 3 of the modified USF Permit No. 71-563876.0008 for the entire Calendar Year, which allowed the Pima County Regional Wastewater Reclamation District to store a maximum of 600 AF for the year.

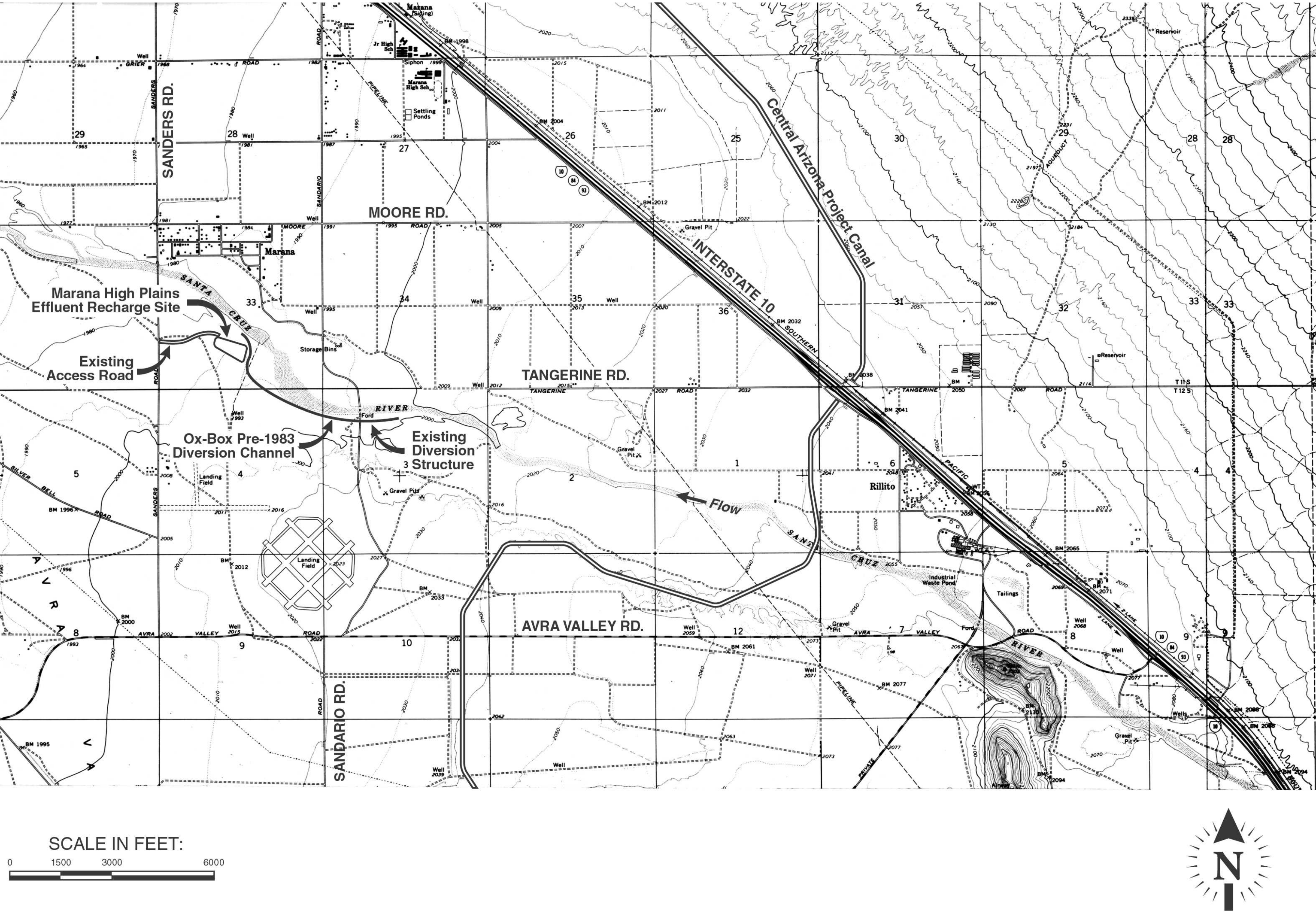
Monitoring of operations has showed no continuing exceedences of water quality standards (Drinking Water Standards) at the project site. On-site and off-site monitoring showed no negative impacts to surrounding operations from a water level perspective.

Infiltration at the facility was relatively good during 2018, maintaining monthly rates over one foot/day during normal operations. The average annual infiltration rate for the entire facility in 2018 was 1.69 feet/day, which is a good rate considering there were very few disruptions to effluent deliveries between the start of operations on January 1 and the end of operations on July 31. 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.

A total of only 4 days resulted in no effluent deliveries to the project during facility operations. All down time was due to washout of the diversion berm by a storm flow event in early July. Facility operations ended on July 31 due to the annual permitted amount of 600 AF being surpassed. This resulted in another 153 days of downtime at the end of the year to allow the basins to dry and for basin maintenance in preparation for Calendar Year 2019. Greater exposure of sands and gravels in Recharge Basins 1-3 and a better quality effluent (lower turbidity and nutrients) delivered by the upstream treatment facilities has made the facility much more efficient; and the goal of 600 AF of recharge per annum more attainable. The addition of the gravity-feed distribution system into 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.

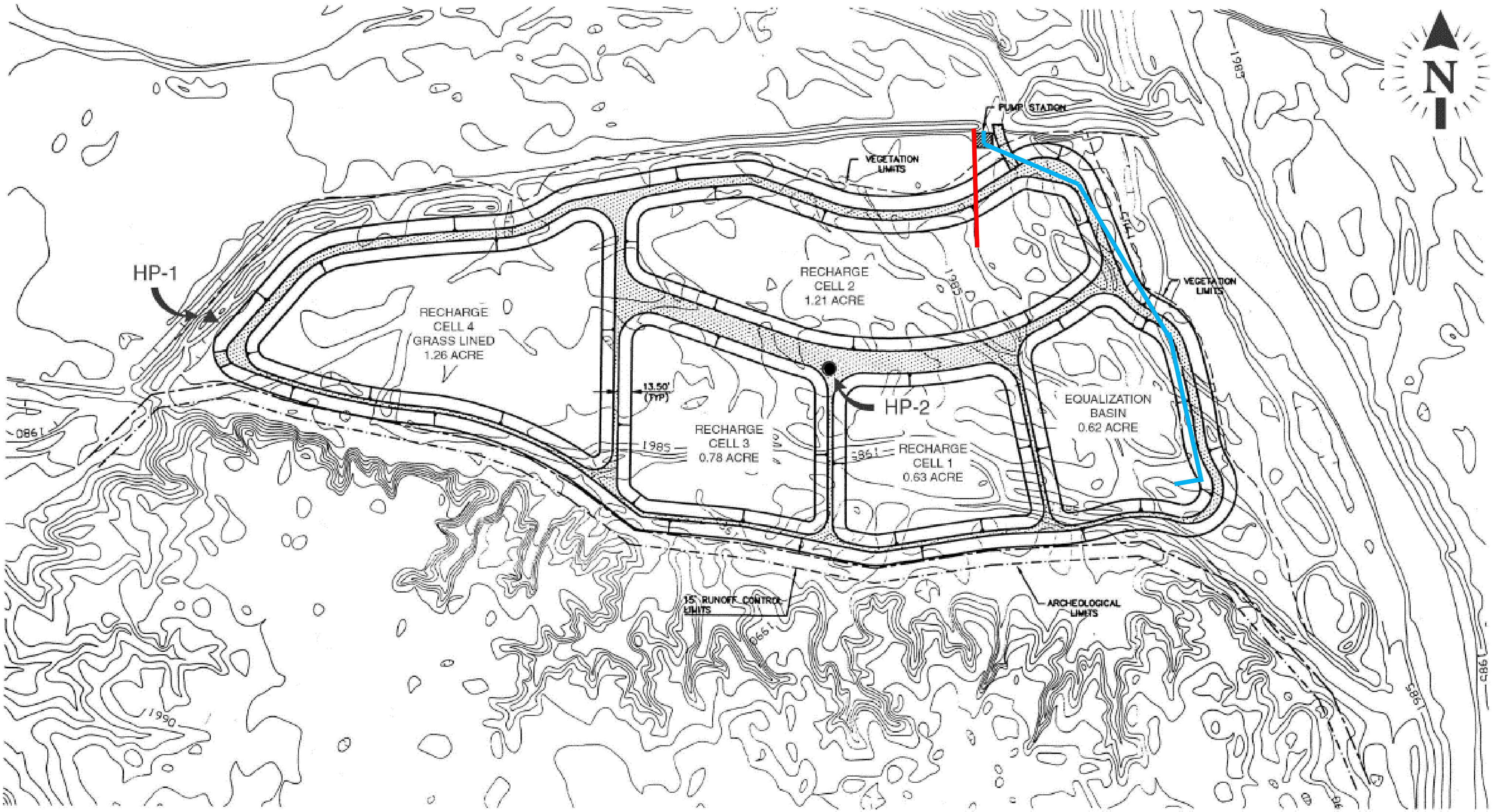
FIGURES

FIGURE 1
Location Map



Pima County Graphic Services db3483 7/02

FIGURE 2
Facility Map



SCALE IN FEET:

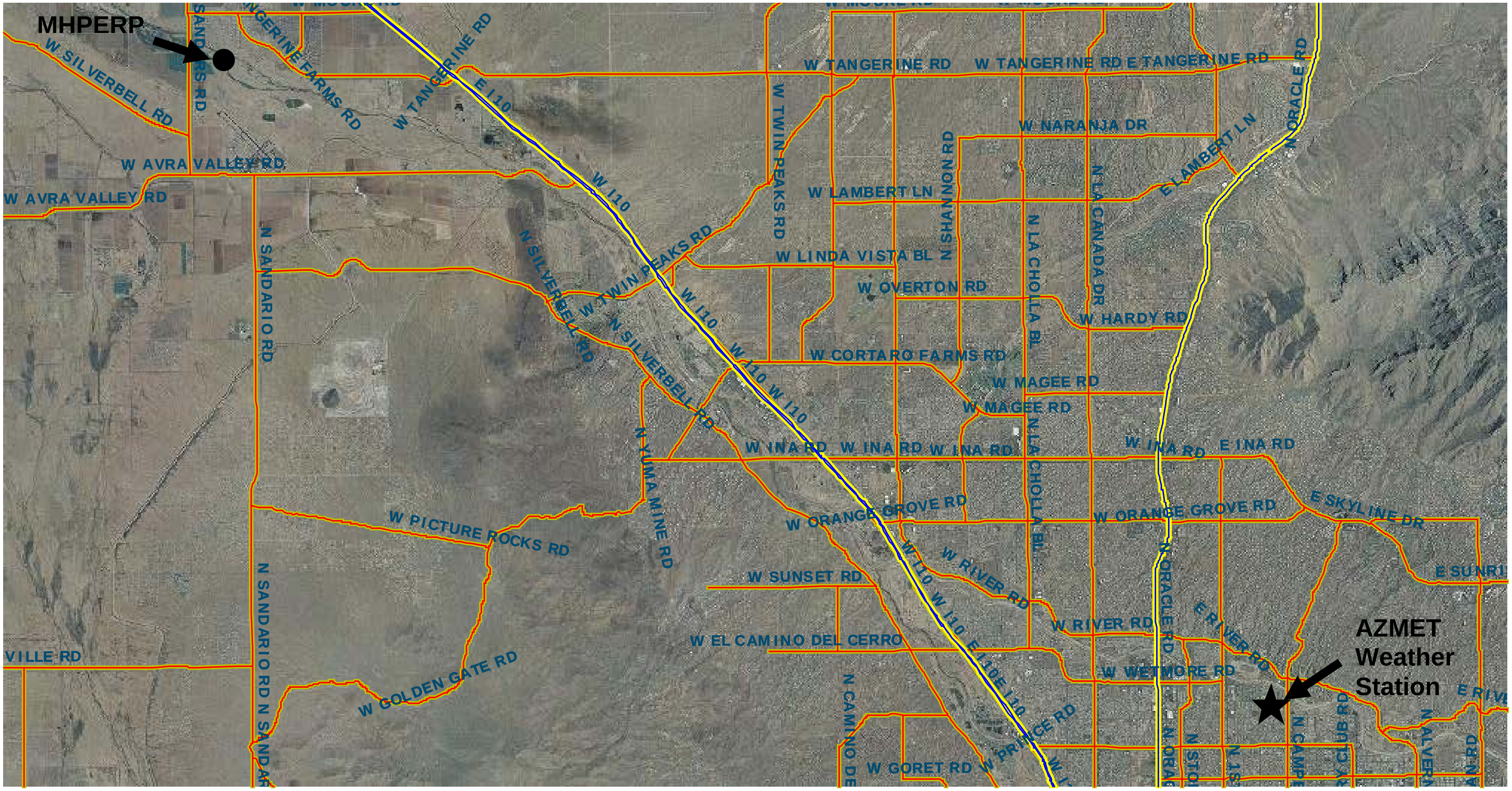
0 25 50 100

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

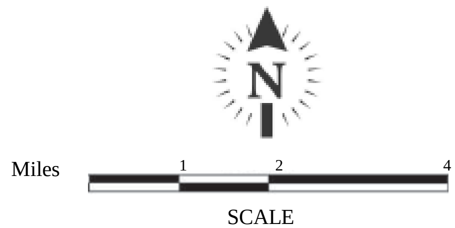
LEGEND

- ▲ 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



LEGEND
★ **Weather Station**

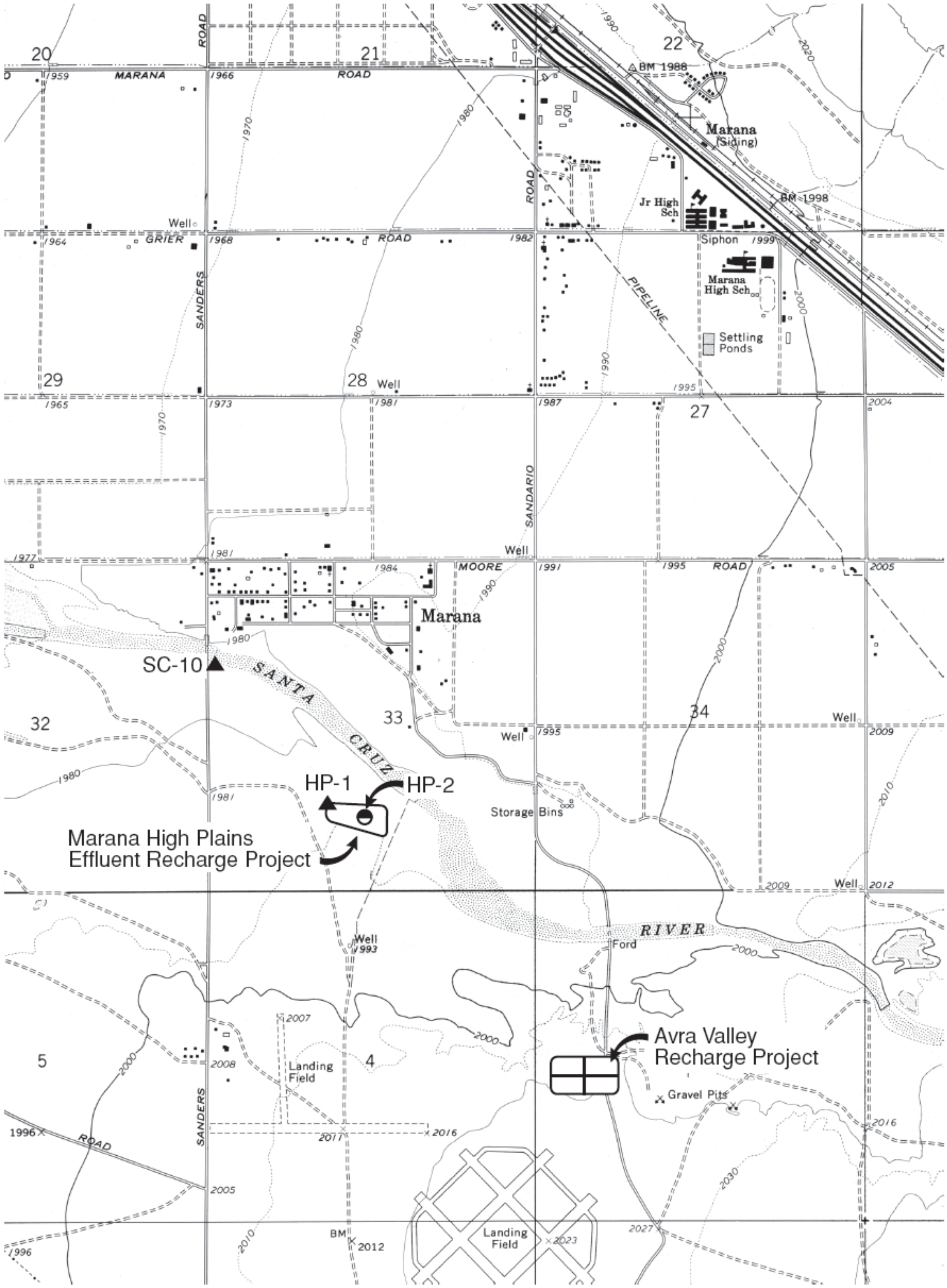


FIGURE 4
Marana High Plains
Effluent Recharge Project
Monitor Wells Location Map

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 2018

Constituent	Unit	Alert Limit	Discharge Limit	Sample Date & Results											
				Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Sep-18	Oct-18	Nov-18	Dec-18
Nutrients															
Total Nitrogen[1]	mg/l	N/A	N/A	10.1	8.1	4.8	6.60	6.10	6.53	4.21	5.85	6.58	4.99	6.72	6.16
Nitrate-Nitrite as N	mg/l	N/A	N/A	7.8	5.7	2.6	4.80	4.40	4.21	4.21	4.33	5.43	3.83	5.08	4.66
Total Kjeldahl Nitrogen (TKN)	mg/l	N/A	N/A	2.3	2.4	2.2	1.80	1.70	2.32	<1.00	1.52	1.15	1.16	1.64	1.50
Metals (Total)															
Free Cyanide	mg/l	0.16	0.2	No Event	<0.05	No Event	No Event	<0.05	No Event	No Event	No Event	<0.01	No Event	No Event	<0.01
Total Fluoride	mg/l	3.2	4	No Event	0.42	No Event	No Event	0.43	No Event	No Event	No Event	0.48	No Event	No Event	0.3
Arsenic	mg/l	0.04	0.05	No Event	0.0037	No Event	No Event	0.0037	No Event	No Event	No Event	0.004	No Event	No Event	0.0024
Barium	mg/l	1.6	2	No Event	0.061	No Event	No Event	0.069	No Event	No Event	No Event	0.067	No Event	No Event	0.054
Beryllium	mg/l	0.0032	0.004	No Event	<0.001	No Event	No Event	<0.001	No Event	No Event	No Event	<0.002	No Event	No Event	<0.002
Cadmium	mg/l	0.004	0.005	No Event	0.0001	No Event	No Event	<0.0001	No Event	No Event	No Event	<0.0001	No Event	No Event	<0.0001
Chromium	mg/l	0.08	0.1	No Event	0.0018	No Event	No Event	0.0014	No Event	No Event	No Event	<0.005	No Event	No Event	<0.005
Lead	mg/l	0.04	0.05	No Event	0.0028	No Event	No Event	0.0026	No Event	No Event	No Event	0.0014	No Event	No Event	0.0021
Thallium	mg/l	0.0016	0.002	No Event	<0.0001	No Event	No Event	<0.0001	No Event	No Event	No Event	<0.0005	No Event	No Event	<0.0005
Nickel	mg/l	0.08	0.1	No Event	0.0027	No Event	No Event	0.0022	No Event	No Event	No Event	<0.02	No Event	No Event	<0.02
Antimony	mg/l	0.0048	0.006	No Event	<0.001	No Event	No Event	<0.001	No Event	No Event	No Event	0.0007	No Event	No Event	<0.0005
Selenium	mg/l	0.04	0.05	No Event	0.00097	No Event	No Event	0.00065	No Event	No Event	No Event	0.002	No Event	No Event	<0.002
Mercury	mg/l	0.0016	0.002	No Event	<0.0002	No Event	No Event	0.00021	No Event	No Event	No Event	<0.0002	No Event	No Event	<0.0002
Volatile Organic Compounds (VOCs)															
para-Dichlorobenzene	mg/l	0.06	0.075	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.004	No Event	No Event
Dichloromethane	mg/l	0.004	0.005	No Event	No Event	No Event	<0.003	No Event	No Event	No Event	No Event	No Event	<0.004	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	<0.004	No Event	No Event
Carbon tetrachloride	mg/l	0.004	0.005	No Event	No Event	No Event	<0.003	No Event	No Event	No Event	No Event	No Event	<0.004	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	<0.004	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	<0.004	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	<0.004	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	<0.004	No Event	No Event
1,1-Dichloroethylene	mg/l	0.0056	0.007	No Event	No Event	No Event	<0.005	No Event	No Event	No Event	No Event	No Event	<0.004	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	<0.004	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	<0.004	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	<0.004	No Event	No Event
1,2,4-Trichlorobenzene	mg/l	0.056	0.07	No Event	No Event	No Event	<0.005	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Vinyl Chloride	mg/l	0.0016	0.002	No Event	No Event	No Event	<0.001	No Event	No Event	No Event	No Event	No Event	<0.001	No Event	No Event
Trichloroethylene	mg/l	0.004	0.005	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.004	No Event	No Event
Hexachlorobenzene	mg/l	0.0008	0.001	No Event	No Event	No Event	<0.00087	No Event	No Event	No Event	No Event	No Event	<0.0003	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	<0.004	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	<0.004	No Event	No Event
Xylenes (Total)	mg/l	8	10	No Event	No Event	No Event	<0.01	No Event	No Event	No Event	No Event	No Event	<0.012	No Event	No Event
Trihalomethane (TTHM)	mg/l	0.08	0.1	No Event	No Event	No Event	<0.004	No Event	No Event	No Event	No Event	No Event	<0.004	No Event	No Event
trans-1,2-Dichloroethylene	mg/l	0.08	0.1	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.004	No Event	No Event
Hexachlorocyclopentadiene	mg/l	0.04	0.05	No Event	No Event	No Event	<0.0054	No Event	No Event	No Event	No Event	No Event	<0.00052	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 2018

Constituent	**Unit**	**Alert Level**	**Aquifer Quality Limit**	**Sample Date & Results**											
				Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Sep-18	Oct-18	Nov-18	Dec-18*
Nutrients															
Total Nitrogen[1]	mg/l	8	10	1.5	1.7	1.17	1.7	1.5	1.2	1.53	0.97	1.40	1.37	1.39	No Event
Nitrate-Nitrite as N	mg/l	8	10	1.5	1.7	0.53	1.7	1.5	1.2	1.53	0.97	1.40	1.37	1.39	No Event
Total Kjeldahl Nitrogen (TKN)	mg/l	N/A	N/A	<0.5	<0.5	0.64	<0.5	<0.5	<1	<1	<1	<1	<1	<1	No Event
Total Coliform (P-Present, A-Absent)	P/A	A	A	A	A	A	A	A	A	A	A	A	A	A	No Event
Metals (Total)															
Free Cyanide	mg/l	0.16	0.2	No Event	<0.5	No Event	No Event	<0.05	No Event	No Event	No Event	<0.01	No Event	No Event	No Event
Total Fluoride	mg/l	3.2	4	No Event	<0.4	No Event	No Event	<0.4	No Event	No Event	No Event	0.29	No Event	No Event	No Event
Arsenic	mg/l	0.04	0.05	No Event	0.0015	No Event	No Event	0.0013	No Event	No Event	No Event	<0.001	No Event	No Event	No Event
Barium	mg/l	1.6	2	No Event	0.093	No Event	No Event	0.083	No Event	No Event	No Event	0.08	No Event	No Event	No Event
Beryllium	mg/l	0.0032	0.004	No Event	<0.001	No Event	No Event	<0.001	No Event	No Event	No Event	<0.002	No Event	No Event	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	<0.0001	No Event	No Event	No Event
Chromium	mg/l	0.08	0.1	No Event	<0.001	No Event	No Event	<0.001	No Event	No Event	No Event	<0.005	No Event	No Event	No Event
Lead	mg/l	0.04	0.05	No Event	<0.0005	No Event	No Event	<0.0005	No Event	No Event	No Event	<0.001	No Event	No Event	No Event
Thallium	mg/l	0.0016	0.002	No Event	<0.0001	No Event	No Event	<0.0001	No Event	No Event	No Event	<0.0005	No Event	No Event	No Event
Nickel	mg/l	0.08	0.1	No Event	0.00055	No Event	No Event	<0.0005	No Event	No Event	No Event	<0.02	No Event	No Event	No Event
Antimony	mg/l	0.0048	0.006	No Event	<0.001	No Event	No Event	<0.001	No Event	No Event	No Event	<0.0005	No Event	No Event	No Event
Selenium	mg/l	0.04	0.05	No Event	0.0012	No Event	No Event	0.0012	No Event	No Event	No Event	<0.002	No Event	No Event	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	No Event	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	<0.003	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	<0.005	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	<0.005	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	<0.001	No Event	No Event	No Event	No Event	No Event	<0.001	No Event	No Event
Trichloroethylene	mg/l	0.004	0.005	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Hexachlorobenzene	mg/l	0.0008	0.001	No Event	No Event	No Event	<0.00086	No Event	No Event	No Event	No Event	No Event	<0.0003	No Event	No Event
cis-1,2-Dichloroethylene	mg/l	0.05	0.07	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Styrene	mg/l	0.08	0.1	No Event	No Event	No Event	<0.002	No Event	No Event	No Event	No Event	No Event	<0.002	No Event	No Event
Xylenes (Total)	mg/l	8	10	No Event	No Event	No Event	<0.01	No Event	No Event	No Event	No Event	No Event	<0.006	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	<0.002	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	<0.0054	No Event	No Event	No Event	No Event	No Event	<0.00052	No Event	No Event

* Well pump malfunctioning, blown fuses and power output not sufficient - samples not collected during this month, including quarterly samples of metals, cyanide and fluoride.

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 2018

Date	Problem	Solution
February 9, 2018	Flow through gravity line into Cell 2 appears to be restricted.	Opening to gravity line (slide ditch gate) was closed and the basin was dried to expose the pipe line outlet. Portions of the gravity line were removed and the new outlet was secured with rebar. The slide ditch gate was opened on March 12 to deliver effluent to Cell 2.
July 11, 2018	No flow in oxbow channel.	Diversion berm washed out due to storm water runoff on July 10th. Berm was repaired on July 14th and recharge operations were restarted on July 16th.
July 31, 2018	Tree and shrub overgrowth along maintenance road and around facility equipment.	Landscape maintenance performed in October 2018 to clear roadway and remove hazards from around facility equipment.
July 31, 2018	Infiltration rates within the recharge cells are declining.	The facility surpassed its annual permitted amount of 600 AF on July 31, 2018. Maintenance activities were performed in December to clear vegetation and remove clogging soil materials from the bottoms of the recharge cells; the cell bottoms were also ripped to improve infiltration rates. Deliveries to the facility were restarted on January 2, 2019.
August 14, 2018	No flow in oxbow channel	Diversion berm washed out due to storm water runoff events. Since permitted amount of 600 acre-feet had been reached previously, the berm was not rebuilt until late December in preparation for Calendar Year 2019 operations.
August 14, 2018	Broken fence lines have allowed cattle to access the facility.	The cattle were removed by the neighboring rancher and the fence lines were repaired in December to keep cattle out of the area.
December 12, 2018	Pump within compliance well stopped working during water quality sample collection.	Fuses were replaced and the pump restarted, but the fuses were quickly blown out again. Electrical wiring to the pump was tested and it appears the pump is not drawing enough power to operate properly. Due to staffing issues and the Holiday Season, the pump was not replaced before December 31st. Pump and associated equipment replacement will be conducted in January/February 2019.

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: 2018

	January		February		March		April		May		June	
	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons
	75111900		75111900		98961740		127391400		127391400		127391400	
Day 1	75111900	0	75111900	0	99966620	1004880	127391400	0	127391400	0	**127391400**	0
2	75111900	0	75111900	0	100989400	1022780	127391400	0	127391400	0	127391400	0
3	75111900	0	75111900	0	101982900	993500	127391400	0	127391400	0	127391400	0
4	75111900	0	75111900	0	102976400	993500	127391400	0	127391400	0	127391400	0
5	75111900	0	75111900	0	104062900	1086500	127391400	0	127391400	0	127391400	0
6	75111900	0	75801450	689550	105056260	993360	127391400	0	127391400	0	127391400	0
7	75111900	0	76899120	1097670	106132680	1076420	127391400	0	127391400	0	127391400	0
8	75111900	0	77942760	1043640	107075420	942740	127391400	0	127391400	0	127391400	0
9	75111900	0	78856260	913500	108098138.6	1022718.6	127391400	0	127391400	0	127391400	0
10	75111900	0	80023720	1167460	109103479.2	1005340.6	127391400	0	127391400	0	127391400	0
11	75111900	0	81191620	1167900	110108840	1005360.8	127391400	0	127391400	0	127391400	0
12	75111900	0	82232150	1040530	111112800	1003960	127391400	0	127391400	0	127391400	0
13	75111900	0	83316160	1084010	112116840	1004040	127391400	0	127391400	0	127391400	0
14	75111900	0	84357140	1040980	113130860	1014020	127391400	0	127391400	0	127391400	0
15	75111900	0	85413620	1056480	114112800	981940	127391400	0	127391400	0	127391400	0
16	75111900	0	86416960	1003340	115220160	1107360	127391400	0	127391400	0	127391400	0
17	75111900	0	87483450	1066490	116134200	914040	127391400	0	127391400	0	127391400	0
18	75111900	0	88550450	1067000	117048720	914520	127391400	0	127391400	0	127391400	0
19	75111900	0	89589550	1039100	118052960	1004240	127391400	0	127391400	0	128035500	644100
20	75111900	0	90680700	1091150	119066980	1014020	127391400	0	127391400	0	129078100	1042600
21	75111900	0	91693400	1012700	120056840	989860	127391400	0	127391400	0	130115300	1037200
22	75111900	0	92731500	1038100	121160340	1103500	127391400	0	127391400	0	131252100	1136800
23	75111900	0	93774000	1042500	122065120	904780	127391400	0	127391400	0	132383200	1131100
24	75111900	0	94779150	1005150	123007320	942200	127391400	0	127391400	0	133414800	1031600
25	75111900	0	95784400	1005250	123948980	941660	127391400	0	127391400	0	134363300	948500
26	75111900	0	96762200	977800	124962500	1013520	127391400	0	127391400	0	135298600	935300
27	75111900	0	97841000	1078800	125968400	1005900	127391400	0	127391400	0	136291800	993200
28	75111900	0	98961740	1120740	126977400	1009000	127391400	0	127391400	0	137393400	1101600
29	75111900	0			127391400	414000	127391400	0	127391400	0	138524100	1130700
30	75111900	0			127391400	0	127391400	0	127391400	0	139631900	1107800
31	75111900	0			127391400	0			127391400	0		
	Total (gal)	**0**	**Total (gal)**	**23849840**	**Total (gal)**	**28429660**	**Total (gal)**	**0**	**Total (gal)**	**0**	**Total (gal)**	**12240500**
	Total (ac-ft)	**0.00**	**Total (ac-ft)**	**73.19**	**Total (ac-ft)**	**87.25**	**Total (ac-ft)**	**0.00**	**Total (ac-ft)**	**0.00**	**Total (ac-ft)**	**37.56**
					1st Qtr Total (gal) =	**52279500**					**2nd Qtr Total (gal) =**	**12240500**
					1st Qtr Total (ac-ft) =	**160.44**					**2nd Qtr Total (ac-ft) =**	**37.56**

USF DAILY FLOWMETER READINGS AND VOLUMES

Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Meter ID: Fm-eq
Year: 2018

	July		August		September		October		November		December	
	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons
	139631900		149044900		149044900		149044900		149044900		149044900	
Day 1	140439300	807400	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
2	141438400	999100	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
3	142527500	1089100	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
4	143453000	925500	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
5	144446900	993900	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
6	145439300	992400	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
7	146400000	960700	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
8	147362700	962700	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
9	148325700	963000	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
10	149044900	719200	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
11	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
12	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
13	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
14	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
15	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
16	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
17	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
18	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
19	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
20	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
21	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
22	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
23	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
24	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
25	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
26	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
27	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
28	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
29	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
30	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0	149044900	0
31	149044900	0	149044900	0			149044900	0			149044900	0
	Total (gal)	**9413000**	**Total (gal)**	**0**	**Total (gal)**	**0**	**Total (gal)**	**0**	**Total (gal)**	**0**	**Total (gal)**	**0**
	Total (ac-ft)	**28.89**	**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) =	**9413000**
3rd Qtr Total (ac-ft) =	**28.89**

4th Qtr Total (gal) =	**0**
4th Qtr Total (ac-ft) =	**0.00**
Annual Total Del. Vol for FM-eq (ac-ft) =	**226.89**

USF DAILY FLOWMETER READINGS AND VOLUMES

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0008

Meter ID: Fm-C2

Year: 2018

	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		23934000		45962000		83762000		106250000	
Day 1	693000	693000	16993000	466000	23934000	0	47717000	1755000	84667000	905000	**106543000**	293000
2	1679000	986000	17392000	399000	23934000	0	49443000	1726000	85564000	897000	107017000	474000
3	2581000	902000	17761000	369000	23934000	0	51084000	1641000	86451000	887000	107451000	434000
4	3426000	845000	18268000	507000	23934000	0	52644000	1560000	87327000	876000	107907000	456000
5	4276000	850000	19852000	1584000	23934000	0	54176000	1532000	88199000	872000	108344000	437000
6	5055000	779000	21580000	1728000	23934000	0	55670000	1494000	89000000	801000	108851000	507000
7	5793000	738000	23167000	1587000	23934000	0	57108000	1438000	89800000	800000	109377000	526000
8	6557000	764000	23934000	767000	23934000	0	58588000	1480000	90582000	782000	109886000	509000
9	7245000	688000	23934000	0	23934000	0	60042000	1454000	91382000	800000	110376000	490000
10	7935000	690000	23934000	0	23934000	0	61452000	1410000	92280000	898000	110886000	510000
11	8476000	541000	23934000	0	23934000	0	62806000	1354000	93081000	801000	111416000	530000
12	9010000	534000	23934000	0	24110000	176000	64140000	1334000	93799000	718000	111935000	519000
13	9527000	517000	23934000	0	24344000	234000	65471000	1331000	94551000	752000	112461000	526000
14	10059000	532000	23934000	0	24610000	266000	66743000	1272000	95310000	759000	112994000	533000
15	10588000	529000	23934000	0	25295000	685000	67980000	1237000	96071000	761000	113501000	507000
16	11132000	544000	23934000	0	26380000	1085000	69208000	1228000	96681000	610000	114004000	503000
17	11659000	527000	23934000	0	27539000	1159000	70415000	1207000	97672000	991000	114585000	581000
18	12178000	519000	23934000	0	28817000	1278000	71606000	1191000	98613000	941000	115027000	442000
19	12619000	441000	23934000	0	30178000	1361000	72758000	1152000	99512000	899000	115383000	356000
20	12953000	334000	23934000	0	31536000	1358000	73867000	1109000	100393000	881000	115680000	297000
21	13224000	271000	23934000	0	32811000	1275000	74948000	1081000	101306000	913000	115979000	299000
22	13510000	286000	23934000	0	34122000	1311000	76004000	1056000	102111000	805000	116250000	271000
23	13795000	285000	23934000	0	35295000	1173000	77059000	1055000	102786000	675000	116508000	258000
24	14100000	305000	23934000	0	36468000	1173000	78092000	1033000	103447000	661000	116758000	250000
25	14435000	335000	23934000	0	37600000	1132000	79087000	995000	104023000	576000	117049000	291000
26	14846000	411000	23934000	0	38786000	1186000	80052000	965000	104564000	541000	117324000	275000
27	15155000	309000	23934000	0	39983000	1197000	80974000	922000	105060000	496000	117616000	292000
28	15465000	310000	23934000	0	41174000	1191000	81893000	919000	105476000	416000	117919000	303000
29	15769000	304000			42390000	1216000	82824000	931000	105954000	478000	118199000	280000
30	16006000	237000			44226000	1836000	83762000	938000	106002000	48000	118456000	257000
31	16527000	521000			45962000	1736000			106250000	248000		
	Total (gal)	**16527000**	**Total (gal)**	**7407000**	**Total (gal)**	**22028000**	**Total (gal)**	**37800000**	**Total (gal)**	**22488000**	**Total (gal)**	**12206000**
	Total (ac-ft)	**50.72**	**Total (ac-ft)**	**22.73**	**Total (ac-ft)**	**67.60**	**Total (ac-ft)**	**116.00**	**Total (ac-ft)**	**69.01**	**Total (ac-ft)**	**37.46**

1st Qtr Total (gal) =	**45962000**
1st Qtr Total (ac-ft) =	**141.05**
2nd Qtr Total (gal) =	**72494000**
2nd Qtr Total (ac-ft) =	**222.48**

USF DAILY FLOWMETER READINGS AND VOLUMES

Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Meter ID: Fm-C2
Year: 2018

	July		August		September		October		November		December	
	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons
	118456000		133792000		133792000		133792000		149044900		149044900	
Day 1	118707000	251000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
2	118950000	243000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
3	119295000	345000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
4	119675000	380000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
5	120097000	422000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
6	120490000	393000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
7	120883000	393000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
8	121274000	391000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
9	121713000	439000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
10	122135000	422000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
11	122204000	69000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
12	122204000	0	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
13	122204000	0	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
14	122204000	0	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
15	122204000	0	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
16	122597000	393000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
17	123446000	849000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
18	124195000	749000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
19	125003000	808000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
20	125790000	787000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
21	126573000	783000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
22	127366000	793000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
23	128192000	826000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
24	128957000	765000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
25	129691000	734000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
26	130414000	723000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
27	131151000	737000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
28	132017000	866000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
29	132663000	646000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
30	133414000	751000	133792000	0	133792000	0	133792000	0	149044900	0	149044900	0
31	133792000	378000	133792000	0			133792000	0			149044900	0
	Total (gal)	**15336000**	**Total (gal)**	**0**	**Total (gal)**	**0**	**Total (gal)**	**0**	**Total (gal)**	**0**	**Total (gal)**	**0**
	Total (ac-ft)	**47.06**	**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) =	**15336000**
3rd Qtr Total (ac-ft) =	**47.06**

4th Qtr Total (gal) =	**0**
4th Qtr Total (ac-ft) =	**0.00**
Annual Total Del. Vol for FM-eq (ac-ft) =	**410.59**

USF WATER QUANTITY REPORTING SUMMARY

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0008

Year: 2018

	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	50.7	0.1	0.0	50.6	
February	73.2	22.7	0.4	0.0	95.4	
March	87.2	67.6	0.7	0.1	154.1	300.1
April	0.0	116.0	0.9	0.0	115.1	
May	0.0	69.0	1.3	0.1	67.5	
June	37.6	37.5	1.5	0.5	73.0	255.7
July	28.9	47.1	2.7	0.1	73.1	
August	0.0	0.0	0.7	0.0	-0.8	
September	0.0	0.0	0.2	0.0	-0.2	72.1
October	0.0	0.0	0.1	0.0	-0.1	
November	0.0	0.0	0.1	0.0	-0.1	
December	0.0	0.0	0.0	0.0	0.0	-0.2
Annual Totals =	**226.9**	**410.6**	**8.9**	**1.0**	**627.7**	

APPENDIX B

Evaporation Calculations & Cooley Method Description

USF EVAPORATION CALCULATIONS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2018

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	8	0.1	11	0.2	0	0.0	0	0.0	4	0.1
Cell 1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	0.0
Cell 2	15	0.1	12	0.2	9	0.1	35	0.8	36	1.0	35	1.1
Cell 3	0	0.0	0	0.0	0	0.0	5	0.1	11	0.3	10	0.3
Cell 4	0	0.0	14	0.2	20	0.3	0	0.0	0	0.0	0	0.0
	15	**0.1**	**34**	**0.4**	**40**	**0.7**	**41**	**0.9**	**48**	**1.3**	**50**	**1.5**

1st Quarter Total Evap (AF) **=**	**1.2**
2nd Quarter Total Evap (AF) **=**	**3.7**

Cooley Adj. Fac	**0.95**

USF EVAPORATION CALCULATIONS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2018

Basin ID	July Wetted Acres	Evap (AF)	August Wetted Acres	Evap (AF)	September Wetted Acres	Evap (AF)	October Wetted Acres	Evap (AF)	November Wetted Acres	Evap (AF)	December Wetted Acres	Evap (AF)
Equal. Basin	7	0.2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Cell 1	4	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Cell 2	49	1.5	21	0.6	10	0.2	7	0.1	6	0.1	3	0.0
Cell 3	12	0.4	3	0.1	0	0.0	0	0.0	0	0.0	0	0.0
Cell 4	18	0.5	3	0.1	0	0.0	0	0.0	0	0.0	0	0.0
	90	**2.7**	**28**	**0.7**	**10**	**0.2**	**7**	**0.1**	**6**	**0.1**	**3**	**0.0**

3rd Quarter Total Evap (AF) **=**	**3.7**

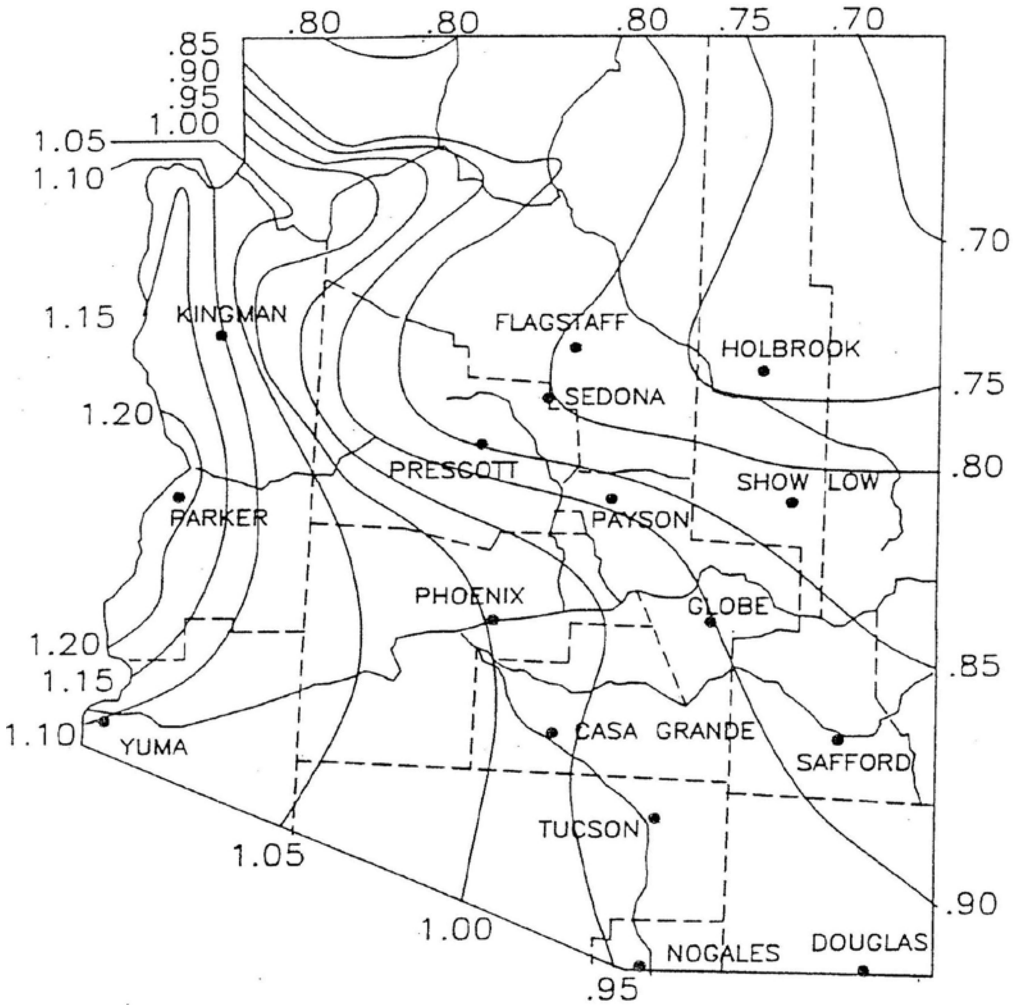
4th Quarter Total Evap (AF) **=**	**0.2**
Annual Total Evap (AF) **=**	**8.9**

COOLEY EVAPORATION INFORMATION

Cooley Monthly Maximum Evaporation Rates
from Cooley, 1970

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

Cooley Evaporation Adjustment Factors for Arizona
from Cooley, 1970



ARIZONA DEPARTMENT OF WATER RESOURCES
HYDROLOGY DIVISION

TECHNICAL BULLETIN

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

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

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

Justification for Using the Maximum Curve of the Cooley Method

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

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

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

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

EVAPORATION FROM OPEN WATER SURFACES IN ARIZONA

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

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

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

How to Estimate Evaporation

Estimation of evaporation consists of three steps.

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

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

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

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

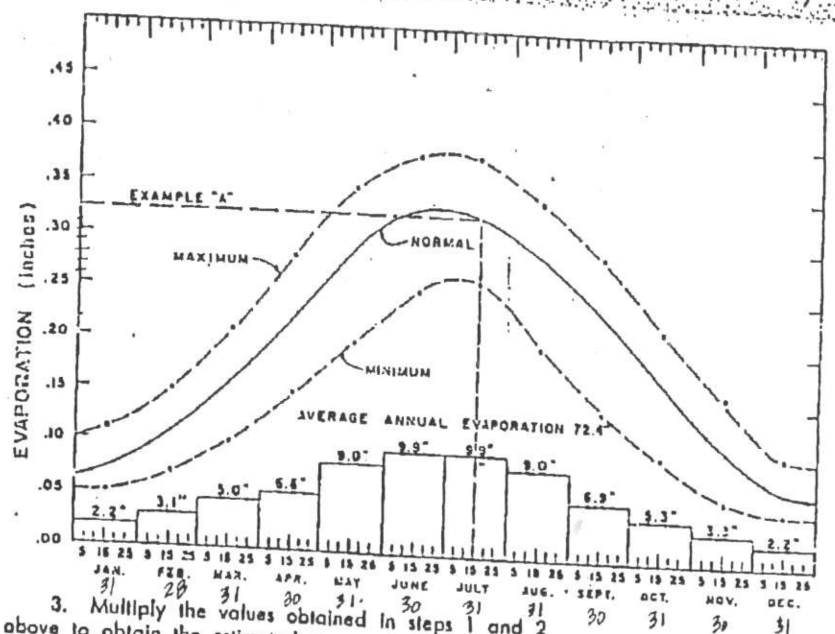


FIGURE 1. Maximum, Normal, and Minimum Daily Evaporation and Average Monthly Evaporation From Open Water Surfaces (Adjustment Factor = 1.00).

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

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

Examples:

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

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

(See over)

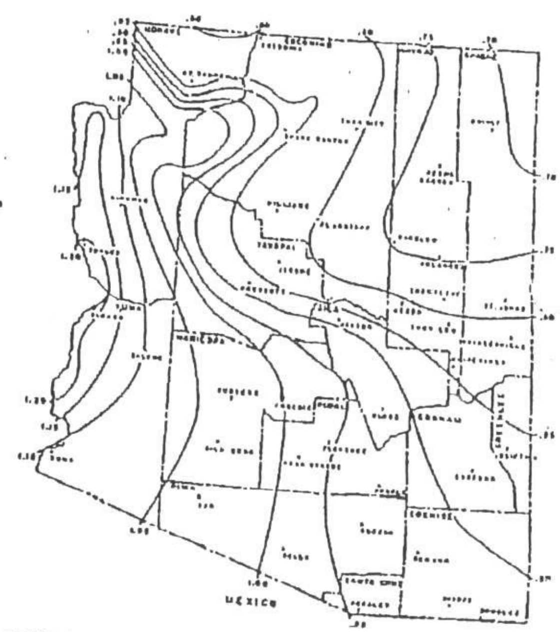


FIGURE 2. Evaporation Adjustment Factors for Arizona

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

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

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

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

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

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

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

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

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

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

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

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

Acknowledgement

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

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

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

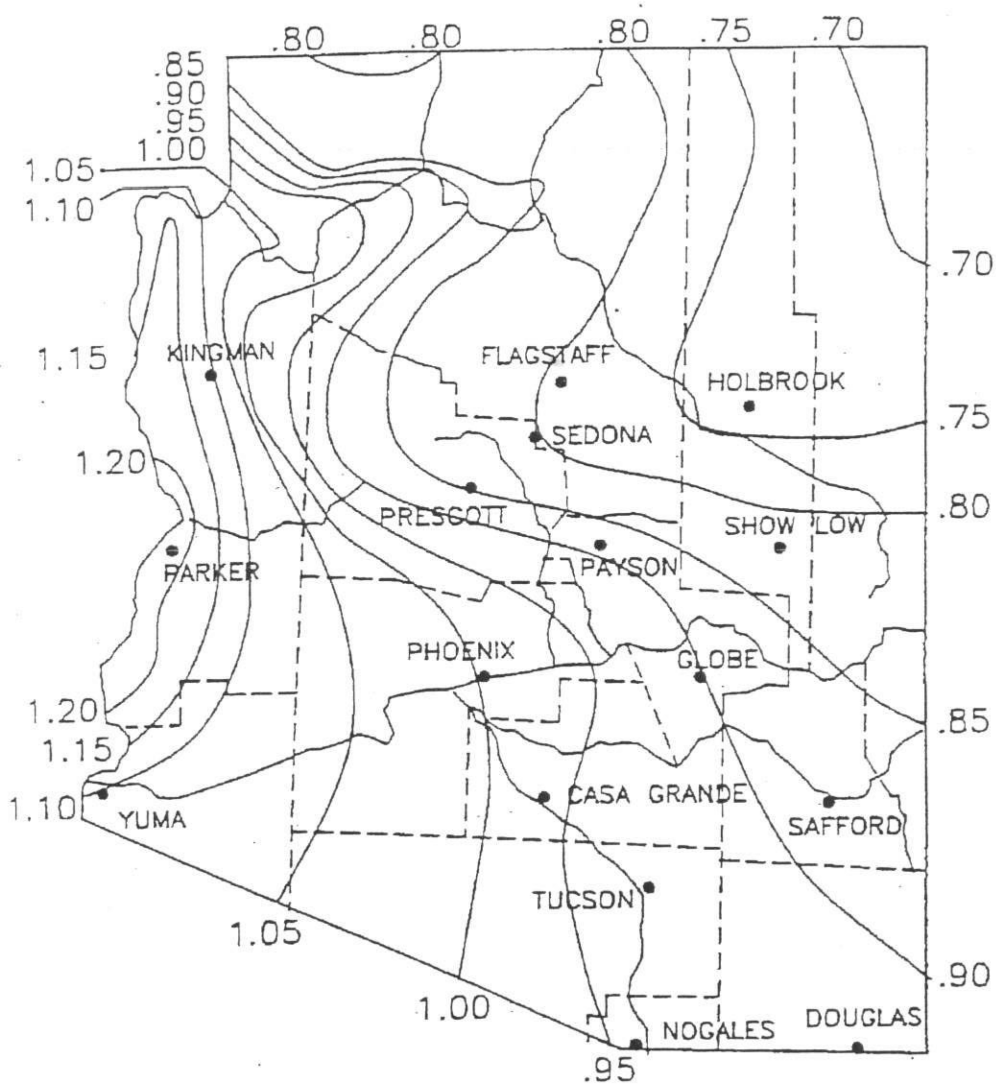
EVAPORATION FROM OPEN WATER SURFACES IN ARIZONA

FOLDER 159

Agricultural Experiment Station
And
Cooperative Extension Service
The University of Arizona

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

FIGURE 10. EVAPORATION ADJUSTMENT FACTORS FOR ARIZONA



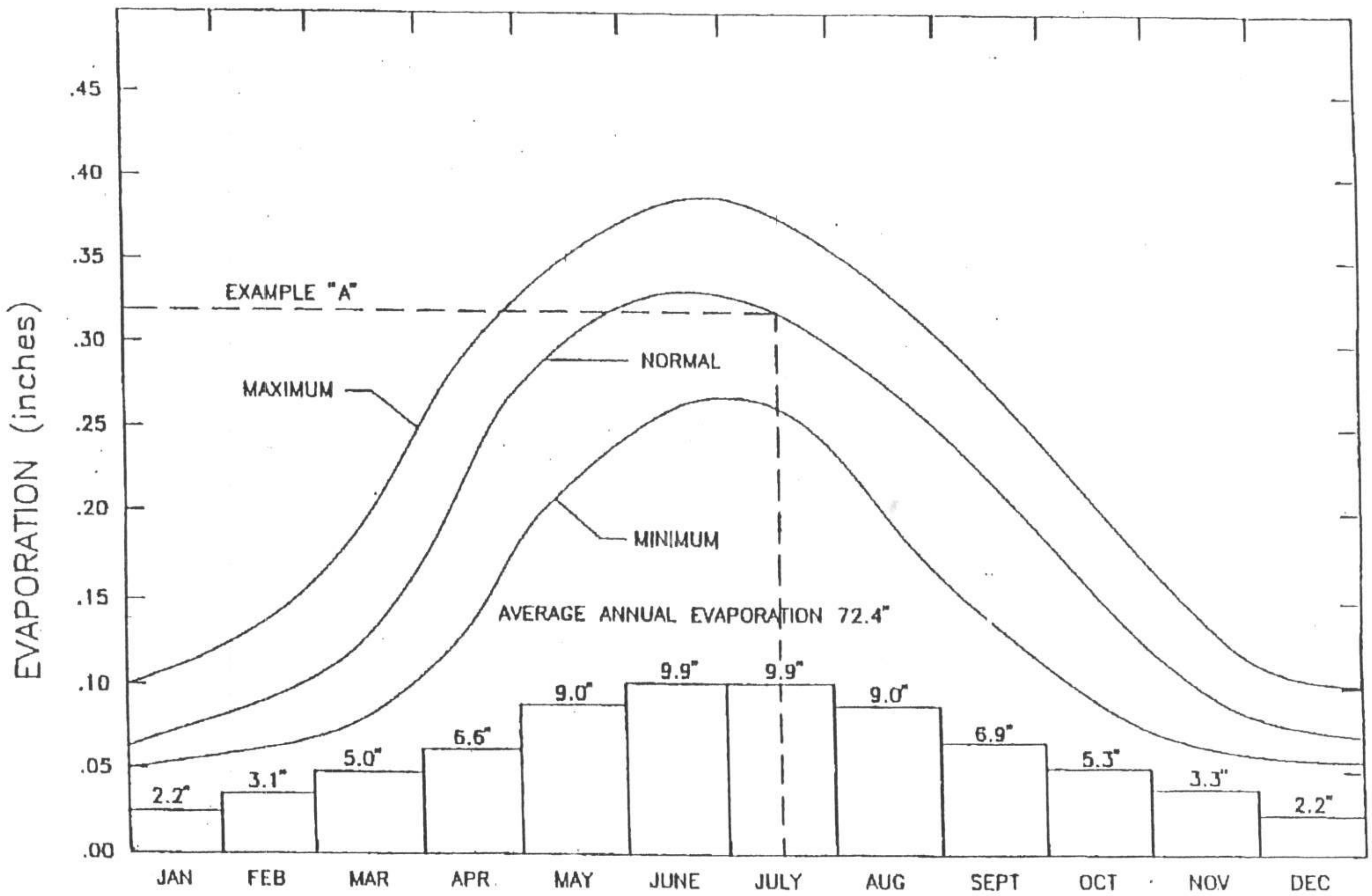


FIGURE 9. MAXIMUM, NORMAL AND MINIMUM DAILY EVAPORATION AND AVERAGE MONTHLY EVAPORATION FROM OPEN WATER SURFACES (Adjustment Factor = 1.00)

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

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

From: Cooley, 1970

APPENDIX C

Daily Wetted Acreages

USF DAILY WETTED ACREAGES
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2018

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	0.121	0	0
2	0	0	0.3025	0	0
3	0	0	0.363	0	0
4	0	0	0.4235	0	0
5	0	0	0.4235	0	0
6	0	0	0.4235	0	0
7	0	0	0.4235	0	0
8	0	0	0.4235	0	0
9	0	0	0.4235	0	0
10	0	0	0.4235	0	0
11	0	0	0.484	0	0
12	0	0	0.484	0	0
13	0	0	0.484	0	0
14	0	0	0.484	0	0
15	0	0	0.484	0	0
16	0	0	0.484	0	0
17	0	0	0.5445	0	0
18	0	0	0.5445	0	0
19	0	0	0.5566	0	0
20	0	0	0.5687	0	0
21	0	0	0.5808	0	0
22	0	0	0.5929	0	0
23	0	0	0.605	0	0
24	0	0	0.605	0	0
25	0	0	0.605	0	0
26	0	0	0.605	0	0
27	0	0	0.605	0	0
28	0	0	0.605	0	0
29	0	0	0.605	0	0
30	0	0	0.605	0	0
31	0	0	0.605	0	0
Total Wetted Acres	**0**	**0**	**15.488**	**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	0.605	0	0
2	0	0	0.605	0	0
3	0	0	0.605	0	0
4	0	0	0.605	0	0
5	0	0	1.0285	0	0
6	0.3224	0	1.089	0	0.126
7	0.341	0	1.1132	0	0.504
8	0.341	0	1.1374	0	0.63
9	0.341	0	1.089	0	0.63
10	0.341	0	1.0285	0	0.63
11	0.341	0	0.605	0	0.63
12	0.341	0	0.5445	0	0.63
13	0.341	0	0.484	0	0.63
14	0.341	0	0.363	0	0.63
15	0.341	0	0.242	0	0.63
16	0.341	0	0.121	0	0.63
17	0.341	0	0.121	0	0.63
18	0.341	0	0.121	0	0.63
19	0.341	0	0.121	0	0.63
20	0.341	0	0.121	0	0.63
21	0.341	0	0.0968	0	0.63
22	0.341	0.0031	0.0847	0	0.63
23	0.341	0	0.0726	0	0.63
24	0.341	0	0.0485	0	0.63
25	0.341	0	0.0363	0	0.63
26	0.341	0	0.0242	0	0.63
27	0.341	0	0.0121	0	0.63
28	0.341	0	0.0121	0	0.63
29					
Total Wetted Acres	**7.8244**	**0.0031**	**12.1364**	**0**	**13.86**

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

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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	0.341	0	0	0	0.63
2	0.341	0	0	0	0.63
3	0.341	0	0	0	0.63
4	0.341	0	0	0	0.63
5	0.341	0	0	0	0.63
6	0.341	0	0	0	0.63
7	0.341	0	0	0	0.63
8	0.341	0	0	0	0.63
9	0.341	0	0	0	0.63
10	0.341	0	0	0	0.63
11	0.341	0	0	0	0.63
12	0.341	0	0.0605	0	0.63
13	0.341	0	0.121	0	0.63
14	0.341	0	0.242	0	0.63
15	0.341	0	0.4235	0	0.63
16	0.341	0	0.4235	0	0.63
17	0.341	0	0.4356	0	0.63
18	0.341	0	0.4356	0	0.63
19	0.341	0	0.4477	0	0.63
20	0.341	0	0.4477	0	0.63
21	0.341	0	0.4598	0	0.63
22	0.341	0	0.4598	0	0.63
23	0.341	0	0.4719	0	0.63
24	0.341	0	0.4719	0	0.63
25	0.341	0	0.4719	0	0.63
26	0.341	0	0.484	0	0.819
27	0.341	0	0.484	0	0.819
28	0.341	0	0.484	0	0.819
29	0.341	0	0.5082	0	0.819
30	0.3224	0	0.605	0	0.63
31	0.31	0	1.0648	0.0078	0.504
Total Wetted Acres	**10.5214**	**0**	**9.0024**	**0.0078**	**20.16**

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	0.248	0	1.1737	0.0585	0.252
2	0.155	0	1.1737	0.039	0
3	0.062	0	1.1737	0.0468	0
4	0.031	0	1.1737	0.0546	0
5	0	0	1.1737	0.0624	0
6	0	0	1.1737	0.0702	0
7	0	0	1.1737	0.078	0
8	0	0	1.1737	0.0858	0
9	0	0	1.1737	0.0936	0
10	0	0	1.1737	0.1014	0
11	0	0	1.1737	0.1092	0
12	0	0	1.1737	0.117	0
13	0	0	1.1737	0.1248	0
14	0	0	1.1737	0.1326	0
15	0	0	1.1737	0.1404	0
16	0	0	1.1737	0.1482	0
17	0	0	1.1737	0.156	0
18	0	0	1.1737	0.1638	0
19	0	0	1.1737	0.1716	0
20	0	0	1.1737	0.1794	0
21	0	0	1.1737	0.195	0
22	0	0	1.1737	0.2106	0
23	0	0	1.1737	0.2262	0
24	0	0	1.1737	0.234	0
25	0	0	1.1737	0.2496	0
26	0	0	1.1737	0.2652	0
27	0	0	1.1737	0.2808	0
28	0	0	1.1737	0.2886	0
29	0	0	1.1737	0.2964	0
30	0	0	1.1737	0.3042	0
Total Wetted Acres	**0.496**	**0**	**35.211**	**4.6839**	**0.252**

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

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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	1.1737	0.312	0
2	0	0	1.1737	0.312	0
3	0	0	1.1737	0.312	0
4	0	0	1.1737	0.312	0
5	0	0	1.1737	0.312	0
6	0	0	1.1737	0.312	0
7	0	0	1.1737	0.312	0
8	0	0	1.1737	0.39	0
9	0	0	1.1737	0.39	0
10	0	0	1.1737	0.39	0
11	0	0	1.1737	0.39	0
12	0	0	1.1737	0.39	0
13	0	0	1.1737	0.39	0
14	0	0	1.1737	0.39	0
15	0	0	1.1495	0.39	0
16	0	0	1.1495	0.39	0
17	0	0	1.1737	0.39	0
18	0	0	1.1737	0.39	0
19	0	0	1.1737	0.39	0
20	0	0	1.1737	0.39	0
21	0	0	1.1737	0.39	0
22	0	0	1.1737	0.39	0
23	0	0	1.1737	0.39	0
24	0	0	1.1737	0.39	0
25	0	0	1.1737	0.39	0
26	0	0	1.1737	0.39	0
27	0	0	1.1737	0.366	0
28	0	0	1.1737	0.351	0
29	0	0	1.1737	0.351	0
30	0	0	1.1737	0.3315	0
31	0	0	1.1495	0.312	0
Total Wetted Acres	**0**	**0**	**36.3121**	**11.3055**	**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	0	1.1495	0.273	0
2	0	0	1.1495	0.234	0
3	0	0	1.1495	0.2418	0
4	0	0	1.1495	0.2496	0
5	0	0	1.1495	0.2574	0
6	0	0	1.1495	0.273	0
7	0	0	1.1495	0.2886	0
8	0	0	1.1737	0.2964	0
9	0	0	1.1737	0.3042	0
10	0	0	1.1737	0.312	0
11	0	0	1.1737	0.3276	0
12	0	0	1.1737	0.351	0
13	0	0	1.1737	0.351	0
14	0	0	1.1737	0.3276	0
15	0	0	1.1737	0.3276	0
16	0	0	1.1737	0.312	0
17	0	0	1.1737	0.312	0
18	0	0	1.1495	0.2925	0
19	0.31	0.00315	1.1495	0.273	0
20	0.341	0.0063	1.1495	0.3744	0
21	0.3844	0.0189	1.1737	0.3744	0
22	0.3844	0.0252	1.1737	0.3432	0
23	0.3844	0.0378	1.1737	0.3588	0
24	0.3844	0.0441	1.1737	0.3666	0
25	0.3844	0.0504	1.1737	0.3744	0
26	0.3844	0.0567	1.1737	0.39	0
27	0.3844	0.063	1.1737	0.39	0
28	0.3844	0.0693	1.1737	0.39	0
29	0.3844	0.0756	1.1737	0.39	0
30	0.3844	0.126	1.1737	0.39	0
Total Wetted Acres	**4.495**	**0.57645**	**34.969**	**9.7461**	**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	0.3844	0.1323	1.737	0.39	0.63
2	0.3844	0.1386	1.737	0.39	0.819
3	0.3844	0.1512	1.737	0.39	0.819
4	0.3844	0.1575	1.737	0.39	0.819
5	0.3844	0.1638	1.737	0.39	0.819
6	0.3844	0.1701	1.737	0.39	0.819
7	0.3844	0.1827	1.737	0.39	0.819
8	0.3844	0.1953	1.737	0.39	0.819
9	0.3844	0.2079	1.737	0.39	0.819
10	0.3844	0.2268	1.737	0.663	0.819
11	0.3844	0.2268	1.1495	0.39	0.819
12	0.3844	0.1764	1.1495	0.39	0.819
13	0.3844	0.126	1.1495	0.39	0.63
14	0.3844	0.0189	1.1495	0.312	0.504
15	0.3844	0.0945	1.1374	0.312	0.378
16	0.3844	0	1.1374	0.312	0.252
17	0.3844	0.0063	1.1495	0.312	0.315
18	0	0.0252	1.1495	0.312	0.3276
19	0	0.0378	1.737	0.312	0.3402
20	0	0.0504	1.737	0.312	0.3654
21	0	0.063	1.737	0.39	0.3906
22	0	0.0756	1.737	0.39	0.4095
23	0	0.0882	1.737	0.39	0.4284
24	0	0.1008	1.737	0.39	0.4536
25	0	0.1134	1.737	0.39	0.4788
26	0	0.126	1.737	0.39	0.504
27	0	0.1386	1.737	0.39	0.504
28	0	0.1449	1.737	0.39	0.504
29	0	0.189	1.737	0.39	0.504
30	0	0.2205	1.737	0.39	0.504
31	0	0.252	1.737	0.39	0.63
Total Wetted Acres	**6.5348**	**4.0005**	**49.1228**	**11.817**	**18.0621**

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	0.1827	1.737	0.39	0.63
2	0	0.126	1.1495	0.39	0.504
3	0	0.063	1.1495	0.39	0.504
4	0	0	1.1374	0.312	0.504
5	0	0	1.1132	0.312	0.4599
6	0	0	1.0648	0.312	0.4158
7	0	0	1.0285	0.2836	0.2646
8	0	0	0.605	0.234	0.1134
9	0	0	0.605	0.195	0
10	0	0	0.605	0.1014	0
11	0	0	0.605	0.078	0
12	0	0	0.605	0.0702	0
13	0	0	0.605	0.0624	0
14	0	0	0.5445	0.0546	0
15	0	0	0.5445	0.0468	0
16	0	0	0.5445	0.039	0
17	0	0	0.5445	0.0234	0
18	0	0	0.5324	0.0156	0
19	0	0	0.5203	0.0078	0
20	0	0	0.5082	0	0
21	0	0	0.4961	0	0
22	0	0	0.48	0	0
23	0	0	0.48	0	0
24	0	0	0.48	0	0
25	0	0	0.48	0	0
26	0	0	0.4719	0	0
27	0	0	0.4598	0	0
28	0	0	0.4477	0	0
29	0	0	0.4356	0	0
30	0	0	0.4235	0	0
31	0	0	0.4235	0	0
Total Wetted Acres	**0**	**0.3717**	**20.8269**	**3.3178**	**3.3957**

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

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September

Date	Equal. Basin Wetted Area (acres)*	Recharge Cell 1 Wetted Area (acres)*	Recharge Cell 2 Wetted Area (acres)*	Recharge Cell 3 Wetted Area (acres)*	Recharge Cell 4 Wetted Area (acres)*
1	0	0	0.4235	0	0
2	0	0	0.4235	0	0
3	0	0	0.4114	0	0
4	0	0	0.3993	0	0
5	0	0	0.3872	0	0
6	0	0	0.3751	0	0
7	0	0	0.363	0	0
8	0	0	0.363	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	0.3025	0	0
17	0	0	0.3025	0	0
18	0	0	0.3025	0	0
19	0	0	0.2904	0	0
20	0	0	0.2904	0	0
21	0	0	0.2904	0	0
22	0	0	0.2904	0	0
23	0	0	0.2904	0	0
24	0	0	0.2783	0	0
25	0	0	0.2783	0	0
26	0	0	0.2783	0	0
27	0	0	0.2783	0	0
28	0	0	0.2783	0	0
29	0	0	0.2662	0	0
30	0	0	0.2662	0	0
Total Wetted Acres	**0**	**0**	**9.7889**	**0**	**0**

October

Date	Equal. Basin Wetted Area (acres)*	Recharge Cell 1 Wetted Area (acres)*	Recharge Cell 2 Wetted Area (acres)*	Recharge Cell 3 Wetted Area (acres)*	Recharge Cell 4 Wetted Area (acres)*
1	0	0	0.2662	0	0
2	0	0	0.2662	0	0
3	0	0	0.2662	0	0
4	0	0	0.2541	0	0
5	0	0	0.2541	0	0
6	0	0	0.2541	0	0
7	0	0	0.2541	0	0
8	0	0	0.2541	0	0
9	0	0	0.2541	0	0
10	0	0	0.2541	0	0
11	0	0	0.242	0	0
12	0	0	0.242	0	0
13	0	0	0.242	0	0
14	0	0	0.242	0	0
15	0	0	0.242	0	0
16	0	0	0.242	0	0
17	0	0	0.242	0	0
18	0	0	0.2299	0	0
19	0	0	0.2299	0	0
20	0	0	0.2299	0	0
21	0	0	0.2299	0	0
22	0	0	0.2299	0	0
23	0	0	0.2299	0	0
24	0	0	0.2299	0	0
25	0	0	0.2178	0	0
26	0	0	0.2178	0	0
27	0	0	0.2178	0	0
28	0	0	0.2178	0	0
29	0	0	0.2178	0	0
30	0	0	0.2178	0	0
31	0	0	0.2178	0	0
Total Wetted Acres	**0**	**0**	**7.4052**	**0**	**0**

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

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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	0.2057	0	0
2	0	0	0.2057	0	0
3	0	0	0.2057	0	0
4	0	0	0.2057	0	0
5	0	0	0.2057	0	0
6	0	0	0.2057	0	0
7	0	0	0.2057	0	0
8	0	0	0.1936	0	0
9	0	0	0.1936	0	0
10	0	0	0.1936	0	0
11	0	0	0.1936	0	0
12	0	0	0.1936	0	0
13	0	0	0.1936	0	0
14	0	0	0.1936	0	0
15	0	0	0.1815	0	0
16	0	0	0.1815	0	0
17	0	0	0.1815	0	0
18	0	0	0.1815	0	0
19	0	0	0.1815	0	0
20	0	0	0.1815	0	0
21	0	0	0.1815	0	0
22	0	0	0.1694	0	0
23	0	0	0.1694	0	0
24	0	0	0.1694	0	0
25	0	0	0.1694	0	0
26	0	0	0.1694	0	0
27	0	0	0.1694	0	0
28	0	0	0.1573	0	0
29	0	0	0.1573	0	0
30	0	0	0.1573	0	0
Total Wetted Acres	**0**	**0**	**5.5539**	**0**	**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	0.1573	0	0
2	0	0	0.1573	0	0
3	0	0	0.1573	0	0
4	0	0	0.1452	0	0
5	0	0	0.1452	0	0
6	0	0	0.1452	0	0
7	0	0	0.1452	0	0
8	0	0	0.1452	0	0
9	0	0	0.1331	0	0
10	0	0	0.1331	0	0
11	0	0	0.1331	0	0
12	0	0	0.121	0	0
13	0	0	0.121	0	0
14	0	0	0.121	0	0
15	0	0	0.1089	0	0
16	0	0	0.1089	0	0
17	0	0	0.1089	0	0
18	0	0	0.0968	0	0
19	0	0	0.0968	0	0
20	0	0	0.0968	0	0
21	0	0	0.0847	0	0
22	0	0	0.0847	0	0
23	0	0	0.0847	0	0
24	0	0	0.0726	0	0
25	0	0	0.0726	0	0
26	0	0	0.0726	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**	**3.3517**	**0**	**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: 2018

	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	0.12	0	0	0.16	0	**0.2262**	0.15	0.0028275
2	0	0.11	0	0	0.16	0	**0.2262**	0.19	0.0035815
3	0	0.11	0	0	0.17	0	**0.2262**	0.2	0.00377
4	0	0.12	0	0	0.15	0	**0.2262**	0.2	0.00377
5	0	0.11	0	0	0.16	0	**0.2262**	0.19	0.0035815
6	0	0.1	0	0	0.17	0	**0.2262**	0.18	0.003393
7	0	0.1	0	0.0372	0.15	0.000465	**0.2262**	0.18	0.003393
8	0	0.09	0	0.2262	0.17	0.0032045	**0.2262**	0.14	0.002639
9	0	0.07	0	0.2262	0.18	0.003393	**0.2262**	0.21	0.0039585
10	0	0.04	0	0.2262	0.18	0.003393	**0.2262**	0.09	0.0016965
11	0	0.09	0	0.2262	0.16	0.003016	**0.2262**	0.15	0.0028275
12	0	0.09	0	0.2262	0.16	0.003016	**0.2262**	0.18	0.003393
13	0	0.12	0	0.2262	0.13	0.0024505	**0.2262**	0.2	0.00377
14	0	0.11	0	0.2262	0.01	0.0001885	**0.2262**	0.18	0.003393
15	0	0.12	0	0.2262	0	0	**0.2262**	0.19	0.0035815
16	0	0.13	0	0.2262	0	0	**0.2262**	0.2	0.00377
17	0	0.12	0	0.2262	0.1	0.001885	**0.2262**	0.21	0.0039585
18	0	0.12	0	0.2262	0.09	0.0016965	**0.2262**	0.15	0.0028275
19	0	0.13	0	0.2262	0.12	0.002262	**0.2262**	0.2	0.00377
20	0	0.06	0	0.2262	0.09	0.0016965	**0.2262**	0.22	0.004147
21	0	0.11	0	0.2262	0.14	0.002639	**0.2262**	0.22	0.004147
22	0	0.08	0	0.2262	0.13	0.0024505	**0.2262**	0.23	0.0043355
23	0	0.12	0	0.2262	0.17	0.0032045	**0.2262**	0.26	0.004901
24	0	0.19	0	0.2262	0.15	0.0028275	**0.2262**	0.13	0.0024505
25	0	0.14	0	0.2262	0.14	0.002639	**0.2262**	0.21	0.0039585
26	0	0.14	0	0.2262	0.17	0.0032045	**0.2514**	0.22	0.004609
27	0	0.14	0	0.2262	0.2	0.00377	**0.3144**	0.22	0.005764
28	0	0.16	0	0.2262	0.09	0.0016965	**0.3774**	0.25	0.0078625
29	0	0.26	0			0	0.4404	0.26	0.009542
30	0	0.17	0				**0.189**	0.27	0.0042525
31	0	0.16	0				**0**	0.25	0
Monthly Evapo-transpiration			**0**			**0.049098**			**0.119871**

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2018

	April			May			June		
Date	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)
1	0.252	0.2	0.0042	0	0.27	0	0.4284	0.35	0.012495
2	0	0.3	0	0	0.22	0	0.4347	0.37	0.01340325
3	0	0.27	0	0	0.28	0	0.441	0.37	0.0135975
4	0	0.26	0	0	0.3	0	0.4473	0.36	0.013419
5	0	0.27	0	0	0.35	0	0.4536	0.34	0.012852
6	0	0.28	0	0	0.34	0	0.4662	0.35	0.0135975
7	0	0.29	0	0	0.28	0	0.4788	0.37	0.014763
8	0	0.31	0	0	0.34	0	0.4914	0.35	0.0143325
9	0	0.29	0	0	0.34	0	0.504	0.32	0.01344
10	0	0.28	0	0	0.35	0	0.5166	0.38	0.016359
11	0	0.3	0	0	0.39	0	0.5418	0.36	0.016254
12	0	0.37	0	0	0.37	0	0.567	0.37	0.0174825
13	0	0.33	0	0	0.3	0	0.567	0.29	0.0137025
14	0	0.29	0	0	0.35	0	0.567	0.37	0.0174825
15	0	0.28	0	0	0.34	0	0.567	0.15	0.0070875
16	0	0.31	0	0	0.33	0	0.567	0.07	0.0033075
17	0	0.32	0	0.0252	0.37	0.000777	0.567	0.3	0.014175
18	0	0.28	0	0.063	0.33	0.0017325	0.567	0.33	0.0155925
19	0	0.35	0	0.126	0.33	0.003465	0.567	0.33	0.0155925
20	0	0.27	0	0.189	0.33	0.0051975	0.6042	0.36	0.018126
21	0	0.24	0	0.189	0.36	0.00567	0.6104	0.37	0.018820667
22	0	0.23	0	0.252	0.34	0.00714	0.6734	0.37	0.020763167
23	0	0.29	0	0.315	0.34	0.008925	0.6734	0.36	0.020202
24	0	0.29	0	0.378	0.35	0.011025	0.6734	0.35	0.019640833
25	0	0.29	0	0.441	0.35	0.0128625	0.6734	0.35	0.019640833
26	0	0.27	0	0.504	0.3	0.0126	0.7124	0.37	0.021965667
27	0	0.28	0	0.504	0.33	0.01386	0.7124	0.37	0.021965667
28	0	0.31	0	0.4725	0.35	0.01378125	0.7124	0.35	0.020778333
29	0	0.35	0	0.504	0.34	0.01428	0.7124	0.35	0.020778333
30	0	0.3	0	0.4725	0.36	0.014175	0.7124	0.36	0.021372
31				0.441	0.38	0.013965			
Monthly Evapo-transpiration			**0.0042**			**0.13945575**			**0.48298875**

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2018

	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	0.2714	0.36	0.008142	0.228	0.3	0.0057	0	0.14	0
2	0.3596	0.37	0.011087667	0.039	0.27	0.0008775	0	0.22	0
3	0.3596	0.36	0.010788	0.039	0.32	0.00104	0	0.22	0
4	0.4226	0.38	0.013382333	0	0.34	0	0	0.2	0
5	0.4856	0.28	0.011330667	0	0.35	0	0	0.24	0
6	0.4856	0.46	0.018614667	0	0.39	0	0	0.27	0
7	0.4856	0.33	0.013354	0	0.33	0	0	0.27	0
8	0.4856	0.33	0.013354	0	0.24	0	0	0.26	0
9	0.4856	0.22	0.008902667	0	0.19	0	0	0.3	0
10	0.5372	0.13	0.005819667	0	0.17	0	0	0.28	0
11	0.4794	0.15	0.0059925	0	0.24	0	0	0.28	0
12	0.2904	0.28	0.006776	0	0.3	0	0	0.27	0
13	0.2652	0.26	0.005746	0	0.29	0	0	0.26	0
14	0	0.07	0	0	0.3	0	0	0.28	0
15	0	0.11	0	0	0.17	0	0	0.26	0
16	0	0.24	0	0	0.22	0	0	0.26	0
17	0	0.28	0	0	0.26	0	0	0.28	0
18	0	0.3	0	0	0.29	0	0	0.28	0
19	0	0.28	0	0	0.3	0	0	0.03	0
20	0	0.22	0	0	0.29	0	0	0.2	0
21	0.039	0.32	0.00104	0	0.16	0	0	0.23	0
22	0.039	0.36	0.00117	0	0.2	0	0	0.31	0
23	0.039	0.36	0.00117	0	0.11	0	0	0.24	0
24	0.039	0.32	0.00104	0	0.2	0	0	0.18	0
25	0.039	0.34	0.001105	0	0.2	0	0	0.2	0
26	0.039	0.34	0.001105	0	0.23	0	0	0.24	0
27	0.039	0.32	0.00104	0	0.27	0	0	0.24	0
28	0.039	0.26	0.000845	0	0.27	0	0	0.23	0
29	0.039	0.3	0.000975	0	0.28	0	0	0.24	0
30	0.039	0.32	0.00104	0	0.25	0	0	0.19	0
31	0.228	0.3	0.0057	0	0.27	0			
Monthly Evapo-transpiration			**0.149520167**			**0.0076175**			**0**

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2018

	October			November			December		
Date	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)
1	0	0.01	0	0	0.13	0	0	0.04	0
2	0	0.07	0	0	0.14	0	0	0.06	0
3	0	0.16	0	0	0.15	0	0	0.08	0
4	0	0.2	0	0	0.14	0	0	0.07	0
5	0	0.2	0	0	0.14	0	0	0.05	0
6	0	0.21	0	0	0.14	0	0	0.06	0
7	0	0.08	0	0	0.14	0	0	0.01	0
8	0	0.16	0	0	0.16	0	0	0.08	0
9	0	0.17	0	0	0.14	0	0	0.08	0
10	0	0.16	0	0	0.15	0	0	0.09	0
11	0	0.11	0	0	0.15	0	0	0.06	0
12	0	0.1	0	0	0.14	0	0	0.1	0
13	0	0.02	0	0	0.26	0	0	0.09	0
14	0	0.12	0	0	0.16	0	0	0.07	0
15	0	0.15	0	0	0.12	0	0	0.03	0
16	0	0.14	0	0	0.13	0	0	0.07	0
17	0	0.21	0	0	0.13	0	0	0.09	0
18	0	0.18	0	0	0.12	0	0	0.1	0
19	0	0.15	0	0	0.11	0	0	0.08	0
20	0	0.23	0	0	0.11	0	0	0.1	0
21	0	0.18	0	0	0.11	0	0	0.04	0
22	0	0.14	0	0	0.02	0	0	0.11	0
23	0	0.03	0	0	0.09	0	0	0.1	0
24	0	0.14	0	0	0.1	0	0	0.09	0
25	0	0.15	0	0	0.11	0	0	0.09	0
26	0	0.15	0	0	0.1	0	0	0.03	0
27	0	0.15	0	0	0.11	0	0	0.06	0
28	0	0.15	0	0	0.11	0	0	0.08	0
29	0	0.14	0	0	0.1	0	0	0.07	0
30	0	0.13	0	0	0.04	0	0	0.07	0
31	0	0.17	0				0	0.04	0
Monthly Evapo-transpiration			**0**			**0**			**0**

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Standardized Reference Evapotranspiration

A New Procedure For Estimating Reference Evapotranspiration In Arizona

Introduction

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

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

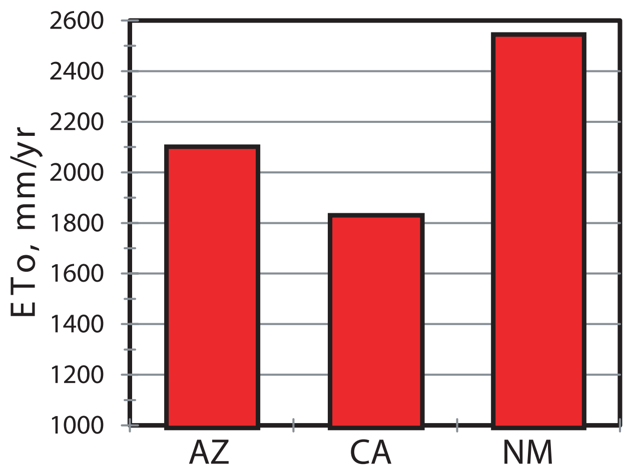

Figure 1. Reference ET (ETo) for Tucson for calendar year 1996 as computed using the published procedures for the public weather networks in Arizona, California, and New Mexico.

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

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

Standardized Reference Evapotranspiration Definition

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

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

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

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

Standardized Reference ET Equation

Generalized Form of Standardized Equation

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

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

Where:

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

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

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:

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

Where:

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

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

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

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

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

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

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

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

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

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

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

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

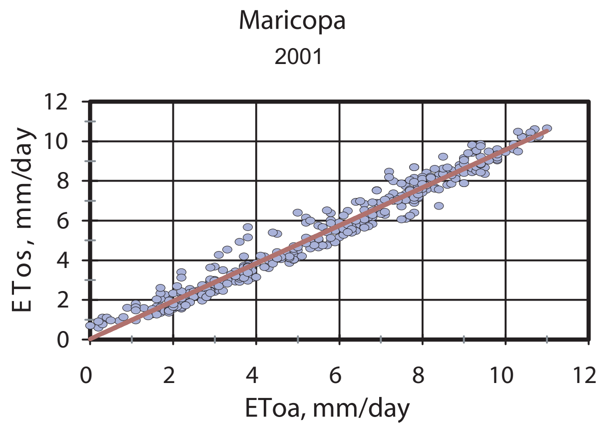

Figure 2. Reference evapotranspiration as computed using the ASCE standardized procedure (ETos) versus reference evapotranspiration computed using procedure employed by AZMET. The line represents the least squares regression line (ETos = 0.03 + 0.95 x ETоa; r^2 = 0.96).

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

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

Comparison of Standardized Reference ET with Original AZMET ETo

A logical question for users of ETo data would be how does the new standardized procedure (ETos) compare with the original AZMET ETo (ETоa) 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 ETоa for locations presently served by AZMET weather stations.

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

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

Long time users of AZMET data may have databases and spreadsheets that contain values of ETоa generated in past years. Users interested in converting ETоa 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 (EToa) computation procedures. Monthly ratios of ETos to EToa are provided in columns labeled "Ratio."

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

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

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

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

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

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

Crop Coefficients and ETos

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

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

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

$$ETc = Kc * EToa$$

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

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

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:

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

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:

$$Rn = Rns - Rnl \quad \text{(A2)}$$

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

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

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

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

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

$$Rnl = Rlu - Rld \quad \text{(A4)}$$

The daily value of Rnl is computed using:

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

where Rnl is net long-wave radiation in MJ m^{-2} d^{-1}, σ is the Stefan-Boltzman constant [= 4.901×10^{-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:

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

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

e_s: Saturation Vapor Pressure

Saturation vapor pressure is computed using:

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

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

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

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

ea: Actual Vapor Pressure

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

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

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

APPENDIX E
Water Level Measurements

USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2018

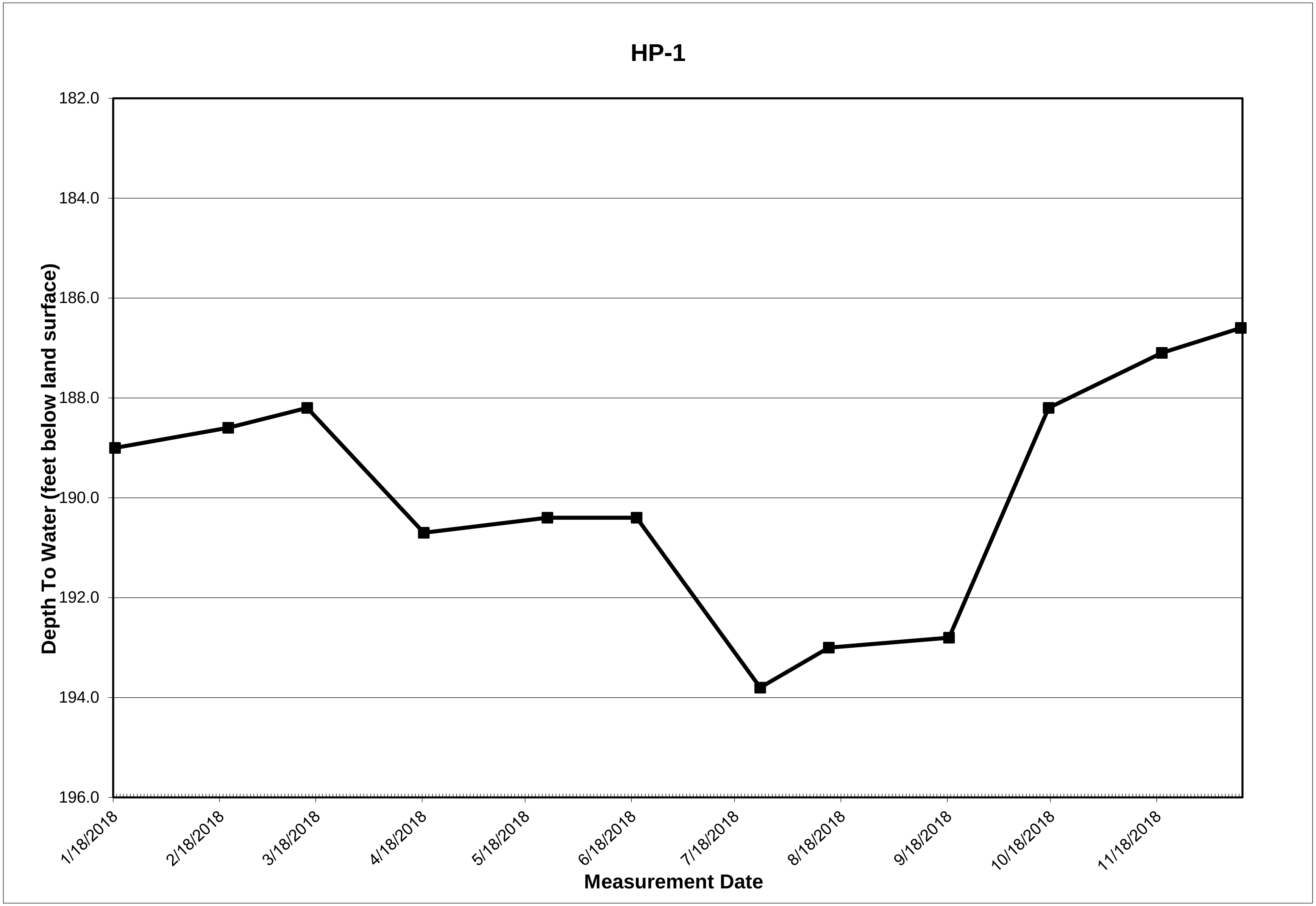
Monitor Point ID	**HP-1**
ADWR Registration Number	55-574110
Cadastral Location	D(11-11)33cad
Measuring Point Elevation (feet amsl)	1985.17
Measuring Point Description	top of port
Measuring Point Height (ft)	
Land Surface Elevation at Wellhead (feet amsl)	1985.17
Permit Alert Level (feet bls)	30
Permit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

Measurement Date	DTW (feet below MP)	DTW (feet bls)	Elevation (feet amsl)	Exceedance Status
1/18/2018	189.0	189.0	1796.2	
2/20/2018	188.6	188.6	1796.6	
3/15/2018	188.2	188.2	1797.0	
4/18/2018	190.7	190.7	1794.5	
5/24/2018	190.4	190.4	1794.8	
6/19/2018	190.4	190.4	1794.8	
7/25/2018	193.8	193.8	1791.4	
8/14/2018	193.0	193.0	1792.2	
9/18/2018	192.8	192.8	1792.4	
10/17/2018	188.2	188.2	1797.0	
11/19/2018	187.1	187.1	1798.1	
12/12/2018	186.6	186.6	1798.6	

* 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: 2018



USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2018

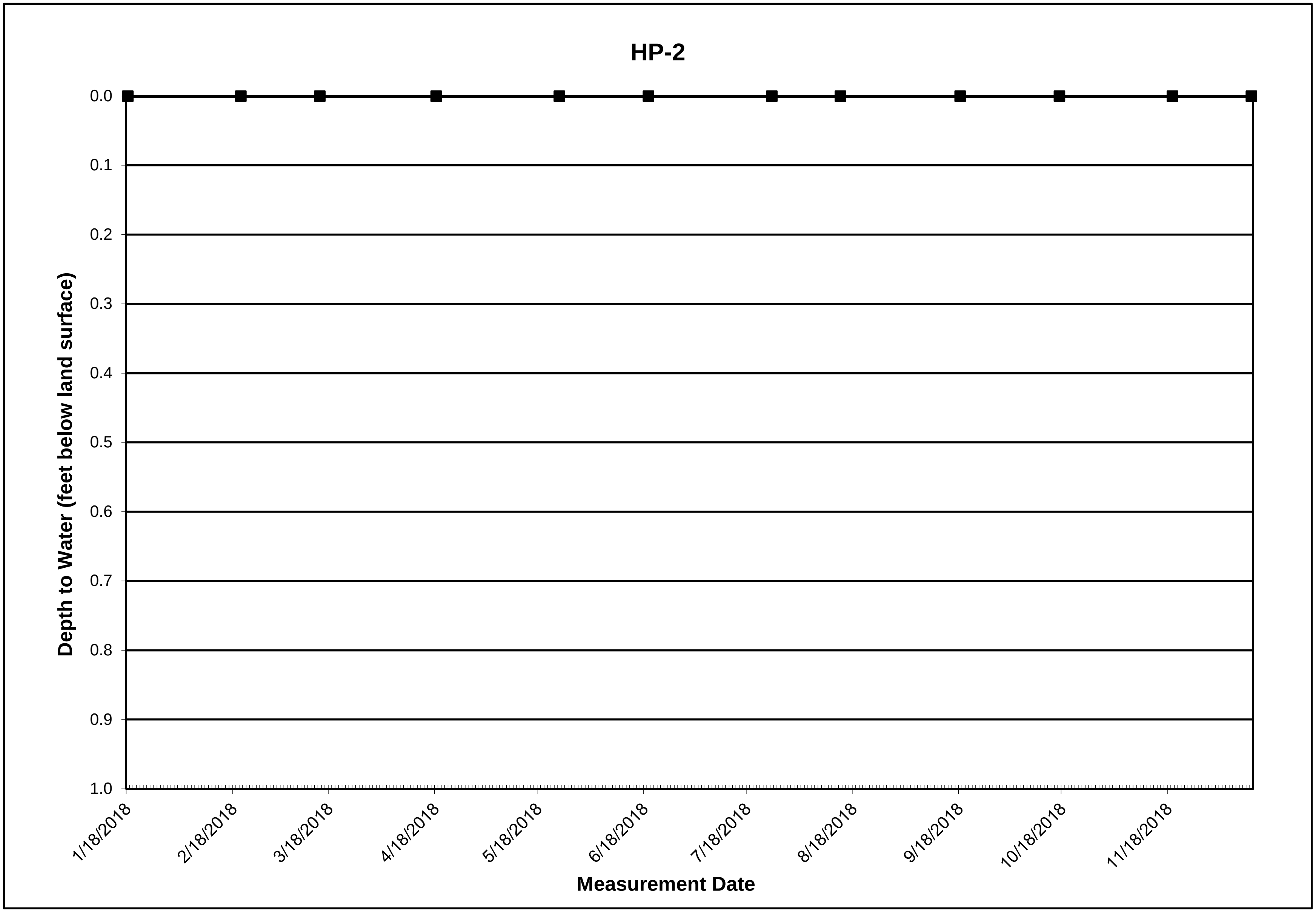
Monitor Point ID	HP-2
ADWR Registration Number	55-593607
Cadastral Location	D(11-11)33cad
Measuring Point Elevation (feet amsl)	1986.75
Measuring Point Description	top of port
Measuring Point Height (ft)	
Land Surface Elevation at Wellhead (feet amsl)	1986.75
Permit Alert Level (feet bls)	30
Permit OPL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

Measurement Date	**DTW (feet below MP)**	**DTW (feet bls)**	**Elevation (feet amsl)**	**Exceedance Status**
1/18/2018	dry			
2/20/2018	dry			
3/15/2018	dry			
4/18/2018	dry			
5/24/2018	dry			
6/19/2018	dry			
7/25/2018	dry			
8/14/2018	dry			
9/18/2018	dry			
10/17/2018	dry			
11/19/2018	dry			
12/12/2018	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: 2018



USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0008
Year: 2018

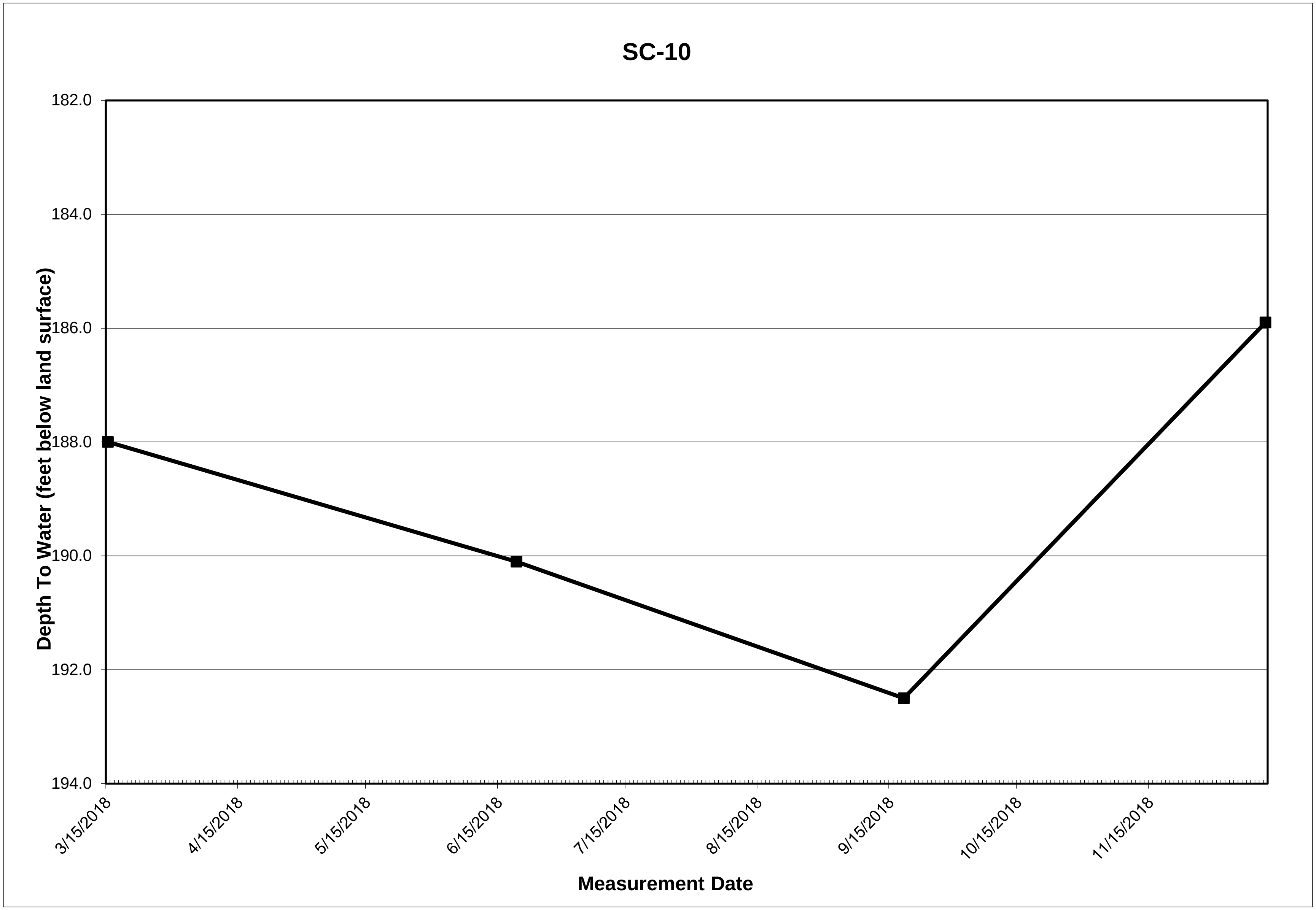
Monitor Point ID	SC-10
ADWR Registration Number	55-520129
Cadastral Location	D(11-11)33bcb
Measuring Point Elevation (feet amsl)	1978.36
Measuring Point Description	top of port
Measuring Point Height (ft)	
Land Surface Elevation at Wellhead (feet amsl)	1978.36
Permit Alert Level (feet bls)	30
Permit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

Measurement Date	**DTW (feet below MP)**	**DTW (feet bls)**	**Elevation (feet amsl)**	**Exceedance Status**
3/15/2018	188.0	188.0	1797.2	
6/19/2018	190.1	190.1	1795.1	
9/18/2018	192.5	192.5	1792.7	
12/12/2018	185.9	185.9	1799.3	

* 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: 2018



APPENDIX F

Infiltration Rate Data & Calculations

INFILTRATION RATE DATA AND CALCULATIONS

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0008

Year: 2018

	Net Recharge Volumes (ac-ft)	Total Wetted Acreages (ac-days)	Infiltration Rate (ft/day)	Quarterly Average Infiltration Rate (ft/day)
January	50.6	15.5	3.27	
February	95.4	33.8	2.82	
March	154.1	39.7	3.88	3.37
April	115.1	40.6	2.83	
May	67.5	47.6	1.42	
June	73.0	49.8	1.47	1.85
July	73.1	89.5	0.82	
August	-0.8	27.9		
September	-0.2	9.8		0.57
October	-0.1	7.4		
November	-0.1	5.6		
December	0.0	3.4		

Totals	**627.7**	**370.6**	**1.69**