# ANNUAL MONITORING REPORT
# 2013

# MARANA HIGH PLAINS EFFLUENT RECHARGE PROJECT

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



*Prepared by*


**David Scalero, Principal Hydrologist**
**Pima County Regional Flood Control District**
**Water Resources Division**
**97 E. Congress St., 3rd Floor**
**Tucson, Arizona 85701**


*for*

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

**March 27, 2014**

TABLE OF CONTENTS

# 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 revegetate the area outside the recharge basins with plants that will improve wildlife habitat value and, once established, could survive if the recharge activities cease;

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

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

The MHPERP facility is comprised of one settling basin (equalization basin) and four spreading basins (recharge cells), totaling 4.5 acres of recharge area (**Figure 2**). A comprehensive description of the MHPERP and the related monitoring plan was provided to the Arizona Department of Water Resources (ADWR) in support of the Constructed Underground Storage Facility (USF) Permit Application for the project filed in June 2007. In addition to the USF Permit (No. 71-563876.0007), the facility has an Aquifer Protection Permit (No. P-103195) from the Arizona Department of Environmental Quality (ADEQ) that authorizes the discharge of treated effluent into the aquifer.

The facility has been operating since February 2003, first as a pilot project and then as a constructed recharge project. In accordance with Sections 2 and 3 of the USF Permit (all versions), this is the eleventh annual report for the MHPERP. This report includes all of the data that was collected during the 2013 Calendar Year.

## 2.0 PROJECT OPERATIONS

A modified USF Permit was approved and signed by the ADWR Assistant Director, Ms. Sandra Fabritz-Whitney, on November 24, 2008. This permit authorizes PCRFCD to store effluent at MHPERP over a twenty-year term (through November 24, 2028) or until the Operation Prohibition Limits are met. Maximum annual storage at the facility is based on three constructed phases as follows:

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

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

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

The facility was operated per Phase 3 of the permit throughout the 2013 Calendar Year. Contingency plans are in place within the current USF Permit to allow the District to perform enhancement functions as needed to maximize recharge at the facility.

### 2.1 Water Delivery

Water is delivered to the MHPERP via the "oxbow" channel, a remnant channel of the Santa Cruz River from when the riverbed was less incised and the channel meandered back and forth across the floodplain. A berm consisting of streambed materials is used to divert some of the effluent flowing down the main channel of the Santa Cruz River into the oxbow channel. Sources of the effluent discharges are the Roger Road Wastewater Treatment Plant and the Ina Road Wastewater Treatment Plant, which are located approximately 15 miles and 10 miles upstream of the diversion structure respectively. The effluent flows down the oxbow channel for about one mile before reaching MHPERP.

A constructed wet well collects the oxbow channel flows and two non-clogging, submersible pumps convey the effluent through an 8-inch line into an equalization basin. The equalization basin is used to provide a more constant source of available effluent for recharge and to help serve as a settling basin for removing particulate materials that could clog the recharge cells. A level sensor is installed in this basin to automatically turn the pumps on and off based on levels within the oxbow channel and the equalization basin. From the equalization basin, the effluent passes through a 16-inch isolation valve into the main distribution line, which feeds into each of the four recharge cells through motorized butterfly valves. A level sensor is installed at each cell to automatically open and close the valves based on pre-set water levels. The valves are closed, either using an electronic switch or manually cranking the turn valve, by the daily operator when the cells are scheduled for a drying cycle.

Deliveries to MHPERP are based on the daily cycle of discharges from the treatment plants to the Santa Cruz River. Peaks in water levels at this site normally occur in the late morning and early evening hours. Deliveries to the facility are impacted by storm water events in the Santa Cruz River that demolish the earthen structure used to divert flows into the oxbow channel. Malfunctioning pumps, faulty valve controls, and basin maintenance can also disrupt deliveries to the recharge cells. Details of all the delivery interruptions for Calendar Year 2013 are provided in Section 6.0 (Facility Inspections and Maintenance) of this report.

## 2.2 Inflow Volumes

Water deliveries into the MHPERP facility are measured using a Magnetflow® Mag Meter installed within the main line that runs from the pumps to the equalization basin (FMeq). The daily totals are read on-site by the facility operator, who compiles the data onto a daily log sheet. The daily log sheets are transmitted to PCRFCD staff on a weekly basis.

**Appendix A** contains the daily flow meter readings and volumes for Calendar Year 2013. 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 2013 is 514.4 acre-feet (AF). Water volumes delivered for recharge by month are as follows: January – 37.2 AF, February – 25.1 AF, March – 17.5 AF, April – 49.8 AF, May – 82.6 AF, June – 71.7 AF, July – 14.1 AF, August – 0.0 AF, September – 0.0 AF, October – 69.2 AF, November – 68.4 AF, and December – 78.6 AF. The total amount (500.3 AF after subtracting evaporation/evapotranspiration) was stored for the Pima County Regional Wastewater Reclamation Department (formerly Pima County Wastewater Management), who has a Water Storage Permit (No. 73-563876.0200) for the facility.

## 2.3 Evaporation/Evapotranspiration

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

Daily and monthly evapotranspiration volumes for the vegetated basins are provided in **Appendix D**. Evapotranspiration for each recharge cell was based on the percentage of vegetation within each basin, which was determined on a monthly basis during routine site inspections. The evapotranspiration volumes are calculated using the daily reference evapotranspiration values determined by the Arizona Meteorological Network (AZMET) at their Tucson weather station (**Figure 3**).[1] AZMET determines reference evapotranspiration (ETo) using a modification to the Penman Equation developed for the California Irrigation Management Information System (CIMIS). An explanation of the procedures used in this computation is also provided in **Appendix D**. No multiplication factor was used in the calculation of reference evapotranspiration (ETo) for the MHPERP because there are no available crop coefficients for the native vegetation in this region.[2]

---

[1] The Marana weather station has been out of service since December 14, 2011 so reference evapotranspiration values were collected from the Tucson weather station for Calendar Year 2013.

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

## 2.4 Recharge Volumes

The water quantity reporting summary is provided at the end of **Appendix A**. This summary includes the monthly net recharge volumes for the facility, which are the sum of the monthly volumes delivered to the recharge cells less the monthly evaporation and evapotranspiration losses. Quarterly sums and the annual sum are also provided on this worksheet. The net recharge (effluent stored) for the facility during the 2013 Calendar Year is 500.3 AF.

## 3.0 HYDROLOGIC MONITORING

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

## 3.1 Basin Water Levels

Water levels within the equalization basin are expected to fluctuate from one to five feet above the bottom elevation of 1,984 feet above mean sea level. Water depths in Recharge Cell 1 can fluctuate from 4 to 5 feet during the wet cycle, while water depths in Recharge Cell 2 can fluctuate from about 5 to 6 feet during the wet cycle.[3] Water depths in Recharge Cells 3 and 4 are expected to fluctuate from six to twenty inches during the wet cycles.[4] Water level sensors within the basins are programmed to automatically open and close the motorized butterfly valves to maintain these ranges if needed. Basin water levels are observed visually on a daily basis to insure that the sensors are working properly. Any malfunctioning systems (valves and level sensors) are operated on a manual basis by the daily operator, based on basin level conditions observed, until they are repaired.

## 3.2 Regional Groundwater Levels

In 2013, groundwater levels were measured for two monitoring wells, one on-site (HP-1) and one off-site (SC-10). Both wells were measured by PCRFCD personnel using either an electric sounder or contact meter. HP-1 was measured on a monthly basis and SC-10 was measured on a quarterly basis.

**Appendix E** contains the water level data and hydrographs for the on-site and off-site monitor wells. All of the monitor wells have alert levels of 30 feet below land surface (bls) and operation prohibition limits of 20 feet bls. Alert levels for the monitoring wells were not exceeded during the 2013 Calendar Year.

---

[3] Water depths have been significantly increased in these two basins due to enhancement activities, but the level sensors are still at the original elevation of 1982 feet.

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

## 3.3 Perched Groundwater Occurrence

**Appendix E** also contains the monitoring data and hydrograph for the one piezometer (HP-2) used to assess perched water conditions at the facility. A trace amount of water was measured in this well during the entire 2013 Calendar Year (depth to water ranged from 81.6 feet bls to 81.7 feet bls. The alert level and operation prohibition limit for this well are set at 30 feet bls and 20 feet bls respectively.

# 4.0 INFILTRATION RATE ASSESSMENT

The average monthly, quarterly and annual infiltration rates for the entire facility during the 2013 Calendar Year are displayed in **Appendix F**. Infiltration rates were estimated using the "volumetric" method, which is simply the total daily inflow divided by the wetted acreage. Total wetted acreage for the facility is a summation of the wetted acreages for the individual recharge cells, which is described below.

Average monthly, quarterly and annual infiltration rates for each of the recharge cells are also displayed in **Appendix F**. The total wetted acreage used to calculate the infiltration rate within each recharge cell is determined using the level sensor on the area/velocity flow meter combined with known topography of the recharge cell bottom. Data downloaded from the flow meter is used to determine average daily water levels in the recharge cells. 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. Daily visual estimates are also provided by the facility operator to support the data collected by the flow meters.

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 method as stated above.

In 2013, monthly infiltration rates for the project ranged from 0.00 feet per day (August and September) to 2.07 feet per day (October). The average infiltration rate for the year was 0.73 feet/day, which is 0.1 feet per day higher than last year's annual average rate. The lowest infiltration rates in 2013 occurred during the Third Quarter, which is the time of year that is expected to have the least amount of infiltration.

Infiltration was the highest in Recharge Cell 2 (2.37 feet/day annual average), which has a bottom substrate that is at or close to coarse sands and gravels. Recharge Cell 1 also had a high rate (1.38 feet/day), which was the result of over-excavation during annual basin maintenance activities in late September and early October that exposed some coarse sands and gravels. Recharge Cell 3, which has a bottom elevation within four to six feet of coarse sands and gravels, had an annual average infiltration rate of 0.63 feet/day. Recharge Cell 4 has the greatest depth to the coarse sands and gravels, approximately 7.5 to 8 feet, which accounts for the low annual average infiltration rate within this basin (0.20 feet/day). The equalization basin had the lowest annual average infiltration rate (0.07 feet/day), but this is primarily due to its function as a settling basin for fine deposits and to no maintenance being performed within the basin bottom during the Calendar Year.

## 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 Organic Compounds (VOCs). Samples are collected from the source water inflow and from monitor well HP-1. Nitrogen forms are monitored more frequently because of the high nitrogen content in effluent water, and the potential for recharge to increase the nitrogen content in the local aquifer through leaching of nearby agricultural soils. Water quality sampling at the MHPERP also serves as a tool for studying nitrogen transformations in riparian and aquatic ecosystems, to determine if nitrogen levels can be reduced through the wetland recharge process.

### 5.2 Chemical Analyses Results

**Table 1** summarizes the results from samples taken during the 2013 Calendar Year. Samples were taken at the oxbow channel (Source Water) and at the compliance well (HP-1). No water could be discharged from HP-1 in December due to leaky discharge pipes and a badly worn out rotor on the pump. As a result, there were no monthly samples for nitrogen analytes and total coliform as well as no Fourth Quarter samples for total metals, free cyanide and total fluoride taken from the compliance well. There were no disruptions for sampling the Source Water.

There were no exceedances of the aquifer quality limits in 2013 for both the Source Water and HP-1. Therefore, there was no violation of the Aquifer Protection Permit (APP) during Calendar Year 2013.

## 6.0 FACILITY INSPECTIONS

Inspections of the facility equipment and functions are required by the APP on a weekly basis. The facility operator at MHPERP performs 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 weekly investigations of the facility to insure quality of the data collected and note any general maintenance needs.

**Table 2** lists the problems that occurred throughout the 2013 Calendar Year and the solutions performed to resolve them. There were little to no effluent deliveries made to the project from late-January through mid-February due to washout of the earthen diversion berm and subsequent turbid flows in the oxbow channel. Facility operations were restarted on February 20$^{th}$ although there were several days of no flow into the facility in March and April due to low infiltration rates in the recharge cells. The earthen diversion berm was washed out on July 6$^{th}$, resulting in no available effluent for the project until mid-August. Although the berm was repaired in mid-August, no deliveries were made to the recharge basins because they were scheduled for maintenance activities to help remove clogging soil layers and increase infiltration rates. Effluent delivery to the facility was restarted on October 7$^{th}$ after recharge Cells 3 and 4 were scraped and cross-ripped; Cells 1 and 2 were scraped and cross-ripped by late October. Effluent deliveries were halted for a couple of short durations in November and December due to small washouts of the earthen diversion berm and oxbow channel bank.

## 7.0 CONCLUSIONS

The volume of water stored at MHPERP for Calendar Year 2013 is 500.3 AF. This is almost 42 AF less than last year's total of 542.2 AF, but it is the second largest total since facility operations began in 2013. The facility operated under Phase 3 of the modified USF Permit No. 71-563876.0007 for the entire Calendar Year, which allowed the District to store a maximum of 600 AF per year.

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

Recharge Cell 2 remains as the best performing basin, having contributed almost 56% of the total amount of effluent stored at the facility over Calendar Year 2013. The large amount of recharge contributed by Recharge Cell 2 is due to the exposure of coarser grained sands and gravels via excavation work as part of Phase 3 of the USF Permit in 2010 and from continued annual maintenance of the basin through October 2013. Recharge Cell 1 contributed just over 17% to the total volume recharged at the project, while Recharge Cells 3 & 4 contributed 14% and 11% respectively. The equalization basin, which did not undergo any maintenance during the Calendar Year, provided only a small amount to the total volume (about 2%).

Infiltration rates were at their highest directly after maintenance activities were performed on each of the basins, and then decreased steadily (and sometimes rapidly) over time. The average annual infiltration rate for the entire facility in 2013 was 0.73 feet/day, which was an increase from last year (total annual rate of 0.63 feet/day), but still below the highest annual infiltration rate of 0.76 feet/day that was recorded in 2008. Recharge Cell 2 had the highest annual infiltration rate in 2013 (2.37 feet/day), while Recharge Cell 4 had the lowest (0.20 feet/day).[5] Excavation within Recharge Cells 1 and 2, and thus exposure of coarse sands and gravels, over the last two years has significantly helped the overall infiltration rate for this facility. However, the very low rate in Recharge Cell 4, the largest recharge basin, continues to keep the overall infiltration rate below one foot per day.

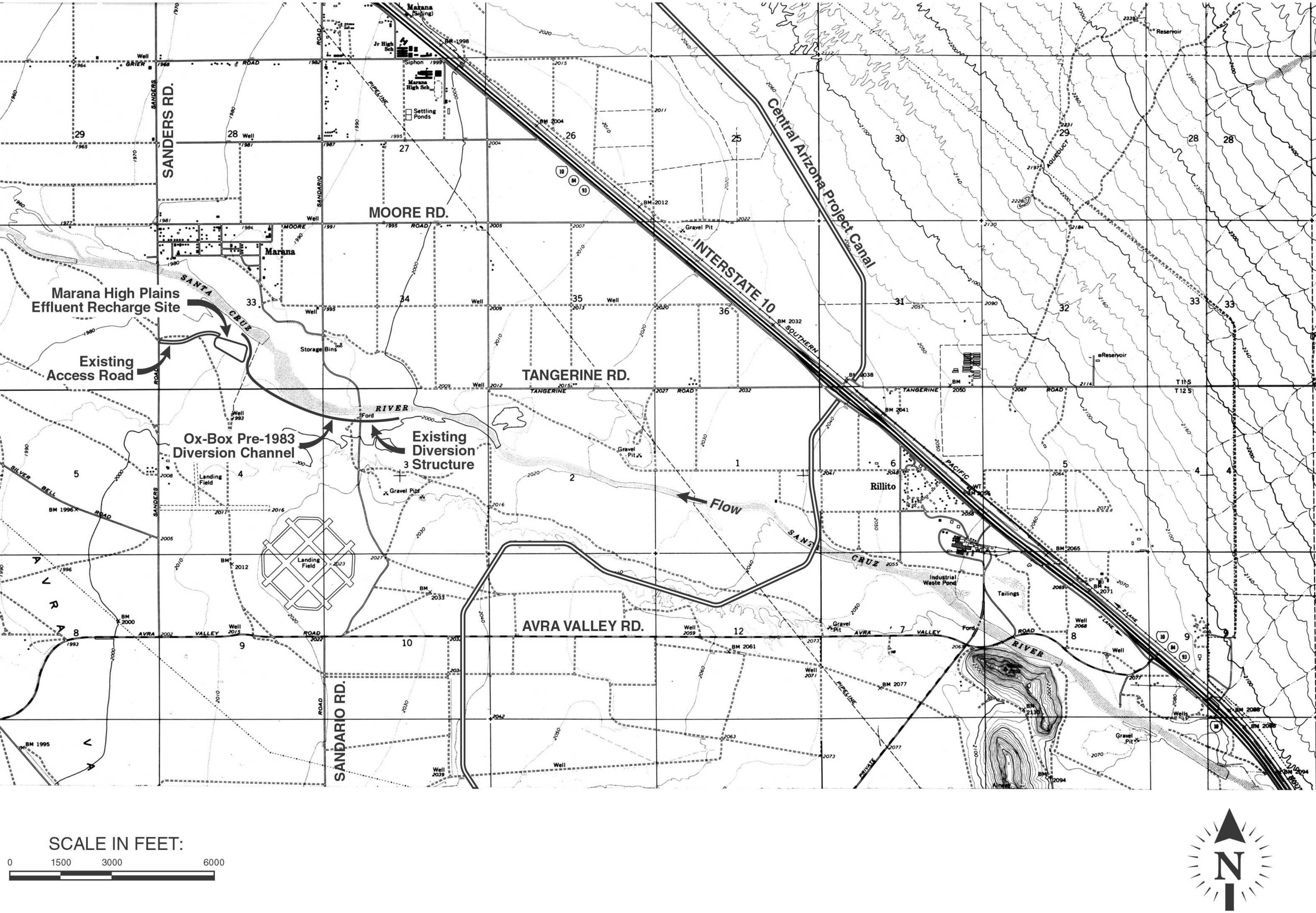
There was a total of 134 days (4.4 months) when no effluent deliveries were made to the project. About 60 percent of this down time (81 days) was due to washout of the diversion berm by storm water flows during the months of January, July, August, September and December. The remaining 40 percent of the down time was due to maintenance activities in the recharge cells. Recharge cell maintenance continues to have a significant effect on infiltration rates by frequently breaking up the clogging layers that form in the basin bottoms. Additional excavation within Recharge Cell 1 during maintenance activities in September through October greatly increased infiltration by exposing more coarse sands and gravels in this basin. Staff will investigate the need for additional excavation in Recharge Cell 3 to help reach the overall goal of 600 AF per year of effluent recharge at this facility.

---

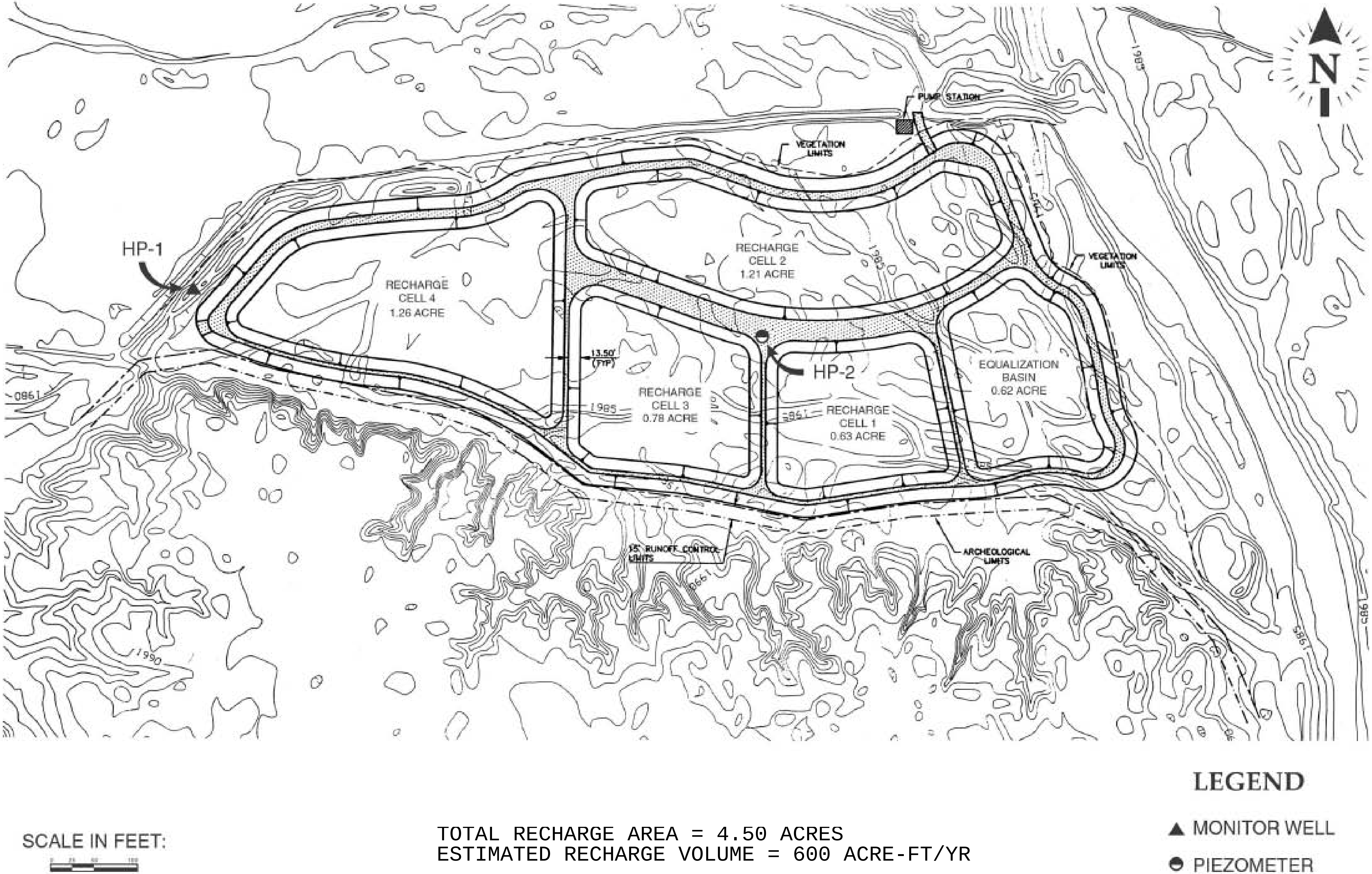
[5] The equalization basin actually had the lowest infiltration rate recorded (0.07 feet/day), but this basin is primarily used for purposes other than recharge to the aquifer so it is not included in the comparison of infiltration rates.

# FIGURES

# FIGURE 1
## Location Map

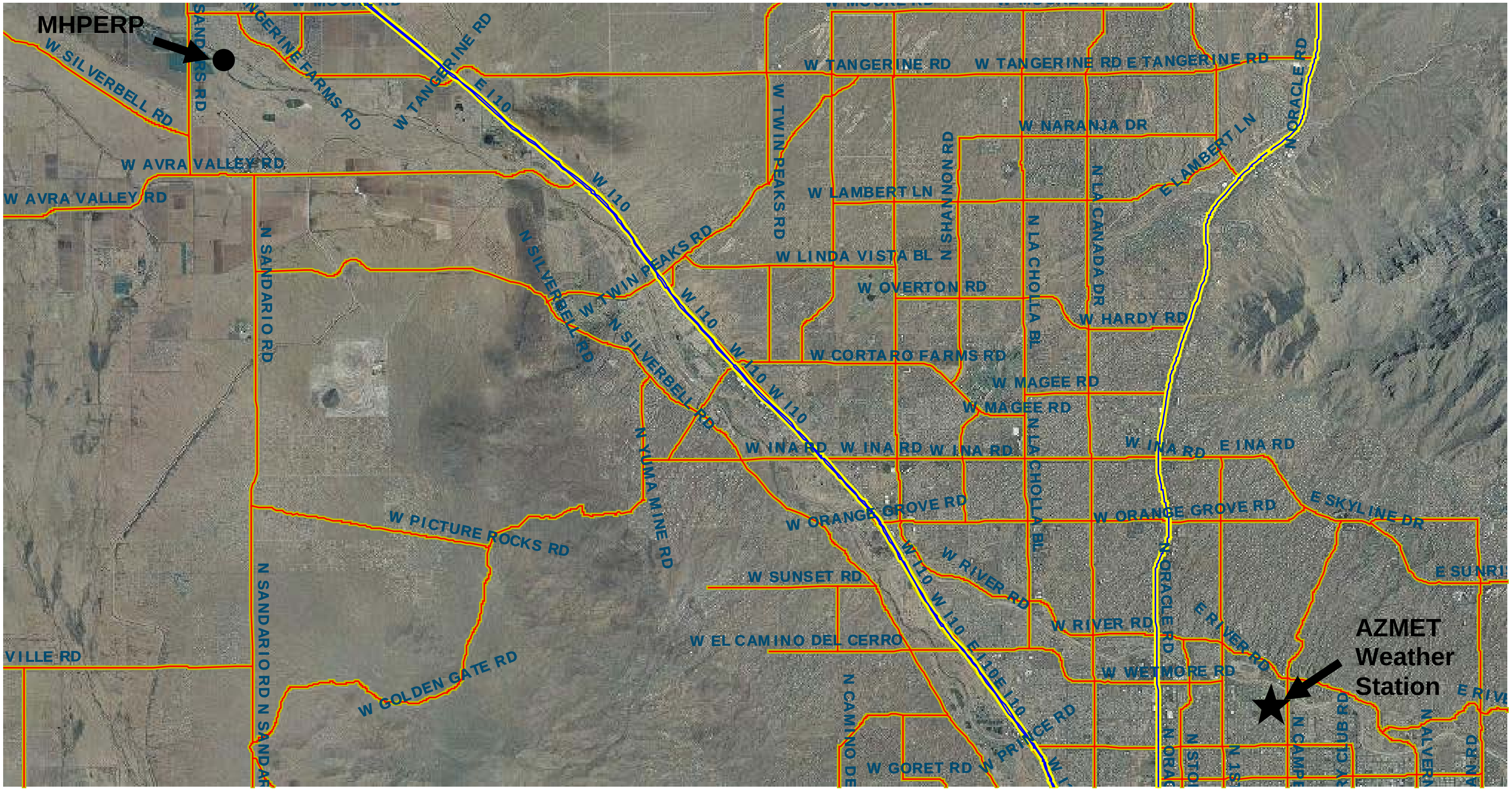


# FIGURE 2
## Facility Map

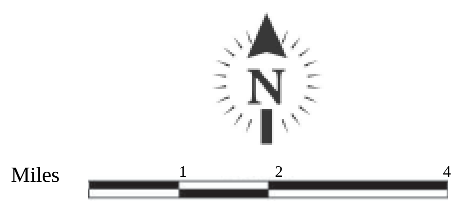



TOTAL RECHARGE AREA = 4.50 ACRES
ESTIMATED RECHARGE VOLUME = 600 ACRE-FT/YR

# FIGURE 3
# Tucson AZMET Weather Station
# Location Map

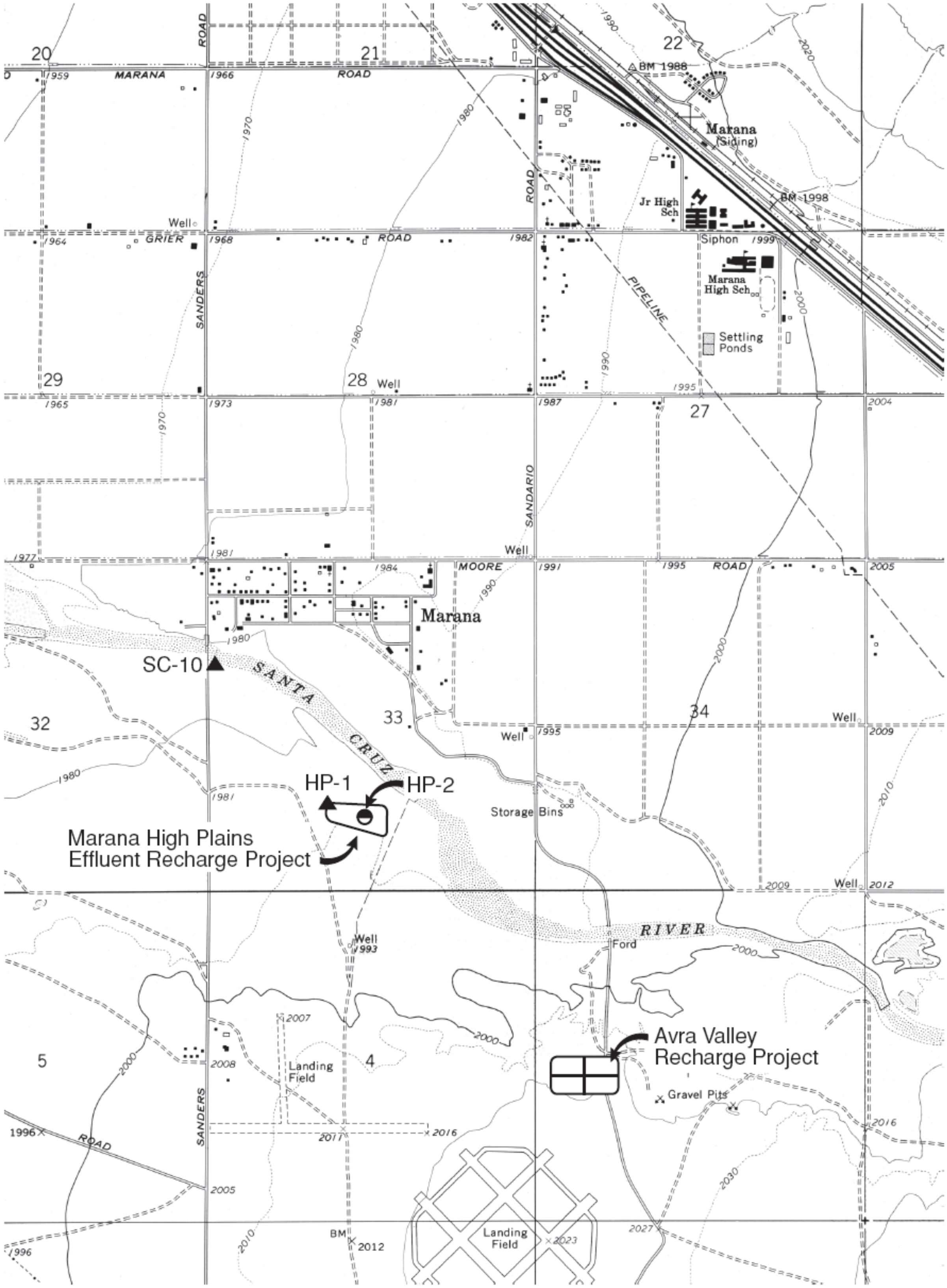



| |
|---|
| **Date on line:** Jan 1 1987 (Day of Year = 1)<br>**Location:** 1 km (p.6 miles) northwest of Intersection of Campbell Ave. & Roger Rd.<br>**Elevation:** 713 meters (2339 ft)<br>**Coordinates:** Latitude = 32º 16’ 49” N; Longitude = 110º 56’ 45” W<br>**Cooperator:** Campus Agricultural Center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




**LEGEND**

★ **Weather Station**




# FIGURE 4

**Marana High Plains**
**Effluent Recharge Project**
**Monitor Wells Location Map**

## LEGEND

▲ MONITOR WELL

◓ PIEZOMETER

N

Miles .5 1 2

SCALE:

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 2013**

| Constituent | Unit | Discharge Limit | Sample Date & Results | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Jan-13 | Feb-13 | Mar-13 | Apr-13 | May-13 | Jun-13 | Jul-13 | Aug-13 | Sep-13 | Oct-13 | Nov-13 | Dec-13 |
| **Nutrients** | | | | | | | | | | | | | | |
| Total Nitrogen[1] | mg/l | N/A | 23.5 | 16.7 | 22.9 | 21.9 | 17.8 | 16.6 | 11.7 | 9.8 | 10.0 | 8.9 | 17.8 | 10.0 |
| Nitrate-Nitrite as N | mg/l | N/A | 4.5 | 4.7 | 7.9 | 9.9 | 8.3 | 9.5 | 8.8 | 9.8 | 10.0 | 7.6 | 8.1 | 10.0 |
| Total Kjeldahl Nitrogen (TKN) | mg/l | N/A | 19.0 | 12.0 | 15.0 | 12.0 | 9.5 | 7.1 | 2.9 | < 1.0 | < 1.0 | 1.3 | 9.7 | < 1.0 |
| **Metals (Total)** | | | | | | | | | | | | | | |
| Free Cyanide | mg/l | 0.2 | No Event | < 0.050 | No Event | No Event | < 0.050 | No Event | No Event | No Event | < 0.050 | No Event | No Event | < 0.050 |
| Total Fluoride | mg/l | 4 | No Event | < 0.040 | No Event | No Event | 0.054 | No Event | No Event | No Event | 0.49 | No Event | No Event | 0.54 |
| Arsenic | mg/l | 0.05 | No Event | 0.0044 | No Event | No Event | 0.0036 | No Event | No Event | No Event | 0.003 | No Event | No Event | 0.0031 |
| Barium | mg/l | 2 | No Event | 0.1 | No Event | No Event | 0.066 | No Event | No Event | No Event | 0.085 | No Event | No Event | 0.073 |
| Beryllium | mg/l | 0.004 | No Event | < 0.0010 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | < 0.0010 | No Event | No Event | < 0.0010 |
| Cadmium | mg/l | 0.005 | No Event | < 0.0010 | No Event | No Event | < 0.0001 | No Event | No Event | No Event | < 0.0010 | No Event | No Event | < 0.0010 |
| Chromium | mg/l | 0.1 | No Event | 0.0045 | No Event | No Event | 0.0008 | No Event | No Event | No Event | < 0.0020 | No Event | No Event | 0.002 |
| Lead | mg/l | 0.05 | No Event | 0.012 | No Event | No Event | 0.0014 | No Event | No Event | No Event | 0.0011 | No Event | No Event | 0.0021 |
| Thallium | mg/l | 0.002 | No Event | < 0.0010 | No Event | No Event | < 0.0001 | No Event | No Event | No Event | < 0.0010 | No Event | No Event | < 0.0010 |
| Nickel | mg/l | 0.1 | No Event | 0.006 | No Event | No Event | 0.0021 | No Event | No Event | No Event | 0.0048 | No Event | No Event | 0.0043 |
| Antimony | mg/l | 0.006 | No Event | < 0.0030 | No Event | No Event | 0.00042 | No Event | No Event | No Event | < 0.0010 | No Event | No Event | < 0.0030 |
| Selenium | mg/l | 0.05 | No Event | < 0.0030 | No Event | No Event | 0.00058 | No Event | No Event | No Event | < 0.0020 | No Event | No Event | < 0.0020 |
| Mercury | mg/l | 0.002 | No Event | < 0.00020 | No Event | No Event | < 0.00020 | No Event | No Event | No Event | < 0.00020 | No Event | No Event | < 0.00020 |
| **Volatile Organic Compounds (VOCs)** | | | | | | | | | | | | | | |
| para-Dichlorobenzene | mg/l | 0.075 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| Dichloromethane | mg/l | 0.005 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0030 | No Event | No Event |
| o-Dichlorobenzene | mg/l | 0.6 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| Carbon tetrachloride | mg/l | 0.005 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0030 | No Event | No Event |
| Toluene | mg/l | 1 | No Event | No Event | < 0.0020 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| Benzene | mg/l | 0.005 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| Monochlorobenzene | mg/l | 0.1 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| Ethylbenzene | mg/l | 0.7 | No Event | No Event | < 0.0020 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| Tetrachloroethylene | mg/l | 0.005 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| 1,1-Dichloroethylene | mg/l | 0.007 | No Event | No Event | < 0.0020 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0050 | No Event | No Event |
| 1,1,1-Trichloroethane | mg/l | 0.2 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| 1,1,2-Trichloroethane | mg/l | 0.005 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| 1,2-Dichloroethane | mg/l | 0.005 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| 1,2-Dichloropropane | mg/l | 0.005 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| 1,2,4-Trichlorobenzene | mg/l | 0.07 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0050 | No Event | No Event |
| Vinyl Chloride | mg/l | 0.002 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0010 | No Event | No Event |
| Trichloroethylene | mg/l | 0.005 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| Hexachlorobenzene | mg/l | 0.001 | No Event | No Event | < 0.00080 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.00081 | No Event | No Event |
| cis--1,2-Dichloroethylene | mg/l | 0.07 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| Styrene | mg/l | 0.1 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| Xylenes (Total) | mg/l | 10 | No Event | No Event | < 0.0030 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.010 | No Event | No Event |
| Trihalomethane (TTHM) | mg/l | 0.1 | No Event | No Event | < 0.0020 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0040 | No Event | No Event |
| trans-1,2-Dichloroethylene | mg/l | 0.1 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| Hexachlorocyclopentadiene | mg/l | 0.05 | No Event | No Event | < 0.00259 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0051 | No Event | No Event |

No Event = No sample taken (No flow, HP-1 pump not operating, or no 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 2013

| Constituent | Unit | Aquifer Quality Limit | Sample Date & Results | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Jan-13 | Feb-13 | Mar-13 | Apr-13 | May-13 | Jun-13 | Jul-13 | Aug-13 | Sep-13 | Oct-13 | Nov-13 | Dec-13* |
| **Nutrients** | | | | | | | | | | | | | | |
| Total Nitrogen[1] | mg/l | 10 | 2.0 | 1.8 | 3.6 | 1.6 | 2.0 | < 2.0 | < 2.0 | 1.9 | 1.9 | 2.0 | 2.1 | No Event |
| Nitrate-Nitrite as N | mg/l | 10 | 2.0 | 1.8 | 1.8 | 1.6 | 2.0 | < 2.0 | < 2.0 | 1.9 | 1.9 | 2.0 | 2.1 | No Event |
| Total Kjeldahl Nitrogen (TKN) | mg/l | N/A | < 1.0 | < 1.0 | 1.8 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | No Event |
| Total Coliform (P-Present, A-Absent) | P/A | A | A | A | A | A | A | A | A | A | A | A | A | No Event |
| **Metals (Total)** | | | | | | | | | | | | | | |
| Free Cyanide | mg/l | 0.2 | No Event | < 0.050 | No Event | No Event | < 0.050 | No Event | No Event | No Event | < 0.050 | No Event | No Event | No Event |
| Total Fluoride | mg/l | 4 | No Event | < 0.40 | No Event | No Event | < 0.40 | No Event | No Event | No Event | < 0.40 | No Event | No Event | No Event |
| Arsenic | mg/l | 0.05 | No Event | < 0.0030 | No Event | No Event | 0.0013 | No Event | No Event | No Event | < 0.0030 | No Event | No Event | No Event |
| Barium | mg/l | 2 | No Event | 0.12 | No Event | No Event | 0.12 | No Event | No Event | No Event | 0.11 | No Event | No Event | No Event |
| Beryllium | mg/l | 0.004 | No Event | < 0.0010 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | < 0.0010 | No Event | No Event | No Event |
| Cadmium | mg/l | 0.005 | No Event | < 0.0010 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | < 0.0010 | No Event | No Event | No Event |
| Chromium | mg/l | 0.1 | No Event | < 0.0010 | No Event | No Event | < 0.0005 | No Event | No Event | No Event | < 0.0020 | No Event | No Event | No Event |
| Lead | mg/l | 0.05 | No Event | < 0.0010 | No Event | No Event | 0.00099 | No Event | No Event | No Event | 0.0014 | No Event | No Event | No Event |
| Thallium | mg/l | 0.002 | No Event | < 0.0010 | No Event | No Event | < 0.0001 | No Event | No Event | No Event | < 0.0010 | No Event | No Event | No Event |
| Nickel | mg/l | 0.1 | No Event | 0.0021 | No Event | No Event | 0.0021 | No Event | No Event | No Event | 0.0055 | No Event | No Event | No Event |
| Antimony | mg/l | 0.006 | No Event | < 0.0030 | No Event | No Event | < 0.0002 | No Event | No Event | No Event | < 0.0030 | No Event | No Event | No Event |
| Selenium | mg/l | 0.05 | No Event | < 0.0030 | No Event | No Event | 0.0013 | No Event | No Event | No Event | < 0.0020 | No Event | No Event | No Event |
| Mercury | mg/l | 0.002 | No Event | < 0.00020 | No Event | No Event | < 0.00020 | No Event | No Event | No Event | < 0.00020 | No Event | No Event | No Event |
| **Volatile Organic Compounds (VOCs)** | | | | | | | | | | | | | | |
| para-Dichlorobenzene | mg/l | 0.075 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| Dichloromethane | mg/l | 0.005 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0030 | No Event | No Event |
| o-Dichlorobenzene | mg/l | 0.6 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| Carbon tetrachloride | mg/l | 0.005 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0030 | No Event | No Event |
| Toluene | mg/l | 1 | No Event | No Event | < 0.0020 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| Benzene | mg/l | 0.005 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| Monochlorobenzene | mg/l | 0.1 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| Ethylbenzene | mg/l | 0.7 | No Event | No Event | < 0.0020 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| Tetrachloroethylene | mg/l | 0.005 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| 1,1-Dichloroethylene | mg/l | 0.007 | No Event | No Event | < 0.0020 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0050 | No Event | No Event |
| 1,1,1-Trichloroethane | mg/l | 0.2 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| 1,1,2-Trichloroethane | mg/l | 0.005 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| 1,2-Dichloroethane | mg/l | 0.005 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| 1,2-Dichloropropane | mg/l | 0.005 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| 1,2,4-Trichlorobenzene | mg/l | 0.07 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0050 | No Event | No Event |
| Vinyl Chloride | mg/l | 0.002 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0010 | No Event | No Event |
| Trichloroethylene | mg/l | 0.005 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| Hexachlorobenzene | mg/l | 0.001 | No Event | No Event | < 0.00080 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.00081 | No Event | No Event |
| cis--1,2-Dichloroethylene | mg/l | 0.07 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| Styrene | mg/l | 0.1 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| Xylenes (Total) | mg/l | 10 | No Event | No Event | < 0.0030 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.010 | No Event | No Event |
| Trihalomethane (TTHM) | mg/l | 0.1 | No Event | No Event | < 0.0020 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0040 | No Event | No Event |
| trans-1,2-Dichloroethylene | mg/l | 0.1 | No Event | No Event | < 0.0010 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0020 | No Event | No Event |
| Hexachlorocyclopentadiene | mg/l | 0.05 | No Event | No Event | < 0.00259 | No Event | No Event | No Event | No Event | No Event | No Event | < 0.0051 | No Event | No Event |

* Well pump was not functioning during the scheduled sampling time (12/11-12/31/13), so the monthly and quarterly samples for the Fourth Quarter were not collected.

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 2013

| Date | Problem | Solution |
|---|---|---|
| January 2013 | Infiltration rate in Cell 3 is very low (~ 0.25 feet/day) | Cell bottom was cross-ripped with a 3-foot ripper mounted to a tractor to help break up the clogging layer in mid-January |
| January 2013 | Earthen diversion berm washed out on January 26th – low to no flow in the oxbow channel | Berm was fully repaired and effluent deliveries were restarted on February 6th. |
| February 2013 | Flow in the oxbow channel is very high and turbid as of February 13th – deliveries were halted | Pumps were shut off until water was less turbid to keep fine-grained material from settling in the recharge basins and clogging the bottom layers. Effluent delivery was restarted on February 20th. |
| March 2013 | Infiltration rate in Cell 1 is low (< 0.5 feet/day) | Cell bottom was cross-ripped with a 3-foot ripper mounted to a tractor to help break up the clogging layer during the third week of April. |
| March 2013 | Infiltration rate in Cell 2 is low (< 0.5 feet/day) | Cell bottom is being scraped and then cross-ripped with a 2-foot ripper mounted to a bulldozer to break up the clogging layer during the second week of April. |
| June 2013 | Flow meter in Cell 2 is not functioning properly - no velocity or level measurements | Replaced flow meter in Cell 2; estimated flow into Cell 2 from June 1st through June 3rd based on inflows into the equalization basin minus flows into Cells 3 and 4. |
| June 2013 | Maintenance roads are congested with quail bush and tree branches | Landscape maintenance crews cleared the vegetation away from the maintenance roads and from around the electrical panels in July to allow for easier access and for safety of maintenance and monitoring personnel. |
| July 2013 | No water in the oxbow channel due to washout of the earthen diversion berm on July 6th. | Berm was repaired in August, but no effluent deliveries were made due to drying of the recharge basins for maintenance. |
| July 2013 | Infiltration rates are low (< 0.5 feet/day) in all of the recharge cells | Cell maintenance is scheduled for when the monsoon season is over and the basins can be accessed by maintenance equipment. Recharge operations were restarted on October 7th after Cells 3 and 4 were scraped and cross-ripped. Cells 1 and 2 were scraped and cross-ripped by late October. |
| November 2013 | Earthen diversion berm washed out on November 23rd due to storm water flows. | Earthen berm was repaired and effluent deliveries were restarted on November 27th. |
| December 2013 | There is very low flow in the oxbow channel noted in the morning of December 9th – water level in wet well is not high enough to run pumps | The earthen diversion berm was inspected and it was discovered that the mouth of the oxbow channel was silted in, thus not allowing enough water to enter the channel. The silt bar was removed and water was allowed to enter back into the oxbow channel. Effluent deliveries to the project were restarted in the afternoon of December 10th. |
| December 2013 | Compliance Well HP-1 is not discharging any water to the surface for water quality sample collection. | The discharge pipes and pump were pulled and inspected on December 18th; a large hole was located in the discharge pipe near the pump and the pump itself was in very poor operating condition. The pump could not be replaced before December 31st, so samples were not collected. |

# APPENDIX A

Daily Flow Volumes &
Water Quantity Summary

# USF DAILY FLOWMETER READINGS AND VOLUMES

Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Meter ID: Fm-eq
Year: 2013

| | January | | February | | March | | April | | May | | June | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Totalizer Reading | Gallons | Totalizer Reading | Gallons | Totalizer Reading | Gallons | Totalizer Reading | Gallons | Totalizer Reading | Gallons | Totalizer Reading | Gallons |
| | 649898760 | | 662027736 | | 670209199 | | 675909512 | | 692128042 | | 719060997 | |
| Day 1 | 650526012 | 627252 | 662169276 | 141540 | 670347688 | 138489 | 676188372 | 278860 | 693101378 | 973336 | **719943717** | 882720 |
| 2 | 651158528 | 632516 | 662309285 | 140009 | 670347688 | 0 | 676594796 | 406424 | 694066350 | 964972 | 720814748 | 871031 |
| 3 | 651793840 | 635312 | 662309285 | 0 | 670347688 | 0 | 676715576 | 120780 | 695000910 | 934560 | 721697626 | 882878 |
| 4 | 652212740 | 418900 | 662309285 | 0 | 670671008 | 323320 | 676715576 | 0 | 695889915 | 889005 | 722590792 | 893166 |
| 5 | 652212740 | 0 | 662309285 | 0 | 671172128 | 501120 | 677021448 | 305872 | 696778920 | 889005 | 723489614 | 898822 |
| 6 | 652212740 | 0 | 662786120 | 476835 | 671589624 | 417496 | 677418888 | 397440 | 697693230 | 914310 | 724390126 | 900512 |
| 7 | 652212740 | 0 | 663457300 | 671180 | 672017199 | 427575 | 677540120 | 121232 | 698659804 | 966574 | 725276928 | 886802 |
| 8 | 652212740 | 0 | 664110608 | 653308 | 672430014 | 412815 | 677540120 | 0 | 699597052 | 937248 | 726165408 | 888480 |
| 9 | 652212740 | 0 | 664634089 | 523481 | 672553264 | 123250 | 677858224 | 318104 | 700549277 | 952225 | 727018404 | 852996 |
| 10 | 652577905 | 365165 | 665061769 | 427680 | 672553264 | 0 | 677981008 | 122784 | 701469055 | 919778 | 727905288 | 886884 |
| 11 | 653106385 | 528480 | 665285678 | 223909 | 672882516 | 329252 | 677981008 | 0 | 702379135 | 910080 | 728775136 | 869848 |
| 12 | 653548544 | 442159 | 665721998 | 436320 | 673007888 | 125372 | 677981008 | 0 | 703280734 | 901599 | 729615352 | 840216 |
| 13 | 654214611 | 666067 | 665851496 | 129498 | 673007888 | 0 | 677981008 | 0 | 704178850 | 898116 | 730464952 | 849600 |
| 14 | 654859464 | 644853 | 665851496 | 0 | 673007888 | 0 | 677981008 | 0 | 705080448 | 901598 | 730975004 | 510052 |
| 15 | 655505972 | 646508 | 665851496 | 0 | 673007888 | 0 | 678339368 | 358360 | 705978786 | 898338 | 731395484 | 420480 |
| 16 | 656162612 | 656640 | 665851496 | 0 | 673007888 | 0 | 679186920 | 847552 | 706893258 | 914472 | 731791668 | 396184 |
| 17 | 656810354 | 647742 | 665851496 | 0 | 673007888 | 0 | 680127696 | 940776 | 707794712 | 901454 | 732198540 | 406872 |
| 18 | 657475226 | 664872 | 665851496 | 0 | 673318507 | 310619 | 681022680 | 894984 | 708709112 | 914400 | 732606946 | 408406 |
| 19 | 658104506 | 629280 | 665851496 | 0 | 673740380 | 421873 | 681960302 | 937622 | 709614263 | 905151 | 733002941 | 395995 |
| 20 | 658743690 | 639184 | 666299956 | 448460 | 674158316 | 417936 | 682884782 | 924480 | 710527744 | 913481 | 733654802 | 651861 |
| 21 | 659386860 | 643170 | 666645460 | 345504 | 674563340 | 405024 | 683785290 | 900508 | 711441315 | 913571 | 734550482 | 895680 |
| 22 | 660029656 | 642796 | 667115221 | 469761 | 674975210 | 411870 | 684686956 | 901666 | 712331482 | 890167 | 735441842 | 891360 |
| 23 | 660638454 | 608798 | 667784821 | 669600 | 675382730 | 407520 | 685603034 | 916078 | 713242227 | 910745 | 736330322 | 888480 |
| 24 | 661158552 | 520098 | 668415764 | 630943 | 675787812 | 405082 | 686513640 | 910606 | 714130681 | 888454 | 737191012 | 860690 |
| 25 | 661652575 | 494023 | 668920480 | 504716 | 675909512 | 121700 | 687428616 | 914976 | 714689431 | 558750 | 738085758 | 894746 |
| 26 | 662027736 | 375161 | 669349600 | 429120 | 675909512 | 0 | 688368300 | 939684 | 715189498 | 500067 | 738927838 | 842080 |
| 27 | 662027736 | 0 | 669783460 | 433860 | 675909512 | 0 | 689304300 | 936000 | 715952668 | 763170 | 739810746 | 882908 |
| 28 | 662027736 | 0 | 670209199 | 425739 | 675909512 | 0 | 690226970 | 922670 | 716538052 | 585384 | 740690742 | 879996 |
| 29 | 662027736 | 0 | | | 675909512 | 0 | 691173066 | 946096 | 717308586 | 770534 | 741564822 | 874080 |
| 30 | 662027736 | 0 | | | 675909512 | 0 | 692128042 | 954976 | 718183046 | 874460 | 742419440 | 854618 |
| 31 | 662027736 | 0 | | | 675909512 | 0 | | | 719060997 | 877951 | | |
| | **Total (gal)** | **12128976** | **Total (gal)** | **8181463** | **Total (gal)** | **5700313** | **Total (gal)** | **16218530** | **Total (gal)** | **26932955** | **Total (gal)** | **23358443** |
| | **Total (ac-ft)** | **37.22** | **Total (ac-ft)** | **25.11** | **Total (ac-ft)** | **17.49** | **Total (ac-ft)** | **49.77** | **Total (ac-ft)** | **82.65** | **Total (ac-ft)** | **71.68** |
| | | | | **1st Qtr Total (gal) =** | **26010752** | | | | | **2nd Qtr Total (gal) =** | **66509928** | |
| | | | | **1st Qtr Total (ac-ft) =** | **79.82** | | | | | **2nd Qtr Total (ac-ft) =** | **204.11** | |

* Flow meter LCD display malfunctioned and was replaced on July 4 - flow meter totalizer reset to zero; FMeq Totalizer Readings for July are based on continuation of previous readings; FMeq Totalizer Readings for August are based on new readings

# USF DAILY FLOWMETER READINGS AND VOLUMES

Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Meter ID: Fm-eq
Year: 2013

| | July | | August | | September | | October | | November | | December | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Totalizer Reading | Gallons | Totalizer Reading | Gallons | Totalizer Reading | Gallons | Totalizer Reading | Gallons | Totalizer Reading | Gallons | Totalizer Reading | Gallons |
| | 742419440 | | 1584954 | | 1584954 | | 1584954 | | 24148036 | | 46440884 | |
| Day 1 | 743287760 | 868320 | 1584954 | 0 | 1584954 | 0 | 1584954 | 0 | 25057833 | 909797 | 47257124 | 816240 |
| 2 | 744163280 | 875520 | 1584954 | 0 | 1584954 | 0 | 1584954 | 0 | 25995273 | 937440 | 48092974 | 835850 |
| 3 | 745038800 | 875520 | 1584954 | 0 | 1584954 | 0 | 1584954 | 0 | 27023292 | 1028019 | 48921608 | 828634 |
| 4 | 745910420 | 871620 | 1584954 | 0 | 1584954 | 0 | 1584954 | 0 | 28048232 | 1024940 | 49761960 | 840352 |
| 5 | 746778740 | 868320 | 1584954 | 0 | 1584954 | 0 | 1584954 | 0 | 29063202 | 1014970 | 50594564 | 832604 |
| 6 | 747024983 | 246243 | 1584954 | 0 | 1584954 | 0 | 1584954 | 0 | 30051892 | 988690 | 51433290 | 838726 |
| 7 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 2087327 | 502373 | 30965862 | 913970 | 52272570 | 839280 |
| 8 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 2976581 | 889254 | 31839335 | 873473 | 53072566 | 799996 |
| 9 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 3881299 | 904718 | 32712984 | 873649 | 53536612 | 464046 |
| 10 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 4830683 | 949384 | 33576984 | 864000 | 53801300 | 264688 |
| 11 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 5789636 | 958953 | 34416456 | 839472 | 54615708 | 814408 |
| 12 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 6787556 | 997920 | 35265830 | 849374 | 55628244 | 1012536 |
| 13 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 7788431 | 1000875 | 36116512 | 850682 | 56662488 | 1034244 |
| 14 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 8657686 | 869255 | 36935172 | 818660 | 57645048 | 982560 |
| 15 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 9590949 | 933263 | 37776716 | 841544 | 58588256 | 943208 |
| 16 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 10530063 | 939114 | 38665196 | 888480 | 59514540 | 926284 |
| 17 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 11458685 | 928622 | 39471860 | 806664 | 60367036 | 852496 |
| 18 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 12458739 | 1000054 | 40278524 | 806664 | 61219540 | 852504 |
| 19 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 13450899 | 992160 | 41112590 | 834066 | 62066412 | 846872 |
| 20 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 14358086 | 907187 | 41926796 | 814206 | 62902724 | 836312 |
| 21 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 15273710 | 915624 | 42739956 | 813160 | 63741604 | 838880 |
| 22 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 16214140 | 940430 | 43543388 | 803432 | 64565162 | 823558 |
| 23 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 16990523 | 776383 | 43770308 | 226920 | 65384242 | 819080 |
| 24 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 17928180 | 937657 | 43770308 | 0 | 66221682 | 837440 |
| 25 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 18872760 | 944580 | 43770308 | 0 | 67070264 | 848582 |
| 26 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 19814520 | 941760 | 43770308 | 0 | 67899496 | 829232 |
| 27 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 20752400 | 937880 | 43947752 | 177444 | 68728506 | 829010 |
| 28 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 21650356 | 897956 | 44762496 | 814744 | 69558746 | 830240 |
| 29 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 22479864 | 829508 | 45594464 | 831968 | 70398200 | 839454 |
| 30 | 747024983 | 0 | 1584954 | 0 | 1584954 | 0 | 23308954 | 829090 | 46440884 | 846420 | 71234876 | 836676 |
| 31 | 747024983 | 0 | 1584954 | 0 | | | 24148036 | 839082 | | | 72066967 | 832091 |
| | **Total (gal)** | **4605543** | **Total (gal)** | **0** | **Total (gal)** | **0** | **Total (gal)** | **22563082** | **Total (gal)** | **22292848** | **Total (gal)** | **25626083** |
| | **Total (ac-ft)** | **14.13** | **Total (ac-ft)** | **0.00** | **Total (ac-ft)** | **0.00** | **Total (ac-ft)** | **69.24** | **Total (ac-ft)** | **68.41** | **Total (ac-ft)** | **78.64** |

| | |
|---|---|
| **3rd Qtr Total (gal) =** | **4605543** |
| **3rd Qtr Total (ac-ft) =** | **14.13** |

| | |
|---|---|
| **4th Qtr Total (gal) =** | **70482013** |
| **4th Qtr Total (ac-ft) =** | **216.30** |
| **Annual Total Del. Vol for FM-eq (ac-ft) =** | **514.37** |

* Flow meter LCD display malfunctioned and was replaced on July 4 - flow meter totalizer reset to zero; FMeq Totalizer Readings for July are based on continuation of previous readings; FMeq Totalizer Readings for August are based on new readings

**USF WATER QUANTITY REPORTING SUMMARY**
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2013

| | **FM-eq Delivered Volumes** (ac-ft) | **Evaporation Losses** (ac-ft) | **Evapotranspiration Losses** (ac-ft) | **Net Recharge Volumes** (ac-ft) | **Quarterly Net Recharge Totals** (ac-ft) |
|---|---|---|---|---|---|
| **January** | 37.2 | 0.8 | 0.0 | 36.4 | |
| **February** | 25.1 | 0.9 | 0.1 | 24.2 | |
| **March** | 17.5 | 1.4 | 0.2 | 15.9 | 76.4 |
| **April** | 49.8 | 1.4 | 0.1 | 48.3 | |
| **May** | 82.7 | 2.3 | 0.3 | 80.0 | |
| **June** | 71.7 | 2.4 | 0.2 | 69.1 | 197.4 |
| **July** | 14.1 | 1.7 | 0.0 | 12.4 | |
| **August** | 0.0 | 0.5 | 0.0 | -0.5 | |
| **September** | 0.0 | 0.1 | 0.0 | -0.1 | 11.8 |
| **October** | 69.2 | 0.6 | 0.0 | 68.6 | |
| **November** | 68.4 | 0.5 | 0.0 | 67.9 | |
| **December** | 78.6 | 0.5 | 0.0 | 78.1 | 214.6 |

| | | | | |
|---|---|---|---|---|
| **Annual Totals =** | **514.4** | **13.2** | **0.9** | **500.3** |

# APPENDIX B

## Evaporation Calculations & Cooley Method Description

**USF EVAPORATION CALCULATIONS**

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0007

Year: 2013

| 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** | 14 | 0.1 | 13 | 0.2 | 15 | 0.3 | 15 | 0.3 | 15 | 0.4 | 15 | 0.5 |
| **Cell 1** | 17 | 0.2 | 14 | 0.2 | 14 | 0.2 | 2 | 0.0 | 11 | 0.3 | 7 | 0.2 |
| **Cell 2** | 27 | 0.3 | 12 | 0.2 | 4 | 0.1 | 4 | 0.1 | 9 | 0.2 | 14 | 0.4 |
| **Cell 3** | 2 | 0.0 | 5 | 0.1 | 19 | 0.3 | 15 | 0.3 | 17 | 0.5 | 16 | 0.5 |
| **Cell 4** | 29 | 0.3 | 26 | 0.3 | 32 | 0.5 | 26 | 0.6 | 32 | 0.9 | 27 | 0.8 |
| | **89** | **0.8** | **70** | **0.9** | **85** | **1.4** | **62** | **1.4** | **84** | **2.3** | **79** | **2.4** |

| | |
|---|---|
| **1st Quarter Total Evap** (AF) **=** | **3.1** |
| **2nd Quarter Total Evap** (AF) **=** | **6.1** |

| | |
|---|---|
| **Cooley Adj. Fac** | **0.95** |

**USF EVAPORATION CALCULATIONS**
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2013

| 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** | 13 | 0.4 | 7 | 0.2 | 1 | 0.0 | 13 | 0.2 | 15 | 0.2 | 14 | 0.1 |
| **Cell 1** | 1 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 3 | 0.0 | 5 | 0.0 |
| **Cell 2** | 17 | 0.5 | 9 | 0.2 | 5 | 0.1 | 5 | 0.1 | 5 | 0.1 | 8 | 0.1 |
| **Cell 3** | 9 | 0.3 | 0 | 0.0 | 0 | 0.0 | 6 | 0.1 | 5 | 0.1 | 11 | 0.1 |
| **Cell 4** | 17 | 0.5 | 2 | 0.0 | 0 | 0.0 | 9 | 0.2 | 15 | 0.2 | 25 | 0.2 |
| | **57** | **1.7** | **17** | **0.5** | **6** | **0.1** | **33** | **0.6** | **43** | **0.5** | **63** | **0.5** |

| | |
|---|---|
| **3rd Quarter Total Evap** (AF) **=** | **2.3** |

| | |
|---|---|
| **4th Quarter Total Evap** (AF) **=** | **1.6** |
| **Annual Total Evap** (AF) **=** | **13.2** |

# 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.

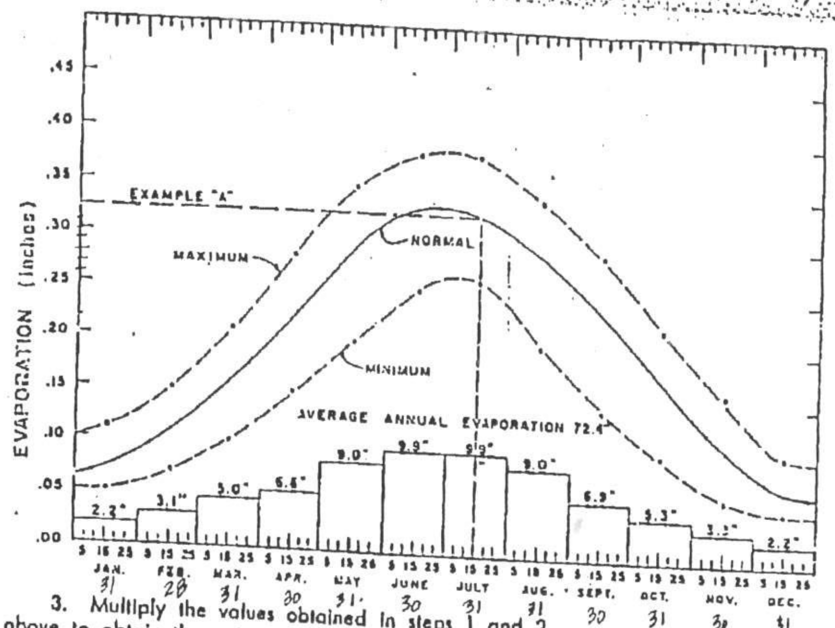



FIGURE 1. Maximum, Normal, and Minimum Daily Evaporation and Average Monthly Evaporation From Open Water Surfaces (Adjustment Factor = 1.00).

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)

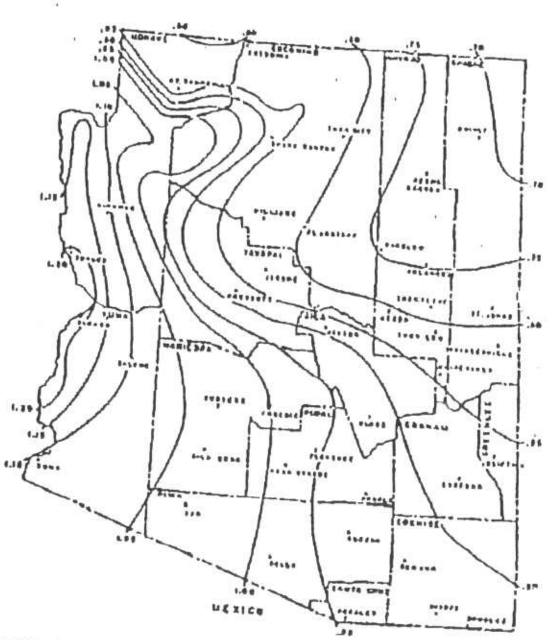



FIGURE 2. Evaporation Adjustment Factors for Arizona

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.

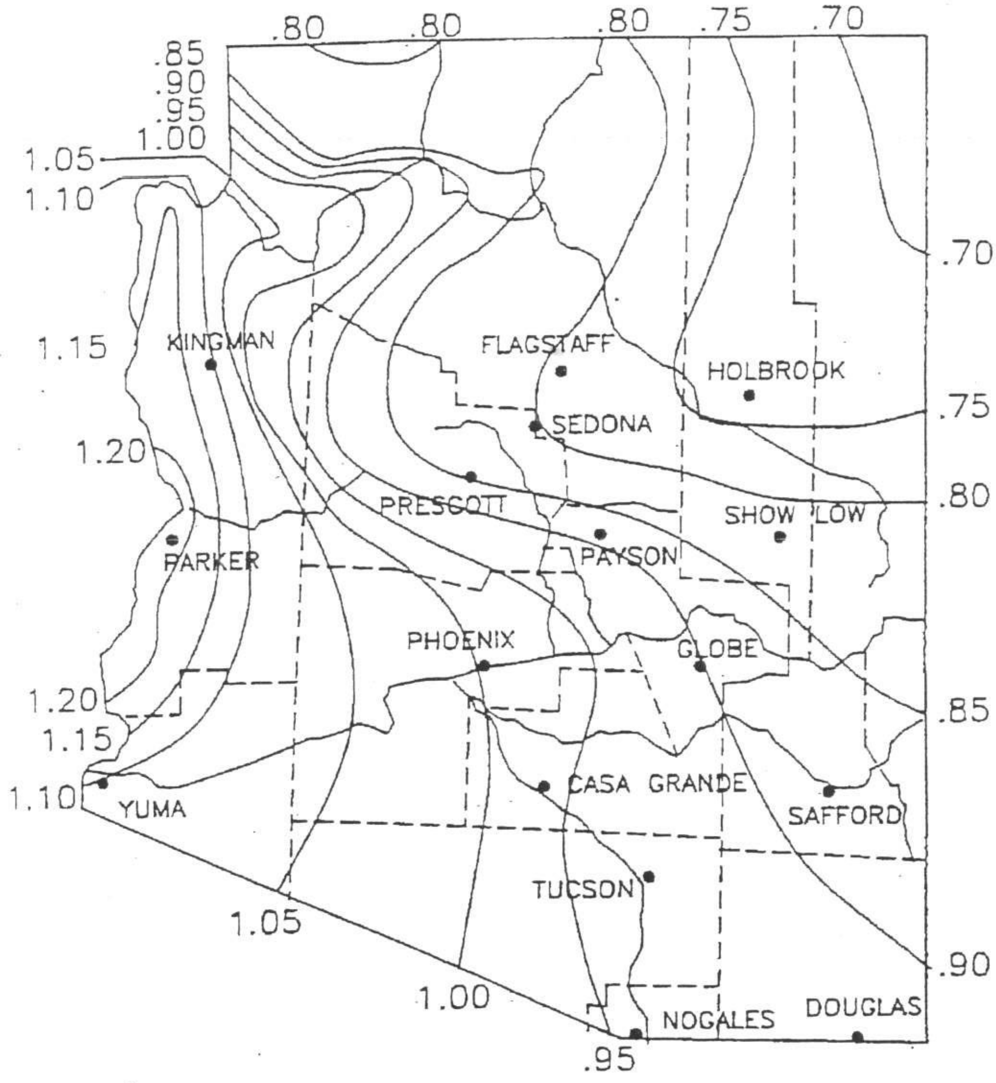
# EVAPORATION FROM OPEN WATER SURFACES IN ARIZONA

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



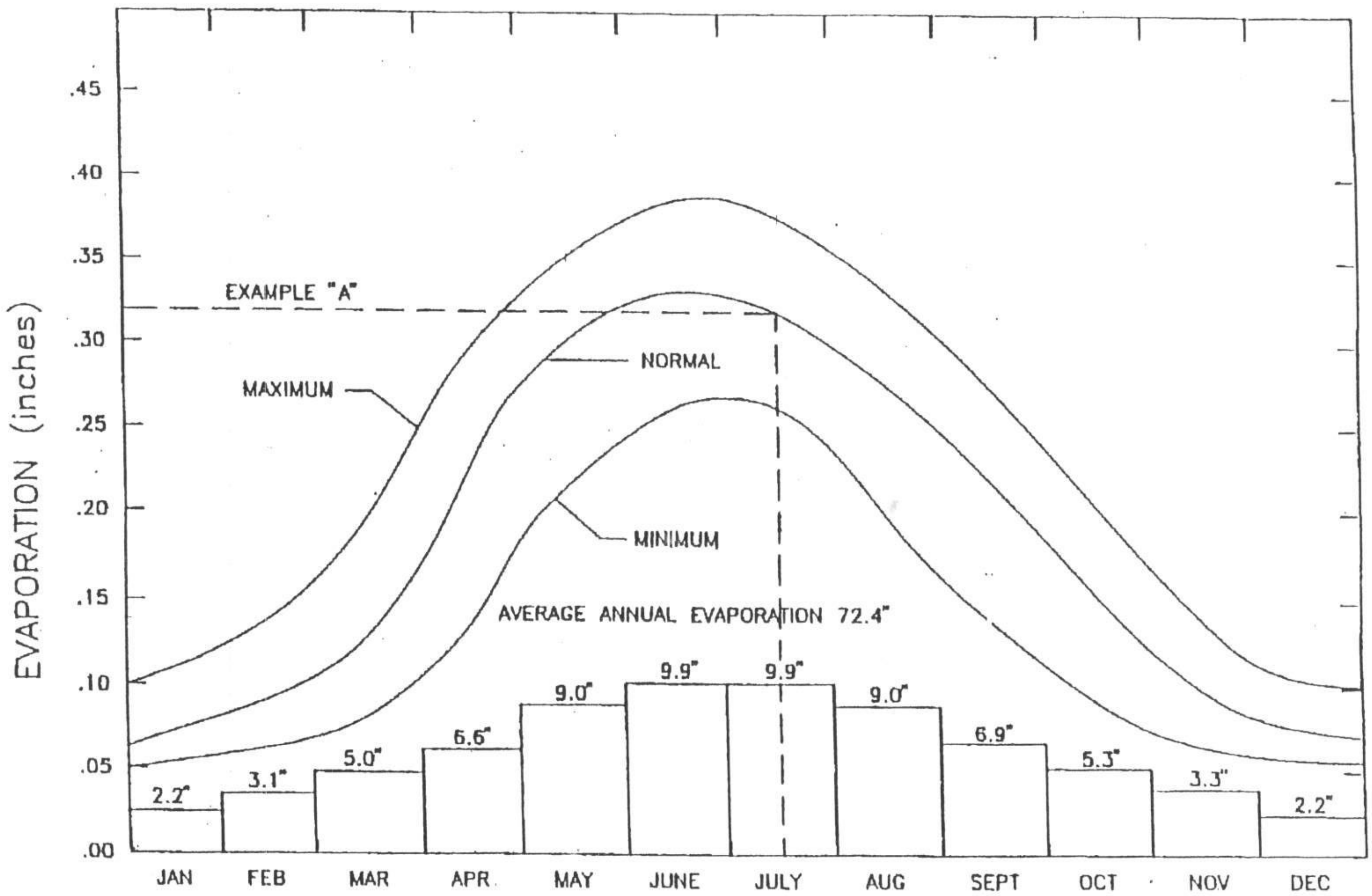



FIGURE 9. MAXIMUM, NORMAL AND MINIMUM DAILY EVAPORATION AND AVERAGE MONTHLY EVAPORATION FROM OPEN WATER SURFACES (Adjustment Factor = 1.00)

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

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

From: Cooley, 1970

# APPENDIX C

## Daily Wetted Acreages

**USF DAILY WETTED ACREAGES**
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2013

## 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 | 0.5208 | 0.252 | 1.21 | 0 | 1.0458 |
| 2 | 0.5208 | 0.189 | 1.21 | 0 | 1.0458 |
| 3 | 0.5208 | 0.1575 | 1.21 | 0 | 1.0458 |
| 4 | 0.5208 | 0.5796 | 1.21 | 0 | 1.0458 |
| 5 | 0.3565 | 0.63 | 1.1737 | 0 | 1.0458 |
| 6 | 0.3565 | 0.63 | 1.0285 | 0 | 1.0458 |
| 7 | 0.3565 | 0.63 | 0.605 | 0 | 1.0458 |
| 8 | 0.3565 | 0.63 | 0.484 | 0 | 1.0458 |
| 9 | 0.3565 | 0.5796 | 0.484 | 0 | 1.0458 |
| 10 | 0.341 | 0.4725 | 0.484 | 0 | 0.63 |
| 11 | 0.3875 | 0.63 | 0.4235 | 0 | 1.0458 |
| 12 | 0.3875 | 0.63 | 0.3932 | 0 | 1.0458 |
| 13 | 0.372 | 0.63 | 0.363 | 0 | 1.0458 |
| 14 | 0.5208 | 0.63 | 0.484 | 0 | 1.0458 |
| 15 | 0.5208 | 0.63 | 0.605 | 0 | 1.0458 |
| 16 | 0.5208 | 0.63 | 1.0285 | 0 | 1.0458 |
| 17 | 0.5208 | 0.5796 | 1.1374 | 0 | 1.0458 |
| 18 | 0.403 | 0.63 | 1.1737 | 0 | 1.0458 |
| 19 | 0.5208 | 0.63 | 1.1495 | 0 | 1.0458 |
| 20 | 0.5208 | 0.63 | 1.21 | 0 | 1.0458 |
| 21 | 0.5208 | 0.63 | 1.21 | 0 | 1.0458 |
| 22 | 0.5208 | 0.63 | 1.21 | 0 | 1.0458 |
| 23 | 0.5208 | 0.6111 | 1.21 | 0 | 1.0458 |
| 24 | 0.5208 | 0.63 | 1.21 | 0 | 0.63 |
| 25 | 0.434 | 0.63 | 1.1495 | 0.39 | 0.63 |
| 26 | 0.372 | 0.63 | 1.1132 | 0.351 | 0.63 |
| 27 | 0.372 | 0.63 | 1.0285 | 0.351 | 0.63 |
| 28 | 0.341 | 0.63 | 0.5445 | 0.312 | 0.63 |
| 29 | 0.341 | 0.5922 | 0.5445 | 0.312 | 0.63 |
| 30 | 0.341 | 0.4725 | 0.5203 | 0.312 | 0.63 |
| 31 | 0.341 | 0.315 | 0.5203 | 0.312 | 0.5922 |
| **Total Wetted Acres** | **13.5067** | **17.4006** | **27.3278** | **2.34** | **28.6398** |

## 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 | 0.341 | 0.315 | 0.605 | 0.273 | 0.5922 |
| 2 | 0.3565 | 0.3087 | 0.5687 | 0.156 | 0.5796 |
| 3 | 0.372 | 0.3024 | 0.5566 | 0.117 | 0.567 |
| 4 | 0.372 | 0.2142 | 0.5445 | 0.078 | 0.567 |
| 5 | 0.372 | 0.126 | 0.5203 | 0.0546 | 0.5544 |
| 6 | 0.372 | 0.315 | 0.5082 | 0.039 | 0.5292 |
| 7 | 0.434 | 0.63 | 0.484 | 0 | 0.504 |
| 8 | 0.4836 | 0.63 | 0.4719 | 0 | 1.0458 |
| 9 | 0.5208 | 0.63 | 0.4598 | 0 | 1.0458 |
| 10 | 0.5208 | 0.63 | 0.4477 | 0 | 1.0458 |
| 11 | 0.5208 | 0.6111 | 0.4356 | 0 | 1.0458 |
| 12 | 0.5208 | 0.63 | 0.4356 | 0 | 1.0458 |
| 13 | 0.5208 | 0.63 | 0.4235 | 0 | 1.0458 |
| 14 | 0.5208 | 0.63 | 0.4235 | 0 | 1.0458 |
| 15 | 0.5208 | 0.5922 | 0.4114 | 0 | 1.0458 |
| 16 | 0.5208 | 0.5796 | 0.4114 | 0 | 1.0458 |
| 17 | 0.5208 | 0.4725 | 0.3993 | 0 | 1.0458 |
| 18 | 0.5208 | 0.315 | 0.3872 | 0 | 1.0458 |
| 19 | 0.5208 | 0.252 | 0.3872 | 0 | 1.0458 |
| 20 | 0.5208 | 0.315 | 0.3751 | 0.39 | 1.0458 |
| 21 | 0.5208 | 0.63 | 0.363 | 0.39 | 1.0458 |
| 22 | 0.403 | 0.63 | 0.363 | 0.234 | 1.0458 |
| 23 | 0.5208 | 0.63 | 0.3509 | 0.39 | 1.0458 |
| 24 | 0.5208 | 0.63 | 0.3388 | 0.39 | 1.0458 |
| 25 | 0.5208 | 0.63 | 0.3267 | 0.39 | 1.0458 |
| 26 | 0.5208 | 0.63 | 0.3267 | 0.6864 | 1.0458 |
| 27 | 0.5208 | 0.63 | 0.3146 | 0.6864 | 1.0458 |
| 28 | 0.5208 | 0.63 | 0.3025 | 0.6864 | 1.0458 |
| 29 | | | | | |
| | | | | | |
| | | | | | |
| **Total Wetted Acres** | **13.4013** | **14.1687** | **11.9427** | **4.9608** | **25.8552** |

**USF DAILY WETTED ACREAGES**
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2013

## 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 | 0.5208 | 0.63 | 0.3025 | 0.6864 | 1.0458 |
| 2 | 0.5208 | 0.63 | 0.3025 | 0.6864 | 1.0458 |
| 3 | 0.5208 | 0.63 | 0.3025 | 0.6864 | 1.0458 |
| 4 | 0.5208 | 0.63 | 0.2904 | 0.39 | 1.0458 |
| 5 | 0.372 | 0.63 | 0.2904 | 0.312 | 1.0458 |
| 6 | 0.3875 | 0.63 | 0.2783 | 0.273 | 1.0458 |
| 7 | 0.5208 | 0.63 | 0.2783 | 0.6864 | 1.0458 |
| 8 | 0.5208 | 0.63 | 0.2662 | 0.6864 | 1.0458 |
| 9 | 0.5208 | 0.63 | 0.2662 | 0.6864 | 1.0458 |
| 10 | 0.4836 | 0.63 | 0.2541 | 0.6864 | 1.0458 |
| 11 | 0.434 | 0.63 | 0.242 | 0.6864 | 1.0458 |
| 12 | 0.5208 | 0.6111 | 0.2057 | 0.6864 | 1.0458 |
| 13 | 0.5208 | 0.5922 | 0.1815 | 0.6864 | 1.0458 |
| 14 | 0.4836 | 0.5796 | 0.1573 | 0.6864 | 1.0458 |
| 15 | 0.4836 | 0.5796 | 0.1331 | 0.6864 | 1.0458 |
| 16 | 0.4836 | 0.4725 | 0.1089 | 0.39 | 1.0458 |
| 17 | 0.4836 | 0.315 | 0.0847 | 0 | 1.0458 |
| 18 | 0.4836 | 0.315 | 0.0726 | 0.39 | 1.0458 |
| 19 | 0.465 | 0.315 | 0.0605 | 0.663 | 1.0458 |
| 20 | 0.5208 | 0.3024 | 0.0605 | 0.6864 | 1.0458 |
| 21 | 0.5208 | 0.2898 | 0.0484 | 0.6864 | 1.0458 |
| 22 | 0.5208 | 0.2835 | 0.0363 | 0.6864 | 1.0458 |
| 23 | 0.5208 | 0.2709 | 0.0242 | 0.6864 | 1.0458 |
| 24 | 0.5208 | 0.2646 | 0.0242 | 0.6864 | 1.0458 |
| 25 | 0.5208 | 0.252 | 0.012 | 0.6864 | 1.0458 |
| 26 | 0.5208 | 0.252 | 0.012 | 0.6864 | 1.0458 |
| 27 | 0.5208 | 0.2457 | 0 | 0.6864 | 1.0458 |
| 28 | 0.5208 | 0.2394 | 0 | 0.6864 | 1.0458 |
| 29 | 0.5208 | 0.2331 | 0 | 0.6864 | 1.0458 |
| 30 | 0.5208 | 0.2268 | 0 | 0.6864 | 1.0458 |
| 31 | 0.5208 | 0.2205 | 0 | 0.663 | 1.0458 |
| **Total Wetted Acres** | **15.4969** | **13.7907** | **4.2953** | **18.8682** | **32.4198** |

## 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 | 0.5208 | 0.1890 | 0.0000 | 0.3900 | 1.0458 |
| 2 | 0.5208 | 0.1890 | 0.0000 | 0.3900 | 1.0458 |
| 3 | 0.5208 | 0.1575 | 0.0000 | 0.3900 | 1.0458 |
| 4 | 0.5208 | 0.1260 | 0.0000 | 0.6630 | 1.0458 |
| 5 | 0.5208 | 0.0945 | 0.0000 | 0.6630 | 1.0458 |
| 6 | 0.5208 | 0.0630 | 0.0000 | 0.6864 | 1.0458 |
| 7 | 0.5208 | 0.0630 | 0.0000 | 0.6864 | 1.0458 |
| 8 | 0.5208 | 0.0315 | 0.0000 | 0.6864 | 1.0458 |
| 9 | 0.4030 | 0.0315 | 0.0000 | 0.6864 | 1.0458 |
| 10 | 0.5208 | 0.0315 | 0.0000 | 0.6864 | 1.0458 |
| 11 | 0.5208 | 0.0000 | 0.0000 | 0.6864 | 1.0458 |
| 12 | 0.5208 | 0.0000 | 0.0000 | 0.6864 | 1.0458 |
| 13 | 0.5208 | 0.0000 | 0.0000 | 0.6864 | 1.0458 |
| 14 | 0.5208 | 0.0000 | 0.0000 | 0.6864 | 1.0458 |
| 15 | 0.5208 | 0.0000 | 0.0605 | 0.6864 | 1.0458 |
| 16 | 0.5208 | 0.0000 | 0.1210 | 0.6630 | 1.0458 |
| 17 | 0.5208 | 0.0000 | 0.1815 | 0.3900 | 1.0458 |
| 18 | 0.5208 | 0.0000 | 0.1815 | 0.3900 | 1.0458 |
| 19 | 0.4030 | 0.0000 | 0.2420 | 0.3900 | 0.6300 |
| 20 | 0.4340 | 0.0000 | 0.2420 | 0.3900 | 0.6300 |
| 21 | 0.4340 | 0.0000 | 0.2420 | 0.3900 | 0.6300 |
| 22 | 0.5208 | 0.0000 | 0.3025 | 0.3510 | 0.5670 |
| 23 | 0.5208 | 0.0000 | 0.3025 | 0.3510 | 0.5670 |
| 24 | 0.5208 | 0.0000 | 0.3025 | 0.3510 | 0.5670 |
| 25 | 0.5208 | 0.0000 | 0.3025 | 0.3120 | 0.5040 |
| 26 | 0.5208 | 0.0000 | 0.3025 | 0.3120 | 0.5040 |
| 27 | 0.5208 | 0.0000 | 0.3025 | 0.3120 | 0.5040 |
| 28 | 0.5208 | 0.0000 | 0.3146 | 0.3120 | 0.5040 |
| 29 | 0.5208 | 0.3150 | 0.3388 | 0.3900 | 0.6300 |
| 30 | 0.5208 | 0.3150 | 0.2420 | 0.6630 | 0.5040 |
| | | | | | |
| **Total Wetted Acres** | **15.2148** | **1.6065** | **3.9809** | **15.327** | **25.5654** |

**USF DAILY WETTED ACREAGES**
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2013

## 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** | 0.4836 | 0.6111 | 0.242 | 0.6864 | 0.63 |
| **2** | 0.434 | 0.63 | 0.121 | 0.6864 | 1.0458 |
| **3** | 0.5208 | 0.63 | 0.0605 | 0.6864 | 1.0458 |
| **4** | 0.5208 | 0.63 | 0 | 0.6864 | 1.0458 |
| **5** | 0.5208 | 0.63 | 0 | 0.6864 | 1.0458 |
| **6** | 0.5208 | 0.5922 | 0 | 0.6864 | 1.0458 |
| **7** | 0.5208 | 0.315 | 0.1815 | 0.6864 | 1.0458 |
| **8** | 0.5208 | 0.252 | 0.1815 | 0.6864 | 1.0458 |
| **9** | 0.5208 | 0.2205 | 0.242 | 0.6864 | 1.0458 |
| **10** | 0.5208 | 0.189 | 0.242 | 0.39 | 1.0458 |
| **11** | 0.5208 | 0.1575 | 0.3025 | 0.39 | 1.0458 |
| **12** | 0.5208 | 0.1098 | 0.3267 | 0.39 | 1.0458 |
| **13** | 0.5208 | 0.062 | 0.3267 | 0.39 | 1.0458 |
| **14** | 0.5208 | 0 | 0.363 | 0.351 | 1.0458 |
| **15** | 0.5208 | 0 | 0.3872 | 0.351 | 1.0458 |
| **16** | 0.5208 | 0 | 0.4598 | 0.351 | 1.0458 |
| **17** | 0.5208 | 0 | 0.484 | 0.351 | 1.0458 |
| **18** | 0.5208 | 0 | 0.5445 | 0.312 | 1.0458 |
| **19** | 0.5208 | 0 | 0.5626 | 0.312 | 1.0458 |
| **20** | 0.5208 | 0.315 | 0.5808 | 0.312 | 1.0458 |
| **21** | 0.5208 | 0.63 | 0.5203 | 0.312 | 1.0458 |
| **22** | 0.5208 | 0.63 | 0.484 | 0.6864 | 0.63 |
| **23** | 0.5208 | 0.6111 | 0.4235 | 0.6864 | 1.0458 |
| **24** | 0.5208 | 0.5796 | 0.242 | 0.6864 | 1.0458 |
| **25** | 0.5208 | 0.5445 | 0.2178 | 0.6864 | 1.0458 |
| **26** | 0.5208 | 0.484 | 0.1815 | 0.6864 | 1.0458 |
| **27** | 0.372 | 0.315 | 0.1634 | 0.6864 | 1.0458 |
| **28** | 0.0434 | 0.315 | 0.1452 | 0.6864 | 1.0458 |
| **29** | 0.5208 | 0.63 | 0.0968 | 0.6864 | 1.0458 |
| **30** | 0.5208 | 0.6111 | 0.3025 | 0.6864 | 1.0458 |
| **31** | 0.5208 | 0.4725 | 0.363 | 0.39 | 1.0458 |
| **Total Wetted Acres** | **15.3946** | **11.1669** | **8.7483** | **16.9572** | **31.5882** |

## 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** | 0.5208 | 0.31 | 0.4235 | 0.39 | 1.0458 |
| **2** | 0.5208 | 0.279 | 0.4477 | 0.39 | 1.0458 |
| **3** | 0.5208 | 0.248 | 0.484 | 0.39 | 1.0458 |
| **4** | 0.4836 | 0.155 | 0.4961 | 0.39 | 1.0458 |
| **5** | 0.5208 | 0.124 | 0.5082 | 0.39 | 1.0458 |
| **6** | 0.5208 | 0.062 | 0.5445 | 0.351 | 1.0458 |
| **7** | 0.5208 | 0 | 0.5808 | 0.351 | 1.0458 |
| **8** | 0.5208 | 0 | 0.605 | 0.351 | 0.63 |
| **9** | 0.5208 | 0 | 0.605 | 0.351 | 0.63 |
| **10** | 0.5208 | 0.441 | 0.605 | 0.351 | 0.567 |
| **11** | 0.434 | 0.5985 | 0.484 | 0.234 | 0.504 |
| **12** | 0.5208 | 0.63 | 0.484 | 0.234 | 0.4095 |
| **13** | 0.5208 | 0.63 | 0.484 | 0.468 | 0.315 |
| **14** | 0.5208 | 0.63 | 0.4598 | 0.6864 | 0.63 |
| **15** | 0.5208 | 0.63 | 0.4477 | 0.6864 | 0.63 |
| **16** | 0.5208 | 0.567 | 0.3751 | 0.6864 | 1.0458 |
| **17** | 0.5208 | 0.504 | 0.3025 | 0.6864 | 1.0458 |
| **18** | 0.5208 | 0.4095 | 0.242 | 0.6864 | 1.0458 |
| **19** | 0.5208 | 0.315 | 0.2178 | 0.6864 | 1.0458 |
| **20** | 0.5208 | 0.0063 | 0.2057 | 0.6864 | 1.0458 |
| **21** | 0.403 | 0 | 0.2057 | 0.6864 | 1.0458 |
| **22** | 0.434 | 0 | 0.3052 | 0.6864 | 1.0458 |
| **23** | 0.4836 | 0 | 0.4235 | 0.6864 | 1.0458 |
| **24** | 0.5208 | 0 | 0.484 | 0.6864 | 1.0458 |
| **25** | 0.5208 | 0 | 0.5445 | 0.6864 | 1.0458 |
| **26** | 0.5208 | 0 | 0.5687 | 0.6864 | 1.0458 |
| **27** | 0.5208 | 0 | 0.5808 | 0.6864 | 1.0458 |
| **28** | 0.5208 | 0 | 0.5808 | 0.6864 | 1.0458 |
| **29** | 0.5208 | 0 | 0.5929 | 0.663 | 1.0458 |
| **30** | 0.5208 | 0 | 0.605 | 0.663 | 1.0458 |
| | | | | | |
| **Total Wetted Acres** | **15.2582** | **6.5393** | **13.8935** | **16.263** | **27.3231** |

**USF DAILY WETTED ACREAGES**
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2013

## 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 | 0.5208 | 0.2520 | 0.6050 | 0.3900 | 0.7560 |
| 2 | 0.5208 | 0.3150 | 0.6050 | 0.3900 | 0.7434 |
| 3 | 0.5208 | 0.2520 | 0.6050 | 0.3820 | 0.7434 |
| 4 | 0.5208 | 0.1575 | 0.6050 | 0.3822 | 0.7434 |
| 5 | 0.5208 | 0.0630 | 0.6050 | 0.3822 | 0.7308 |
| 6 | 0.5208 | 0.0315 | 0.6050 | 0.3744 | 0.7308 |
| 7 | 0.5208 | 0.0126 | 0.6050 | 0.3744 | 0.7182 |
| 8 | 0.5208 | 0.0063 | 0.6050 | 0.3744 | 0.7182 |
| 9 | 0.5208 | 0.0000 | 0.5929 | 0.3666 | 0.7056 |
| 10 | 0.4836 | 0.0000 | 0.5808 | 0.3666 | 0.7056 |
| 11 | 0.4836 | 0.0000 | 0.5687 | 0.3666 | 0.6930 |
| 12 | 0.4650 | 0.0000 | 0.5687 | 0.3588 | 0.6930 |
| 13 | 0.4650 | 0.0000 | 0.5566 | 0.3588 | 0.6804 |
| 14 | 0.4340 | 0.0000 | 0.5566 | 0.3588 | 0.6678 |
| 15 | 0.4340 | 0.0000 | 0.5445 | 0.3510 | 0.6552 |
| 16 | 0.3720 | 0.0000 | 0.5445 | 0.3510 | 0.6426 |
| 17 | 0.3720 | 0.0000 | 0.5324 | 0.3510 | 0.6300 |
| 18 | 0.3720 | 0.0000 | 0.5324 | 0.3432 | 0.6174 |
| 19 | 0.3720 | 0.0000 | 0.5324 | 0.3354 | 0.5922 |
| 20 | 0.3720 | 0.0000 | 0.5203 | 0.3354 | 0.5670 |
| 21 | 0.3720 | 0.0000 | 0.5203 | 0.3354 | 0.5418 |
| 22 | 0.3565 | 0.0000 | 0.5203 | 0.3120 | 0.5040 |
| 23 | 0.3565 | 0.0000 | 0.5082 | 0.2340 | 0.5040 |
| 24 | 0.3565 | 0.0000 | 0.5082 | 0.1950 | 0.4410 |
| 25 | 0.3565 | 0.0000 | 0.4961 | 0.1560 | 0.3150 |
| 26 | 0.3565 | 0.0000 | 0.4961 | 0.0780 | 0.2520 |
| 27 | 0.3565 | 0.0000 | 0.4840 | 0.0390 | 0.1890 |
| 28 | 0.3565 | 0.0000 | 0.4840 | 0.0156 | 0.1890 |
| 29 | 0.3565 | 0.0000 | 0.4719 | 0.0000 | 0.1890 |
| 30 | 0.3565 | 0.0000 | 0.4719 | 0.0000 | 0.1764 |
| 31 | 0.3565 | 0.0000 | 0.4598 | 0.0000 | 0.1764 |
| **Total Wetted Acres** | **13.2494** | **1.0899** | **16.8916** | **8.6578** | **17.2116** |

## 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 | 0.3100 | 0.0000 | 0.4598 | 0.0000 | 0.2898 |
| 2 | 0.3100 | 0.0000 | 0.4356 | 0.0000 | 0.2520 |
| 3 | 0.3100 | 0.0000 | 0.4114 | 0.0000 | 0.2142 |
| 4 | 0.3100 | 0.0000 | 0.3630 | 0.0000 | 0.1764 |
| 5 | 0.3100 | 0.0000 | 0.3388 | 0.0000 | 0.1260 |
| 6 | 0.3100 | 0.0000 | 0.3146 | 0.0000 | 0.0882 |
| 7 | 0.3100 | 0.0000 | 0.3025 | 0.0000 | 0.0630 |
| 8 | 0.2480 | 0.0000 | 0.3025 | 0.0000 | 0.5040 |
| 9 | 0.2480 | 0.0000 | 0.3025 | 0.0000 | 0.0060 |
| 10 | 0.2480 | 0.0000 | 0.2904 | 0.0000 | 0.0000 |
| 11 | 0.2480 | 0.0000 | 0.2904 | 0.0000 | 0.0000 |
| 12 | 0.2480 | 0.0000 | 0.2904 | 0.0000 | 0.0000 |
| 13 | 0.2480 | 0.0000 | 0.2783 | 0.0000 | 0.0000 |
| 14 | 0.2480 | 0.0000 | 0.2662 | 0.0000 | 0.0000 |
| 15 | 0.2480 | 0.0000 | 0.2662 | 0.0000 | 0.0000 |
| 16 | 0.2480 | 0.0000 | 0.2662 | 0.0000 | 0.0000 |
| 17 | 0.2480 | 0.0000 | 0.2541 | 0.0000 | 0.0000 |
| 18 | 0.2480 | 0.0000 | 0.2541 | 0.0000 | 0.0000 |
| 19 | 0.1240 | 0.0000 | 0.2420 | 0.0000 | 0.0000 |
| 20 | 0.1240 | 0.0000 | 0.2420 | 0.0000 | 0.0000 |
| 21 | 0.1240 | 0.0000 | 0.2420 | 0.0000 | 0.0000 |
| 22 | 0.1240 | 0.0000 | 0.2178 | 0.0000 | 0.0000 |
| 23 | 0.1240 | 0.0000 | 0.2178 | 0.0000 | 0.0000 |
| 24 | 0.1240 | 0.0000 | 0.2178 | 0.0000 | 0.0000 |
| 25 | 0.1240 | 0.0000 | 0.2178 | 0.0000 | 0.0000 |
| 26 | 0.1240 | 0.0000 | 0.2178 | 0.0000 | 0.0000 |
| 27 | 0.1240 | 0.0000 | 0.2178 | 0.0000 | 0.0000 |
| 28 | 0.1240 | 0.0000 | 0.2178 | 0.0000 | 0.0000 |
| 29 | 0.1240 | 0.0000 | 0.2178 | 0.0000 | 0.0000 |
| 30 | 0.1240 | 0.0000 | 0.2057 | 0.0000 | 0.0000 |
| 31 | 0.1240 | 0.0000 | 0.2057 | 0.0000 | 0.0000 |
| **Total Wetted Acres** | **6.51** | **0** | **8.5668** | **0** | **1.7196** |

**USF DAILY WETTED ACREAGES**
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2013

### 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 | 0.0930 | 0.0000 | 0.1936 | 0.0000 | 0.0000 |
| 2 | 0.0930 | 0.0000 | 0.1936 | 0.0000 | 0.0000 |
| 3 | 0.0930 | 0.0000 | 0.1936 | 0.0000 | 0.0000 |
| 4 | 0.0930 | 0.0000 | 0.1936 | 0.0000 | 0.0000 |
| 5 | 0.0930 | 0.0000 | 0.1936 | 0.0000 | 0.0000 |
| 6 | 0.0620 | 0.0000 | 0.1936 | 0.0000 | 0.0000 |
| 7 | 0.0620 | 0.0000 | 0.1936 | 0.0000 | 0.0000 |
| 8 | 0.0620 | 0.0000 | 0.1936 | 0.0000 | 0.0000 |
| 9 | 0.0620 | 0.0000 | 0.1936 | 0.0000 | 0.0000 |
| 10 | 0.0620 | 0.0000 | 0.1936 | 0.0000 | 0.0000 |
| 11 | 0.0620 | 0.0000 | 0.1936 | 0.0000 | 0.0000 |
| 12 | 0.0620 | 0.0000 | 0.1936 | 0.0000 | 0.0000 |
| 13 | 0.0310 | 0.0000 | 0.1936 | 0.0000 | 0.0000 |
| 14 | 0.0310 | 0.0000 | 0.1936 | 0.0000 | 0.0000 |
| 15 | 0.0310 | 0.0000 | 0.1815 | 0.0000 | 0.0000 |
| 16 | 0.0124 | 0.0000 | 0.1815 | 0.0000 | 0.0000 |
| 17 | 0.0124 | 0.0000 | 0.1815 | 0.0000 | 0.0000 |
| 18 | 0.0062 | 0.0000 | 0.1815 | 0.0000 | 0.0000 |
| 19 | 0.0000 | 0.0000 | 0.1815 | 0.0000 | 0.0000 |
| 20 | 0.0000 | 0.0000 | 0.1815 | 0.0000 | 0.0000 |
| 21 | 0.0000 | 0.0000 | 0.1815 | 0.0000 | 0.0000 |
| 22 | 0.0000 | 0.0000 | 0.1210 | 0.0000 | 0.0000 |
| 23 | 0.0000 | 0.0000 | 0.1210 | 0.0000 | 0.0000 |
| 24 | 0.0000 | 0.0000 | 0.0605 | 0.0000 | 0.0000 |
| 25 | 0.0000 | 0.0000 | 0.0605 | 0.0000 | 0.0000 |
| 26 | 0.0000 | 0.0000 | 0.0484 | 0.0000 | 0.0000 |
| 27 | 0.0000 | 0.0000 | 0.3630 | 0.0000 | 0.0000 |
| 28 | 0.0000 | 0.0000 | 0.0363 | 0.0000 | 0.0000 |
| 29 | 0.0000 | 0.0000 | 0.0363 | 0.0000 | 0.0000 |
| 30 | 0.0000 | 0.0000 | 0.0242 | 0.0000 | 0.0000 |
| | | | | | |
| **Total Wetted Acres** | **1.023** | **0** | **4.8521** | **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 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 3 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 4 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 5 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 6 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 7 | 0.4340 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 8 | 0.5208 | 0.0000 | 0.0000 | 0.3900 | 0.0000 |
| 9 | 0.5208 | 0.0000 | 0.0000 | 0.6630 | 0.0000 |
| 10 | 0.5208 | 0.0000 | 0.0000 | 0.3900 | 0.5040 |
| 11 | 0.4836 | 0.0000 | 0.0000 | 0.6630 | 1.0458 |
| 12 | 0.4340 | 0.0000 | 0.0000 | 0.6630 | 1.0458 |
| 13 | 0.5208 | 0.0000 | 0.0000 | 0.6630 | 1.0458 |
| 14 | 0.5208 | 0.0000 | 0.0000 | 0.6864 | 1.0458 |
| 15 | 0.4836 | 0.0000 | 0.1210 | 0.6864 | 1.0458 |
| 16 | 0.5208 | 0.0000 | 0.2420 | 0.3510 | 0.6300 |
| 17 | 0.5208 | 0.0000 | 0.2420 | 0.3120 | 0.5670 |
| 18 | 0.5208 | 0.0000 | 0.3025 | 0.0780 | 0.5355 |
| 19 | 0.5208 | 0.0000 | 0.3267 | 0.0000 | 0.5040 |
| 20 | 0.5208 | 0.0000 | 0.3630 | 0.0000 | 0.4410 |
| 21 | 0.5208 | 0.0000 | 0.3630 | 0.0000 | 0.3780 |
| 22 | 0.5208 | 0.0000 | 0.3025 | 0.0000 | 0.2520 |
| 23 | 0.5208 | 0.0000 | 0.3025 | 0.0000 | 0.1890 |
| 24 | 0.5208 | 0.0000 | 0.3388 | 0.0000 | 0.1260 |
| 25 | 0.5208 | 0.0000 | 0.3388 | 0.0000 | 0.0882 |
| 26 | 0.5208 | 0.0000 | 0.3509 | 0.0000 | 0.0504 |
| 27 | 0.5208 | 0.0000 | 0.3388 | 0.0000 | 0.0000 |
| 28 | 0.5208 | 0.0000 | 0.3388 | 0.0000 | 0.0000 |
| 29 | 0.5208 | 0.0000 | 0.3509 | 0.0000 | 0.0000 |
| 30 | 0.5208 | 0.0315 | 0.3630 | 0.0390 | 0.0000 |
| 31 | 0.5208 | 0.0945 | 0.0605 | 0.1170 | 0.0000 |
| **Total Wetted Acres** | **12.772** | **0.126** | **5.0457** | **5.7018** | **9.4941** |

**USF DAILY WETTED ACREAGES**
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2013

## 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 | 0.5208 | 0.1260 | 0.0242 | 0.2340 | 0.0000 |
| 2 | 0.5208 | 0.1890 | 0.0000 | 0.2730 | 0.0000 |
| 3 | 0.5208 | 0.1890 | 0.0000 | 0.3120 | 0.0000 |
| 4 | 0.5208 | 0.1890 | 0.0000 | 0.3510 | 0.0000 |
| 5 | 0.5208 | 0.1890 | 0.0000 | 0.3900 | 0.0000 |
| 6 | 0.4340 | 0.1890 | 0.0000 | 0.6864 | 0.0000 |
| 7 | 0.5208 | 0.1953 | 0.0000 | 0.6630 | 0.0000 |
| 8 | 0.5208 | 0.2394 | 0.0000 | 0.6630 | 0.0000 |
| 9 | 0.5208 | 0.2394 | 0.0000 | 0.3900 | 0.0000 |
| 10 | 0.5208 | 0.2520 | 0.0000 | 0.3900 | 0.0000 |
| 11 | 0.5208 | 0.2520 | 0.0000 | 0.3900 | 0.0000 |
| 12 | 0.5208 | 0.2520 | 0.0605 | 0.3510 | 0.1260 |
| 13 | 0.5208 | 0.1260 | 0.1815 | 0.1560 | 0.2520 |
| 14 | 0.5208 | 0.0315 | 0.3025 | 0.0390 | 0.4410 |
| 15 | 0.5208 | 0.0000 | 0.3025 | 0.0000 | 0.5670 |
| 16 | 0.5208 | 0.0000 | 0.3025 | 0.0000 | 0.6300 |
| 17 | 0.5208 | 0.0000 | 0.4235 | 0.0000 | 0.7560 |
| 18 | 0.5208 | 0.0000 | 0.4538 | 0.0000 | 0.9450 |
| 19 | 0.4836 | 0.0000 | 0.4840 | 0.0000 | 0.9450 |
| 20 | 0.5208 | 0.0000 | 0.4840 | 0.0000 | 0.9828 |
| 21 | 0.5208 | 0.0000 | 0.4840 | 0.0000 | 1.0080 |
| 22 | 0.5208 | 0.0000 | 0.5082 | 0.0000 | 1.0458 |
| 23 | 0.5208 | 0.0000 | 0.3025 | 0.0000 | 1.0458 |
| 24 | 0.5208 | 0.0000 | 0.1694 | 0.0000 | 1.0458 |
| 25 | 0.5208 | 0.0000 | 0.0363 | 0.0000 | 0.6300 |
| 26 | 0.4030 | 0.0000 | 0.0000 | 0.0000 | 1.0458 |
| 27 | 0.4030 | 0.0000 | 0.0000 | 0.0000 | 0.9450 |
| 28 | 0.5208 | 0.0000 | 0.0242 | 0.0000 | 0.6300 |
| 29 | 0.5208 | 0.0000 | 0.2420 | 0.0000 | 0.8190 |
| 30 | 0.5208 | 0.0000 | 0.2420 | 0.0000 | 1.0458 |
| | | | | | |
| **Total Wetted Acres** | **15.2644** | **2.6586** | **5.0276** | **5.2884** | **14.9058** |

## 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 | 0.403 | 0 | 0.5445 | 0.0000 | 1.0458 |
| 2 | 0.403 | 0.093 | 0.5808 | 0.1560 | 1.0458 |
| 3 | 0.403 | 0.217 | 0.363 | 0.3120 | 1.0458 |
| 4 | 0.403 | 0.2268 | 0.121 | 0.6630 | 1.0458 |
| 5 | 0.403 | 0.2331 | 0.0968 | 0.6864 | 1.0458 |
| 6 | 0.403 | 0.2646 | 0.0121 | 0.6864 | 1.0458 |
| 7 | 0.4836 | 0.2835 | 0 | 0.6864 | 1.0458 |
| 8 | 0.4836 | 0.315 | 0 | 0.6864 | 1.0458 |
| 9 | 0.4836 | 0.315 | 0 | 0.6864 | 1.0458 |
| 10 | 0.403 | 0.1575 | 0 | 0.2730 | 1.0458 |
| 11 | 0.403 | 0.1575 | 0 | 0.2340 | 1.0458 |
| 12 | 0.403 | 0.1575 | 0 | 0.2496 | 1.0458 |
| 13 | 0.403 | 0.2205 | 0 | 0.5850 | 1.0458 |
| 14 | 0.434 | 0.252 | 0 | 0.6630 | 1.0458 |
| 15 | 0.434 | 0.2835 | 0 | 0.6864 | 1.0458 |
| 16 | 0.403 | 0.315 | 0 | 0.6864 | 1.0458 |
| 17 | 0.403 | 0.315 | 0 | 0.6864 | 1.0458 |
| 18 | 0.403 | 0.315 | 0.121 | 0.6864 | 1.0458 |
| 19 | 0.5208 | 0.2394 | 0.363 | 0.6240 | 1.0458 |
| 20 | 0.5208 | 0.126 | 0.3872 | 0.5850 | 1.0458 |
| 21 | 0.5208 | 0.063 | 0.4235 | 0.1560 | 0.6300 |
| 22 | 0.5208 | 0.0315 | 0.3872 | 0.0780 | 0.6300 |
| 23 | 0.5208 | 0.0063 | 0.363 | 0.0000 | 0.6300 |
| 24 | 0.5208 | 0 | 0.4235 | 0.0000 | 0.6300 |
| 25 | 0.5208 | 0 | 0.4356 | 0.0000 | 0.5040 |
| 26 | 0.5208 | 0 | 0.4477 | 0.0000 | 0.3780 |
| 27 | 0.5208 | 0 | 0.484 | 0.0000 | 0.3150 |
| 28 | 0.5208 | 0 | 0.5445 | 0.0000 | 0.2772 |
| 29 | 0.5208 | 0 | 0.5566 | 0.0000 | 0.1512 |
| 30 | 0.5208 | 0 | 0.5687 | 0.0000 | 0.0252 |
| 31 | 0.5208 | 0 | 0.5808 | 0.0000 | 0.0252 |
| **Total Wetted Acres** | **14.3282** | **4.5877** | **7.8045** | **10.7562** | **25.1118** |

# APPENDIX D

## Evapotranspiration Calculations & AZMET Method Description

**Evapotranspiration Calculations**
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2013

| | 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** | 0.2266 | 0.07 | 0.001321833 | 0 | 0.12 | 0 | **0.3698** | 0.16 | 0.004930667 |
| **2** | 0.2266 | 0.08 | 0.001510667 | 0 | 0.12 | 0 | **0.3464** | 0.18 | 0.005196 |
| **3** | 0.2762 | 0.09 | 0.0020715 | 0 | 0.06 | 0 | **0.2918** | 0.17 | 0.004133833 |
| **4** | 0.2762 | 0.09 | 0.0020715 | 0 | 0.09 | 0 | **0.2452** | 0.22 | 0.004495333 |
| **5** | 0.2142 | 0.08 | 0.001428 | 0 | 0.12 | 0 | **0.2142** | 0.16 | 0.002856 |
| **6** | 0.2142 | 0.07 | 0.0012495 | 0 | 0.12 | 0 | **0.2142** | 0.18 | 0.003213 |
| **7** | 0.189 | 0.09 | 0.0014175 | 0 | 0.12 | 0 | **0.2918** | 0.21 | 0.0051065 |
| **8** | 0.1134 | 0.08 | 0.000756 | 0.1196 | 0.13 | 0.001295667 | **0.3388** | 0.13 | 0.003670333 |
| **9** | 0.0252 | 0.12 | 0.000252 | 0.2452 | 0.07 | 0.001430333 | **0.3202** | 0.06 | 0.001601 |
| **10** | 0 | 0.09 | 0 | 0.3072 | 0.11 | 0.002816 | **0.314** | 0.19 | 0.004971667 |
| **11** | 0.063 | 0.09 | 0.0004725 | 0.2762 | 0.03 | 0.0006905 | **0.3078** | 0.19 | 0.0048735 |
| **12** | 0.2142 | 0.07 | 0.0012495 | 0.2452 | 0.1 | 0.002043333 | **0.3202** | 0.2 | 0.005336667 |
| **13** | 0.2142 | 0.08 | 0.001428 | 0.2762 | 0.11 | 0.002531833 | **0.3202** | 0.22 | 0.005870333 |
| **14** | 0.2576 | 0.09 | 0.001932 | 0.2762 | 0.13 | 0.002992167 | **0.2516** | 0.23 | 0.004822333 |
| **15** | 0.2762 | 0.08 | 0.001841333 | 0.2762 | 0.13 | 0.002992167 | **0.236** | 0.26 | 0.005113333 |
| **16** | 0.2266 | 0.1 | 0.001888333 | 0.2576 | 0.19 | 0.004078667 | **0.2204** | 0.26 | 0.004775333 |
| **17** | 0.2452 | 0.13 | 0.002656333 | 0.2452 | 0.18 | 0.003678 | **0.2204** | 0.27 | 0.004959 |
| **18** | 0.2142 | 0.11 | 0.0019635 | 0.2266 | 0.11 | 0.002077167 | **0.2204** | 0.23 | 0.004224333 |
| **19** | 0.282 | 0.12 | 0.00282 | 0.2266 | 0.19 | 0.003587833 | **0.2142** | 0.22 | 0.003927 |
| **20** | 0.282 | 0.11 | 0.002585 | 0.2452 | 0.02 | 0.000408667 | **0.2578** | 0.17 | 0.003652167 |
| **21** | 0.1888 | 0.13 | 0.002045333 | 0.2266 | 0.07 | 0.001321833 | **0.3698** | 0.14 | 0.004314333 |
| **22** | 0.1754 | 0.12 | 0.001754 | 0.2142 | 0.1 | 0.001785 | **0.3698** | 0.26 | 0.008012333 |
| **23** | 0.125 | 0.09 | 0.0009375 | 0.2266 | 0.13 | 0.002454833 | **0.4008** | 0.26 | 0.008684 |
| **24** | 0.031 | 0.02 | 5.16667E-05 | 0.2762 | 0.16 | 0.003682667 | **0.4008** | 0.25 | 0.00835 |
| **25** | 0 | 0.07 | 0 | 0.3072 | 0.14 | 0.003584 | **0.3698** | 0.25 | 0.007704167 |
| **26** | 0 | 0.06 | 0 | 0.3198 | 0.17 | 0.0045305 | **0.3388** | 0.24 | 0.006776 |
| **27** | 0 | 0.04 | 0 | 0.3464 | 0.16 | 0.004618667 | **0.3388** | 0.25 | 0.007058333 |
| **28** | 0 | 0.05 | 0 | 0.3698 | 0.17 | 0.005238833 | **0.3388** | 0.26 | 0.007340667 |
| **29** | 0 | 0.12 | 0 | | | 0 | 0.292 | 0.27 | 0.00657 |
| **30** | 0 | 0.1 | 0 | | | | **0.2764** | 0.18 | 0.004146 |
| **31** | 0 | 0.07 | 0 | | | | **0.2266** | 0.26 | 0.004909667 |
| **Monthly Evapo-transpiration** | | | **0.0357035** | | | **0.057838667** | | | **0.161593833** |

**Evapotranspiration Calculations**
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2013

| | 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** | 0.2266 | 0.27 | 0.0050985 | 0.0218 | 0.33 | 0.0005995 | 0.2762 | 0.35 | 0.008055833 |
| **2** | 0.2762 | 0.28 | 0.006444667 | 0.2466 | 0.34 | 0.006987 | 0.2762 | 0.37 | 0.008516167 |
| **3** | 0.2762 | 0.27 | 0.0062145 | 0.3136 | 0.37 | 0.009669333 | 0.2762 | 0.39 | 0.0089765 |
| **4** | 0.2762 | 0.23 | 0.005293833 | 0.9936 | 0.33 | 0.027324 | 0.1952 | 0.36 | 0.005856 |
| **5** | 0.2452 | 0.29 | 0.005925667 | 0.9936 | 0.33 | 0.027324 | 0.1952 | 0.36 | 0.005856 |
| **6** | 0.2918 | 0.28 | 0.006808667 | 0.9936 | 0.27 | 0.022356 | 0.1258 | 0.35 | 0.003669167 |
| **7** | 0.3698 | 0.27 | 0.0083205 | 0.9316 | 0.27 | 0.020961 | 0.2644 | 0.37 | 0.008152333 |
| **8** | 0.3698 | 0.31 | 0.009553167 | 0.913 | 0.25 | 0.019020833 | 0.0124 | 0.41 | 0.000423667 |
| **9** | 0.3078 | 0.19 | 0.0048735 | 0.2734 | 0.3 | 0.006835 | 0.0124 | 0.4 | 0.000413333 |
| **10** | 0.3698 | 0.23 | 0.007087833 | 0.2266 | 0.24 | 0.004532 | 0.0124 | 0.38 | 0.000392667 |
| **11** | 0.3136 | 0.26 | 0.006794667 | 0.2762 | 0.35 | 0.008055833 | 0 | 0.41 | 0 |
| **12** | 0.3136 | 0.12 | 0.003136 | 0.2762 | 0.38 | 0.008746333 | 0.031 | 0.4 | 0.001033333 |
| **13** | 0.2902 | 0.3 | 0.007255 | 0.2762 | 0.37 | 0.008516167 | 0.062 | 0.39 | 0.002015 |
| **14** | 0.2386 | 0.31 | 0.006163833 | 0.251 | 0.35 | 0.007320833 | 0.1556 | 0.36 | 0.004668 |
| **15** | 0.1570 | 0.33 | 0.0043175 | 0.251 | 0.37 | 0.007739167 | 0.1556 | 0.3 | 0.00389 |
| **16** | 0.1250 | 0.34 | 0.003541667 | 0.251 | 0.35 | 0.007320833 | 0.1808 | 0.33 | 0.004972 |
| **17** | 0.0940 | 0.28 | 0.002193333 | 0.251 | 0.35 | 0.007320833 | 0.134 | 0.36 | 0.00402 |
| **18** | 0.0376 | 0.3 | 0.00094 | 0.2384 | 0.35 | 0.006953333 | 0.1406 | 0.36 | 0.004218 |
| **19** | 0.0000 | 0.28 | 0 | 0.1754 | 0.33 | 0.0048235 | 0.191 | 0.38 | 0.006048333 |
| **20** | 0.0000 | 0.3 | 0 | 0.125 | 0.37 | 0.003854167 | 0.2666 | 0.37 | 0.008220167 |
| **21** | 0.0000 | 0.31 | 0 | 0.0314 | 0.33 | 0.0008635 | 0.3078 | 0.37 | 0.0094905 |
| **22** | 0.0124 | 0.31 | 0.000320333 | 0.0932 | 0.36 | 0.002796 | 0.3078 | 0.37 | 0.0094905 |
| **23** | 0.0062 | 0.33 | 0.0001705 | 0.3446 | 0.37 | 0.010625167 | 0.314 | 0.38 | 0.009943333 |
| **24** | 0.0000 | 0.31 | 0 | 0.3698 | 0.36 | 0.011094 | 0.3136 | 0.38 | 0.009930667 |
| **25** | 0.0062 | 0.34 | 0.000175667 | 0.3698 | 0.36 | 0.011094 | 0.259 | 0.35 | 0.007554167 |
| **26** | 0.0124 | 0.3 | 0.00031 | 0.3698 | 0.34 | 0.010477667 | 0.2356 | 0.37 | 0.007264333 |
| **27** | 0.0124 | 0.31 | 0.000320333 | 0.3078 | 0.33 | 0.0084645 | 0.1726 | 0.41 | 0.005897167 |
| **28** | 0.0310 | 0.32 | 0.000826667 | 0.3698 | 0.35 | 0.010785833 | 0.091 | 0.31 | 0.002350833 |
| **29** | 0.0310 | 0.34 | 0.000878333 | 0.323 | 0.34 | 0.009151667 | 0.0376 | 0.31 | 0.000971333 |
| **30** | 0.0062 | 0.34 | 0.000175667 | 0.2918 | 0.35 | 0.008510833 | 0.6424 | 0.34 | 0.018201333 |
| **31** | | | | 0.2762 | 0.34 | 0.007825667 | | | |
| **Monthly Evapo-transpiration** | | | **0.103140333** | | | **0.3079485** | | | **0.170490667** |

**Evapotranspiration Calculations**
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2013

| | 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** | 0.0310 | 0.26 | 0.000671667 | 0.0000 | 0.1 | 0 | 0.0000 | 0.23 | 0 |
| **2** | 0.0310 | 0.35 | 0.000904167 | 0.0000 | 0.12 | 0 | 0.0000 | 0.12 | 0 |
| **3** | 0.0310 | 0.35 | 0.000904167 | 0.0000 | 0.26 | 0 | 0.0000 | 0.13 | 0 |
| **4** | 0.0310 | 0.36 | 0.00093 | 0.0000 | 0.13 | 0 | 0.0000 | 0.17 | 0 |
| **5** | 0.0310 | 0.19 | 0.000490833 | 0.0000 | 0.19 | 0 | 0.0000 | 0.21 | 0 |
| **6** | 0.0310 | 0.29 | 0.000749167 | 0.0000 | 0.17 | 0 | 0.0000 | 0.15 | 0 |
| **7** | 0.0124 | 0.27 | 0.000279 | 0.0000 | 0.26 | 0 | 0.0000 | 0.13 | 0 |
| **8** | 0.0124 | 0.29 | 0.000299667 | 0.0000 | 0.28 | 0 | 0.0000 | 0.1 | 0 |
| **9** | 0.0124 | 0.31 | 0.000320333 | 0.0000 | 0.27 | 0 | 0.0000 | 0.1 | 0 |
| **10** | 0.0062 | 0.24 | 0.000124 | 0.0000 | 0.27 | 0 | 0.0000 | 0.19 | 0 |
| **11** | 0.0062 | 0.2 | 0.000103333 | 0.0000 | 0.28 | 0 | 0.0000 | 0.26 | 0 |
| **12** | 0.0000 | 0.2 | 0 | 0.0000 | 0.27 | 0 | 0.0000 | 0.26 | 0 |
| **13** | 0.0000 | 0.3 | 0 | 0.0000 | 0.3 | 0 | 0.0000 | 0.25 | 0 |
| **14** | 0.0000 | 0.29 | 0 | 0.0000 | 0.28 | 0 | 0.0000 | 0.24 | 0 |
| **15** | 0.0000 | 0.29 | 0 | 0.0000 | 0.28 | 0 | 0.0000 | 0.26 | 0 |
| **16** | 0.0000 | 0.13 | 0 | 0.0000 | 0.26 | 0 | 0.0000 | 0.31 | 0 |
| **17** | 0.0000 | 0.27 | 0 | 0.0000 | 0.29 | 0 | 0.0000 | 0.29 | 0 |
| **18** | 0.0000 | 0.33 | 0 | 0.0000 | 0.2 | 0 | 0.0000 | 0.27 | 0 |
| **19** | 0.0000 | 0.18 | 0 | 0.0000 | 0.24 | 0 | 0.0000 | 0.27 | 0 |
| **20** | 0.0000 | 0.19 | 0 | 0.0000 | 0.24 | 0 | 0.0000 | 0.22 | 0 |
| **21** | 0.0000 | 0.22 | 0 | 0.0000 | 0.18 | 0 | 0.0000 | 0.23 | 0 |
| **22** | 0.0000 | 0.23 | 0 | 0.0000 | 0.23 | 0 | 0.0000 | 0.27 | 0 |
| **23** | 0.0000 | 0.29 | 0 | 0.0000 | 0.25 | 0 | 0.0000 | 0.23 | 0 |
| **24** | 0.0000 | 0.11 | 0 | 0.0000 | 0.19 | 0 | 0.0000 | 0.24 | 0 |
| **25** | 0.0000 | 0.11 | 0 | 0.0000 | 0.13 | 0 | 0.0000 | 0.28 | 0 |
| **26** | 0.0000 | 0.15 | 0 | 0.0000 | 0.15 | 0 | 0.0000 | 0.27 | 0 |
| **27** | 0.0000 | 0.19 | 0 | 0.0000 | 0.25 | 0 | 0.0000 | 0.18 | 0 |
| **28** | 0.0000 | 0.25 | 0 | 0.0000 | 0.21 | 0 | 0.0000 | 0.21 | 0 |
| **29** | 0.0000 | 0.3 | 0 | 0.0000 | 0.13 | 0 | 0.0000 | 0.22 | 0 |
| **30** | 0.0000 | 0.32 | 0 | 0.0000 | 0.11 | 0 | 0.0000 | 0.24 | 0 |
| **31** | 0.0000 | 0.22 | 0 | 0.0000 | 0.27 | 0 | | | |
| **Monthly Evapo-transpiration** | | | **0.005776333** | | | **0** | | | **0** |

**Evapotranspiration Calculations**
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2013

| | October | | | November | | | December | | |
|---|---|---|---|---|---|---|---|---|---|
| **Date** | Wetted Vegetated Area (acres) | Daily AZMET ETo (inches) | Daily Evapo-Transpiration (acre-feet) | Wetted Vegetated Area (acres) | Daily AZMET ETo (inches) | Daily Evapo-Transpiration (acre-feet) | Wetted Vegetated Area (acres) | Daily AZMET ETo (inches) | Daily Evapo-Transpiration (acre-feet) |
| **1** | 0.0000 | 0.22 | 0 | 0.062 | 0.15 | 0.000775 | 0.2142 | 0.08 | 0.001428 |
| **2** | 0.0000 | 0.21 | 0 | 0.0124 | 0.19 | 0.000196333 | 0.2142 | 0.09 | 0.0016065 |
| **3** | 0.0000 | 0.24 | 0 | 0.0124 | 0.13 | 0.000134333 | 0.1890 | 0.1 | 0.001575 |
| **4** | 0.0000 | 0.24 | 0 | 0.0124 | 0.14 | 0.000144667 | 0.1134 | 0.1 | 0.000945 |
| **5** | 0.0000 | 0.24 | 0 | 0.0062 | 0.13 | 6.71667E-05 | 0.1188 | 0.03 | 0.000297 |
| **6** | 0.0000 | 0.22 | 0 | 0.0156 | 0.15 | 0.000195 | 0.1188 | 0.07 | 0.000693 |
| **7** | 0.0000 | 0.22 | 0 | 0.0062 | 0.23 | 0.000118833 | 0.0626 | 0.08 | 0.000417333 |
| **8** | 0.0620 | 0.22 | 0.001136667 | 0.0124 | 0.15 | 0.000155 | 0.0470 | 0.04 | 0.000156667 |
| **9** | 0.0620 | 0.22 | 0.001136667 | 0.0124 | 0.14 | 0.000144667 | 0.0470 | 0.09 | 0.0003525 |
| **10** | 0.0930 | 0.13 | 0.0010075 | 0.0124 | 0.15 | 0.000155 | 0.0252 | 0.06 | 0.000126 |
| **11** | 0.1952 | 0.17 | 0.002765333 | 0.0124 | 0.15 | 0.000155 | 0.0252 | 0.09 | 0.000189 |
| **12** | 0.2142 | 0.19 | 0.0033915 | 0.0124 | 0.21 | 0.000217 | 0.0252 | 0.09 | 0.000189 |
| **13** | 0.3072 | 0.23 | 0.005888 | 0.0124 | 0.19 | 0.000196333 | 0.0252 | 0.08 | 0.000168 |
| **14** | 0.3154 | 0.19 | 0.004993833 | 0.031 | 0.13 | 0.000335833 | 0.0252 | 0.09 | 0.000189 |
| **15** | 0.2516 | 0.2 | 0.004193333 | 0.031 | 0.07 | 0.000180833 | 0.0408 | 0.1 | 0.00034 |
| **16** | 0.0124 | 0.19 | 0.000196333 | 0.062 | 0.15 | 0.000775 | 0.0720 | 0.09 | 0.00054 |
| **17** | 0.0310 | 0.19 | 0.000490833 | 0.062 | 0.11 | 0.000568333 | 0.0954 | 0.1 | 0.000795 |
| **18** | 0.0062 | 0.19 | 9.81667E-05 | 0.0376 | 0.13 | 0.000407333 | 0.0954 | 0.07 | 0.0005565 |
| **19** | 0.0062 | 0.19 | 9.81667E-05 | 0.0314 | 0.13 | 0.000340167 | 0.0562 | 0.13 | 0.000608833 |
| **20** | 0.0124 | 0.2 | 0.000206667 | 0.0376 | 0.11 | 0.000344667 | 0.0562 | 0.03 | 0.0001405 |
| **21** | 0.0620 | 0.2 | 0.001033333 | 0.0376 | 0.07 | 0.000219333 | 0.0310 | 0.04 | 0.000103333 |
| **22** | 0.0620 | 0.2 | 0.001033333 | 0.0376 | 0.01 | 3.13333E-05 | 0.0310 | 0.07 | 0.000180833 |
| **23** | 0.0620 | 0.19 | 0.000981667 | 0.0314 | 0 | 0 | 0.0310 | 0.08 | 0.000206667 |
| **24** | 0.0124 | 0.2 | 0.000206667 | 0.0376 | 0.08 | 0.000250667 | 0.0620 | 0.09 | 0.000465 |
| **25** | 0.0310 | 0.19 | 0.000490833 | 0.0124 | 0.08 | 8.26667E-05 | 0.0620 | 0.11 | 0.000568333 |
| **26** | 0.0310 | 0.16 | 0.000413333 | 0.0252 | 0.15 | 0.000315 | 0.0620 | 0.15 | 0.000775 |
| **27** | 0.0310 | 0.18 | 0.000465 | 0 | 0.14 | 0 | 0.0620 | 0.15 | 0.000775 |
| **28** | 0.0620 | 0.17 | 0.000878333 | 0.062 | 0.11 | 0.000568333 | 0.0620 | 0.09 | 0.000465 |
| **29** | 0.0124 | 0.2 | 0.000206667 | 0.062 | 0.09 | 0.000465 | 0.0620 | 0.1 | 0.000516667 |
| **30** | 0.0434 | 0.16 | 0.000578667 | 0.1754 | 0.06 | 0.000877 | 0.0620 | 0.09 | 0.000465 |
| **31** | 0.0620 | 0.15 | 0.000775 | | | | 0.0620 | 0.1 | 0.000516667 |
| **Monthly Evapo-transpiration** | | | **0.032665833** | | | **0.008415833** | | | **0.016350333** |

THE UNIVERSITY OF ARIZONA®
Cooperative Extension

# STANDARDIZED REFERENCE EVAPOTRANSPIRATION

## A NEW PROCEDURE FOR ESTIMATING REFERENCE EVAPOTRANSPIRATION IN ARIZONA

### Introduction

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

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

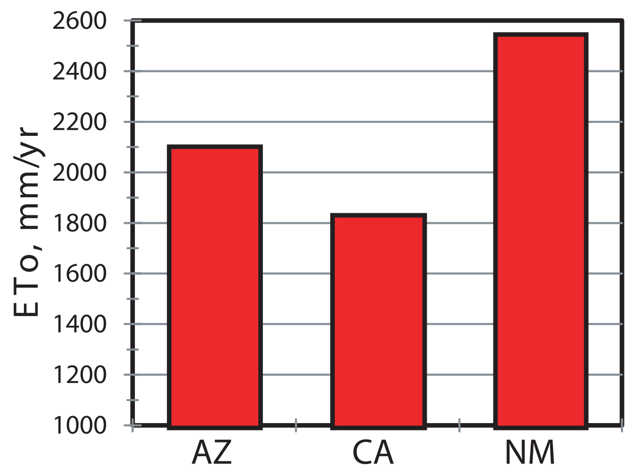


Figure 1. Reference ET (ETo) for Tucson for calendar year 1996 as computed using the published procedures for the public weather networks in Arizona, California, and New Mexico.

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


11/2005 AZ1324
THE UNIVERSITY OF ARIZONA
COLLEGE OF AGRICULTURE AND LIFE SCIENCES
TUCSON, ARIZONA 85721



PAUL W. BROWN
*Extension Specialist, Biometeorology*


*This information has been reviewed by university faculty.*


cals.arizona.edu/pubs/water/az1324.pdf

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:

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

Where:

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

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

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

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

$\gamma$ = 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 $d^{-1}$

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

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

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

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

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

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

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

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

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

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

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

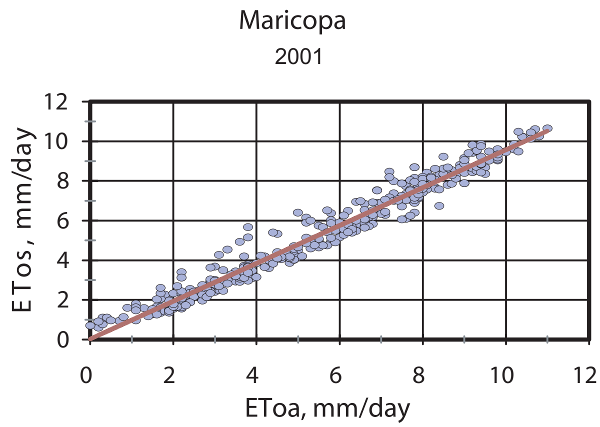



Figure 2. Reference evapotranspiration as computed using the ASCE standardized procedure (ETos) versus reference evapotranspiration computed using procedure employed by AZMET. The line represents the least squares regression line ( ETos = 0.03 + 0.95 x ETo a; $r^2$ = 0.96).

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

## Data Required To Compute ETos

Both meteorological and non-meteorological data are required for the computation of ETos. The required meteorological data include: 1) daily solar radiation (MJ $m^{-2}$ $d^{-1}$), 2) mean daily vapor pressure (kPa), 3) mean daily wind speed (m $s^{-1}$), and 4) maximum and minimum air temperature for the day ($^{o}$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 (ETo a) data. To answer this question, AZMET computed daily ETos for the period 1 January 1998 through 31 December 2001 (4 years), then compared the monthly, seasonal, and annual totals of ETos against similar totals of ETo a for locations presently served by AZMET weather stations.

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

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

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

## Converting Past ETo a to ETos

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

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

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

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

Table 2 continued. Mean monthly values of reference evapotranspiration for all AZMET station sites for the period 1998-2001 computed using the ASCE standardized (ETos) and original AZMET (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 ETos. Monthly ratios provide the best means of converting short term data sets (e.g., daily, weekly or monthly totals of ETos). *Users wishing to obtain actual computed values of ETos for past years should contact AZMET. As part of the move to adopt ETos, AZMET will generate ETos for its entire database which extends back to 1987 at some locations.*

## Crop Coefficients and ETos

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

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

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

$$ETc = Kc * ETos$$

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

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

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

$$ETc = Kc * ETos$$

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

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

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

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

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

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

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

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

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

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

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

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

## References


Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration: Guidelines for computing crop water requirements. Irrigation & Drainage Paper 56. Food and Agriculture Organization, United Nations. Rome, IT.

Brown, P.W. 1998. AZMET computation of reference crop evapotranspiration. Arizona Meteorological Network [Online]. Available at **cals.arizona.edu/azmet/et2.htm** (verified 1 Nov. 2002).

Brown, P. and D. Kopec. 2000. Converting Reference Evapotranspiration Into Turf Water Use. Turf Irrigation Management Series: II. Extension Report AZ1195. College of Agriculture, University of Arizona.

Itenfisu, D., R.L. Elliott, R.G. Allen, and I.A. Walter. 2000. Comparison of reference evapotranspiration calculations across a range of climates. p. 216-227. Proc., 4th Decennial National Irrig. Symp. Phoenix, AZ. ASAE, St. Joseph, MI.

Jensen, M.E., R.D. Burman, and R.G. Allen (ed.). 1990. Evapotranspiration and Irrigation Water Requirements. ASCE Manuals and Reports on Engineering Practice No. 70., New York.

Sammis, T. 1996. Penman's Equation Referenced to Grass [Online]. Available at **weather.nmsu.edu/math/penmans.html** (verified 1 Nov. 2002).

Snyder, R. and W. Pruitt. 1985. Estimating reference evapotranspiration with hourly data. Chpt. VII. *In* R. Snyder et al. (ed.) California Irrigation Management Information System Final Report. Univ. of California-Davis. Land, Air and Water Resources Paper #10013.

Tanner, C.B. and W.L. Pelton. 1960. Potential evapotranspiration estimates by the approximate energy balance method of Penman. J. Geophysical Research. 65:3391-3413.

Walter, I.A., R.G. Allen, R. Elliott, D. Itenfisu, P. Brown, M.E. Jensen, B. Mecham, T.A. Howell, R. Snyder, S. Eching, T. Spofford, M. Hattendorf, D. Martin, R.H. Cuenca, and J.L. Wright. 2004. The ASCE Standardized Reference Evapotranspiration Equation. Final Draft. Envir. Water Resources Institute, ASCE.

Van Bavel, C.H.M. 1966. Potential evaporation: the combination concept and its experimental verification. Water Resource Research 2(3):455-467.

# 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 ($^oC$).

### Rn: Net Radiation

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

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

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

Clear sky solar radiation (Rso) is computed using:

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

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

Extraterrestrial radiation is computed from earth-sun geometry using:

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

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

The relative distance factor is computed using:

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

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

The solar declination angle is computed using:

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

The sunset angle is computed using:

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

### γ: Psychrometer Constant

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

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

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

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

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

### T: Mean Air Temperature

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

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

where Tmax and Tmin are the maximum and minimum air temperatures ($^oC$) 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 ($^oC$) .

### 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; $^oC$ ) 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

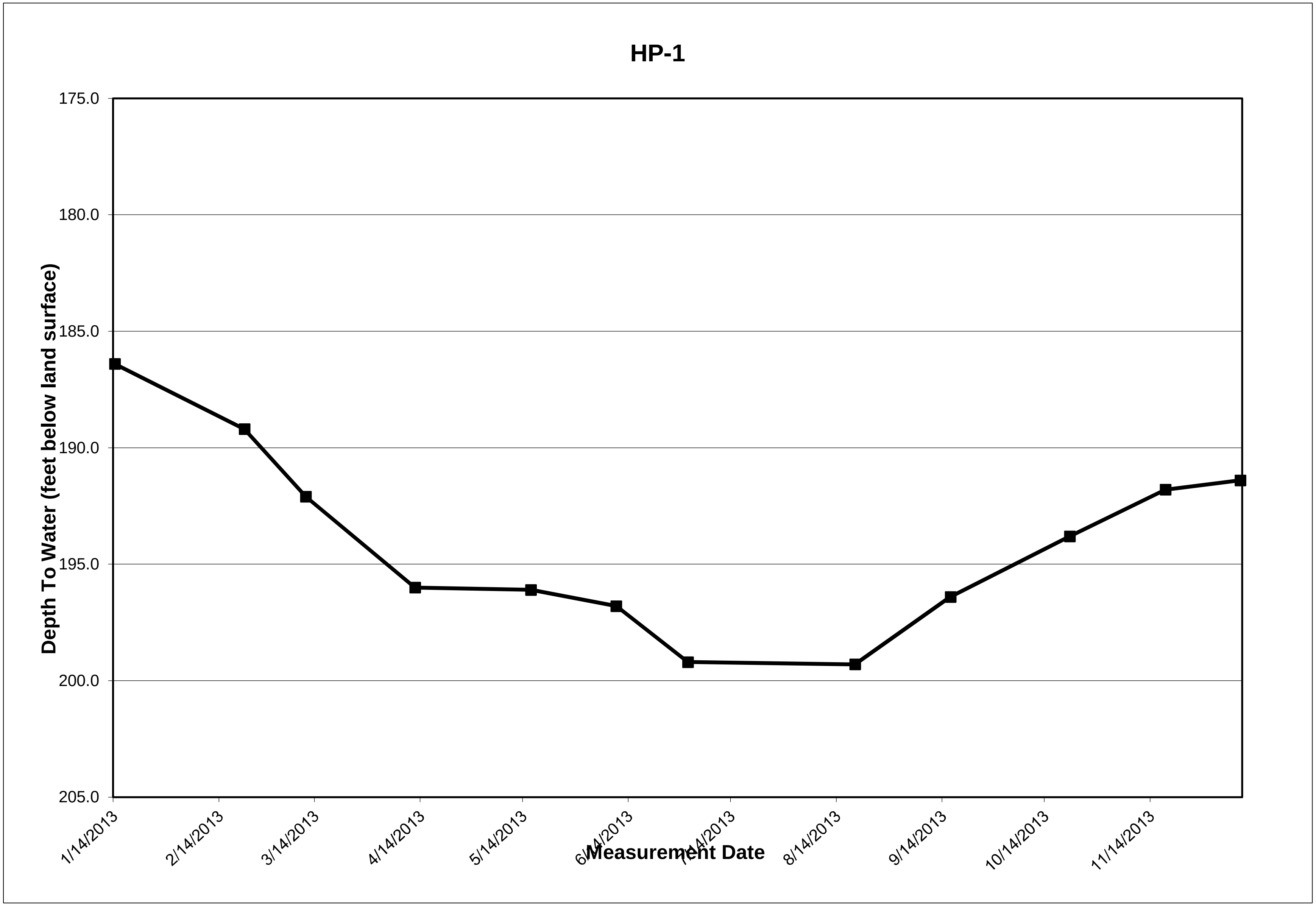
**USF WATER LEVEL MEASUREMENTS**
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2013

| **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** |
| 1/14/2013 | 186.4 | 186.4 | 1798.8 | |
| 2/21/2013 | 189.2 | 189.2 | 1796.0 | |
| 3/11/2013 | 192.1 | 192.1 | 1793.1 | |
| 4/12/2013 | 196.0 | 196.0 | 1789.2 | |
| 5/16/2013 | 196.1 | 196.1 | 1789.1 | |
| 6/10/2013 | 196.8 | 196.8 | 1788.4 | |
| 7/1/2013 | 199.2 | 199.2 | 1786.0 | |
| 8/19/2013 | 199.3 | 199.3 | 1785.9 | |
| 9/16/2013 | 196.4 | 196.4 | 1788.8 | |
| 10/21/2013 | 193.8 | 193.8 | 1791.4 | |
| 11/18/2013 | 191.8 | 191.8 | 1793.4 | |
| 12/10/2013 | 191.4 | 191.4 | 1793.8 | |

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

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

**USF WATER LEVEL MEASUREMENTS**
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2013



**USF WATER LEVEL MEASUREMENTS**
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2013

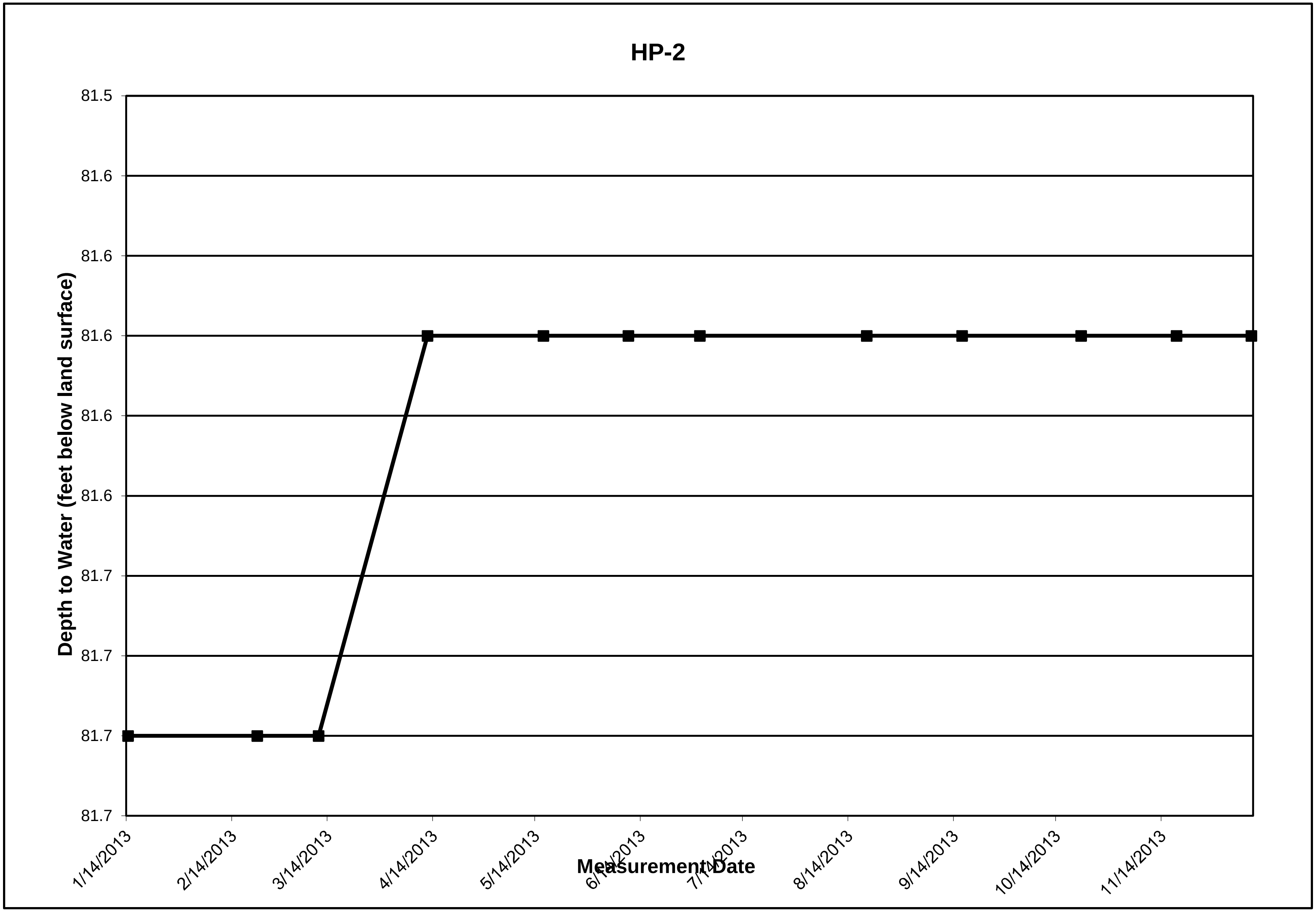
| | |
|---|---|
| **Monitor Point ID** | HP-2 |
| ADWR Registration Number | 55-593607 |
| Cadastral Location | D(11-11)33cad |
| Measuring Point Elevation (feet amsl) | 1986.75 |
| Measuring Point Description | top of port |
| Measuring Point Height (ft) | |
| Land Surface Elevation at Wellhead (feet 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** |
|---|---|---|---|---|
| 1/14/2013 | 81.7 | 81.7 | 1903.5 | |
| 2/21/2013 | 81.7 | 81.7 | 1903.5 | |
| 3/11/2013 | 81.7 | 81.7 | 1903.5 | |
| 4/12/2013 | 81.6 | 81.6 | 1903.6 | |
| 5/16/2013 | 81.6 | 81.6 | 1903.6 | |
| 6/10/2013 | 81.6 | 81.6 | 1903.6 | |
| 7/1/2013 | 81.6 | 81.6 | 1903.6 | |
| 8/19/2013 | 81.6 | 81.6 | 1903.6 | |
| 9/16/2013 | 81.6 | 81.6 | 1903.6 | |
| 10/21/2013 | 81.6 | 81.6 | 1903.6 | |
| 11/18/2013 | 81.6 | 81.6 | 1903.6 | |
| 12/10/2013 | 81.6 | 81.6 | 1903.6 | |

* 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. 71-563876.0007
Year: 2013



**USF WATER LEVEL MEASUREMENTS**

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0007

Year: 2013

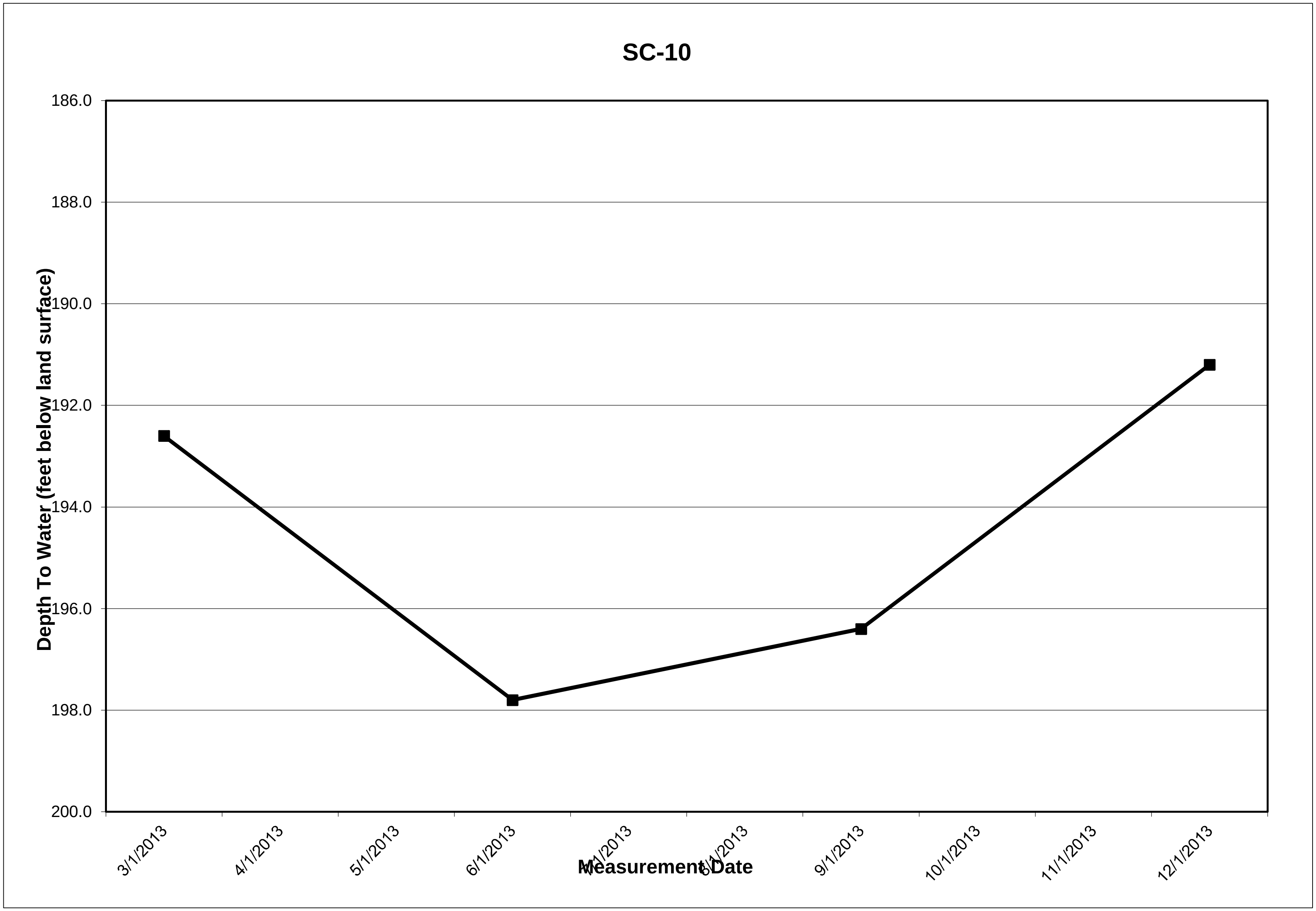
| | |
|---|---|
| **Monitor Point ID** | SC-10 |
| ADWR Registration Number | 55-520129 |
| Cadastral Location | D(11-11)33bcb |
| Measuring Point Elevation (feet amsl) | 1978.36 |
| Measuring Point Description | top of port |
| Measuring Point Height (ft) | |
| Land Surface Elevation at Wellhead (feet 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 |
|---|---|---|---|---|
| 3/11/2013 | 192.6 | 192.6 | 1792.6 | |
| 6/10/2013 | 197.8 | 197.8 | 1787.4 | |
| 9/16/2013 | 196.4 | 196.4 | 1788.8 | |
| 12/10/2013 | 191.2 | 191.2 | 1794.0 | |

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

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

**USF WATER LEVEL MEASUREMENTS**
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2013



# APPENDIX F

## Infiltration Rate Data & Calculations

**INFILTRATION RATE DATA AND CALCULATIONS**
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2013

| | **Net Recharge Volumes** (ac-ft) | **Total Wetted Acreages** (ac-days) | **Infiltration Rate** (ft/day) | **Quarterly Average Infiltration Rate** (ft/day) |
|---|---|---|---|---|
| **January** | 36.4 | 89.2 | 0.41 | |
| **February** | 24.2 | 70.3 | 0.34 | |
| **March** | 15.9 | 84.9 | 0.19 | 0.31 |
| **April** | 48.3 | 61.7 | 0.78 | |
| **May** | 80.0 | 83.9 | 0.95 | |
| **June** | 69.1 | 79.3 | 0.87 | 0.88 |
| **July** | 12.4 | 57.1 | 0.22 | |
| **August** | -0.5 | 16.8 | | |
| **September** | -0.1 | 5.9 | | 0.15 |
| **October** | 68.6 | 33.1 | 2.07 | |
| **November** | 67.9 | 43.1 | 1.57 | |
| **December** | 78.1 | 62.6 | 1.25 | 1.55 |

| | | | |
|---|---|---|---|
| **Totals** | **500.3** | **687.9** | **0.73** |

## CELL 1: INFILTRATION RATE DATA AND CALCULATIONS

Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2013

| | Net Recharge Volumes (ac-ft) | Total Wetted Acreages (ac-days) | Infiltration Rate (ft/day) | Quarterly Average Infiltration Rate (ft/day) |
|---|---|---|---|---|
| **January** | 9.4 | 17.4 | 0.54 | |
| **February** | 11.3 | 14.2 | 0.80 | |
| **March** | 2.7 | 2.9 | 0.92 | 0.68 |
| **April** | 3.0 | 1.6 | 1.85 | |
| **May** | 10.9 | 11.2 | 0.98 | |
| **June** | 6.4 | 6.5 | 0.97 | 1.05 |
| **July** | 0.5 | 1.1 | 0.45 | |
| **August** | 0.0 | 0.0 | | |
| **September** | 0.0 | 0.0 | | 0.45 |
| **October** | 1.9 | 0.1 | 14.31 | |
| **November** | 19.1 | 2.7 | 7.18 | |
| **December** | 20.7 | 4.6 | 4.51 | 5.64 |
| **Totals** | **85.7** | **62.3** | **1.38** | |

## CELL 2: INFILTRATION RATE DATA AND CALCULATIONS

Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2013

| | Net Recharge Volumes (ac-ft) | Total Wetted Acreages (ac-days) | Infiltration Rate (ft/day) | Quarterly Average Infiltration Rate (ft/day) |
|---|---|---|---|---|
| **January** | 25.1 | 27.3 | 0.92 | |
| **February** | -0.2 | 11.9 | | |
| **March** | -0.1 | 4.3 | | 0.57 |
| **April** | 38.3 | 4.0 | 9.63 | |
| **May** | 44.3 | 8.8 | 5.06 | |
| **June** | 53.3 | 13.9 | 3.83 | 5.10 |
| **July** | 13.0 | 16.9 | 0.77 | |
| **August** | -0.2 | 8.6 | | |
| **September** | -0.2 | 4.3 | | 0.42 |
| **October** | 41.8 | 5.1 | 8.28 | |
| **November** | 27.4 | 5.0 | 5.45 | |
| **December** | 36.7 | 7.8 | 4.70 | 5.92 |
| **Totals** | **279.1** | **117.8** | **2.37** | |

**CELL 3: INFILTRATION RATE DATA AND CALCULATIONS**

Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2013

| | Net Recharge Volumes (ac-ft) | Total Wetted Acreages (ac-days) | Infiltration Rate (ft/day) | Quarterly Average Infiltration Rate (ft/day) |
|---|---|---|---|---|
| January | 0.6 | 2.3 | 0.25 | |
| February | 6.2 | 5.2 | 1.19 | |
| March | 9.3 | 20.5 | 0.45 | 0.57 |
| April | 6.0 | 16.0 | 0.38 | |
| May | 6.4 | 21.3 | 0.30 | |
| June | 2.7 | 17.2 | 0.16 | 0.28 |
| July | -0.3 | 8.7 | | |
| August | 0.0 | 0.0 | | |
| September | 0.0 | 0.0 | | |
| October | 12.4 | 5.8 | 2.14 | |
| November | 13.1 | 5.3 | 2.47 | |
| December | 14.9 | 11.2 | 1.33 | 1.81 |
| **Totals** | **71.2** | **113.5** | **0.63** | |

**CELL 4: INFILTRATION RATE DATA AND CALCULATIONS**

Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2013

| | Net Recharge Volumes (ac-ft) | Total Wetted Acreages (ac-days) | Infiltration Rate (ft/day) | Quarterly Average Infiltration Rate (ft/day) |
|---|---|---|---|---|
| January | 2.6 | 32.6 | 0.08 | |
| February | 3.3 | 30.3 | 0.11 | |
| March | 2.9 | 39.1 | 0.07 | 0.09 |
| April | 1.1 | 28.7 | 0.04 | |
| May | 17.3 | 37.1 | 0.47 | |
| June | 6.6 | 31.1 | 0.21 | 0.26 |
| July | -0.5 | 17.2 | | |
| August | -0.1 | 1.7 | | |
| September | 0.0 | 0.0 | | |
| October | 8.1 | 10.5 | 0.77 | |
| November | 8.5 | 15.2 | 0.56 | |
| December | 4.0 | 26.3 | 0.15 | 0.40 |
| **Totals** | **53.9** | **269.8** | **0.20** | |

**EQUALIZATION BASIN: INFILTRATION RATE DATA AND CALCULATIONS**

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0007

Year: 2013

| | Net Recharge Volumes (ac-ft) | Total Wetted Acreages (ac-days) | Infiltration Rate (ft/day) | Quarterly Average Infiltration Rate (ft/day) |
|---|---|---|---|---|
| **January** | -1.3 | 14.2 | | |
| **February** | 3.5 | 14.3 | 0.25 | |
| **March** | 1.2 | 16.4 | 0.08 | 0.08 |
| **April** | -0.1 | 16.1 | | |
| **May** | 1.2 | 17.0 | 0.07 | |
| **June** | 0.2 | 16.2 | 0.01 | 0.03 |
| **July** | -0.2 | 6.5 | | |
| **August** | -0.2 | 6.5 | | |
| **September** | 0.0 | 1.0 | | |
| **October** | 4.4 | 13.7 | 0.32 | |
| **November** | -0.2 | 15.9 | | |
| **December** | 1.9 | 15.0 | 0.13 | 0.14 |

| | | | |
|---|---|---|---|
| **Totals** | **10.6** | **152.7** | **0.07** |