ANNUAL MONITORING REPORT
2011

MARANA HIGH PLAINS EFFLUENT RECHARGE PROJECT

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

Pima County, Arizona
Board of Supervisors

Ann Day, District 1
Ramon Valadez, Chair, District 2
Sharon Bronson, District 3
Raymond J. Carroll, District 4
Richard Elias, District 5

County Administrator
Chuck Huckelberry

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

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1.0 INTRODUCTION

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

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

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

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

- To 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 ninth annual report for the MHPERP. This report includes all of the data that was collected during the 2011 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;

Phase 3: 600 acre-feet per annum after re-excavation of Recharge Cell 2.

The facility was operated per Phase 3 of the permit throughout the 2011 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 manually, using an electronic switch, 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 2011 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 2011. 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 2011 is 417.53 acre-feet (AF). Water volumes stored for recharge by month are as follows: January – 19.97 AF, February – 31.72 AF, March – 36.54 AF, April – 46.63 AF, May – 34.87 AF, June – 50.28 AF, July – 25.28 AF, August – 15.45 AF, September – 6.89 AF, October – 13.15 AF, November – 75.92 AF, and December – 60.83 AF. The total amount (397.2 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 Marana and Tucson weather stations (**Figures 3 and 4**).[1] AZMET determines reference evapotranspiration (ETo) using a modification to the Penman Equation developed for the California Irrigation Management Information System (CIMIS). An explanation of the procedures used in this computation is also provided in **Appendix D**. No multiplication factor was used in the calculation of reference evapotranspiration (ETo) for the MHPERP because there are no available crop coefficients for the native vegetation in this region.[2]

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[1] The Marana weather station was deactivated on December 14, 2011. Reference evapotranspiration values were collected from the Tucson weather station from December 15th through December 31st.

[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 2011 Calendar Year is 397.2 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 5**). Off-site monitoring consists of quarterly water level measurements for one monitor well, SC-10.

3.1 Basin Water Levels

Water levels within the equalization basin are expected to fluctuate from one to five feet above the bottom elevation of 1,984 feet above mean sea level. Water depths in Recharge Cells 1, 3 and 4 are expected to fluctuate from three to twelve inches during the wet cycles.[3] Water depths in Recharge Cell 2 can fluctuate from about 5 to 6 feet during the wet cycle.[4] Water level sensors within the basins are programmed to automatically open and close the motorized butterfly valves to maintain these ranges. Basin water levels are observed visually on a daily basis to insure that the sensors are working properly.

3.2 Regional Groundwater Levels

In 2011, groundwater levels were measured for two monitoring wells, one on-site (HP-1) and one off-site (SC-10). Well HP-1 was measured on a monthly basis by PCRFCD personnel using an electric sounder. Well SC-10 was measured on a quarterly basis by PCRWRD personnel using an electric sounder, with the data transferred to PCRFCD

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 2011 Calendar Year. The water level in the on-site monitoring well, HP-1, declined 4.1 feet over the last year (from 181.1 feet bls in December 2010 to 185.2 feet below land surface in December 2011). This is the first year that groundwater levels have declined in the on-site and off-site wells since operations began in 2003.[5] The most likely reason for the decline in groundwater levels was the drop in water deliveries to the Lower Santa Cruz Recharge Project (by far the largest source of recharge to the region), which totaled 22,830 AF in 2011

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[3] Water depths are measured from a base elevation of 1982 feet above mean sea level. The bottoms of the basins have been lowered approximately 6 inches by regular maintenance activities to remove vegetation and clogging soil layers.

[4] Water depth has been significantly increased in this basin due to enhancement activities, but the level sensor is still at the original elevation of 1982 feet.

[5] Groundwater levels in well SC-10 declined 5 feet from December 2010 to November 2011.

compared to the yearly average of 37,769 AF from 2004 through 2010. Another possible source for groundwater declines in the area could be increased groundwater pumping, but this could not be confirmed by the date of this report.

3.3 Perched Groundwater Occurrence

Appendix E also contains the monitoring data and hydrograph for the one piezometer (HP-2) used to assess perched water conditions at the facility. This eighty-foot deep well was dry during the entire 2011 Calendar Year. The alert level and operation prohibition limit for this well are set at 30 feet bls and 20 feet bls respectively.

4.0 INFILTRATION RATE ASSESSMENT

The average monthly, quarterly and annual infiltration rates for the entire facility during the 2011 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 2011, monthly infiltration rates for the project ranged from 0.11 feet per day (September) to 2.43 feet per day (November). The average infiltration rate for the year was 0.54 feet/day, which is similar to last year's annual average rate of 0.57 feet/day. The lowest infiltration rates in 2011 occurred during the Third Quarter, which is the time of year that one would expect to have the least amount of infiltration.

Infiltration was highest in Recharge Cell 2 (1.10 feet/day annual average), which has a bottom substrate that is at or close to coarse sands and gravels. Recharge Cells 1 and 3, which have bottom elevations within four to six feet of coarse sands and gravels, had annual average infiltration rates of approximately 0.5 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 (0.27 feet/day). The equalization basin had the lowest annual average infiltration rate (0.08 feet/day), but this is primarily due to its function as a settling basin for fine deposits and to the limited amount of maintenance performed within the basin bottom.

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 sampling taken during the 2011 Calendar Year. Samples were taken at the oxbow channel and at monitor well HP-1. There were no sampling events for total metals, cyanide and fluoride at the diversion structure in the Third Quarter due to periodic washouts of the berm during scheduled sampling times. There were no disruptions for the sampling at monitor well HP-1.

Total coliform was reported above the alert levels set by the APP for this facility (monitor well HP-1) in March and November of 2011. ADEQ was notified after each occurrence and the appropriate contingency plan action was put into place to resolve the problem: chlorination of the well and discharge pipes. Sampling frequency was changed from monthly to weekly after each occurrence until four (4) consecutive samples had negative ("absent") results. There were no exceedances of the aquifer quality limits in 2011, so there was no violation of the Aquifer Protection Permit (APP). There were no exceedances reported for all the other analytes during Calendar Year 2011.

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 2011 Calendar Year and the solutions performed to resolve them. Major disruptions to effluent deliveries for the project occurred from late-July to late-August due to washout of the earthen diversion berm and from mid-September to late-October to allow for maintenance of all the recharge basins, including the equalization basin. Minor disruptions to effluent deliveries occurred in February (6 days) due to maintenance performed on Recharge Cells 1 through 4, in April (approximately one week) due to malfunctioning pump switches and in December (approximately 3 days) due to very low flows in the oxbow channel.

7.0 CONCLUSIONS

The volume of water stored at MHPERP for Calendar Year 2011 is 397.2 AF. This is 14.3 AF below last year and 16.7 AF below the largest amount of annual storage for the facility that was recorded in 2009. The facility operated under Phase 3 of the modified USF Permit No. 71-563876.0007 for the entire Calendar Year, thus allowing 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. However, there were two instances where alert levels were exceeded for total coliform in the monitor well, HP-1. PCRFCD staff successfully treated the well after both events based upon results from subsequent and more stringent monitoring per the Aquifer Protection Permit; monitoring frequency returned to normal once four consecutive results showed no presence of total coliform. On-site and off-site monitoring showed no negative impacts to surrounding operations from a water level perspective.

Recharge Cell 2 is still the best performing basin, having contributed 52% of the total amount of effluent stored at the facility over Calendar Year 2011; this is similar to 2010, when the recharge cell contributed 51% of the total amount stored at the project. The large amount of recharge contributed by Recharge Cell 2 is most likely 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 maintenance of the basin in March and October of 2011. Recharge Cells 1, 3 and 4 contributed almost 48% (about 16% per cell) to the total volume recharged at the project. The equalization basin, which had some minor maintenance in October, provided less than 0.5% to the total volume.

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 2011 was 0.54 feet/day, indicating a steady decline since the highest annual infiltration rate of 0.76 feet/day was recorded in 2008.[6] The most likely cause for the declining infiltration rates was the inclusion of the Equalization Basin, which had significantly lower infiltration than the rest of the basins, to the overall recharge area in November 2008. Another significant reason for the drop in yearly infiltration rates for the project is the steady infiltration declines in both the Equalization Basin and Recharge Cell 4 (the largest basin in the project).[7] Recharge Cell 2 had the highest annual infiltration rate in 2011 (1.10 feet/day), while Recharge Cell 4 had the lowest (0.27 feet/day).[8] The reason for this difference is most likely the differing depths to coarse grained materials (sands and gravels) in the basin bottoms.

There was a total of 110 days (3.67 months) when no effluent deliveries were made to the project. Approximately 54% of this down time (60 days) was due to drying and maintaining the recharge basins to help increase infiltration rates that were substantially low (< 0.5 feet/day). Based upon this observation, PCRFCD staff is looking to incorporate some basin maintenance activities (primarily deep ripping of the basin bottoms) during the scheduled drying cycles for each of the basins over the next year. This action will

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[6] The average infiltration rates for 2009 and 2010 were 0.63 feet/day and 0.57 feet/day respectively.

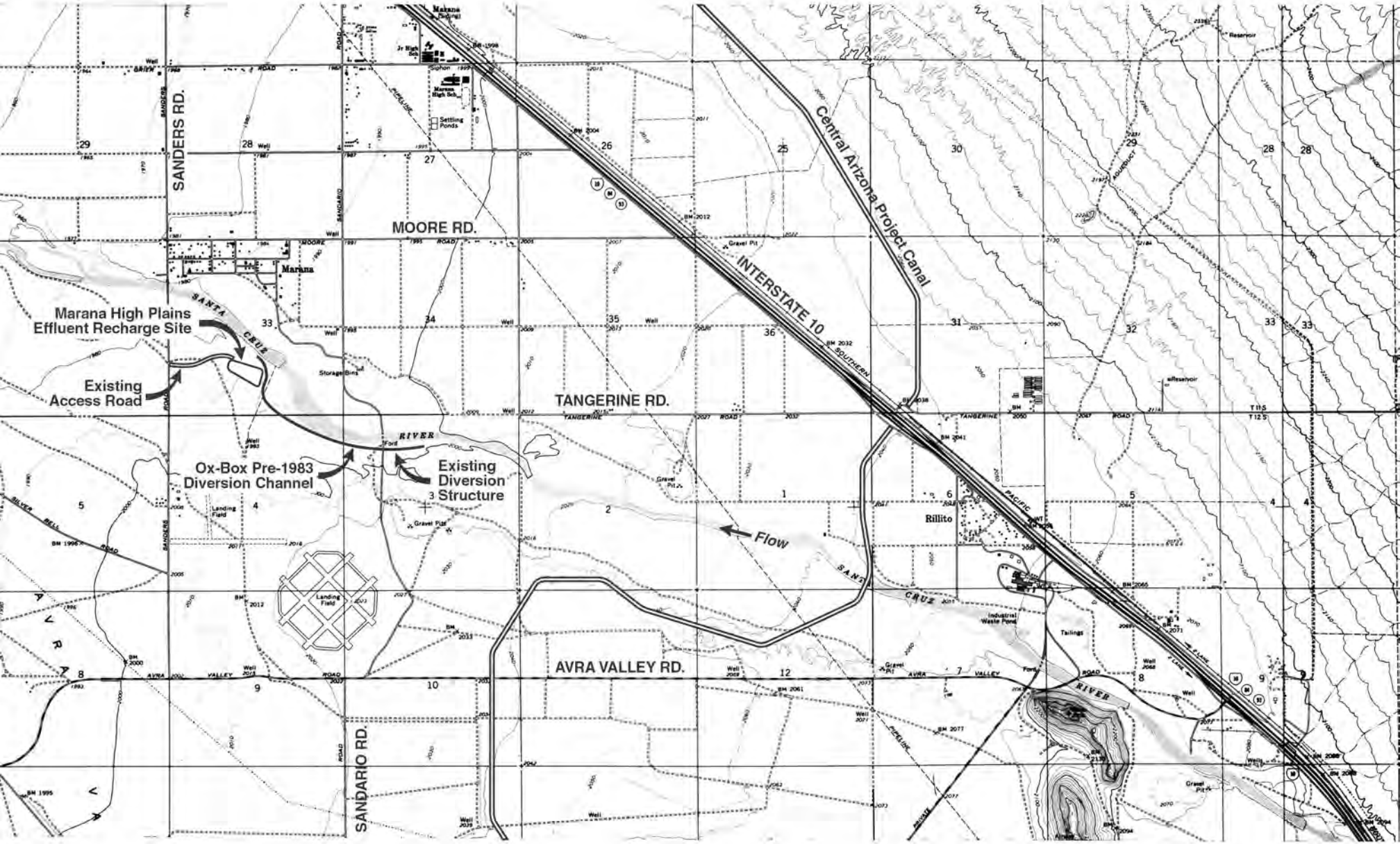
[7] The Equalization Basin had annual average infiltration rates of 0.22 feet/day in 2009, 0.16 feet/day in 2010, and 0.08 feet/day in 2011. Recharge Cell 4 had annual average infiltration rates of 0.29 feet/day in 2008, 0.37 feet/day in 2009, 0.29 feet/day in 2010, and 0.27 feet/day in 2001.

[8] The equalization basin actually had the lowest infiltration rate recorded (0.03 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.

hopefully keep infiltration rates high over the course of the entire year by frequently breaking up the clogging layers that form in the basin bottoms.

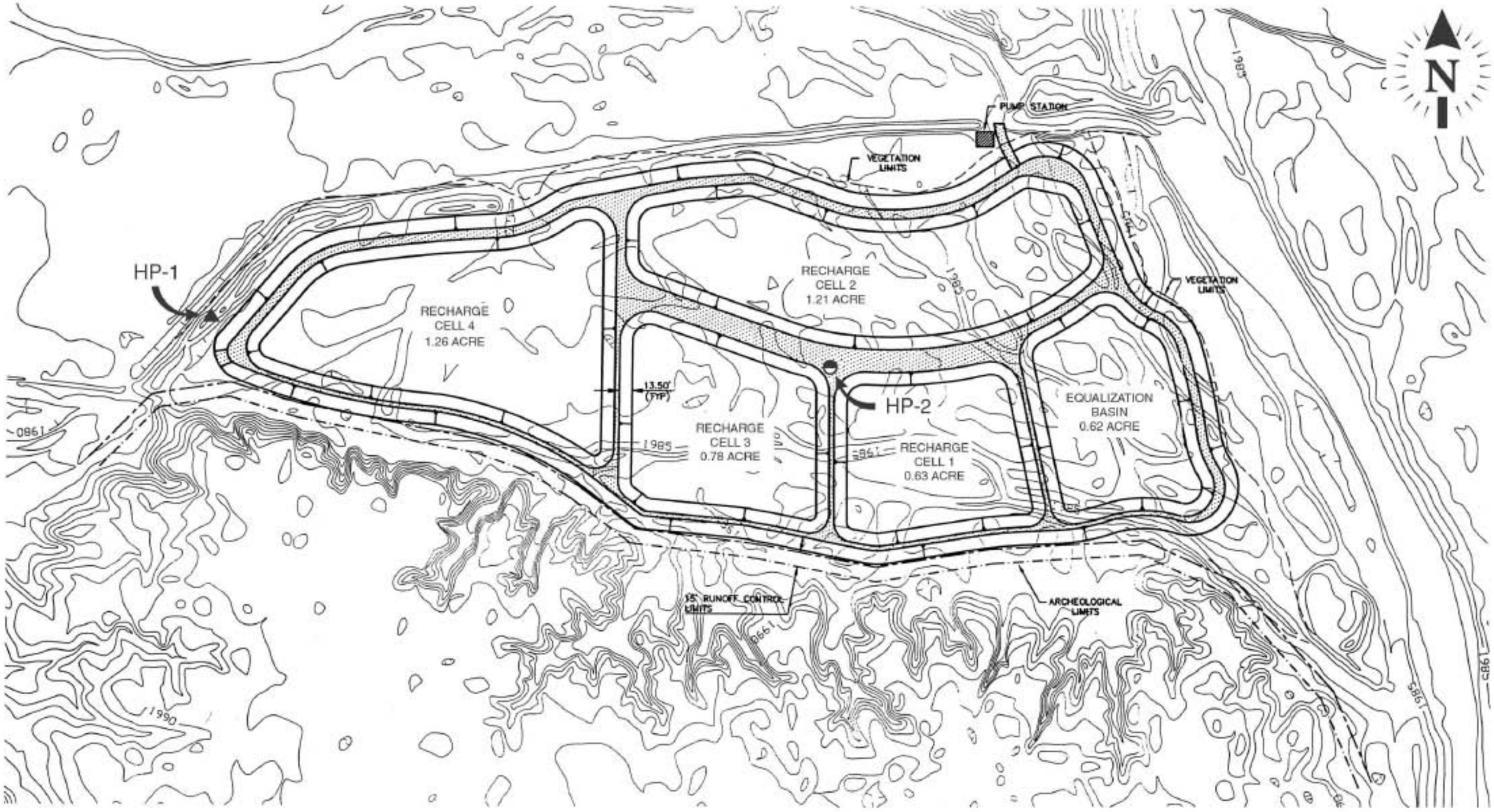
FIGURES

FIGURE 1
Location Map



Pima County Graphic Services db3483 7/02

FIGURE 2
Facility Map



LEGEND

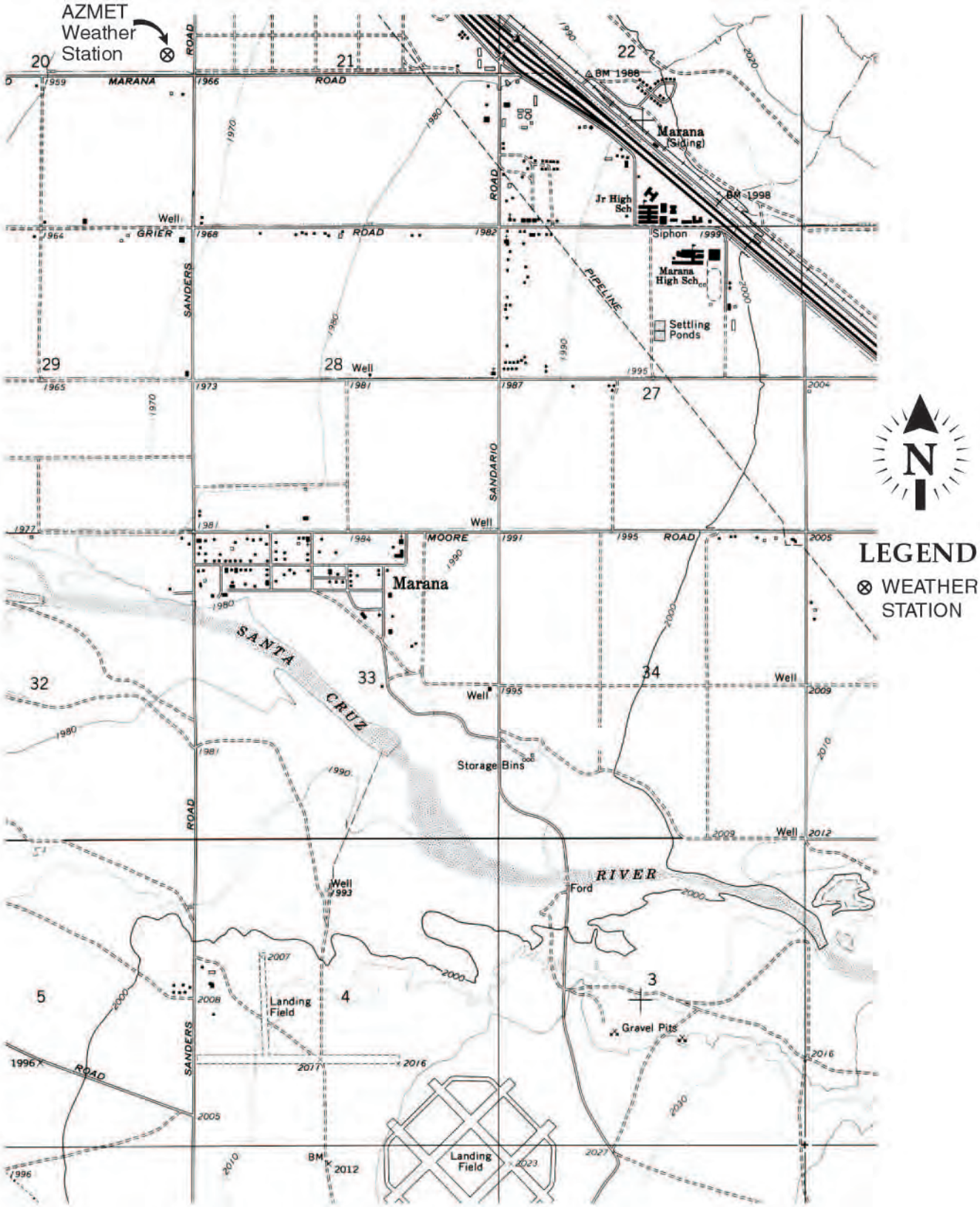
▲ MONITOR WELL

◓ PIEZOMETER

SCALE IN FEET:

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

Pima County Graphic Services db3492 7/02



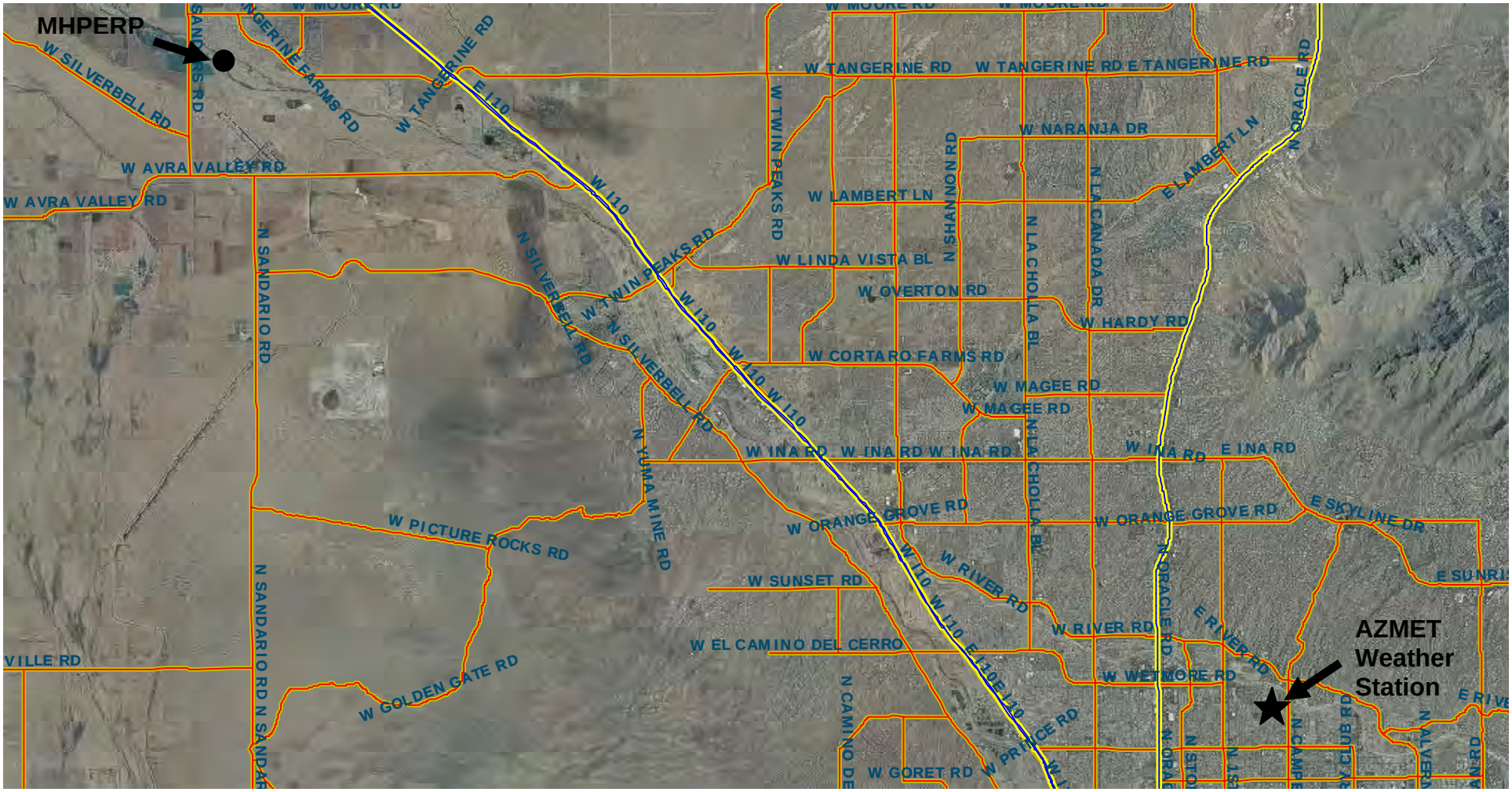
Date on line: Sep 1 1987 (Julian Day 244)
Location: 1.6 km (1 mile) west of I-10 on Trico-Marana Rd.
Elevation: 601 meters (1972 ft)
Coordinates: Latitude = 32° 27' 40" N; Longitude = 111° 14' 00" W
Cooperator: Marana Agricultural Center College of Agri., Univ. of Arizona

FIGURE 3
Marana High Plains Effluent Recharge Project : AZMET Weather Station Location Map

Miles .5 1 2
SCALE:

Pima County Graphic Services af5071 5/03

FIGURE 4
Tucson AZMET Weather Station
Location Map



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

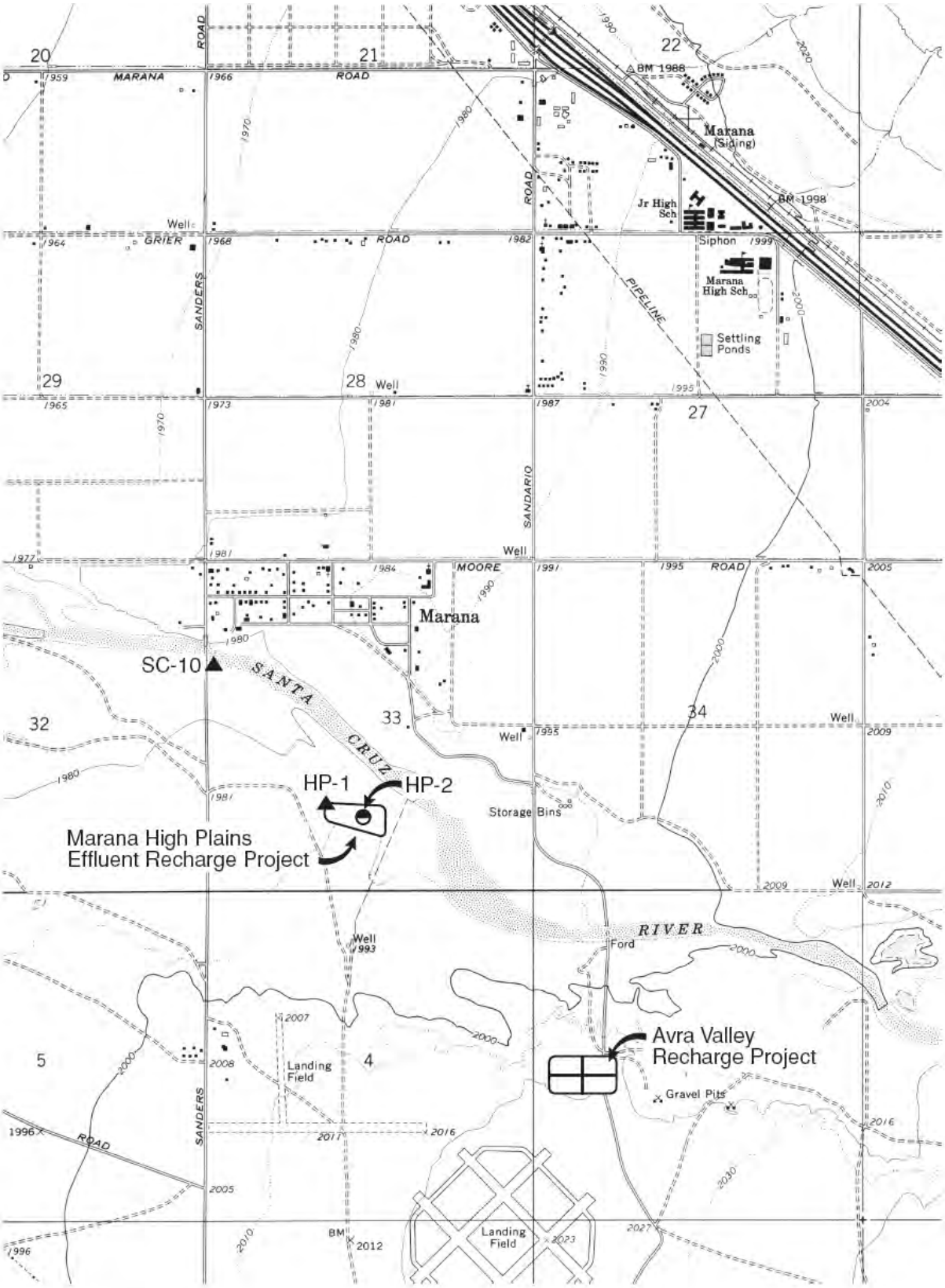
N

Miles 1 2 4

SCALE

LEGEND

★ **Weather Station**



LEGEND

▲ MONITOR WELL

◓ PIEZOMETER

N

Miles .5 1 2

SCALE:

FIGURE 5
Marana High Plains Effluent Recharge Project Monitor Wells Location Map

Pima County Graphic Services mhperpFig4 db 3-10

TABLES

TABLE 1A
MARANA HIGH PLAINS EFFLUENT RECHARGE PROJECT
WATER QUALITY SUMMARY - SOURCE WATER DIVERSION
CALENDAR YEAR 2011

Constituent	Unit	Discharge Limit	Sample Date & Results											
			Jan-11	Feb-11	Mar-11	Apr-11	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11
Nutrients														
Total Nitrogen[1]	mg/l	N/A	31.4	29.7	30.1	20.2	26.2	29.0	28.1	23.0	No Event	31.4	41.2	35.5
Nitrate-Nitrite as N	mg/l	N/A	7.4	5.7	7.1	8.2	8.2	8.0	7.1	8.0	No Event	3.4	2.2	1.5
Total Kjeldahl Nitrogen (TKN)	mg/l	N/A	24.0	24.0	23.0	12.0	18.0	21.0	21.0	15.0	No Event	28.0	39.0	24.0
Metals (Total)														
Free Cyanide	mg/l	0.2	No Event	< 0.020	No Event	< 0.0080	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.050
Total Fluoride	mg/l	4	No Event	0.47	No Event	0.63	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.40
Arsenic	mg/l	0.05	No Event	0.0048	No Event	0.0043	No Event	No Event	No Event	No Event	No Event	No Event	No Event	0.0046
Barium	mg/l	2	No Event	0.063	No Event	0.072	No Event	No Event	No Event	No Event	No Event	No Event	No Event	0.093
Beryllium	mg/l	0.004	No Event	< 0.0010	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010
Cadmium	mg/l	0.005	No Event	< 0.0010	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010
Chromium	mg/l	0.1	No Event	< 0.0010	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010
Lead	mg/l	0.05	No Event	0.0019	No Event	0.0012	No Event	No Event	No Event	No Event	No Event	No Event	No Event	0.0012
Thallium	mg/l	0.002	No Event	< 0.0010	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010
Nickel	mg/l	0.1	No Event	0.0052	No Event	0.0036	No Event	No Event	No Event	No Event	No Event	No Event	No Event	0.0045
Antimony	mg/l	0.006	No Event	< 0.0030	No Event	< 0.0030	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0030
Selenium	mg/l	0.05	No Event	< 0.0020	No Event	< 0.0020	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0020
Mercury	mg/l	0.002	No Event	< 0.00020	No Event	< 0.00020	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.00020
Volatile Organic Compounds (VOCs)														
para-Dichlorobenzene	mg/l	0.075	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Dichloromethane	mg/l	0.005	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
o-Dichlorobenzene	mg/l	0.6	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Carbon tetrachloride	mg/l	0.005	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Toluene	mg/l	1	No Event	< 0.0020	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Benzene	mg/l	0.005	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Monochlorobenzene	mg/l	0.1	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Ethylbenzene	mg/l	0.7	No Event	< 0.0020	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Tetrachloroethylene	mg/l	0.005	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
1,1-Dichloroethylene	mg/l	0.007	No Event	< 0.0020	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
1,1,1-Trichloroethane	mg/l	0.2	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
1,1,2-Trichloroethane	mg/l	0.005	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
1,2-Dichloroethane	mg/l	0.005	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
1,2-Dichloropropane	mg/l	0.005	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
1,2,4-Trichlorobenzene	mg/l	0.07	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.00054	No Event	No Event
Vinyl Chloride	mg/l	0.002	No Event	< 0.0010	No Event	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	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Hexachlorobenzene	mg/l	0.001	No Event	< 0.010*	No Event	No Event	No Event	< 0.00059	No Event	No Event	No Event	< 0.00059	No Event	No Event
cis--1,2-Dichloroethylene	mg/l	0.07	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Styrene	mg/l	0.1	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Xylenes (Total)	mg/l	10	No Event	< 0.0030	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0020	No Event	No Event
Trihalomethane (TTHM)	mg/l	0.1	No Event	< 0.0050	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
trans-1,2-Dichloroethylene	mg/l	0.1	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Hexachlorocyclopentadiene	mg/l	0.05	No Event	< 0.010	No Event	No Event	No Event	< 0.00264	No Event	No Event	No Event	< 0.00264	No Event	No Event

* Laboratory detection limit is greater than Aquifer Quality Limit, which is in violation of the APP; Laboratory for analysis changed to Pima County Compliance & Regulatory Affairs Office Laboratory to meet appropriate detection limits - sampling conducted in 2nd Quarter

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 2011

Constituent	Unit	Aquifer Quality Limit	Sample Date & Results											
			Jan-11	Feb-11	Mar-11	Apr-11	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11
Nutrients														
Total Nitrogen[1]	mg/l	10	2.0	1.9	2.0	1.9	1.7	1.9	1.8	1.7	1.8	1.9	1.9	2.0
Nitrate-Nitrite as N	mg/l	10	2.0	1.9	2.0	1.9	1.7	1.9	1.8	1.7	1.8	1.9	1.9	2.0
Total Kjeldahl Nitrogen (TKN)	mg/l	N/A	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Total Coliform (P-Present, A-Absent)	P/A	A	A	A	P	A	A	A	A	A	A	A	P	A
Metals (Total)														
Free Cyanide	mg/l	0.2	No Event	< 0.020	No Event	< 0.0080	No Event	No Event	No Event	No Event	< 0.0080	No Event	No Event	< 0.050
Total Fluoride	mg/l	4	No Event	< 0.40	No Event	0.41	No Event	No Event	No Event	No Event	< 0.40	No Event	No Event	< 0.40
Arsenic	mg/l	0.05	No Event	0.0018	No Event	0.0017	No Event	No Event	No Event	No Event	0.0018	No Event	No Event	0.0011
Barium	mg/l	2	No Event	0.12	No Event	0.14	No Event	No Event	No Event	No Event	0.13	No Event	No Event	0.095
Beryllium	mg/l	0.004	No Event	< 0.0010	No Event	< 0.0010	No Event	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	< 0.0010	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event	< 0.0010
Chromium	mg/l	0.1	No Event	< 0.0010	No Event	< 0.0010	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event	< 0.0010
Lead	mg/l	0.05	No Event	< 0.0010	No Event	0.0015	No Event	No Event	No Event	No Event	0.0015	No Event	No Event	0.0023
Thallium	mg/l	0.002	No Event	< 0.0010	No Event	< 0.0010	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event	< 0.0010
Nickel	mg/l	0.1	No Event	0.0048	No Event	0.0030	No Event	No Event	No Event	No Event	0.0034	No Event	No Event	0.0041
Antimony	mg/l	0.006	No Event	< 0.0030	No Event	< 0.0030	No Event	No Event	No Event	No Event	< 0.0030	No Event	No Event	< 0.0030
Selenium	mg/l	0.05	No Event	< 0.0020	No Event	< 0.0020	No Event	No Event	No Event	No Event	0.0021	No Event	No Event	< 0.0020
Mercury	mg/l	0.002	No Event	< 0.00020	No Event	< 0.00020	No Event	No Event	No Event	No Event	0.00041	No Event	No Event	< 0.00020
Volatile Organic Compounds (VOCs)														
para-Dichlorobenzene	mg/l	0.075	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Dichloromethane	mg/l	0.005	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
o-Dichlorobenzene	mg/l	0.6	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Carbon tetrachloride	mg/l	0.005	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Toluene	mg/l	1	No Event	< 0.0020	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Benzene	mg/l	0.005	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Monochlorobenzene	mg/l	0.1	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Ethylbenzene	mg/l	0.7	No Event	< 0.0020	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Tetrachloroethylene	mg/l	0.005	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
1,1-Dichloroethylene	mg/l	0.007	No Event	< 0.0020	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
1,1,1-Trichloroethane	mg/l	0.2	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
1,1,2-Trichloroethane	mg/l	0.005	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
1,2-Dichloroethane	mg/l	0.005	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
1,2-Dichloropropane	mg/l	0.005	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
1,2,4-Trichlorobenzene	mg/l	0.07	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.00054	No Event	No Event
Vinyl Chloride	mg/l	0.002	No Event	< 0.0010	No Event	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	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Hexachlorobenzene	mg/l	0.001	No Event	< 0.010[a]	No Event	No Event	No Event	< 0.00059	No Event	No Event	No Event	< 0.00059	No Event	No Event
cis--1,2-Dichloroethylene	mg/l	0.07	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Styrene	mg/l	0.1	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Xylenes (Total)	mg/l	10	No Event	< 0.0030	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0020	No Event	No Event
Trihalomethane (TTHM)	mg/l	0.1	No Event	< 0.0050	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
trans-1,2-Dichloroethylene	mg/l	0.1	No Event	< 0.0010	No Event	No Event	No Event	No Event	No Event	No Event	No Event	< 0.0010	No Event	No Event
Hexachlorocyclopentadiene	mg/l	0.05	No Event	< 0.010	No Event	No Event	No Event	< 0.00264	No Event	No Event	No Event	< 0.00264	No Event	No Event

[a] Laboratory detection limit is greater than Aquifer Quality Limit, which is in violation of the APP; Laboratory for analysis changed to Pima County Compliance & Regulatory Affairs Office Laboratory to meet appropriate detection limits; sampling conducted in 2nd Quarter

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 2011

Date	Problem	Solution
February 2011	Recharge volumes were declining due to buildup of clogging materials in all of the basins	Basin maintenance was performed in the recharge cells, excluding the equalization basin: removal of approximately 6 inches of soil materials and cross-ripping basin bottoms with a 36-inch, ripping tool on the back of a tractor
February 2011	Flow meter in Recharge Cell 3 has been washed out of outlet pipe and is no longer measuring flow into the cell accurately	Valve was closed and the recharge cell was dried; the pipe fitting for the flow meter was glued back into the outlet pipe with silicone cement; the flow meter was recalibrated and placed back onto the fitting; the valve was reopened for flow deliveries
March 2011	Compliance Well HP-1 tested positive ("present") for total coliform from a sample collected on March 21st, which is an Alert Level exceedance for the Aquifer Protection Permit (APP)	Result was verified from a sample collected on March 24th and ADEQ was notified of the problem; the well was chlorinated and the pump was run for approximately 30 minutes to clean out the discharge pipes; weekly samples collected in April through May produced negative ("absent") results, indicating no violation of the APP's Aquifer Quality Limits; a summary report was provided to ADEQ and monitoring frequency changed back to monthly.
April 2011	Submersible pumps at the wet well are not turning on	Inspection of the pump system determined that the pump control switches were damaged and could no longer operate the pumps. The pump switches were replaced and the pumps turned back on.
July 2011	Water in the wet well (and oxbow channel) was very turbid and at a very low level (below the tops of the pumps) on July 25th.	Pumps were turned off and the diversion berm was inspected for damages from stormwater events; flows into the oxbow channel were restored on August 26th
September 2011	Infiltration rates were greatly declining in all of the recharge basins (ranged from 0.15 feet/day to 0.34 feet/day from July through September); there was a large buildup of weeds within and around each of the basins and along the maintenance road	Basin maintenance was conducted on all of the recharge cells in October, including the equalization basin: vegetation was pruned around the basin edges and along the roadway, approximately 4 to 8 inches of soil materials were removed from the basin bottoms and the basin bottoms were cross-ripped with a 36-inch, ripping tool on the back of a tractor
November 2011	Compliance Well HP-1 tested positive ("present") for total coliform from a sample collected on November 17th, which is an Alert Level exceedance for the APP (fecal coliform was "absent")	Result was verified from a sample collected on November 21st and ADEQ was notified of the problem; the well was chlorinated and the pump was run for approximately 40 minutes to clean out the well and discharge pipes; four (4) consecutive samples collected from November through December produced negative ("absent") results, indicating no violation of the APP's Aquifer Quality Limits; a summary report was provided to ADEQ and monitoring frequency changed back to monthly.
December 2011	Flows in the oxbow channel and wet well are turbid from storm water runoff; water levels in the wet well is too low to run the pumps	Inspection of the diversion berm indicated that the mouth of the oxbow channel was plugged with channel materials and a portion of the berm was washed out after recent storm flow events; the berm was repaired and the channel materials removed to allow water to flow freely into the oxbow channel

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: 2011

	January		February		March		April		May		June	
	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons
	331485700		337992750		348329960		360235500		375430600		386791930	
Day 1	331862800	377100	337992750	0	349145000	815040	360710700	475200	375430600	0	387493980	702050
2	332157820	295020	337992750	0	349978475	833475	361067100	356400	375430600	0	387701550	207570
3	332502410	344590	338028750	36000	350792075	813600	361067100	0	375656750	226150	387990431	288881
4	332636810	134400	338460750	432000	351417400	625325	361067100	0	376275650	618900	388264031	273600
5	332924810	288000	338892750	432000	351585445	168045	361593600	526500	376643750	368100	388523231	259200
6	333212810	288000	339180750	288000	351753490	168045	362378400	784800	376730450	86700	389200031	676800
7	333500810	288000	339180750	0	351942890	189400	363098400	720000	376968940	238490	390020831	820800
8	333677560	176750	339180750	0	352583690	640800	363314524	216124	376968940	0	390841631	820800
9	333828310	150750	339180750	0	353367050	783360	363314524	0	376968940	0	391619231	777600
10	334068416	240106	339353550	172800	354150410	783360	363314524	0	377371612	402672	392222785	603554
11	334362416	294000	339699150	345600	354763760	613350	363314524	0	377861212	489600	392913985	691200
12	334684736	322320	340044750	345600	355109360	345600	363314524	0	378350812	489600	393518785	604800
13	334684736	0	340266510	221760	355282160	172800	363314524	0	378840412	489600	394123585	604800
14	334864736	180000	340337772	71262	355514960	232800	363314524	0	379330012	489600	394750635	627050
15	335181536	316800	340337772	0	355740560	225600	363880800	566276	379819612	489600	395600235	849600
16	335498336	316800	340854070	516298	356051760	311200	364672800	792000	380154252	334640	396277035	676800
17	335641436	143100	341362270	508200	356246490	194730	365464800	792000	380287992	133740	396958155	681120
18	335854644	213208	342096670	734400	356577690	331200	366256800	792000	380460904	172912	397610542	652387
19	335946444	91800	342922130	825460	356908890	331200	367048800	792000	380633816	172912	398162929	552387
20	335946444	0	343747590	825460	357240090	331200	367826400	777600	380878616	244800	398660926	497997
21	335946444	0	344573050	825460	357571290	331200	368589600	763200	381123416	244800	399171026	510100
22	335946444	0	345366200	793150	357902490	331200	369345600	756000	381123416	0	399883826	712800
23	335946444	0	345878090	511890	358233690	331200	370094400	748800	381357456	234040	400171826	288000
24	336115950	169506	346266900	388810	358564890	331200	370828800	734400	381741768	384312	400517426	345600
25	336322350	206400	346682250	415350	358724090	159200	371548800	720000	382441649	699881	400772131	254705
26	336667950	345600	347179050	496800	358724090	0	372254680	705880	383155930	714281	401097631	325500
27	337013550	345600	347675850	496800	358724090	0	372960280	705600	383904730	748800	401495891	398260
28	337359150	345600	348329960	654110	358896090	172000	373802680	842400	384667930	763200	402129491	633600
29	337704750	345600			359246350	350260	374645080	842400	385387930	720000	402742490	612999
30	337992750	288000			359760300	513950	375430600	785520	386093530	705600	403174490	432000
31	337992750	0			360235500	475200			386791930	698400		
	Total (gal)	**6507050**	**Total (gal)**	**10337210**	**Total (gal)**	**11905540**	**Total (gal)**	**15195100**	**Total (gal)**	**11361330**	**Total (gal)**	**16382560**
	Total (ac-ft)	**19.97**	**Total (ac-ft)**	**31.72**	**Total (ac-ft)**	**36.54**	**Total (ac-ft)**	**46.63**	**Total (ac-ft)**	**34.87**	**Total (ac-ft)**	**50.28**

1st Qtr Total (gal) =	**28749800**
1st Qtr Total (ac-ft) =	**88.23**

2nd Qtr Total (gal) =	**42938990**
2nd Qtr Total (ac-ft) =	**131.77**

USF DAILY FLOWMETER READINGS AND VOLUMES

Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Meter ID: Fm-eq
Year: 2011

	July		August		September		October		November		December	
	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons
	403174490		411412720		416448300		418692448		422977200		447716697	
Day 1	403505090	330600	411412720	0	416743000	294700	418692448	0	423783600	806400	448548519	831822
2	403764290	259200	411412720	0	417247000	504000	418692448	0	424561200	777600	449370759	822240
3	404052290	288000	411412720	0	417427000	180000	418692448	0	425322830	761630	450171304	800545
4	404357939	305649	411412720	0	417652000	225000	418692448	0	426185260	862430	451034664	863360
5	404511439	153500	411412720	0	417862000	210000	418692448	0	427013260	828000	451889324	854660
6	404511439	0	411412720	0	418087000	225000	418692448	0	427860340	847080	452744040	854716
7	404511439	0	411412720	0	418308332	221332	418692448	0	428686986	826646	453625416	881376
8	404511439	0	411412720	0	418544936	236604	418692448	0	429545348	858362	454475016	849600
9	404511439	0	411412720	0	418692448	147512	418692448	0	430388722	843374	455277000	801984
10	404511439	0	411412720	0	418692448	0	418692448	0	431300071	911349	456094920	817920
11	404511439	0	411412720	0	418692448	0	418692448	0	432213338	913267	456944104	849184
12	404511439	0	411412720	0	418692448	0	418692448	0	432995416	782078	457775656	831552
13	404949814	438375	411412720	0	418692448	0	418692448	0	433871896	876480	458632516	856860
14	405705814	756000	411412720	0	418692448	0	418692448	0	434728696	856800	459052556	420040
15	406454614	748800	411412720	0	418692448	0	418692448	0	435585496	856800	459297484	244928
16	407196214	741600	411412720	0	418692448	0	418692448	0	436441400	855904	459736974	439490
17	407930614	734400	411412720	0	418692448	0	418692448	0	437276600	835200	460124140	387166
18	408652560	721946	411412720	0	418692448	0	418692448	0	438116120	839520	460124140	0
19	409372560	720000	411412720	0	418692448	0	418692448	0	438955640	839520	460124140	0
20	410092560	720000	411412720	0	418692448	0	418692448	0	439795920	840280	460274080	149940
21	410391500	298940	411412720	0	418692448	0	418692448	0	440587920	792000	461059598	785518
22	410644920	253420	411412720	0	418692448	0	418692448	0	441386996	799076	461598348	538750
23	410961720	316800	412158988	746268	418692448	0	418692448	0	442204326	817330	462100687	502339
24	411278520	316800	413026801	867813	418692448	0	418692448	0	443119584	915258	462614767	514080
25	411412720	134200	413894614	867813	418692448	0	418692448	0	443762816	643232	463457069	842302
26	411412720	0	414609334	714720	418692448	0	418964320	271872	444534656	771840	463745369	288300
27	411412720	0	415042234	432900	418692448	0	419814814	850494	445333948	799292	464123064	377695
28	411412720	0	415402234	360000	418692448	0	420644400	829586	446108700	774752	464985044	861980
29	411412720	0	415762234	360000	418692448	0	421407600	763200	446900700	792000	465822632	837588
30	411412720	0	416122234	360000	418692448	0	422170800	763200	447716697	815997	466691582	868950
31	411412720	0	416448300	326066			422977200	806400			467539742	848160
	Total (gal)	**8238230**	**Total (gal)**	**5035580**	**Total (gal)**	**2244148**	**Total (gal)**	**4284752**	**Total (gal)**	**24739497**	**Total (gal)**	**19823045**
	Total (ac-ft)	**25.28**	**Total (ac-ft)**	**15.45**	**Total (ac-ft)**	**6.89**	**Total (ac-ft)**	**13.15**	**Total (ac-ft)**	**75.92**	**Total (ac-ft)**	**60.83**

3rd Qtr Total (gal) =	**15517958**
3rd Qtr Total (ac-ft) =	**47.62**

4th Qtr Total (gal) =	**48847294**
4th Qtr Total (ac-ft) =	**149.91**
Annual Total Del. Vol for FM-eq (ac-ft) =	**417.53**

USF WATER QUANTITY REPORTING SUMMARY
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2011

	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	20.0	0.8	0.0	19.2	
February	31.7	0.8	0.0	30.9	
March	36.5	1.3	0.2	35.1	85.1
April	46.6	1.2	0.1	45.3	
May	34.9	1.9	0.3	32.6	
June	50.3	3.1	0.5	46.7	124.6
July	25.3	2.6	0.4	22.3	
August	15.5	1.2	0.1	14.2	
September	6.9	1.2	0.2	5.5	42.0
October	13.1	0.2	0.0	12.9	
November	75.9	0.4	0.0	75.5	
December	60.8	0.5	3.2	57.1	145.6

Annual Totals =	**417.5**	**15.1**	**5.2**	**397.2**

APPENDIX B

Evaporation Calculations & Cooley Method Description

USF EVAPORATION CALCULATIONS

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0007

Year: 2011

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	12	0.2	14	0.2	13	0.3	12	0.3	12	0.4
Cell 1	10	0.1	8	0.1	17	0.3	7	0.1	8	0.2	14	0.4
Cell 2	33	0.3	26	0.3	7	0.1	13	0.3	12	0.3	35	1.0
Cell 3	14	0.1	7	0.1	11	0.2	4	0.1	8	0.2	13	0.4
Cell 4	12	0.1	8	0.1	29	0.5	18	0.4	29	0.8	29	0.9
	83	**0.8**	**63**	**0.8**	**78**	**1.3**	**55**	**1.2**	**69**	**1.9**	**102**	**3.1**

1st Quarter Total Evap (AF) **=**	**2.8**

2nd Quarter Total Evap (AF) **=**	**6.2**

Cooley Adj. Fac	**0.95**

USF EVAPORATION CALCULATIONS

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0007

Year: 2011

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	1	0.0	5	0.1	12	0.3	5	0.1	13	0.2	12	0.1
Cell 1	12	0.4	5	0.1	13	0.3	3	0.1	7	0.1	9	0.1
Cell 2	30	0.9	13	0.4	2	0.0	0	0.0	5	0.1	14	0.1
Cell 3	15	0.5	10	0.3	15	0.3	1	0.0	0	0.0	8	0.1
Cell 4	27	0.8	11	0.3	9	0.2	3	0.0	5	0.1	17	0.1
	86	**2.6**	**44**	**1.2**	**51**	**1.2**	**12**	**0.2**	**31**	**0.4**	**59**	**0.5**

3rd Quarter Total Evap (AF) **=**	**4.9**

4th Quarter Total Evap (AF) **=**	**1.1**
Annual Total Evap (AF) **=**	**15.1**

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 Conservation 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.

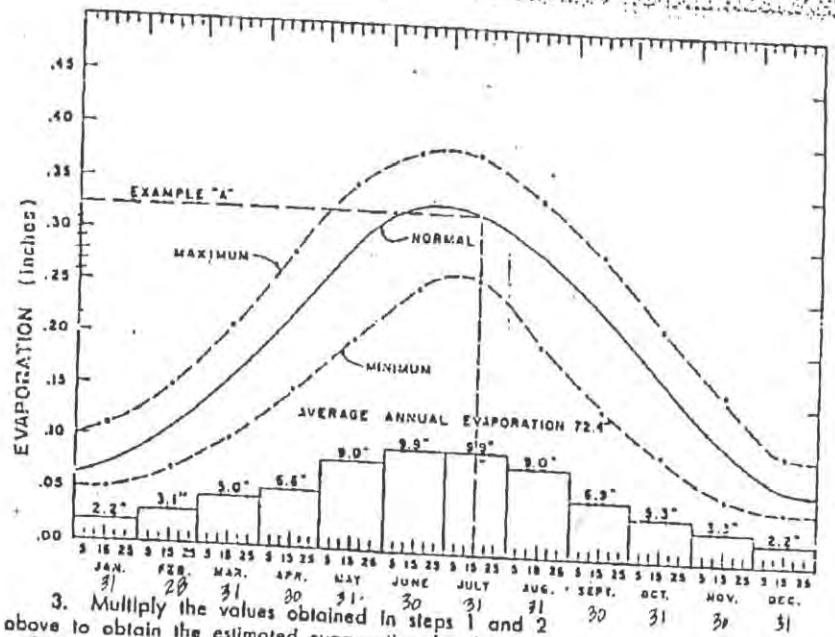


FIGURE 1. Maximum, Normal, and Minimum Daily Evaporation and Average Monthly Evaporation From Open Water Surfaces (Adjustment Factor = 1.00).

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

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

(See over)

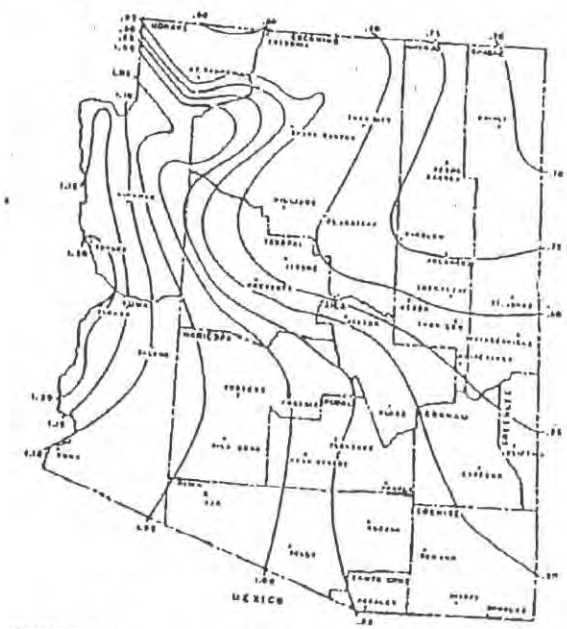


FIGURE 2. Evaporation Adjustment Factors for Arizona

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

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

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

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

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

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

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

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

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

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

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

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

Acknowledgement

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

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

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

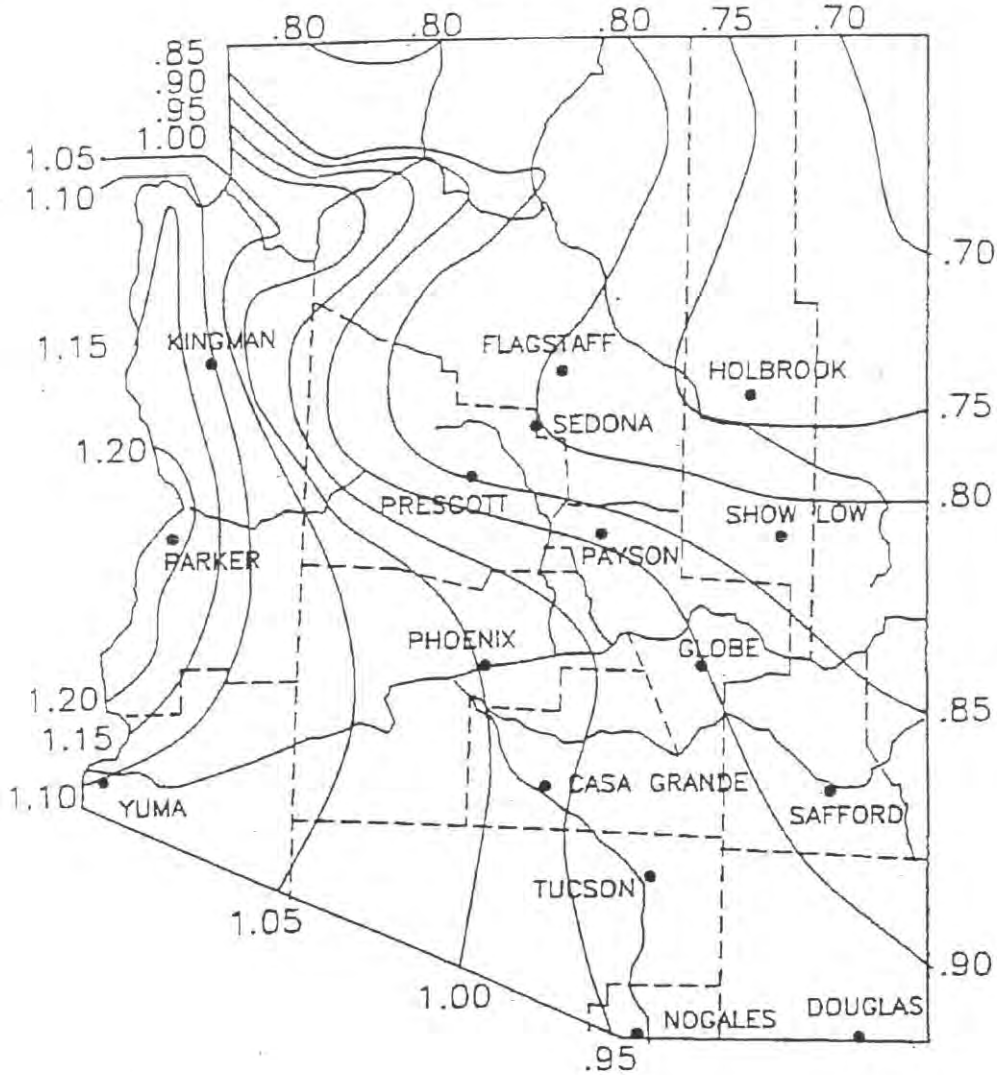
EVAPORATION FROM OPEN WATER SURFACES IN ARIZONA

FOLDER 159

Agricultural Experiment Station
And
Cooperative Extension Service
The University of Arizona

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

FIGURE 10. EVAPORATION ADJUSTMENT FACTORS FOR ARIZONA



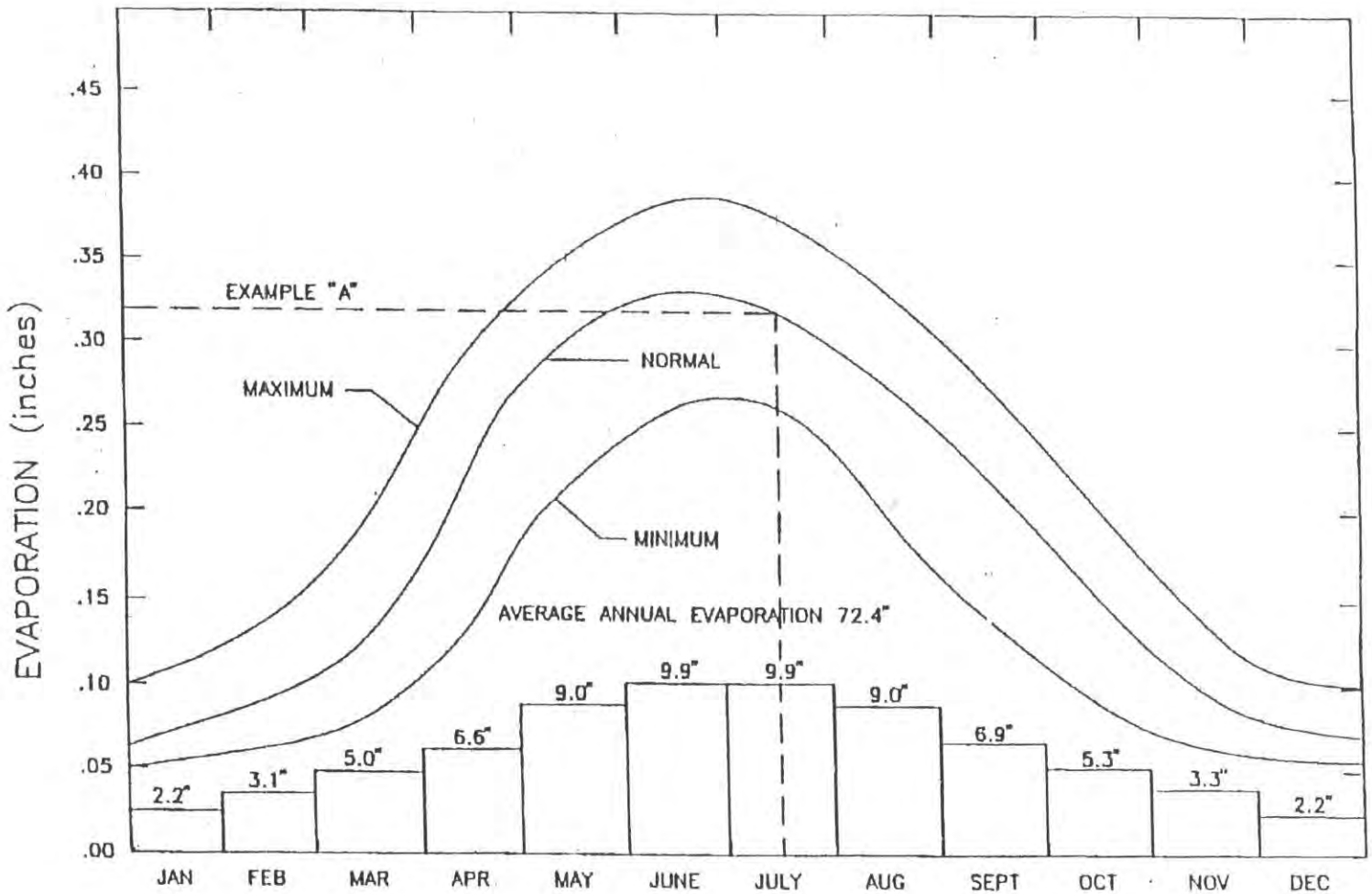


FIGURE 9. MAXIMUM, NORMAL AND MINIMUM DAILY EVAPORATION AND AVERAGE MONTHLY EVAPORATION FROM OPEN WATER SURFACES (Adjustment Factor = 1.00)

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

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

From: Cooley, 1970

APPENDIX C

Daily Wetted Acreages

USF DAILY WETTED ACREAGES
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2011

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	0.4650	0.6300	1.1374	0.5850	1.0332
2	0.4650	0.6300	1.1374	0.6396	1.0332
3	0.4650	0.6111	1.1374	0.6396	1.0332
4	0.4650	0.6111	1.1374	0.6396	1.0332
5	0.4650	0.5922	1.1374	0.6396	1.0332
6	0.4650	0.5796	1.1374	0.6396	1.0332
7	0.4650	0.5796	1.1374	0.6396	0.6300
8	0.4650	0.5796	1.1374	0.6396	0.5040
9	0.4650	0.4725	1.1374	0.6396	0.5040
10	0.4650	0.4725	1.1374	0.6396	0.4410
11	0.4650	0.3150	1.1374	0.6396	0.4410
12	0.4650	0.2835	1.1374	0.6396	0.3780
13	0.4650	0.2835	1.1374	0.6396	0.3780
14	0.4650	0.2835	1.1374	0.6396	0.3150
15	0.4650	0.2835	1.1374	0.3900	0.3150
16	0.4650	0.2520	1.1374	0.3510	0.2520
17	0.4650	0.2520	1.1374	0.3510	0.2520
18	0.4650	0.2520	1.1374	0.3510	0.1890
19	0.4650	0.2520	1.1374	0.3510	0.1890
20	0.4650	0.2205	1.1374	0.3120	0.1890
21	0.4030	0.2205	1.1374	0.3120	0.1260
22	0.4030	0.2205	1.0285	0.3120	0.1260
23	0.4030	0.1890	0.4840	0.2730	0.0630
24	0.4030	0.1890	0.6050	0.2730	0.0630
25	0.4030	0.1890	0.6050	0.2730	0.0000
26	0.4030	0.1575	1.1374	0.2340	0.0000
27	0.4650	0.1575	1.1374	0.2340	0.0000
28	0.4650	0.1575	1.1374	0.2340	0.0000
29	0.4650	0.1575	1.1374	0.2340	0.0000
30	0.4650	0.1260	1.1374	0.1950	0.0000
31	0.4650	0.1260	1.1374	0.1950	0.0000
Total Wetted Acres	**14.043**	**10.3257**	**33.4323**	**13.7748**	**11.5542**

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	0.4650	0.1260	1.1374	0.2340	0.0000
2	0.4650	0.1260	1.1374	0.1950	0.0000
3	0.4030	0.0945	1.1495	0.1950	0.0000
4	0.4650	0.0945	1.1374	0.1560	0.0000
5	0.4650	0.0945	1.1374	0.1560	0.0000
6	0.4650	0.0630	1.1374	0.1170	0.0000
7	0.4650	0.0630	1.1374	0.1170	0.0000
8	0.4650	0.0630	1.1374	0.0780	0.0000
9	0.4340	0.0315	1.1374	0.0780	0.0000
10	0.4030	0.0315	1.1495	0.0390	0.0000
11	0.4650	0.0000	1.1374	0.0390	0.0000
12	0.4650	0.0000	1.1374	0.0000	0.0000
13	0.4650	0.0000	1.1374	0.0000	0.0000
14	0.4650	0.0000	1.1374	0.0000	0.0000
15	0.4650	0.0000	1.1374	0.0000	0.0000
16	0.4340	0.5796	1.1374	0.0000	0.0000
17	0.4030	0.5796	1.0890	0.3900	0.0000
18	0.4495	0.5922	1.0648	0.3900	0.0000
19	0.4650	0.5922	1.0285	0.6396	0.0000
20	0.4650	0.6111	0.6050	0.6396	0.6300
21	0.4650	0.5922	0.6050	0.6396	0.6300
22	0.4030	0.5922	0.5445	0.6396	1.0332
23	0.4030	0.5922	0.5445	0.3120	1.0332
24	0.4030	0.5796	0.5445	0.3900	1.0332
25	0.4030	0.5922	0.5445	0.3900	1.0332
26	0.4030	0.5922	0.5445	0.3900	1.0332
27	0.4030	0.5796	0.5445	0.3900	1.0332
28	0.4030	0.4725	0.5445	0.3900	1.0332
29					
Total Wetted Acres	**12.3225**	**8.3349**	**26.4264**	**7.0044**	**8.4924**

USF DAILY WETTED ACREAGES
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2011

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	0.4030	0.5922	0.5445	0.5850	1.0332
2	0.4185	0.5922	0.5445	0.6396	1.0332
3	0.4030	0.5796	0.5445	0.6396	1.0332
4	0.4030	0.6111	0.5445	0.6396	0.6300
5	0.4185	0.5922	0.5445	0.6396	0.5040
6	0.4340	0.6111	0.5445	0.3120	0.3150
7	0.4495	0.6111	0.5445	0.3120	0.0000
8	0.4185	0.5922	0.4840	0.3900	0.6300
9	0.4030	0.5922	0.4840	0.5850	1.0332
10	0.4185	0.3150	0.4235	0.6396	1.0332
11	0.4340	0.3150	0.4235	0.6396	1.0332
12	0.4650	0.3150	0.3025	0.6396	1.0332
13	0.4650	0.3150	0.2420	0.3120	1.0332
14	0.4650	0.3150	0.1815	0.5850	1.0332
15	0.4650	0.3150	0.1210	0.6396	1.0332
16	0.4495	0.5796	0.1210	0.6396	1.0332
17	0.4650	0.6300	0.0605	0.6396	1.0332
18	0.4495	0.5922	0.0000	0.5850	1.0332
19	0.4650	0.5922	0.0000	0.0000	1.0332
20	0.4650	0.6111	0.0000	0.0000	1.0332
21	0.4650	0.5922	0.0000	0.0000	1.0332
22	0.4650	0.6111	0.0000	0.0000	1.0332
23	0.4650	0.6111	0.0000	0.0000	1.0332
24	0.4650	0.5922	0.0000	0.0000	1.0332
25	0.4650	0.6111	0.0000	0.0000	1.0332
26	0.4650	0.5922	0.0000	0.0000	1.0332
27	0.4650	0.6111	0.0000	0.0000	1.0332
28	0.4650	0.5922	0.0000	0.0000	1.0332
29	0.4650	0.6111	0.0000	0.0000	1.0332
30	0.4185	0.6300	0.0000	0.6396	1.0332
31	0.4030	0.6111	0.0000	0.6396	1.0332
Total Wetted Acres	**13.764**	**16.9344**	**6.655**	**11.3412**	**28.9422**

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	0.4650	0.5796	0.0000	0.6396	1.0332
2	0.4650	0.4725	0.0000	0.6396	1.0332
3	0.4650	0.3150	0.0000	0.6396	1.0332
4	0.4650	0.3150	0.0000	0.6396	1.0332
5	0.4650	0.2835	0.5445	0.5850	1.0332
6	0.4650	0.2520	0.6050	0.3900	1.0332
7	0.4650	0.2205	0.6050	0.3120	1.0332
8	0.4650	0.1890	0.6050	0.2340	1.0332
9	0.4650	0.1575	0.1210	0.1560	1.0332
10	0.4650	0.1260	0.0605	0.0780	0.6300
11	0.4495	0.0945	0.0000	0.0585	0.5040
12	0.4340	0.0630	0.0000	0.0390	0.5040
13	0.4185	0.0315	0.0000	0.0390	0.4410
14	0.4030	0.0063	0.0000	0.0078	0.4410
15	0.4185	0.0063	0.6050	0.0000	0.3780
16	0.4185	0.0000	0.6050	0.0000	0.3780
17	0.4185	0.0000	0.6050	0.0000	0.3150
18	0.4185	0.0000	0.6050	0.0000	0.3150
19	0.4030	0.0000	0.5445	0.0000	0.2520
20	0.4650	0.0000	0.5445	0.0000	0.1890
21	0.4650	0.0000	0.6050	0.0000	0.1260
22	0.4650	0.0000	0.6050	0.0000	0.1260
23	0.4650	0.0000	0.5445	0.0000	0.0630
24	0.4650	0.0000	0.5445	0.0000	0.0000
25	0.4650	0.5796	0.6050	0.0000	0.0000
26	0.4650	0.5796	0.6050	0.0000	0.0000
27	0.4650	0.5796	0.6050	0.0000	0.6300
28	0.4030	0.5922	1.1374	0.0000	1.0332
29	0.4030	0.6111	1.1132	0.0000	1.0332
30	0.4650	0.5796	0.6050	0.0000	1.0332
Total Wetted Acres	**13.423**	**6.6339**	**13.0196**	**4.4577**	**17.6904**

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May

Date	Equal. Basin Wetted Area (acres)*	Recharge Cell 1 Wetted Area (acres)*	Recharge Cell 2 Wetted Area (acres)*	Recharge Cell 3 Wetted Area (acres)*	Recharge Cell 4 Wetted Area (acres)*
1	0.4030	0.6111	0.5445	0.0000	1.0332
2	0.4030	0.5922	0.4840	0.0000	1.0332
3	0.4030	0.6111	0.4840	0.0000	1.0332
4	0.4030	0.6111	0.4235	0.0000	1.0332
5	0.4030	0.6111	0.4235	0.0000	1.0332
6	0.4030	0.5796	0.3630	0.3900	1.0332
7	0.4030	0.5796	0.3630	0.3900	1.0332
8	0.4030	0.4725	0.3025	0.3120	1.0332
9	0.4030	0.3150	0.3025	0.3900	0.6300
10	0.4030	0.3150	0.2420	0.3900	0.5040
11	0.4030	0.3150	0.2420	0.5460	0.6300
12	0.4030	0.2520	0.2420	0.5460	0.9828
13	0.4030	0.2520	0.2420	0.3900	0.9828
14	0.4030	0.2520	0.2420	0.3120	0.9828
15	0.4030	0.2520	0.2420	0.3120	0.9828
16	0.4030	0.2520	0.2420	0.3120	0.9828
17	0.4030	0.2520	0.2420	0.3120	0.9828
18	0.4030	0.2205	0.2420	0.3120	0.9828
19	0.4030	0.1890	0.0605	0.3120	0.9828
20	0.4030	0.1575	0.0605	0.3120	0.9828
21	0.4030	0.1260	0.0605	0.3120	0.9828
22	0.4030	0.0945	0.0605	0.3120	0.9828
23	0.4030	0.0630	0.0605	0.3120	0.9828
24	0.4030	0.0315	0.3025	0.3120	0.6300
25	0.4030	0.0315	0.4840	0.2730	0.9828
26	0.4030	0.0063	0.5445	0.2340	0.9828
27	0.4030	0.0063	0.5445	0.1560	0.9828
28	0.4030	0.0000	0.6050	0.0780	0.9828
29	0.4030	0.0000	0.6050	0.0390	0.9828
30	0.4030	0.0000	1.1132	0.0156	0.9828
31	0.4030	0.0000	1.2100	0.0078	0.9828
Total Wetted Acres	**12.493**	**8.0514**	**11.5797**	**7.5894**	**29.3328**

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	0.4030	0.0000	1.1737	0.0000	0.9828
2	0.4030	0.0000	1.0648	0.0000	0.9828
3	0.4030	0.0000	1.0648	0.0000	0.9828
4	0.4030	0.0000	1.0648	0.0000	0.9828
5	0.4030	0.0000	1.0648	0.0000	0.9828
6	0.4030	0.0000	1.0890	0.3120	0.9828
7	0.4030	0.3150	1.1132	0.3120	0.9828
8	0.4030	0.3150	1.1374	0.3120	0.9828
9	0.4030	0.5796	1.1374	0.3120	0.9828
10	0.4030	0.6111	1.1495	0.5460	0.9828
11	0.4030	0.6111	1.1374	0.5460	0.9828
12	0.4030	0.6111	1.1374	0.5460	0.9828
13	0.4030	0.6300	1.1374	0.5460	0.6300
14	0.4030	0.6300	1.1374	0.5460	0.6300
15	0.4030	0.6300	1.1374	0.5460	0.9828
16	0.4030	0.6300	1.1374	0.5460	0.9828
17	0.4030	0.6111	1.1374	0.5460	0.9828
18	0.4030	0.5922	1.1374	0.5460	0.9828
19	0.4030	0.6111	1.1737	0.5460	0.9828
20	0.4030	0.6300	1.2100	0.5460	0.9828
21	0.4030	0.6111	1.2100	0.5460	0.9828
22	0.4030	0.6111	1.2100	0.5460	0.9828
23	0.4030	0.5796	1.2100	0.5460	0.9828
24	0.4030	0.6300	1.2100	0.5460	0.9828
25	0.4030	0.5796	1.2100	0.5460	0.9828
26	0.4030	0.6300	1.2100	0.5460	0.9828
27	0.4030	0.6300	1.2100	0.5460	0.9828
28	0.4030	0.6300	1.2100	0.5460	0.9828
29	0.4030	0.5922	1.1737	0.5460	0.9828
30	0.4030	0.6300	1.1374	0.5460	0.9828
Total Wetted Acres	**12.09**	**14.1309**	**34.5334**	**12.714**	**28.7784**

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July

Date	Equal. Basin Wetted Area (acres)*	Recharge Cell 1 Wetted Area (acres)*	Recharge Cell 2 Wetted Area (acres)*	Recharge Cell 3 Wetted Area (acres)*	Recharge Cell 4 Wetted Area (acres)*
1	0.1860	0.6300	1.1132	0.5460	0.9828
2	0.1147	0.6300	1.2100	0.5460	0.9828
3	0.1054	0.6111	1.2100	0.5460	0.9828
4	0.1240	0.5922	1.2100	0.5460	0.9828
5	0.0465	0.5796	1.2100	0.5460	0.9828
6	0.0000	0.4725	1.2100	0.5460	0.9828
7	0.0000	0.3150	1.2100	0.5460	0.9828
8	0.0000	0.2520	1.1495	0.3900	0.9828
9	0.0000	0.2520	1.1374	0.3900	0.9828
10	0.0000	0.2205	1.0648	0.3900	0.9828
11	0.0000	0.2205	1.0285	0.3705	0.9828
12	0.0000	0.1890	0.5445	0.3510	0.6300
13	0.0000	0.1890	0.5445	0.3510	0.5040
14	0.0310	0.1418	0.4840	0.3120	0.9828
15	0.0310	0.0945	0.4840	0.3900	0.9828
16	0.0310	0.3150	0.4235	0.3900	0.9828
17	0.1550	0.5796	0.4235	0.3900	0.9828
18	0.1395	0.6300	0.5445	0.5460	0.9828
19	0.1240	0.6111	1.1495	0.5460	0.9828
20	0.1147	0.5796	1.2100	0.5460	0.9828
21	0.0000	0.6111	1.2100	0.5460	0.9828
22	0.0000	0.6111	1.2100	0.5460	0.9828
23	0.0000	0.5922	1.2100	0.5460	0.9828
24	0.0000	0.5796	1.2100	0.5460	0.9828
25	0.0000	0.4725	1.2100	0.5460	0.9828
26	0.0000	0.3150	1.1737	0.5460	0.6300
27	0.0000	0.2520	1.1374	0.5460	0.5040
28	0.0000	0.2205	1.1132	0.5460	0.5040
29	0.0000	0.1890	1.0285	0.5460	0.5040
30	0.0000	0.1575	0.6050	0.5460	0.4410
31	0.0000	0.1260	0.6050	0.5460	0.4410
Total Wetted Acres	**1.2028**	**12.2315**	**30.2742**	**15.1905**	**26.7624**

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	0.3410	0.0000	0.6050	0.3900	0.4410
2	0.3410	0.0000	0.6050	0.3900	0.3780
3	0.3100	0.0000	0.6050	0.3120	0.3780
4	0.3100	0.0000	0.6050	0.3120	0.3780
5	0.3100	0.0000	0.6050	0.3120	0.3150
6	0.0000	0.0000	0.6050	0.3120	0.3150
7	0.0000	0.0000	0.5445	0.3120	0.3150
8	0.0000	0.0000	0.5445	0.3120	0.2520
9	0.0000	0.0000	0.5445	0.2730	0.2520
10	0.0000	0.0000	0.5445	0.2730	0.1890
11	0.0000	0.0000	0.4840	0.2730	0.1890
12	0.0000	0.0000	0.4840	0.2730	0.1260
13	0.0000	0.0000	0.4840	0.2730	0.1260
14	0.0000	0.0000	0.4840	0.2730	0.0630
15	0.0000	0.0000	0.4235	0.2340	0.0630
16	0.0000	0.0000	0.4235	0.2340	0.0000
17	0.0000	0.0000	0.4235	0.2340	0.0000
18	0.0000	0.0000	0.4235	0.2340	0.0000
19	0.0000	0.0000	0.3630	0.2340	0.0000
20	0.0000	0.0000	0.3630	0.1950	0.0000
21	0.0000	0.0000	0.3630	0.1950	0.0000
22	0.0000	0.0000	0.3630	0.1950	0.0000
23	0.4030	0.0000	0.3025	0.3120	0.0000
24	0.4030	0.5922	0.3025	0.3900	0.5040
25	0.4030	0.5796	0.3025	0.3900	0.6300
26	0.4030	0.6111	0.3025	0.3900	0.9828
27	0.4030	0.5922	0.2420	0.5460	0.9828
28	0.4030	0.6111	0.2420	0.5460	0.9828
29	0.4030	0.5796	0.2420	0.5460	0.9828
30	0.4030	0.6111	0.2420	0.5460	0.9828
31	0.4030	0.5796	0.1815	0.5460	0.9828
Total Wetted Acres	**5.239**	**4.7565**	**13.2495**	**10.257**	**10.8108**

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September

Date	Equal. Basin Wetted Area (acres)*	Recharge Cell 1 Wetted Area (acres)*	Recharge Cell 2 Wetted Area (acres)*	Recharge Cell 3 Wetted Area (acres)*	Recharge Cell 4 Wetted Area (acres)*
1	0.4030	0.5796	0.1815	0.5460	0.9828
2	0.4030	0.6174	0.1815	0.5460	0.9828
3	0.4030	0.6174	0.1815	0.5460	0.9828
4	0.4030	0.6174	0.1815	0.5460	0.6300
5	0.4030	0.6174	0.1815	0.5460	0.5670
6	0.4030	0.6174	0.1815	0.5460	0.5670
7	0.4030	0.6174	0.1815	0.5460	0.5670
8	0.4030	0.6174	0.1815	0.5460	0.5670
9	0.4030	0.6174	0.1815	0.5460	0.5040
10	0.4030	0.6300	0.1210	0.5460	0.5040
11	0.4030	0.6300	0.1210	0.5460	0.4410
12	0.4030	0.6300	0.1210	0.5460	0.4410
13	0.4030	0.6300	0.0605	0.5460	0.3780
14	0.4030	0.6111	0.0605	0.5460	0.3780
15	0.4030	0.5922	0.0000	0.5460	0.3150
16	0.4030	0.5796	0.0000	0.5460	0.2520
17	0.4030	0.5796	0.0000	0.5460	0.1890
18	0.4030	0.4725	0.0000	0.5460	0.1260
19	0.4030	0.3150	0.0000	0.5460	0.0630
20	0.4030	0.2835	0.0000	0.5460	0.0000
21	0.4030	0.2520	0.0000	0.3900	0.0000
22	0.3875	0.2520	0.0000	0.3900	0.0000
23	0.3875	0.2205	0.0000	0.3900	0.0000
24	0.3875	0.2205	0.0000	0.3900	0.0000
25	0.3875	0.1890	0.0000	0.3900	0.0000
26	0.3720	0.1890	0.0000	0.3510	0.0000
27	0.3720	0.1575	0.0000	0.3510	0.0000
28	0.3720	0.1575	0.0000	0.3510	0.0000
29	0.3720	0.1260	0.0000	0.3510	0.0000
30	0.3565	0.1260	0.0000	0.3120	0.0000
Total Wetted Acres	**11.8575**	**13.3623**	**2.1175**	**14.586**	**9.4374**

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	0.36225	0.0945	0	0.312	0
2	0.36225	0.0945	0	0.0312	0
3	0.341	0.063	0	0.0312	0
4	0.341	0.063	0	0.0312	0
5	0.341	0.0315	0	0.0312	0
6	0.31	0.0315	0	0.0312	0
7	0.31	0.0315	0	0.0234	0
8	0.31	0	0	0.0234	0
9	0.31	0	0	0.0234	0
10	0.063	0	0	0.0234	0
11	0.063	0	0	0.0234	0
12	0.031	0	0	0.0234	0
13	0.031	0	0	0.0234	0
14	0.0124	0	0	0.0234	0
15	0.0124	0	0	0.0195	0
16	0.0062	0	0	0.0195	0
17	0.0062	0	0	0.0195	0
18	0.0062	0	0	0.0195	0
19	0	0	0	0.0195	0
20	0	0	0	0.0195	0
21	0	0	0	0.0195	0
22	0	0	0	0.0195	0
23	0	0	0	0.0156	0
24	0	0	0	0.0156	0
25	0	0	0	0.0156	0
26	0	0.315	0	0.0156	0
27	0	0.315	0	0.0156	0
28	0.4898	0.5922	0	0.0156	0.504
29	0.4898	0.6111	0	0.014	0.63
30	0.4898	0.5922	0	0.014	0.63
31	0.4898	0.5922	0	0.014	0.9828
Total Wetted Acres	**5.1781**	**3.4272**	**0**	**0.9468**	**2.7468**

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November

Date	Equal. Basin Wetted Area (acres)*	Recharge Cell 1 Wetted Area (acres)*	Recharge Cell 2 Wetted Area (acres)*	Recharge Cell 3 Wetted Area (acres)*	Recharge Cell 4 Wetted Area (acres)*
1	0.4898	0.5922	0	0.014	1.0458
2	0.4898	0.6111	0	0.014	1.0458
3	0.4898	0.5922	0.0121	0.014	1.0458
4	0.434	0.6111	0.0212	0.014	1.0458
5	0.4898	0.6111	0.0302	0	0.63
6	0.4898	0.5922	0.0302	0	0.504
7	0.4526	0.6111	0.0302	0	0
8	0.4898	0.5922	0.0363	0	0
9	0.434	0.5922	0.0363	0	0
10	0.403	0.5796	0.0605	0	0
11	0.403	0.252	0.0786	0	0
12	0.403	0	0.0968	0	0
13	0.403	0	0.121	0	0
14	0.403	0	0.121	0	0
15	0.403	0	0.1452	0	0
16	0.403	0	0.1815	0	0
17	0.403	0	0.2057	0	0
18	0.403	0	0.2238	0	0
19	0.403	0	0.242	0	0
20	0.403	0	0.2722	0	0
21	0.403	0	0.3025	0	0
22	0.403	0	0.3025	0	0
23	0.403	0	0.3328	0	0
24	0.403	0	0.3328	0	0
25	0.403	0	0.363	0	0
26	0.403	0	0.363	0	0
27	0.403	0	0.3932	0	0
28	0.403	0	0.4235	0	0
29	0.403	0.315	0.3509	0	0.063
30	0.403	0.4725	0.3388	0.39	0.063
Total Wetted Acres	**12.7224**	**7.0245**	**5.4478**	**0.446**	**5.4432**

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	0.5922	0.3025	0.195	0.504
2	0.403	0.5922	0.242	0.39	0.504
3	0.403	0.5796	0.1815	0.624	1.0458
4	0.403	0.6111	0.121	0.624	1.0458
5	0.403	0.5922	0.1089	0.624	1.0458
6	0.403	0.6111	0.1331	0.624	1.0458
7	0.403	0.5796	0.3025	0.39	1.0458
8	0.403	0.5922	0.3025	0.312	1.0458
9	0.403	0.6111	0.3025	0.078	1.0458
10	0.403	0.5922	0.363	0	1.0458
11	0.403	0.5796	0.484	0	0.63
12	0.403	0.5922	0.484	0	0.63
13	0.403	0.6111	0.605	0	0.63
14	0.403	0.5796	0.605	0	0.63
15	0.341	0.315	0.605	0	0.63
16	0.372	0	0.5445	0	0.63
17	0.403	0	0.5445	0	0.63
18	0.403	0	0.484	0	0.567
19	0.403	0	0.363	0	0.504
20	0.403	0	0.363	0	0.441
21	0.403	0	0.484	0.39	0.315
22	0.403	0	0.484	0.39	0.252
23	0.372	0	0.5445	0.39	0.126
24	0.3875	0	0.5445	0.39	0.063
25	0.3875	0	0.605	0.39	0.0252
26	0.3875	0	0.605	0.39	0
27	0.372	0	0.484	0.234	0
28	0.372	0	0.5445	0.234	0.0126
29	0.403	0	0.605	0.312	0.126
30	0.403	0	0.605	0.39	0.252
31	0.403	0	0.605	0.39	0.441
Total Wetted Acres	**12.2605**	**8.631**	**13.552**	**7.761**	**16.9092**

APPENDIX D

Evapotranspiration Calculations & AZMET Method Description

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2011

	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	0.3588	0.07	0.002093	0.0543	0.14	0.000632917	0.2466	0.19	0.0039045
2	0.3977	0.09	0.00298275	0.0465	0.13	0.00050375	0.2888	0.2	0.004813333
3	0.4191	0.1	0.0034925	0.0186	0.11	0.0001705	0.2850	0.2	0.00475
4	0.4036	0.08	0.002690667	0.0543	0.12	0.0005425	0.1842	0.22	0.003377
5	0.3125	0.05	0.001302083	0.0930	0.13	0.0010075	0.1184	0.2	0.001973333
6	0.2679	0.06	0.0013395	0.1550	0.15	0.0019375	0.0310	0.25	0.000645833
7	0.2583	0.11	0.00236775	0.1240	0.17	0.001756667	0.0388	0.26	0.000839583
8	0.2720	0.1	0.002266667	0.0543	0.22	0.000994583	0.0734	0.19	0.001162167
9	0.2410	0.1	0.002008333	0.0310	0.15	0.0003875	0.1332	0.22	0.002442
10	0.2255	0.07	0.001315417	0.0186	0.15	0.0002325	0.3296	0.26	0.007141333
11	0.2331	0.1	0.0019425	0.0543	0.16	0.000723333	0.3748	0.27	0.008433
12	0.2330	0.11	0.002135833	0.0775	0.19	0.001227083	0.4133	0.24	0.008266
13	0.1864	0.13	0.002019333	0.1085	0.22	0.001989167	0.3818	0.24	0.007636
14	0.1475	0.14	0.001720833	0.1395	0.21	0.00244125	0.3278	0.24	0.006556
15	0.1474	0.13	0.001596833	0.0543	0.21	0.00095025	0.4292	0.24	0.008584
16	0.1473	0.11	0.00135025	0.0310	0.2	0.000516667	0.3574	0.27	0.008040375
17	0.1628	0.13	0.001763667	0.0186	0.13	0.0002015	0.3261	0.32	0.008696
18	0.1473	0.13	0.00159575	0.0388	0.14	0.000452083	0.2794	0.27	0.006285375
19	0.1473	0.16	0.001964	0.1089	0.23	0.00208725	0.2481	0.24	0.004962
20	0.0620	0.13	0.000671667	0.1635	0.08	0.00109	0.2791	0.31	0.007210083
21	0.0186	0.13	0.0002015	0.1497	0.13	0.00162175	0.2636	0.22	0.004832667
22	0.0186	0.14	0.000217	0.2070	0.16	0.00276	0.2559	0.18	0.00383775
23	0.0186	0.15	0.0002325	0.2202	0.18	0.003303	0.2791	0.21	0.00488425
24	0.0186	0.15	0.0002325	0.2526	0.15	0.0031575	0.3256	0.21	0.005698
25	0.0186	0.13	0.0002015	0.2310	0.19	0.0036575	0.3411	0.23	0.00653775
26	0.0186	0.14	0.000217	0.1680	0.17	0.00238	0.3101	0.22	0.005685167
27	0.0543	0.15	0.000678125	0.1680	0.11	0.00154	0.2481	0.22	0.0045485
28	0.0620	0.17	0.000878333	0.1176	0.16	0.001568	0.2791	0.24	0.005582
29	0.1240	0.16	0.001653333			0	0.2791	0.26	0.006047167
30	0.1395	0.19	0.00220875				0.3434	0.28	0.008012667
31	0.1085	0.09	0.00081375				0.3624	0.3	0.00906
Monthly Evapo-transpiration			**0.046153625**			**0.03983225**			**0.170443833**

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2011

	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	0.3981	0.31	0.010282958	0.2454	0.3	0.006135	0.3789	0.35	0.01105125
2	0.4754	0.36	0.014262	0.2454	0.37	0.0075665	0.4167	0.37	0.01284825
3	0.4288	0.33	0.011792	0.3508	0.35	0.010231667	0.3915	0.39	0.01272375
4	0.3822	0.28	0.008918	0.4438	0.34	0.012574333	0.3789	0.4	0.01263
5	0.3185	0.31	0.008227917	0.4186	0.33	0.0115115	0.3314	0.37	0.010218167
6	0.3180	0.19	0.005035	0.4420	0.36	0.01326	0.2810	0.45	0.0105375
7	0.3440	0.31	0.008886667	0.3664	0.38	0.011602667	0.4099	0.4	0.013663333
8	0.1841	0.31	0.004755917	0.2674	0.41	0.009136167	0.4070	0.41	0.013905833
9	0.1031	0.02	0.000171833	0.1029	0.3	0.00257125	0.4070	0.37	0.012549167
10	0.0717	0.19	0.00113525	0.0699	0.24	0.001398	0.5349	0.39	0.01738425
11	0.0388	0.25	0.000807292	0.2502	0.31	0.0064635	0.5344	0.4	0.017813333
12	0.0310	0.27	0.0006975	0.4674	0.33	0.0128535	0.4185	0.43	0.01499625
13	0.0248	0.3	0.00062	0.3524	0.37	0.010865667	0.4150	0.43	0.014870833
14	0.0186	0.28	0.000434	0.4632	0.37	0.014282	0.3716	0.39	0.012077
15	0.0248	0.31	0.000640667	0.4942	0.39	0.0160615	0.5914	0.42	0.020699
16	0.0248	0.32	0.000661333	0.4942	0.36	0.014826	0.6273	0.49	0.02561475
17	0.0248	0.35	0.000723333	0.4942	0.32	0.013178667	0.6038	0.46	0.023145667
18	0.0248	0.37	0.000764667	0.4787	0.27	0.01077075	0.6348	0.42	0.022218
19	0.0186	0.3	0.000465	0.4225	0.26	0.009154167	0.6347	0.5	0.026445833
20	0.0465	0.3	0.0011625	0.4380	0.31	0.011315	0.6038	0.39	0.0196235
21	0.0620	0.32	0.001653333	0.4564	0.33	0.012551	0.6662	0.41	0.022761833
22	0.0930	0.32	0.00248	0.3120	0.34	0.00884	0.7127	0.41	0.024350583
23	0.1550	0.25	0.003229167	0.3178	0.4	0.010593333	0.6507	0.41	0.02223225
24	0.1550	0.34	0.004391667	0.2926	0.35	0.008534167	0.6507	0.38	0.0206055
25	0.1550	0.28	0.003616667	0.4942	0.35	0.014414167	0.6507	0.37	0.02006325
26	0.1550	0.34	0.004391667	0.4942	0.4	0.016473333	0.5476	0.33	0.015059
27	0.0717	0.31	0.00185225	0.4535	0.39	0.01473875	0.5631	0.39	0.01830075
28	0.0690	0.34	0.001955	0.4535	0.44	0.016628333	0.6662	0.4	0.022206667
29	0.2454	0.37	0.0075665	0.4564	0.45	0.017115	0.7282	0.39	0.0236665
30	0.2795	0.33	0.00768625	0.2810	0.32	0.007493333	0.7282	0.36	0.021846
31				0.2558	0.34	0.007247667			
Monthly Evapo-transpiration			**0.119266333**			**0.340386917**			**0.536108**

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2011

	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	0.6972	0.6972	0.04050732	0.0234	0.32	0.000624	0.6100	0.26	0.013216667
2	0.6259	0.6259	0.032645901	0.0234	0.35	0.0006825	0.6274	0.3	0.015685
3	0.5914	0.5914	0.029146163	0.0000	0.19	0	0.5518	0.3	0.013795
4	0.5866	0.5866	0.028674963	0.0000	0.28	0	0.5266	0.33	0.0144815
5	0.4701	0.4701	0.018416168	0.0000	0.31	0	0.4888	0.26	0.010590667
6	0.4236	0.4236	0.01495308	0.0000	0.28	0	0.4888	0.27	0.010998
7	0.4080	0.4080	0.013872	0.0000	0.25	0	0.4888	0.29	0.011812667
8	0.2754	0.2754	0.00632043	0.0000	0.28	0	0.4888	0.31	0.012627333
9	0.2394	0.2394	0.00477603	0.0000	0.26	0	0.4888	0.26	0.010590667
10	0.1260	0.1260	0.001323	0.0000	0.22	0	0.4268	0.24	0.008536
11	0.1008	0.1008	0.00084672	0.0000	0.25	0	0.3580	0.22	0.006563333
12	0.0756	0.0756	0.00047628	0.0000	0.15	0	0.3487	0.17	0.004939917
13	0.0000	0.0000	0	0.0000	0.29	0	0.3394	0.21	0.0059395
14	0.3082	0.3082	0.007915603	0.0000	0.29	0	0.3177	0.18	0.0047655
15	0.3316	0.3316	0.009163213	0.0000	0.27	0	0.2726	0.21	0.0047705
16	0.3316	0.3316	0.009163213	0.0000	0.24	0	0.2571	0.22	0.0047135
17	0.4556	0.4556	0.017297613	0.0000	0.28	0	0.2026	0.27	0.0045585
18	0.5727	0.5727	0.027332108	0.0000	0.26	0	0.2026	0.27	0.0045585
19	0.6352	0.6352	0.033623253	0.0000	0.13	0	0.1870	0.28	0.004363333
20	0.6259	0.6259	0.032645901	0.0000	0.28	0	0.1480	0.28	0.003453333
21	0.4860	0.4860	0.019683	0.0000	0.23	0	0.0544	0.22	0.000997333
22	0.4860	0.4860	0.019683	0.0000	0.28	0	0.0389	0.3	0.0009725
23	0.4734	0.4734	0.01867563	0.1147	0.32	0.003058667	0.0389	0.3	0.0009725
24	0.4104	0.4104	0.01403568	0.2249	0.36	0.006747	0.0389	0.29	0.000940083
25	0.3348	0.3348	0.00934092	0.3160	0.28	0.007373333	0.0389	0.27	0.00087525
26	0.3096	0.3096	0.00798768	0.4924	0.37	0.015182333	0.0000	0.29	0
27	0.2340	0.2340	0.004563	0.6037	0.29	0.014589417	0.0000	0.22	0
28	0.1872	0.1872	0.00292032	0.6039	0.28	0.014091	0.0000	0.24	0
29	0.1716	0.1716	0.00245388	0.5732	0.31	0.014807667	0.0000	0.25	0
30	0.1560	0.1560	0.002028	0.6166	0.31	0.015928833	0.0000	0.3	0
31	0.1560	0.1560	0.002028	0.6007	0.31	0.015518083			
Monthly Evapo-transpiration			**0.43249807**			**0.108602833**			**0.175717083**

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2011

	October			November			December		
Date	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)
1	0	0.19	0	0.0996	0.18	0.001494	1.6349	0.1	0.013624117
2	0	0.2	0	0.2374	0.17	0.003363167	2.6542	0.02	0.004423605
3	0	0.2	0	0.3004	0.16	0.004005333	3.5558	0.04	0.011852684
4	0	0.21	0	0.2384	0.17	0.003377333	4.5300	0.03	0.011324943
5	0	0.2	0	0.0434	0.11	0.000397833	5.4892	0.06	0.027445989
6	0	0.07	0	0.031	0.09	0.0002325	6.4890	0.08	0.043260217
7	0	0.19	0	0.0124	0.06	0.000062	7.4889	0.08	0.049925747
8	0	0.2	0	0.031	0.1	0.000258333	8.4891	0.08	0.056593722
9	0	0.19	0	0.0062	0.15	0.0000775	9.4889	0.1	0.079073979
10	0	0.2	0	0.0062	0.22	0.000113667	10.4269	0.12	0.104269137
11	0	0.21	0	0.0062	0.07	3.61667E-05	11.3580	0.1	0.094650301
12	0	0.2	0	0.0062	0.06	0.000031	12.3487	0.04	0.041162437
13	0	0.21	0	0.0062	0.01	5.16667E-06	13.3394	0	0
14	0	0.2	0	0.0062	0.1	5.16667E-05	14.3178	0.04	0.047725839
15	0	0.22	0	0.0062	0.09	0.0000465	15.2726	0.07	0.089090438
16	0	0.22	0	0.0062	0.1	5.16667E-05	16.2572	0.14	0.189666769
17	0	0.22	0	0.0062	0.11	5.68333E-05	17.2027	0.09	0.129019926
18	0	0.19	0	0.0062	0.11	5.68333E-05	18.2027	0.03	0.045506642
19	0	0.21	0	0.0062	0.08	4.13333E-05	19.1870	0	0
20	0	0.21	0	0.0062	0.09	0.0000465	20.1480	0.06	0.100740233
21	0	0.17	0	0.0062	0.06	0.000031	21.0544	0.06	0.105272155
22	0	0.18	0	0.0062	0.1	5.16667E-05	22.0390	0.07	0.128560551
23	0	0.18	0	0.0062	0.13	6.71667E-05	23.1537	0.07	0.135063058
24	0	0.12	0	0.0062	0.11	5.68333E-05	24.2639	0.08	0.161759046
25	0	0.19	0	0.0062	0.07	3.61667E-05	25.3549	0.11	0.232420248
26	0	0.21	0	0.0062	0.09	0.0000465	26.4924	0.09	0.198693349
27	0	0.17	0	0.0062	0.14	7.23333E-05	27.6038	0.09	0.207028293
28	0.062	0.15	0.000775	0.0062	0.1	5.16667E-05	28.6047	0.09	0.21453545
29	0.1054	0.13	0.001141833	0.0062	0.1	5.16667E-05	29.5744	0.09	0.221807951
30	0.1054	0.16	0.001405333	0.0062	0.12	0.000062	30.6181	0.11	0.280665617
31	0.1064	0.15	0.00133				31.6020	0.08	0.2106802
Monthly Evapo-transpiration			**0.004652167**			**0.014332333**			**3.235842644**

THE UNIVERSITY OF ARIZONA®
Cooperative Extension

STANDARDIZED REFERENCE EVAPOTRANSPIRATION

A NEW PROCEDURE FOR ESTIMATING REFERENCE EVAPOTRANSPIRATION IN ARIZONA

Introduction

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

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

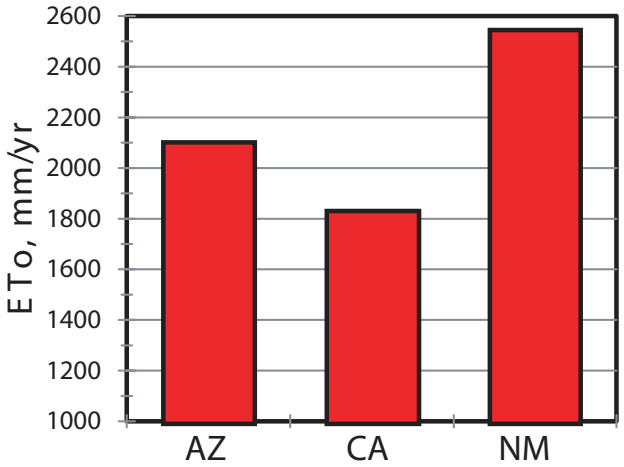

Figure 1. Reference ET (ETo) for Tucson for calendar year 1996 as computed using the published procedures for the public weather networks in Arizona, California, and New Mexico.

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

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COLLEGE OF AGRICULTURE AND LIFE SCIENCES
TUCSON, ARIZONA 85721

PAUL W. BROWN
Extension Specialist, Biometeorology

This information has been reviewed by university faculty.

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

Standardized Reference Evapotranspiration Definition

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

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

ABBREVIATION	EXPLANATION
ET	Evapotranspiration
ETc	Evapotranspiration of a particular crop or vegetation type
ETo	Reference Evapotranspiration in general
ETos	Standardized Reference Evapotranspiration for Short Reference Crop
ETrs	Standardized Reference Evapotranspiration for Tall Reference Crop
ETsz	Standardized Reference Evapotranspiration in general
EToa	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})

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

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

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

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

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

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

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

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

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

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

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

Standardized Equation To Be Used By AZMET

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

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

Where:

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

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

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

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

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

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

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

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

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

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

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

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

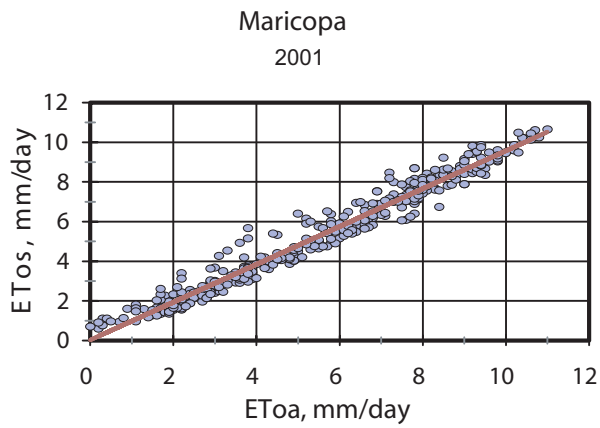

Figure 2. Reference evapotranspiration as computed using the ASCE standardized procedure (ETos) versus reference evapotranspiration computed using procedure employed by AZMET. The line represents the least squares regression line (ETos = 0.03 + 0.95 x EToa; r^2 = 0.96).

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

Data Required To Compute ETos

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

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

Comparison of Standardized Reference ET with Original AZMET ETo

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

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

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

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

Converting Past EToa to ETos

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

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

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

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

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

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

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

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

where **Ratio** represents the appropriate annual, seasonal or monthly ratio from Tables 2 and 3. Annual ratios should be used only to adjust annual totals of EToa. Monthly ratios provide the best means of converting short term data sets (e.g., daily, weekly or monthly totals of EToa). *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 (EToa). To obtain an estimate of turf water use in Tucson for May one would multiply the Kc (0.75) times the May EToa value for Tucson (258.1 mm from Table 2):

$$ETc = Kc * EToa$$

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

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

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

$$ETc = Kc * ETos$$

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

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

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

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

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

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

where Kc_{os} and Kc_{az} are the crop coefficient values appropriate for use with ETos and EToa, respectively; and **Ratio** is the ratio of ETos to EToa 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 EToa 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 EToa. 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 EToa are generally much less than 1.0.

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Appendix

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

Δ: Slope of Saturation Vapor Pressure vs. Temperature Relationship

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

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

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

Rn: Net Radiation

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

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

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

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

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

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

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

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

The daily value of Rnl is computed using:

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

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

Clear sky solar radiation (Rso) is computed using:

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

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

Extraterrestrial radiation is computed from earth-sun geometry using:

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

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

The relative distance factor is computed using:

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

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

The solar declination angle is computed using:

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

The sunset angle is computed using:

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

γ: Psychrometer Constant

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

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

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

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

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

T: Mean Air Temperature

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

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

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

u_2: Wind Speed

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

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

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

e_s: Saturation Vapor Pressure

Saturation vapor pressure is computed using:

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

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

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

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

ea: Actual Vapor Pressure

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

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

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

Any products, services, or organizations that are mentioned, shown, or indirectly implied in this publication do not imply endorsement by The University of Arizona.

APPENDIX E

Water Level Measurements

USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2011

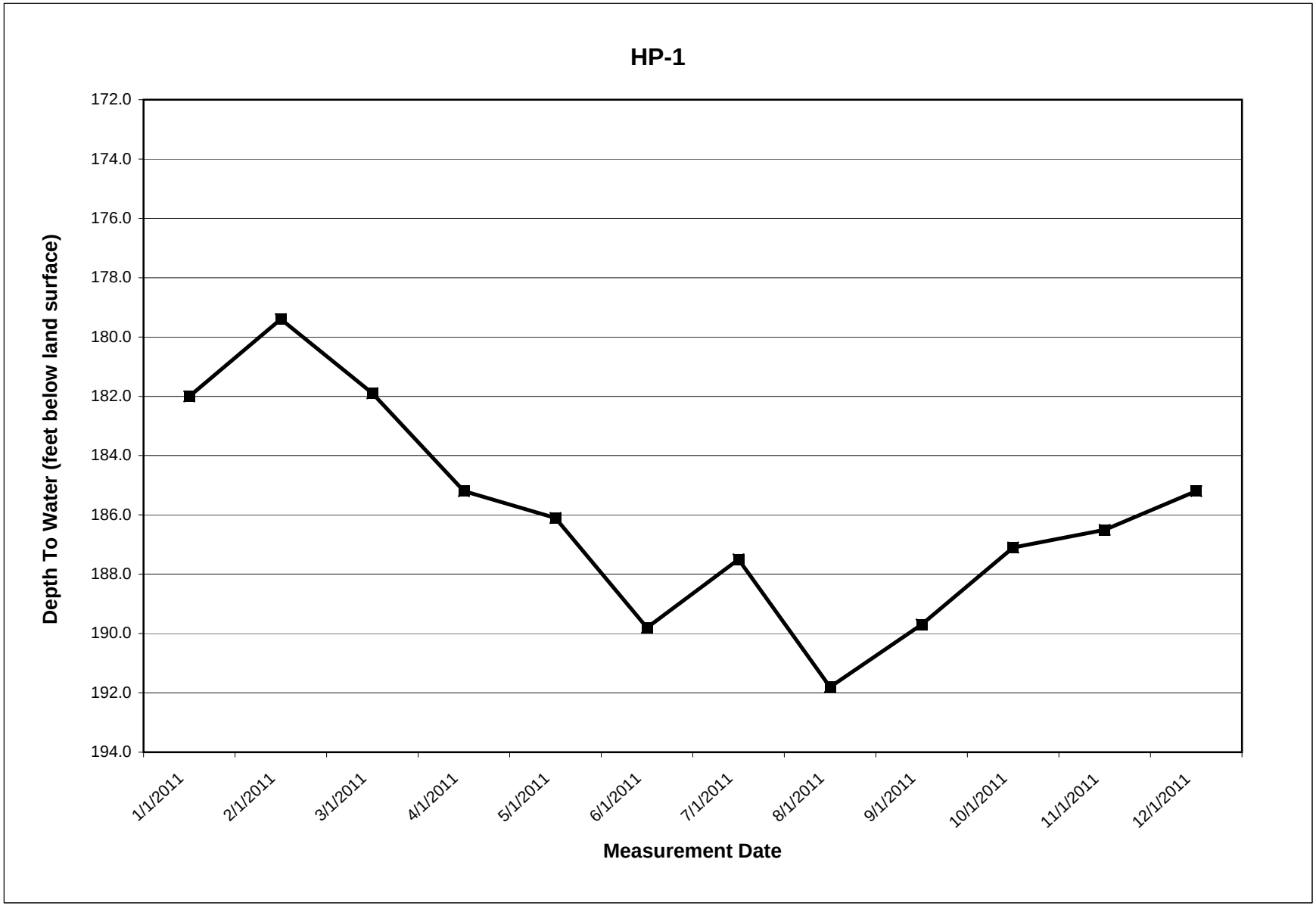
Monitor Point ID	**HP-1**
ADWR Registration Number	55-574110
Cadastral Location	D(11-11)33cad
Measuring Point Elevation (feet amsl)	1985.17
Measuring Point Description	top of port
Measuring Point Height (ft)	
Land Surface Elevation at Wellhead (feet amsl)	1985.17
Permit Alert Level (feet bls)	30
Permit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

Measurement Date	**DTW (feet below MP)**	**DTW (feet bls)**	**Elevation (feet amsl)**	**Exceedance Status**
1/20/2011	182.0	182.0	1803.2	
2/15/2011	179.4	179.4	1805.8	
3/21/2011	181.9	181.9	1803.3	
4/20/2011	185.2	185.2	1800.0	
5/17/2011	186.1	186.1	1799.1	
6/23/2011	189.8	189.8	1795.4	
7/18/2011	187.5	187.5	1797.7	
8/15/2011	191.8	191.8	1793.4	
9/20/2011	189.7	189.7	1795.5	
10/26/2011	187.1	187.1	1798.1	
11/17/2011	186.5	186.5	1798.7	
12/19/2011	185.2	185.2	1800.0	

* 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: 2011



USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2011

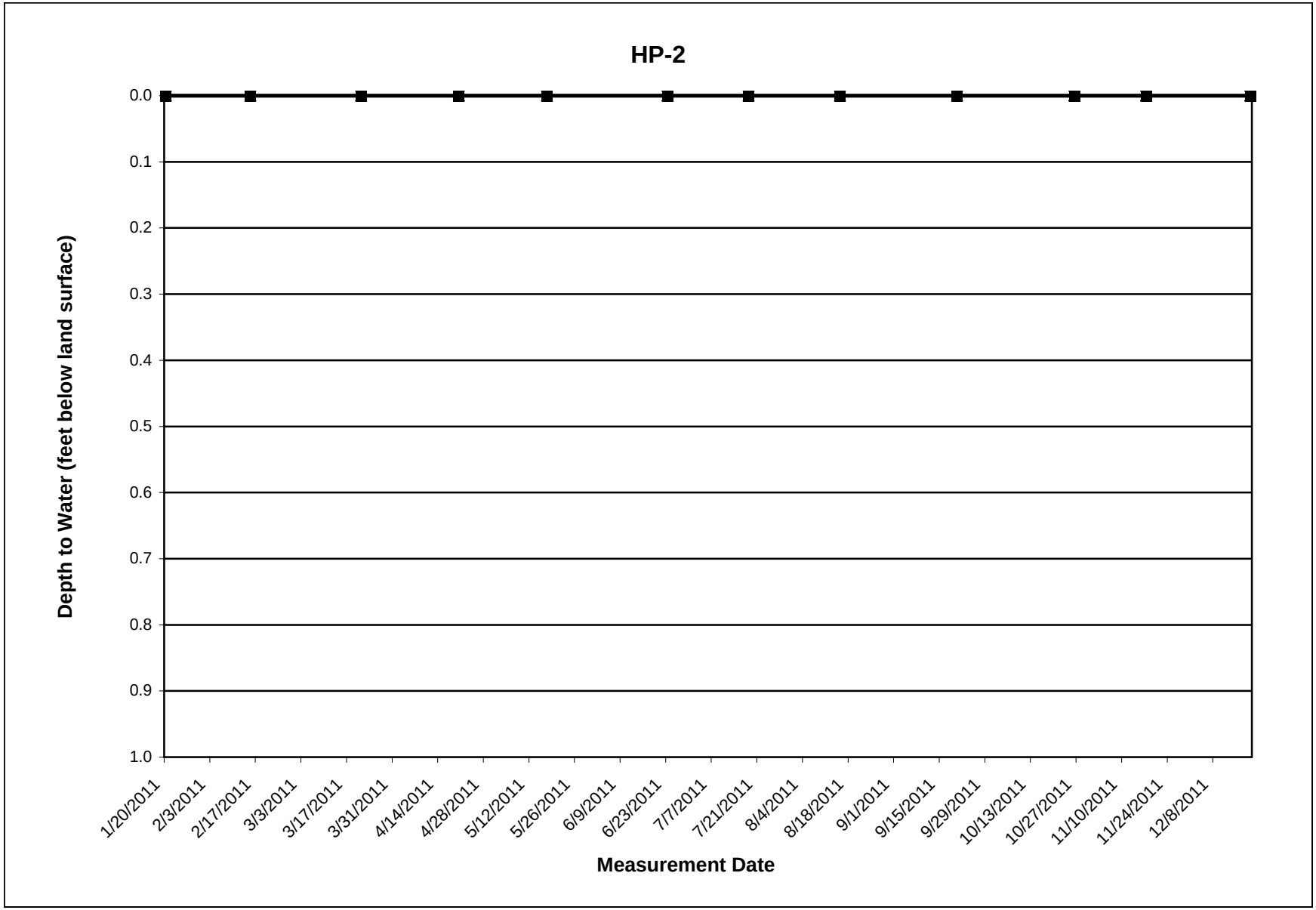
Monitor Point ID	HP-2
ADWR Registration Number	55-593607
Cadastral Location	D(11-11)33cad
Measuring Point Elevation (feet amsl)	1986.75
Measuring Point Description	top of port
Measuring Point Height (ft)	
Land Surface Elevation at Wellhead (feet amsl)	1986.75
Permit Alert Level (feet bls)	30
Permit OPL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

Measurement Date	DTW (feet below MP)	DTW (feet bls)	Elevation (feet amsl)	Exceedance Status
1/20/2011	dry			
2/15/2011	dry			
3/21/2011	dry			
4/20/2011	dry			
5/17/2011	dry			
6/23/2011	dry			
7/18/2011	dry			
8/15/2011	dry			
9/20/2011	dry			
10/26/2011	dry			
11/17/2011	dry			
12/19/2011	dry			

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

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

USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2011



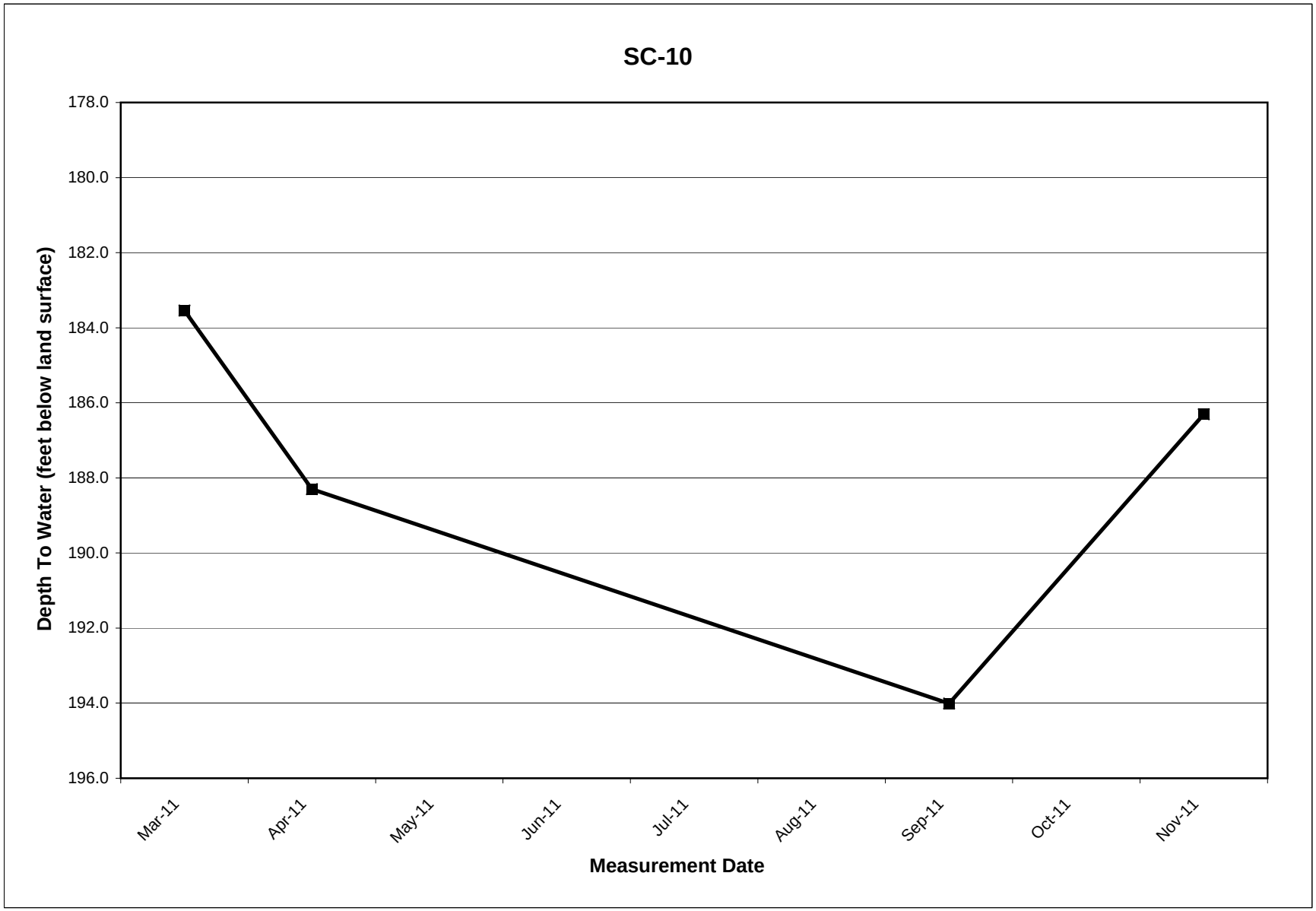
USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2011

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**
3/17/2011	183.5	183.5	1801.6	
4/19/2011	188.3	188.3	1796.9	
9/9/2011	194.0	194.0	1791.2	
11/30/2011	186.3	186.3	1798.9	

* 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: 2011



APPENDIX F

Infiltration Rate Data & Calculations

INFILTRATION RATE DATA AND CALCULATIONS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2011

	Net Recharge Volumes (ac-ft)	**Total Wetted Acreages** (ac-days)	**Infiltration Rate** (ft/day)	**Quarterly Average Infiltration Rate** (ft/day)
January	19.2	83.1	0.23	
February	30.9	62.6	0.49	
March	35.1	77.6	0.45	0.38
April	45.3	55.2	0.82	
May	32.6	69.0	0.47	
June	46.7	102.2	0.46	0.55
July	22.3	85.7	0.26	
August	14.2	44.3	0.32	
September	5.5	51.4	0.11	0.23
October	12.9	12.3	1.05	
November	75.5	31.1	2.43	
December	57.1	59.1	0.97	1.42

Totals	**397.2**	**733.7**	**0.54**

CELL 1: INFILTRATION RATE DATA AND CALCULATIONS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2011

	Net Recharge Volumes (ac-ft)	Total Wetted Acreages (ac-days)	Infiltration Rate (ft/day)	Quarterly Average Infiltration Rate (ft/day)
January	0.2	10.3	0.02	
February	13.0	8.3	1.56	
March	8.5	16.9	0.50	0.61
April	1.0	6.6	0.16	
May	1.1	8.1	0.14	
June	7.4	14.1	0.52	0.33
July	1.6	12.2	0.13	
August	2.8	4.8	0.59	
September	2.9	13.4	0.22	0.24
October	7.7	3.4	2.23	
November	10.5	7.0	1.49	
December	4.5	8.6	0.52	1.19
Totals	**61.1**	**113.8**	**0.54**	

CELL 2: INFILTRATION RATE DATA AND CALCULATIONS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2011

	Net Recharge Volumes (ac-ft)	Total Wetted Acreages (ac-days)	Infiltration Rate (ft/day)	Quarterly Average Infiltration Rate (ft/day)
January	18.3	33.4	0.55	
February	8.4	26.4	0.32	
March	0.0	6.7		0.40
April	36.0	12.8	2.80	
May	18.1	11.6	1.57	
June	23.2	34.5	0.67	1.31
July	11.1	30.3	0.37	
August	0.0	13.3		
September	0.0	1.6		0.25
October	0.0	0.0		
November	54.8	5.5	10.06	
December	38.2	13.6	2.82	4.89
Totals	**208.1**	**189.6**	**1.10**	

CELL 3: INFILTRATION RATE DATA AND CALCULATIONS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2011

	Net Recharge Volumes (ac-ft)	Total Wetted Acreages (ac-days)	Infiltration Rate (ft/day)	Quarterly Average Infiltration Rate (ft/day)
January	0.8	15.0	0.05	
February	5.4	7.4	0.72	
March	11.0	12.8	0.86	0.49
April	0.0	4.9		
May	7.3	8.0	0.91	
June	11.1	17.1	0.65	0.61
July	7.1	19.6	0.36	
August	6.2	11.4	0.54	
September	3.9	19.0	0.21	0.34
October	0.0	1.0		
November	0.2	0.5	0.42	
December	10.1	8.2	1.23	1.07
Totals	**63.1**	**125.0**	**0.50**	

CELL 4: INFILTRATION RATE DATA AND CALCULATIONS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2011

	Net Recharge Volumes (ac-ft)	Total Wetted Acreages (ac-days)	Infiltration Rate (ft/day)	Quarterly Average Infiltration Rate (ft/day)
January	0.0	12.6		
February	6.9	9.6	0.73	
March	15.1	34.2	0.44	0.39
April	7.7	19.9	0.38	
May	5.5	35.4	0.15	
June	4.9	35.9	0.14	0.20
July	4.5	32.4	0.14	
August	3.9	12.5	0.31	
September	0.0	10.3		0.15
October	3.3	2.8	1.16	
November	4.6	5.9	0.77	
December	6.6	18.1	0.36	0.54
Totals	**62.9**	**229.6**	**0.27**	

EQUALIZATION BASIN: INFILTRATION RATE DATA AND CALCULATIONS

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0007

Year: 2011

	Net Recharge Volumes (ac-ft)	**Total Wetted Acreages** (ac-days)	**Infiltration Rate** (ft/day)	**Quarterly Average Infiltration Rate** (ft/day)
January	0.0	17.2		
February	0.0	13.8		
March	0.6	15.5	0.04	0.01
April	0.7	15.6	0.04	
May	0.6	17.5	0.03	
June	0.2	16.5	0.01	0.03
July	0.0	13.0		
August	1.6	6.6	0.24	
September	0.0	14.6		0.05
October	2.0	5.5	0.37	
November	5.5	13.4	0.41	
December	1.0	12.8	0.08	0.27

Totals	**12.2**	**161.8**	**0.08**