ANNUAL MONITORING REPORT
2010

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
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TABLE OF CONTENTS

1.0 INTRODUCTION

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

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

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

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

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

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

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

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

The facility has been operating since February 2003, first as a pilot project and then as a constructed recharge project. In accordance with Sections 2 and 3 of the USF Permit (all versions), this is the eighth annual report for the MHPERP. This report includes all of the data that was collected during the 2010 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 2 of the permit from January 1, 2010 through April 19, 2010. Excavation work in Recharge Cell 2 was completed by the District in early April. Approval for Phase 3 operation was provided by Tracey Carpenter, hydrologist in the ADWR Recharge and Surface Water Unit, in an email dated September 29, 2010. Phase 3 operations began on April 20^{th} and ran through the end of the Calendar Year.

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 2010 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. This point is listed as FMeq in the USF Permit. 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 monthly basis.

Appendix A contains the daily flow meter readings and volumes for Calendar Year 2010. 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 2010 is 426.63 acre-feet (AF). Water volumes stored for recharge by month are as follows: January – 60.58 AF, February – 0.00 AF, March – 21.64 AF, April – 49.64 AF, May – 58.15 AF, June – 30.75 AF, July – 30.44 AF, August – 0.00 AF, September – 42.19 AF, October – 65.83 AF, November – 35.51 AF, and December – 31.88 AF. The total amount 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 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 weather station (**Figure 3**). 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.[1]

[1] 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 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 for the facility during the 2010 Calendar Year is 411.5 AF.

3.0 HYDROLOGIC MONITORING

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

3.1 Basin Water Levels

Water levels within the equalization basin are expected to fluctuate from one to five feet above the bottom elevation of 1,984 feet above mean sea level. Water depths in each of the recharge cells are expected to fluctuate from three to twelve inches during the wet cycles.[2] Water levels 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 2009, groundwater levels were measured for two monitoring wells, one on-site (HP-1) and one off-site (SC-10). Wells HP-1 and SC-10 were respectively measured on a monthly and quarterly basis by PCRFCD personnel using an electric sounder.

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 2010 Calendar Year. The water levels in the on-site monitoring well, HP-1, and the off-site monitoring well, SC-10, increased approximately 2.3 feet and 3.7 feet respectively over the last calendar year.[3] This increase is most likely the result of continued operation of the surrounding recharge facilities: Lower Santa Cruz Recharge Project, Avra Valley Recharge Project and Lower Santa Cruz Managed Recharge Project.

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

[3] Depth to water in HP-1 was 183.4 feet bls in December 2009 and 181.1 feet bls in 2010; depth to water in SC-10 was 185.0 feet bls in December 2009 and 181.3 feet bls in December 2010

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 2010 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 2010 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.

Overall, monthly infiltration rates for the project ranged from 0.28 feet per day to 1.19 feet per day. For the most part, all of the recharge cells displayed a similar pattern in infiltration rates throughout the year. As expected, infiltration rates started high in January and steadily declined through the month of June with a small increase occurring in April after excavation work was performed in Recharge Cell 2. Rates jumped back up in September after a one-month shutdown during the Monsoon Season and subsequent maintenance performed within all of the recharge cells.

Average infiltration rates were the lowest during the Fourth Quarter of 2010, which was not expected. The low rates within this quarter were most likely the result of unseasonably warmer fall weather resulting in an increase in fine sediment deposits from algae blooms and die-offs occurring from September through mid- December within all of the recharge cells. PCRFCD staff developed a new schedule for the wet/dry cycles in each of the recharge cells to help maintain higher infiltration rates throughout the year. PCRFCD has also scheduled maintenance during the early part of Calendar Year 2011 to help reestablish higher infiltration rates.

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 2010 Calendar Year. Samples were taken at the oxbow channel and at monitoring well HP-1. There were no sampling events in January and February at the oxbow channel due to wash out of the diversion berm. There were no disruptions for the sampling at HP-1 due to malfunctioning well equipment. There were no analytes reported above the alert levels set by the APP for this facility.

6.0 FACILITY INSPECTIONS

Inspections of the facility equipment and functions are required by the Aquifer Protection Permit 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 2010 Calendar Year and the solutions performed to resolve them. Effluent deliveries to the project were halted from late-January to mid-March and from August through mid-September due to separate washouts of the earthen diversion berm. Recharge Cell 2 was not operated from mid-March through mid-April to allow for the completion of Phase 3 excavation work. Operation of Recharge Cells 3 and 4 was temporarily halted in late April through early May as the result of a power outage. Motorized valve controls in Recharge Cells 3 and 4 were damaged by flooding of the underground vaults due to malfunctioning level sensors and subsequent overflow of the basins. PCRFCD personnel coordinated the installation of culverts in all of the recharge cells to help keep electrical equipment safe from being flooded in the future.

7.0 CONCLUSIONS

The volume of water stored at MHPERP for Calendar Year 2010 is 411.5 AF. This is just 2.4 AF below the largest amount of annual storage for the facility, which was recorded last Calendar Year. Phase 3 of the modified USF Permit No. 71-563876.0007 was constructed and approved in April, thus allowing the District to store a maximum of 600 acre-feet per year. Recharge at MHPERP did not increase over the last year despite the completion of Phase 3. This result may be due to the facility down time during the late winter to early spring period as a result of diversion berm washout, power outage, equipment failures, and excavation within Cell 2.

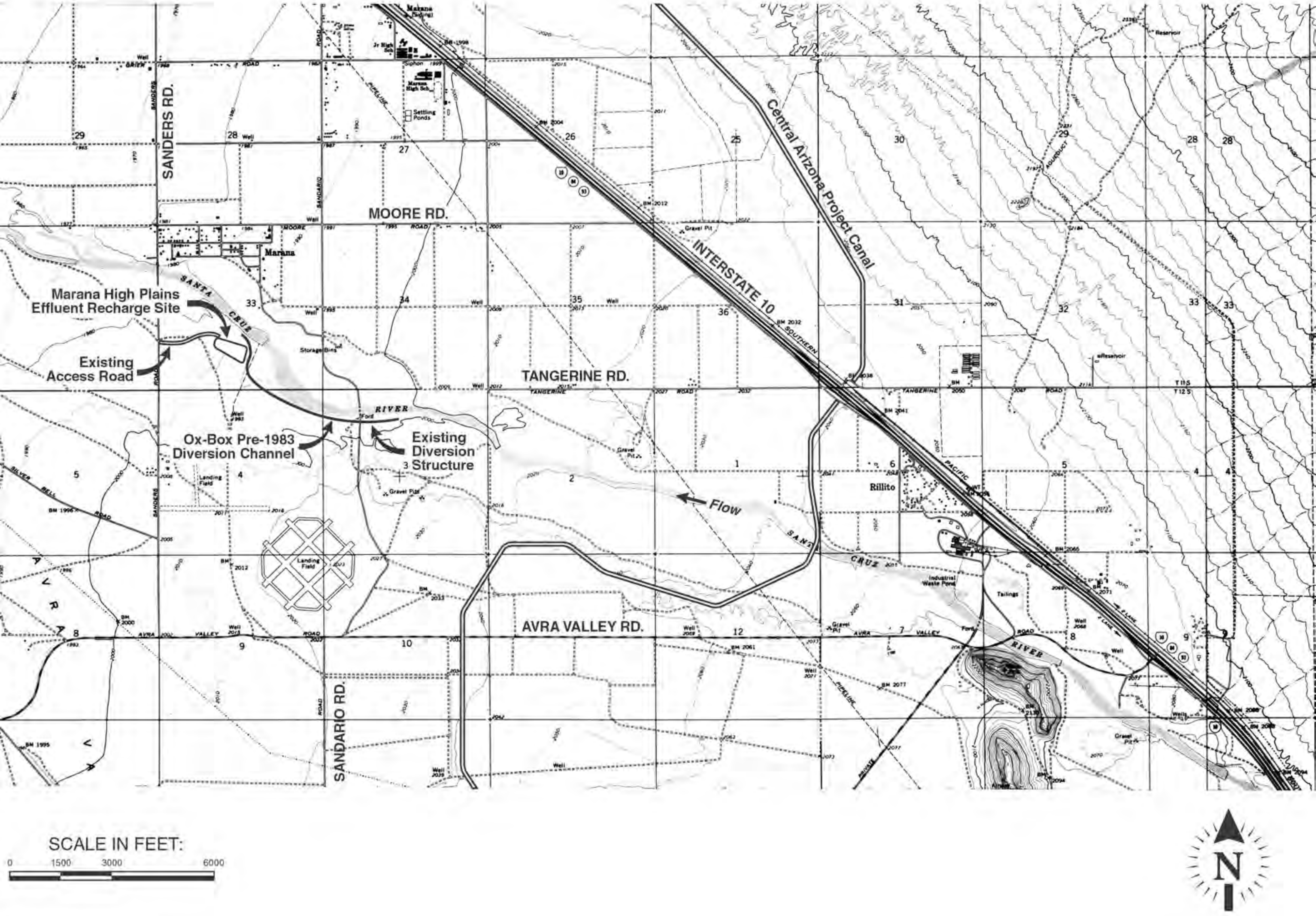
Monitoring of operations has shown no exceedences of water quality standards or water alert levels at the project site. Off-site monitoring showed no negative impacts to surrounding operations from a water level perspective.

Recharge Cell 2 had by far the best performance over the course of the calendar year, contributing 51% of the total amount of effluent stored at the facility. This is most likely due to the exposure of coarser grained sand and gravels via excavation work as part of Phase 3 of the USFP, and the cell being maintained for clogging layer removal twice during the year, as opposed to once during the year in the other cells. Cells 1, 3 and 4 contributed 15%, 13% and 16% to the total volume respectively. The equalization basin, which did not have any maintenance throughout the year, only provided 5% to the total volume.

Infiltration rates for the fourth quarter of the calendar year were much lower than expected. This is probably the result of a buildup of algal clogging layers due to unseasonably warm temperatures experienced during this time period. Basin maintenance is being planned for early 2011 to help reestablish high infiltration rates, and PCRFCD staff has re-developed a wet/dry schedule in an effort to maintain higher infiltration rates during the year. PCRFCD is also investigating basin maintenance and ripping schedules that may improve the efficiency of facility operations.

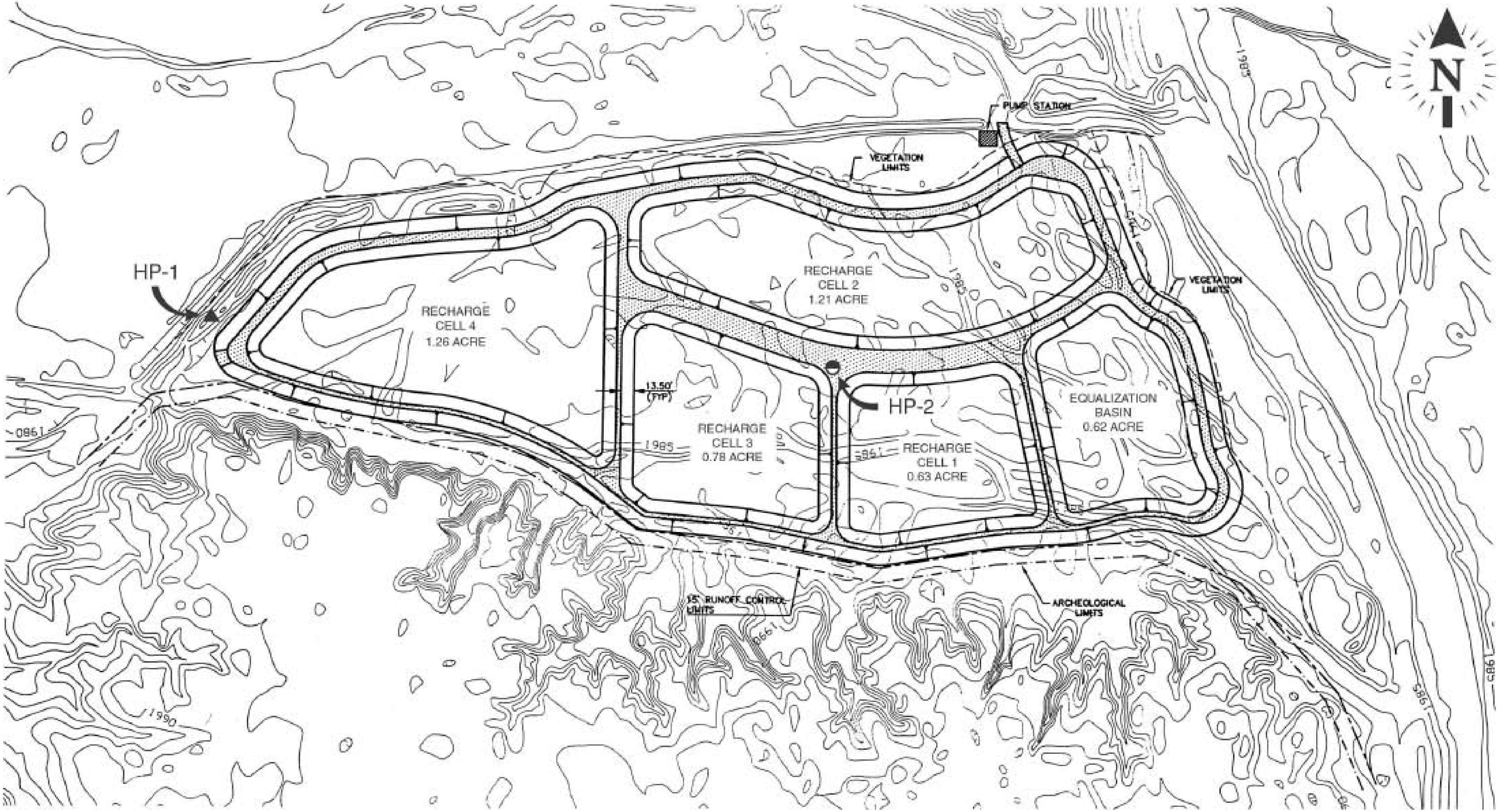
FIGURES

FIGURE 1
Location Map



Pima County Graphic Services db3483 7/02

FIGURE 2
Facility Map



LEGEND

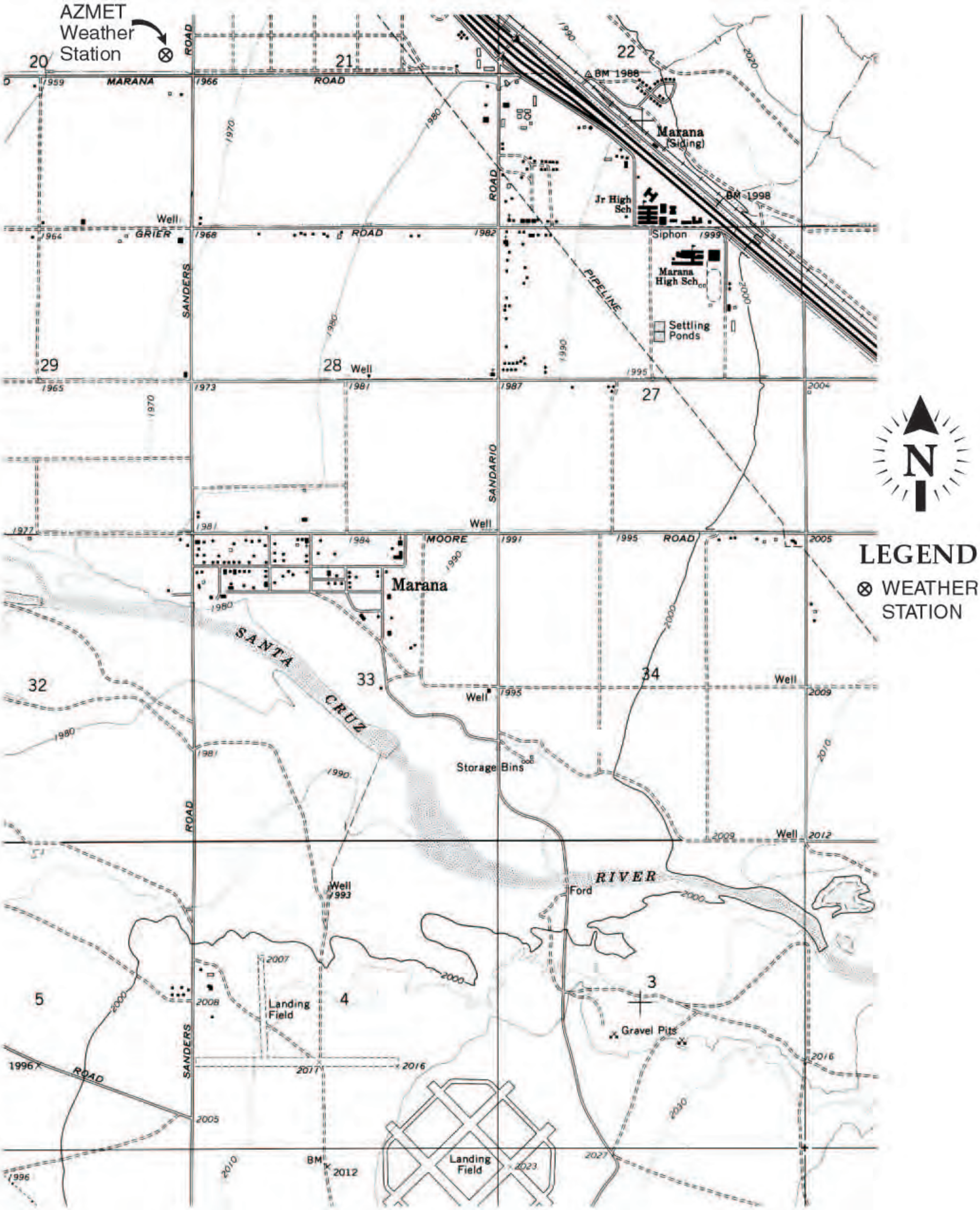
▲ MONITOR WELL

◓ PIEZOMETER

SCALE IN FEET:

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

Pima County Graphic Services ds3483 7/02



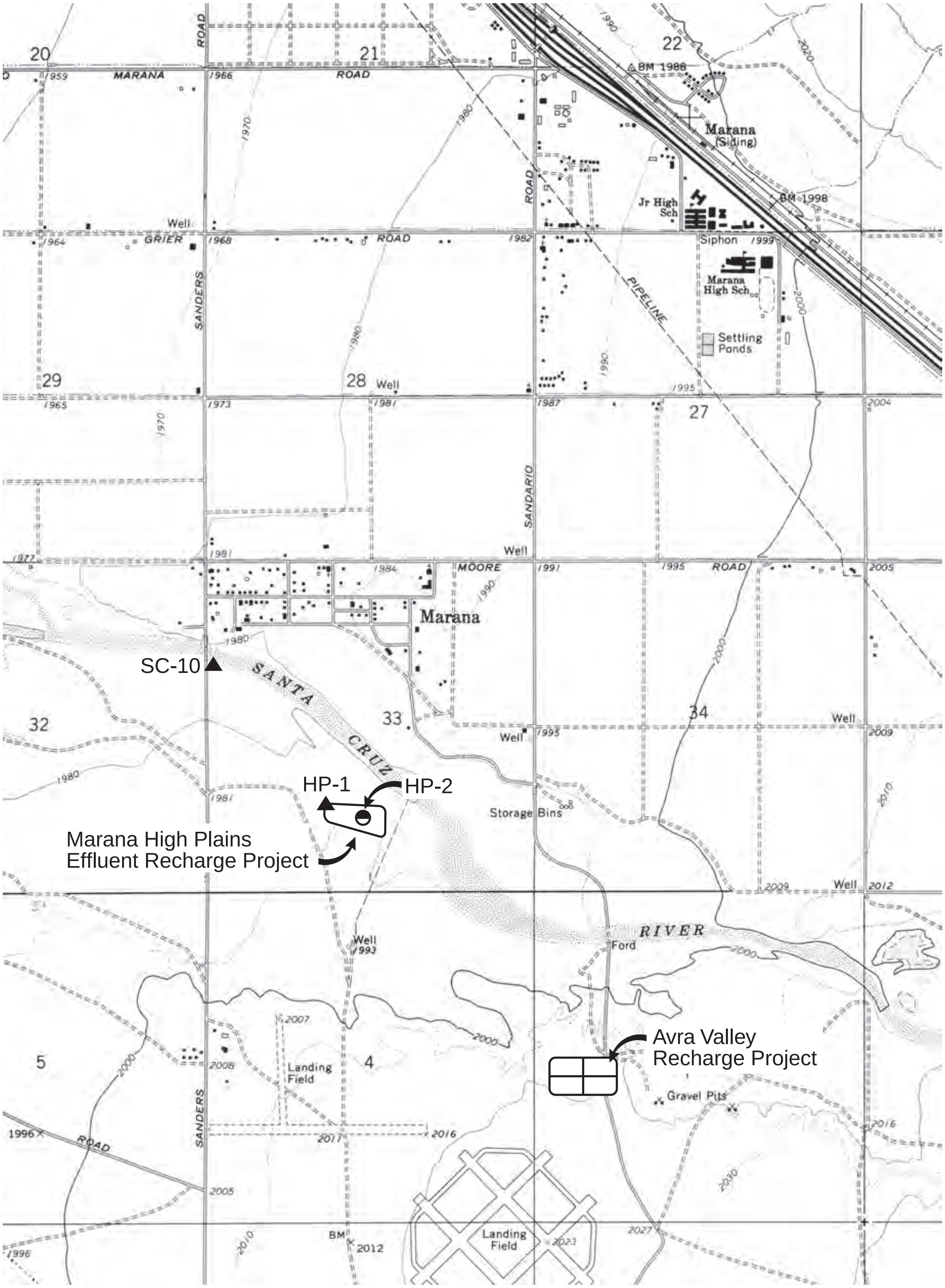
Date on line: Sep 1 1987 (Julian Day 244)
Location: 1.6 km (1 mile) west of I-10 on Trico-Marana Rd.
Elevation: 601 meters (1972 ft)
Coordinates: Latitude = 32° 27' 40" N; Longitude = 111° 14' 00" W
Cooperator: Marana Agricultural Center College of Agri., Univ. of Arizona

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



LEGEND

▲ MONITOR WELL

◓ PIEZOMETER

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FIGURE 4

Marana High Plains Effluent Recharge Project : Monitor Well Location Map

Miles .5 1 2

SCALE:

TABLES

TABLE 1A
MARANA HIGH PLAINS EFFLUENT RECHARGE PROJECT
WATER QUALITY SUMMARY - SOURCE WATER DIVERSION
CALENDAR YEAR 2010

Constituent	Unit	Discharge Limit	Sample Date & Results											
			Jan-10	Feb-10	Mar-10	Apr-10	May-10	Jun-10	Jul-10	Aug-10	Sep-10	Oct-10	Nov-10	Dec-10
Nutrients														
Total Nitrogen[1]	mg/l	N/A	no event	no event	27.6	27.5	22.4	25.0	19.9	22.6	17.4	22.4	29.0	29.0
Nitrate-Nitrite as N	mg/l	N/A	no event	no event	6.6	6.5	7.4	7.0	6.9	9.6	7.4	8.4	7.0	6.0
Total Kjeldahl Nitrogen (TKN)	mg/l	N/A	no event	no event	21.0	21.0	15.0	18.0	13.0	13.0	10.0	15.0	22.0	23.0
Metals (Total)														
Free Cyanide	mg/l	0.2	no event	no event	< 0.020	no event	< 0.020	no event	no event	no event	< 0.020	no event	< 0.020	no event
Total Fluoride	mg/l	4	no event	no event	0.42	no event	0.41	no event	no event	no event	0.40	no event	0.52	no event
Arsenic	mg/l	0.05	no event	no event	0.0046	no event	0.0035	no event	no event	no event	0.0062	no event	0.0041	no event
Barium	mg/l	2	no event	no event	0.11	no event	0.078	no event	no event	no event	0.15	no event	0.077	no event
Beryllium	mg/l	0.004	no event	no event	< 0.0010	no event	< 0.0010	no event	no event	no event	< 0.0010	no event	< 0.0010	no event
Cadmium	mg/l	0.005	no event	no event	< 0.0010	no event	< 0.0010	no event	no event	no event	< 0.0010	no event	< 0.0010	no event
Chromium	mg/l	0.1	no event	no event	< 0.0010	no event	< 0.0010	no event	no event	no event	< 0.0010	no event	< 0.0010	no event
Lead	mg/l	0.05	no event	no event	0.0023	no event	0.0019	no event	no event	no event	0.0085	no event	< 0.0010	no event
Thallium	mg/l	0.002	no event	no event	< 0.0010	no event	< 0.0010	no event	no event	no event	< 0.0010	no event	< 0.0010	no event
Nickel	mg/l	0.1	no event	no event	0.0040	no event	0.0033	no event	no event	no event	0.0036	no event	0.0033	no event
Antimony	mg/l	0.006	no event	no event	< 0.0030	no event	< 0.0030	no event	no event	no event	< 0.0030	no event	< 0.0030	no event
Selenium	mg/l	0.05	no event	no event	< 0.0020	no event	< 0.0020	no event	no event	no event	< 0.0020	no event	< 0.0020	no event
Mercury	mg/l	0.002	no event	no event	< 0.00020	no event	< 0.00020	no event	no event	no event	< 0.00020	no event	< 0.00020	no event
Volatile Organic Compounds (VOCs)														
para-Dichlorobenzene	mg/l	0.075	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Dichloromethane	mg/l	0.005	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
o-Dichlorobenzene	mg/l	0.6	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Carbon tetrachloride	mg/l	0.005	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Toluene	mg/l	1	no event	no event	no event	no event	0.0012	no event	no event	no event	no event	< 0.0020	no event	no event
Benzene	mg/l	0.005	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Monochlorobenzene	mg/l	0.1	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Ethylbenzene	mg/l	0.7	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0020	no event	no event
Tetrachloroethylene	mg/l	0.005	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
1,1-Dichloroethylene	mg/l	0.007	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
1,1,1-Trichloroethane	mg/l	0.2	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
1,1,2-Trichloroethane	mg/l	0.005	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
1,2-Dichloroethane	mg/l	0.005	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
1,2-Dichloropropane	mg/l	0.005	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
1,2,4-Trichlorobenzene	mg/l	0.07	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Vinyl Chloride	mg/l	0.002	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Trichloroethylene	mg/l	0.005	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Hexachlorobenzene	mg/l	0.001	no event	no event	no event	no event	< 0.010	no event	no event	no event	no event	< 0.010	no event	no event
cis--1,2-Dichloroethylene	mg/l	0.07	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Styrene	mg/l	0.1	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Xylenes (Total)	mg/l	10	no event	no event	no event	no event	< 0.0020	no event	no event	no event	no event	< 0.0030	no event	no event
Trihalomethane (TTHM)	mg/l	0.1	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0050	no event	no event
trans-1,2-Dichloroethylene	mg/l	0.1	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Hexachlorocyclopentadiene	mg/l	0.05	no event	no event	no event	no event	< 0.010	no event	no event	no event	no event	< 0.010	no event	no event

No Event = No sample taken (No flow, HP-1 pump not operating, or no testing required)
No Set Alert Levels per APP #103195
[1] Total Nitrogen = Nitrate-Nitrite as N + TKN (APP #103195)

TABLE 1B
MARANA HIGH PLAINS EFFLUENT RECHARGE PROJECT
WATER QUALITY SUMMARY - COMPLIANCE WELL HP-1
CALENDAR YEAR 2010

Constituent	Unit	Aquifer Quality Limit	Sample Date & Results											
			Jan-10	Feb-10	Mar-10	Apr-10	May-10	Jun-10	Jul-10	Aug-10	Sep-10	Oct-10	Nov-10	Dec-10
Nutrients														
Total Nitrogen[1]	mg/l	10	1.6	2.0	2.1	2.1	2.1	1.8	2.2	1.9	1.8	2.1	2.2	1.4
Nitrate-Nitrite as N	mg/l	10	1.6	2.0	2.1	2.1	2.1	1.8	2.2	1.9	1.8	2.1	2.2	1.4
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	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent
Metals (Total)														
Free Cyanide	mg/l	0.2	no event	< 0.020	no event	no event	< 0.020	no event	no event	no event	< 0.020	no event	< 0.020	no event
Total Fluoride	mg/l	4	no event	< 0.40	no event	no event	< 0.40	no event	no event	no event	0.53	no event	< 0.40	no event
Arsenic	mg/l	0.05	no event	0.0016	no event	no event	< 0.0010	no event	no event	no event	0.0014	no event	0.0021	no event
Barium	mg/l	2	no event	0.13	no event	no event	0.14	no event	no event	no event	0.14	no event	0.15	no event
Beryllium	mg/l	0.004	no event	< 0.0010	no event	no event	< 0.0010	no event	no event	no event	< 0.0010	no event	< 0.0010	no event
Cadmium	mg/l	0.005	no event	< 0.0010	no event	no event	< 0.0010	no event	no event	no event	< 0.0010	no event	< 0.0010	no event
Chromium	mg/l	0.1	no event	< 0.0010	no event	no event	< 0.0010	no event	no event	no event	< 0.0010	no event	< 0.0010	no event
Lead	mg/l	0.05	no event	< 0.0010	no event	no event	0.03	no event	no event	no event	< 0.0010	no event	0.001	no event
Thallium	mg/l	0.002	no event	< 0.0010	no event	no event	< 0.0010	no event	no event	no event	< 0.0010	no event	< 0.0010	no event
Nickel	mg/l	0.1	no event	0.0029	no event	no event	0.0033	no event	no event	no event	< 0.0010	no event	0.0032	no event
Antimony	mg/l	0.006	no event	< 0.0030	no event	no event	< 0.0030	no event	no event	no event	< 0.0030	no event	< 0.0030	no event
Selenium	mg/l	0.05	no event	< 0.0020	no event	no event	< 0.0020	no event	no event	no event	< 0.0020	no event	< 0.0020	no event
Mercury	mg/l	0.002	no event	< 0.00020	no event	no event	< 0.00020	no event	no event	no event	< 0.00020	no event	< 0.00020	no event
Volatile Organic Compounds (VOCs)														
para-Dichlorobenzene	mg/l	0.075	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Dichloromethane	mg/l	0.005	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
o-Dichlorobenzene	mg/l	0.6	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Carbon tetrachloride	mg/l	0.005	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Toluene	mg/l	1	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0020	no event	no event
Benzene	mg/l	0.005	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Monochlorobenzene	mg/l	0.1	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Ethylbenzene	mg/l	0.7	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0020	no event	no event
Tetrachloroethylene	mg/l	0.005	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
1,1-Dichloroethylene	mg/l	0.007	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0020	no event	no event
1,1,1-Trichloroethane	mg/l	0.2	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
1,1,2-Trichloroethane	mg/l	0.005	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
1,2-Dichloroethane	mg/l	0.005	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
1,2-Dichloropropane	mg/l	0.005	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
1,2,4-Trichlorobenzene	mg/l	0.07	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Vinyl Chloride	mg/l	0.002	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Trichloroethylene	mg/l	0.005	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Hexachlorobenzene	mg/l	0.001	no event	no event	no event	no event	< 0.010	no event	no event	no event	no event	< 0.010	no event	no event
cis--1,2-Dichloroethylene	mg/l	0.07	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Styrene	mg/l	0.1	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Xylenes (Total)	mg/l	10	no event	no event	no event	no event	< 0.0020	no event	no event	no event	no event	< 0.0030	no event	no event
Trihalomethane (TTHM)	mg/l	0.1	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0050	no event	no event
trans-1,2-Dichloroethylene	mg/l	0.1	no event	no event	no event	no event	< 0.0010	no event	no event	no event	no event	< 0.0010	no event	no event
Hexachlorocyclopentadiene	mg/l	0.05	no event	no event	no event	no event	< 0.010	no event	no event	no event	no event	< 0.010	no event	no event

No Event = No sample taken (No flow, HP-1 pump not operating, or no test required)
1 Total Nitrogen = Nitrate-Nitrite as N + TKN (APP #103195)

TABLE 2
MARANA HIGH PLAINS EFFLUENT RECHARGE PROJECT
FACILITY INSPECTIONS: PROBLEMS AND RELATED SOLUTIONS
CALENDAR YEAR 2010

Date	Problem	Solution
January 2010	No flow in the oxbow channel – diversion berm washed out	Diversion berm repaired on March 18th; flow deliveries restored to facility on March 19th
March 2010	Submersible pumps are not operating in sequence in "auto" mode with the level sensor in the equalization basin; Pump #1 will only operate briefly (< 10 seconds) and Pump #2 will only operate in the on position	Pump #2 was run manually (in the on position) until the pump switch system was repaired later in the month
April 2010	No power available to Recharge Cells 3 and 4	Electrical wiring was repaired and power restored to the cells on May 21st; both cells were operated briefly during the outage with flow measurements estimated based on daily levels observed in the basins
May 2010	Electronic valve controls will not operate in Cells 3 and 4 due to damage by flooding of the vaults	The valves in Cells 3 and 4 were operated manually using the crank wheel; daily observation of the basin levels determined when the valves should be opened or closed
July 2010	Excessive weeds (Russian thistle and Bermuda grass) are blocking access to the electronic control panels and causing safety concerns with regards to poisonous snakes and insects	A landscape contractor was hired to remove weeds around the panels and along the maintenance road; trees were also pruned to ease vehicle access to the site
July 2010	Low flow in the oxbow channel; water appears to be mostly storm water	Contractor repaired diversion berm and cleaned out oxbow channel and wet well – flow deliveries reestablished by September 13th
September 2010	Recharge basins are clogged with fine materials and vegetation	Contractor cleared the basin bottoms of vegetation, excavated the clogging layers (~ 4-5 inches) and ripped the basin bottoms (down to ~ 36 inches)
November 2010	Underground vaults holding the motorized valves in Cells 1 and 4 are repeatedly being flooded as the basins are being filled with water; level sensor malfunctions in the past have caused flooding within the vaults in Cells 3 and 4, causing damage to the motorized valve controls	Staff coordinated the installation of culverts in Cells 1 through 4 to allow water to overflow at elevations below the motorized valve equipment; staff also sealed the outlet pipes in Cells 1 and 4 with silicon sealant to help keep water from flowing back into the vaults
December 2010	Area/Velocity probe for the flow meter in Cell 3 has been washed out of the outlet pipe, causing errors in flow readings	The cell was dried and the probe was reset within the outlet pipe; flows for the previous day were estimated based on water delivery to the project and water levels recorded within the basin
December 2010	Infiltration rates are very low within Cells 1, 3 and 4 despite long periods of drying between operation	District staff developed a new wet/dry cycle based on past data; maintenance will be performed on the cells in early 2011 to breakup clogging layers and increase infiltration

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: 2010

	January		February		March		April		May		June	
	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons
	192468782		212209700		212209700		219259550		235436148		254385869	
Day 1	193577689	1108907	212209700	0	212209700	0	219774285	514735	236364948	928800	**254805529**	419660
2	194686596	1108907	212209700	0	212209700	0	220220095	445810	237293748	928800	255418979	613450
3	195795503	1108907	212209700	0	212209700	0	220508095	288000	238222548	928800	255886271	467292
4	196789305	993802	212209700	0	212209700	0	220674026	165931	239119242	896694	256399471	513200
5	197849145	1059840	212209700	0	212209700	0	221096690	422664	239981802	862560	256684671	285200
6	198908985	1059840	212209700	0	212209700	0	221426595	329905	240844362	862560	256965471	280800
7	199968825	1059840	212209700	0	212209700	0	221714595	288000	241706922	862560	257339871	374400
8	200967793	998968	212209700	0	212209700	0	222045795	331200	242569482	862560	257663871	324000
9	201926833	959040	212209700	0	212209700	0	222376995	331200	243432042	862560	257944671	280800
10	202885873	959040	212209700	0	212209700	0	222736995	360000	243818397	386355	258171071	226400
11	203844913	959040	212209700	0	212209700	0	223096995	360000	244228797	410400	258406171	235100
12	204808129	963216	212209700	0	212209700	0	223698795	601800	245141655	912858	258623771	217600
13	205774369	966240	212209700	0	212209700	0	224446395	747600	246054513	912858	258852871	229100
14	206740609	966240	212209700	0	212209700	0	225193995	747600	246744833	690320	259099771	246900
15	207706849	966240	212209700	0	212460950	251250	225941692	747697	247148033	403200	259338271	238500
16	208673089	966240	212209700	0	212924630	463680	226748092	806400	247551233	403200	259573671	235400
17	209639329	966240	212209700	0	213057417	132787	227554492	806400	248235833	684600	259817011	243340
18	210605569	966240	212209700	0	213057417	0	228360892	806400	249089565	853732	260161459	344448
19	211260467	654898	212209700	0	213323526	266109	229054132	693240	249924765	835200	260161459	0
20	211675763	415296	212209700	0	213818886	495360	229608532	554400	250738365	813600	260161459	0
21	212091059	415296	212209700	0	214314246	495360	230155732	547200	251043967	305602	260161459	0
22	212209700	118641	212209700	0	214809606	495360	230695732	540000	251385247	341280	260161459	0
23	212209700	0	212209700	0	215304966	495360	231228532	532800	251726527	341280	260161459	0
24	212209700	0	212209700	0	216140166	835200	231754132	525600	252014823	288296	260161459	0
25	212209700	0	212209700	0	216975366	835200	232272532	518400	252443119	428296	260639209	477750
26	212209700	0	212209700	0	217641366	666000	232783732	511200	252821519	378400	261575209	936000
27	212209700	0	212209700	0	218180264	538898	233269603	485871	253159919	338400	262511209	936000
28	212209700	0	212209700	0	218607252	426988	233824003	554400	253466406	306487	263447209	936000
29	212209700	0			218646150	38898	234507348	683345	253772893	306487	264018409	571200
30	212209700	0			218960030	313880	235436148	928800	254079380	306487	264407209	388800
31	212209700	0			219259550	299520			254385869	306489		
	Total (gal)	**19740918**	**Total (gal)**	**0**	**Total (gal)**	**7049850**	**Total (gal)**	**16176598**	**Total (gal)**	**18949721**	**Total (gal)**	**10021340**
	Total (ac-ft)	**60.58**	**Total (ac-ft)**	**0.00**	**Total (ac-ft)**	**21.64**	**Total (ac-ft)**	**49.64**	**Total (ac-ft)**	**58.15**	**Total (ac-ft)**	**30.75**
				1st Qtr Total (gal) =		**26790768**				**2nd Qtr Total (gal) =**		**45147659**
				1st Qtr Total (ac-ft) =		**82.22**				**2nd Qtr Total (ac-ft) =**		**138.55**

USF DAILY FLOWMETER READINGS AND VOLUMES

Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Meter ID: Fm-eq
Year: 2010

	July		August		September		October		November		December	
	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons	Totalizer Reading	Gallons
	264407209		274326792		274326792		288075630		309527640		321099040	
Day 1	264816119	408910	274326792	0	274326792	0	288939630	864000	309919320	391680	321500755	401715
2	265155029	338910	274326792	0	274326792	0	289803630	864000	310311000	391680	321805255	304500
3	265428629	273600	274326792	0	274326792	0	290667630	864000	310721824	410824	322093255	288000
4	265631829	203200	274326792	0	274326792	0	291531630	864000	311297824	576000	322338255	245000
5	265869429	237600	274326792	0	274326792	0	292395630	864000	311729824	432000	322566755	228500
6	266121429	252000	274326792	0	274326792	0	293259630	864000	311729824	0	323159855	593100
7	266380629	259200	274326792	0	274326792	0	294123630	864000	311729824	0	323453455	293600
8	266828245	447616	274326792	0	274326792	0	294987630	864000	311729824	0	323740855	287400
9	267253045	424800	274326792	0	274326792	0	295851630	864000	312435424	705600	324204090	463235
10	267677845	424800	274326792	0	274326792	0	296715630	864000	313285024	849600	324532890	328800
11	268102645	424800	274326792	0	274326792	0	297579630	864000	313904224	619200	324920445	387555
12	268527445	424800	274326792	0	274326792	0	298326630	747000	314383780	479556	325323645	403200
13	268952245	424800	274326792	0	274712397	385605	299190630	864000	314678210	294430	325600430	276785
14	269377045	424800	274326792	0	275572580	860183	300054630	864000	315005090	326880	326116630	516200
15	269801845	424800	274326792	0	276266702	694122	300918630	864000	315331970	326880	326638630	522000
16	270288079	486234	274326792	0	276960824	694122	301763916	845286	315864800	532830	327020800	382170
17	270820879	532800	274326792	0	277836344	875520	302581836	817920	316728800	864000	327301600	280800
18	271310479	489600	274326792	0	278730342	893998	303452336	870500	317243340	514540	327582400	280800
19	271742479	432000	274326792	0	279624340	893998	304316336	864000	317243340	0	327863200	280800
20	272030479	288000	274326792	0	280481140	856800	305180336	864000	317243340	0	328151200	288000
21	272455279	424800	274326792	0	281027020	545880	305957936	777600	317243340	0	328439200	288000
22	272665104	209825	274326792	0	281876620	849600	306366520	408584	317243340	0	328727200	288000
23	272874929	209825	274326792	0	282089550	212930	306712120	345600	317722370	479030	329015200	288000
24	273270192	395263	274326792	0	282946350	856800	307057720	345600	318543170	820800	329202400	187200
25	273594192	324000	274326792	0	283803150	856800	307403320	345600	319363970	820800	329490400	288000
26	273939792	345600	274326792	0	284659950	856800	307721880	318560	319963970	600000	329778400	288000
27	274227792	288000	274326792	0	285516750	856800	308060280	338400	320453970	490000	330135500	357100
28	274326792	99000	274326792	0	286373550	856800	308398680	338400	320653970	200000	330552600	417100
29	274326792	0	274326792	0	287224590	851040	308744280	345600	320811040	157070	330830600	278000
30	274326792	0	274326792	0	288075630	851040	309135960	391680	321099040	288000	331118600	288000
31	274326792	0	274326792	0			309527640	391680			331485700	367100
	Total (gal)	**9919583**	**Total (gal)**	**0**	**Total (gal)**	**13748838**	**Total (gal)**	**21452010**	**Total (gal)**	**11571400**	**Total (gal)**	**10386660**
	Total (ac-ft)	**30.44**	**Total (ac-ft)**	**0.00**	**Total (ac-ft)**	**42.19**	**Total (ac-ft)**	**65.83**	**Total (ac-ft)**	**35.51**	**Total (ac-ft)**	**31.88**

3rd Qtr Total (gal) =	**23668421**
3rd Qtr Total (ac-ft) =	**72.64**

4th Qtr Total (gal) =	**43410070**
4th Qtr Total (ac-ft) =	**133.22**
Annual Total Del. Vol for FM-eq (ac-ft) =	**426.63**

USF WATER QUANTITY REPORTING SUMMARY

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0007

Year: 2010

	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	60.6	0.5	0.1	60.0	
February	0.0	0.0	0.0	0.0	
March	21.6	0.5	0.1	21.1	81.1
April	49.6	1.3	0.2	48.2	
May	58.2	2.8	0.3	55.1	
June	30.8	1.8	0.2	28.8	132.1
July	30.4	2.4	0.1	27.9	
August	0.0	0.0	0.0	0.0	
September	42.2	0.8	0.1	41.3	69.3
October	65.8	1.8	0.1	63.9	
November	35.5	1.2	0.1	34.2	
December	31.9	0.9	0.1	30.9	129.0

Annual Totals =	**426.6**	**13.9**	**1.2**	**411.5**

APPENDIX B

Evaporation Calculations & Cooley Method Description

USF EVAPORATION CALCULATIONS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2010

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	10	0.1	0	0.0	7	0.1	13	0.3	14	0.4	13	0.4
Cell 1	7	0.1	0	0.0	3	0.1	14	0.3	18	0.5	5	0.1
Cell 2	9	0.1	0	0.0	0	0.0	7	0.2	33	0.9	26	0.8
Cell 3	4	0.0	0	0.0	5	0.1	8	0.2	12	0.3	9	0.3
Cell 4	23	0.2	0	0.0	13	0.2	15	0.3	23	0.6	6	0.2
	54	**0.5**	**0**	**0.0**	**28**	**0.5**	**58**	**1.3**	**100**	**2.8**	**59**	**1.8**

1st Quarter Total Evap (AF) **=**	**1.0**
2nd Quarter Total Evap (AF) **=**	**5.8**

Cooley Adj. Fac	**0.95**

USF EVAPORATION CALCULATIONS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2010

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	14	0.4	0	0.0	8	0.2	14	0.3	14	0.2	14	0.1
Cell 1	12	0.4	0	0.0	6	0.1	17	0.3	15	0.2	16	0.1
Cell 2	34	1.0	0	0.0	3	0.1	30	0.5	25	0.3	35	0.3
Cell 3	7	0.2	0	0.0	9	0.2	12	0.2	16	0.2	14	0.1
Cell 4	15	0.4	0	0.0	8	0.2	29	0.5	27	0.3	31	0.2
	81	**2.4**	**0**	**0.0**	**35**	**0.8**	**102**	**1.8**	**96**	**1.2**	**111**	**0.9**

3rd Quarter Total Evap (AF) **=**	**3.2**

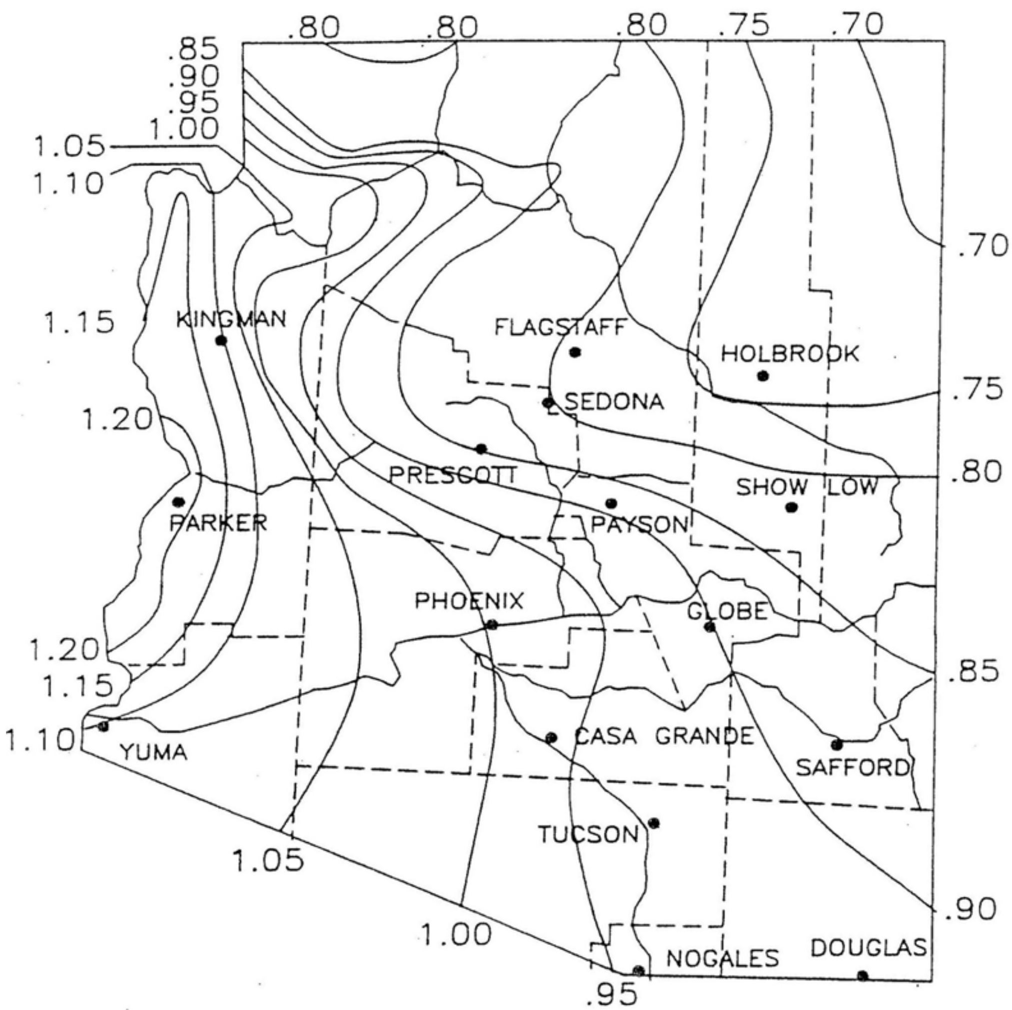
4th Quarter Total Evap (AF) **=**	**3.9**
Annual Total Evap (AF) **=**	**13.9**

COOLEY EVAPORATION INFORMATION

Cooley Monthly Maximum Evaporation Rates
from Cooley, 1970

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

Cooley Evaporation Adjustment Factors for Arizona
from Cooley, 1970



ARIZONA DEPARTMENT OF WATER RESOURCES
HYDROLOGY DIVISION

TECHNICAL BULLETIN

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

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

- The Cooley Method is very consistent, in that, the daily evaporation rates and adjustment factors are fixed and do not change over time. This allows for a very simplified calculation method that is identical from year to year.

- The Cooley method is easy to use and can be adopted by a wide range of permittees and facilities. Especially as it relates to the collecting, reporting, and reviewing of the data and calculations. This has proven to be a benefit for new facility operators and changes in personnel at the Department. This is an important factor to consider when taking into account a duration of twenty years or longer for some facilities.

- The consistency of the Cooley Method makes it easy for the Department to review and verify calculation parameters when reviewing a new application and/or determining long term storage credits.

- The Cooley Method can be used without the Department demanding extraneous monitoring cost. The information required such as, wet/dry status of the basin(s) and the volume of water discharged are currently required in the USF permit for credit calculations and infiltration calculations.

- The Cooley Method unlike other empirical methods was designed specifically for Arizona.

- Other methods of determining evaporation can be very accurate, however, they are relatively expensive, requiring intensive measurements and calculation efforts to obtain evaporation values. In Hydrology's experience the difference between these methods and Cooley is negligible. This is especially true given the relatively small ratio of evaporation to the total amount of water recharged.

- The daily evaporation rates and adjustment factors, determined by Cooley, are used by the Arizona Department of Environmental Quality (ADEQ Engineering Bulletin No. 12). Thus having consistency between state agencies.

Justification for Using the Maximum Curve of the Cooley Method

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

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

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

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

EVAPORATION FROM OPEN WATER SURFACES IN ARIZONA

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

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

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

How to Estimate Evaporation

Estimation of evaporation consists of three steps.

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

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

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

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

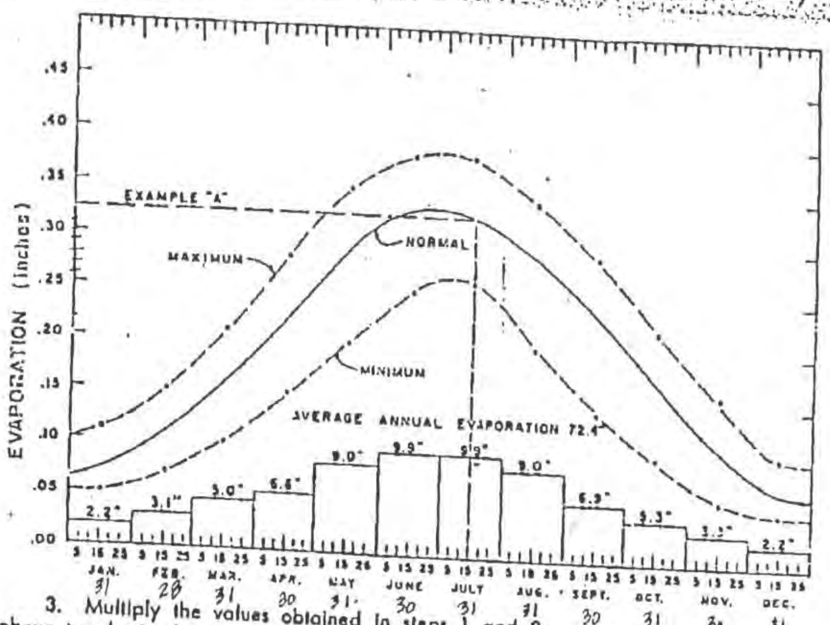


FIGURE 1. Maximum, Normal, and Minimum Daily Evaporation and Average Monthly Evaporation From Open Water Surfaces (Adjustment Factor = 1.00).

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

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

Examples:

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

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

(See over)

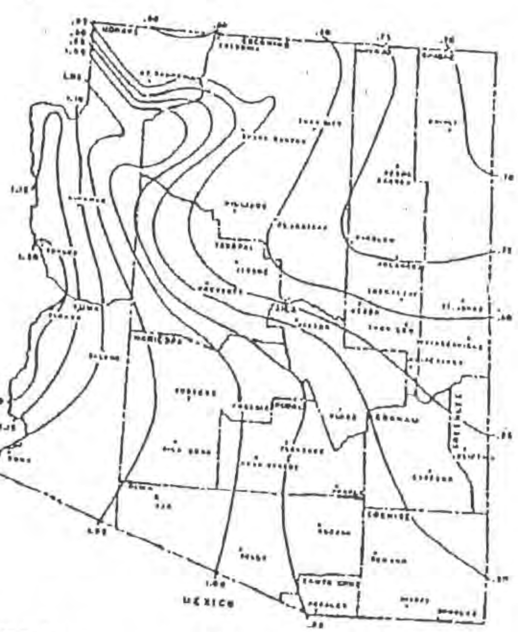


FIGURE 2. Evaporation Adjustment Factors for Arizona

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

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

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

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

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

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

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

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

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

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

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

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

Acknowledgement

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

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

EVAPORATION FROM OPEN WATER SURFACES IN ARIZONA

FOLDER 159

Agricultural Experiment Station

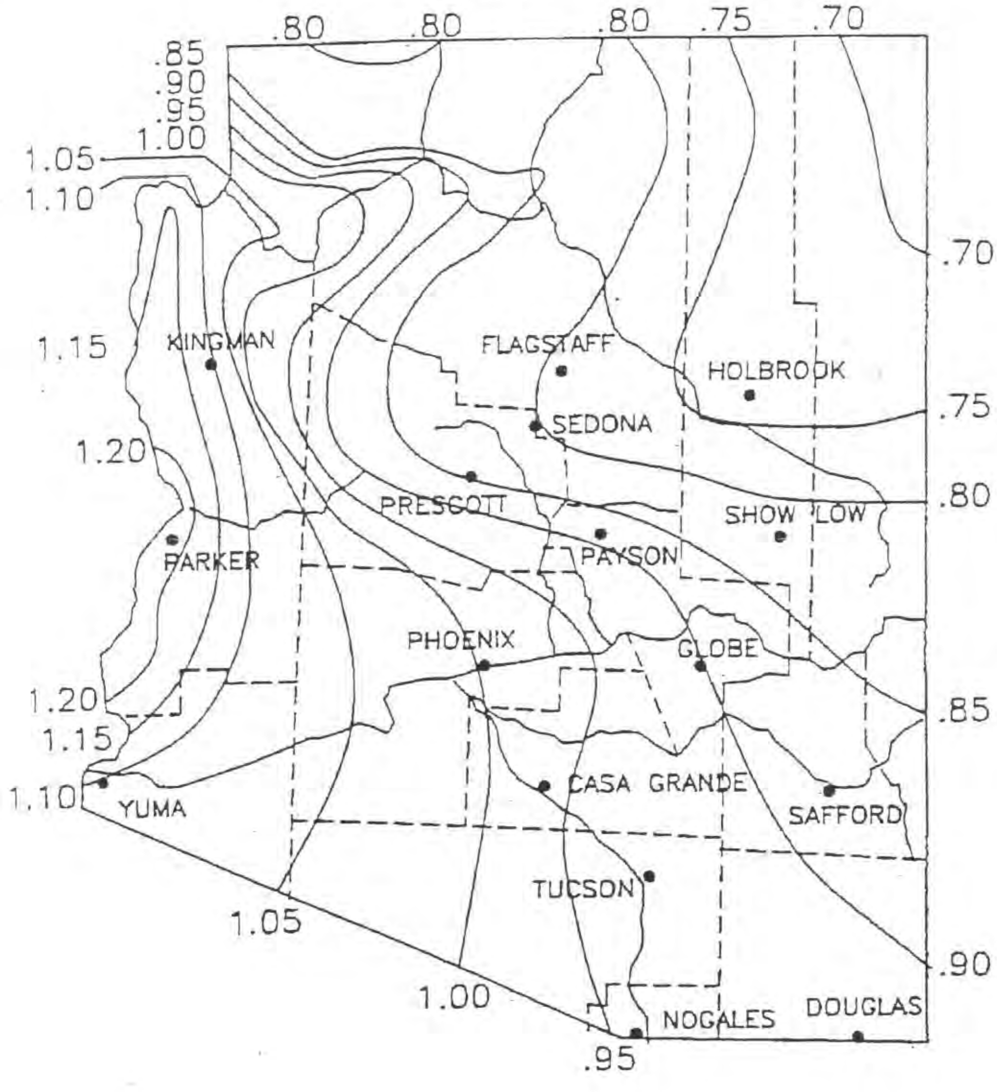
And

Cooperative Extension Service

The University of Arizona

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

FIGURE 10. EVAPORATION ADJUSTMENT FACTORS FOR ARIZONA



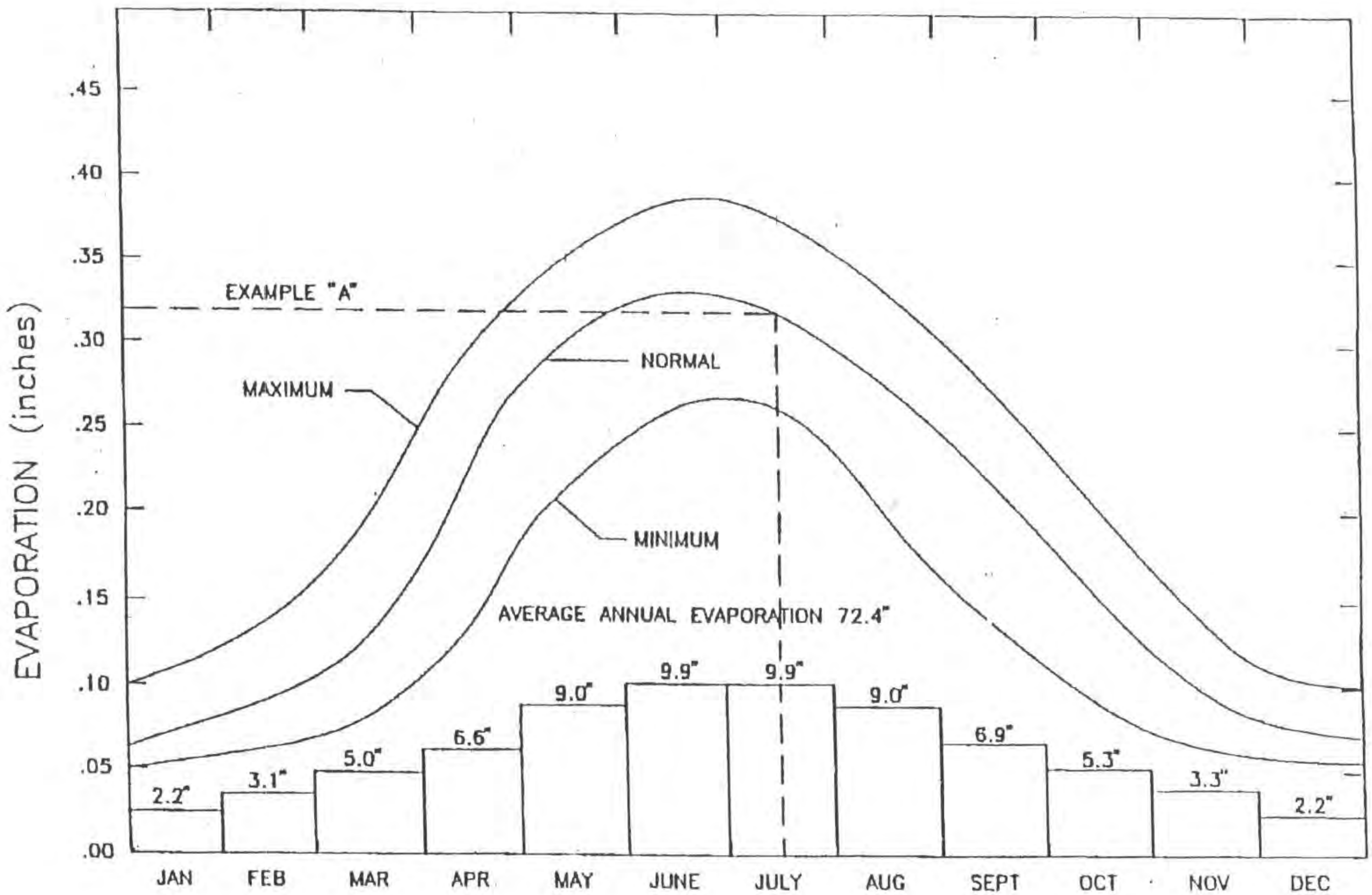


FIGURE 9. MAXIMUM, NORMAL AND MINIMUM DAILY EVAPORATION AND AVERAGE MONTHLY EVAPORATION FROM OPEN WATER SURFACES (Adjustment Factor = 1.00)

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

	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: 2010

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	0.403	0.5922	0.363	0.585	0.9954
2	0.403	0.5922	0.4235	0.315	0.9954
3	0.403	0.5922	0.484	0.039	0.9954
4	0.403	0.5922	0.484	0.039	0.9954
5	0.403	0	0.484	0	0.9954
6	0.403	0	0.484	0	0.9954
7	0.403	0	0.605	0	0.9954
8	0.403	0.0315	0.605	0.195	0.9954
9	0.403	0.1575	0.363	0.585	0.9954
10	0.403	0.5796	0.121	0.585	0.9954
11	0.403	0.6111	0.0605	0.585	0.9954
12	0.403	0.63	0.121	0.585	0.9954
13	0.403	0.0315	0.121	0	0.9954
14	0.403	0	0.3025	0	0.9954
15	0.403	0	0.363	0.039	0.9954
16	0.403	0.0315	0.4235	0.039	0.9954
17	0.403	0.0315	0.484	0.039	0.9954
18	0.403	0.315	0.5445	0.039	0.9954
19	0.403	0.5796	0.605	0.039	0.9954
20	0.403	0.6111	0.484	0.039	0.9954
21	0.403	0.6111	0.363	0.039	0.9954
22	0.403	0.5796	0.3025	0.121	0.9954
23	0.403	0	0.121	0	0.9954
24	0.3875	0	0.121	0	0.315
25	0.3875	0	0.0605	0	0
26	0.372	0	0.0605	0	0
27	0	0	0	0	0
28	0	0	0	0	0
29	0	0	0	0	0
30	0	0	0	0	0
31	0	0	0	0	0
Total Wetted Acres	**10.416**	**7.1694**	**8.954**	**3.907**	**23.2092**

February

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

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

USF DAILY WETTED ACREAGES
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2010

March

Date	Equal. Basin Wetted Area (acres)*	Recharge Cell 1 Wetted Area (acres)*	Recharge Cell 2 Wetted Area (acres)*	Recharge Cell 3 Wetted Area (acres)*	Recharge Cell 4 Wetted Area (acres)*
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0.3875	0	0	0	0
16	0.465	0	0	0	0
17	0.465	0	0	0	0
18	0.465	0	0	0	0
19	0.465	0	0	0.039	0.9954
20	0.4185	0	0	0.121	0.9954
21	0.403	0	0	0.121	0.9954
22	0.403	0	0	0.585	0.9954
23	0.403	0	0	0.585	0.9954
24	0.403	0	0	0.585	0.9954
25	0.403	0	0	0.585	0.9954
26	0.403	0.0315	0	0.585	0.9954
27	0.403	0.5796	0	0.585	0.9954
28	0.434	0.63	0	0.585	0.9954
29	0.465	0.63	0	0.585	0.9954
30	0.465	0.63	0	0	0.9954
31	0.465	0.63	0	0	0.9954
Total Wetted Acres	**7.316**	**3.1311**	**0**	**4.961**	**12.9402**

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	0.403	0.6111	0	0.585	0.9954
2	0.403	0.6111	0	0.585	0.9954
3	0.465	0.6111	0	0.585	0.9954
4	0.465	0.6111	0	0.585	0.9954
5	0.465	0.6111	0	0.585	0.9954
6	0.465	0.6111	0	0.39	0.9954
7	0.465	0.6111	0	0	0.9954
8	0.434	0.6111	0	0	0.9954
9	0.403	0.6111	0	0	0.9954
10	0.465	0.6111	0	0	0.9954
11	0.465	0.6111	0	0	0.9954
12	0.465	0.6111	0.0605	0	0.9954
13	0.465	0.6111	0.121	0	0.9954
14	0.465	0.6111	0.121	0	0.9954
15	0.465	0.6111	0.3025	0	0.9954
16	0.465	0.6111	0.3025	0	0.315
17	0.465	0.6111	0.605	0	0.063
18	0.465	0.6111	0.605	0	0.063
19	0.465	0.6111	0.605	0	0
20	0.465	0.5796	0.605	0	0
21	0.465	0.315	0.605	0	0
22	0.434	0.0315	0.3025	0.39	0
23	0.403	0	0.3025	0.585	0
24	0.403	0	0.3025	0.585	0
25	0.403	0	0.3025	0.585	0
26	0.403	0	0.121	0.585	0
27	0.403	0.0315	0.03605	0.585	0
28	0.403	0.0315	0.605	0.585	0
29	0.403	0.5796	0.605	0.585	0
30	0.403	0.6111	0.605	0.585	0
Total Wetted Acres	**13.206**	**13.7907**	**7.11455**	**8.385**	**15.372**

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

USF DAILY WETTED ACREAGES
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2010

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	0.403	0.6111	0.605	0.585	0
2	0.403	0.6111	1.0285	0.585	0
3	0.403	0.6111	1.1374	0.39	0.063
4	0.403	0.5796	0.605	0.039	0.945
5	0.465	0.6111	0.3025	0	0.9954
6	0.434	0.5796	1.0648	0	0.9954
7	0.4185	0.6111	1.1374	0	0.9954
8	0.4495	0.5922	1.1374	0	0.9954
9	0.465	0.5796	1.1374	0	0.945
10	0.465	0.6111	1.1132	0.195	0.315
11	0.465	0.5796	1.0648	0.585	0.945
12	0.403	0.5796	1.0285	0.585	0.9954
13	0.403	0.6111	1.089	0.585	0.9954
14	0.403	0.6111	1.1374	0.585	0.9954
15	0.403	0.5796	1.1374	0.585	0.9954
16	0.403	0.5922	1.1374	0.585	0.9954
17	0.403	0.5796	1.374	0.585	0.9954
18	0.403	0.6111	1.1374	0.585	0.9954
19	0.403	0.6111	1.1374	0.585	0.9954
20	0.465	0.6111	1.1374	0.585	0.9954
21	0.465	0.6111	1.1132	0.585	0.9954
22	0.465	0.6111	1.1374	0.585	0.9954
23	0.465	0.5796	1.1374	0.585	0.9954
24	0.465	0.4725	1.1132	0.585	0.9954
25	0.465	0.6111	1.1374	0.585	0.9954
26	0.465	0.5922	1.1374	0.39	0.945
27	0.465	0.5796	1.1132	0.39	0.315
28	0.465	0.6111	1.1132	0.195	0.315
29	0.465	0.6111	1.1132	0.195	0.063
30	0.465	0.5796	1.1132	0.039	0.063
31	0.465	0.5922	1.1132	0.039	0.063
Total Wetted Acres	**13.578**	**18.4149**	**32.9913**	**11.817**	**22.8942**

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	0.465	0.5922	1.1253	0.039	0.0315
2	0.465	0.5796	1.1253	0.39	0.063
3	0.465	0.4725	1.1253	0.585	0
4	0.465	0.1575	1.1253	0.585	0
5	0.465	0	1.1253	0.585	0
6	0.465	0	1.1253	0.585	0
7	0.465	0	1.1253	0.585	0
8	0.465	0	1.1253	0.585	0
9	0.465	0	1.1253	0.585	0
10	0.465	0	1.1253	0.585	0
11	0.465	0	1.1253	0.585	0
12	0.465	0	1.1253	0.195	0
13	0.465	0	1.1253	0.039	0
14	0.465	0	1.1253	0.039	0
15	0.465	0	1.1253	0.039	0
16	0.465	0	1.1253	0.039	0
17	0.465	0	1.1253	0.039	0
18	0.465	0.1575	1.1253	0	0.315
19	0.4495	0.1575	1.0285	0	0.9954
20	0.4495	0	0.121	0	0.315
21	0.434	0	0.121	0	0
22	0.434	0	0.121	0	0
23	0.4185	0	0.121	0	0
24	0.403	0	0.121	0	0
25	0.403	0.1575	0.121	0.039	0.315
26	0.403	0.315	0.121	0.195	0.315
27	0.403	0.4725	0.3025	0.585	0.9954
28	0.403	0.6111	1.0285	0.585	0.9954
29	0.403	0.6111	1.1253	0.585	0.9954
30	0.403	0.6111	1.1253	0.585	0.9954
Total Wetted Acres	**13.3765**	**4.8951**	**25.7125**	**8.658**	**6.3315**

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

USF DAILY WETTED ACREAGES
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2010

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	0.403	0.6111	1.1253	0.585	0.9954
2	0.403	0.5796	1.1253	0.585	0.9954
3	0.403	0.1575	1.1253	0.585	0.9954
4	0.403	0	1.1253	0.195	0.945
5	0.4495	0	1.1253	0	0
6	0.4495	0	1.1253	0	0
7	0.4495	0	1.1253	0	0
8	0.434	0.1575	1.1253	0.195	0.315
9	0.434	0.5796	1.089	0.195	0.315
10	0.434	0.6111	1.0648	0.195	0.945
11	0.434	0.6111	1.089	0.195	0.9954
12	0.434	0.6111	1.1132	0.195	0.9954
13	0.434	0.6111	1.1132	0.195	0.9954
14	0.403	0.6111	1.1132	0.195	0.9954
15	0.403	0.6111	1.1132	0.195	0.9954
16	0.403	0.6111	1.1253	0.195	0.9954
17	0.465	0.5796	1.1253	0	0.9954
18	0.465	0.121	1.1253	0	0.315
19	0.465	0	1.1253	0	0.315
20	0.465	0.121	1.1253	0	0.063
21	0.465	0.6111	1.1253	0.39	0.063
22	0.465	0.6111	1.1253	0.585	0.063
23	0.465	0.6111	1.1253	0.585	0.063
24	0.465	0.6111	1.1253	0.585	0.063
25	0.465	0.6111	1.1253	0.585	0.063
26	0.465	0.6111	1.1253	0.039	0.063
27	0.465	0.6111	1.1253	0.039	0
28	0.465	0.5796	1.1253	0.039	0
29	0.403	0.315	1.089	0.039	0.585
30	0.403	0.0315	1.0284	0	0.315
31	0.403	0	0.121	0	0.063
Total Wetted Acres	**13.5625**	**12.3884**	**33.5653**	**6.591**	**14.508**

August

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

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

USF DAILY WETTED ACREAGES
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2010

September

Date	Equal. Basin Wetted Area (acres)*	Recharge Cell 1 Wetted Area (acres)*	Recharge Cell 2 Wetted Area (acres)*	Recharge Cell 3 Wetted Area (acres)*	Recharge Cell 4 Wetted Area (acres)*
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0.314	0.0315	0	0.039	0
14	0.403	0.315	0	0.195	0
15	0.403	0.6111	0	0.585	0
16	0.403	0.6111	0	0.663	0
17	0.403	0.6111	0	0.663	1.0584
18	0.403	0.63	0	0.39	1.0584
19	0.4185	0.5922	0	0.195	1.0584
20	0.4185	0.6111	0	0.195	1.0584
21	0.434	0.6111	0.1815	0.585	1.0584
22	0.4495	0.5796	0.1815	0.663	1.0584
23	0.4185	0.5796	0.1815	0.663	1.0584
24	0.434	0.1575	0.3025	0.663	0.315
25	0.434	0	0.3025	0.663	0.063
26	0.4495	0	0.363	0.663	0.0378
27	0.4495	0	0.4235	0.663	0.0252
28	0.465	0	0.484	0.663	0.0126
29	0.465	0.0315	0.484	0.663	0.0126
30	0.465	0.4725	0.484	0.663	0
Total Wetted Acres	**7.63**	**6.4449**	**3.388**	**9.477**	**7.875**

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	0.465	0.6111	0.484	0.39	0.063
2	0.465	0.6111	0.484	0	1.0584
3	0.465	0.6111	0.605	0	1.0584
4	0.465	0.6111	0.605	0.039	1.0584
5	0.465	0.5796	0.605	0.195	1.0584
6	0.465	0.5796	0.605	0.195	1.0584
7	0.465	0.5796	1.0285	0.195	1.0584
8	0.465	0.5796	1.0285	0.195	1.0584
9	0.465	0.6111	1.0648	0.195	1.0584
10	0.465	0.6111	1.1374	0.195	0.063
11	0.465	0.5922	1.1374	0.195	0.063
12	0.465	0.5796	1.0285	0.195	0.315
13	0.465	0.5922	1.0285	0.195	1.0584
14	0.465	0.5922	1.089	0.39	1.0584
15	0.465	0.5922	1.1374	0.585	1.0584
16	0.465	0.6111	1.1737	0.663	1.0584
17	0.465	0.63	1.1495	0.663	1.0584
18	0.465	0.63	1.1495	0.663	1.0584
19	0.465	0.63	1.1374	0.663	1.0584
20	0.465	0.63	1.1374	0.663	1.0584
21	0.465	0.5922	1.1374	0.663	1.0584
22	0.465	0.5796	1.1374	0.663	1.0584
23	0.465	0.4725	1.1374	0.663	1.0584
24	0.465	0.315	1.1374	0.663	1.0584
25	0.465	0.315	1.1374	0.39	1.0584
26	0.465	0.315	1.1374	0.39	1.0584
27	0.465	0.315	1.1374	0.351	1.0584
28	0.465	0.2835	1.1374	0.351	1.0584
29	0.465	0.2835	1.089	0.351	1.0584
30	0.465	0.4725	0.5445	0.312	1.0584
31	0.465	0.63	0.484	0.663	0.63
Total Wetted Acres	**14.415**	**16.6383**	**30.0322**	**11.934**	**28.6524**

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

USF DAILY WETTED ACREAGES

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0007

Year: 2010

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	0.465	0.5796	0.484	0.6396	0.378
2	0.465	0.63	0.484	0.6396	0.252
3	0.465	0.6111	0.4235	0.6396	0.312
4	0.465	0.5922	0.363	0.6396	1.0332
5	0.465	0.63	0.3025	0.6396	1.0332
6	0.465	0.6111	0.242	0.6396	1.0332
7	0.465	0.5796	0.1815	0.6396	1.0332
8	0.465	0.63	0.121	0.6396	1.0332
9	0.465	0.6111	0.605	0.585	1.0332
10	0.465	0.5922	1.0648	0.39	1.0332
11	0.465	0.6111	1.1374	0.39	1.0332
12	0.465	0.63	1.1374	0.312	1.0332
13	0.465	0.6111	1.1374	0.312	0.504
14	0.465	0.5922	1.1374	0.273	0.504
15	0.465	0.6111	1.1374	0.273	0.441
16	0.465	0.63	1.1374	0.312	0.504
17	0.465	0.6111	1.1374	0.39	1.0332
18	0.465	0.5922	1.1374	0.6396	1.0332
19	0.434	0.5796	1.1132	0.6396	1.0332
20	0.403	0.4725	1.0285	0.6396	1.0332
21	0.403	0.4725	0.484	0.6396	1.0332
22	0.403	0.315	0.484	0.585	1.0332
23	0.465	0.315	0.484	0.39	1.0332
24	0.465	0.315	1.0648	0.39	1.0332
25	0.465	0.252	1.1374	0.6396	1.0332
26	0.465	0.252	1.1374	0.6396	1.0332
27	0.465	0.252	1.1374	0.6396	1.0332
28	0.465	0.2205	1.1374	0.6396	1.0332
29	0.465	0.2205	1.1374	0.6396	1.0332
30	0.465	0.189	1.1374	0.6396	1.0332
Total Wetted Acres	**13.733**	**14.8113**	**24.8534**	**16.1148**	**26.6586**

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	0.465	0.189	1.1374	0.6396	1.0332
2	0.465	0.1575	1.1374	0.6396	1.0332
3	0.465	0.126	1.1374	0.6396	1.0332
4	0.465	0.0945	1.1374	0.39	1.0332
5	0.465	0.0063	1.1374	0.39	1.0332
6	0.465	0.5796	1.1374	0.351	1.0332
7	0.465	0.63	1.1374	0.351	1.0332
8	0.465	0.5922	1.1374	0.312	1.0332
9	0.465	0.63	1.1374	0.312	1.0332
10	0.465	0.6111	1.1374	0.39	1.0332
11	0.465	0.5922	1.1374	0.39	1.0332
12	0.465	0.6111	1.1374	0.39	1.0332
13	0.465	0.63	1.1374	0.39	1.0332
14	0.465	0.6111	1.1374	0.312	1.0332
15	0.465	0.5796	1.1374	0.6396	1.0332
16	0.465	0.63	1.1374	0.6396	1.0332
17	0.465	0.63	1.1374	0.6396	1.0332
18	0.465	0.63	1.1374	0.6396	1.0332
19	0.465	0.63	1.1374	0.6396	0.63
20	0.465	0.6111	1.1132	0.6396	0.504
21	0.465	0.5796	1.1374	0.6396	1.0332
22	0.465	0.63	1.1374	0.6396	1.0332
23	0.465	0.63	1.1374	0.585	1.0332
24	0.465	0.6111	1.1374	0.312	1.0332
25	0.465	0.5922	1.1374	0.312	1.0332
26	0.465	0.5922	1.1374	0.273	1.0332
27	0.465	0.63	1.1374	0.273	1.0332
28	0.465	0.63	1.1374	0.234	1.0332
29	0.465	0.6111	1.1374	0.234	1.0332
30	0.465	0.6111	1.1374	0.195	1.0332
31	0.465	0.5922	1.1374	0.39	1.0332
Total Wetted Acres	**14.415**	**16.4808**	**35.2352**	**13.8216**	**31.0968**

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

APPENDIX D

Evapotranspiration Calculations & AZMET Method Description

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2010

	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	0.4596	0.11	0.004213	0	0.16	0	**0**	0.11	0
2	0.2646	0.12	0.002646	0	0.15	0	**0**	0.14	0
3	0.2646	0.13	0.0028665	0	0.17	0	**0**	0.16	0
4	0.2646	0.12	0.002646	0	0.24	0	**0**	0.17	0
5	0.2646	0.13	0.0028665	0	0.26	0	**0**	0.16	0
6	0.2646	0.1	0.002205	0	0.16	0	**0**	0.19	0
7	0.2646	0.11	0.0024255	0	0.16	0	**0**	0.07	0
8	0.2646	0.12	0.002646	0	0.07	0	**0**	0.02	0
9	0.372	0.13	0.00403	0	0.11	0	**0**	0.11	0
10	0.3354	0.09	0.0025155	0	0.09	0	**0**	0.14	0
11	0.4344	0.14	0.005068	0	0.12	0	**0**	0.13	0
12	0.4128	0.16	0.005504	0	0.14	0	**0**	0.15	0
13	0.2646	0.12	0.002646	0	0.13	0	**0**	0.17	0
14	0.2394	0.11	0.0021945	0	0.13	0	**0**	0.17	0
15	0.2268	0.12	0.002268	0	0.07	0	**0**	0.18	0
16	0.2394	0.12	0.002394	0	0.2	0	**0.031**	0.2	0.000516667
17	0.2394	0.09	0.0017955	0	0.06	0	**0.062**	0.23	0.001188333
18	0.2394	0.08	0.001596	0	0.14	0	**0.0465**	0.26	0.0010075
19	0.2394	0.15	0.0029925	0	0.16	0	**0.1444**	0.17	0.002045667
20	0.2646	0.12	0.002646	0	0.18	0	**0.2646**	0.24	0.005292
21	0.2646	0.13	0.0028665	0	0.18	0	**0.2646**	0.2	0.00441
22	0.2394	0.08	0.001596	0	0.15	0	**0.3972**	0.23	0.007613
23	0.1638	0.08	0.001092	0	0.18	0	**0.4596**	0.05	0.001915
24	0	0.09	0	0	0.19	0	**0.4596**	0.18	0.006894
25	0	0.09	0	0	0.22	0	**0.4596**	0.22	0.008426
26	0	0.09	0	0	0.22	0	**0.4596**	0.24	0.009192
27	0	0.05	0	0	0.2	0	**0.4596**	0.22	0.008426
28	0	0	0	0	0.22	0	**0.4362**	0.24	0.008724
29	0	0.09	0			0	0.2956	0.24	0.005912
30	0	0.07	0				**0.3266**	0.3	0.008165
31	0	0.1	0				**0.3324**	0.35	0.009695
Monthly Evapo-transpiration			**0.063719**			**0**			**0.089422167**

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2010

Date	April			May			June		
	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)	Wetted Vegetated Area (acres)	Daily AZMET ETo (inches)	Daily Evapo-Transpiration (acre-feet)
1	0.2835	0.15	0.00354375	0.1326	0.31	0.0034255	0.0896	0.39	0.002912
2	0.4785	0.2	0.007975	0	0.35	0	0.0896	0.36	0.002688
3	0.5095	0.25	0.010614583	0	0.3	0	0.0741	0.35	0.00216125
4	0.4839	0.26	0.0104845	0	0.33	0	0.2536	0.36	0.007608
5	0.3203	0.33	0.00880825	0.3014	0.44	0.011051333	0.2691	0.37	0.00829725
6	0.392	0.24	0.00784	0.2646	0.41	0.0090405	0.2846	0.38	0.009012333
7	0.33	0.26	0.00715	0.2394	0.36	0.007182	0.2846	0.39	0.0092495
8	0.2835	0.28	0.006615	0.1638	0.34	0.004641	0.3001	0.38	0.009503167
9	0.2835	0.29	0.00685125	0.1085	0.44	0.003978333	0.2922	0.38	0.009253
10	0.2835	0.31	0.00732375	0.155	0.35	0.004520833	0.2532	0.41	0.008651
11	0.3455	0.31	0.008925417	0.062	0.39	0.002015	0.1361	0.48	0.005444
12	0.4075	0.36	0.012225	0.3594	0.3	0.008985	0.1206	0.38	0.003819
13	0.4133	0.25	0.008610417	0.4596	0.33	0.012639	0.1051	0.35	0.003065417
14	0.3377	0.28	0.007879667	0.4596	0.34	0.013022	0.0896	0.36	0.002688
15	0.2873	0.28	0.006703667	0.4596	0.33	0.012639	0.0741	0.39	0.00240825
16	0.1739	0.15	0.00217375	0.4362	0.38	0.013813	0.0586	0.42	0.002051
17	0.1739	0.27	0.00391275	0.4596	0.4	0.01532	0.0431	0.39	0.00140075
18	0.1739	0.25	0.003622917	0.4596	0.34	0.013022	0.0121	0.43	0.000433583
19	0.1739	0.17	0.002463583	0.4596	0.33	0.012639	0.1638	0.39	0.0053235
20	0.093	0.24	0.00186	0.5216	0.35	0.015213333	0	0.42	0
21	0.031	0.28	0.000723333	0.6146	0.42	0.021511	0	0.43	0
22	0	0.12	0	0.6146	0.42	0.021511	0	0.39	0
23	0.1326	0.14	0.001547	0.5739	0.46	0.0219995	0	0.4	0
24	0.1482	0.26	0.003211	0.4515	0.31	0.01166375	0	0.39	0
25	0.1716	0.3	0.00429	0.2374	0.33	0.0065285	0	0.41	0
26	0.195	0.31	0.0050375	0.093	0.36	0.00279	0	0.43	0
27	0.195	0.32	0.0052	0.093	0.37	0.0028675	0.2964	0.4	0.00988
28	0.195	0.39	0.0063375	0.0775	0.39	0.00251875	0.4551	0.43	0.01630775
29	0.195	0.31	0.0050375	0.093	0.35	0.0027125	0.4672	0.42	0.016352
30	0.2139	0.28	0.004991	0.0775	0.38	0.002454167	0.4672	0.42	0.016352
31				0.093	0.4	0.0031			
Monthly Evapo-transpiration			**0.171958083**			**0.2628035**			**0.15486075**

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2010

	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	0.4672	0.38	0.014794667	0	0.29	0	0	0.28	0
2	0.3841	0.37	0.011843083	0	0.22	0	0	0.31	0
3	0.1759	0.43	0.006303083	0	0.3	0	0	0.34	0
4	0.0121	0.37	0.000373083	0	0.33	0	0	0.32	0
5	0.0121	0.35	0.000352917	0	0.34	0	0	0.3	0
6	0.0121	0.35	0.000352917	0	0.27	0	0	0.22	0
7	0.0121	0.35	0.000352917	0	0.27	0	0	0.23	0
8	0.0121	0.35	0.000352917	0	0.24	0	0	0.26	0
9	0	0.37	0	0	0.27	0	0	0.3	0
10	0	0.26	0	0	0.3	0	0	0.28	0
11	0.0189	0.35	0.00055125	0	0.29	0	0	0.29	0
12	0.0189	0.34	0.0005355	0	0.3	0	0	0.27	0
13	0.1827	0.33	0.00502425	0	0.31	0	0	0.28	0
14	0.2457	0.23	0.00470925	0	0.32	0	0.0186	0.29	0.0004495
15	0.2583	0.36	0.007749	0	0.31	0	0.0186	0.29	0.0004495
16	0.2515	0.17	0.003562917	0	0.17	0	0.1356	0.29	0.003277
17	0.1759	0.34	0.004983833	0	0.19	0	0.1122	0.31	0.0028985
18	0.0741	0.32	0.001976	0	0.29	0	0.1824	0.32	0.004864
19	0.1361	0.36	0.004083	0	0.31	0	0.2264	0.34	0.006414667
20	0.1361	0.33	0.00374275	0	0.31	0	0.2264	0.32	0.006037333
21	0.1361	0.25	0.002835417	0	0.19	0	0.2326	0.21	0.0040705
22	0.3111	0.2	0.005185	0	0.25	0	0.3262	0.11	0.002990167
23	0.2612	0.27	0.005877	0	0.27	0	0.1298	0.2	0.002163333
24	0.1946	0.31	0.005027167	0	0.24	0	0.1012	0.26	0.002192667
25	0.0586	0.31	0.001513833	0	0.37	0	0.1012	0.27	0.002277
26	0.093	0.26	0.002015	0	0.09	0	0.1324	0.33	0.003641
27	0.0896	0.17	0.001269333	0	0.23	0	0.1324	0.3	0.00331
28	0.1051	0.21	0.00183925	0	0.22	0	0.1401	0.25	0.00291875
29	0	0.16	0	0	0.28	0	0.1401	0.26	0.0030355
30	0	0.25	0	0	0.23	0	0.1631	0.3	0.0040775
31	0	0.14	0	0	0.25	0			
Monthly Evapo-transpiration			**0.097205333**			**0**			**0.055066917**

Evapotranspiration Calculations
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2010

	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	0.093	0.25	0.0019375	0.2334	0.18	0.003501	0.3909	0.13	0.00423475
2	0.062	0.23	0.001188333	0.2334	0.19	0.0036955	0.4191	0.16	0.005588
3	0.2103	0.25	0.00438125	0.2644	0.24	0.005288	0.388	0.14	0.004526667
4	0.2481	0.28	0.005789	0.4292	0.26	0.009299333	0.2734	0.15	0.0034175
5	0.2481	0.18	0.0037215	0.5222	0.22	0.009573667	0.223	0.14	0.002601667
6	0.3314	0.23	0.006351833	0.4833	0.21	0.00845775	0.1744	0.15	0.00218
7	0.2229	0.24	0.004458	0.4288	0.2	0.007146667	0.1996	0.14	0.002328667
8	0.1473	0.2	0.002455	0.3822	0.21	0.0066885	0.25	0.15	0.003125
9	0.0465	0.22	0.0008525	0.3336	0.16	0.004448	0.2655	0.15	0.00331875
10	0.0465	0.23	0.00089125	0.3054	0.17	0.0043265	0.3519	0.13	0.00381225
11	0.0465	0.24	0.00093	0.161	0.13	0.001744167	0.349	0.12	0.00349
12	0.0465	0.23	0.00089125	0.1668	0.14	0.001946	0.3432	0.12	0.003432
13	0.0969	0.29	0.00234175	0.093	0.16	0.00124	0.30445	0.15	0.003805625
14	0.2103	0.27	0.00473175	0.093	0.16	0.00124	0.3198	0.15	0.0039975
15	0.2229	0.21	0.00390075	0.093	0.16	0.00124	0.4426	0.11	0.004057167
16	0.2775	0.2	0.004625	0.0775	0.16	0.001033333	0.4224	0.05	0.00176
17	0.3183	0.22	0.0058355	0.3025	0.15	0.00378125	0.309	0.05	0.0012875
18	0.3651	0.21	0.00638925	0.3823	0.18	0.0057345	0.2993	0.08	0.001995333
19	0.3651	0.2	0.006085	0.3514	0.16	0.004685333	0.2175	0.09	0.00163125
20	0.3651	0.11	0.00334675	0.3234	0.22	0.005929	0.4036	0.06	0.002018
21	0.3651	0.09	0.00273825	0.2826	0.12	0.002826	0.3977	0.09	0.00298275
22	0.3651	0.13	0.00395525	0.2466	0.1	0.002055	0.3743	0.06	0.0018715
23	0.32605	0.12	0.0032605	0.1959	0.09	0.00146925	0.3663	0.07	0.00213675
24	0.31045	0.17	0.004398042	0.3519	0.12	0.003519	0.3818	0.15	0.0047725
25	0.2636	0.16	0.003514667	0.4442	0.12	0.004442	0.3411	0.11	0.00312675
26	0.2539	0.15	0.00317375	0.4523	0.13	0.004899917	0.3411	0.05	0.00142125
27	0.2539	0.17	0.003596917	0.4599	0.17	0.00651525	0.3663	0.08	0.002442
28	0.1434	0.24	0.002868	0.4288	0.1	0.003573333	0.3663	0.04	0.001221
29	0.093	0.25	0.0019375	0.4132	0.11	0.003787667	0.3663	0.05	0.00152625
30	0.093	0.22	0.001705	0.388	0.1	0.003233333	0.3897	0.04	0.001299
31	0.1476	0.17	0.002091						0
Monthly Evapo-transpiration			**0.104342042**			**0.12731925**			**0.085407375**

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).

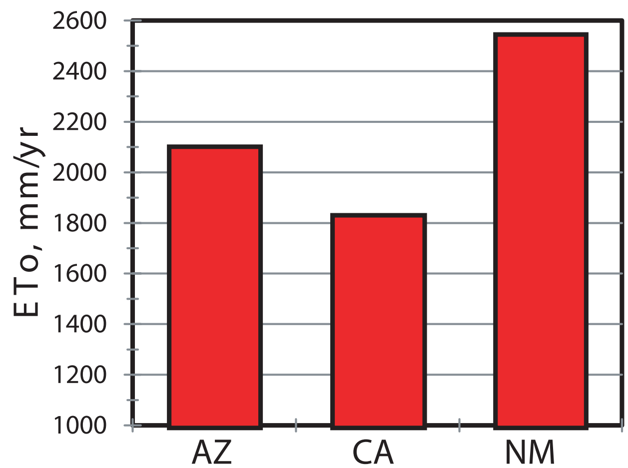


Figure 1. Reference ET (ETo) for Tucson for calendar year 1996 as computed using the published procedures for the public weather networks in Arizona, California, and New Mexico.

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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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 (ETos) procedure compare across months and locations.

Standardized Reference Evapotranspiration Definition

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

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

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

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

Standardized Reference ET Equation

Generalized Form of Standardized Equation

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

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

Where:

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

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

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 °C^{-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 (°C)

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 °C^{-1})

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

γ = psychrometer constant (kPa °C^{-1})

T = mean daily air temperature measured at 1.5 m above ground level (°C)

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

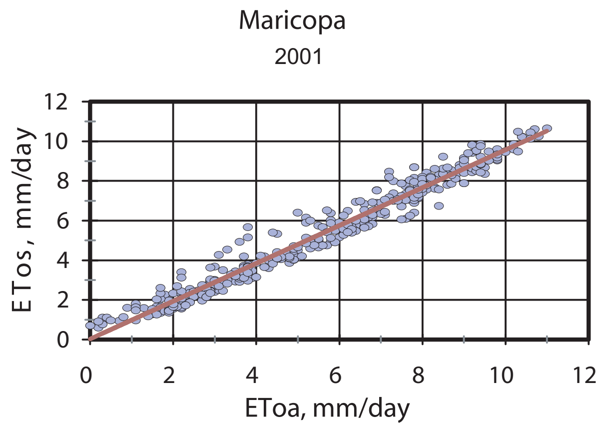


Figure 2. Reference evapotranspiration as computed using the ASCE standardized procedure (ETos) versus reference evapotranspiration computed using procedure employed by AZMET. The line represents the least squares regression line (ETos = 0.03 + 0.95 x ETos; r^2 = 0.96).

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

Data Required To Compute ETos

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

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

Comparison of Standardized Reference ET with Original AZMET ETo

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

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

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

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

$$\text{ETos} = \text{Ratio} * \text{ETox} \qquad (3)$$

Table 2. Mean monthly values of reference evapotranspiration for all AZMET station sites for the period 1998-2001 computed using the ASCE standardized (ETos) and original AZMET (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 ETo*a*. Monthly ratios provide the best means of converting short term data sets (e.g., daily, weekly or monthly totals of ETo*a*). *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 (ETo*a*). To obtain an estimate of turf water use in Tucson for May one would multiply the Kc (0.75) times the May ETo*a* value for Tucson (258.1 mm from Table 2):

$$ETc = Kc * ETo_a$$

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

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

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

$$ETc = Kc * ETo_s$$

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

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

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 ETo*a*, respectively; and **Ratio** is the ratio of ETos to ETo*a* 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 ETo*a* 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 ETo*a*. 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 ETo*a* are generally much less than 1.0.

References

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

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

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

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

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

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

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

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

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

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

Appendix

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

Δ: Slope of Saturation Vapor Pressure vs. Temperature Relationship

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

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

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

Rn: Net Radiation

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

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

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

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

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

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

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

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

The daily value of Rnl is computed using:

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

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

Clear sky solar radiation (Rso) is computed using:

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

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

Extraterrestrial radiation is computed from earth-sun geometry using:

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

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

The relative distance factor is computed using:

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

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

The solar declination angle is computed using:

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

The sunset angle is computed using:

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

γ: Psychrometer Constant

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

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

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

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

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

T: Mean Air Temperature

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

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

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

u_2:Wind Speed

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

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

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

e_s: Saturation Vapor Pressure

Saturation vapor pressure is computed using:

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

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

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

where Tex is either Tmax or Tmin (^oC) .

ea: Actual Vapor Pressure

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

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

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

APPENDIX E

Water Level Measurements

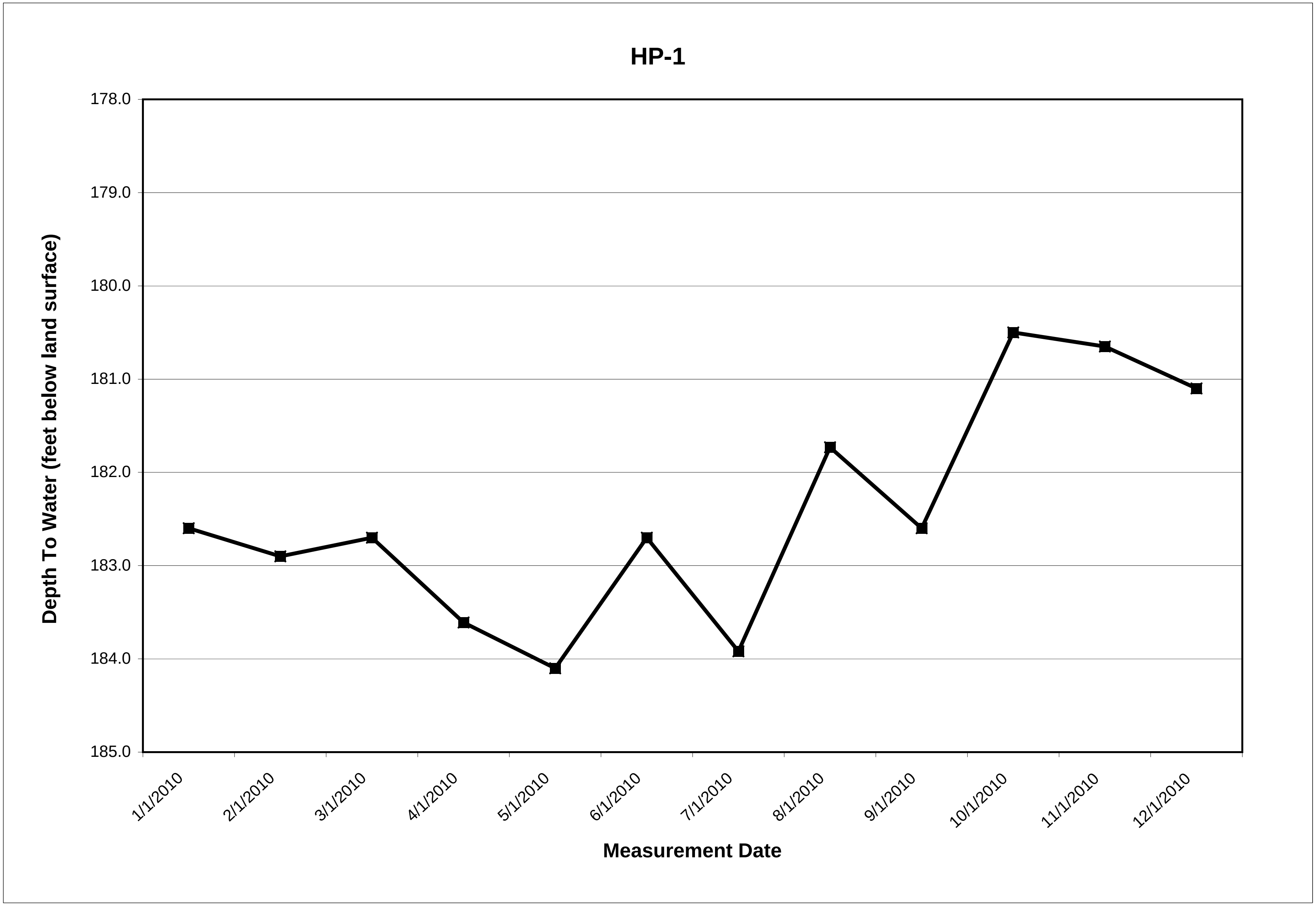
USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2010

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**
1/19/2010	182.6	182.6	1802.6	
2/16/2010	182.9	182.9	1802.3	
3/15/2010	182.7	182.7	1802.5	
4/14/2010	183.6	183.6	1801.6	
5/12/2010	184.1	184.1	1801.1	
6/11/2010	182.7	182.7	1802.5	
7/19/2010	183.9	183.9	1801.3	
8/10/2010	181.7	181.7	1803.4	
9/20/2010	182.6	182.6	1802.6	
10/26/2010	180.5	180.5	1804.7	
11/15/2010	180.7	180.7	1804.5	
12/13/2010	181.1	181.1	1804.1	

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

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

USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2010



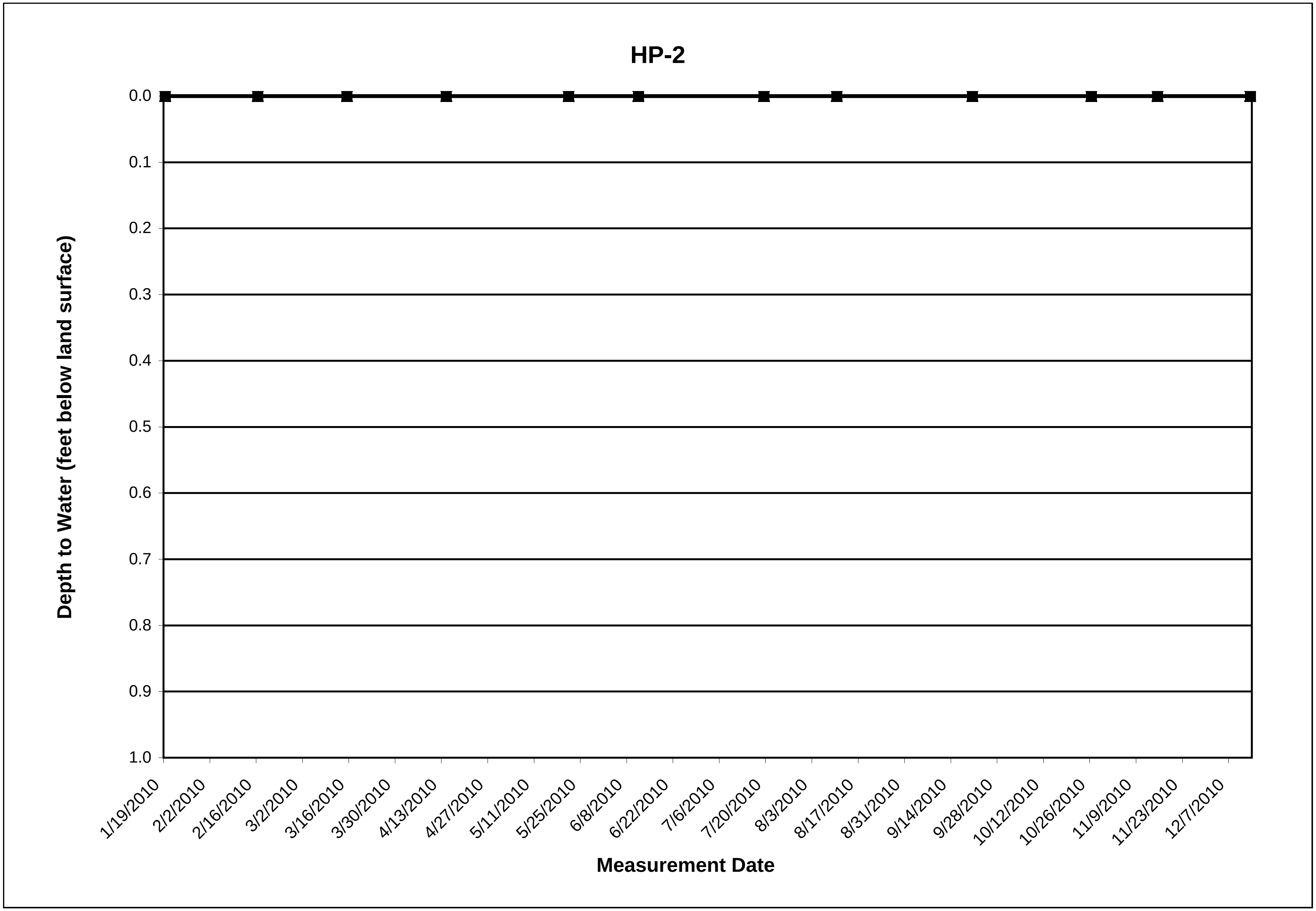
USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2010

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**
1/19/2010	dry			
2/16/2010	dry			
3/15/2010	dry			
4/14/2010	dry			
5/21/2010	dry			
6/11/2010	dry			
7/19/2010	dry			
8/10/2010	dry			
9/20/2010	dry			
10/26/2010	dry			
11/15/2010	dry			
12/13/2010	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: 2010



USF WATER LEVEL MEASUREMENTS
Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2010

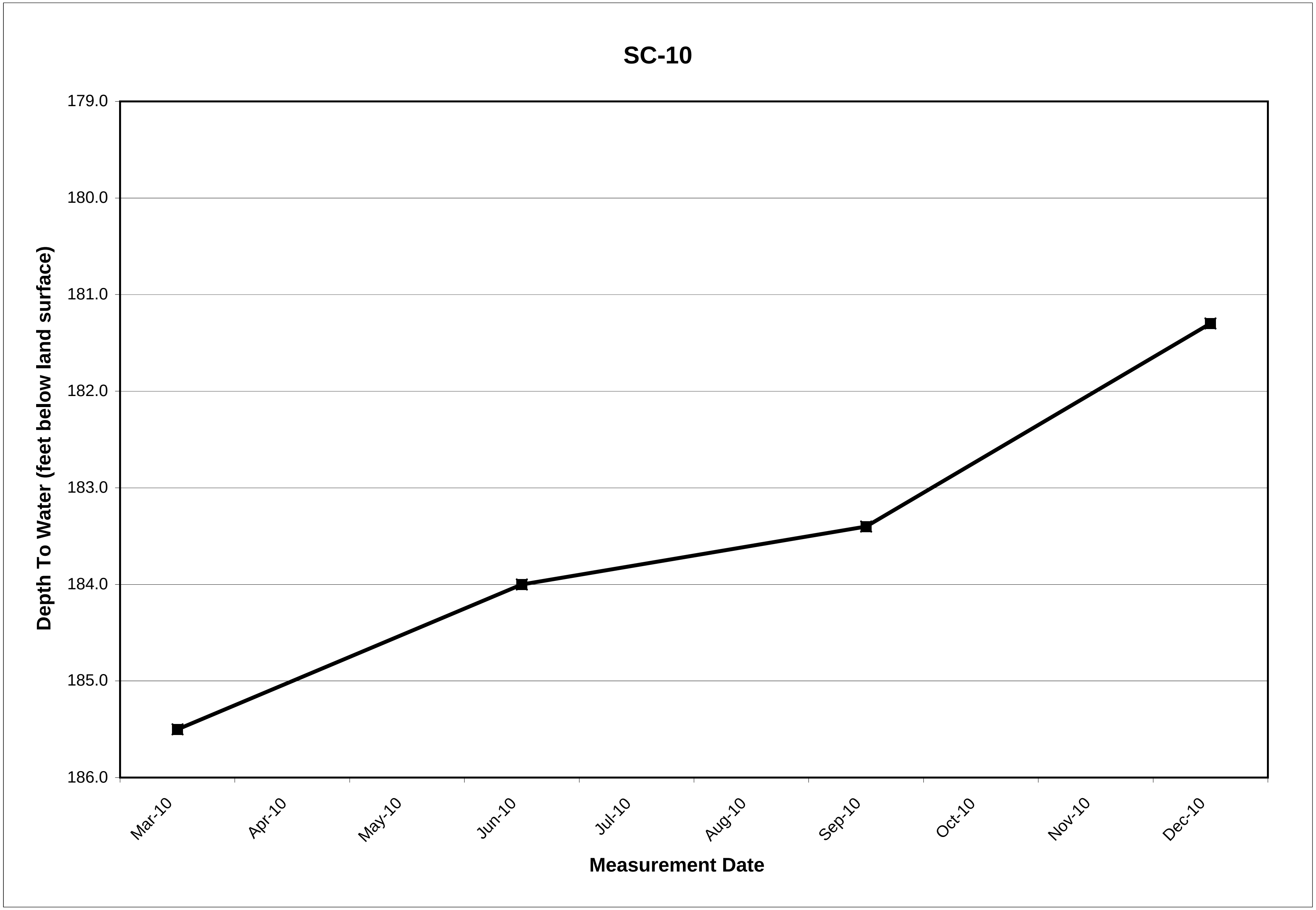
Monitor Point ID	SC-10
ADWR Registration Number	55-520129
Cadastral Location	D(11-11)33bcb
Measuring Point Elevation (feet amsl)	1978.36
Measuring Point Description	top of port
Measuring Point Height (ft)	
Land Surface Elevation at Wellhead (feet amsl)	1978.36
Permit Alert Level (feet bls)	30
Permit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

Measurement Date	**DTW (feet below MP)**	**DTW (feet bls)**	**Elevation (feet amsl)**	**Exceedance Status**
3/30/2010	185.5	185.5	1799.7	
6/11/2010	184.0	184.0	1801.2	
9/20/2010	183.4	183.4	1801.8	
12/13/2010	181.3	181.3	1803.9	

* 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: 2010



APPENDIX F

Infiltration Rate Data & Calculations

INFILTRATION RATE DATA AND CALCULATIONS

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0007

Year: 2010

	Net Recharge Volumes (ac-ft)	**Total Wetted Acreages** (ac-days)	**Infiltration Rate** (ft/day)	**Quarterly Average Infiltration Rate** (ft/day)
January	60.0	53.7	1.12	
February	0.0	0.0		
March	21.1	28.3	0.74	0.99
April	48.2	57.9	0.83	
May	55.1	99.7	0.55	
June	28.8	59.0	0.49	0.61
July	27.9	80.6	0.35	
August	0.0	0.0		
September	41.3	34.8	1.19	0.60
October	63.9	101.7	0.63	
November	34.2	96.2	0.36	
December	30.9	111.0	0.28	0.42
Totals	**411.5**	**722.9**	**0.57**	

CELL 1: INFILTRATION RATE DATA AND CALCULATIONS

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0007

Year: 2010

	Net Recharge Volumes (ac-ft)	Total Wetted Acreages (ac-days)	Infiltration Rate (ft/day)	Quarterly Average Infiltration Rate (ft/day)
January	9.4	7.2	1.31	
February	0.0	0.0		
March	2.6	3.1	0.84	1.17
April	8.0	13.8	0.58	
May	8.3	18.4	0.45	
June	4.1	4.9	0.84	0.55
July	5.6	12.4	0.45	
August	0.0	0.0		
September	7.4	6.4	1.15	0.69
October	10.0	16.6	0.60	
November	3.6	14.8	0.24	
December	3.2	16.5	0.19	0.35
Totals	**62.1**	**114.2**	**0.54**	

CELL 2: INFILTRATION RATE DATA AND CALCULATIONS

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0007

Year: 2010

	Net Recharge Volumes (ac-ft)	Total Wetted Acreages (ac-days)	Infiltration Rate (ft/day)	Quarterly Average Infiltration Rate (ft/day)
January	26.4	9.0	2.95	
February	0.0	0.0		
March	0.0	0.0		2.95
April	28.4	7.1	3.99	
May	35.3	33.0	1.07	
June	17.0	25.7	0.66	1.23
July	13.9	33.6	0.41	
August	0.0	0.0		
September	15.6	3.4	4.60	0.80
October	31.2	30.0	1.04	
November	18.1	24.9	0.73	
December	22.4	35.2	0.64	0.80
Totals	**208.4**	**201.8**	**1.03**	

CELL 3: INFILTRATION RATE DATA AND CALCULATIONS

Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2010

	Net Recharge Volumes (ac-ft)	Total Wetted Acreages (ac-days)	Infiltration Rate (ft/day)	Quarterly Average Infiltration Rate (ft/day)
January	6.5	4.8	1.37	
February	0.0	0.0		
March	7.1	6.2	1.13	1.24
April	5.0	10.3	0.48	
May	3.2	14.4	0.22	
June	4.0	10.6	0.38	0.35
July	3.3	7.4	0.45	
August	0.0	0.0		
September	10.8	10.4	1.04	0.79
October	8.0	12.8	0.62	
November	4.8	18.1	0.26	
December	2.1	15.1	0.14	0.32
Totals	**54.7**	**110.0**	**0.50**	

CELL 4: INFILTRATION RATE DATA AND CALCULATIONS

Marana High Plains Recharge Facility
USF Permit No. 71-563876.0007
Year: 2010

	Net Recharge Volumes (ac-ft)	Total Wetted Acreages (ac-days)	Infiltration Rate (ft/day)	Quarterly Average Infiltration Rate (ft/day)
January	14.5	28.9	0.50	
February	0.0	0.0		
March	7.2	16.2	0.45	0.48
April	2.8	19.0	0.15	
May	5.6	27.2	0.21	
June	3.6	7.5	0.48	0.22
July	4.5	16.2	0.28	
August	0.0	0.0		
September	5.0	8.9	0.56	0.38
October	11.1	32.5	0.34	
November	7.3	31.2	0.24	
December	3.5	36.0	0.10	0.22
Totals	**65.0**	**223.5**	**0.29**	

EQUALIZATION BASIN: INFILTRATION RATE DATA AND CALCULATIONS

Marana High Plains Recharge Facility

USF Permit No. 71-563876.0007

Year: 2010

	Net Recharge Volumes (ac-ft)	Total Wetted Acreages (ac-days)	Infiltration Rate (ft/day)	Quarterly Average Infiltration Rate (ft/day)
January	3.2	10.4	0.31	
February	0.0	0.0		
March	4.1	7.7	0.54	0.41
April	4.2	14.9	0.28	
May	2.7	15.3	0.18	
June	0.2	14.7	0.01	0.16
July	0.7	14.5	0.05	
August	0.0	0.0		
September	2.5	8.2	0.30	0.14
October	3.7	16.3	0.23	
November	0.4	16.5	0.02	
December	-0.2	18.2		0.08

Totals	**21.4**	**136.8**	**0.16**