THE IMPACT AND VALUE OF ACCURATE EVAPOTRANSPIRATION NETWORKS IN TEXAS HIGH PLAINS PRODUCTION AGRICULTURE


HIGHLIGHTS
- Irrigation scheduling using accurate ET network data can conserve energy and water.
- ET networks can be a valuable, cost effective, and feasible management tool in water policy.
- The Texas High Plains ET Network saved irrigated producers an estimated $US 22M dollars annually.
- ET network benefits and use extend beyond the agricultural sector.

ABSTRACT. Evapotranspiration (ET) networks have been developed and used to support weather and related ET information needs of U.S. agricultural production for nearly half a century, but many networks have been affected by inherent problems associated with sustaining operations. Consequently, these challenges have led to the discontinuation of network service in many cases. Most ET networks have been impacted by inadequate financial support compounded by inadequate public awareness and understanding of their usefulness and value in irrigation management, water conservation and water planning, and policy activities. Data accuracy is vital to usefulness, yet network data quality is often degraded when limited resources result in reduced equipment maintenance and data QA/QC. A discussion of ET network requirements and associated costs is presented. Estimates of the value and pumping reduction using the Texas High Plains ET networks are presented documenting the improvements of crop water use estimates and the impact associated with these improvements on irrigation groundwater withdrawal.

Keywords. ET network, Evapotranspiration network, Irrigation scheduling, Irrigation value, Water management tools, Water savings.

People plan their days and activities around weather conditions and schedule longer-term activities around expected weather. However, despite its importance in production agriculture, weather information has not been widely adopted and used in irrigation management decisions. This assertion is supported by the continuing low rate of adoption of weather-based irrigation scheduling or other science-based irrigation scheduling generally in the U.S. (USDA-NASS, 2018). What is also concerning is that larger farms are the least likely to use advanced irrigation scheduling methods according to USDA-ERS data (2013). While progress has been made in the adoption of science-based scheduling, it is far from the anticipated rate of adoption given the advances in technologies and tools. Furthermore, the soil moisture “feel” method (USDA-NRCS, 2001) ranked highest in all states although some more advanced methods (e.g., soil sensing and ET-based) had modest usage in California, Nebraska, and Washington. It can be noted that in many states, crop consulting services (commercial or government supported) played a large role in the scheduling methods used, which might encapsulate a portion of soil sensing and ET-based methodologies.

IRRIGATION SCHEDULING

The first statewide effort in Texas to quantify crop water use for irrigation scheduling was reported by the Texas Board of Water Engineers (TBWE, 1960). These estimated values were targeted mainly for use with surface irrigation methods. Crop water use values published in the TBWE report were for average monthly and bi-weekly planting periods and adjusted for various topographical and latitude
regions of the state. Other TBWE crop data values were acquired from parts of Texas, California, and Arizona, and some values were estimated based on other crops.

More accurate and timely crop water use estimates were needed as adoption and application capacities of center pivot systems developed. In the Texas High Plains (THP), that need was addressed with the development and operation of the large weighing lysimeter program initiated by Terry Howell and Jean Steiner, USDA-ARS, Bushland, Texas, in the 1980s and continues today (Marek et al., 1988; Howell et al., 1995, 2004, 2006; Evett et al., 2016). The research effort has led to the acquisition of accurate crop water use data and is a tribute to the programmatic vision and ET research team commitment to excellence in field-based crop water use research.

In earlier times, instrumentation and telecommunication issues with sensors were appreciable hurdles to technology adoption, and thus data acquisition and transmission were deemed not feasible or profitable in farm operations. Today, those limitations have largely been overcome. Communication by wireless radio, cellular service and satellite are now readily available. By the early 1980s, reliable digital data loggers with improved instruments together with telecommunication to personal computers became available and affordable for remote access. Furthermore, communication capabilities became more advanced with electronic dissemination capabilities (e.g., fax, cellular phone and internet) aided by the users’ increased familiarity with the technologies and use of personal computers. Within the Texas High Plains ET Network (TXHPET) service area, it was estimated that over 20 million pages of irrigation data were disseminated via fax and/or electronically to producers, crop consultants and other users during the network’s period of operation (Porter et al., 2007). Overall, broader Extension training and demonstrations, higher education training, and commercial availability of better instrumentation at lower cost helped advance the use of irrigation scheduling in production agriculture. Yet, these tools have not been widely integrated into individual farm management operations. One reason is the discounted recognition and assessment of the required management and time associated with the implementation, management, and use of the data. Part, if not much, of the disassociation stems from the emphasis on sales and marketing of products and tools, rather than return on end-users’ investments from new technology and management additions. This has been particularly true in the last two decades where “smart” devices and better electronics have been developed. Nonetheless, despite new and precision technologies development, adoption is lagging, and profitability concerns are yet to be addressed.

Economic considerations in a producer’s decision to adopt technology include management and maintenance costs, which are often unknown and vary with their operation and technical capability. Additionally, many non-agriculture industries do not understand or relate well to agricultural operations and see agriculture only as a new potential market. Also, commercial sales personnel generally do not have an adequate understanding of the management and time demands of most irrigated producers, particularly with larger farm operations. The same can be stated for some researchers, scientists, and extension personnel. Furthermore, it should be noted that producers are in the irrigated production business to earn a profit. Water conservation is often an ancillary interest, viewed primarily as an added benefit. Disregarding management costs and ignoring potential additional profit are major reasons why irrigation scheduling has not been widely adopted over the last 50 years. Water conservation districts are now more aware of the necessity of having accurate crop water use information as well as State and Federal agencies that often cost-share new irrigation technology purchases.

DEVELOPMENT AND OPERATION OF EVAPOTRANSPIRATION NETWORKS

In the U.S. there have been numerous ET networks established over time where at least one of their objectives was to address improved irrigation scheduling (table 1). While each network generally has catalogued data, NOAA NWS (National Weather Service) data are of limited usefulness in accurate reference evapotranspiration (ETo) calculations (Allen et al., 2005). NWS locations are generally sited for non-agricultural purposes and/or do not include all the needed parameters for ET calculations with NOAA’s longer-term data records involving airport sites (Marek et al., 2010; Nielson-Gammon, 2017).

In Texas, there have been several ET networks established over time (table 2). Generally, all the networks were centrally operated from a university, and most are no longer in operation or accessible.

Since the computation of reference ET (ETo) is from meteorological data, an assessment was conducted of the stations providing some degree of meteorological data in Texas (Marek et al., 2010). The scope/extent of available stations in Texas is shown in figure 1.

Table 1. Major U.S. ET networks.

<table>
<thead>
<tr>
<th>U.S. ET Network</th>
<th>Location</th>
<th>Years of Operation</th>
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</thead>
<tbody>
<tr>
<td>California Irrigation Management Information System (CIMIS, 1982)</td>
<td>California, Davis</td>
<td>1982-present</td>
</tr>
<tr>
<td>The Arizona Meteorological Network (AZMET, 2020)</td>
<td>Arizona, Tucson</td>
<td>1986-present</td>
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<tr>
<td>High Plains Regional Climate Center (HPRCC, 2020);</td>
<td>Nebraska, Lincoln</td>
<td>1987-present</td>
</tr>
<tr>
<td>New Mexico State University Climate Center (NMUCC, 2020)</td>
<td>New Mexico, Las Cruces</td>
<td>1983-present</td>
</tr>
<tr>
<td>Colorado Agricultural Meteorological Network (CoAgMet, 1992)</td>
<td>Colorado, Fort Collins</td>
<td>1992-present</td>
</tr>
<tr>
<td>North Dakota Agricultural Weather Network (NAWN, 2020)</td>
<td>North Dakota, Fargo</td>
<td>1989-present</td>
</tr>
<tr>
<td>Kansas Mesonet (2020)</td>
<td>Kansas, Manhattan</td>
<td>1986-present</td>
</tr>
<tr>
<td>Oklahoma Mesonet (2020)</td>
<td>Oklahoma, Norman</td>
<td>1994-present</td>
</tr>
<tr>
<td>Missouri Agricultural Weather Station Network (AgEBB, 2020)</td>
<td>Missouri, Columbia</td>
<td>1992-present</td>
</tr>
<tr>
<td>Florida Automated Weather Network (FAWN, 2020)</td>
<td>Florida, Gainesville</td>
<td>~1997-present</td>
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While it would appear that the state of Texas is adequately covered with available weather stations, the assessment determined that the number and quality of weather parameters were generally lacking because sensor and support resources were limited, and networks lacked adequately trained support personnel. The standard for automated agricultural weather stations and data reporting can be found in the ASABE engineering practice standard EP501.1 (2015). The American Society of Civil Engineers (ASCE) Evapotranspiration Committee developed standardized and recommended methods to compute reference (ETo) for a short reference crop (cool-season grass at 0.11 m height) and a taller reference crop (alfalfa at 0.30 m) (Allen et al., 2005). Instrumentation and data parameters for agriculturally based ET networks can be found in Howell et al. (1984) and Marek et al. (1996). Marek et al. (2010) also reviewed the various methods of ETo computation and recommended the adoption of the ASCE Standardized Reference Evapotranspiration Equation method (Allen et al., 2005).

It should be obvious that few, if any, television and school network sites are acceptable for ETo calculations. It has been surmised that these stations are educational tools, and their data are not comparable to properly sited, instrumented and maintained agriculturally representative weather station networks (Marek et al., 2010).

### COST OF OPERATING AN EVAPOTRANSPIRATION NETWORK

The costs of operating an ET network vary according to the goals, instrumentation, support equipment, facilities, agency support, and coverage area. For the TXHPET network, a regional network representing over 90 counties with 18 weather stations, the nominal cost estimate was in the range of $US 250,000 annually. This value did not include management (principal investigator or manager salary) cost. It should be noted that network costs are not proportional. That is, essential items can be used across a flexible number of stations but are limited to a maximum number before additional equipment and technical staff are required. A maintenance route of all TXHPET sites required two service personnel nearly a week of effort and travel of nearly 3,200 km.

The largest portion of TXHPET costs (based on records from 20 years) was for technical personnel salary and fringe benefits. Sensor and electronic equipment replacement and upgrades, recalibration expenses, vehicles, trailers, mileage, data transmission charges, travel, repairs, fuel, office supplies, cell phone, and tool costs were included in the operational costs. In addition, data and internet server security, oversight, and maintenance added to the operational costs.

<table>
<thead>
<tr>
<th>ET Network</th>
<th>Location</th>
<th>Years of Operation</th>
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<tbody>
<tr>
<td>South Plains ET Network (SPET)</td>
<td>Lubbock</td>
<td>1998-2015</td>
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<tr>
<td>Precision Irrigators Network (PIN)</td>
<td>Uvalde</td>
<td>2006-2010</td>
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<tr>
<td>West Texas Network</td>
<td>San Angelo</td>
<td>2001-2010</td>
</tr>
<tr>
<td>Texas ET Weather</td>
<td>College Station</td>
<td>1994-present</td>
</tr>
<tr>
<td>Crop-Weather Program for South Texas (CWP)</td>
<td>Corpus Christi</td>
<td>2000-present</td>
</tr>
<tr>
<td>Rio Grande Ag Weather Network</td>
<td>Weslaco</td>
<td>2013-2017</td>
</tr>
<tr>
<td>West Texas Mesonet</td>
<td>Lubbock</td>
<td>2000-present</td>
</tr>
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</table>

Figure 1. Weather stations of all sources located within Texas (TAMUDCE, 2011).
Other ET network budgets will vary, particularly if they support multi-state acquisition and maintenance. Most data end users believe the data should be available free of charge, indicating the lack of awareness of real structural and maintenance costs.

**Water Savings Using ET Network Data in the Texas High Plains**

Water use has been dramatically reduced in the THP with the use of accurate crop water demand values and data-based irrigation scheduling. Producer records indicate that by using the TXHPET Network estimated daily crop ET (ETc), irrigators were able to reduce seasonal irrigation water use by a mean of 508 m$^3$ ha$^{-1}$ without an appreciable difference in crop yield. The reduction of pumping depended on the producers’ confidence in accurate and representative ET network data. Today, there is a nominal estimated annual pumping of 1.9 Gm$^3$ yr$^{-1}$ in the northern region of Texas (TWDB, 2016) and is based on average weather and rainfall conditions. Given that the additional 508 m$^3$ ha$^{-1}$ would have otherwise been pumped, the resulting potential reduced irrigation water pumping for the northern THP region is on the order of 277 Mm$^3$ yr$^{-1}$.

**Value of ET Networks**

The value of the TXHPET network can be assessed in part by estimating the energy cost savings used to pump irrigation water. Using a nominal value of $0.0875$ m$^3$ (regional cost of energy per volume pumped and based on mean well depth, pumping efficiency, etc. (Amosson et al., 2015), the energy cost for the pumping of 277 Mm$^3$ yr$^{-1}$ computes to $\$24.2$M. Summing that potential annual savings for the 22 years of TXHPET operation results in a total estimated savings of over $\$533$M. Considering the THP irrigated area of the Panhandle and Llano Estacado regions (Texas Regions A and O; TWDB, 2019), the annual pumping cost reduction has previously been estimated to be approximately $\$22$M; thus, not all producers adopted the ET based scheduling practice. Nonetheless, the TXHPET network value far exceeded the operational costs.

The use of ET networks and associated weather data are not limited to agricultural irrigation. Neilson-Gammon et al. (2017) indicated an estimated 20:1 return on network data investment. Fippins (2017) with the WaterMyYard program in Texas (17,000 subscribers) reported an annual water savings of over 6.74 km$^3$ yr$^{-1}$ primarily on lawns which represented a municipal water cost savings to users of $\$7.84$M. There have been other indirect uses of ET network data (crop insurance, environmental compliance, pesticide applications and drift claims, etc.) but their value has largely been ignored, discounted and/or not tabulated.

**Discussion**

The cost-to-benefit comparison is not to provide precise values but rather to indicate the relative net value that ET networks offer (return on investment), and hence that they are warranted in irrigation management practice. People generally pay attention to the weather and schedule their activities accordingly. Even more so, agricultural irrigators should make use of representatively available weather information, where available. However, unless the management costs are adequately assessed with a practice and the added value determined, adoption of irrigation scheduling methods will remain low.

ET Network operational costs are not insignificant, but when one considers the amount of funding that Texas and other states annually invest for water conservation efforts, the costs are justifiable. Unlike the federally based NOAA National Weather Service, ET networks generally are not supported directly through government funding sources, and many people believe that network activity should be supported by irrigators who benefit from the data. While the point is valid, ultimately the costs and benefits are of societal concern. It should be mentioned that the National Weather Service has had no responsibility to acquire and provide any agriculturally based service data.

In Texas, a study was recently undertaken to conduct the feasibility of a statewide ET network with the purpose to support agriculture and public safety (Nielsen-Gammon et al., 2017). The assessment advocated the establishment of a TexMesonet, and this is not without numerous challenges; only one of which is cost. Others include station equipment, equipment uniformity, sensors, data quality assurance/quality control (QA/QC), maintenance, and personnel support issues. Many of these same issues were also identified and discussed in an earlier report by Marek et al. (2010). Currently, the state has provided some support for the TexMesonet development through the TWDB (the state’s water agency) although its primary purpose was for flood prediction/mitigation and not water conservation. According to the Nielsen-Gammon report (Nielsen-Gammon et al., 2017), the statewide TexMesonet system startup costs were estimated to range from $\$25$M to $\$40$M and personnel needs were tabulated to be up to 7.5 FTE’s. Furthermore, while initial development plans have started, it has not been fully determined as to the entire operational and oversight structure of the system.

**Conclusion**

ET networks have been developed throughout the U.S. and Texas at times, and there are broad uses of accurate data. However, without adequate technical commitment and financial support, networks cannot be maintained long term and subsequently result in data quality decline. The greatest use of ET network data should be in accurate ETo and ETc daily computations for use in irrigation scheduling applications with advanced irrigation systems, as improved irrigation management is critical to full realization of their benefits. Future production demands with increasingly limited water resources will require advanced precision in irrigation management. As urban populations increase, the existing strain on limited water resources will also continue.
The USDA Agricultural Research Service, Kansas State University, USDA-ARS Ogallala Aquifer Program, other groundwater Water Conservation District Research Grant Program, the Water Development Board, the High Plains Underground Conservation districts and crop commodity groups. (The Ogallala Aquifer Program (OAP) is a consortium between the USDA Agricultural Research Service, Kansas State University, Texas A&M University, Texas Tech University and West Texas A&M University.) The authors also gratefully acknowledge the reviewers of this article.

REFERENCES