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Energy Use and Irrigation Scheduling for Efficient Water Use

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Specific Cooperative Agreement
Final Report
for completion of Texas AgriLife Contract No. 58-6209
submitted to
Dr. Terry Howell, P.E., D. WRE
Project ADODR
USDA ARS Bushland, Texas

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Texas Water Resources Institute
make every drop count

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September 15, 2010

Energy Use and Irrigation Scheduling for Efficient Water Use

Thomas Marek and Dana Porter

This final contract report documents research activities conducted under the reimbursable agreement between the USDA-ARS and the Texas Agricultural Experiment Station - College Station, TX. The parent project is **CRIS 6209-13000-010-04S "Water and Energy for Efficient Irrigation".** (The Texas Agricultural Experiment Station agency was renamed during the period of this effort to Texas AgriLife Research by statutory authority.)

Executive Summary

Texas High Plains Evapotranspiration (TXHPET) network personnel continued to operate and maintain the network of 15 to 18 weather stations to provide timely weather and evapotranspiration (ET) data in support of related research and extension projects. This network provided computational and dissemination services including a listserv email program to supply data to researchers on a daily basis. Approximately 1.7 million pages of ET and meteorological data were distributed by the TXHPET system over the duration of this agreement. The data were utilized in 21 refereed journal articles and 156 other publications and presentations, as well as in numerous other publications by other (non-related CRIS projects based at USDA-ARS Lubbock, Texas A&M University, West Texas A&M University, Texas Tech University, Texas AgriLife Research and Texas AgriLife Extension Service). The project also developed a research design for infrastructure expansion of the reference ET facility at Bushland for advanced aerodynamic studies. In addition, a new web based user profile using the TXHPET network data is under development to provide more integrated tools and greater benefit to users.

Objective

The objectives of this cooperative research project were to

1) Maintain and coordinate the North Plains ET (evapotranspiration) network of weather stations and associated facsimile, email, and internet information delivery,

2) Provide irrigation sprinkler system design and field support for installation for an expanded turf grass for a weather station at Bushland,

3) Provide cooperative regional evapotranspiration mapping research, and

4) Provide cooperative regional groundwater pumping mapping with GIS (geographic information systems).

Approach

The current North Plains ET (NPET) and the South Plains ET (SPET) networks (now jointly known as the Texas High Plains ET Network) consist of approximately 15 to 18 weather station sites and were maintained and the data achieved with quality control/assurance procedures and made available to facsimile subscribers, email, and via internet downloads. A 5 ac site adjoining the Bushland ARS evapotranspiration weather station is to be irrigated by sprinklers with turf grass for expansion of the existing fetch area. The network ET data will be used in regional energy balance models and integrated with GIS (geographic information systems) for estimating crop water use. Also, regional land use mapping integrated with GIS (geographic information systems) will be used to estimate groundwater pumping.

Performance Activity

Texas High Plains Evapotranspiration Network

The Texas North Plains and South Plains ET networks were effectively merged to establish the Texas High Plains ET (TXHPET) Network which was comprised (at one time) of up to 20 current and historical weather stations. In 2005, the new TXHPET website http://txhighplainset.tamu.edu was unveiled (see figure 1). It features user-friendly menu-driven data query capabilities, through which end-users can access daily or hourly meteorological or ET data from any combination of weather stations within the TXHPET Network, and for any period of record. This new website provides advanced, updated, standardized, precision irrigation scheduling data and associated meteorological data to irrigated producers daily. Data may be downloaded in text, table, stock graphic (see figure 2) and user-directed graphic formats, as well as in SI or English units. Alternative data formats (fax printout, hourly, cumulative daily) are available on the site to accommodate historic end-users needing these formats/files for inputs into other crop models. Educational materials and other information are also provided to assist

end users in a variety of data applications. The TXHPET website development team was awarded a Blue Ribbon Award in the 2006 American Society of Agricultural and Biological Engineers Educational Aids Competition. In addition to the web-based data access, the TXHPET development team established a user-directed subscription listserv through which data are delivered daily through e-mail. Subsequently, e-mail delivery of user-selected weather stations and formats has largely replaced fax subscriptions and has become the predominant means of dissemination, although some fax delivery is still maintained. Since 2005, an estimated 1.7 million pages of reference ET, crop ET, heat unit (growing degree day) and crop growth stage and other relevant data have been disseminated through the TXHPET website, listserv and fax delivery options.

The TXHPET network is currently comprised of 17 active weather stations located throughout the High Plains region of Texas (see figure 3). The primary purpose of this network is to collect and disseminate accurate and representative weather data to support research and remote sensing projects. An ancillary network purpose has been to aid producers in their agricultural production by providing a complete suite of data and tools for implementation of advanced water conservation and management applications developed through research. Typical meteorological measurements taken by the TXHPET Network from the stations include air temperature, relative humidity, wind speed and direction, solar radiation, precipitation, soil temperature at 2 and 6 inches, actual vapor pressure, vapor pressure deficit, standard deviation of wind direction, and barometric pressure (at selected sites). Readings are taken at 6 second intervals, and data recorded represent hourly average values, except for rainfall which has 15 minute output for intensity purposes.

Dramatic increases in usage corresponding to higher energy prices reflect the need and value of the TXHPET network system. A user profile for the TXHPET website is under development to create new decision support system tools to further assist users in their production decisions. This new user profile will also make the website even easier to use and with added features beneficial to growers, crop consultants, and researchers. The listserv website (see figure 4) was updated to allow easier changes to personal information, increased security, and added content to help users understand the differing file types (see figures 5 and 6) and to more easily navigate the site.

Essential to the TXHPET operations are data QA/QC, storage and security, as well as maintenance and upgrades of weather stations, sensors, computer and communications hardware and software. Funds of this project were used in part to cover associated costs and to support qualified, technical personnel responsible for these essential support activities. The total cost of

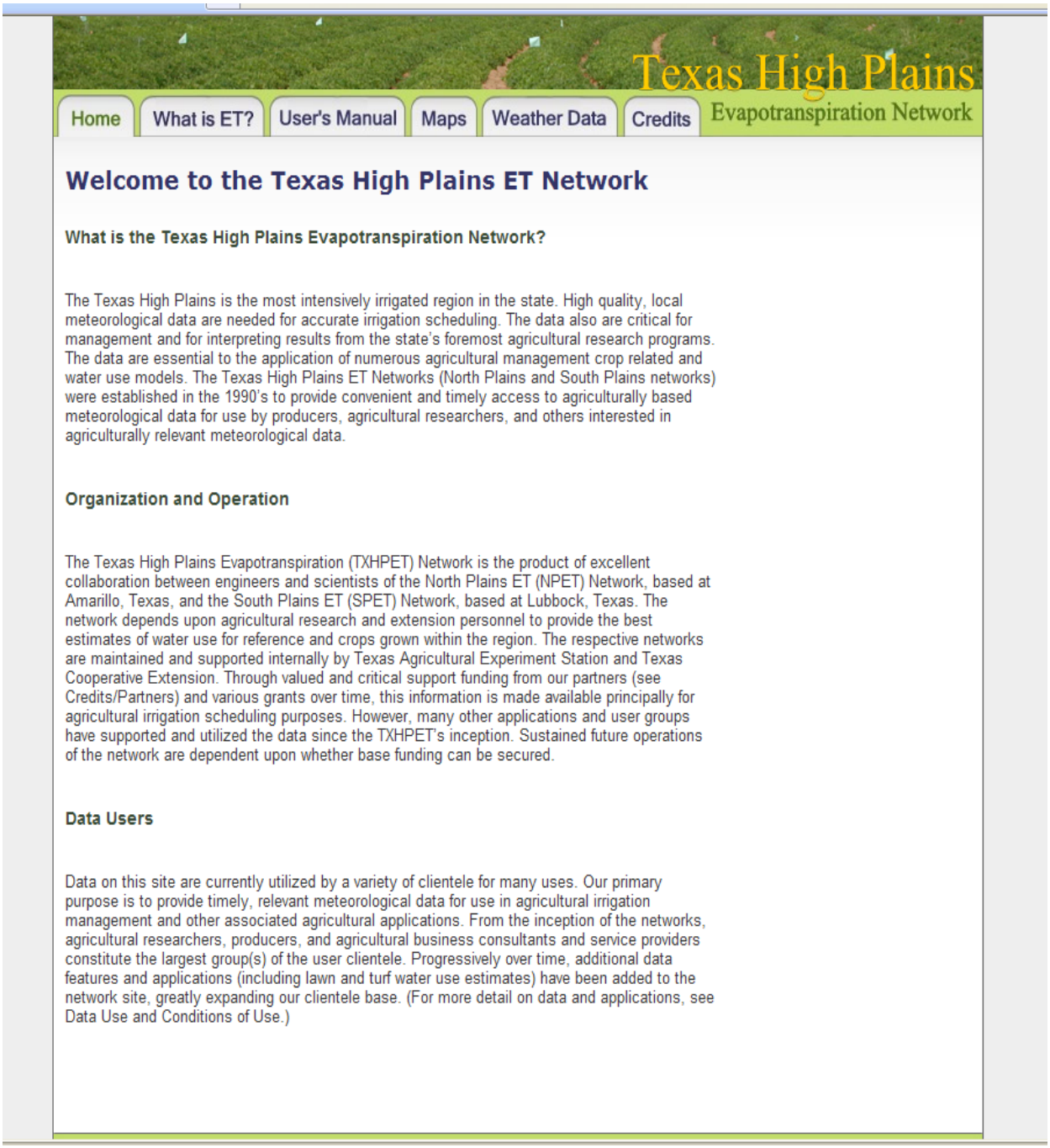

Figure 1. Home page of the TXHPET Network website.

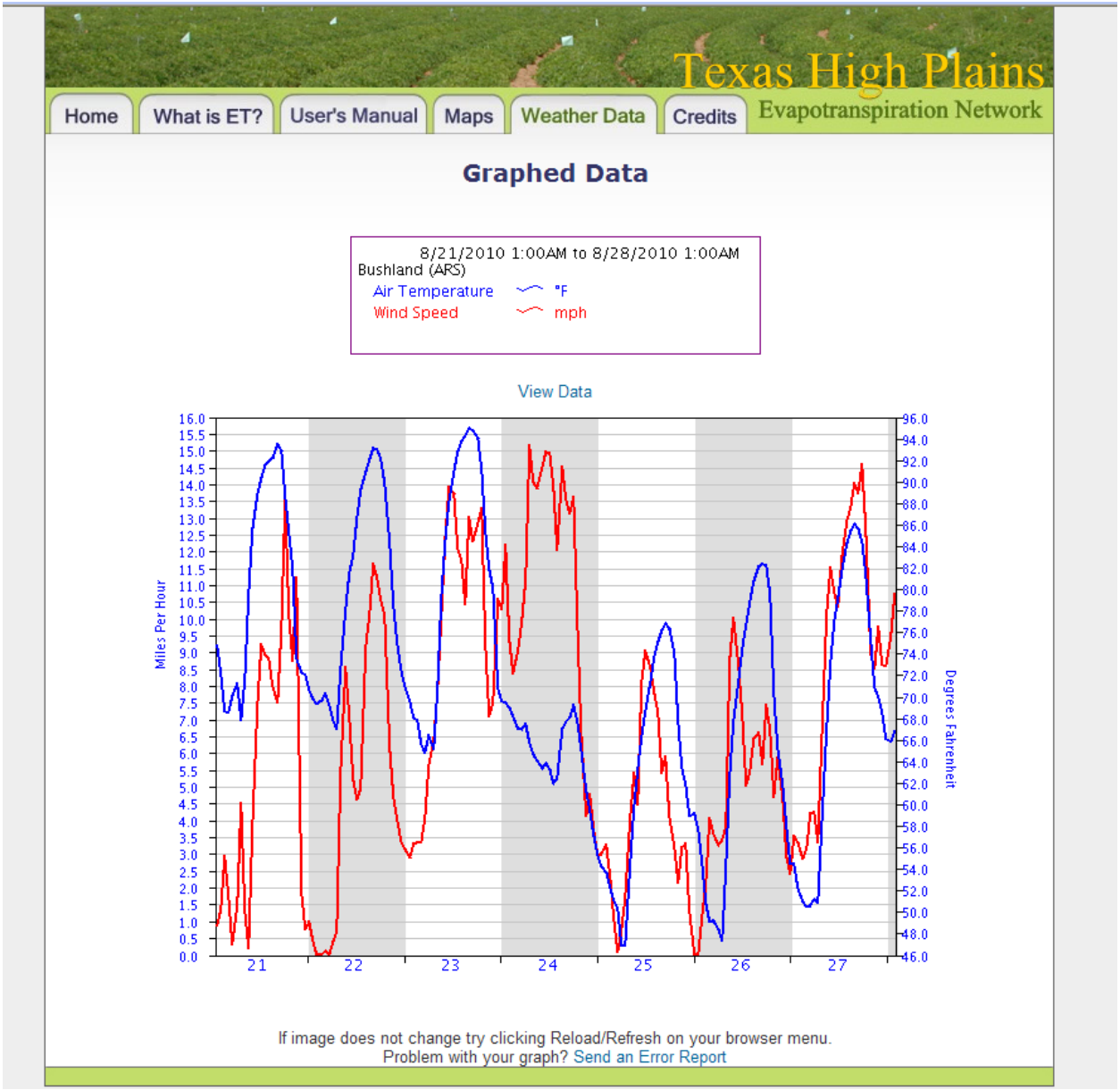

Figure 2. Example of graphical output from data of the TXHPET website.

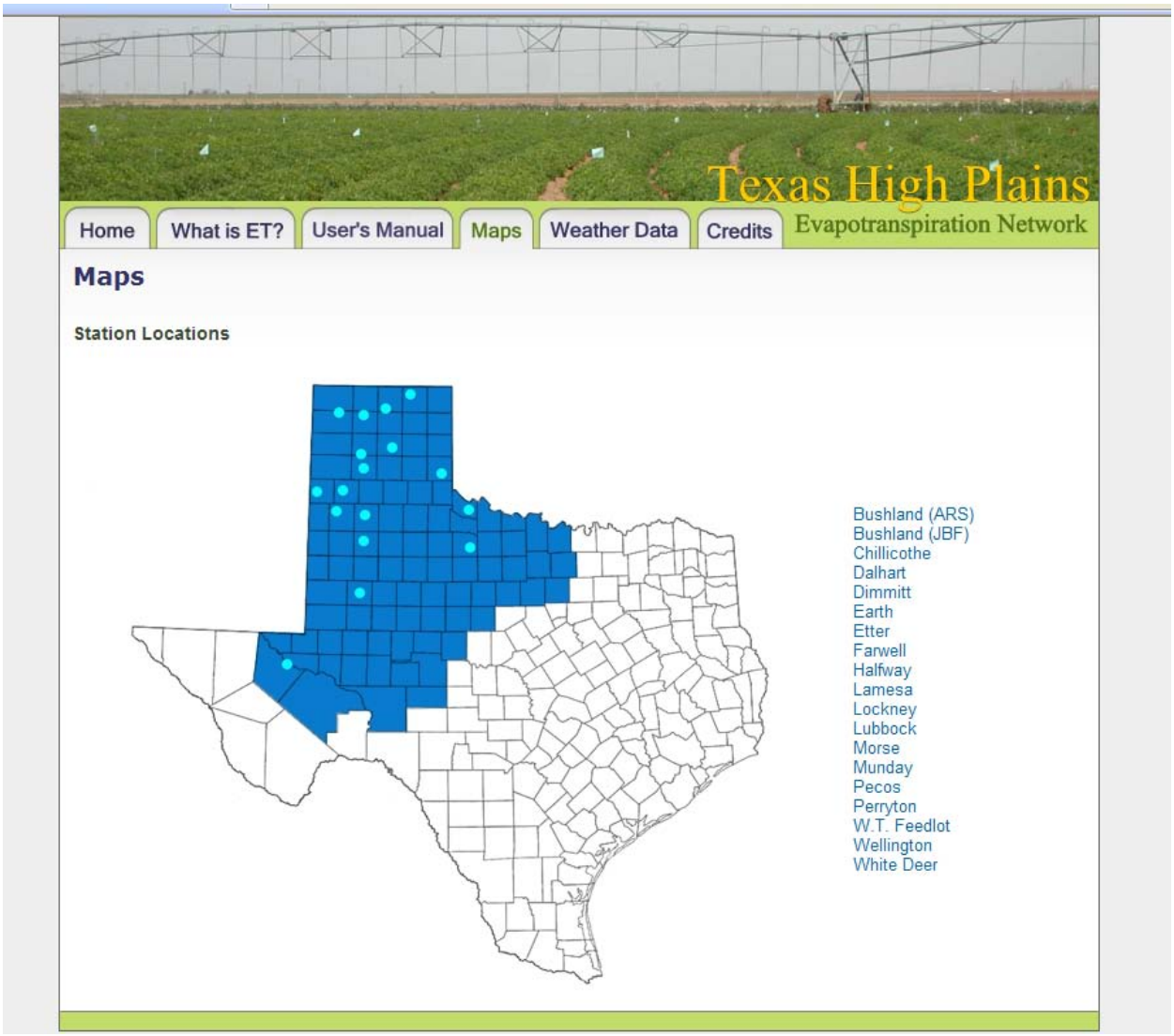

Figure 3. Location of the 17 weather stations within the TXHPET network.

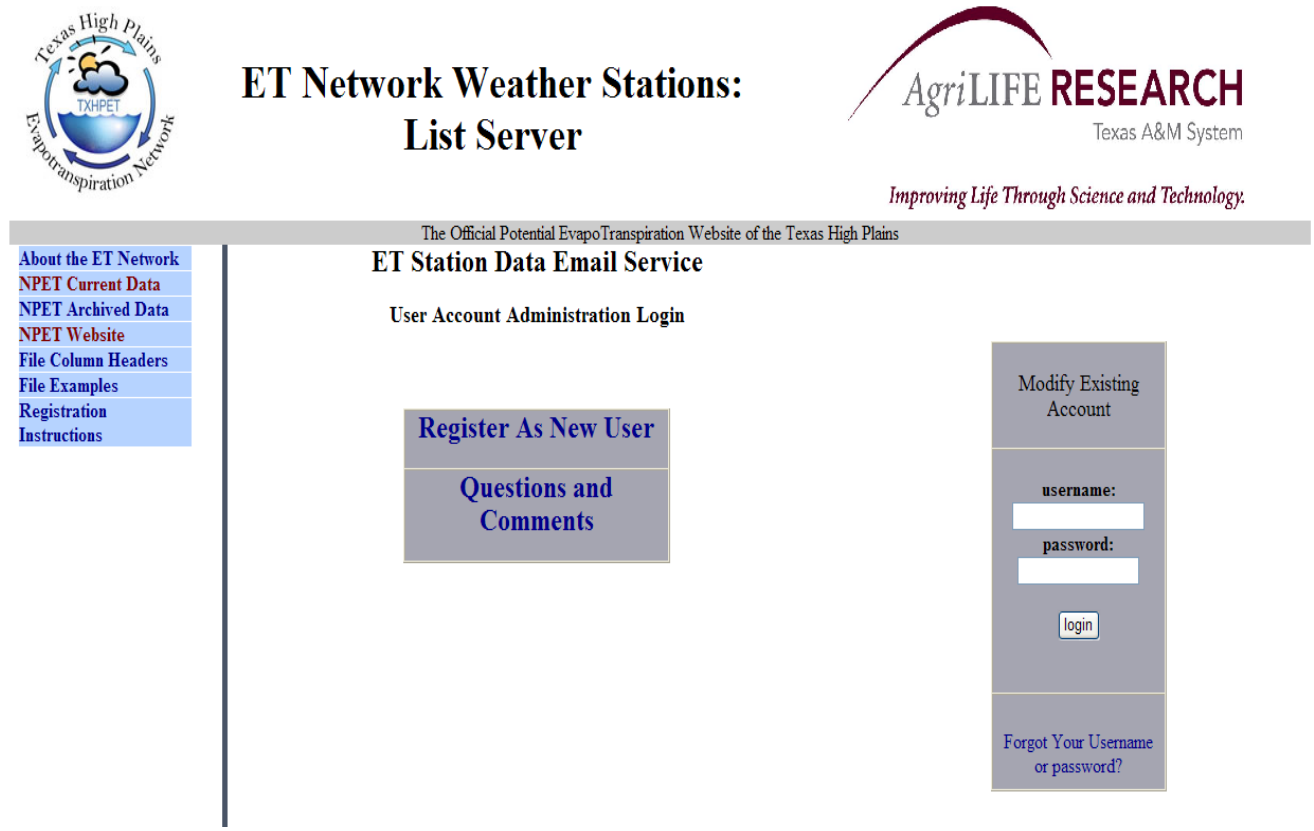

Figure 4. Homepage of the TXHPET listserv website.

North Plains ET Network Weather Station, Dimmitt, TX

Date	ETo	Temperatures (F) ---Air-- Max	Min	Soil Min 2in.	6in.	Prec. in.	Growing Degrees Days (F) Crn	Srg	Pnt	Cot	Soy	Wht
	in.											
06/13/05	.32	92	47	67	75	0.00	18	21	18	10	21	31
06/14/05	.24	83	54	69	76	0.00	18	18	14	8	22	34
06/15/05	.30	93	54	69	76	0.00	20	23	19	13	24	34
10-day avg min soil temp				70	75	Wind	8.3	mph from 181 deg.				

CORN Seed Date	Acc GDD	Short Season Var. Water Use Growth Stage	Day	3day	7day -----in/d-----	Seas. in.	Long Season Var. Water Use Growth Stage	Day	3day	7day -----in/d-----	Seas. in.
04/01	1068	10-leaf	.35	.33	.32	9.5	10-leaf	.35	.33	.32	9.5
04/15	926	8-leaf	.30	.29	.26	7.0	8-leaf	.30	.29	.26	7.0
05/01	758	6-leaf	.26	.24	.23	4.9	6-leaf	.26	.24	.23	4.9
05/15	599	4-leaf	.21	.20	.17	3.1	4-leaf	.21	.20	.17	3.1

SORGHUM Seed Date	Acc GDD	Short Season Var. Water Use Growth Stage	Day	3day	7day -----in/d----	Seas. in.	Long Season Var. Water Use Growth Stage	Day	3day	7day -----in/d----	Seas. in.
05/01	801	5-leaf	.21	.20	.20	5.1	4-leaf	.18	.17	.17	4.9
05/15	639	4-leaf	.18	.17	.16	3.5	4-leaf	.18	.17	.16	3.5
06/01	328	Emerged	.12	.11	.12	1.7	Emerged	.12	.11	.12	1.7
06/15	23	Seeded	.12	.09	.09	0.1	Seeded	.12	.10	.09	0.1

COTTON Seed Date	Acc GDD	North Plains Area Water Use Growth Stage	Day	3day	7day -----in/d----	Seas. in.	South Plains Area Water Use Growth Stage	Day	3day	7day -----in/d----	Seas. in.
05/01	349	Emerged	.15	.14	.14	3.4	Emerged	.15	.14	.14	3.4
05/15	316	Emerged	.15	.14	.14	2.8	Emerged	.15	.14	.14	2.8
06/01	174	Emerged	.15	.14	.11	1.1	Emerged	.15	.14	.11	1.1
06/15	13	Seeded	.04	.08	.10	0.0	Seeded	.04	.08	.10	0.0

WHEAT Seed Date	Acc GDD	Growth Stage	Water Use Day	3day	7day -----in/d----	Seas. in.
08/15	6406	Phy Mat	.06	.11	.14	28.7
09/10	5502	H Dough	.15	.14	.16	25.3
10/01	4803	H Dough	.15	.14	.16	24.0
10/15	4464	H Dough	.15	.14	.16	23.1

Fescue/Bluegrass lawn water use 0.30 inch
Bermuda grass lawn water use 0.22 inch
Buffalo grass lawn water use 0.15 inch

Figure 5. TXHPET listserv fax file data format.

Station:BUSHLAND (ARS),TX Long 102 deg 5 min Lat 35 deg 11 min
Date:09/22/10 Year/DOY:2010265 Elev: 1187 m Bar. Corr: 13.4
Sunrise 636 Sunset 1845 Daylight time = 12 hours 9 minutes

Time	Rs	Ts2	Ts6	Tair	TDew	RH	AVP	VPD	WSpd	Wdir	SDd	PREC	BP	ETos	Etrs
CST	W/m^2	C	C	C	C	%	kPa	kPa	m/s	deg	deg	mm	kPa	mm	mm
100	0.0	24.2	25.3	19.9	16.6	82	1.89	0.43	6.1	80	0	0.00	88.2	0.02	0.04
200	0.0	23.7	25.0	19.4	16.7	84	1.90	0.36	5.3	73	3	0.00	88.2	0.02	0.03
300	0.0	23.4	24.7	19.1	16.7	86	1.90	0.30	4.6	70	2	0.00	88.2	0.01	0.02
400	0.0	23.0	24.4	18.5	16.6	89	1.89	0.24	4.0	69	2	0.00	88.2	0.00	0.01
500	0.0	22.7	24.2	18.5	16.7	89	1.90	0.23	5.1	94	4	0.00	88.2	0.01	0.01
600	0.0	22.6	23.9	19.4	16.7	85	1.90	0.35	5.9	96	37	0.00	88.2	0.02	0.03
700	2.3	22.6	23.7	19.8	16.6	82	1.88	0.42	5.1	106	3	0.00	88.3	0.02	0.03
800	83.8	22.6	23.5	20.2	16.6	80	1.89	0.47	4.9	104	0	0.00	88.3	0.07	0.12
900	219.4	22.8	23.4	21.3	16.8	76	1.92	0.61	6.1	104	0	0.00	88.3	0.18	0.26
1000	199.4	23.5	23.3	22.2	16.7	71	1.90	0.77	6.5	104	0	0.00	88.4	0.22	0.31
1100	241.5	23.9	23.4	22.5	16.4	69	1.87	0.86	7.1	104	0	0.00	88.4	0.26	0.37
1200	301.7	24.4	23.5	22.8	16.6	68	1.89	0.88	7.0	104	0	0.00	88.3	0.29	0.40
1300	240.0	24.8	23.6	22.6	16.8	70	1.92	0.82	7.2	104	0	0.00	88.3	0.26	0.36
1400	371.3	24.9	23.8	22.4	17.4	73	1.98	0.72	7.6	83	9	0.00	88.2	0.30	0.40
1500	373.2	25.4	23.9	24.0	16.9	65	1.93	1.05	8.4	78	0	0.00	88.1	0.36	0.50
1600	261.8	25.7	24.0	23.6	17.1	67	1.95	0.96	9.3	68	12	0.00	88.1	0.30	0.44
1700	179.0	25.4	24.2	21.8	17.7	78	2.03	0.58	8.4	95	21	0.00	88.1	0.18	0.27
1800	71.3	24.6	24.2	22.4	16.7	70	1.91	0.80	9.1	309	59	0.00	88.1	0.18	0.29
1900	4.6	24.0	24.1	21.5	16.6	74	1.89	0.67	8.0	307	17	0.00	88.1	0.06	0.09
2000	0.0	23.6	23.9	21.3	16.5	74	1.88	0.66	6.9	301	16	0.00	88.1	0.05	0.08
2100	0.0	23.3	23.8	21.0	16.4	75	1.86	0.63	6.5	35	59	0.00	88.1	0.05	0.08
2200	0.0	22.9	23.6	19.8	16.9	83	1.92	0.39	4.9	98	16	0.00	88.1	0.03	0.04
2300	0.0	22.5	23.4	19.6	16.9	85	1.93	0.35	6.0	81	23	0.00	88.1	0.03	0.04
2400	0.0	22.1	23.2	19.1	17.0	88	1.94	0.28	7.7	303	29	0.25	88.1	0.02	0.04
Sum	9.2 MJ											0.25		2.92	4.27
Avg		23.7	23.9	20.9	16.8	78	1.91	0.58	6.6	82	52		88.2		
Max	1202.7	25.8	25.6	25.2	19.0	90	2.20	1.33	14.6				88.4		
Time	1436	1539	0	1438	1617	430	1617	1439	1533				953		
Min		21.9	23.0	18.1	16.0	58	1.82	0.20					88.0		
Time		2357	2354	419	2022	1439	2022	430					2354		

Precipitation by 15 minute periods
2345 0.25

Figure 6. TXHPET listserv PRT file data format.

network operations over the 5 year period exceeded the amount of this cooperative grant and were utilized with Texas AgriLife cropping system and other irrigation program grant funds to attain the targeted services and goals. (It is estimated that approximately $150,000 to $200,000 annually are required for appropriate network personnel, operations, maintenance, travel, telecommunications and replacement services.) The TXHPET meteorological stations were visited generally for routine and troubleshooting maintenance and grounds keeping tasks which included replacing sensors, bearings, solar panels, wiring, batteries, and numerous cables. A maintenance trip to all TXHPET stations generally required in excess of a week of travel with two qualified personnel conducting the procedures, and required overnight lodging for certain sites. Additionally a new Texas AgriLife network support trailer was custom outfitted with necessary equipment for field site maintenance procedures at the respective weather station sites. This trailer replaced the previous support trailer lost by theft in 2007 from the Texas AgriLife Research and Extension Center - Amarillo parking lot.

Fetch Study Infrastructure

The objective of the fetch portion of the project is to determine the effects of wind patterns and velocities on ET after interaction with an obstruction (i.e. tall crop) and to study the laminar dynamics of sensor data. The study site has been selected adjacent to the existing ARS reference lysimeter and ET site, and design plans have been drafted for the expansion layout of the irrigation system. The required alterations to the existing infrastructure, dryland plot area of other research projects and the reference grass subsurface irrigation control and valve systems have been analyzed, reviewed and recommended to Dr. Terry Howell in the winter of 2010. A copy of the draft fetch infrastructure recommendations are included in appendix A. Delay to implementation is due to existing cropping constraints of other research studies and rainfall and watershed divergence issues around the existing reference ET facility.

Regional ET and Groundwater Pumping Mapping

A regional agricultural water use estimation demand model was previously developed and revised to provide accurate and representative water use estimates for the 2011 Panhandle Regional Water Plan. This model is overwhelmingly dependent upon irrigation water demand use values since irrigation represents about 97% of the total agricultural water use. The irrigation portion of the model utilizes multiple crop ET values for each of the 21 counties in the Panhandle (Region A) of Texas as outlined by the Texas Water Development Board, the state's water regulatory agency. The respective crop ET values per county are multiplied by the number of planted irrigated acres to provide a regional crop water demand currently for 11 different crops. Crop ET is estimated using reference ET calculated from the TXHPET weather data multiplied by a growth stage-based crop coefficient for each crop. The crop ET values are subsequently multiplied by the number of planted irrigated acres for each crop to yield the respective county crop water demand. Average effective rainfall (by county) is then subtracted from the crop water demand to yield the total combined crop county based irrigation demand. These values can then be summed and sorted to yield the irrigation demand for several scales. The model allows for irrigation demand to be estimated by crop per county, by crop per region, county total and total regional irrigation demand. In 2009, the number of crops categories was increased from 8 to 11 with the addition of alfalfa, forage sorghum and sunflowers. This change was necessary due to changes within the region but principally due to the changes in crop

production in response to expansion of the dairy industry in the region in the last 5 years since the prior water demand projections.

Impact of Activity

TXHPET data and information support were provided for over 20 federal and state agency CRIS projects at the Texas AgriLife Research and Extension at Amarillo, Lubbock, Vernon, Chillicothe, Uvalde, Temple and College Station, the USDA-ARS at Bushland, West Texas A&M University at Canyon and various programs at Texas Tech University for research, extension, educational efforts and teaching. Other applications included meteorological modeling, crop modeling, irrigation scheduling and water resources management. County level crop irrigation demand estimates were derived and represent accurate estimations (as validated against actual producer records) for the Texas Panhandle (Region A Water Planning Group) using the Texas A&M – Amarillo (TAMA) model incorporating crop ET data with crop categories and FSA acreages. Also, the leveraging of this project resources includes new grant projects (discussed later).

Additional outcomes of the project data included a total of 21 refereed publications, plus numerous other publications, theses, dissertations and research reports by other agencies and programs not directly linked to this project. These articles either directly or indirectly utilized TXHPET data in the respective research study or analysis. Other papers, presentations, articles, educational and technology transfer products, extension activities, etc. totaled 156 and are listed in the outcome section. A journal article by P.H. Gowda, G.B. Senay, T.A. Howell, T.H. Marek entitled “Lysimetric Evaluation of Simplified Surface Energy Balance Approach in the Texas High Plains” and published in 2010 in APPLIED ENGINEERING IN AGRICULTURE (Vol. 25, No. 5) was recognized with an American Society of Agricultural and Biological Engineers (ASABE) 2010 Superior Paper Award. The team was recognized at the 2010 ASABE International Meeting in Pittsburg, PA.

Collaboration between the USDA-ARS-Soil and Water Management Research Unit at Bushland and Texas AgriLife Research and Extension Service at Amarillo and Lubbock continues to be highly effective, and has resulted in successful leveraging of funding for associated research and development project efforts (but not for general network operations and maintenance). Ongoing

and new projects are addressing: 1) a statewide assessment of ET networks, 2) siting and instrumentation standards for agriculturally based weather stations, 3) development of educational resources to promote better understanding and application of ET-based data for irrigation management, 4) educational opportunities for agricultural producers, crop consultants, and water resources managers, 5) educational packages for the general public, including youth, 6) enhancements of the TAMA model and 7) applications and farm-level irrigation resource decision support tools. A subsequent state water agency grant for educational water videos, including one for youth and others for advanced irrigation users, was awarded to this cooperative team.

Outcome - Publications (based on or using TXHPET data).

Refereed:

Baumhardt, R.L., S. Staggenborg, P.H. Gowda, P.D. Colaizzi, and T.A. Howell. 2009. Modeling irrigation management strategies to maximize cotton yield and water use efficiency. Agron. J. 101:460-468.

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Giovanni, P., J. Ko, A. Wentz, D. Leskovar, T. Marek and T. Howell. 2007. Determination of crop coefficients (Kc) for irrigation management of crops. In *Proc. 28th Annual International Irrigation Show*, 706-719. Falls Church, Va.: Irrigation Association.

Gowda, P., J. Chavez, P. Colaizzi, T. Howell, R. Schwartz and T. Marek. 2007. Relationship Between LAI and Landsat TM Spectral Vegetation Indices in the Texas Panhandle. ASABE Paper No. 072013. St. Joseph, Mich.: American Society of Agricultural and Biological Engineers.

Hernandez, J., P. Gowda, D. Misra, T. Marek and T. Howell. 2008. Groundwater modeling of the Texas High Plains using MODFLOW. Paper No. H21D-0861. Washington, D.C.: American Geophysical Union.

Hernandez, J.E., P.H. Gowda, D. Misra, T.H. Marek, and T.A. Howell. 2009. Calibrating Northern Texas High Plains groundwater model. 2009 ASABE Annual International Meeting, Reno Nevada, June 21-24, 11 p [CDROM].

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Porter, Dana and A. Michael Schubert. 2006. Irrigation management strategies for peanut production under water-limited conditions. ASABE Paper No. 062087. 2006 International Meeting of the American Society of Agricultural and Biological Engineers, Portland, OR, July 9-12, 2006.
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Porter, Dana. 2007. Water issues in agriculture. Presented at: Binational Water Congress, Saltillo, Mexico. November 29-30, 2007.
Porter, Dana. 2008. "Managing irrigation for water use efficiency." Presented at South Texas Irrigation Conference, Uvalde, TX. February 19, 2008.
Porter, Dana O., Freddie Lamm, Larry Schwankl and Ken Schackel. 2009. Microirrigation for sustainable water use: Research and outreach through a multi-state collaboration. In: Proceedings of the 2009 Irrigation Association Technical Conference, San Antonio, Texas, December 2-5, 2009.

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Special reports and bulletins

Boman, Randy, Dana Porter and Jim Bordovsky. 2008. Irrigation management strategies for High Plains cotton. Texas AgriLife Extension and Research Center, Lubbock. Texas.

Bynum, J., T. Cothren, T. Marek and G. Piccinni. 2007. Tools for implementing water conservation best management pPractices in Texas - Precision Irrigation Network. Texas Water Development Board. Contract # 2005-358-023. Texas Agricultural Experiment Station, Texas Water Resources Institute, College Station, Texas. August. 11 pp.

Gaskins, D., S. Amosson, T. Marek, D. Jones, B. Guerrero and F. Bretz. 2006. Natural gas irrigation situation analysis - Phase I: Characterize the natural gas driven irrigation market. Report for National Renewable Energy Laboratory Division. Texas Agricultural Experiment Station – Amarillo, Texas. April. 18 pp.

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Marek, T., D. Porter, T. Howell, N. Kenny and P. Gowda. 2009. "Understanding ET and its use in irrigation scheduling: a TXHPET Network series user manual." Manual Version 1.01. AREC Publication No. 09-02.

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Technical Report for Texas Water Development Board and Region A Panhandle Regional Planning Group through Freese and Nichols, Inc. AREC #09-21. Texas AgriLife Research and Extension Center - Amarillo, Texas. April 24. 83 pp.

Porter, D. 2008. End of season irrigation management for cotton. In: *FOCUS on South Plains Agriculture*. Vol. 47. No. 15. August 29, 2008. Texas AgriLife Extension and Research Center, Lubbock. Texas. Available at: http://lubbock.tamu.edu/focus/Focus2008/August_29/2008_Late_Season_Irrigation.pdf

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Papers and presentations

Invited papers, presentations, and lectures

Amosson, S., T. Marek, D. Gaskins, F. Bretz, B. Guerrero, D. Jones and L. Almas. 2005. Presentation: Water management strategies to conserve groundwater in Texas' Region A. UCOWR. Santa Fe, NM.

Bordovsky, James P. and Dana O. Porter. 2006. Comparison of Subsurface Drip Irrigation uniformity designs on cotton production. ASABE Paper No. 062276. Presented at: 2006 International Meeting of the American Society of Agricultural and Biological Engineers, Portland, OR, July 9-12, 2006.

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Gaskins, D., S. Amosson, D. Jones, L. Almas, F. Bretz, B. Guerrero, T. Marek and L. New. 2006. Water management strategies for reducing irrigation demands in the Texas Panhandle. Poster at Soil and Water Conservation Southern Conservation Systems Conference. Amarillo, TX. May

Marek, Thomas, Paul Colaizzi, Terry Howell, Don Dusek and Dana Porter. 2006. Estimating seasonal crop ET using calendar and heat unit based crop coefficients in the Texas High Plains Evapotranspiration Network. ASABE Paper No. 062206.

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Porter, Dana and A. Michael Schubert. 2006. Irrigation management strategies for peanut production under water-limited conditions. ASABE Paper No. 062087. Poster presented at: 2006 International Meeting of the American Society of Agricultural and Biological Engineers, Portland, OR, July 9-12, 2006.

Porter, Dana. 2006. Drift minimization and chemigation. Presented at Alternative Crops Conference, sponsored by Crosby County TCE. 2/7/2006 (Attendance: 24).

Porter, Dana. 2006. Landscape Irrigation Systems and Efficient Irrigation Management. Presented at: South Plains Master Gardener class, Lubbock, TX. 02/07/06. (Attendance: 16)

Porter, Dana. 2006. Irrigation management for South Plains peanut production. Presented at: Peanut Production Workshop, Seminole, TX 02/28/06. (Attendance: 30)

Porter, Dana. 2006. Efficient irrigation management and the Texas High Plains ET Network. Presented at: Texas Water Development Board Lockney Area Project Producers Irrigation Meeting, Muncy, TX. 03/02/06. (Attendance: 40) Presentation broadcast live on KFLP FM 106.5 “All Ag All Day” Show.

Porter, Dana. 2006. Intensive management for drip irrigated cotton production. Presented at: Lynn & Garza Counties Water Management Conference, Tahoka, TX. 03/28/06. (Attendance: 40)

Porter, Dana. 2006. New developments in the Texas High Plains Evapotranspiration Network. Presented at: Lubbock County Water Conference. Lubbock, TX. 03/30/06. (Attendance: 20)

Porter, Dana. 2006. Subsurface drip irrigation management. Presented at: Hockley County SDI Irrigation Seminar. Levelland, TX. 04/18/06. (Attendance: 28)

Porter, Dana. 2006. Lawn and turf irrigation: Efficient, effective water management. Presented at Terry County Ornamental and Turf Grass Conference, Brownfield, TX. 08/03/2006 (Attendance: 30)

Porter, Dana. 2006. Cotton irrigation management in 2006. Presented at: Lynn County Irrigated Cotton Turn Row Meeting. Lamesa, TX. 08/01/06 (Attendance: 20)

Porter, Dana. 2006. Texas High Plains Evapotranspiration Network: New developments. Presented at: North Plains Field Station (Etter) Field Day, Etter, TX. 08/09/06 (Attendance: 55)

Porter, Dana. 2006. Texas High Plains Evapotranspiration Network. Presented at: Floyd County Ag Tour, Floyd County, TX. 09/19/06. (Attendance: 36)

Porter, Dana. 2006. Subsurface drip irrigation. Presented at: Crosby County Ag Tour, Crosby County, TX. 09/29/06. (Attendance: 21)

Porter, D. and L. New. 2006. TCE North Region water conservation and irrigation training for county extension agents. Training events on August 22, 2006 (Advanced training, Amarillo, TX) and August 30, 2006 (Lubbock). Texas Cooperative Extension, Texas A&M University System.

Boman, R (and D. Porter). 2006. TCE North Region agent training - Cotton 101. Workshop taught by TCE and TAES faculty based in the Texas Southern High Plains was held July 20, 2006 at the Texas A&M University Agricultural Research and Extension Center at Lubbock. Texas Cooperative Extension, Texas A&M University System.

Porter, D. 2006. Irrigation research in the Texas High Plains. Seminar for faculty and graduate students in the Department of Biological and Agricultural Engineering, Texas A&M University, College Station, Texas. November 15.

Porter, Dana and Jim Bordovsky. 2006. Subsurface drip irrigation research at Ag-CARES. In: 2006 Annual Report. Texas A&M University Agricultural Research and Extension Center. Lubbock, TX.

Porter, Dana. 2006. Irrigation Management for South Plains Peanut Production. Presented at: Peanut Production Workshop, Levelland, TX 03/01/06. (Attendance: 32)

Porter, Dana. 2006. Subsurface drip irrigation research activities at AgCARES. Presented at: AgCARES and Dawson County Agriculture Tour, Lamesa, TX. 08/29/06 (Attendance: 80)

Porter, Dana. 2008. Irrigation management using soil moisture and ET information. Presented at: Lower Rio Grande Valley Irrigation Conference. Mercedes, TX. 10/29/08.

Porter, Dana. 2008. Water issues in agriculture. Invited guest lecture, WMHS 602: Contemporary Issues in Water Resources course, Ron Kaiser, instructor. 11/11/08.

Porter, Dana. 2008. Irrigation systems management. Presented at: Southern Region Cotton Conference, Haskell, TX. 01/14/08.

Porter, Dana. 2008. Efficient irrigation for turf and landscape and introduction to rainwater harvesting. Presented at: South Plains Master Gardeners class. 02/12/08.

Porter, Dana. 2008. Technology transfer and the Ogallala Aquifer Program. Presented at: 2009 Annual Meeting of the USDA-ARS Ogallala Aquifer Initiative research group, Garden City, Kansas. 03/10/09 - 03/12/09.

Porter, Dana. 2008. Making the most of irrigation technology: refining irrigation management. West Texas Agricultural Chemicals Institute Annual Conference, Lubbock, TX. 09/10/08.

Porter, Dana. 2009. Evolving irrigation management for 2009. Presented at: 2009 Annual Meeting of the High Plains Association of Crop Consultants. Lubbock, TX. 03/03/09.

Porter, Dana. 2010. Irrigation management in an integrated production system. 2010 Annual Meeting of the High Plains Association of Crop Consultants. Lubbock, TX. 03/02/10.

Porter, Dana. 2010. Irrigation management for water-limited production systems**.** West Texas Agricultural Chemicals Institute Annual Conference, Lubbock, TX. 09/15/10.

Presentations:

Amosson, Steve. Area impact of agriculture, economics and water management strategies. Presented at: Consortium for Irrigation Research and Education (CIRE) annual meeting, Amarillo and Bushland, Texas May 27-29, 2009.

Marek, Thomas. 2009. Overview of water issues in the Texas High Plains. Presented at: Consortium for Irrigation Research and Education (CIRE) annual meeting, Amarillo and Bushland, Texas, May 27-29, 2009.

Marek, Thomas. 2009. Groundwater districts and the Panhandle Water Planning Group. Presented on behalf of C.E. Williams at: Consortium for Irrigation Research and Education (CIRE) annual meeting, Amarillo and Bushland, Texas, May 27-29, 2009.

Marek, Thomas, Terry Howell, Paul Colaizzi, Steve Evett and Judy Tolk. 2009. USDA-ARS Conservation Systems Research Laboratory research programs, projects and facilities tour. Presented at: Consortium for Irrigation Research and Education (CIRE) annual meeting, Amarillo and Bushland, Texas, May 27-29, 2009.

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Porter, Dana. 2009. Irrigation practices, research programs and Extension/Outreach in the Texas High Plains. Presented at: Consortium for Irrigation Research and Education (CIRE) annual meeting, Amarillo and Bushland, Texas, May 27-29, 2009.

Newspaper articles & presentations to non-science audiences:

Ledbetter, Kay. 2006.Weather stations collect data to help producers determine water needs for crops. North Texas E-News.com. June 3, 2006.

McAlavy, Tim. 2006. Irrigation timing, method affects bottom line. High Plains Journal online. June 5, 2006. Available at: www.hpj.com/archives/2006/jun06/jun5/Irrigationtimingmethodaffec.cfm Also printed in Southwest Farm Press. June 2006.

Marek, T. 2006. The Texas Panhandle drought of 2006? North Plains Research Field 2006 Ag Day Proceedings. AREC 06-32. TAES- Amarillo/Etter, TX.

Marek, T., T. Howell and D. Porter. 2006. Calculating crop water use in the Northern Texas High Plains. North Plains Research Field 2006 Ag Day Proceedings. AREC 06-32. TAES- Amarillo/Etter, TX.

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Porter, D. and T. Marek: 2006. Texas High Plains Evapotranspiration Network. Presentation at the North Plains Research Field Day, Etter, TX. August 9.

Porter, Dana. 2006. Texas High Plains Evapotranspiration Network assists producers with irrigation scheduling decisions. The Cross Section. High Plains Underground Water Conservation District No. 1. April 5, 2006.

Porter, Dana. 2008. Ogallala Aquifer Initiative technology transfer efforts in Texas. Presented at: 2008 Annual Meeting of the USDA-ARS Ogallala Aquifer Initiative research group, Amarillo, TX. 03/11/08 - 03/13/08

Porter, Dana. 2008. Irrigation Management. Presented via TTVN at: Trans-Pecos Crop and Forage Meeting, Fort Stockton, TX. 01/15/08.

Porter, Dana. 2008. Irrigation management tools: Soil moisture management and evapotranspiration-based irrigation scheduling. Presented in: Making the Most of Irrigation, Irrigation Training Program Workshop series, Lubbock, TX. 02/01/08.

Porter, Dana. 2008. Efficient irrigation management: Technology and tools. Presented at: Hale-Swisher Counties Crops Conference, Plainview, TX. 02/06/08.

Porter, Dana. 2009. Late season irrigation management for cotton. *Southwest Farm Press*. August 10, 2009.

Porter, Dana. 2009. SDI field day slated Aug. 25. Southwest Farm Press. August 18, 2009. Accessed Monday, 08/18/09 at: http://southwestfarmpress.com/irrigation/subsurface-drip-irrigation-0818/.

Media Appearances

Porter, Dana. 2008. Irrigation update for the Texas Southern High Plains. Ag Talk on FOX Talk
AM 950. Live interview and call-in show with host, Eddie Griffis.
November 24, 2008.

Smith, Ron. 2008. Knowledge of soils, plants is crucial to efficient irrigation. *Southwest Farm Press.* October 2, 2008. Posted online Oct 14, 2008 at: http://southwestfarmpress.com/irrigation/soil-irrigation-1014.

Presentations at Extension meetings

Kenny, Nicholas. 2008. Late Season Soil Water Management. Stratford Corn and Cotton Field day. 8/26.

Kenny, Nicholas. 2008.2008. Cotton Heat Unit and Irrigation Requirements. Moore County Monsanto Field day. 9/4.

Kenny, Nicholas. 2008. Impacting Water Costs. Gulf Coast Irrigation Conference. 11/18.

Kenny, Nicholas. 2008. Impacting Water Costs. Moore County Ag. Day. 12/16.

Kenny, Nicholas. 2008. Impacting Water Costs. Amarillo Natural Gas producer seminar at the Amarillo Gun Club. 12/17.

Kenny, Nicholas. 2009. Impacting Water Costs. High Plains Irrigation Conference. 1/14.

Kenny, Nicholas. 2009. Sherman County Ag. Day; “Impacting Water Costs.” 1/19.

Kenny, Nicholas. 2009. Impacting Water Costs. South Texas Irrigation Conference. 1/20.
Kenny, Nicholas. 2009. Impacting Water Costs. Dalhart Extension Co-op Meeting; 1/27.
Kenny, Nicholas. 2009. Impacting Water Costs. Dalhart Ag. Appreciation Day;.2/24
Kenny, Nicholas. 2009. North Plains Cotton Irrigation. Dumas Cotton Day. 2/25.
Kenny, Nicholas. 2009. Impacting Water Costs. Gray County Ag. Conference; 2/25.
Kenny, Nicholas. 2009. Residential Landscape Irrigation. Randal Co. Ag 101 Series. 2/26.
Kenny, Nicholas. 2009. Impacting Water Costs. Quail Peanut Meeting. 3/4.
Kenny, Nicholas. 2009. South Plains Cotton Irrigation Strategies. Hereford Cotton Conference;. 3/5.
Kenny, Nicholas. 2009. Irrigation Strategies for Cotton and Wheat. Briscoe County Ag. Conference.. 3/5.
Kenny, Nicholas. 2009. Armstrong County Producer Breakfast: "Water Management: Irrigation to Crop Water Demand". 5/26.
Porter, Dana. 2008. Irrigation Scheduling. Presented at: Irrigation Training Program. . Chillicothe, TX. 08/20/08.
Porter, Dana. 2008. Subsurface Drip Irrigation Research at AgCARES. 2008. Presented at: AgCARES and Dawson County Agriculture Tour, Lamesa, TX. 08/20/08.
Porter, Dana. 2008. Late Season Irrigation Management for Cotton. Presented at: Lubbock County Late Season Management Meeting and Field Tour, Lubbock, TX. 08/27/08.
Porter, Dana. 2008. Irrigation best management practices: Managing soil moisture." Presented at: Swisher County Ag Day. Tulia, TX. 12/09/08.
Porter, Dana. 2009. "Irrigation Technologies and Best Management Practices." Presented at: West Plains Ag Conference, Levelland, TX. 01/19/09.
Porter, Dana. 2009. Irrigation technologies and best management practices. Presented at: Llano Estacado Cotton Conference, Muleshoe, TX. 01/21/09.
Porter, Dana. 2009. Soil moisture and efficient irrigation management. Presented at Hale and Swisher Counties Crop Conference, Plainview, TX.02/10/09
Porter, Dana. 2009. Efficient irrigation for turf and landscape and introduction to rainwater harvesting. Presented at: South Plains Master Gardeners class. 02/10/09.
Porter, Dana. 2010. Irrigation technologies. West Plains Agricultural Conference. Levelland, TX. 01/18/10.
Porter, Dana. 2010. Subsurface drip irrigation. Terry County SDI Workshop, Brownfield, TX. 01/19/10.
Porter, Dana. 2010. Irrigation management in an integrated production system. Llano Estacado Cotton Conference. Muleshoe, TX. 01/21/10.
Porter, Dana. 2010. Irrigation management for Texas High Plains peanut production. Peanut Workshop. Brownfield, TX. 03/01/10.
Porter, Dana. 2010. Irrigation management. Crosby County Soil Moisture Workshop. Lorenzo, TX. 05/05/10.
Porter, Dana. 2010. Irrigation management: Mid-season to harvest. Mid-Season Cotton Management Meeting. Plainview, TX. 07/08/10.

Abstracts:

Gaskins, D., S. Amosson, D. Jones, L. Almas, F. Bretz, B. Guerrero, T. Marek and L. New. 2006. Water management strategies for reducing irrigation demands in the Texas Panhandle. Abstract in *J. Agric. and Appl. Economics* 38.2: 472.

Gowda, P., R. Baumhardt, T. Howell and T. Marek. 2008. Planting date forecast for cotton using minimum and maximum air temperature. Abstract. *38th Annual Biological Systems Simulation Group Conference*, 50-51. Griffin, Ga.: Biological Systems Simulation Group.

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Piccinni, G., T. Gerik, E. Steglich, D. Leskovar, J. Ko, T. Marek and T. Howell. 2006. Crop simulation and crop evapotranspiration for irrigation management of spinach. Abstract in *HortScience*, 41(4): 971. *American Society for Horticulture Science Meeting*. Alexandria, Va.: American Society for Horticulture Science.

Piccinni, G., J. Ko, T. Gerik, E. Steglich, D. Leskovar, T. Marek, W. Harman and A. Kemanian. 2006. Crop simulation and crop evapotranspiration for irrigation management of corn and spinach. *Agronomy Abstracts*, CD-ROM. Madison, Wisc.: American Society of Agronomy – Crop Science Society of America – Soil Science Society of America.

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Appendix A

Bushland Fetch Study Sprinkler System

Preliminary Layout and Design
by

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for

USDA-ARS CPRL Bushland, Texas

6 November 2009

Background

A large, uniform grass vegetation plot has been identified as necessary infrastructure at the United States Department of Agriculture Bushland Conservation Research Laboratory in Bushland, Texas in order to perform atmospheric impact analysis relating to ongoing and proposed Evapotranspiration (ET) studies. The base infrastructure improvements related to the plot include the design, installation, and implementation of a solid-set, turf sprinkler irrigation system for the establishment and maintenance of a grass “fetch” plot.

The proposed Fetch Plot area is approximately 5.3-acres currently used for dryland crop research (See Figure 1 below). The water source for the proposed Fetch Plot is a storage reservoir, the North

Figure 1: Aerial view of the Bushland fetch plot (green outline) and irrigation reservoir (blue outline).

Reservoir, located approximately 800 ft. northeast of the northeast corner of the Fetch Plot. Water storage in the North Reservoir is exclusively provided from multiple on-site groundwater wells (existing).

Design Criteria

A primary design criterion of the Bushland Fetch Plot is suitable application capacity to meet 100% Reference Evapotranspiration (ET_{os}, grass reference) on a daily basis throughout the year. Using the ET_{os} data gathered over the last ten years, the peak daily ET_{os} from the Bushland grass reference plot is 0.35-inches and the seasonal ET_{os} is 67-inches. Annual precipitation is typically between 15- and 20-inches with no representative seasonal average. Ideal maximum application time is 5-hours per day during the annual peak water use period of June and July.

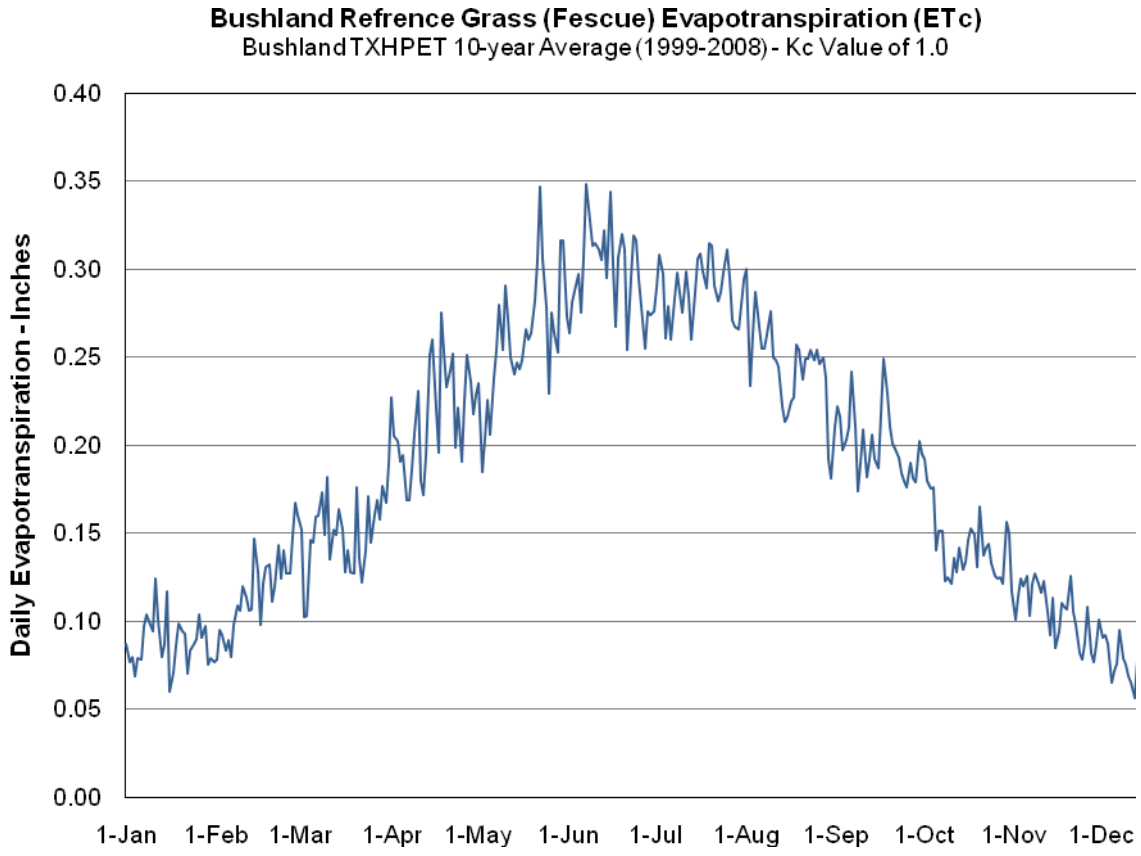

Figure 2: Bushland daily ET chart.

The soil type for the Bushland Fetch Plot is primarily Pullman Clay Loam with a narrow strip of Pantex Silty Clay Loam on the Eastern diagonal Edge (see Figure 3). The design infiltration rate is 1.44 inches per hour at 10 minutes after application and 0.10 inches per hour at 20 hours after application as listed for Deaf Smith County Pullman Soil infiltration data found in Pullman Soils: Distribution, Importance, Variability & Management (Unger and Pringle, pg.16). Given the significant infiltration immediately following application and very little slope on the Fetch Plot, it is concluded that an application rate of up to

1 inch per hour is acceptable for limited run times. (Refer to Figure 4 for the application rate analysis curve.)

Figure 3: Web soil survey screen shot of Bushland fetch plot with area of interest (AOI).

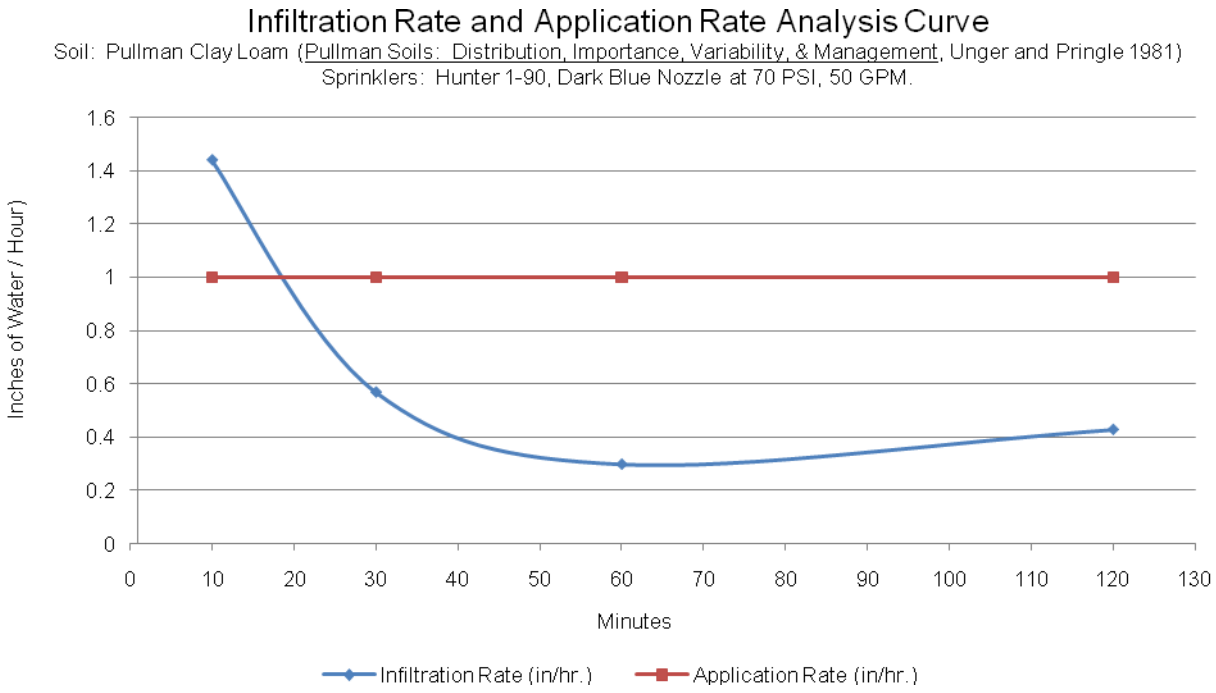

Figure 4**.** Pullman clay loam infiltration rate and Hunter I-90 application rate over time.

Design and Significant Components

The irrigation system design is based on an irrigation capacity of 200 gallons per minute (GPM) to best match the North Reservoir recharge of the Irrigation Well #8 located approximately 0.15 miles (~650 feet) south of the storage pond. Irrigation Well #8 is equipped with a new electrical submersible pump and motor. The pumping plant was measured in 2009 (by Colaizzi and Kenny) to produce 218 GPM (4 Sept.). Given the limited capacity of the North Reservoir, the ability to closely match groundwater delivery with the Fetch Plot sprinkler system draw is highly desired from an operational perspective.

The 200 GPM irrigation system capacity allows for the peak daily application of 0.35" in 4 hours and 15 minutes across the 5.4-acre plot. The sprinkler system layout divides the Plot into 12 similarly sized zones. The water application rate per zone is 1.00 inch per hour and the average run-time at full capacity is 21 minutes per zone. Zones with half-arc patterns will operate for a shorter period and full-arc zones will operate for a longer period to match the total water application target (See Appendix 1: Precipitation Tables).

To sufficiently meet the operational requirements, a new pumping plant at the North Reservoir and a new delivery pipeline to the Fetch Plot will be required, in addition to the components of the existing configuration at the North Reservoir pump control station. In addition, it is planned that the current sprinkler and drip irrigation controls for the existing ET grass plot are relocated to the area just north of the proposed fetch plot, coinciding with the new control valve manifold location (Note: The proposed Fetch Plot controller can also control the drip area). The additions included in this project are considered complementary to existing irrigation systems and associated controls to maintain existing operational and research protocol requirements. The components associated with the Fetch Plot are intended to operate in relative isolation, using only a common water source.

An additional infrastructure upgrade that is recommended but not included in the scope of this project is the reworking of the pipeline and controls of the pumps that deliver water to the North Reservoir. An integrated and automated pump, pipeline, and valving system for water delivery to the North Reservoir would allow for a stable water level within the North Reservoir, making automatic delivery adjustments based on various irrigation draws regardless of irrigation timing and quantity protocols of the surrounding research. In light of the daily, early morning irrigation of the proposed Fetch Plot, it is anticipated that the increased burden of "next day irrigation" capacity of the North Reservoir could be eliminated through automation.

Pumping Plant

The recommended pump is a five-stage Goulds 6CLC submersible turbine pump with a 20 horsepower, 6", standard submersible motor manufactured by Franklin Electric (Model # 23661481). The pump efficiency at the design point of 200 GPM with 263' total dynamic head is 76%. This design point is slightly to the high-flow side of the maximum efficiency point to maximize the pump's overall lifetime efficiency as pump wear and/or water yield decline occurs. It is anticipated that the pump may be placed in an existing sump at the current North Reservoir pump cluster. Consideration of Net Positive Suction Head Requirements with the existing sump will be taken into account.

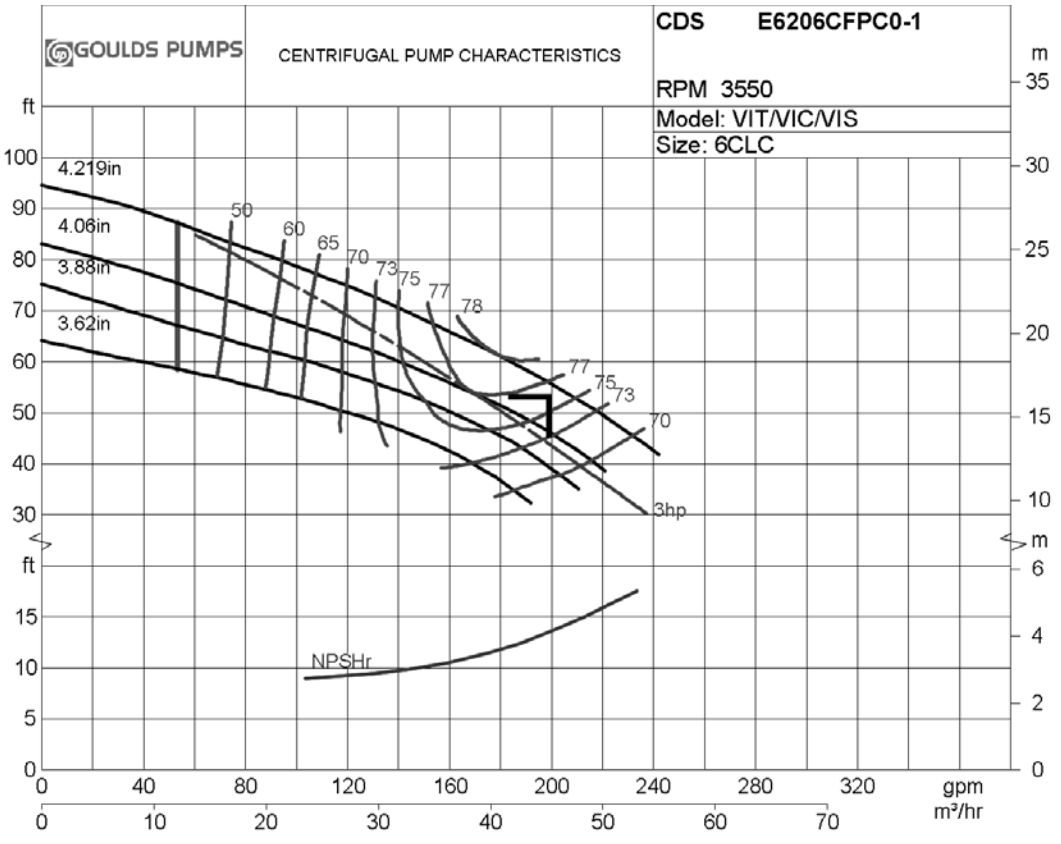

Figure 5**.** Goulds model 6CLC pump characteristics.

Sprinkler System – Controller

The proposed automatic controller for the Fetch Plot is the Hunter ICC-800-PL, an 8-station standalone controller. The Hunter ICC series operates on 120VAC input and produces 24VDC output compatible with standard automatic valves. The Hunter Mini-Weather Station with the Freeze Sensor (MWS-FR) is to be installed with the bypass switch box to allow the controller to responding to coarse weather parameters. The controller will be located on the west side of the irrigation pond near the pumping plant.

The controller is to be utilized in conjunction with an Underhill 2-Wire ICC-48 Module that allows the Hunter ICC series controller to operate in 2-wire mode when used in conjunction with Underhill signal decoders. Benefits to this system include reduced control wire requirement, increased system expansion potential, and simplified electronic troubleshooting.

(http://www.underhill.us/index.htm)

Figure 6. Hunter ICC-800-PL with Underhill 2-wire ICC-48 module.

Sprinkler System – Automatic Control Valves

Figure 7. Hunter mini-weather station with freeze sensor.

3" Irritrol 100P3 Automatic Control valves will be used to control the 12 irrigation zones in the Fetch Plot. Each zone will utilize two control valves in series for the security of operational redundancy. All 24 valves will be assembled in a manifold north of the Fetch Plot, outside of a formal study area to allow for minimal research disturbance during valve maintenance. Additionally, the valves will be assembled with threaded unions to allow for quick removal and replacement. An Underhill 2-Wire Decoder is required for each zone (one decoder will control both zone control valves) and is to be installed within the valve boxes. The Underhill 2-Wire Decoder is programmed using a programming tool following the installation of the irrigation system. Note, a small building or custom valve box should be considered instead of valve boxes for housing the valve manifold and decoder as it will provide superior component protection and ease of access.

(http://www.underhill.us/index.htm)

Figure 8. Irritrol 100P3 irrigation valve and Underhill 2-wire decode.

The sprinkler head selected for the Fetch Plot is the Hunter I-90 with the Dark Blue (size, rated flow) nozzle. The sprinkler layout is in an 80 ft. nominal spacing square orientation. The operational design pressure point is at 70psi, producing a rated 79 ft. throw radius at 48.5 GPM per head. The 48-head system will use 24 adjustable heads (I-90-ADV) and 24 full heads (I-90-36V), primarily grouped with like heads to match application rates within each zone. The heads are to be split into 12 zones with 4-heads per zone. Sprinkler heads are to be attached to the irrigation lateral using 1 ½" pre-manufactured swing joints to decrease impact damage (see Figure 9).

Sprinkler System – Sprinklers *(www.hunterindistries.com)*

Figure 9. Hunter I-90 sprinkler head and Hunter I-90 on a 1-½" swing joint

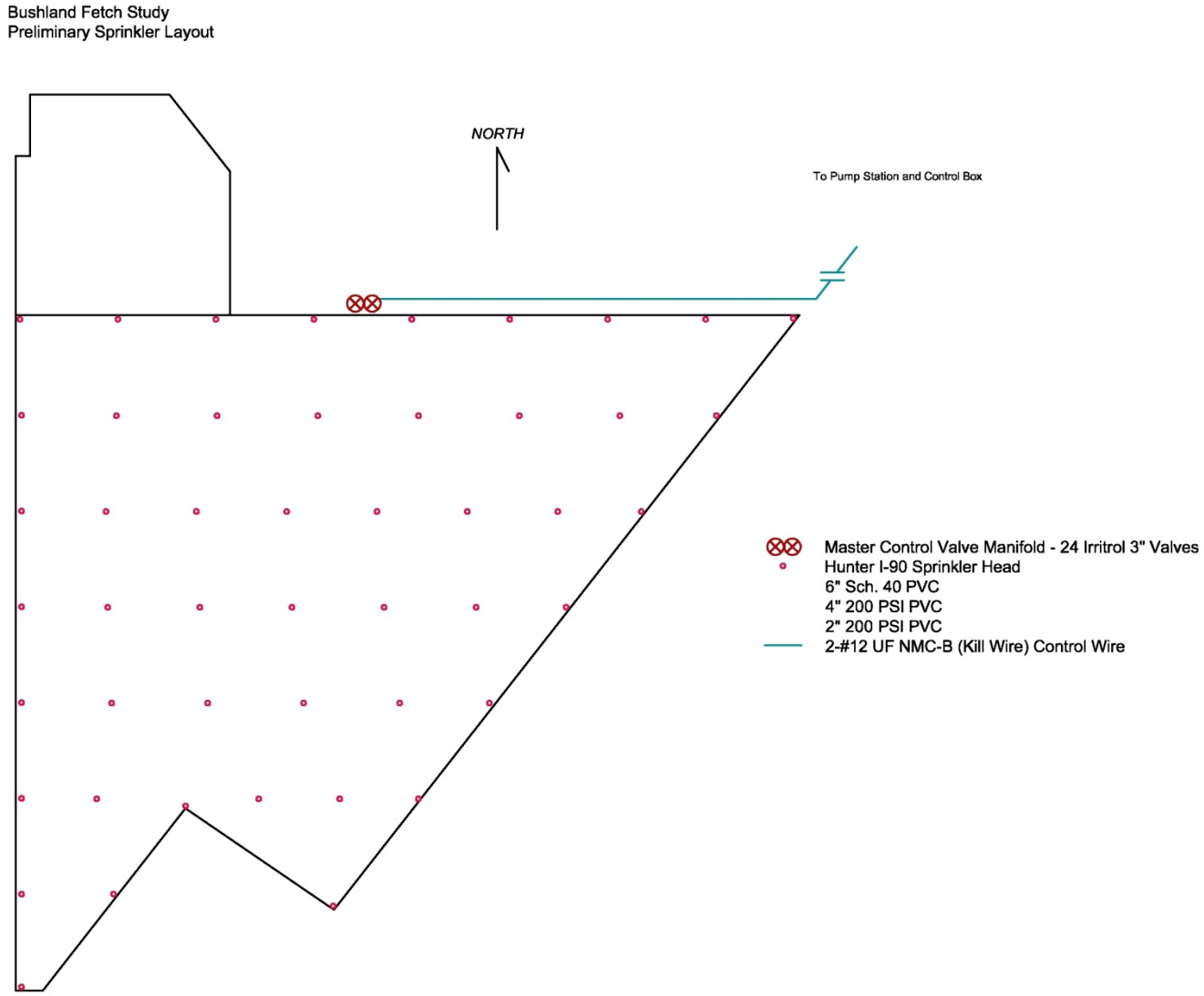

Figure 10: Bushland fetch control valve, sprinkler head, and control wire layout.

Pipeline and System Layout

The main delivery pipeline from the pump station to the Fetch Plot control valves is to be 6" Schedule 40 PVC. The valve manifolds are to be primarily 4" PVC fittings with final reduction to 3" just prior to the control valves. The pipeline is then to be belled back to 6" Schedule 40 PVC following the control valve to deliver water to each specific zone. The irrigation laterals are 4" 200PSI rated PVC reduced to 2" 200PSI rated PVC at the end of each zone. Every zone is to be fitted with a ¾" automatic drain, installed below ground at the low spot of each irrigation zone and surrounded by approximately 1 cubic foot of pea-sized gravel.

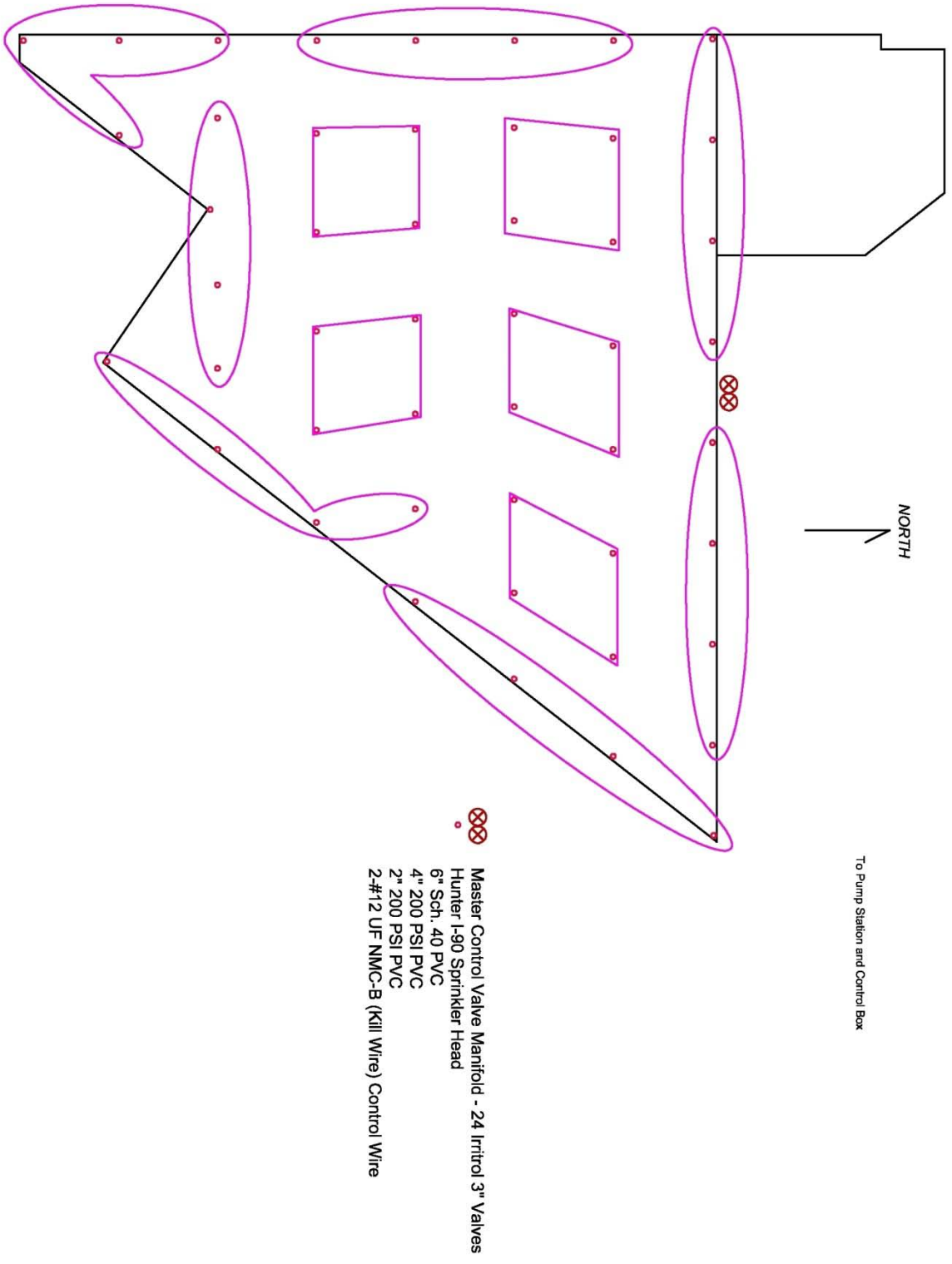

Figure 11. Bushland fetch plot control valve, sprinkler head, and irrigation zones.

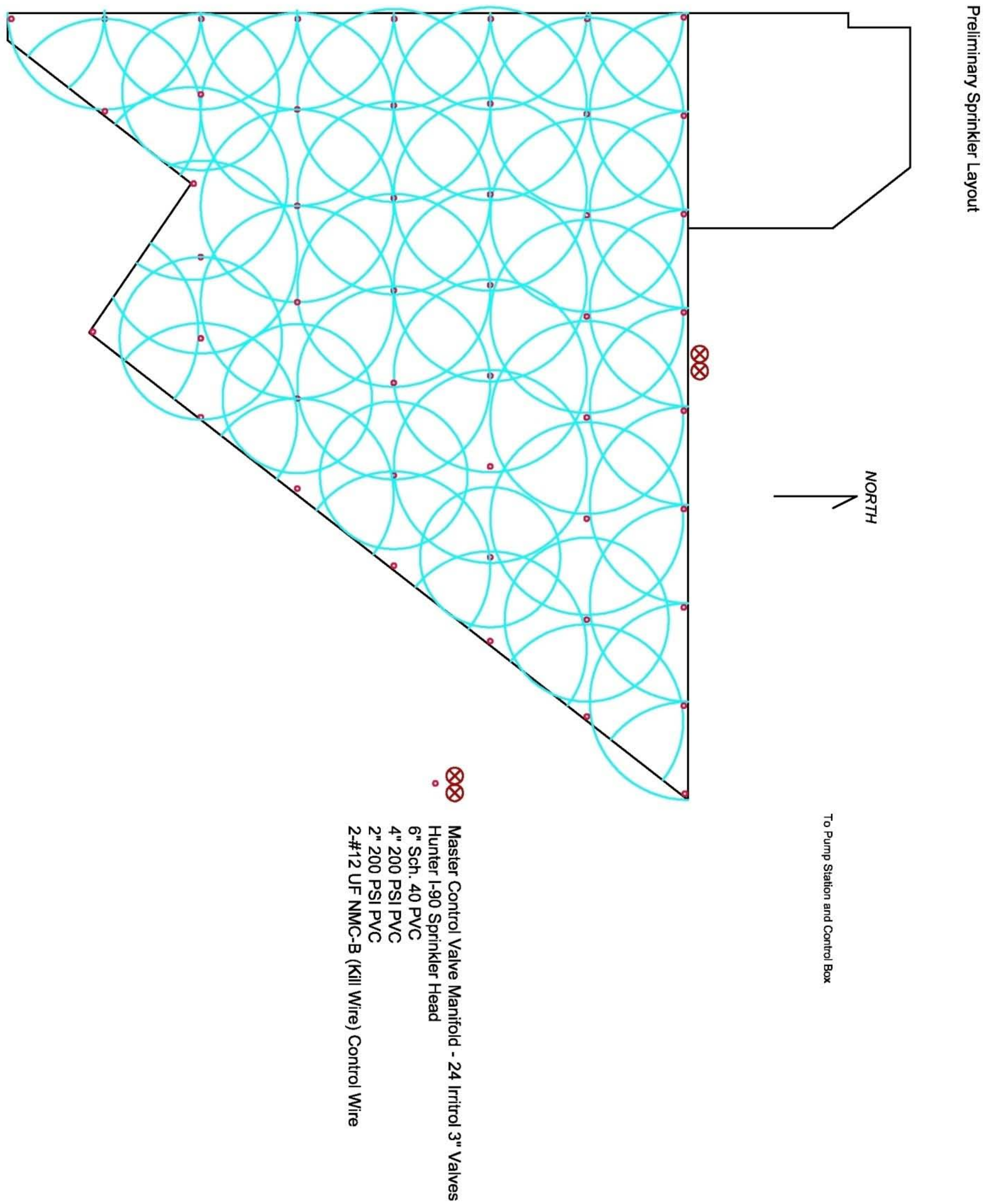

Figure 12. Bushland fetch plot sprinkler head and sprinkler overlap profile.

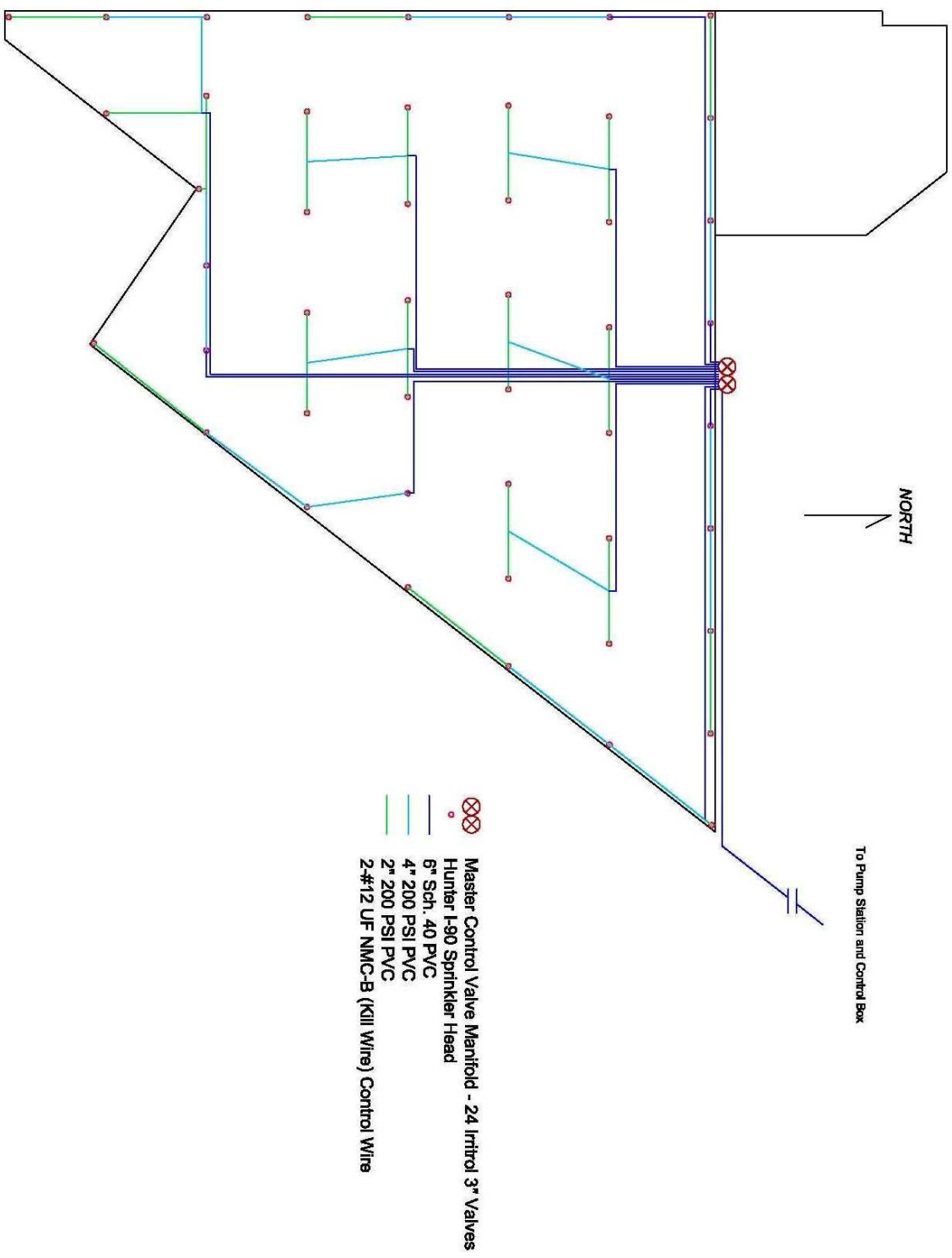

Figure 13. Bushland fetch plot control valve, sprinkler head, and pipeline layout.

Irrigation System Costs

The total anticipated component and equipment cost for the sprinkler system for the Bushland Fetch Plot is approximately $46,800 (Tables 1 and 2). The pumping plant component is $9,800 and the sprinkler system component is $37,000. This cost does not include pump, irrigation controller, or valve housing. **Note that the costs quoted are available dealer cost and will likely increase if purchased through a retailer.** Pump component pricing is provided by Global Pump of Amarillo, Texas (806-373-0478) and sprinkler system prices are quoted by Layne Hardesty, Equipment Supply Co., Inc.., Lubbock, Texas (806-747-0004).

Associated operating costs are best described by the energy cost required to pump and pressurize the irrigation system. Expecting an annual maximum depth of application of 30-inches across the 5.4-acre Fetch Plot, the annual pumping energy cost is projected at approximately $800 (See Appendix 3: Seasonal Energy Use Profile).

Table 1. Pumping plant component list.

Bushland Fetch Plot Pumping Plant Component List

	Component	Quantity		Unit Cost		Extended
1	Goulds 6" Pump, 5-stage, 6CLC	1	$	2,215.00	$	2,215.00
2	Franklin 6", 20hp Motor, 460V 3-Phase, #23661481	1	$	2,901.00	$	2,901.00
3	Siemens ESP100 Starter Panel	1	$	1,136.10	$	1,136.10
4	Cooling Shield	1	$	77.00	$	77.00
5	#10 Power Wire	25	$	1.64	$	41.00
6	Pressure Gauge	2	$	15.00	$	30.00
7	Flow meter	1	$	1,200.00	$	1,200.00
8	Column Pipe				$	500.00
9	Pump Stand and pipeline				$	1,200.00
10	Misc Fittings and Supplies				$	500.00
	TOTAL				**$**	**9,800.10**

Table 2. Sprinkler component list.

Bushland Fetch Sprinkler Component List

	Component	Quantity		Unit Cost		Extended
1	PVC Pipe- 6" Sch. 40 (ft)	4860	$	2.80	$	13,608.00
2	6" 90° ELL (soc x soc)	48	$	28.21	$	1,354.08
3	6" TEE (soc x soc)	25	$	44.31	$	1,107.75
4	6" - 4" Reducing Bushing	25	$	13.34	$	333.50
5	PVC Pipe - 4" 200PSI	1520	$	1.39	$	2,112.80
6	4" ELL (soc x soc)	12	$	8.88	$	106.56
7	4" TEE (soc x soc)	15	$	13.17	$	197.55
8	4" - 3" Reducing Bushing (soc x soc)	32	$	5.39	$	172.48
9	4" - 2" Reducing Bushing (soc x soc)	35	$	5.39	$	188.65
10	4" - 1 1/2" Reducing TEE (socx soc x fipt)	24	$	13.77	$	330.48
11	4" Slip Union	28	$	34.76	$	973.28
12	3" Male Adapter (mipt x soc)	30	$	3.59	$	107.70
13	PVC Pipe - 3" 200PSI	60	$	1.00	$	60.00
14	PVC Pipe - 2" 200PSI	1520	$	0.41	$	624.11
15	2" ELL (soc x soc)	45	$	1.30	$	58.50
16	2" TEE (soc x soc)	10	$	1.60	$	16.00
17	2" x 1 1/2" Reducing TEE (soc x soc x fipt)	18	$	2.81	$	50.58
18	2" x 1 1/2" Reducing ELL (soc x soc x fipt)	25	$	2.60	$	65.00
19	2" 45" ell	18	$	1.60	$	28.80
20	2" x 3/4" Reducer Bushing (soc x fipt)	18	$	1.45	$	26.10
21	*8% PVC Increase*				*$*	*1,721.75*
22	King Automatic Drain Valve 3/4" MPT Inlet	15	$	2.71	$	40.65
23	PVC Primer (Gallon)	5	$	36.10	$	180.50
24	PVC Glue (Gallon)	5	$	36.00	$	180.00
25	Hunter ICC 8-station controller	1	$	216.00	$	216.00
26	Underhill 2-wire ICC-48 module	1	$	169.00	$	169.00
27	Underhill 2-wire Programmer	1	$	298.00	$	298.00
28	Underhill Decoder	14	$	46.00	$	644.00
29	Hunter Mini Weather Station w/ Freeze Senson	1	$	125.00	$	18.60
30	Hunter By-pass switch	1	$	25.65	$	25.65
31	UF NMC-B (Kill Wire) 2-#12 (1.250 ft.)	1	$	465.00	$	465.00
32	4' x 5/8" Copper Ground Rod	5	$	15.00	$	75.00
33	Copper Grounding Rod Clamp 5/8"	5	$	2.00	$	10.00
34	Northstar Orange Wire Nut (QTY 50)	2	$	24.81	$	49.62
35	Irritrol 3" Valve 100P3	24	$	201.30	$	4,831.20
36	Hunter 1-90-ADV Sprinkler (Dk. Blue Nozzle)	25	$	93.00	$	2,325.00
37	Hunter 1-90-36V Sprinkler (Dk. Blue Nozzle)	25	$	93.00	$	2,325.00
38	1 1/2" Swing Joint	50	$	33.85	$	1,692.50
39	Teflon Tape (rolls)	10	$	0.50	$	5.00
40	20" Jumbo Rectangular Valve Box	4	$	43.29	$	173.16
	TOTAL				$	36,967.56

Appendix 1: Precipitation tables

Precipitation Table

Perimeter (Partial-Head) Zones

System Flow	200	GPM
AVG. Application Rate	1.50	in/hr.

Minutes of Operation	Inches Applied
5	0.13
6	0.15
7	0.18
8	0.20
9	0.23
10	0.25
11	0.28
12	0.30
13	0.33
14	0.35
15	0.38
16	0.40
17	0.43
18	0.45
19	0.48
20	0.50
25	0.63
30	0.75
35	0.88
40	1.00
45	1.13
50	1.25
55	1.38
60	1.50

Interior (Full-Head) Zones

System Flow	200	GPM
AVG. Application Rate	0.70	in/hr.

Minutes of Operation	Inches Applied
5	0.06
6	0.07
7	0.08
8	0.09
9	0.11
10	0.12
11	0.13
12	0.14
13	0.15
14	0.16
15	0.18
16	0.19
17	0.20
18	0.21
19	0.22
20	0.23
25	0.29
30	0.35
35	0.41
40	0.47
45	0.53
50	0.58
55	0.64
60	0.70

Appendix 2. Delivery pipeline friction loss analysis.

Bushland Fetch Friction Loss Analysis

	Delivery	Most Demanding Zone			
			Zone 12		
Pipe Diameter (in.)	6	6	4	4	2
Pipe Diameter (ft.)	0.500	0.500	0.333	0.333	0.167
Pipe Area (sq.ft.)	0.1963	0.1963	0.0872	0.0872	0.0218
Zones	12	1	1	1	1
Total Flow (gpm)	200	200	150	100	50
Total Flow (cfs)	0.44	0.44	0.33	0.22	0.11
Q=VA					
Vmax = 5 ft./sec.					
V=	2.26	2.26	3.82	2.55	5.10

PVC Pipe Friction					
Hazen-Williams Equation	Delivery		Zone12		
	6"	6"	4"	4"	2"
k1	10.46	10.46	10.46	10.46	10.46
L	1100	650	240	160	160
Q	200	200	150	100	50
C	140	140	140	140	140
D	6	6	4	4	2
hf	3.6	2.1	3.3	1.0	8.5
psi	1.6	0.9	1.4	0.5	3.7
Pressure Balance					
Beginning					
PSI	97	93.3	79.8	77.5	76.2
Feet	224.1	215.5	184.4	179.0	176.0
Necessary					
PSI	79.83	77.52	76.20	70	70
Feet	184.4	179.0	176.0	161.7	161.7
Losses (Feet)					
Pipe	3.6	2.1	3.3	1.0	8.5
Fittings, Valves, etc.*	5.00	28.94	2.00	2.00	5.00
Elevation	0	0	0	0	0
Total Losses	8.6	31.1	5.3	3.0	13.5
Net Head (Feet)	215.5	184.4	179.0	176.0	162.5
Operating Pressure (PSI)	93.3	79.8	77.5	76.2	70.3

*Irritrol 3" Control valve shows friction loss of 4.1 ft. at 200 GPM.

Appendix 3. Seasonal energy use profile.

Seasonal Energy Consumption

System Flow	200	GPM
Fetch Plot Acres	5.29	Acres
Pressure	105	PSI
Lift	20	ft.
Total Dynamic Head	262.55	ft.
Pump Efficiency	76%	
Required Output HP	17.45	HP
Required Input HP	22.96	HP
Consumed Power	17.13	kWh/hr.
Consumed Power / Acre-inch	38.55	KWh/Acre-inch
Consumed Energy / Acre-inch	131,524	BTU / Acre-inch
Energy Cost	$ 0.13	/ kWh

Annual Inches Applied	Annual Energy Consumed (BTU)	Annual Energy Cost
15	10,436,463	$ 397.64
20	13,915,283	$ 530.18
25	17,394,104	$ 662.73
30	20,872,925	$ 795.28
35	24,351,746	$ 927.82
40	27,830,567	$ 1,060.37