Report for 2002KS7B: Development of a Framework for a Coupled Hydrologic-Economic Modeling Tool

There are no reported publications resulting from this project.

Report Follows:

Development of a Framework For A Coupled Hydrologic-Economic Modeling Tool

Progress Report

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1. Statement of Problem

This proposal addresses the critical issue of groundwater declines in the High Plains Aquifer of western Kansas. Groundwater is crucial for sustained economic vitality of this rural, agricultural region. These groundwater resources are limited and being depleted. There is a clear need for a modeling tool to help identify economically viable groundwater management strategies to sustain this important region.

This will contribute to the following objective of the State Water Plan.

3.1.6 By 2010, reduce water level decline rates within the Ogallala Aquifer and implement enhanced water management in targeted areas.

The hydrology of groundwater flow in western Kansas is fairly well understood. Much of this region is in transition from pre-development conditions, with a large volume of groundwater in storage, to depleting conditions, with less available storage. The economic transition of agriculture in western Kansas is also fairly well understood. As less water becomes available for irrigation, land use choices favor less water intensive farming practices such as dry-land wheat and grazing land.

The trends in the irrigation economy in western Kansas were reviewed by Peterson and Bernardo (2003). Although groundwater levels continue to decline throughout most of the region, irrigated acreage and total water use have remained relatively stable. During the 1990s, a rapidly increasing share of irrigated acreage was planted to water-intensive crops (corn and alfalfa). Over the same period, many irrigators invested in more efficient irrigation technology, converting from inefficient flood systems to more efficiency center pivot sprinkler systems. Groundwater withdrawals during recent decades were likely encouraged by falling real energy prices and government support programs for crop prices.

While the groundwater hydrology and economic transition of western Kansas are fairly well understood, the links between these two processes is not well understood. In particular, we do not have a scientific tool that links farm economy to physical hydrologic processes. The framework for such a tool is being developed for this proposal.

2. Research Objectives

The goal is to develop a framework for linking hydrologic and economic models. Specific objectives include:

- Assemble hydrologic and economic data for the GMD4 Sheridan County Special Study Area.
- Construct hydrologic and economic models of the study area.
- Use knowledge developed in creating the hydrologic and economic models to design data structures and flow of data within a fully coupled hydrologic-economic modeling tool.

The final design will enable a modeling tool to forecast the impact of groundwater management strategies on water availability and farm profits.

3. Methodology

Hydrologic and economic models are being developed for the GMD4 Sheridan County Special Study Area in western Kansas. This study area has been identified in cooperation with Groundwater Management District #4. A hydrologic model has been developed for the area including wells and regional groundwater withdrawal. An economic model has also been developed to describe irrigation decisions. Both models are being run forward in time to predict the future hydrologic and economic conditions assuming groundwater management strategies and policy do not change.

The goal of constructing this model of groundwater flow and economic decisions is to develop understanding related to coupling hydrologic and economic models. This knowledge is being used to design data structures and the flow of data within a coupled model. It is expected that the final design that is developed for this project will enable future development of a fully coupled, automated hydrologic-economic modeling tool, as part of a future project.

Methodology to develop a linked hydrologic/economic model is described in this section. First, the data used within the models are identified. Next, the individual hydrologic and economic modeling tools are described. Finally, the integrated modeling environment is described.

Data

Hydrologic and geologic data are required for the groundwater model. The data type and online source for this data follows:

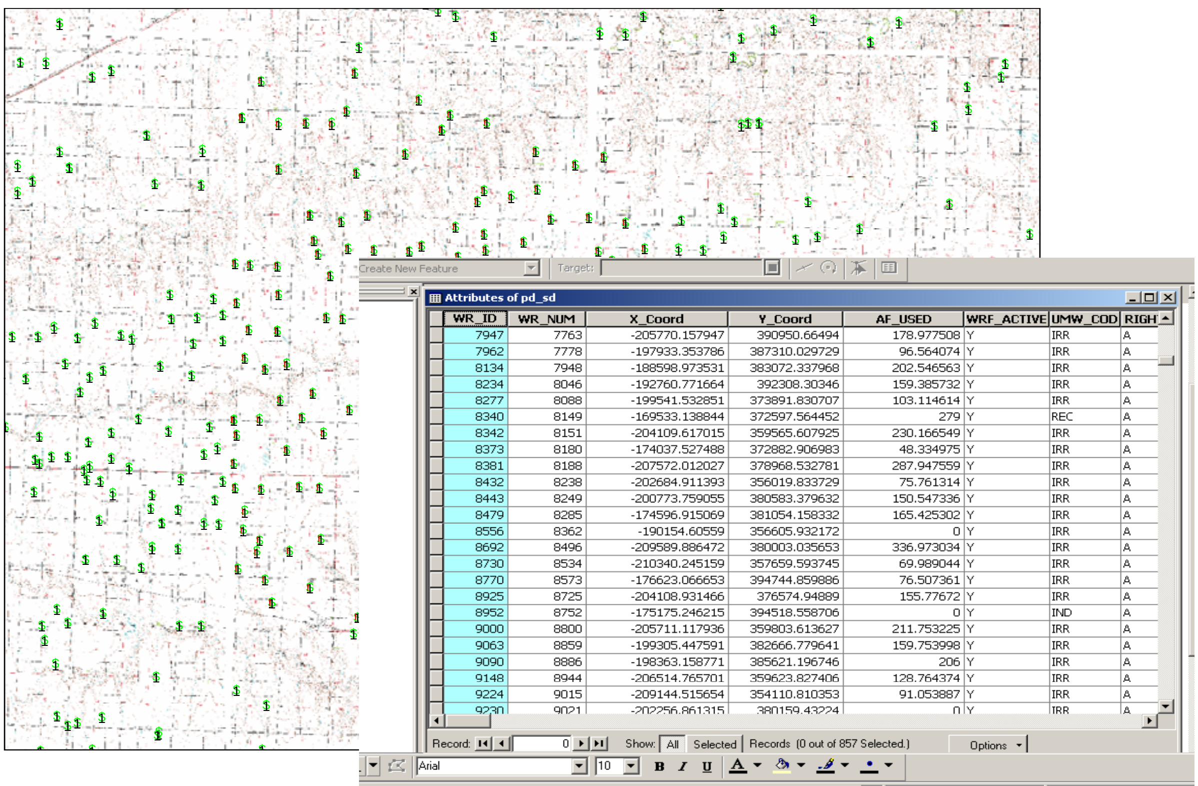
- Recharge
  DASC (Data Access Service Center)
  http://gisdasc.kgs.ukans.edu/metadata/kats.html
- Hydraulic Conductivity
  USGS Open File Report 98-548
  http://water.usgs.gov/GIS/metadata/usgswrd/ofr98-548.html
- Specific Yield
  USGS Open File Report 98-414
  http://water.usgs.gov/GIS/metadata/usgswrd/ofr98-414.html
- Saturated Thickness
  USGS Open File Report 99-264 (pre-development)
  http://water.usgs.gov/GIS/metadata/usgswrd/ofr99-264.htm
  USGS Open File Report 00-300 (1996-1997)
  http://water.usgs.gov/GIS/metadata/usgswrd/ofr00-300_sattk9697.html
  USGS Open File Report 99-262 (1980)
  http://water.usgs.gov/GIS/metadata/usgswrd/ofr99-262.htm
- Aquifer Base (Bedrock Elevation)
  USGS Open File Report 98-393
  http://water.usgs.gov/GIS/metadata/usgswrd/ofr98-393.html
- Land Elevation
  DASC

http://gisdasc.kgs.ukans.edu/metadata/dem_24k.html
http://gisdasc.kgs.ukans.edu/metadata/dem_100k.html
http://gisdasc.kgs.ukans.edu/metadata/dem_250k.html

- Wells (location and pumping rate)
  DASC
  http://gisdasc.kgs.ukans.edu/metadata/wimas.html

The data requirements for the economic model include parcel-level and time-series variables. The parcel data include the several of hydrologic variables listed above as well as water use, land use, and type of irrigation system. Hydrologic conditions (specifically, depth to water, saturated thickness, and hydraulic conductivity) affect the economics of water use because they influence pumping costs and well yields. The remaining parcel data are available from the Water Information Management & Analysis System (WIMAS) database listed in the above table. This database includes the annual report data for all irrigated parcels in the state; for our purposes only the parcels in western Kansas for the years 1990-2000 were obtained. A sample of what this database looks like is shown below.

Water Information Management & Analysis System (WIMAS)



WR_ID	WR_NUM	X_Coord	Y_Coord	AF_USED	WRF_ACTIVE	UMW_COD	RIGH
7947	7763	-205770.157947	390950.66494	178.977508	Y	IRR	A
7962	7778	-197933.353786	387310.029729	96.564074	Y	IRR	A
8134	7948	-188598.973531	383072.337968	202.546563	Y	IRR	A
8234	8046	-192760.771664	392308.30346	159.385732	Y	IRR	A
8277	8088	-199541.532851	373891.830707	103.114614	Y	IRR	A
8340	8149	-169533.138844	372597.564452	279	Y	REC	A
8342	8151	-204109.617015	359565.607925	230.166549	Y	IRR	A
8373	8180	-174037.527488	372882.906983	48.334975	Y	IRR	A
8381	8188	-207572.012027	378968.532781	287.947559	Y	IRR	A
8432	8238	-202684.911393	356019.833729	75.761314	Y	IRR	A
8443	8249	-200773.759055	380583.379632	150.547336	Y	IRR	A
8479	8285	-174596.915069	381054.158332	165.425302	Y	IRR	A
8556	8362	-190154.60559	356605.932172	0	Y	IRR	A
8692	8496	-209589.886472	380003.035653	336.973034	Y	IRR	A
8730	8534	-210340.245159	357659.593745	69.989044	Y	IRR	A
8770	8573	-176623.066653	394744.859886	76.507361	Y	IRR	A
8925	8725	-204108.931466	376574.94889	155.77672	Y	IRR	A
8952	8752	-175175.246215	394518.558706	0	Y	IND	A
9000	8800	-205711.117936	359803.613627	211.753225	Y	IRR	A
9063	8859	-199305.447591	382666.779641	159.753998	Y	IRR	A
9090	8886	-198363.158771	385621.196746	206	Y	IRR	A
9148	8944	-206514.765701	359623.827406	128.764374	Y	IRR	A
9224	9015	-209144.515654	354110.810353	91.053887	Y	IRR	A
9230	9021	-202256.861315	380159.43224	0	Y	IRR	A

(Source:http://mapster.kgs.ukans.edu/dasc/catalog/coredata.html)

The relevant time series variables include climatic variables and prices. Descriptions of these data and their sources follow:

- Expected crop prices

Computed from time-series models of monthly NASS crop prices
http://www.nass.usda.gov:81/ipedb/

- Energy prices
  Index constructed from BLS Kansas energy prices
  http://www.bls.gov/eag/eag.KS.htm
- Input prices
  Index of prices paid by farmers for all production items
- Evapotranspiration (ET), rainfall
  K-State Research and Extension Weather Data Library
  http://www.oznet.ksu.edu/wdl/

The calculations for expected crop prices and energy prices are described in Appendix A. The role of each variable in the economic model is discussed in the following section.

Modeling Tools

Hydrologic and economic models have been developed for the study area. The purpose of the groundwater model is to examine how the groundwater head in the study area declines over time. The purpose of the economic model is to examine how the economic conditions of local water users change over time as groundwater levels decline. Both models will be run in tandem on a yearly cycle to forecast the evolution of hydrologic and economic conditions.

A groundwater model has been developed for the study area that places the local hydrogeology into the regional context of flow in the High Plains Aquifer. The yearly pumping of all wells in the study area is modeled using the Theis solution. Regional flow produced by recharge and bedrock formations with changing elevation will also be included. The complete theory behind these models may be found in Strack (1989) or Haitjema (1995).

The computer program MLAEM has been used for this investigation for two reasons:

1. The local detail of each well is implicitly incorporated into the model. This is important, since the economic model needs information about the head and pumping rate of each well.
2. A GIS-interface is available for this program. This is important, since the fully coupled hydrologic-economic model will eventually be linked to the state's GIS-databases.

The purpose of the economic model is to predict irrigators' water-use and land-use decisions. This decision process is modeled using the conceptual framework of Chambers and Just (1989). Each irrigator makes the two decisions in a sequential fashion by parcel; the crop selection is first made and the levels of water use and other inputs are then chosen.

These two decisions are most usefully analyzed in reverse order. Assuming z_i acres on a given parcel have been planted to crop i, the conditional expected profit from that crop is given by

(1) $$\pi_i(p_y^i, \mathbf{p}_x, p_e, \boldsymbol{\theta}, z_i) = \max_{w_i, \mathbf{x}_i} \left\{ p_y^i f_i(w_i, \mathbf{x}_i, z_i, \boldsymbol{\theta}) - \mathbf{p}_x \cdot \mathbf{x}_i - c(p_e, \boldsymbol{\theta}) w_i \right\}$$

where $\mathbf{p}_y^i$ is the expected price of crop *i*, $\mathbf{x}_i$ is a vector of non-water variable inputs used for crop *i* (e.g., fertilizer, seed), $\mathbf{p}_x$ is the corresponding input price vector, p_e is the price of energy, θ represents site-specific characteristics (hydrologic conditions, soil type, irrigation system type, etc.), *f*(·) is the production function for crop *i*, and *c*(·) is the marginal cost function of water delivery. Equation (1) implies crop-specific water demand function of the form

(2) $$w_i(p_y^i, \mathbf{p}_x, p_e, \boldsymbol{\theta}, z_i)$$

That is, the water use for the *i*th crop on a given parcel depends on the price crop *i*, the prices of other inputs and energy, site specific factors, and the acreage planted to crop *i*.

The profit-maximizing crop selection can be found from the crop specific profit functions in equation (1). That is, if a parcel contains a total of *z* acres and there are a total of *m* crop alternatives, an irrigator sets acreage levels by solving

(3) $$\max_{z_1,\ldots z_n}\left\{\sum_{i=1}^{m}\pi_i(p_y^i, \mathbf{p}_x, p_e, \boldsymbol{\theta}, z_i) : \sum_{i=1}^{m} z_i = z\right\}$$

The solutions to this problem are the acreage allocation equations:

(4) $$z_i(\mathbf{p}_y, \mathbf{p}_x, p_e, \boldsymbol{\theta}, z),$$

where $\mathbf{p}_y = (p_y^1, \ldots, p_y^m)$ is the vector of crop prices.

Empirically estimated versions of equations (2) and (4) form the basis of the economic modeling tool. Equation (2) can be consistently estimated for each crop using ordinary least squares (OLS) regression, given data on water use on the crop in question, prices, site-specific factors, and irrigated acreage. Equation (4), however, requires the use of limited dependent variable regression techniques (Greene, 1993) because each z_i is restricted between zero and *z*.

Preliminary estimates of the crop water use equations in (2) have been obtained, while estimation of (4) is underway. To estimate the water use equations, individual datasets for each of the five major crops in western Kansas were created. Over the $T = 11$ year period of available data (1990 – 2000), the crop-*i* dataset contains a total of $N_i = \sum_{t=1}^{T} n_{it}$ observations, where n_{it} is the number of parcels planted to crop *i* in year *t*. The regression equation for each crop was specified as a quadratic form:

(5) $$w_j = \sum_{k=1}^{K}\beta_k r_{kj} + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K}\delta_{kl} r_{kj} r_{lj} + \varepsilon_j, \quad j = 1, \ldots, N_i$$

where *j* indexes observations, w_j is observed water use, r_{kj} is the *k*th regressor (i.e., the r_{kj}'s are the arguments of w_i(.) in equation (2)), the β_k's and δ_{kl}'s are parameters to be estimated, and ε_j is a mean-zero random disturbance variable.

The datasets to estimate equation (5) were compiled from all points of diversion in the WIMAS database in western Kansas for the period 1990-2000. To account for time-series and fixed cross-sectional effects, a time trend variable and county dummy variables (with Sheridan county as the base) were included as additional regressors. The summary statistics of the regression data are in table B1 (Appendix B). These statistics verify that alfalfa and corn receive substantially more water than the other crops and were grown on more parcels.

The estimation results are in tables B2 – B6 in appendix B. The overall fit of the regressions was adequate, with adjusted R-squares ranging from about 0.41 to 0.62. Most of the individual coefficients are statistically different from zero at the 95% level of confidence or higher. The magnitudes of the individual coefficients are difficult to interpret because in the quadratic form each regressor affects the dependent variable through one or more terms (equation (5)). To aid in interpretation, the elsticities of all independent variables are reported in the table below.

Estimated Elasticities

Variable	Alfalfa	Corn	Sorghum	Soybeans	Wheat
NUMYEAR	0.451	0.296	0.383	0.141	-0.010
ACRES_IRR	0.729	0.817	0.889	0.787	0.927
EXPRICE	1.094	1.045	1.479	0.056	0.122
ST	0.074	0.094	0.127	0.010	0.083
HYDRACOND	-0.0224	0.002	0.049	-0.009	-0.133
RAIN 1	-0.128	-0.059	-0.102	-0.002	-0.019
RAIN 2	-0.077	-0.022	0.010	-0.015	-0.120
RAIN 3	-0.230	-0.249	-0.259	-0.379	-0.196
TOTALET	0.256	0.365	0.508	0.287	0.067
METER	-0.055	-0.075	-0.097	-0.014	-0.108
PRICEINDEX	-4.962	-2.995	-10.192	-0.902	-0.981
HPIVOT	0.043	0.847	1.175	0.634	-0.026
LPIVOT	0.110	1.026	0.452	-0.872	1.634
OTHER	-1.078	-0.014	-2.942	-0.737	-4.709
SPRINKLER	0.323	0.067	1.218	-5.401	-1.895
DTW[a]					
FLOOD	0.060	0.249	0.174	0.093	0.131
HPIVOT	0.070	0.204	0.148	0.045	0.057
LPIVOT	0.046	0.222	0.149	0.071	0.095
OTHER	0.061	0.249	0.174	0.094	0.128
SPRINKLER	0.056	0.248	0.171	0.091	0.130
EINDEX[a]					
FLOOD	-0.821	-2.502	-2.677	0.202	0.906
HPIVOT	-0.805	-2.729	-2.949	-0.062	0.947
LPIVOT	-0.807	-2.688	-2.680	0.496	0.692
OTHER	-0.811	-2.505	-2.651	0.213	0.980
SPRINKLER	-0.825	-2.503	-2.684	0.227	0.926

[a] Because of the ineraction terms in the estimated equations, the elasticites for depth to water (*DTW*) and energy index depend (*EINDEX*) on the irrigation system.

Each elasticity value is the percentage change in water use in response to a 1% change of an independent variable, holding all else constant. As expected, water use responds positively to changes in the expected output price (*EXPRICE*), although the effect is substantially stronger for alfalfa, corn, and sorghum than for soybeans and wheat. Also as expected, water use is inversely related to changes in rainfall (*RAIN_1*, *RAIN_2*, *RAIN_3*), but the rainfall elastiticities are all less than one in absolute value; these estimates suggest that rainfall and irrigation water are not perfect substitutes. The negative elasticities for *METER* imply that reported water use is smaller for metered wells, or equivalently, irrigators without meters tend to over-report water consumption.

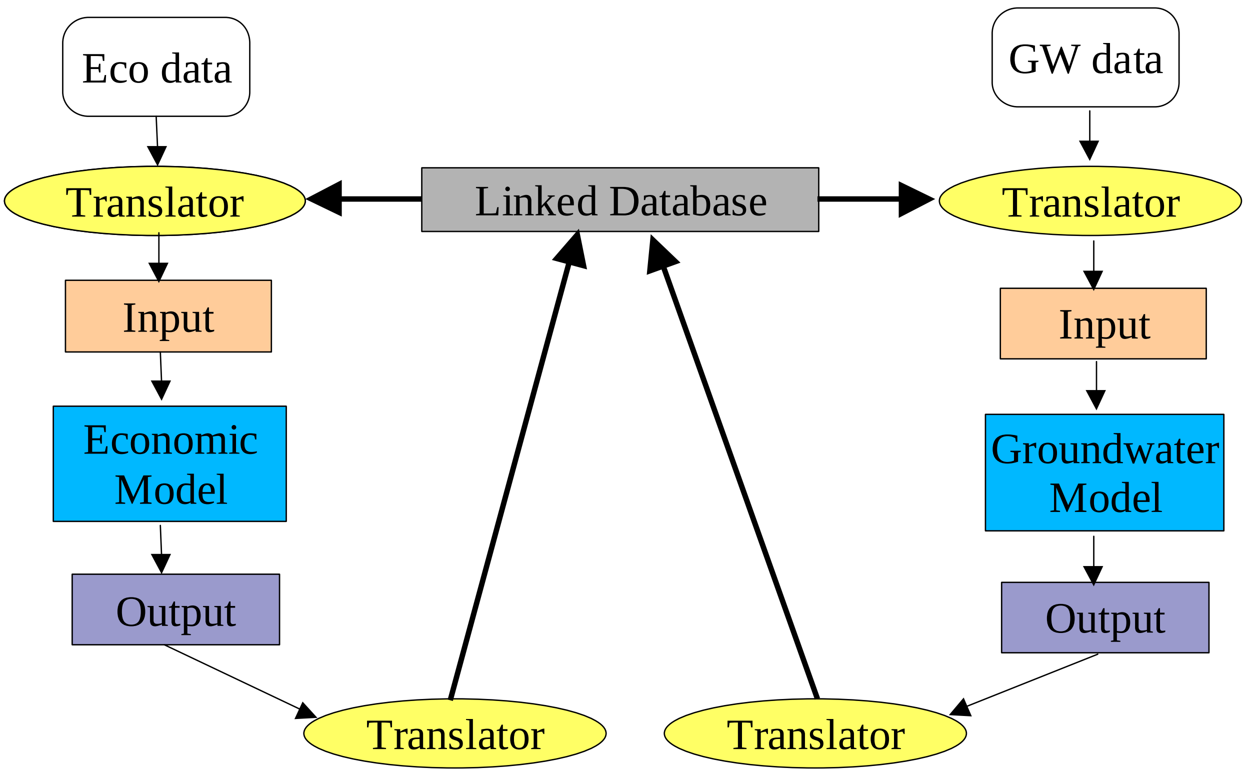
Many of the results explain recent irrigation trends in western Kansas. For example, water use has not declined significantly during the 1990s even though irrigators have rapidly adopted more efficient irrigation systems (Peterson and Bernardo, 2003). This trend is consistent with the positive estimated elasticities for efficient irrigation systems (*HPIVOT* and *LPIVOT*). Because flood irrigation is the base system type, this indicates that irrigators actually increase water use on all crops after a high-efficiency system is installed (except for soybeans with an *LPIVOT* system). The policy significance of this finding is that policies to encourage investments in high efficiency systems may not result in groundwater conservation. A trend toward increased water use is also reflected in the positive elasticities for *NUMYEAR*, indicating that the amount of groundwater pumped on a typical corn field is increasing each year throughout the time period, all else held constant.

Integrated Modeling Environment

Data structures are being designed that contain information needed for input and output of each model. The flow of data between models has also been identified. A linked database contains information about both hydrology and economics. Information is organized using records, where each record contains information about one well. Additional data is needed for both the groundwater model (e.g., aquifer properties) and the economic model (e.g., prices). Translators are being developed to assemble data and format it into input data that is immediately accessible by the groundwater and economic models. Output results from the groundwater and economic models are then used to fill the linked database. In this way, future projections of groundwater data (e.g., pumping rates and groundwater elevations) and economic data (e.g., costs and benefits) can be assembled for individual wells.

As of the writing of this project report, we are able to run each model independently using this data design. We will run the models in tandem over a number of years and include this information in the final report. We will also put forth the final design of the data structures in the final report.

Economic Model - Groundwater Model Coupling Diagram



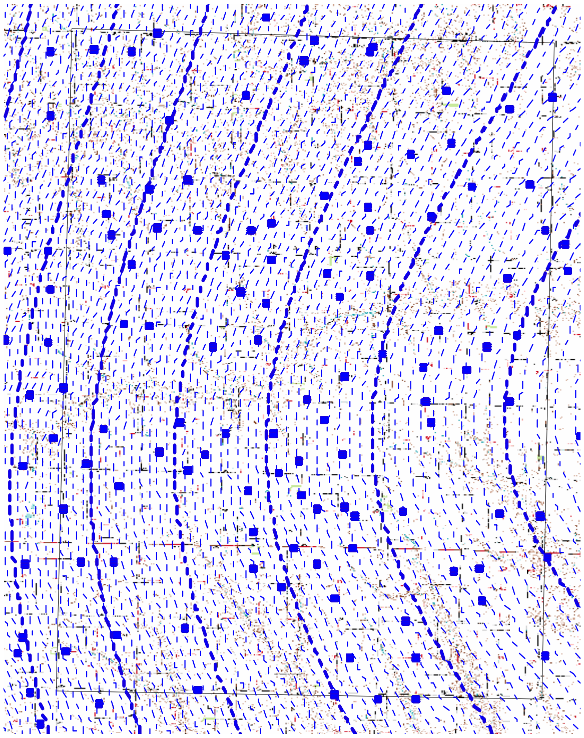
4. Principal Findings

In this section, we will show preliminary results from running groundwater models and economic models in the study region. The following figure shows the groundwater elevation within the study region at two times; the left-hand figure is the elevation prior to pumping during the growing season and the right-hand figure is at the end of the growing season. This model was constructed using the published aquifer and recharge data from online sources listed earlier. The pumping rate for each well was obtained from the WIMAS database. This data is obtained from water use reports, which must be filed with the Department of Agriculture in Kansas for each water permit.

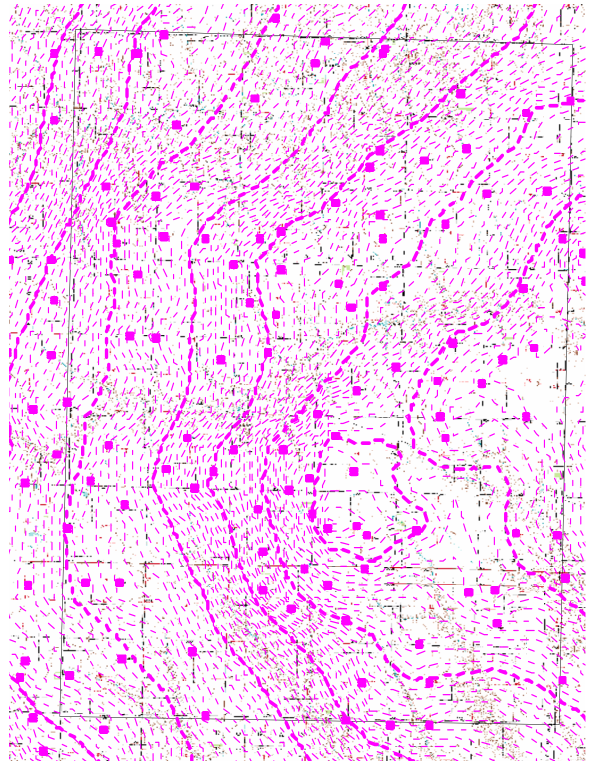
The groundwater model is being run backwards in time and compared to historical drawdowns in the region, which have averaged about 0.3m/year for the past 40 years. Predicated groundwater elevations are also being compared to observation wells in the region. Model results show that groundwater elevations are accurately reproduced by the model, with predicted elevations within 1-2m of field observations.

The groundwater model is also being run forward in time to forecast the groundwater elevation at future times. Results from these calculations will be integrated with results from the economic model in the final report.

Groundwater head at start of growing season



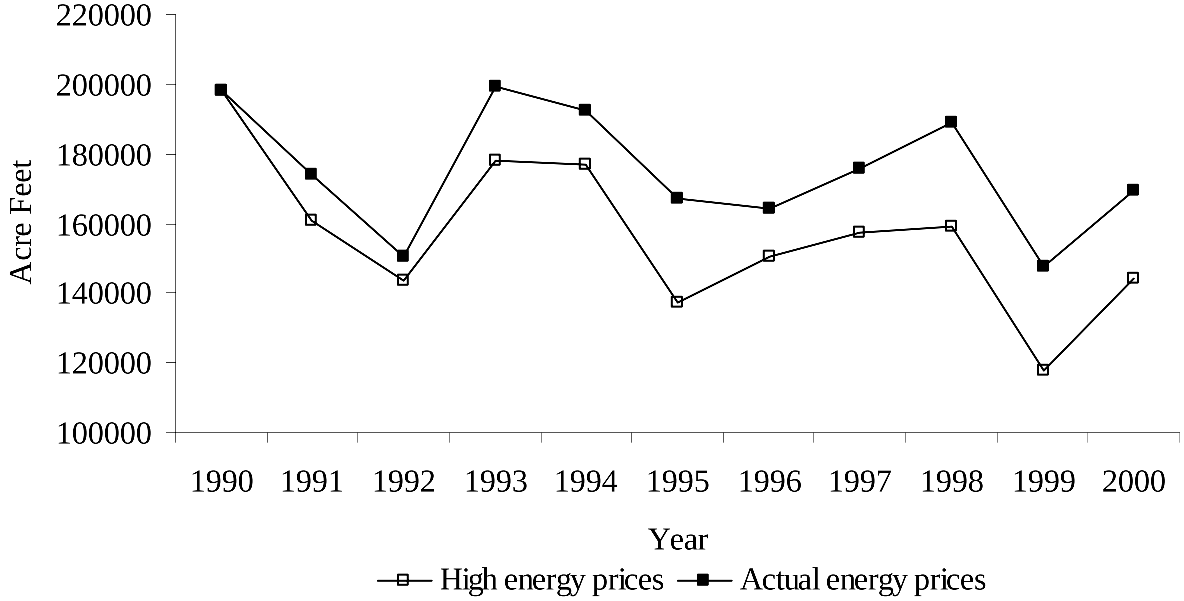
Groundwater head after 80 days of pumping



The water-use equations from the economic model were used to conduct several counter-factual simulations. For example, to investigate the effect of energy prices on corn irrigation, the regression equation for corn was used to predict water use when energy prices were held constant at their highest level observed during the study period. To determine the effect of such a change on total irrigation in all of western Kansas, the predicted values were aggregated across all observations in the dataset. The figure below compares this simulated trajectory to the one for actual energy prices. The highest energy prices throughout the time period were in 1990; if energy prices would have remained at this level, total acre feet pumped would have fallen by an average of 18,480 acre feet per year after 1990 for a total reduction of 203,272 acre feet over the 11 year time period (representing 10.5% of actual water use).

An important limitation of the simulation in the figure is that it does not account for changes in crop acreage or hydrologic conditions. With higher energy prices, producers are likely to substitute land out of corn production into crops that are less water intensive. Similarly, the induced changes water depth would have affected pumping costs. These linkages will be addressed in the fully coupled model to be described in the final report.

Simulated Effect of Energy Prices on Corn Irrigation, Western Kansas



5. Significance

Data has been identified and assembled to model groundwater flow and economics within the GMD 4 Sheridan County Special Study Area. Models of this study area are being constructed and validated against historical data. This effort is leading to knowledge necessary to develop a fully coupled hydrologic-economic modeling tool.

This pilot study is expected to lead to future proposals that will develop a fully coupled hydrologic-economic modeling tool with GIS support. Such a tool will be capable of analyzing the impact of various groundwater management strategies on the agriculture economy of Kansas. This will enable proactive identification of economically viable groundwater management strategies. The work being performed for this project is creating the framework necessary for future model development.

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Appendix A: Expected output prices and energy price index

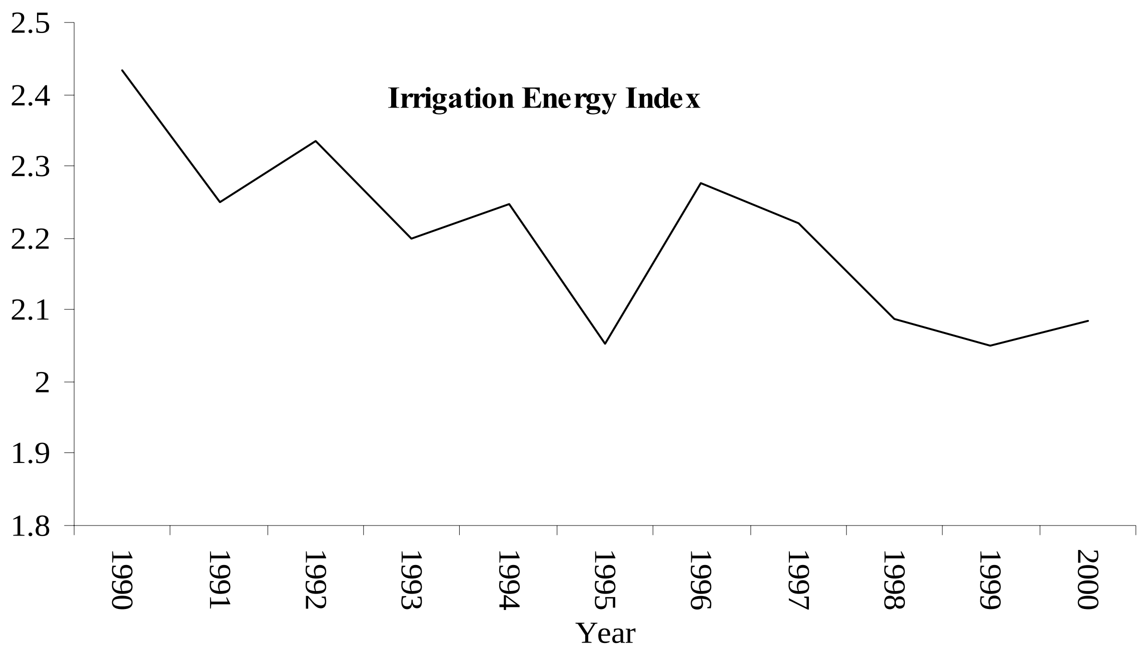
At the time water use decisions are made, an irrigator's expectation of output price is unobservable. Expected price data were constructed using the hypothesis of quasi-rational expectations: irrigators are assumed to form price expectations based on previous price trends. Time-series models of prices for the five major crops in western Kansas (alfalfa, corn, grain sorghum, soybeans, and wheat) were estimated from monthly price data obtained from the National Agricultural Statistics Service (NASS).

These time series models produce a function that predicts the expected price in month *m* as a function of prices in a fixed number of previous months: $E[P_m \mid I_{m-1}] = f(P_{m-1},...,P_{m-n})$, where $E[P_m \mid I_{m-1}]$ denotes the expected price in month m given information available in month $m - 1$. By iterating this function over a number of months, it is possible to obtain an estimate of prices in month P_{m+x} given information at $m - 1$. For all crops, expected price variables were generated as the expected price following harvest, given information available at planting.

The energy price index (*EINDEX)* was developed to reflect energy costs of irrigators in Western Kansas. It is defined as:

$$EINDEX = (\pi_{\text{electricity}} * P_{\text{electricity}}) + (\pi_{\text{gas}} * P_{\text{gas}}) + (\pi_{\text{propane}} * P_{\text{propane}}) + (\pi_{\text{diesel}} * P_{\text{diesel}}),$$

where π_x is the percent of wells powered by energy source *x* in a given year (taken from the *1997 Census of Agriculture*, NASS) and P_x is the price of energy source *x* in BTU's, expressed in 1977 dollars). As shown in the graph below, this index value reflects a general declining trend in energy prices during the study period.



Appendix B: Regression Statistics

Table B1. Statistics of Water-Use Data Regression Data

Variable	Description	Data Means (Standard Deviation)				
		Alfalfa	Corn	Sorghum	Soybean	Wheat
AF_USED	Irrigation water use (acre feet)	220.93 (114.92)	185.47 (115.51)	103.23 (95.04)	139.47 (87.45)	110.61 (99.04)
NUMYEAR	Year (1990=1, 2000=11)	5.24 (3.15)	5.68 (3.06)	3.57 (2.79)	5.96 (3.59)	4.10 (3.12)
ACRES_IRR	Acres irrigated	131.21 (50.86)	133.32 (65.09)	102.79 (62.42)	121.19 (59.07)	131.43 (61.78)
EXPRICE	Expected commodity price ($)	46.56 (5.85)	1.76 (0.42)	3.00 (0.55)	3.96 (0.66)	2.08 (0.54)
DTW	Depth to groundwater (ft)	117.97 (65.85)	143.44 (58.58	124.62 (55.08)	132.50 (57.95)	132.54 (60.45)
ST	Aquifer saturated thickness (ft)	204.78 (96.36)	153.29 (102.84)	102.95 (88.23)	142.71 (94.73)	172.74 (106.31)
HYDRACOND	Hydraulic conductivity (ft/day)	84.13 (23.20)	80.61 (24.27)	79.36 (25.76)	82.93 (23.83)	78.81 (25.87)
EINDEX	Index of energy prices	2.19 (0.12)	2.19 (0.11)	2.24 (0.11)	2.18 (0.13)	2.23 (0.12)
RAIN_1	Previous October-December rainfall (in)	2.06 (1.21)	1.91 (1.30)	2.04 (1.19)	1.91 (1.35)	1.99 (1.19)
RAIN_2	January-March rainfall (in)	7.37 (2.64)	6.71 (2.59)	6.46 (2.84	6.80 (2.61)	7.12 (2.94)
RAIN_3	May-August rainfall (in)	9.51 (6.97)	10.09 (6.12)	8.99 (5.27)	8.82 (4.82)	8.81 (5.82)
TOTALET	Growing season evapotranspiration (in)	36.46 (5.46)	39.13 (5.74)	32.39 (5.02)	35.44 (5.35)	48.02 (9.94)
METER	Dummy for metered well	0.55 (0.50)	0.44 (0.50)	0.25 (0.43	0.42 (0.49)	0.35 (0.48)
PRICEINDEX	Index of Prices Paid by producers	108.86 (6.43)	109.80 (6.28)	105.81 (6.33)	109.31 (6.47)	106.71 (6.46)
HPIVOT	Dummy for high-pressure center pivot system	0.60 (0.49)	0.42 (0.49)	0.30 (0.46)	0.41 (0.49)	0.49 (0.50)
LPIVOT	Dummy for low-pressure center pivot system	0.22 (0.42)	0.28 (0.45)	0.06 (0.25)	0.32 (0.47)	0.17 (0.38)
OTHER	Dummy for other system type	0.01 (0.10)	0.03 (0.18)	0.01 (0.11)	0.01 (0.12)	0.02 (0.13)
SPRINKLER	Dummy for fixed sprinkler system	0.03 (0.17)	0.01 (0.07)	0.01 (0.09)	0.01 (0.06)	0.01 (0.11)
Number of observations		10,352	45,444	4,251	1,699	6,185

Table B2. Regression Results: Alfalfa Water Use

Variable	Coefficent	Standard Error	P-Value
INTERCEPT	6009.384	1241.883	<.0001
NUMYEAR	18.997	5.579	0.001
ACRES IRR	1.537	0.034	<.0001
ACRESIRR^2	-0.001	0.000059	<.0001
EXPRICE	28.266	9.873	0.004
EXPRICE^2	-0.248	0.099	0.012
DTW	0.294	0.074	<.0001
DTW2	-0.00077	0.00015	<.0001
ST	0.192	0.064	0.003
ST2	-0.00027	0.000094	0.004
HYDRACOND	1.462	0.304	<.0001
HYDRACOND^2	-0.010	0.0020	<.0001
*ST*HYDRACOND*	0.00083	0.00037	0.028
*DTW*HYDRACOND*	-0.00059	0.00058	0.314
EINDEX	-82.624	34.077	0.015
RAIN 1	-23.579	6.772	0.0005
RAIN 1^2	2.395	1.241	0.054
RAIN 2	3.595	4.913	0.464
RAIN 2^2	-0.399	0.353	0.259
RAIN 3	-10.921	1.867	<.0001
RAIN 3^2	0.294	0.050	<.0001
TOTALET	2.510	4.275	0.557
TOTALET^2	-0.013	0.053	0.805
METER	-12.542	2.513	<.0001
PRICEINDEX	-115.168	24.521	<.0001
PRICEINDEX^2	0.483	0.105	<.0001
HPIVOT	8.978	70.580	0.899
*EINDEX*HPIVOT*	2.667	32.080	0.934
*DTW*HPIVOT*	0.032	0.037	0.376
LPIVOT	23.258	81.354	0.775
*EINDEX*LPIVOT*	6.035	37.226	0.871
*DTW*LPIVOT*	-0.116	0.043	0.007
OTHER	-226.970	207.613	0.274
*EINDEX*OTHER*	102.788	94.695	0.278
*DTW*OTHER*	0.217	0.118	0.065
SPRINKLER	67.991	126.135	0.590
*EINDEX*SPRINKLER*	-15.025	57.869	0.795
*DTW*SPRINKLER*	-0.224	0.093	0.016
Adjusted R-Square	0.4892		

Table B3. Regression Results: Corn Water Use

Variable	Coefficent	Standard Error	P-Value
INTERCEPT	4684.734	293.588	<.0001
NUMYEAR	9.690	1.402	<.0001
ACRES IRR	1.384	0.016	<.0001
ACRESIRR^2	-0.00093	0.000	<.0001
EXPRICE	299.167	35.149	<.0001
EXPRICE^2	-53.641	7.757	<.0001
DTW	0.399	0.032	<.0001
DTW2	-0.00027	0.000068	<.0001
ST	0.249	0.022	<.0001
ST2	-0.00044	0.000036	<.0001
HYDRACOND	0.428	0.112	0.000
HYDRACOND^2	-0.0027	0.00073	0.000
*ST*HYDRACOND*	0.0018	0.00014	<.0001
*DTW*HYDRACOND*	-0.0018	0.00026	<.0001
EINDEX	-212.511	10.566	<.0001
RAIN 1	-4.926	1.766	0.005
RAIN 1^2	-0.221	0.331	0.505
RAIN 2	-7.220	1.030	<.0001
RAIN 2^2	0.492	0.076	<.0001
RAIN 3	-8.507	0.381	<.0001
RAIN 3^2	0.194	0.011	<.0001
TOTALET	1.915	1.124	0.088
TOTALET^2	-0.0023	0.014	0.870
METER	-14.567	0.970	<.0001
PRICEINDEX	-80.246	5.303	<.0001
PRICEINDEX^2	0.342	0.023	<.0001
HPIVOT	96.084	19.184	<.0001
*EINDEX*HPIVOT*	-45.785	8.648	<.0001
*DTW*HPIVOT*	-0.140	0.014	<.0001
LPIVOT	116.446	23.402	<.0001
*EINDEX*LPIVOT*	-56.744	10.765	<.0001
*DTW*LPIVOT*	-0.124	0.016	<.0001
OTHER	-1.630	46.658	0.972
*EINDEX*OTHER*	-4.455	21.319	0.835
*DTW*OTHER*	0.0044	0.029	0.883
SPRINKLER	7.647	117.901	0.948
*EINDEX*SPRINKLER*	2.407	52.998	0.964
*DTW*SPRINKLER*	-0.250	0.070	0.0004
Adjusted R-Square	0.6206		

Table B4. Regression Results: Grain Sorghum Water Use

Variable	Coefficent	Standard Error	P-Value
INTERCEPT	6174.383	743.753	<.0001
NUMYEAR	11.069	2.697	<.0001
ACRES IRR	0.988	0.042	<.0001
ACRESIRR^2	-0.00047	0.00011	<.0001
EXPRICE	156.414	42.122	0.0002
EXPRICE^2	-17.588	5.784	0.002
DTW	0.160	0.085	0.059
DTW2	-0.00006	0.00019	0.739
ST	0.108	0.065	0.095
ST2	0.000093	0.00012	0.423
HYDRACOND	0.327	0.308	0.288
HYDRACOND^2	-0.002	0.002	0.359
*ST*HYDRACOND*	0.00062	0.00046	0.171
*DTW*HYDRACOND*	-0.00028	0.00078	0.719
EINDEX	-123.135	22.671	<.0001
RAIN 1	4.538	5.235	0.386
RAIN 1^2	-2.377	0.975	0.015
RAIN 2	-1.874	2.473	0.449
RAIN 2^2	0.158	0.171	0.356
RAIN 3	-5.140	1.146	<.0001
RAIN 3^2	0.120	0.032	0.000
TOTALET	14.378	3.461	<.0001
TOTALET^2	-0.197	0.051	0.000
METER	-10.203	2.906	0.001
PRICEINDEX	-113.101	13.179	<.0001
PRICEINDEX^2	0.487	0.060	<.0001
HPIVOT	89.197	60.114	0.138
*EINDEX*HPIVOT*	-41.482	26.867	0.123
*DTW*HPIVOT*	-0.072	0.042	0.084
LPIVOT	34.306	92.709	0.711
*EINDEX*LPIVOT*	-2.032	42.069	0.962
*DTW*LPIVOT*	-0.324	0.077	<.0001
OTHER	-223.394	185.087	0.228
*EINDEX*OTHER*	98.944	83.399	0.236
*DTW*OTHER*	0.028	0.148	0.848
SPRINKLER	92.469	274.314	0.736
*EINDEX*SPRINKLER*	-33.828	124.319	0.786
*DTW*SPRINKLER*	-0.286	0.173	0.097
Adjusted R-Square	0.5587		

Table B5. Regression Results: Soybean Water Use

Variable	Coefficent	Standard Error	P-Value
INTERCEPT	3000.003	1512.110	0.047
NUMYEAR	3.304	6.743	0.624
ACRES IRR	1.078	0.051	<.0001
ACRESIRR^2	-0.00071	0.000058	<.0001
EXPRICE	49.573	49.926	0.321
EXPRICE^2	-6.015	6.654	0.366
DTW	0.012	0.146	0.937
DTW2	0.00032	0.00029	0.269
ST	-0.144	0.115	0.214
ST2	0.00054	0.00021	0.010
HYDRACOND	0.846	0.511	0.098
HYDRACOND^2	-0.0055	0.0036	0.124
*ST*HYDRACOND*	0.0013	0.00078	0.088
*DTW*HYDRACOND*	-0.0011	0.0014	0.409
EINDEX	12.953	49.534	0.794
RAIN 1	2.577	8.698	0.767
RAIN 1^2	-0.720	1.627	0.658
RAIN 2	-2.155	4.976	0.665
RAIN 2^2	0.135	0.364	0.710
RAIN 3	-10.133	2.146	<.0001
RAIN 3^2	0.235	0.059	<.0001
TOTALET	17.149	6.218	0.006
TOTALET^2	-0.226	0.087	0.010
METER	-1.976	4.701	0.674
PRICEINDEX	-61.353	25.799	0.018
PRICEINDEX^2	0.275	0.111	0.013
HPIVOT	93.508	94.674	0.324
*EINDEX*HPIVOT*	-41.262	42.865	0.336
*DTW*HPIVOT*	-0.123	0.068	0.072
LPIVOT	-128.652	117.852	0.275
*EINDEX*LPIVOT*	58.579	54.929	0.286
*DTW*LPIVOT*	-0.073	0.076	0.339
OTHER	-108.718	390.290	0.781
*EINDEX*OTHER*	47.087	185.723	0.800
*DTW*OTHER*	0.101	0.201	0.615
SPRINKLER	-796.636	591.938	0.179
*EINDEX*SPRINKLER*	382.780	277.360	0.168
*DTW*SPRINKLER*	-0.411	0.469	0.381
Adjusted R-Square	0.5115		

Table B6. Regression Results: Wheat Water Use

Variable	Coefficent	Standard Error	P-Value
INTERCEPT	1107.056	833.297	0.184
NUMYEAR	-0.282	2.333	0.904
ACRES IRR	0.790	0.046	<.0001
ACRESIRR^2	-0.000038	0.00010	0.711
EXPRICE	-21.397	31.405	0.496
EXPRICE^2	6.694	6.935	0.335
DTW	0.049	0.087	0.574
DTW2	0.00023	0.00018	0.197
ST	0.162	0.061	0.008
ST2	-0.00032	0.00010	0.001
HYDRACOND	2.051	0.321	<.0001
HYDRACOND^2	-0.015	0.002	<.0001
*ST*HYDRACOND*	0.0010	0.00039	0.009
*DTW*HYDRACOND*	0.00011	0.00071	0.873
EINDEX	44.955	33.401	0.178
RAIN 1	8.296	6.046	0.170
RAIN 1^2	-2.348	1.100	0.033
RAIN 2	-8.537	4.194	0.042
RAIN 2^2	0.469	0.322	0.146
RAIN 3	-4.475	1.714	0.009
RAIN 3^2	0.115	0.052	0.028
TOTALET	1.900	2.439	0.436
TOTALET^2	-0.018	0.024	0.448
METER	-12.365	2.958	<.0001
PRICEINDEX	-23.136	15.387	0.133
PRICEINDEX^2	0.104	0.070	0.139
HPIVOT	-2.445	62.993	0.969
*EINDEX*HPIVOT*	4.146	28.176	0.883
*DTW*HPIVOT*	-0.126	0.038	0.001
LPIVOT	154.531	82.597	0.061
*EINDEX*LPIVOT*	-60.946	37.758	0.107
*DTW*LPIVOT*	-0.171	0.052	0.001
OTHER	-445.289	163.335	0.006
*EINDEX*OTHER*	208.884	75.013	0.005
*DTW*OTHER*	-0.116	0.089	0.189
SPRINKLER	-179.230	230.651	0.437
*EINDEX*SPRINKLER*	89.250	104.511	0.393
*DTW*SPRINKLER*	-0.045	0.141	0.748
Adjusted R-Square	0.4051		