Department of Agriculture
Division of Water Resources
Topeka Field Office
6531 SE Forbes Ave., Suite B
Topeka, KS 66619

State of Kansas

Phone: (785) 296-5733
Fax: (785) 296-8298
www.agriculture.ks.gov

Governor Jeff Colyer, M.D.
Jackie McClaskey, Secretary of Agriculture

May 9, 2018

Board of Directors
Big Bend Groundwater Management District #5
125 S. Main St.
Stafford, KS 67578

Directors,

Attached are two documents that were developed to explain 1) how KDA-DWR envisions using Climate-based water use estimation to help evaluate the performance of your proposed LEMA, and 2) an updated description of the Climate-based water use estimation method KDA-DWR has developed.

Please review these documents and let us know what questions and comments you have.

Regards,

Chris Beightel, P.E.
Program Manager
Water Management Services
Division of Water Resources
Kansas Department of Agriculture

Using climate-based water use estimation to evaluate the performance of efforts to reduce water use in the proposed GMD5 LEMA area 2020-2024

David Barfield, Chris Beightel. KDA-DWR, May 9, 2018.

To reach the goal of halving the rate of increase in pumping depletions to Rattlesnake Creek streamflow ("Depletions") the LEMA management plan will set an allowable level of groundwater withdrawals in the region where pumping impacts the stream, one allowable level for the LEMA area and another for Zone D.

The allowable levels of pumping were derived by Balleau Groundwater Inc., on behalf of the district by determining the level of pumping reductions from the modeled baseline future, in Zone D[1] needed to halve the rate of increase in depletions when combined with a reduction of 19,000 AF within the LEMA boundary. Table 1 below summarizes these determinations:

Table 1. Reductions required to halve the rate of increase of depletions to Rattlesnake Creek streamflow

Area	Average pumping in baseline future (AF/year)	Reduction to halve the rate of depletion (AF/year)	Average Allowable future pumping (AF/year)	Gross Percentage Reduction
LEMA (inc. Zone D)	230,000	23,000	207,000	10.00%
Zone D	30,000	4,000	26,000	13.33%

Subtracting the reduction from the baseline average pumping gives the average allowable future pumping of groundwater in the LEMA ("Total LEMA Volume") and Zone D ("Total Zone D Volume") over 2020-2029.

Dividing the reductions by average pumping gives the Gross Percentage Reduction needed to halve the rate of increase of Depletions over 2020-2029.

GMD5 has requested that, as part of evaluating whether the actions taken by district water users year-to-year are on track after five years to meet the longer-term goals, allowable withdrawals be adjusted to recognize yearly climate variations. For instance, if the first five-year evaluation period is drier than the baseline average period, there should be a way to allow water users to use relatively more water than they would in a wet period while still working towards the longer-term water reduction goal.

To facilitate this, the Method relates irrigation pumping to precipitation and crop demand (measured as evapotranspiration ("ET")) with high confidence using 2000-2016 data. See Perkins S, Barfield D, Beightel C, Engelhaupt D, Lanterman L, and Pugh G. 2018. An improved water use estimator applied to GMD5 and subareas, 2000-2016 climate and procedures: a regression relationship of groundwater irrigation water use to precipitation and ET. The resulting relationship for this period is the "baseline behavior"- what irrigators have been doing. Water

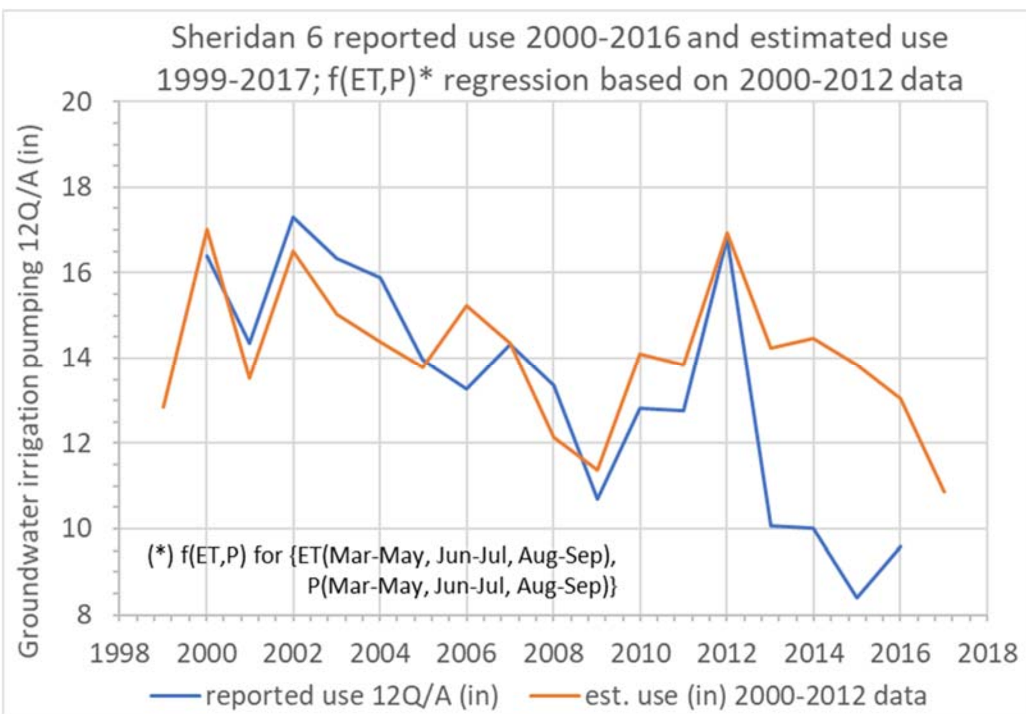
[1] Zone D refers to the area evaluated by the model to have a 40% or greater pumping impact to Rattlesnake Creek streamflow over ten years of pumping. That is, for every 100 acre-feet pumped in this area, 40 acre-feet or more eventually comes from streamflow.

savings over 2020-2024 will then be determined as a change from the baseline behavior, i.e. given similar precipitation patterns and crop demand the Method will show the extent to which the basin's irrigators, via end gun removal and other means, have changed their behavior to reduce water use.

The Total LEMA Volume and Total Zone D Volume over 2020-2029 will be defined in the LEMA management plan and will not be changed by applying the Method. However, the Method would be used to determine whether the basin is on track by evaluating the 5-year period 2020-2024.

To demonstrate how the Method can be used to identify changes to pumping behavior under newly implemented corrective controls, consider the case of the SD-6 LEMA in GMD4 where KDA-DWR applied the Method to identify the baseline behavior over 2000-2012, then used it to compare the water use estimated using the Method ("Climate-based Estimated Use") with the actual reported water use over 2013-2016 when the SD-6 LEMA's controls were in place. Figure 1 below shows that, even when adjusted for climate, using crop demand (ET) and precipitation, water users in SD-6 used significantly less water than their previous behavior would have predicted. For 2013-2016, the area reduced their use 33% compared to the pre-LEMA behavior, well exceeding the LEMA's 20% reduction goal.

Figure 1. Estimated and actual water use in the SD-6 LEMA



How the Method would be applied to the Rattlesnake Creek LEMA-wide test

Beginning in 2021, each LEMA WR owner will be responsible for submitting their water use report to KDA-DWR by January 31 for the previous year's water use. KDA-DWR recommends that water users use online water use reporting to increase efficiency and reduce errors.

Also beginning in 2021, by February 22, KDA-DWR will compile water use within the LEMA and Zone D and will compare it to the water use estimated by the Method and with annual use expectations to stay within the Total LEMA Volume. In any given year, water use across the LEMA should be approximately the volume of pumping estimated using the Method, minus the Gross Percentage Reduction

Example:

> If in 2020, the Climate-based Estimated Use based on recent acres and climate factors is 230,000 acre-feet across the LEMA, and
>
> If the Gross Percentage Reduction is 10% (meaning allowable pumping is 90% of the modeled baseline average),
>
> Then to be on target, LEMA water use would have to use approximately 230,000 – 23,000 = 207,000 acre-feet for the year. Consider the examples in the table below comparing Climate-based Estimated Use to actual use.
>
> If, in 2025, the actual total water use over the LEMA 2020-2024 is found to be less than or equal to 90% of the Climate-based Estimated Use over the LEMA 2020-2024 is then the LEMA will be considered "on track."

Table 2. Example of tracking performance of the Rattlesnake Creek LEMA over 2020-2024

Year	Estimated Use	Climate-Based Estimated Use - Gross Percentage Reduction (10%)	Climate-based Estimated Use - Gross Percentage Reduction (10%) (cumulative)	Actual water use	Water use on track + over /- under	Percentage
Example of water use "on track"						
2020	233,335	210,002	210,002	210,002	0	90.0%
2021	225,626	203,063	413,065	196,295	6,769	87.0%
2022	219,211	197,290	610,355	195,098	2,192	89.0%
2023	244,144	219,730	830,084	224,612	-4,883	92.0%
2024	217,357	195,621	1,025,706	189,101	6,521	87.0%
Totals	1,139,673	1,025,706		1,015,107		89.1%
Example of water use NOT "on track"						
2020	233,335	210,002	210,002	214,668	-4,667	92.0%
2021	225,626	203,063	413,065	209,832	-6,769	93.0%
2022	219,211	197,290	610,355	197,290	0	90.0%
2023	244,144	219,730	830,084	214,847	4,883	88.0%
2024	217,357	195,621	1,025,706	202,142	-6,521	93.0%
Totals	1,139,673			1,039,382		91.2%

Report cards for individual water users

Each water right subject to the LEMA control provisions ("LEMA WR") will be provided with a water use target[2] for 2020-2029. The sum of all water use targets will be equal to the Total LEMA Volume.

Each year, KDA-DWR will prepare for each group of water rights a report card comparing reported use with its water use targets adjusted for climate ("Report Card"). While the sum of these water use targets will equal the water use allowed for the entire LEMA, the reductions required for individual water rights will be different than the Gross Percentage Reduction factor for the entire LEMA. For example, a senior LEMA WR farther from the stream may receive an allocation that translates to a 5% reduction from its long-term average use, while a junior right closer to the stream may be allocated a 17% reduction from its average use.

[2] The water use target will consider the relative priority of the water right and its impact to Rattlesnake Creek streamflow. The target will not be enforced for 2020-2024, but rather will serve as a guide to help water users plan their operations and evaluate their progress towards meeting the long-term water reduction goals of the LEMA.

The individual water right Report Card will contrast the year's use versus its annualized target, adjusted for climate.

Examples:

Given: The modeled average use in the LEMA is 230,000 acre-feet. Then,

$$Climate\ Adjustment\ Factor = \frac{LEMA\ Climate\ based\ Estimated\ Use}{230{,}000}$$

Ex 1:

If the Climate-based Estimated Use in the LEMA in 2020 is 219,000 acre-feet, then the Climate Adjustment Factor is 219,000/230,000 = 0.952 (95.2%) indicating a lower irrigation demand year.

If the example water right has a five-year water use target of 750 acre-feet, or 150 acre-feet per year on average, then the report card will say that, to be on target for the long-term water use goals, the water right should have used approximately 95.2% of one year's worth of its water use target; 150 X .952 = 142.8 acre-feet.

Ex 2:

If the Climate-based Estimated Use in the LEMA in 2021 is 244,144 acre-feet. 244,144 / 230,000 = 106% indicating a drier, higher irrigation demand year.

The same water right described above would be expected to use 150 X 1.06 = 159.2 acre-feet.

Note in the example in Table 3 below, the average Climate-based Estimated Use 227,268 acre-feet over the LEMA 2020-2024 is slightly less than modeled average of 230,000 acre-feet, so following the report card guidance results in using less than the five-year water use target. But this also puts this water user and all the LEMA water users in a better position to stay within the Total LEMA Volume if 2025-2029 is drier and crop demands increase.

Table 3. Example of tracking performance of an individual LEMA water right over 2020-2024

Year	LEMA Climate-based Estimated Use	Climate Adjustment Factor (Climate-based Estimated Use / modeled avg. use 230,000)	One-year's worth of five-year allocation (150 AF) times Climate Adjustment Factor	Actual water use	Actual water use (cumulative)	Water target over/under
Example of water use "on target"						
2020	230,000	1.00	150.0	149	149	1
2021	225,626	0.98	147.1	147	296	0
2022	219,211	0.95	143.0	144	440	-1
2023	244,144	1.06	159.2	156	596	3
2024	217,357	0.95	141.8	142	738	0
Avg.	227,268					
Example of water use NOT "on target"						
2020	230,000	1.00	150.0	155	155	-5
2021	225,626	0.98	147.1	153	308	-6
2022	219,211	0.95	143.0	148	456	-5
2023	244,144	1.06	159.2	160	616	-1
2024	217,357	0.95	141.8	152	768	-10
Avg.	227,268					

An improved water use estimator applied to GMD5 and subareas, 2000-2016 climate and procedures: a regression relationship of groundwater irrigation water use to precipitation and ET

Sam Perkins, David Barfield, Chris Beightel, David Engelhaupt, Jeff Lanterman and Ginger Pugh
KDA-DWR, May 9, 2018

This Memo describes an estimator for water use in GMD5 Zone A and related subareas, and comparison of climatic conditions for the regression period 2000-2016 against years 1981-2017. It represents an improvement over regression models described in a memo dated January 9, 2018.

An improved regression model to estimate groundwater irrigation pumping in terms of reference evapotranspiration (ET) and precipitation (P) has been developed for Zone A in GMD5, along with variations for all of GMD5, the proposed LEMA and Zone D. Climatic conditions for the regression period 2000-2016 are compared with the period 1981-2017.

- Regression model update: an improved estimator was found for water use in GMD5 Zone A with coefficient of determination (R^2) = 0.98 and standard error (s.e.) = 3.9 KAF. Predictor variables are ET (May, Jun-Jul, Aug-Sep) and P (Apr-May, Jun-Jul, Aug). Geoff Bohling, Kansas Geological Survey, reviewed the improved model and used advanced statistical tools to assess its predictive accuracy. Geoff found that the model holds up well; his review is in Appendix A.
- Versions of the improved estimator were developed for the entire GMD5, the proposed LEMA and for Rattlesnake-Zenith depletion response zones A (10 percent) and D (40 percent). Tables 1-3 summarize regression statistics, model coefficients and coefficient significance (p-values) for all four zones.
- Climatic conditions: mean precipitation and reference ET for regression years 2000-2016 are compared against the period 1981-2017 in terms of non-exceedance percentiles. These are 48 percent for precipitation and 58 percent for reference ET, although both ET and P show upward trends. These statistics suggest that the regression period 2000-2016 is sufficiently representative of the period 1981-2017. Tables 4 and 5 summarize precipitation and reference ET for various time periods over years 1981-2017 and for individual years 2013-2017.
- Procedures update: A second version of the scripts for mapping PRISM precipitation and temperature data and reference ET onto model grid domains was produced that map these data onto PLSS sections in Kansas. Documentation, processors, procedure input files and results are provided in backup folder PRISM_to_KS.

Background

As noted in the Jan 9 memo provided to GMD5, the area designated as Zone A includes all PLSS sections where GMD5 groundwater model simulations show a 10 percent or greater depletion response in Rattlesnake C streamflow at the Zenith gage to groundwater pumping. The Jan 9 memo described five regression relationships to estimate groundwater irrigation pumping as functions of reference ET, precipitation or both. The regression models are based on WRIS pumping data and PRISM climatic data for years 2000-2016, and were developed to estimate future pumping reductions agreed to as part of a proposed Local Enhanced Management Area (LEMA), while accounting for annual variation in pumping demand with ET and P. The LEMA includes Zone A and all of Rattlesnake C basin within GMD5.

An improved regression model

The regression models reported in the Jan 9 memo for Zone A ranged from f1(P), a function of a single variable, annual precipitation, to f5(ET,P), a function of five variables, including two for ET (Jun-Jul and Aug-Sep) and three for P (Mar-May, Jun-Jul and Aug-Sep). The improved regression model, f7(ET,P) is a function of six predictor variables, including three for reference ET (May, Jun-Jul, Aug-Sep) and three for P (Apr-May, Jun-Jul, Aug). Variations on this model have been developed for four zones, including all of GMD5, the proposed LEMA, and depletion response zones A and D. Statistics for all four of these are listed in Tables 1-3.

The regression estimate of annual use is evaluated for a given year by $f7(ET_i, P_i) = \sum_{i=1}^{3} a_i\, ET_i + \sum_{i=1}^{3} b_i\, P_i$, a summation over six products of coefficents (listed in Table 2, below) and their associated predictive variables ET_i (May, Jun-Jul, Aug-Sep) and P_i (Apr-May, Jun-Jul, Aug). This is calculated in sheet ZoneA of the backup file 1981-2017_ppt_eth_ZoneA.xlsm with Excel's SUMPRODUCT function in range N2:N28 as the product of coefficients in range G37:L37 with the ET and precipitation data in range G2:L28. The backup files are described in greater detail below.

For Zone A, the f7 model standard error is 0.28 inches, or 3.9 KAF, which is 2.0 pct of mean pumping. Compared with the f5 model standard error of 6.5 KAF, the f7 model reduces the estimate uncertainty by 40 percent. The standard deviation taken over a five-year running average of annual error for the f7 model is 1 KAF, or 0.50 pct of mean pumping. Fig. 1 plots estimated vs. reported use (inches) for 2000-2016, and shows a linear trend with R^2=0.98. Fig. 2 compares time series for estimated and reported use for 1991-2016. Fig. 3 plots error of the estimate for regression years 2000-2016, showing both annual error and the five-year running average error. The average error over any five-year period for 2000-2016 ranges from -1,580 to +1,249 ac-ft/yr, or from -0.8 to +0.7 percent of mean pumping for years 2000-2016.

Regression model review

Geoff Bohling, Associate Scientist and geostatistics expert at Kansas Geological Survey, Geohydrology Section, conducted an independent review of the improved regression model. The regression model dataset was provided to Geoff as **1991-2016_pumping_vs_ppt_eth_GMD5_ZoneA_2018_0227_sp.xlsx,** which is included with the backup for this memo.

Geoff applied advanced statistical methods, including jackknife regression to test the model's robustness, calculation of the condition number of the covariance matrix as a check on collinearity effects, and an automated method to select predictor variables to optimize the regression model. Geoff's review is included as Appendix A, and provides strong support for the model. From his analysis, Geoff found the following:

- The jackknife regression model was very similar to the original regression model f7(ET,P); the two are compared in Fig. A1.
- Collinearity should not be a problem based on the condition number of the covariance matrix.
- The automated variable selection method did not find a better model than the f7(ET,P) model.

Water use estimators for GMD5, LEMA and Zones A and D

Versions of the f7(ET,P) water use estimator were also developed for all of GMD5, the proposed LEMA and Zone D (40 percent depletion response zone). Tables 1-3 summarize the estimators for these and for Zone A.

Table 1, summary statistics, shows that the r-squared values for GMD5, LEMA and Zone D are nearly the same as for Zone A; and that the standard error as a fraction of mean reported use is 2 percent for GMD5, the LEMA and Zone A, and is 3 percent for Zone D.

Table 2 lists estimator coefficients for the four regression models. These are evaluated as described above for the Zone A model in corresponding Excel files listed below under description of backup files.

Table 3 lists the p-values corresponding to the regression coefficients. Amost all of the model coefficients have p-values that are much less than 0.05, a conventional threshold for evaluating significance. The only exceptions are the August precipitation coefficients for the GMD5 and Zone D models.

Figs. 4-6 plot annual reported and estimated use (inches) for GMD5, the LEMA and for Zone D, respectively. They show that estimated use tracks reported use about as closely as the estimator for Zone A, as the high r-squared values suggest.

Figs. 7 and 8 plot reported and estimated use, respectively, for the four zones (inches). The comparisons show little difference in water use between the LEMA and Zone A, whereas GMD5 and Zone D show more significant variance from the LEMA and Zone A..

Climatic conditions

Climatic data for regression model years 2000-2016 were compared against the longer period 1981-2017, which includes the current 30-year normal period 1981-2010, to assess how well the climatic data used in the regression models represents the longer period 1981-2017. Revised scripts (summarized below) were used to map PRISM precipitation and temperature data and reference ET to PLSS sections in Kansas for years 1981-2017, and to calculate spatial averages over Zone A for precipitation and ET.

Tables 4 and 5 summarize precipitation and reference ET, respectively, for Zone A over various periods from 1981-2017, and for individual years 2013-2017. Mean annual and May-September precipitation for 2000-2016 both have a non-exceedance value of approximately 0.48. Mean annual and May-September reference ET for 2000-2016 both have non-exceedance values of approximately 0.58. These indicate that precipitation for the regression period is just below the median, at 48 pct, and reference ET for the regression period is higher, at 58 pct, compared to the extended normal period. The linear trends indicate that both precipitation and reference ET may be increasing over time. However, PRISM documentation cautions against using the spatial datasets on which our analysis is based for multi-decadal trends; see http://www.prism.oregonstate.edu/documents/PRISM_datasets.pdf , p. 6, "Time Series Datasets."

Procedures update

An Appendix to the memo dated January 9, 2018 documents scripts used to map PRISM monthly spatial data including precipitation and monthly average daily temperature minimum and maximum onto model grid cells (PRISM_to_grid_mo.f); to calculate Hargreaves-Samani reference ET at each grid cell (ETref_HS.f90); and to calculate and write files of spatially averaged precipitation and reference ET for a specified zone such as Zone A (PRISM_to_grid_mo_nper.f and ETref_HS_Zone.f90). These scripts are written in Fortran and are compiled and linked using GFortran (https://gcc.gnu.org/wiki/GFortran).

Since submitting the Jan 9 memo, a second version of these scripts was developed that does not reference a model grid, but instead references a list of locations and their associated geographical coordinates. The scripts include PRISM_to_state_mo.f, PRISM_to_state_mo_nper_zone.f90 and ETref_HS_state_Zone.f90. The grid-independent version was developed to map PRISM climatic data and reference ET onto all PLSS sections in Kansas, and has been used for this work. The effect of mapping the PRISM data onto PLSS sections instead of model grid cells was found to have a negligibly small effect on the spatial averages taken over the zones of interest.

Reference ET is calculated as described in the Jan 9 memo: "The temperature data (average minimum and maximum daily temperature for each month, tmin and tmax) are used to calculate Hargreaves and Samani (1985, H-S) reference ET as outlined by Snyder and Eching (2005) for monthly time steps. The H-S method performs well among reduced-dataset methods of calculating ET in comparative studies by Xu and Singh (2002) and by Shahidian et al. (2012)."

The grid-independent scripts operate similarly to the grid-based scripts, and the documentation in the Appendix to the Jan 9 memo roughly applies, but without requiring grid specifications. The grid-independent version of the scripts should be applicable to any area of interest within the continental United States, which corresponds to the spatial extent of the PRISM data. An update of documentation for the grid-independent version of scripts is provided separately with backup data as file Documentation of procedures to map PRISM climatological data and Hargreaves ET onto PLSS sections.docx; see backup folder PRISM_to_KS.

References

Hargreaves, G.H. and Z.A. Samani, 1985. Reference crop evapotranspiration from temperature. Transaction of ASAE 1(2):96-99.

Snyder, R.L. and S. Eching, 2002. Penman-Monteith daily (24-hour) and Hargreaves-Samani Equations for Estimating Reference Evapotranspiration from Monthly Data. UC-Davis.
Monthly reference ET: http://biomet.ucdavis.edu/Evapotranspiration/PMmonXLS/PMmon.htm

Appendix A. Jackknife regression [email from Geoff Bohling, Kansas Geological Survey]

Sent: Tuesday, February 27, 2018 3:31 PM
To: Perkins, Sam [KDA] <Sam.Perkins@ks.gov>
Subject: jackknife regression

Sam -

Well, the jackknife regression basically says that your model seems to be about as good as you think it is. I've attached a plot showing the actual pumping/area versus time, along with the values predicted using regular regression (what you've already done) and those predicted using a jackknife approach. In the jackknife approach, the predicted value for each year is from a regression model fit to the data from all the other years, with the "prediction" year withheld from the data set. As I said, this gives a more robust assessment of the predictive accuracy of the model and would also help to identify influential outliers (indicated by large differences between the regular and jackknife predictions).

As you can see from the plot, the jackknife predictions are very similar to the regular predictions. The regular regression model has (as you know), a sum squared residual of 0.64, a residual standard error (rms residual) of 0.25, and an R-squared 99%. The comparable quantities computed from the jackknife residuals are 1.88, 0.43, and 97%. I'm actually not completely sure how many degrees of freedom to use in computing that rms residual, so that could be a little off . . . but the jackknife results seem to indicate that the model is pretty good, regardless.

These jackknife results use all six of your predictor variables (the three ET values and the three PPT values). I also did a bit of work with a model selection procedure that aims to identify models of optimal complexity -- meaning models that give the best balance between model size (number of predictor variables) and data fit. The idea is that smaller (less complex) models usually generalize better, so it's preferable to use a smaller model rather than a larger model unless the larger model gives a significantly better fit to the training data -- and there are various statistics to measure that trade-off. Anyway, that analysis basically just said, yup, the model using all six predictor variables is the best (of all the possible models you could construct using different subsets of those six variables).

So, the long and short of it is, keep on keepin' on . . .

Geoff
--
Geoffrey C. Bohling
Associate Scientist, Geohydrology
Kansas Geological Survey
The University of Kansas
(785) 864-2093
geoff@kgs.ku.edu

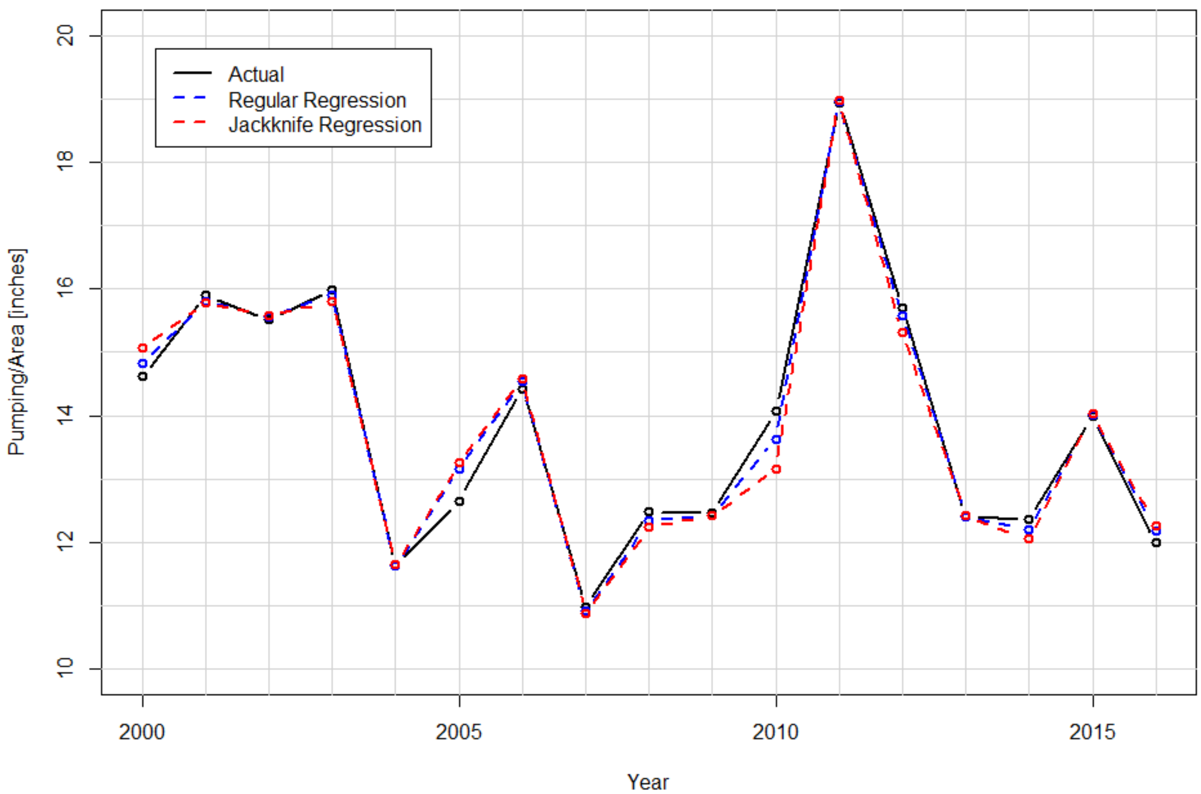


Fig. A1. Comparison of reported use, regular regression and jackknife regression for 2000-2016.

Backup: Microsoft Excel files

Regression model update
Regression models for GMD5, the LEMA and zones A and D and their associated data are in the four following files:

1981-2017_ppt_eth_ZoneA.xlsm	[sheet ZoneA: Figs. 1-3]
1981-2017_ppt_eth_GMD5.xlsm	[sheet GMD5: Fig. 4; sheet Summary: T. 1-3; Sheet rep_use_In: Fig. 7; sheet est_use_in: Fig. 8]
1981-2017_ppt_eth_LEMA.xlsm	[sheet LEMA: Fig. 5]
1981-2017_ppt_eth_ZoneD.xlsm	[sheet ZoneD: Fig. 6]

Tables 1-3 in this memo, which summarize regression models for the four zones, are from sheet Summary in the above file for GMD5.

Tables 4 and 5, which summarize precipitation and ET, respectively for various time periods and individual years 2013-2017, are from file **ZoneA_reported_est_use_ET_P.xlsx**.

Each of the above four files named for a zone, such as 1981-2017_ppt_eth_ZoneA.xlsm, also contains a sheet named for the zone (GMD5, LEMA, ZoneA or ZoneD). This sheet contains the data for the zone's regression model for estimated use in the following ranges:

A1:E27: reported irrigation use, area and ratio (inches) for 1991-2016. This water use summary for each zone comes from file **gmd5_wuse_1991-2016_de_20180125_zone_summary.xlsx** (see below).

G1:L28: predictive variables, including reference ET for May, Jun-Jul and Aug-Sep (cols G:I) and precipitation for Apr-May, Jun-Jul and Aug (cols. J:L). These are based on monthly data in sheets 1981-2017_ETH and 1981-2017_PPT for the zone.

F35:L38: regression model coefficients and p-values.
N2:N28: estimated use (inches) calculated as SUMPRODUCT of coefficients (G37:L37) with ET and precipitation in range G2:L28 for each year 1991-2017. [regression is based on years 2000-2016]
O2:O27: estimate error, inches [col. N – col. E]
P6:P27: 5-year average error, in/yr (taken over current year and previous four years)
R2:R27: estimated use (acre-feet) as product of reported irrigated area (col. D) and regression estimate (inches, col. N) / 12.
S2:S27: estimate error, acre-feet [col. R – col. C]
T6:T27: 5-year average error,af/yr (taken over current year and previous four years)
N39: plot of estimated vs. reported irrigation pumping per unit area (inches) for 2000-2016.
U39: time series plot of estimated and reported irrigation pumping per unit area for 1991-2017.

Monthly precipitation, P and reference ET were summarized for each of the zones (i.e. spatially averaged over P or T associated with PLSS sections within the corresponding zones) using the processors PRISM_to_state_mo_nper_zone.f90 and ETref_HS_state_Zone.f90. Summary text files were imported into the respective four Excel files listed below ("Regression model update"). The predictor variables are based on these monthly data.

Reported water use summaries for GMD5, the LEMA and zones A and D are in file **gmd5_wuse_1991-2016_de_20180125_zone_summary.xlsx**. These summaries are based on David Engelhaupt's Jan 25 query of GMD5 water use. 1991-2016 summaries by zone are in cols. A:E (GMD5), H:K (LEMA), P:S (Zone A) and V:Y (Zone D).

File **1991-2016_pumping_vs_ppt_eth_GMD5_ZoneA_2018_0227_sp.xlsx** with regression model dataset was provided to Geoff Bohling. KGS for his analysis of the regression model, in Appendix A. Sheet Intro identifies locations of the pumping, ET and precipitation datasets in the file.

Tables 1-3: Summary statistics, regression coefficients and associated significance (p-values) for water use estimators f7(ET,P) for GMD5, LEMA, Zone A and Zone D.

T. 1. Summary statistics.

Zone	R^2	s.e. (in)	s.e. af	mean use af	s.e./ mean use	s.e. 5yr av '04-'16
GMD5	0.974	0.32	12,360	497,420	0.024849	2,886
LEMA	0.977	0.29	5063	242,151	0.020908	1250
Zone A	0.981	0.29	3,938	191,827	0.020531	976
Zone D	0.966	0.45	1,030	30,949	0.033275	254

T. 2. Regression coefficients.

	c1	c2	c3	c4	c5	c6
Zone	May	Jun-Jul.et	Aug-Sep.et	Apr-May.ppt	Jun-Jul.ppt	Aug.ppt
GMD5	-1.22549	1.001571	1.0930902	-0.308	-0.25564	-0.13146
LEMA	-1.26881	1.24691	0.8570711	-0.27972	-0.19319	-0.21422
Zone A	-1.52742	1.32166	0.9133472	-0.30258	-0.20033	-0.23043
Zone D	-1.6263	1.36512	0.9010729	-0.29519	-0.27915	-0.15867

T. 3. Regression coefficient p-values.

	c1	c2	c3	c4	c5	c6
Zone	May	Jun-Jul.et	Aug-Sep.et	Apr-May.ppt	Jun-Jul.ppt	Aug.ppt
GMD5	0.006608	0.000331	6.783E-05	1.12E-05	0.00047	0.072249
LEMA	0.002199	1.27E-05	0.0001474	5.18E-06	0.001281	0.002918
Zone A	0.00057	6.44E-06	6.573E-05	1.84E-06	0.001111	0.001518
Zone D	0.006185	8.54E-05	0.0017717	4.7E-05	0.00108	0.078601

T. 4. Precipitation summary for Zone A over various periods from 1981-2017 and annual statistics for 2013-2017 (preliminary for 2017).

		mean precipitation		percentiles	
statistic	period	annual	May-Sep	annual	May-Sep
median	1981-2017	27.41	17.31	0.50	0.50
mean	1981-2017	26.51	16.36	0.44	0.48
mean	1991-2007	27.32	17.12	0.47	0.49
mean	2003-2012	27.17	16.63	0.47	0.48
mean	2000-2016	27.23	16.66	0.47	0.48
mean	2013-2016	28.97	18.45	0.60	0.58
annual	2013	30.774	20.367	0.82	0.79
annual	2014	25.814	18.433	0.42	0.58
annual	2015	29.292	15.693	0.63	0.42
annual	2016	29.997	19.324	0.71	0.68
annual	2017	27.936	13.384	0.55	0.26

T. 5. Summary of reference ET (Hargreaves-Samani for short grass) for Zone A over various periods from 1981-2017 and annual statistics for 2013-2017 (preliminary for 2017).

		mean ET		percentiles	
statistic	period	annual	May-Sep	annual	May-Sep
median	1981-2017	41.86	27.40	0.50	0.50
mean	1981-2017	41.79	27.63	0.47	0.53
mean	1991-2007	41.67	27.49	0.47	0.48
mean	2003-2012	42.33	27.99	0.64	0.63
mean	2000-2016	42.24	27.93	0.63	0.61
mean	2013-2016	41.51	27.20	0.43	0.45
annual	2013	40.30	27.40	0.18	0.50
annual	2014	40.97	27.25	0.34	0.45
annual	2015	41.86	27.04	0.50	0.34
annual	2016	42.90	27.12	0.79	0.42
annual	2017	42.67	27.63	0.74	0.53

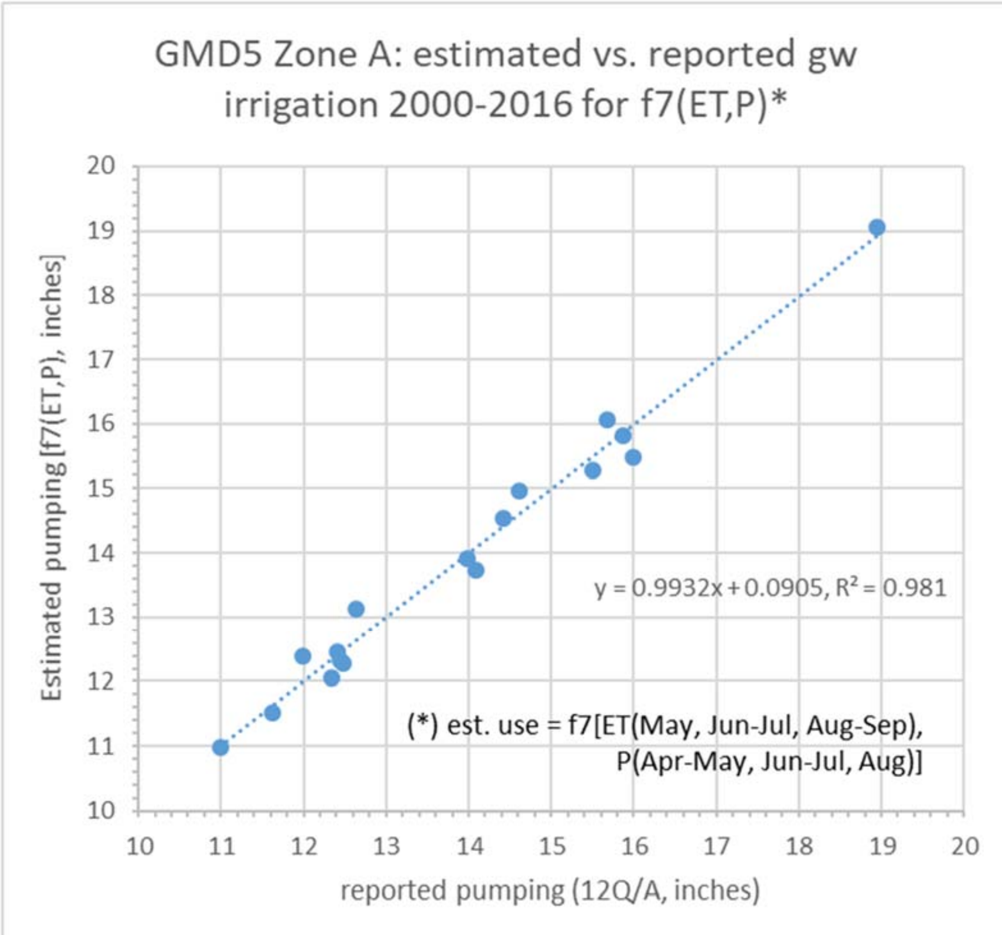


Fig. 1. Estimated vs. reported groundwater irrigation water use in Zone A for years 2000-2016.

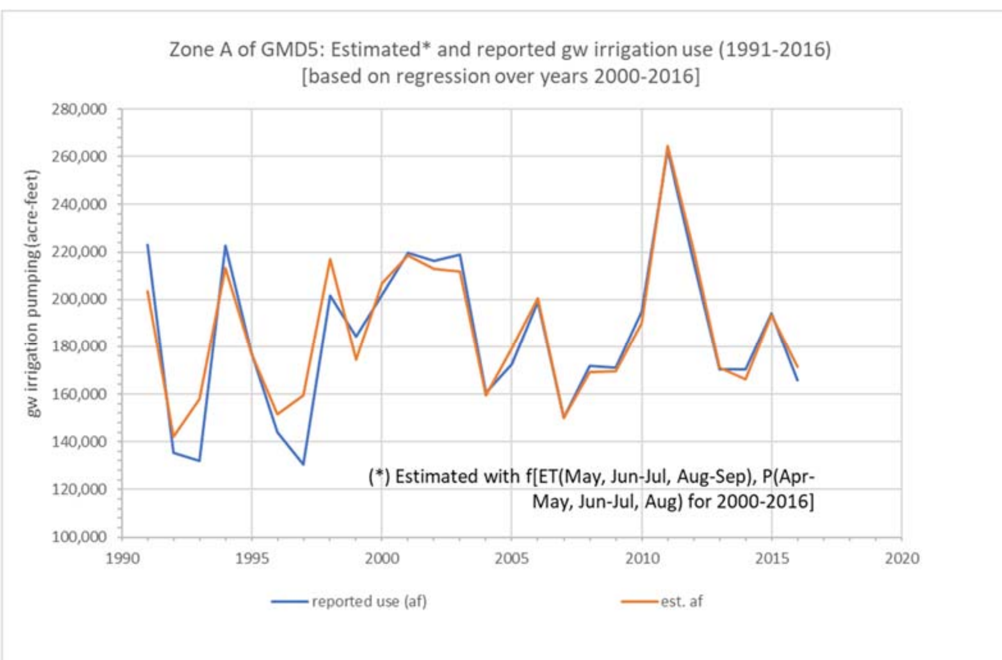


Fig. 2. Estimated and reported groundwater irrigation water use in Zone A of GMD5 1991-2016.

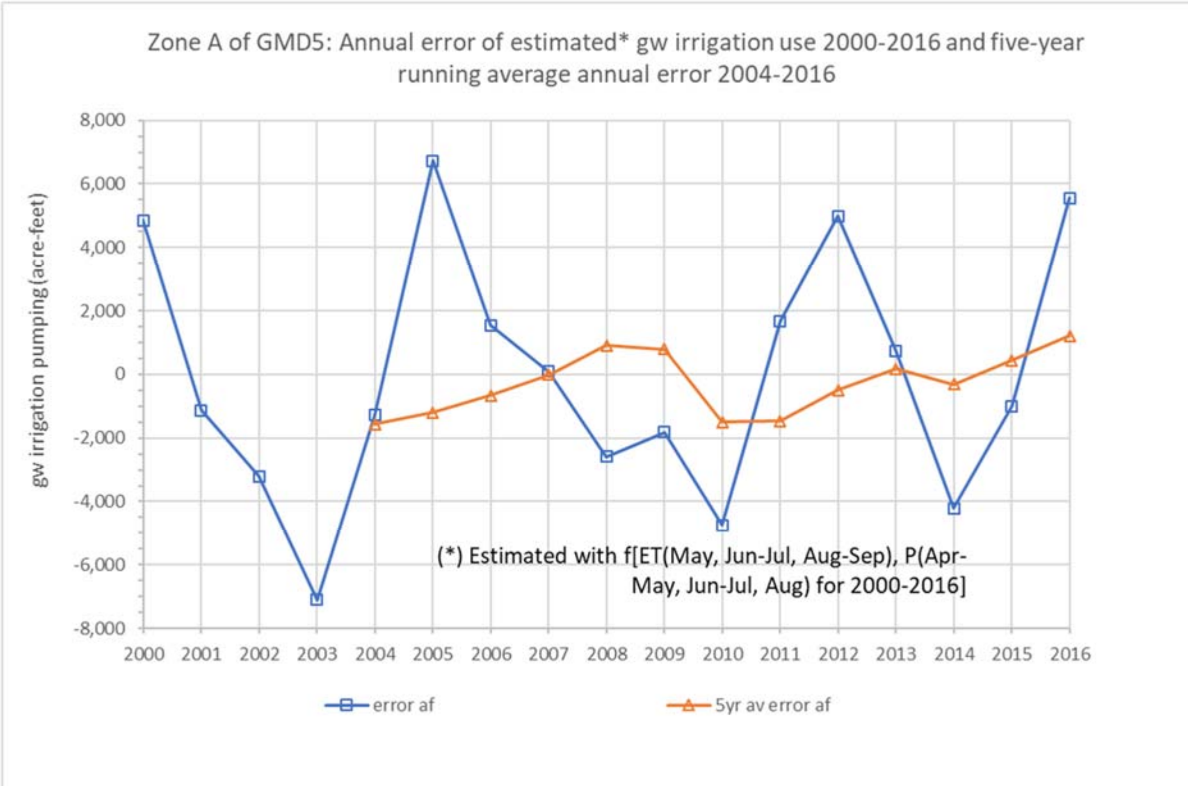


Fig. 3. Annual error and five-year running average error of water use estimator f7(ET,P) for Zone A.

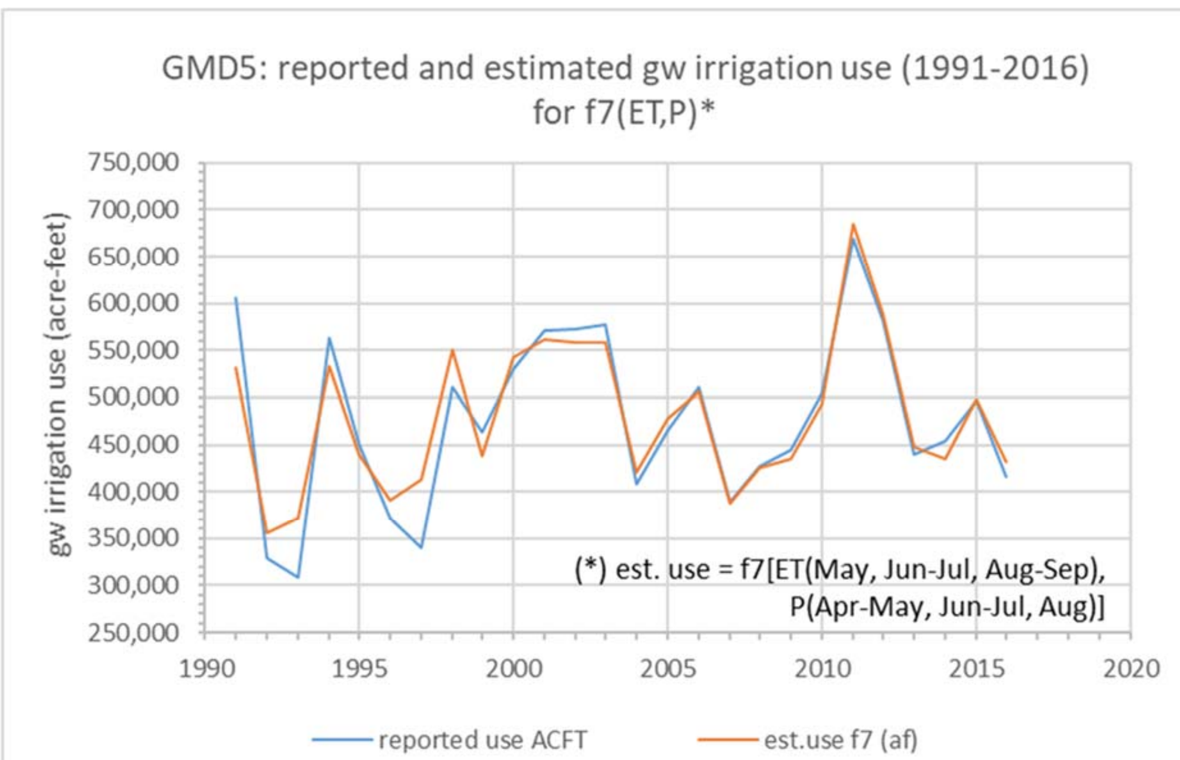


Fig. 4. Estimated and reported groundwater irrigation water use in GMD5 for years 1991-2016.

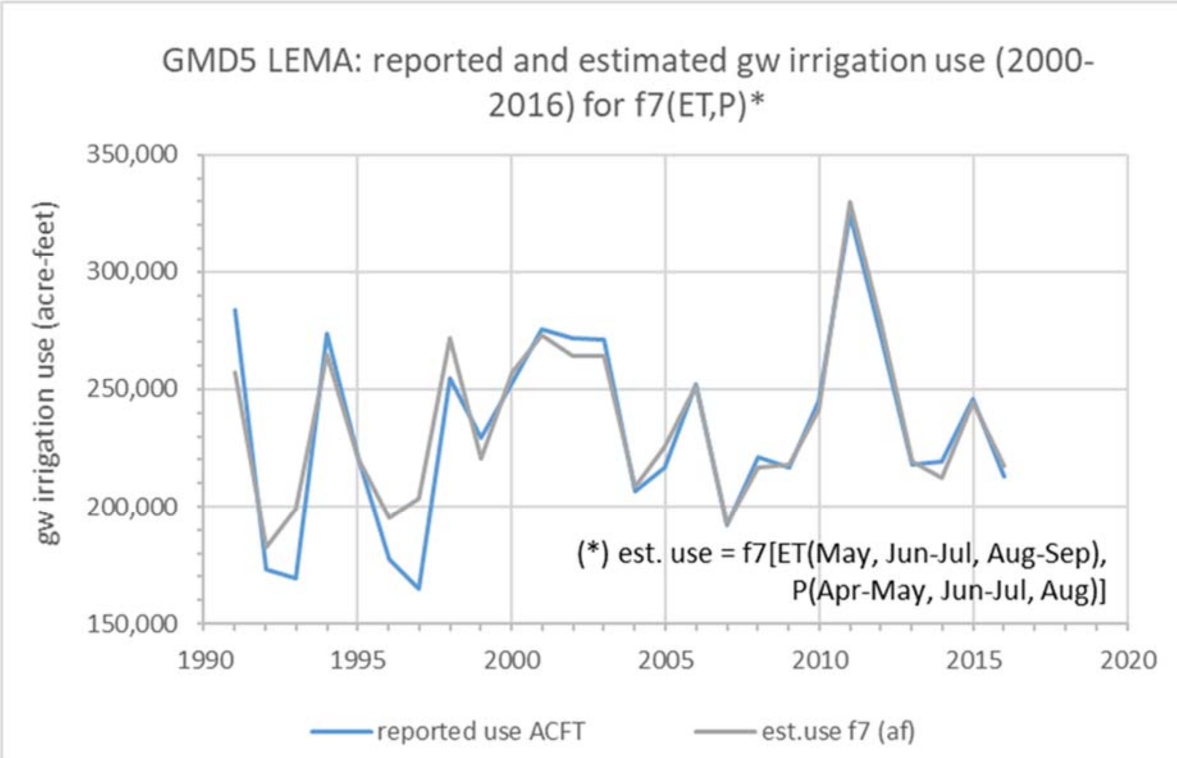


Fig. 5. Estimated and reported groundwater irrigation water use in the GMD5 LEMA 1991-2016.

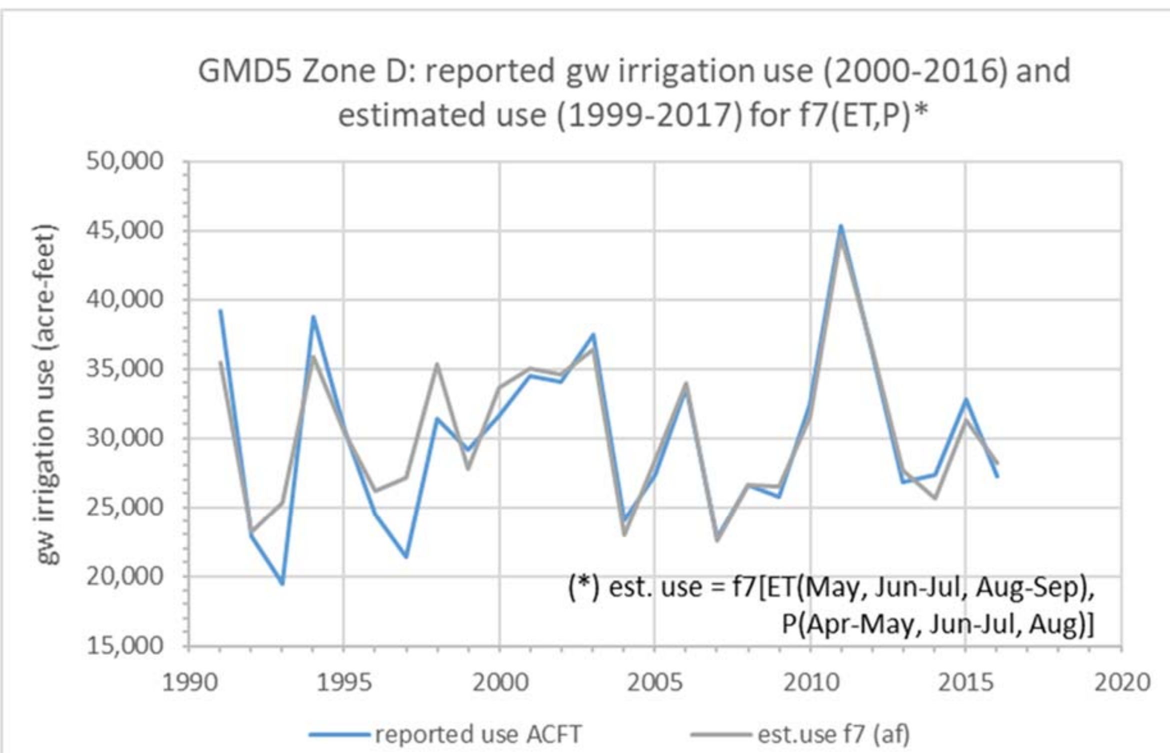


Fig. 6. Estimated and reported groundwater irrigation water use in Zone D of GMD5 1991-2016

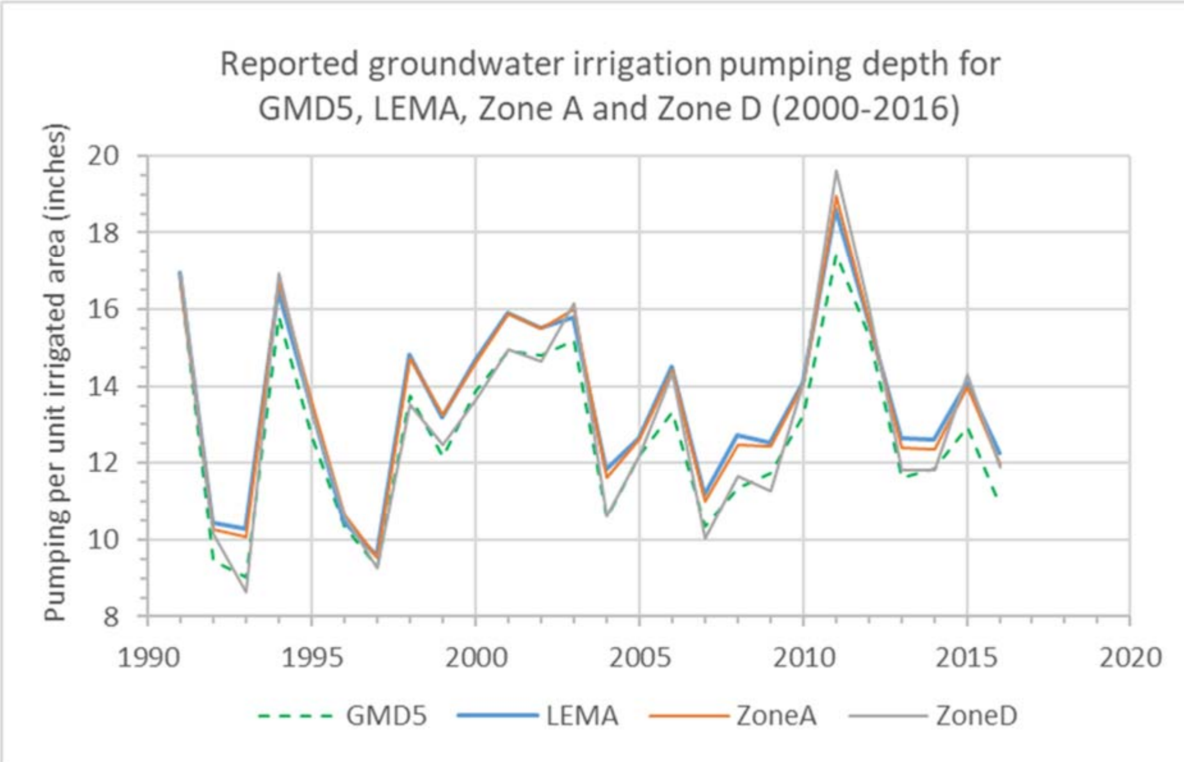


Fig. 7. Compare reported use (inches) for GMD5, LEMA, Zone A and Zone D 1991-2016.

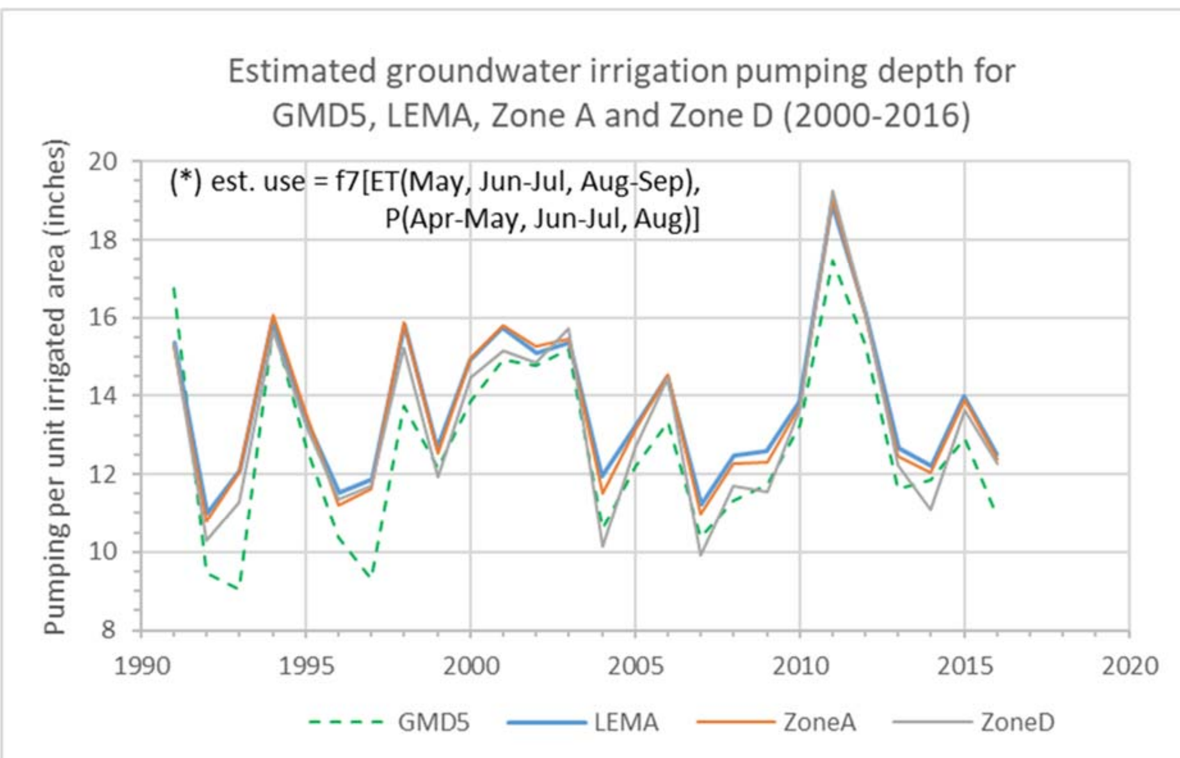


Fig. 8. Compare estimated use (inches) for GMD5, LEMA, Zone A and Zone D 1991-2016.