1996

Water Use Estimation and Forecasting for the Kentucky River Basin: A Preliminary Draft Report

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WATER USE ESTIMATION AND FORECASTING FOR THE KENTUCKY RIVER BASIN: A PRELIMINARY DRAFT REPORT

by

The University of Kentucky
Kentucky Water Resources Research Institute Economics Group

June 1996

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June 12, 1996

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We estimate aggregate monthly water use for summer, peak demand and nonsummer off-peak demand periods for the Kentucky River Basin. Using Kentucky Division of Water use data, U.S. Census data for county demographic and economic conditions, and U.S. Weather Service data for weather conditions we estimate use for the 1970-1993 period. Our model allows for idiosyncratic effects of each of the 27 counties in the sample. We find factors such as population and manufacturing employment effect use and temperature and rainfall in current and preceding months effect use during the summer, peak period. The model predicts well within the sample period. Population forecasts, both moderate and high growth series, from the Kentucky Data Center are used along with manufacturing employment forecasts for water use forecasts. Water use forecasts are made for years out to 2020 under 1930 drought conditions for comparison with water supply estimates. The use estimates are made assuming pricing and other demand management policies remain constant. For Pool 9 under 1930 weather conditions and high (moderate) population growth, water use is forecast to be 70 (55) MGD, which is 220 (220) gallons per person per day. For the Basin aggregate water use is forecast to be 129 (110) MGD. An Excel 5.0 spreadsheet was developed to make forecasts for various assumptions concerning: population growth and the degree to which new users come on line to water and sewer systems.

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I. AGGREGATE MONTHLY WATER USE FOR THE KENTUCKY RIVER BASIN

Overview

Water use varies tremendously in different locations. A recent article in The Economist (January 27, 1996, p.100) reported water use in 23 countries. Water use ranged from a high of 1,870 cubic meters per person per year in the United States to only 205 cubic meters per person per year in Britain, only slightly more than water use in Columbia and Switzerland. Water demand varies across areas within the United States as well, see Foster and Beattie (1981). Recognizing the importance of geographic location in understanding water use, we have chosen to estimate water use with a model and data which are specific to the Kentucky River Basin.

Water use is based on data from the Division of Water (DOW), Kentucky Cabinet for Natural Resources and Environmental Protection.[1] It is monthly use data, by permit type, by pool for the 27 counties wholly within the Kentucky River Basin. Our estimates are for aggregate use including all types of users. We estimate aggregate use since DOW permit type is only loosely related to actual type of use. Variables related to type of use, such as percentage of employment in manufacturing, are used to explain aggregate use. The period 1970-1993 is long enough to give sufficient degrees of freedom for estimation and uses the most current (1993) economic data.

Average monthly demand is estimated and converted to average daily demand by dividing by the number of days in the month. Separate water use equations are estimated for both: (1) the base months of October through May and (2) the summer, peak months of June through September. Demands are likely to be very different for off-peak, winter months and peak, summer months, see; for example, Feather and Braybrooke (1995), Kiefer and DeWitt (1995), Lyman (1992) and Danielson (1979).

The amount and type of activity and the terms of availability influence water use. The choice of variables to explain and forecast water use in the Basin is based upon our review of the water demand and forecasting literature and discussions of the full WRRI team and open advisory committee. The studies reviewed include the ones listed above as well as studies such as Howe and Linaweaver (1967), Hewitt and Hanemann (1995) and Davis *et al.* (1991). The types of factors are: population, economic measures, weather variables, variables which allow for unmeasured county-specific factors, and a time trend.

Factors Influencing Water Use

We estimate a model of water use aggregated to the county level. We use the county, rather than permit, as our unit of analysis so that we can use characteristics such as population, income, employment, and manufacturing. Characteristics such as these are available at the county, but not permit, level. We postulate that demand for water will depend on six distinct types of factors.

1. <u>Economic and Demographic Factors</u> (E). These factors include population, employment, manufacturing employment, and percentage of housing units that are single family units, and real (inflation-adjusted) per capita income. The Center for Business and Economic Research at the University of Kentucky supplied these data from the U.S. Census of Population.

2. <u>Public Water and Sewer Use</u> (U). From the Census of Population, we have obtained the percentage of housing units on public water and sewer.

3. <u>Weather Conditions</u> (C). Weather conditions are included in the equation for the peak months because the demand for watering lawns, gardens and trees depends on the weather. Conditions are not included for off-peak months because off-peak use is primarily for drinking, bathing and other indoor activities. Included are measures of average weekly rainfall in the month, the average mean temperature (average of high and low temperature for the day), number of days of rain (per week) in the month as well as rainfall and temperature in the preceding month. These lagged variables allow for a cumulative effect of dry, hot spells. The weather data are U.S. Weather Service, National Oceaniographic and Atmospheric Administration data.[2]

4. <u>Monthly Variation</u> (M). By the use of indicator (dummy) variables we allow for the use of water to vary specifically by month independently of any changes in weather or other factors in that month. For the peak months we have a dummy variable for each month except September and similarly for the off-peak months for which we exclude December. The value of the dummy variable is one if the observation is in the month and zero otherwise. In estimating the peak season demand, then, we have three monthly dummy variables included while we include seven monthly dummy variables for the off-peak demand.

5. <u>Year-specific Effects (T).</u> We allow for the possibility that the use of water may vary through time independently of any changes in income, employment, or any other demographic characteristics by including indicator (dummy) variables for each year. T takes on the value of one if the observation is in the year and the value of zero otherwise. We exclude the dummy variable for 1970. As an alternative way to allow for effects over time in our scenario analysis, we exclude the set of year dummy variables and include a linear time trend variable which takes on a value of one for 1970 and increases by one each year.

6. <u>County-specific Effects</u> (L). There are many determinants of the use of water in an area that are difficult to quantify. As our data are in a *panel* in which we have both a cross-section of observations (counties) and a time-series (1970-1993) rather than simply a cross section (only one year of data on all the counties) or a time-series (all years but a single county). Panel data provides us the opportunity to control for factors in a county that may affect the demand for water but do not change significantly over time even if we

do not have data on these factors. Since we do not have water rates, these L variables capture the differences in rate structure within the Basin[3]. In our estimation we control for these factors through dummy variables, one for each county (excluding Anderson) with each variable having a value of one for any observation of the county and zero otherwise. The counties considered in the Basin are: Anderson, Boyle, Breathitt, Carroll, Clark, Clay, Estill, Fayette, Franklin, Garrard, Grant, Henry, Jessamine, Knott, Lee, Leslie, Letcher, Lincoln, Madison, Mercer, Owen, Owsley, Perry, Powell, Scott, Wolfe, and Woodford.

These six types of determinants of water use are the basis for our set of explanatory variables to be used in the estimation.

Regression Model of Water Use

A general form of the equation to be estimated for the peak season is

$$MGD_{cmy} = \beta_0 + \beta_E E_{cy} + \beta_U U_{cy} + \beta_C C_{my} + \beta_T T_y + \beta_M M_m + \beta_L L_c \qquad (1)$$

where MGD is the average daily intake of water in the county measured in millions of gallons (millions of gallons per day). The notations E, U, C, T, M, and L refer to the factors discussed above and β_i is the impact of factor i on the demand for water (MGD). The terms β are the coefficients to be estimated in the regression analysis. The subscripts refer to county (c), month (m), and year (y) as each observation is a county at a particular time (month and year). The subscript on the variables refers to how that variable variables, for example, the economic factors (E) such as population and income are only reported on a yearly basis so the value of these variables is the same for the county for all the months in the year. The climate measures, in contrast, vary with each month but are the same for each county in the Basin.

The equation to be estimated for the winter season

$$MGD_{cmy} = \beta_0 + \beta_E E_{cy} + \beta_U U_{cy} + \beta_T T_y + \beta_M M_m + \beta_L L_c \qquad (2)$$

The only difference in the general specification of the estimating equation is that for the off-peak months we exclude weather conditions as these are unlikely to influence demand during these months.

Panel Estimation Techniques

The largest set of variables in our estimation is the set of 27 indicator (dummy) variables for the counties. Essentially, the purpose of this set of variables is to: (1) allow for each county to have a unique intercept in the regression equation, i.e., not restrict each county to have the same intercept; and (2) to eliminate the estimation of coefficients for variables that do not change over the time period. The technique we are using is referred to as fixed-effect estimation.

a frequently used technique with panel (cross-sectional, time-series) data (see Griliches, 1974; Chamberlain, 1984; Hausman, 1981).

The use of the fixed-effect estimation, that is, the inclusion of county dummy variables, is particularly important in our application, since we do not have water rate data or have included variables that may affect water use in the counties but do not change over time. For example, factors such as county size (area), topography, and alternative water sources affect water demand but do not change dramatically, if at all, over time in these counties. Thus the use of this technique actually reduces data requirements for the model.

Function Form

Equations (1) and (2) give a general linear specifications for the estimating equations. In fact, this specification is extremely restrictive and, given the large differences in the populations of the counties in our sample, probably a misspecification of the water use equation for a county. The most problematic aspect of the simple linear model is that it restricts the impact of a change in a factor (explanatory variable) such as climatic conditions to be the same for all counties. For example, an increase in monthly temperature or decrease in rainfall would have the same impact on **aggregate** water use (MGD) in both Fayette county (population of 219,000) and Owen county (population of 9,574).

An alternative specification that does not restrict changes in conditions to have the same impact on aggregate use is estimating per-capita use and excluding population as an explanatory variable. This specification would require that the impact of a change in an explanatory variable have the same impact on per-capita use.

Another alternative is the log-linear specification in which we would estimate the relationship between the natural logarithm of MGD and the natural logarithm of (some) of the explanatory variables such as population. This specification would require that the same percentage change in an explanatory variable have the same percentage change in MGD as any other county. For example, a 10% increase in income in all counties would lead to the same percent increase in water use.

We estimated linear models of aggregate water use and per-capita use, and the logarithmic model. Surprisingly the explanatory power (adjusted R^2) of the models of per-capita and logarithmic water use were weaker than the simple linear model.

As an alternative to these three specifications we estimated a more generalized linear model in which all the explanatory variables in the simple linear model, equations (1) and (2), are interacted with population. This more general specification relaxes the requirement that the impact of a change in an explanatory variable on aggregate water use is the same for all counties. However, it is less restrictive than the model of per-capita use as it does not require the same change in per-capita use with a change in any explanatory variable. Letting P denote population we could express this model by

$$MGD_{cmy} = \beta_0 + \beta_E E_{cy} + \beta_{EP} P_{cy} E_{cy} + \beta_U U_{cy} + \beta_{UP} P_{cy} U_{cy} + \beta_{CT} P_{cy} T_y + \beta_M M_m + \beta_{PM} P_{cy} M_m + \beta_L L_c + \beta_P P_{cy} L_c \quad (3)$$

where we form a set of explanatory variables that are simply the product of the set of variables we described earlier with population. This function form is used in the estimation of water use for the Basin.

Linear Trend Model

As mentioned before, an alternative specification of the model is to capture the changes in water demand over time that are independent of the other factors through use of a linear trend rather than the year dummy variable. The major difference between these two approaches occurs in forecasting. Using the year dummy variable approach we are essentially assuming that the only changes in water use in the future arise because of changes in factors such as population, employment, and public water and sewer use. If none of these factors changed in the future, predicted water use would be the same as it was in 1994. As our forecasts will suggest, essentially the model with year dummies predicts the same per capita water use in 2000, 2010, and 2020 as we had in 1994.

Using the trend model we allow for the use of water to change independently of factors such as population. Essentially, we estimate the trend in the intensity (per-capita use) of water during the period 1970-1993. If, independently of growth in population, employment, and the population served, water use increased at five percent per year, this model would predict the same growth. As the forecasts will show, this model predicts substantial increases in per capita water use.

Estimation Results for Past Use

We estimated our base model, the year dummies with interactions, as shown in equation (3), separately for peak and off-peak use seasons. The results of this estimation is reported in *Table 1a*. As *Table 1a* shows the explanatory power of these regressions is quite high with R^2 in both models approximately 0.98. In addition, a number of the coefficients are significantly different from zero at 95% confidence intervals or better (t-statistic > 1.96). Given the large number of observations (1992 for peak and 3982 for off-peak) and the time-series nature of the data, high R^2 are not particularly surprising.

An inconvenience associated with the use of interaction terms in a model is interpreting the coefficients obtained in estimation. Since population enters a number of different terms, the impact of population depends upon the magnitude of several coefficients as well as the value of the variables with which it is interacted. To obtain some indication of the individual impact of the explanatory variables, *Table 2* gives the impact of an increase in population evaluated at the 1994 means of all variables with which it is interacted. The impact is obtained by taking the partial derivative of equation (3) with respect to population. As the top part of *Table 2a* shows, June water use increases by 60 gallons per person per day. This increase is about 23.3 gallons per day for an additional person. As the top part of *Table 2b* shows the increase in the off-peak season is 81 gallons per day per person.

Table 2 also gives the impacts of other explanatory variables when evaluated at different population levels. We consider a range of population levels, each represented by a county in the Basin. The impacts are shown for five counties. Generally, we find that weather, particularly for larger counties, has the expected impact – rain decreases water use and temperature increases it. The trend variable suggests that water use is increasing over time independently of increases in income and population.

Table 1b gives the estimated coefficients for our alternative model but with the linear trend. The precision in the estimation (R-squared) is quite similar to our base model as are the estimated coefficients.

Forecast Reliability within the Sample

The high values for R^2 indicate that the model explains much of the variation in water use among these counties in the past twenty-five years. However, as both a check on and illustration of the reliability of our estimates we have plotted predicted water use versus actual water use for several months. *Figures 1a-f* plot predicted (with Δ line) versus actual (solid line) use for Fayette county for all peak months as well as the off-peak months of March and October. Generally, in the peak months the model performed well for Fayette county predictions with the exception of the 1988 drought and some of the years in the early 1970's. As off-peak months have much less variation in actual use over time, the model fits the data much better for March and October.

Figures 2a-d provide the same plots for June, the month with the most variation in use, and March, a month with less variation, for the counties which in 1994 were the next four largest users: Franklin, Madison, Perry, and Clark. For these counties the fit is not as close, however, a gap between predicted and actual use, measured in MGD, is much smaller for these counties than it is for Fayette county. Given the extreme variation in use in Franklin and Clark counties it is not surprising that predicted and actual water use differ substantially in these counties. Water use in Madison county, which has had a much smoother growth, matches very well with its predicted use. *Figures 2e-2h* plot the actual versus predicted use for the month of March for the same counties.

The high R^2 and graphical comparisons of predicted and actual water use indicate that the model has significant explanatory power. Given we only have past experience to use in forecasting future use, a model that predicts the past well, is a promising start for forecasting future use.

Determining Pool Use for Forecasts

While our estimation is based on county, not permit or pool, withdrawals, effective management of water in the Basin requires that we know the withdrawals from pools and not simply counties. To obtain an estimate of the pool withdrawals we calculated, for each month in 1994, the fraction of county withdrawals from each permit in that county. The number, the *Permit Share*, is then used to determine how any future forecasted changes in county water use should be distributed among the permits in the county. Since we know which pool each permit hold draws from, we can then allocate water use according to pool.

Projections of Future Demographic and Economic Conditions

Price, Sawyer, and Scobee (1995) of the Kentucky State Data Center forecast population for each county in Kentucky. Population growth depends upon natural increase and net migration. Two forecasts are made. Survival, fertility and net migration rates were applied to the population residing in households. U.S. Census data along with data from the Kentucky Cabinet for Human Resources are used. The moderate growth series uses the 1990 census as a base and migration flows of the 1980s are maintained. The high growth series uses the 1994 estimates from the U.S. Bureau of the Census and projects migration based on the 1990-94 trends. The high growth series reflects more growth primarily because Kentucky has been gaining more people than it has been losing through migration during the 1990s in contrast to the net losses during the 1980s. Price, Sawyer, and Scobee maintain that the high growth series is the better forecast since it is based on more recent data and more closely resembles the preferred forecast of the U.S. Census Bureau. For example, for Kentucky for the period 1990-2020 the high growth series forecasts 23% growth, the U.S. Census Bureau Preferred series forecast 17% growth, and the moderate growth series forecasts 7% growth.

Woods & Poole Economics, Inc. (1994) forecasts manufacturing employment for each county in Kentucky. The regional model simultaneously estimates regional and national values by linking counties together for regional flows and constraining the total flows to the national estimates. Central to the model are 183 groups of contiguous counties called Economic Areas. Data from the U.S. Department of Commerce Bureau of Economic Analysis are used to forecast employment using an export-base approach. This approach identifies basic industries such as manufacturing which produce output that is exported from the region and to which growth is tied. Much of the historical data is county-level employment by one-digit industry code for each year from 1969-92. An example of a growth forecast relevant to our model is for manufacturing employment for Fayette County from 1994 to 2020. Manufacturing employment is forecast to grow 18% but slower than total employment so that the percentage of employment in manufacturing declines from 9.3% to 8.7%. Such forecasts are made for each county and used along with the population forecasts to forecast future water use.

Forecasts of Water Use

The purpose of estimating a water demand (use) equation is to assist us in forecasting the impact of different conditions we may expect to see in the future, including droughts, income growth, more public water users, and population growth. Using the 1994 actual water use as a starting point for forecasts, we apply our estimated coefficients from our base model to adjust the 1994 use to reflect the alternative forecast scenarios.

In the table below we summarize the forecasted water use for pool 9 and the entire basin for 2000, 2010, and 2020 in the month of June for both the moderate and high growth scenarios for our base model and for the moderate growth for our alternative model.

Forecasted Use: Pool 9 and Basin, MGD for June, Base Model (with Year Dummies)							
	1994	*2000 M*	*2000 H*	*2010 M*	*2010 H*	*2020 M*	*2020 H*
Pool 9	*50.8*	*50.8*	*54.8*	*54*	*62.7*	*55.3*	*70.1*
Per Capita	*220*	*210*	*220*	*210*	*220*	*220*	*220*
Basin Total	*100*	*101*	*106.3*	*106.7*	*118.7*	*109.7*	*128.7*
Forecasted Use: Pool 9 and Basin, MGD for June, Alternative Model (with Linear Trend)							
	1994	*2000 M*	*2000 H*	*2010 M*	*2010 H*	*2020 M*	*2020 H*
Pool 9	*50.8*	*58.4*	----	*71.2*	---	*84.2*	---
Per Capita	*220*	*240*	----	*280*	---	*320*	---
Basin Total	*100*	*114*	-----	*139*	---	*164.7*	---

As this table indicates, there is a significant difference in the forecasted water use between our base model (with Year Dummies) and the alternative (with Linear Trend). The reason for this difference can be seen by examining the forecast per capita use in the two models. Using the base model, per capita use (in pool 9) is virtually unchanged while between 1994 and 2020 the linear trend model predicts a forty-five percent increase in per-capita use. Figures 3a - 3e gives the forecasted water use by pool for the months of March and June-September for our base model with the high-growth projections, our preferred forecast..

The Impact of Drought Conditions on Current Use

The first scenario we consider is the impact of a drought now. Essentially we are examining the impact of a drought on water use given current economic and demographic conditions (population, income, employment). The marginal impacts of our weather variables reported in *Table 2a* (and common sense) suggests that we should see increased water use in drought conditions. While the focus of most of our analysis is on the 1930 drought conditions, we first consider the impact of two other droughts as well: 1953 and 1988. *Table 3* gives a summary of the summer weather for the years 1930, 1953, 1988, and our base, 1994.

Figures 4a-d gives the predicted water use by pool for 1994 with the drought conditions of 1930, 1953, and 1988 as well the actual 1994 weather. In June, the drought that increases use the most significantly is the drought of 1988, though the increase is only .4 MGD in pool 9 and .5 MGD for the entire basin. The drought of 1930 leads to the greatest use of water in July with an increase in use in pool 9 of 3 MGD and 4.3 MGD for the entire basin. In August the drought that increased water use the most was that in 1988, though the increase for basin was only 2.1 MGD, the increase in August water use from the 1930 drought is 1.4 for August.

The Impact of an Expansion of Public Water Supply

Figure 5 predicts the impacts of public water expanding to 100% of the population of each of the counties and public sewer service reaching a minimum of 50% in each county. The projected use, by pool for June of each of the years 2000, 2010, and 2020, is based the high growth scenario and 1994 weather conditions. Also included in *Figure 5* is the actual 1994 water use. While, as we might expect, the increase in public water has only limited impact on projected future use in Fayette county, where almost 100% of users are already on public water, it does have substantial impacts for other counties with much lower public water and sewer rates. The mean percentage of houses on public water in the Basin counties in 1994 is 69% and only 39% for the mean of public sewer. To see the contrast compare *Figure 3b*, in which there is no change in public water and sewer use from the 1994 rates, to *Figure 5*.

Forecast Programming

Forecasts were made using an *Excel 5.0* spreadsheet. The program we developed is designed to enable a user to choose from a number of alternative weather conditions (1930, 1953, 1988, or 1994) or to input their own weather conditions. The user can also predict water use for 1994, 2000, 2010, and 2020 using both high and moderate growth projections. Public water and sewer projections are at the complete discretion of the user, with the user being able to choose the percentage of users on public water and sewer for each of the Basin counties.

Given the parameters chosen by the user, water use by pool and permit is then calculated. The worksheet *Template* reports use by permit (by pool) while the worksheet *Pool* reports use aggregated to the pool.

II. IRRIGATION IN AGRICULTURE

Since less in known about agricultural use of water for irrigation in the Kentucky River Basin we could not estimate water use in the same manner as use through existing water systems. A different approach is taken which relies on inventories of agricultural activity, use rates of the activities, and the sources of water supply other than the Kentucky River.

Irrigation Water Demand

Irrigation water demand can be roughly estimated by the following equation:

Irrigation water demand = (daily water demand per acre) (total irrigated land)

In this study, the total irrigated land in the Basin was obtained from the U.S. Census of Agriculture from 1964 to 1992. We did not find county-level data on irrigation in Kentucky in the Census of Agriculture prior to 1964.

Two estimates of daily per-acre water demand in the Kentucky River Basin (KRB) can be obtained. The lower one is 845 gallons, estimated based on a per-acre irrigation rate, which on the average was 6 inches per day during summer days in the 1970s. see Red River Study (1978). For a one in 20 year drought, five time greater water demand was assumed, see Red River Study (1978). Since one inch water is equivalent to 2,715.3 gallons according to Walker *et al.* (undated), multiplying this demand by five and then dividing by 90 days yields 845 gallons per day.

The higher and more recent estimate from the Walker *et al.* study is 8,146 gallons (0.3 inches) per day, for row crops by sprinkler irrigation systems Table 4 contains the irrigation water demand for seven agricultural census years, estimated using the two irrigation rates.

Over the years 1982, 1987 and 1992, the average irrigation water demand is estimated to be from 6.84 to 65.91 MGD. The higher estimate is an upper bound on irrigation demand for crops for reasons which will be explained below.

Determinants of Irrigated Land

There is a general increasing trend in irrigated land. The average irrigated land since the 1980s is about 1.5 times as great as that during the 1960s and 1970s. Variation in irrigated land between census years is attributable to weather factors, such as precipitation and temperature during summer days. Shown in Figures 9 and 10, from June to August, 1987, precipitation was lower than the normal and temperature higher than the normal. In contrast, 1992 summer was characterized with much higher precipitation and lower temperature (Climate District 3 includes Bluegrass region, and Climate District 4 is Eastern Kentucky). These differences clearly have influences on the change in irrigated land change.

In many KRB counties, census data on irrigated crop acres were withheld to avoid disclosing data for individual farms, so that we cannot be directly analyze the impact of changes in irrigated harvested crops on total irrigated land. Instead, we investigate the relationship between irrigated land (*IRRI*) and harvested land of three principal crops in the KRB counties: corn (*CORN*), tobacco (*TOBA*), and hay crops (*HAY*), using a time series cross-section regression procedure with census data from 1962 to 1992. To control the impacts of weather changes, we also included regressors, such as standardized monthly precipitation (*SDPR*) and temperature (*SDTE*) from May to July at the climate-district level. The regression result is shown in Table 5.

The regression results suggest two relevant findings.

1. Harvested tobacco land is one of the most important determinants of irrigated land. With other factors fixed, a one hundred-acre increase in tobacco land would raise irrigated land by about 8.6 acres. This finding is consistent with the fact that 8 percent of land planted in tobacco is irrigated in Kentucky according to the 1987 Census of Agriculture data.

2. Above normal precipitation decreases irrigated land while above normal temperature

increases irrigated land, though the temperature relationship is not statistically significant. If other factors are at their average levels, a dry year with summer monthly precipitation lower than the average by one standard deviation (about 0.8 in.) would increase irrigated land by 87 acres.

Irrigation Methods and Water Sources

The demand on the Kentucky River Basin for use in agricultural irrigation depends not only upon the quantity and type of crops, but also upon the irrigation method and other sources of water. We do not have information about the Kentucky River Basin, but we do have information about the state as a whole. Bajwa *et al.* (1992) report results of the 1988 irrigation survey of the entire state. They find:

- sprinkler systems are the most widely-used irrigation systems
- well water accounts for 56 percent of the total water sources
- on-farm surface water accounts for about 40 percent
  and
- off-farm water suppliers account for only 3.4 percent.

County-level data on irrigation water sources are available only in 1982 Census of Agriculture. In contrast to the statewide practice, irrigation water sources in the Kentucky River Basin are dominated by on-farm surface water, which account for 93.9%, and on-farm wells account for only 3.4%. Similar to statewide practice off-farm water supply accounts for only a small share, 2.7% (in acreage).[4]

Applying this share of 2.7% to the estimated irrigation water demand, the demand for off-farm suppliers was estimated at 0.18 to 1.78 MGD.

Map 1 shows the acreage irrigated by on-farm surface water in 1982 in the KRB counties based on the 1982 U.S. Census of Agriculture. The counties with less than 10 acres of crops irrigated using on-farm surface water are Knott, Letcher, Perry, Powell and Lee which are in or near the head waters of the Kentucky River. The counties with more than 1,000 acres of crops irrigated using on-farm surface water are Henry, Scott, Fayette and Owen which are closer to the mouth at the Ohio River.

Livestock Water Demand

Livestock water demand can be estimated according to the animal inventory numbers and daily water demand per animal. Livestock inventory data were obtained from the 1982, 1987, and 1992 Census of Agriculture. Daily animal water demand were estimated quite differently, see Red River Report (1978), Walker *et al.* (undated) and Schwendeman (1987). With two earlier estimates of per-animal daily demand, we estimated the total livestock water demand in the KRB counties shown in Table 6.

Map 2 shows that livestock water demand is higher in the central KRB counties.

Total Agricultural Water Demand

Total agricultural water demand can then be estimated by adding together the average irrigation for the years 1982, 1987 and 1992 (average of the last three years in Table 4) and the average livestock water demand for the same three years (average of the three years in Table 5).

With the lower water demand rates:

6.84 for crops + 4.18 for livestock = 11.02 MGD

With the higher water demand rates:

65.91 for crops + 10.20 for livestock = 76.11 MGD

However, neither of these two estimates are our best estimate of the amount of agricultural demand for water from the Kentucky River during a drought. They are both likely to be overestimates for reasons discussed in the next section.

Forecasting Irrigation and Livestock Water Use during Drought Conditions

As shown in the Determinants of Irrigated Land section above, weather factors are clearly important in farmers' decision on irrigation. But, during a drought economic factors also affect farmers' irrigation decisions. Based on team member Dayuan Hu's talks with extension experts and people with experience in farming in the central Kentucky, we judge that the higher estimate of daily irrigation water demand will not be reached during a drought comparable to the 1930 drought.

The regression analysis showed that changes in tobacco acreage will significantly affect the changes in the total irrigated harvested cropland in the KRB basin. Unlike most of other crop production activities, tobacco production and marketing is a government restricted activity under an allotment program. Understanding tobacco farmers' behavior under government regulations is certainly helpful for predicting changes in irrigation water demand in the KRB during a drought.

Tobacco production is based on a national quota system. According to historical production records, quotas are attached to individual farmers and convey the right to plant and market a certain amount of tobacco each year, see Allen (1990). In a poor harvest year, the unused part of the quota can be carried over to the next year. Therefore, any loss caused by a poor harvest can be made up by increasing tobacco planting and marketing in the next year. This characteristic of the tobacco program would clearly reduce the tobacco farmers' efforts to irrigate tobacco land against a drought when irrigation is costly.

Another related agricultural policy is the disaster payments program. In 1988 and 1989, Congress passed legislation mandating disaster payments for farmers who suffered losses because of disastrous weather conditions, primarily the droughts of those years. These disaster payments are usually based on a fraction of what a farmer normally would have produced. Total disaster payments are limited to $100,000 per year per person, see Allen (1990). If a drought is severe, instead of trying to pay the increasing irrigation cost, a farmer may well choose to wait for a disaster payment from the federal government.

In addition, when water supplies are restricted during a drought, to a certain extent, labor and capital can be substituted for water. Research in the western U.S. has shown that irrigation water can be conserved significantly with only small losses in farmer income, see Bernardo and Whittlesey (1989).

Generally in the Kentucky River Basin it is not profitable to irrigate relatively low value crops such as corn, wheat, hay and soybeans. Available agricultural census data show that irrigation is mainly used for high valued crops such as tobacco and vegetables. Before paying land and quota charges (about $1,253), profits from producing and selling tobacco average only $738.75 from 1991 to 1993 in Kentucky and Tennessee, see Kentucky Agriculture Statistics (1994). Outlook for tobacco production is mixed at best Constant pressure in the U.S. Congress may make it difficult even to sustain the current sales obtained by Kentucky farmers in recent years, see Snell (1995).

Even for tobacco, the use of district water for irrigation is generally not profitable. Only for vegetable production is district water sometimes considered profitable. Vegetable production has been expanded during the past decade, but most growers engage in small scale production. In the KRB counties, total vegetable land is only 767 acres, which is just about 10% of irrigated tobacco land. Considering that only 8.7% to 18% of vegetable land has been irrigated in Kentucky during the past decade, changes in vegetable irrigation are unlikely to significantly affect district water demand in the KRB.

The effects of these factors are likely to dramatically reduce the irrigation demand during a drought below the estimate of 76 MGD. We think 76 is an extreme upper bound and even 11 is too high. Since most irrigation water comes from on-farm water supplies, only about 3% of irrigation water comes from off-farm suppliers, and there are strong economic forces, both from farm programs and from agricultural markets, which limit the attractiveness of large-scale irrigation. If we double (to 6%)the percentage of irrigation water coming from off-farm suppliers and use the extreme upper bound of 76 MGD, we get an estimate of agricultural demand for Kentucky River water of about 5 MGD. This estimate is our best estimate of irrigation demand. It will come from areas which are near pool 9 and further downstream.

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Notes

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1. We thank Leon Smothers and Dionne Fields, Kentucky Cabinet for Natural Resources and Environmental Protection, Division of Water, for supplying the data.

2. We thank Tom Priddy in the Agriculture Weather Section, College of Agriculture, University of Kentucky for supplying the data.

3 Following a suggestion from Hugh Archer we contacted Steve Bashen at the Kentucky Rural Water Association to get data from a recent project with rural water systems in the Basin. We received a diskette with rates and some other 1966 information for rural water systems. The rate data might have been useful in decomposing the county-specific effects in the demand estimation model, but it could not be matched to the DOW, permit based data. 1996 water use data for each water system is not readily available for a separate water demand analysis.

4. In many eastern Kentucky counties, data on irrigated acreage by on-farm well water and by off-farm supplied water were withheld to avoid disclosing data for individual farms. But information about the number of farms that irrigated land by on-farm well or off-farm supplier's water is reported. We estimated the average irrigated acreage according to the reported counties, and then applied the average acreage per irrigated farm to estimate total acreage in the counties with disclosure problems.

Table 1a: Estimates of Use for Basin, 1970-1993 using Year Dummies				
	Summer Estimates		*Winter Estimates*	
Variable	**Coefficient.**	**t-Statistic**	**Coefficient.**	**t-Statistic**
Population	0.0576	0.76	-0.01415	-0.285
Income	-0.0301	-0.51	0.007176	0.541
Population*Income	-0.0000	-0.02	-0.00127	-2.349
Employment/Population	0.8994	0.89	-0.01239	-1.111
%Single Family Dwelling	0.0359	2.38	-0.00125	-2.64
Population	-0.0024	-3.80	-2.43067	-3.695
% Employment, Manufacturing	0.5542	0.53	0.217954	0.28
% on Public Water	-0.0240	-2.18	-0.06569	-8.32
Population*(% on Water)	0.0010	2.27	0.002122	6.336
% on Public Sewer	-0.0165	-1.28	-0.054	-6
Population*(% on Sewer)	0.0024	4.61	0.003893	10.372
Temperature (average daily)	-0.0333	-2.06	---	---
Population*Temperature	0.0013	4.19	---	---
Rain (Inches per week)	-0.0504	-0.63	---	---
Population*Rain	-0.0012	-0.75	---	---
Days of Rain	0.1420	2.88	---	---
Population*(Days of Rain)	-0.0058	-6.03	---	---
Temperature_1 (previous month)	0.0181	1.17	---	---
Population*Temperature_1	-0.0011	-3.43	---	---
Rain_1 (previous month)	-0.0047	-0.07	---	---
Population*Rain_1	0.0015	1.08	---	---
June	0.1325	0.72	---	---
Population*June	-0.0058	-1.59	---	---
July	-0.0747	-0.51	---	---
Population*July	0.0037	1.24	---	---
August	-0.0925	-0.66	---	---
Population*August	0.0052	1.88	---	---
January	---	---	-0.08912	-1.13
Population*January	---	---	0.005716	3.677
February	---	---	0.079752	1.011
Population*February	---	---	-0.00156	-1.004
March	---	---	0.127799	1.616
Population*March	---	---	-0.00372	-2.391
April	---	---	0.017662	0.224
Population*April	---	---	0.004422	2.843
May	---	---	-0.15478	-1.956
Population*May	---	---	0.015733	10.113
October	---	---	-0.19737	-2.51
Population*October	---	---	0.016654	10.717
November	---	---	-0.04933	-0.627
Population*November	---	---	0.005545	3.568

	Summer Estimates		*Winter Estimates*	
Variable	**Coefficient.**	**t-Statistic**	**Coefficient.**	**t-Statistic**
Boyle	-0.0231	-0.05	-0.51869	-1.535
Breathitt	-0.9838	-1.84	-3.21762	-8.607
Clark	-0.0173	-0.04	-1.7583	-4.828
Clay	0.0218	0.04	-2.32851	-5.534
Estill	-0.1005	-0.35	-1.20683	-5.7
Fayette	2.8289	0.37	-32.5361	-6.097
Franklin	3.6626	3.73	2.038303	2.794
Garrard	-0.9991	-3.91	-1.29142	-6.771
Grant	-1.2146	-3.57	-2.37662	-9.58
Jessamine	-0.1512	-0.35	-1.90119	-6.067
Knott	-1.4427	-1.80	-4.68232	-8.432
Lee	-1.5969	-2.91	-3.01642	-7.565
Leslie	-0.6812	-0.97	-3.66891	-7.731
Letcher	0.2738	0.38	-2.32337	-4.502
Lincoln	-0.6885	-1.62	-2.223	-7.341
Madison	0.9536	0.80	-3.83177	-4.478
Mercer	-0.1672	-0.71	-0.63687	-3.651
Owen	-1.4001	-3.08	-2.62665	-7.793
Owsley	-2.2949	-3.34	-4.03157	-8.078
Perry	1.3804	1.85	-0.85086	-1.573
Powell	-1.5421	-3.94	-2.8476	-10.11
Wolfe	-2.5273	-3.51	-4.81137	-9.218
Woodford	-0.3701	-1.26	0.210667	1.057
1971	1.2484	5.77	0.191507	1.247
1972	0.8840	3.20	0.511034	2.454
1973	2.5240	6.57	0.620279	2.177
1974	1.8724	3.74	0.291479	0.793
1975	2.5186	4.19	0.346208	0.773
1976	2.6576	3.66	0.127652	0.238
1977	2.8653	3.43	-0.04875	-0.079
1978	3.0916	3.27	-0.03123	-0.045
1979	4.0191	3.84	1.078474	1.388
1980	1.9913	4.91	2.107646	7.06
1981	1.9754	4.81	2.038065	6.638
1982	2.3925	5.21	1.981584	5.783
1983	2.7435	5.07	2.138764	5.373
1984	2.7657	4.29	1.712658	3.569
1985	3.0237	4.08	1.373056	2.498
1986	3.1029	3.71	1.274544	2.056
1987	3.1512	3.38	1.049669	1.523
1988	3.8579	3.75	1.235449	1.625
1989	4.3845	3.90	1.583358	1.898
1990	2.8320	4.75	2.732918	6.172
1991	2.6089	4.28	2.689976	5.969

Variable	Summer Estimates Coefficient.	t-Statistic	Winter Estimates Coefficient.	t-Statistic
1993	2.4052	3.70	2.782717	5.793
Population*1971	-0.0635	-13.57	-0.01427	-4.172
Population*1972	-0.0495	-5.71	-0.04128	-6.458
Population*1973	-0.1231	-9.02	-0.06449	-6.385
Population*1974	-0.1058	-5.61	-0.07151	-5.149
Population*1975	-0.1244	-5.42	-0.0845	-4.96
Population*1976	-0.1502	-5.41	-0.08571	-4.167
Population*1977	-0.1510	-4.69	-0.09182	-3.849
Population*1978	-0.1738	-4.77	-0.10236	-3.782
Population*1979	-0.2056	-4.96	-0.14351	-4.669
Population*1980	-0.0662	-4.46	-0.07976	-7.384
Population*1981	-0.0677	-4.45	-0.07172	-6.432
Population*1982	-0.0887	-5.00	-0.08555	-6.577
Population*1983	-0.1012	-4.75	-0.10261	-6.549
Population*1984	-0.1142	-4.49	-0.09408	-4.979
Population*1985	-0.1375	-4.62	-0.1014	-4.587
Population*1986	-0.1334	-3.93	-0.10867	-4.305
Population*1987	-0.1350	-3.54	-0.11323	-4.006
Population*1988	-0.1698	-4.05	-0.12734	-4.089
Population*1989	-0.2111	-4.58	-0.15348	-4.482
Population*1990	-0.0943	-3.87	-0.10367	-5.732
Population*1991	-0.0776	-3.12	-0.10441	-5.674
Population*1992	-0.1022	-3.94	-0.1079	-5.628
Population*1993	-0.0598	-2.25	-0.09805	-4.992
Constant	0.3998	0.16	7.534341	6.018
Number of Obs	1992		3982	
F	1392.08		1813.31	
Prob > F	0		0	
R-Squared	0.986		0.9777	
Adj. R-Squared	0.9853		0.9772	
Root MSE	0.96161		1.0195	

Table 1b: Estimates of Use for Basin, 1970-1993 using Linear Trend				
	Summer Estimates		*Winter Estimates*	
Variable	**Coefficient.**	**t-Statistic**	**Coefficient.**	**t-Statistic**
Population	-0.30503	-6.421	-0.03913	-1.388
Income	0.116018	2.703	0.004237	0.511
Population*Income	-0.00412	-2.878	-0.00029	-1.048
Employment/Population	-2.96822	-3.442	-4.49E-06	-8.137
%Single Family Dwelling	-0.00093	-0.627	0.003733	4.158
Population	-3.2E-05	-0.929	-0.00015	-6.638
% Employment, Manufacturing	1.624238	1.49	-0.00048	-0.071
% on Public Water	0.015258	1.755	-0.01793	-3.641
Population*(% on Water)	-0.00023	-0.578	0.000627	2.556
% on Public Sewer	0.002374	0.229	-0.01689	-2.714
Population*(% on Sewer)	0.00089	4.218	0.001489	11.067
Temperature (average daily)	-0.03605	-2.656	---	---
Population*Temperature	0.002265	8.209	---	---
Rain (Inches per week)	-0.04357	-0.547	---	---
Population*Rain	-0.00168	-1.067	---	---
Days of Rain	0.173767	3.502	---	---
Population*(Days of Rain)	-0.00732	-7.393	---	---
Temperature_1 (previous month)	0.000291	0.022	---	---
Population*Temperature_1	0.000694	2.63	---	---
Rain_1 (previous month)	0.078421	1.098	---	---
Population*Rain_1	-0.00211	-1.486	---	---
Trend	-0.05141	-2.78	0.051079	4.604
Population*Trend	0.005092	7.304	0.000338	0.789
June	-0.07138	-0.384	---	---
Population*June	0.011939	3.208	---	---
July	-0.12274	-0.796	---	---
Population*July	0.002788	0.889	---	---
August	-0.06534	-0.524	---	---
Population*August	-0.00232	-0.924	---	---
January	---	---	-0.09748	-1.3
Population*January	---	---	0.005757	3.706
February	---	---	0.057682	0.769
Population*February	---	---	-0.0014	-0.898
March	---	---	0.094305	1.257
Population*March	---	---	-0.00345	-2.223
April	---	---	-0.01842	-0.246
Population*April	---	---	0.004704	3.028
May	---	---	-0.18468	-2.464
Population*May	---	---	0.015957	10.273
October	---	---	-0.21275	-2.844
Population*October	---	---	0.01678	10.807
November	---	---	-0.07009	-0.937

Variable	Summer Estimates: Coefficient.	Summer Estimates: t-Statistic	Winter Estimates: Coefficient.	Winter Estimates: t-Statistic
Population*November	---	---	0.005723	3.686
Boyle	2.374715	9.524	1.059795	4.132
Breathitt	0.403113	0.796	-1.8151	-6.139
Clark	2.460591	10.954	0.114508	0.454
Clay	1.095344	1.84	-1.54231	-4.304
Estill	0.297459	0.99	-1.21063	-6.851
Fayette	47.66624	11.7	3.516076	1.256
Franklin	9.562072	20.04	6.289415	12.909
Garrard	-0.30808	-1.189	-0.69026	-4.202
Grant	-0.42537	-1.29	-1.36956	-6.6
Jessamine	1.453734	5.658	-0.7075	-3.135
Knott	-0.03946	-0.05	-3.09535	-6.916
Lee	-0.455	-0.937	-1.68814	-5.73
Leslie	0.5656	0.865	-2.09725	-5.883
Letcher	1.305286	1.895	-1.93208	-4.411
Lincoln	0.202239	0.478	-1.6231	-6.152
Madison	6.398755	9.592	0.369795	0.646
Mercer	0.728628	3.895	-0.12298	-0.786
Owen	-0.23558	-0.556	-1.25828	-5.057
Owsley	-0.77321	-1.336	-2.40784	-6.744
Perry	3.104609	4.663	-0.25694	-0.559
Powell	-1.02401	-2.738	-1.94889	-8.829
Wolfe	-0.55359	-0.939	-2.27032	-6.469
Woodford	0.340645	1.514	0.475314	3.056
Constant	3.384234	2.069	3.480534	5.881
Number of Obs	2080		4465	
F	1392.08		1813.31	
Prob > F	0		0	
R-Squared	0.986		0.9747	
Adj. R-Squared	0.979		0.97	
Root MSE	1.13		1.0299	

Table 2a: Marginal Impacts for Summer

Results of Estimation with Population Interactions(Summer)

Marginal Impact of Another Person 60 Gallons
(includes all interactions with variables evaluated at their means)

Marginal Impacts of Factors Evaluated at Alternative Population Levels

County	Owen	Clay	Perry	Franklin	Madison
Population	9,574	22,776	30,238	45,605	61,960
Income ($1000 per capita, 94)	-0.0305	-0.0312	-0.0316	-0.0323	-0.0331
Single Homes (%)	0.0126	-0.0194	-0.0375	-0.0748	-0.1145
Public Water (%)	-0.0143	-0.0009	0.0067	0.0224	0.0390
Sewer (%)	0.0065	0.0382	0.0562	0.0931	0.1324
Temperature (Average)	-0.0204	-0.0026	0.0075	0.0282	0.0503
Rain (inches per week)	-0.0615	-0.0768	-0.0854	-0.1032	-0.1222
Rain Days (Days week)	0.0865	0.0100	-0.0332	-0.1222	-0.2170
Temperature_1	0.0080	-0.0059	-0.0138	-0.0300	-0.0473
Rain_1	0.0095	0.0291	0.0402	0.0630	0.0872

Table 2b: Marginal Impacts for Winter

Results of Estimation with Population Interactions(Summer)

Marginal Impact of Another Person 81 Gallons
(includes all interactions with variables evaluated at their means)

Marginal Impacts of Factors Evaluated at Alternative Population Levels

County	Owen	Clay	Perry	Franklin	Madison
Population	9,574	22,776	30,238	45,605	61,960
Income ($1000 per capita, 94)	-0.0050	-0.0219	-0.0314	-0.0509	-0.0718
Single Homes (%)	-0.0244	-0.0409	-0.0502	-0.0695	-0.0899
Public Water (%)	-0.0454	-0.0174	-0.0015	0.0311	0.0658
Sewer (%)	-0.0167	0.0347	0.0637	0.1235	0.1872

Table 3: Summer Weather, 1994, 1988, 1953, 1930

Year	Month	Temperature	Rain	Rain Days	Temp_1	Rain_1
1994	June	75.07	0.96	1.5	59.1425	1.215
	July	77.5	0.5525	2.75	75.07	0.96
	August	73.8575	0.8	1.75	77.5	0.5525
	September	66.4975	0.2975	1.5	73.8575	0.8
1988	June	74.215	0.1525	0.25	63.555	0.755
	July	78.965	0.87	2.5	74.215	0.1525
	August	79.3375	0.9575	1.5	78.965	0.87
	September	67.535	1.4875	2	79.3375	0.9575
1953	June	77	0.9275	2.25	67.5	1.3675
	July	77.5	0.9175	2.25	77	0.9275
	August	76.5	0.61	1.5	77.5	0.9175
	September	70	0.395	1.2	76.5	0.61
1930	June	72	0.4725	1.25	67	0.8225
	July	79	0.1125	1.25	72	0.4725
	August	76	0.4225	2.75	79	0.1125
	September	72	0.7	1.75	76	0.4225

Table 4. Estimates of Daily Irrigation Water Demand in the KRB

Year	Irrigated land (acre)	Irrigation water demand (MGD)	
		Lower rate	Higher rate
1964	4,521	2.820	36.828
1969	8,272	6.990	67.384
1974	4,267	3.606	34.759
1978	4,807	4.062	39.158
1982	8,686	7.340	70.756
1987	10,320	8.720	84.067
1992	5,267	4.451	42.905

Source: For irrigated land, U.S. Census of Agriculture, 1964-1992. Water demand is estimated as described in text.

Table 4. Estimates of Daily Irrigation Water Demand in the KRB

Year	Irrigated land (acre)	Irrigation water demand (MGD)	
		Lower rate	Higher rate
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1969	8,272	6.990	67.384
1974	4,267	3.606	34.759
1978	4,807	4.062	39.158
1982	8,686	7.340	70.756
1987	10,320	8.720	84.067
1992	5,267	4.451	42.905

Source: For irrigated land, U.S. Census of Agriculture, 1964-1992. Water demand is estimated as described in text.

Over the years 1982, 1987 and 1992, the average irrigation water demand is estimated to be from 6.84 to 65.91 MGD. This range is an upper bound on irrigation demand for crops for reasons which will be explained below.

County-level data on irrigation water sources are available only in 1982 Census of Agriculture. In contrast to the statewide practice, irrigation water sources in the Kentucky River Basin are dominated by on-farm surface water, which account for 93.9%, and on-farm wells account for only 3.4%. Similar to statewide practice off-farm water supply accounts for only a small share, 2.7% (in acreage).

Applying this share of 2.7% to the estimated irrigation water demand, the demand for off-farm suppliers was estimated at 0.18 to 1.78 MGD.

Table 5. Time Series Cross-section Regression Results for Determinants of Irrigated Land, Kentucky River Basin Counties, Seven Agriculture Census Years, 1964-1992

Variable	Parameter estimate	Standard error	t-statistics
Intercept	66.294	75.142	0.882
Harvested cropland:			
corn (*CORN*)	0.011	0.011	0.992
tobacco (*TOBA*)	0.086	0.032	2.712
hay crops (*HAY*)	0.001	0.005	0.141
Standardized monthly			
precipitation (*SDPR*)	-87.314	43.465	-2.008
temperature (*SDTE*)	21.295	48.582	0.438
Number of counties	27		
Time series length	7		
Degree of freedom	182		
Estimation method	Dasilva		

Source: Estimated as described in text.

Table 6. Livestock daily water demand in the KRB

Item	Inventory number			Higher estimate (gallons per head)[a]	Water demand (000 gallons)		
	82	87	92		82	87	92
Cattle and Calves [b]	563,424	518,600	542,085	20	8451	7779	8131
Milk cows	35,832	28,730	21,878	45	1,612	1,293	985
Horses	29,973	36,797	32,926	20	599	736	659
Sheep	9,401	8,210	9650	2	19	16	19
Hogs	58,377	45,640	25,156	2.25	131	103	57
Chickens (hundred)	963	306	126	5	5	2	1
Total					10,818	9,928	9,851

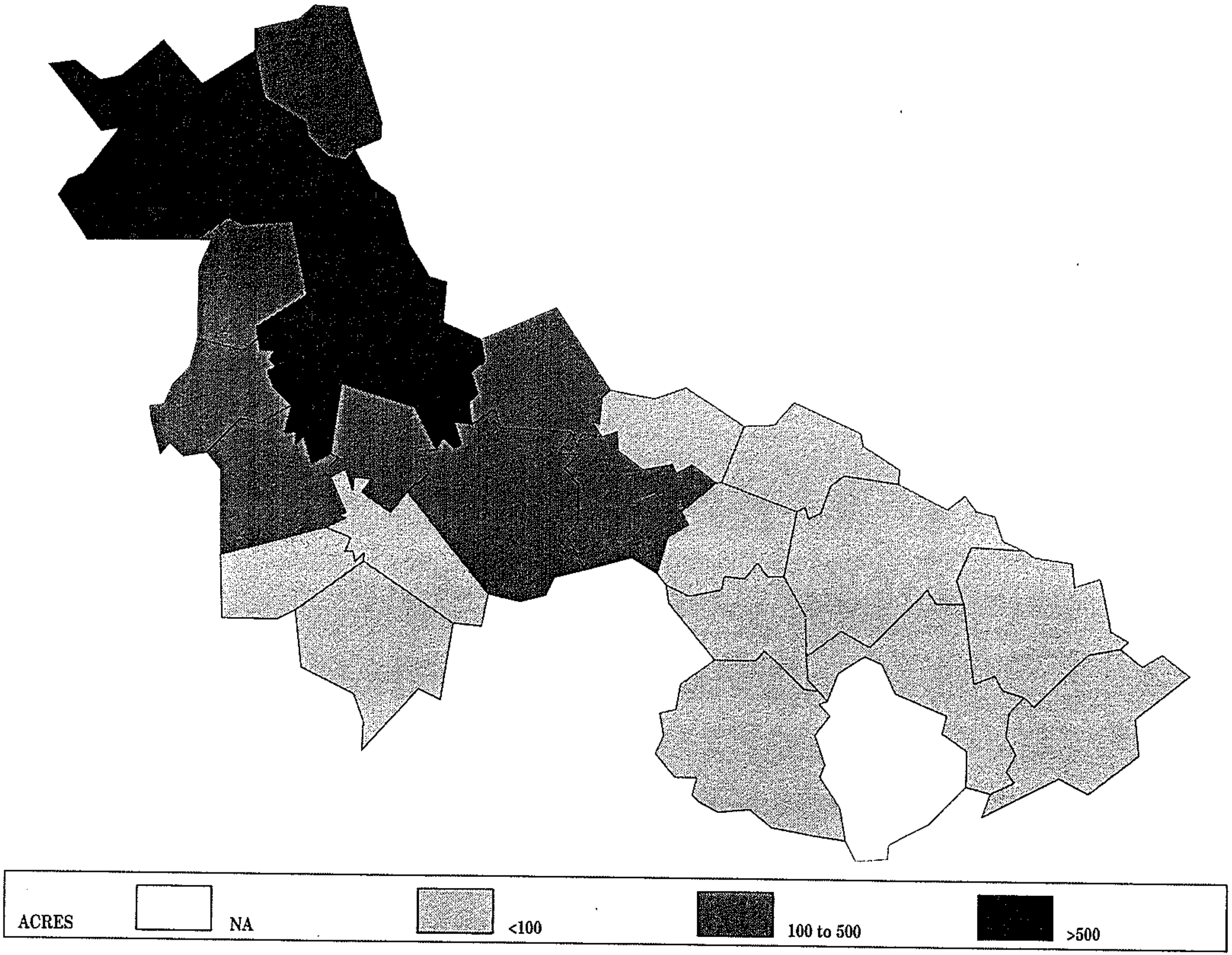
Item	Lower estimate (gallons per head)[c]	Water demand (000 gallons)		
		82	87	92
Cattle and Calves	4.5	2,35	2,33	2,39
Milk cows	40	1,433	1,149	875
Horses	12	360	442	395
Sheep	2	19	16	19
Hogs	4	233	182	101
Chickens (hundred)	5	5	2	1
Total		4,585	4,124	3,830

[a] For cattle and calves, milk cows, and hogs, refer to Red River Report (1978). Daily water demand per horse is assumed to be the same as a full-grown beef cow. For sheep and chickens, refer to Walker *et al.* (undated).

[b] Cattle and calves number was estimated under an assumption of half full-grown animals and half calves.

[c] Not available in Schwendeman (1987) and assumed to be the same as the earlier estimate.

Map 1. Principal Source of Irrigation Water: On – Farm surface 1982



Map 2. Livestock Daily Water Demand (Average of 1982, 1987, & 1992)

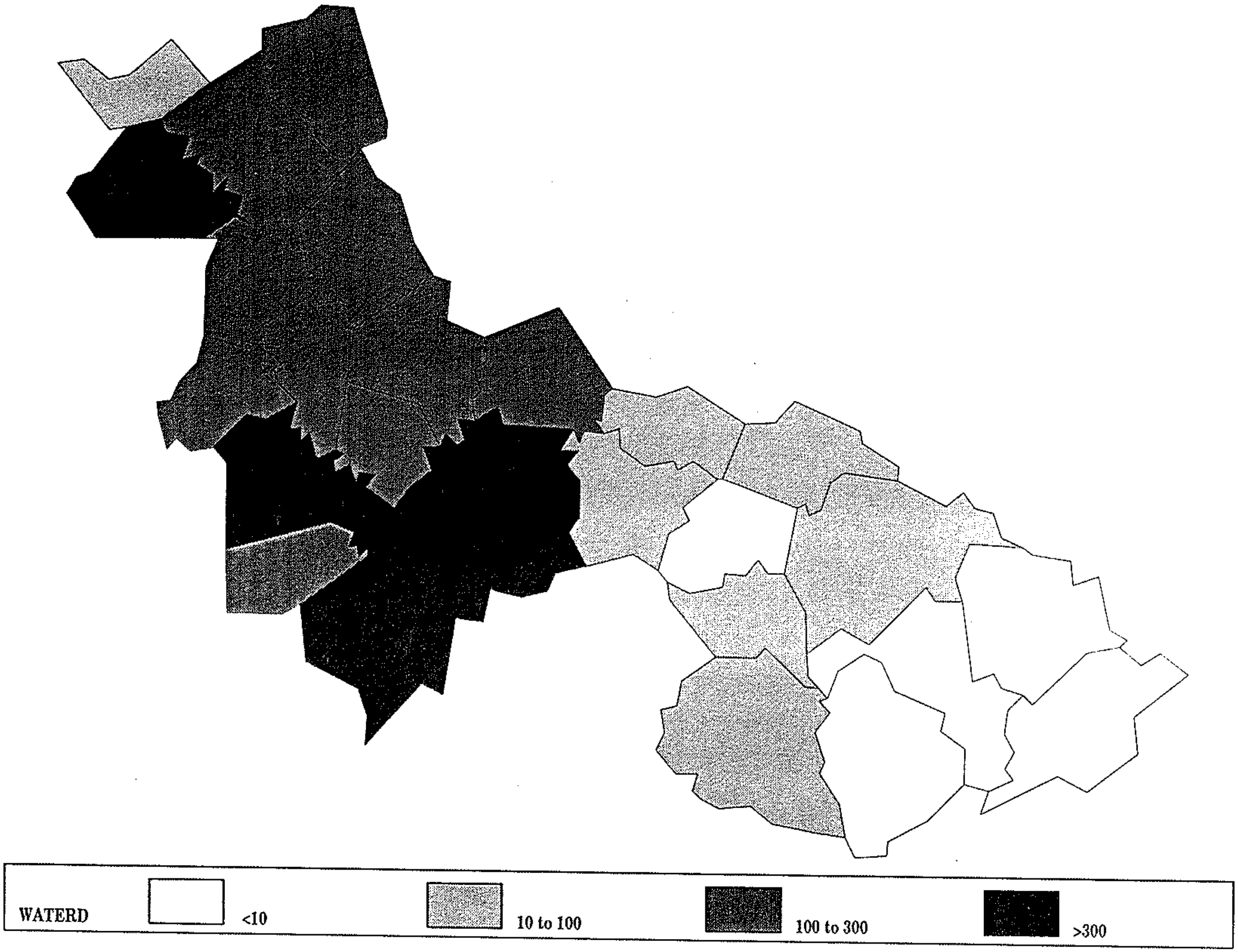


Figure 1a: Fayette County, June Actual versus Predicted Use

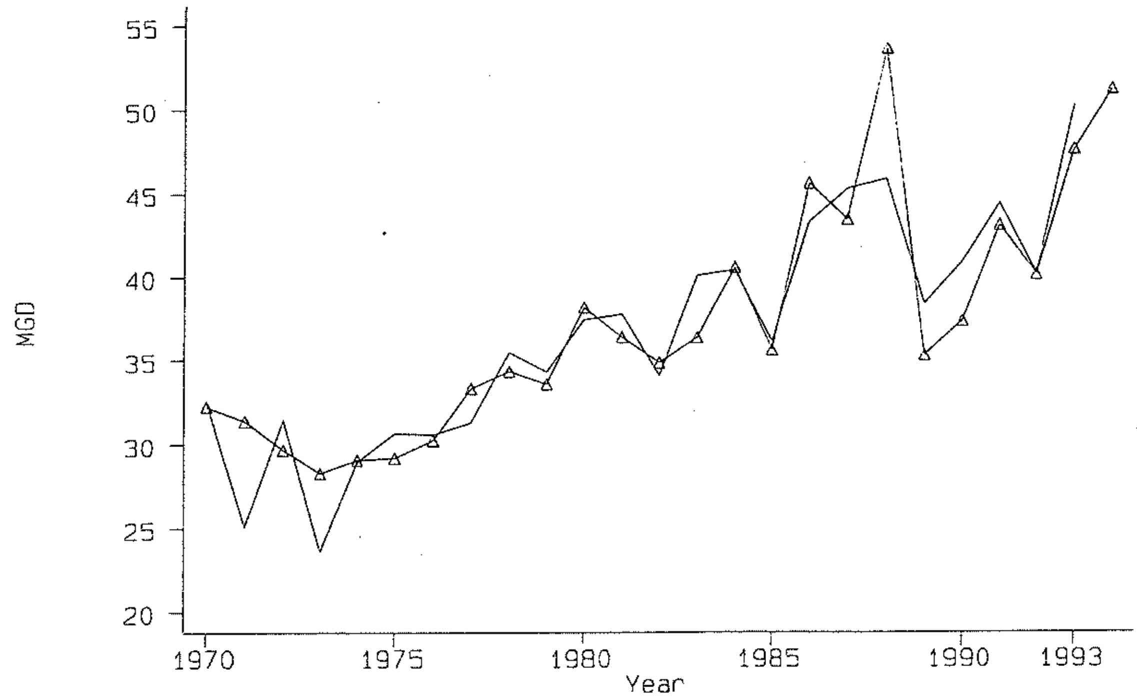


Figure 1b: Fayette County, July Actual versus Predicted Use

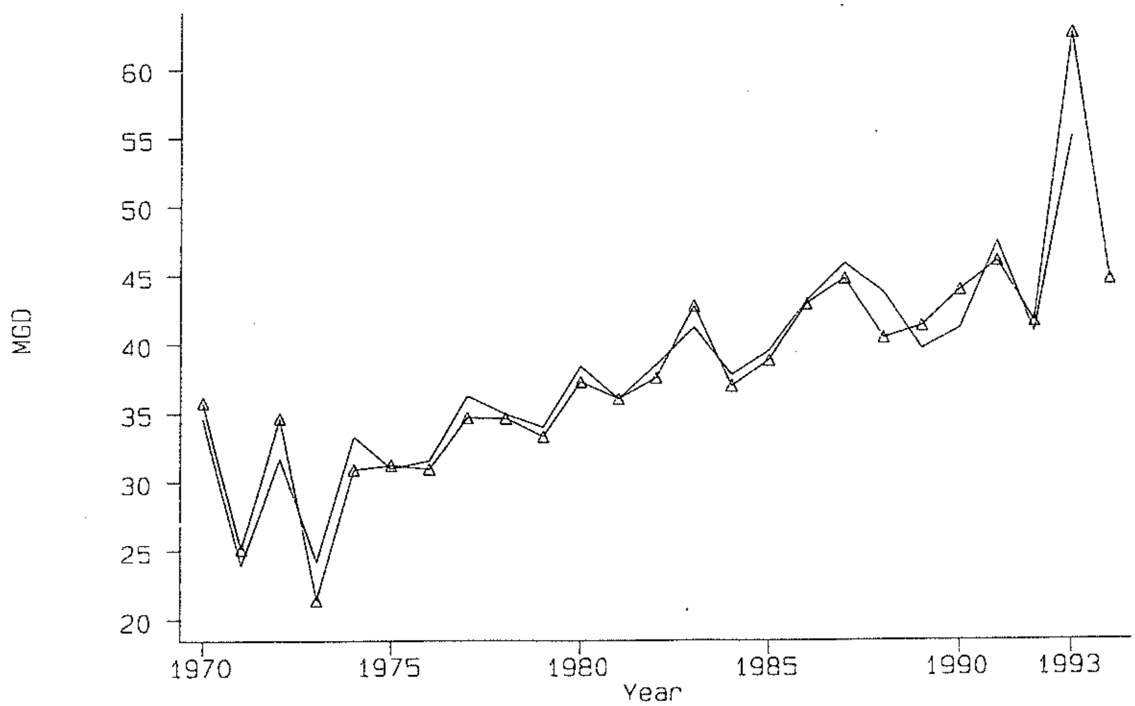


Figure 1c: Fayette County, August Actual versus Predicted Use

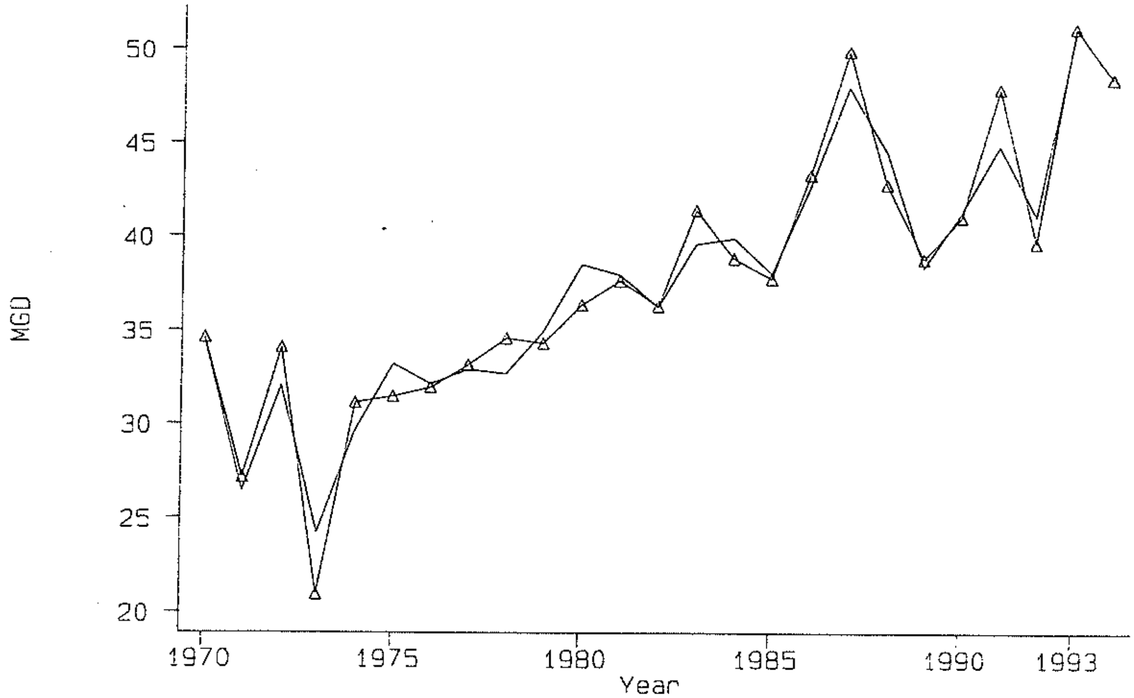


Figure 1d: Fayette County, September Actual versus Predicted Use

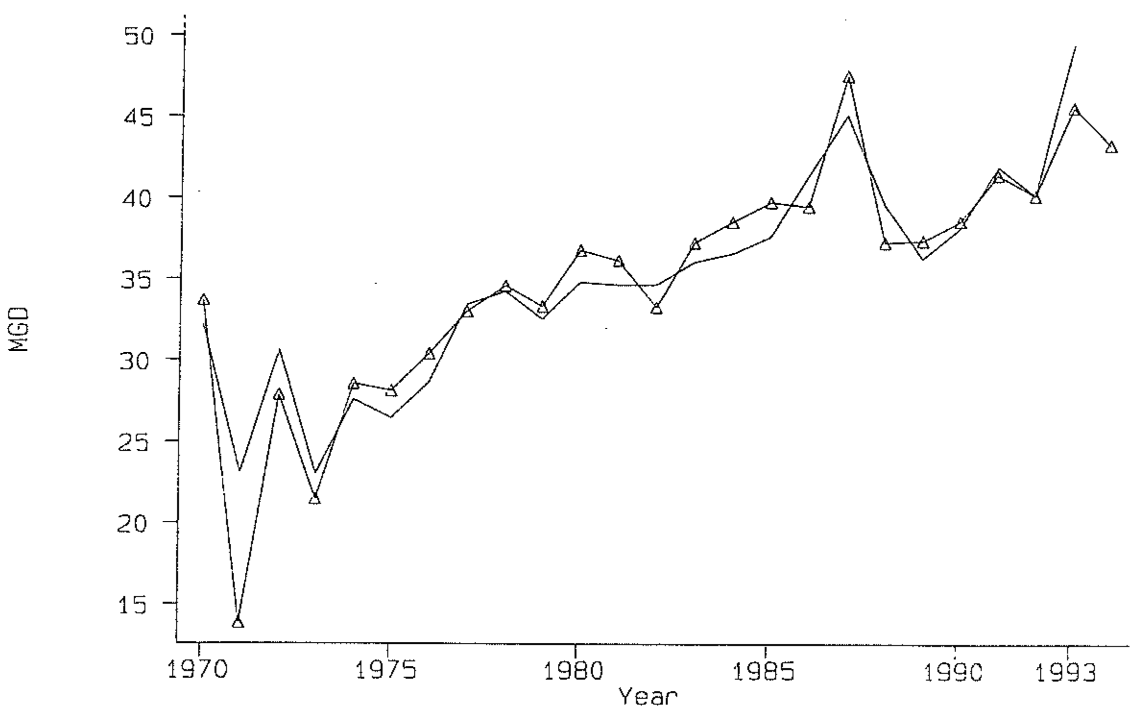


Figure 1e: Fayette County, March Actual versus Predicted Use

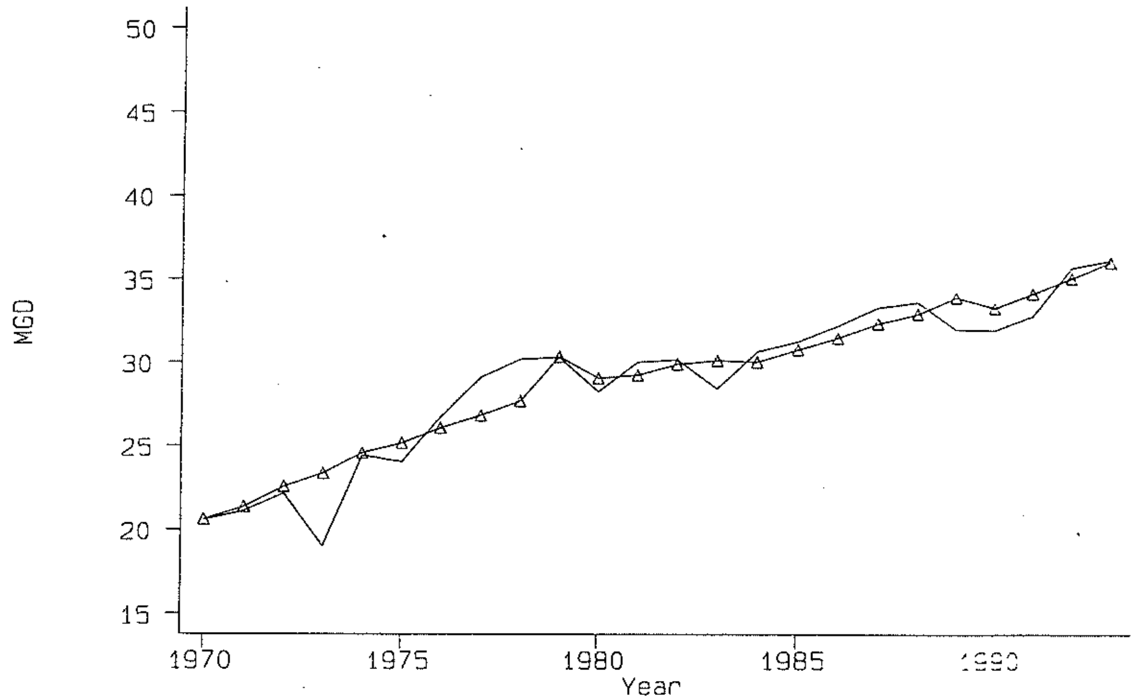


Figure 1f: Fayette County, October Actual versus Predicted Use

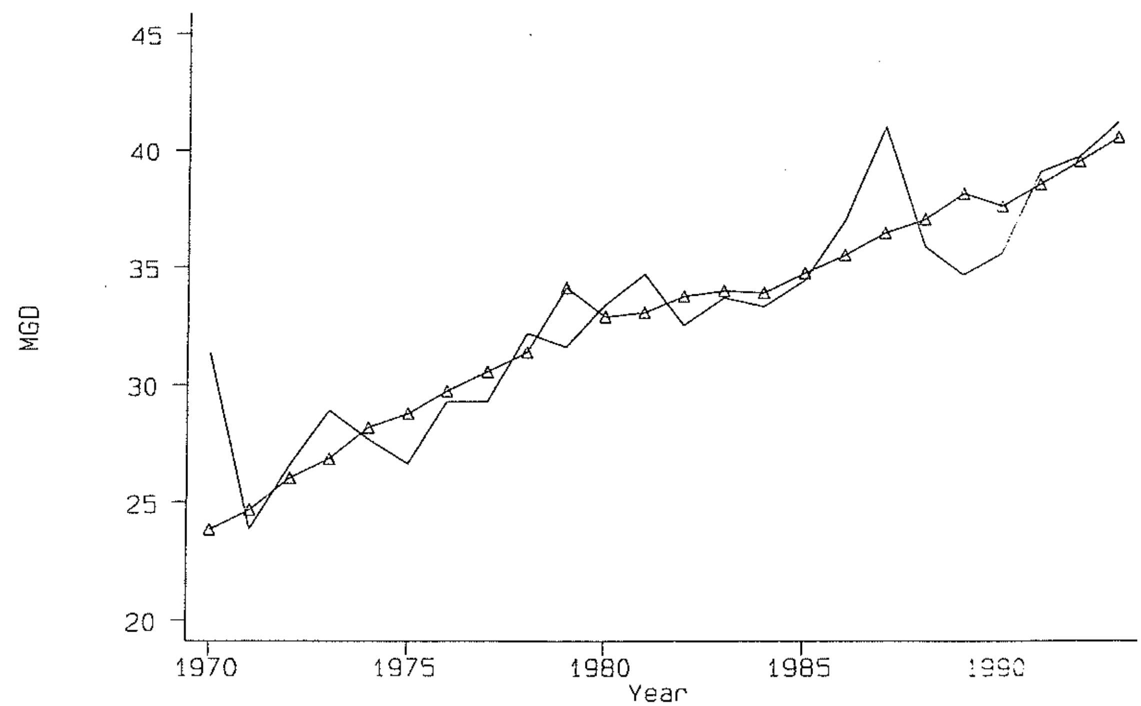


Figure 2a: Perry County, June Actual versus Predicted Use

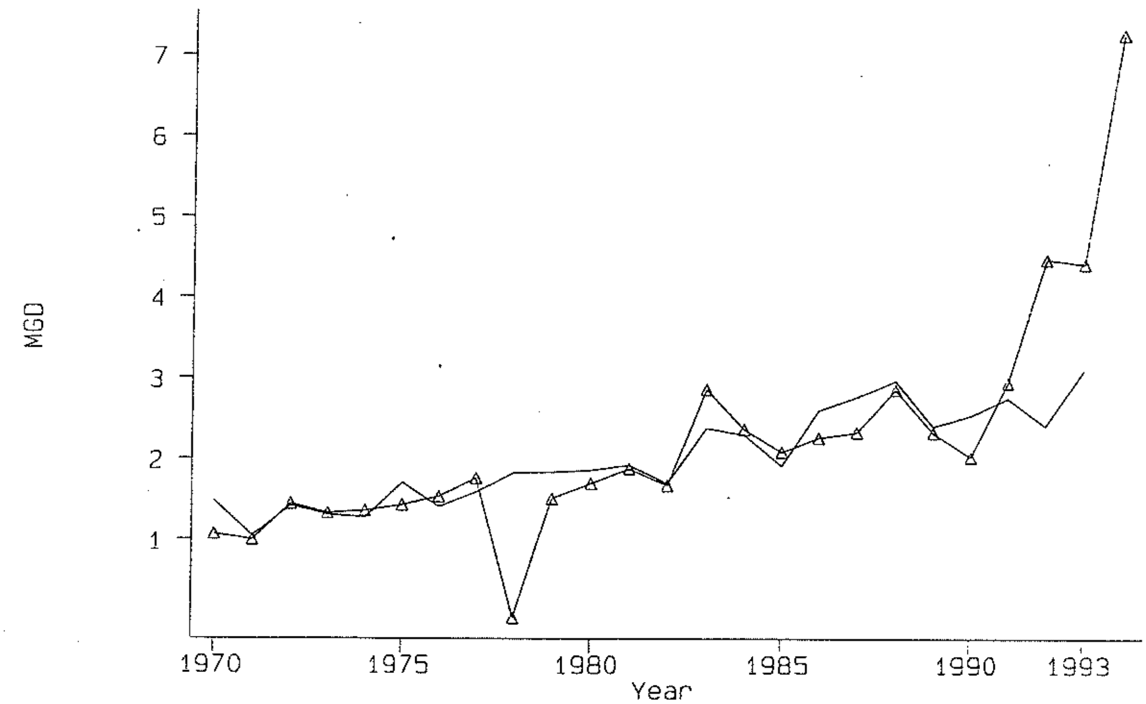


Figure 2b: Clark County, June Actual versus Predicted Use

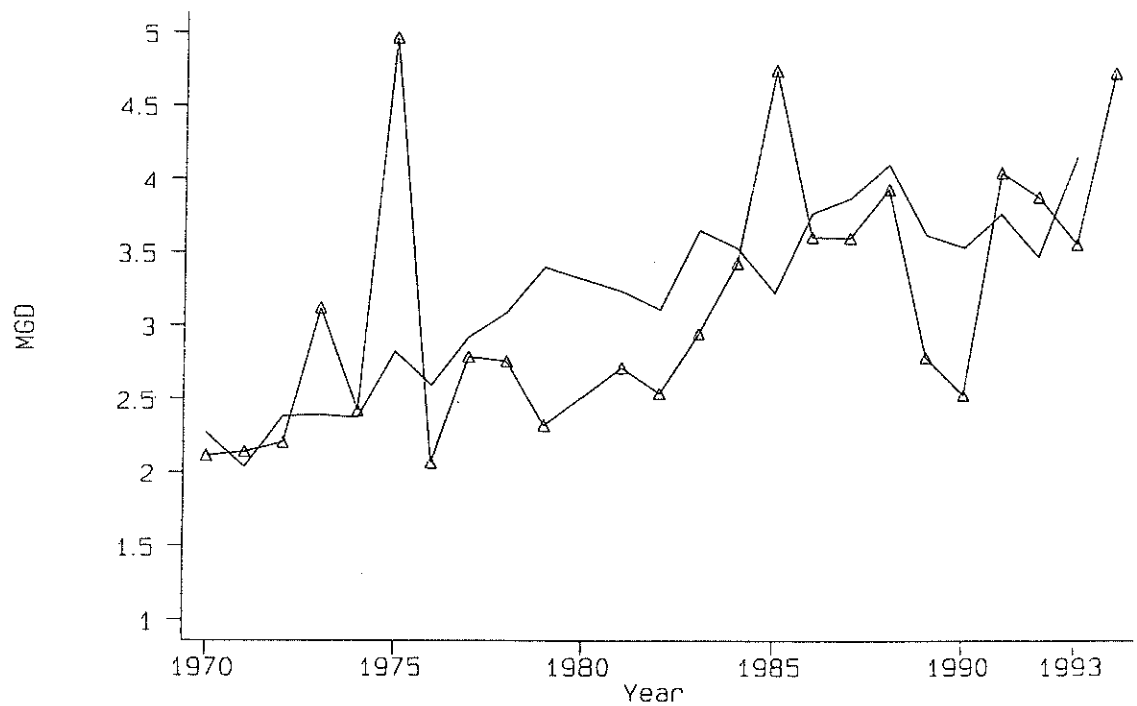


Figure 2c: Franklin County, June Actual versus Predicted Use

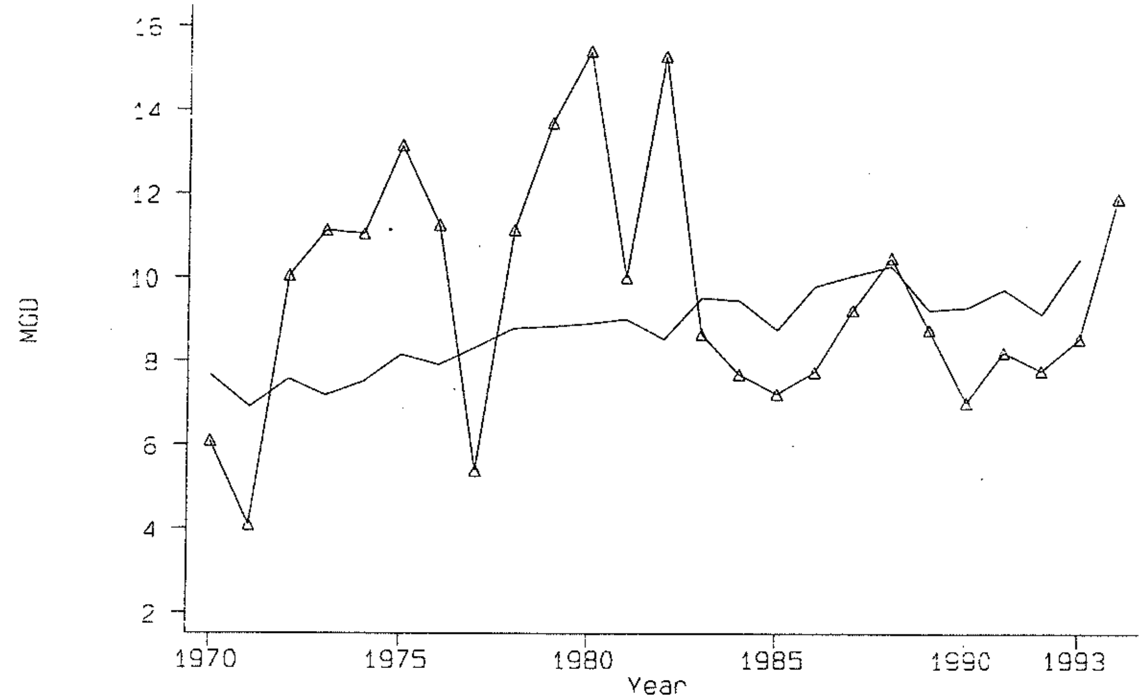


Figure 2d: Madison County, June Actual versus Predicted Use

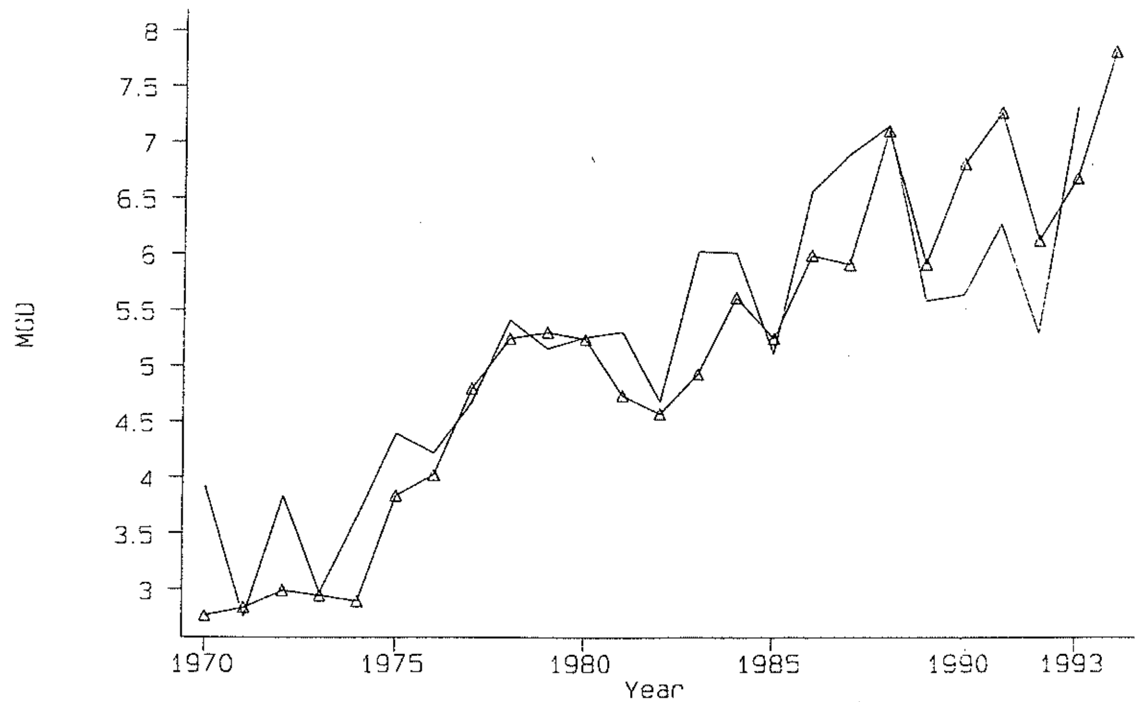


Figure 2e: Franklin County, March Actual versus Predicted Use

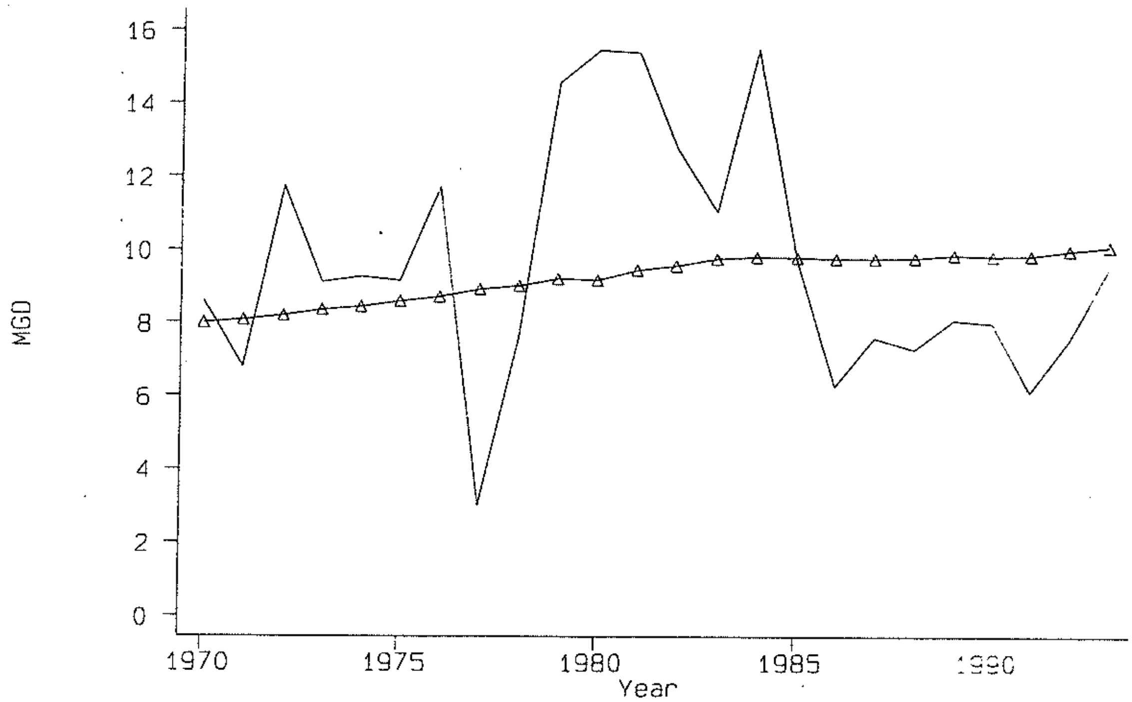


Figure 2f: Madison County, March Actual versus Predicted Use

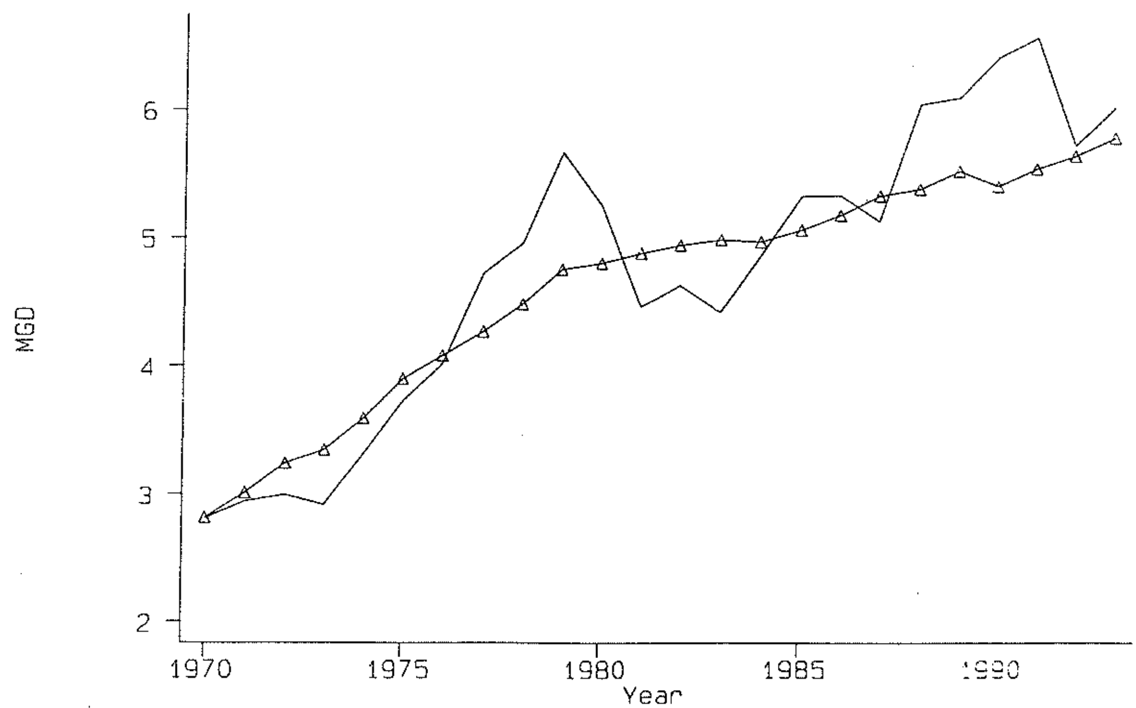


Figure 2g: Perry County, March Actual versus Predicted Use

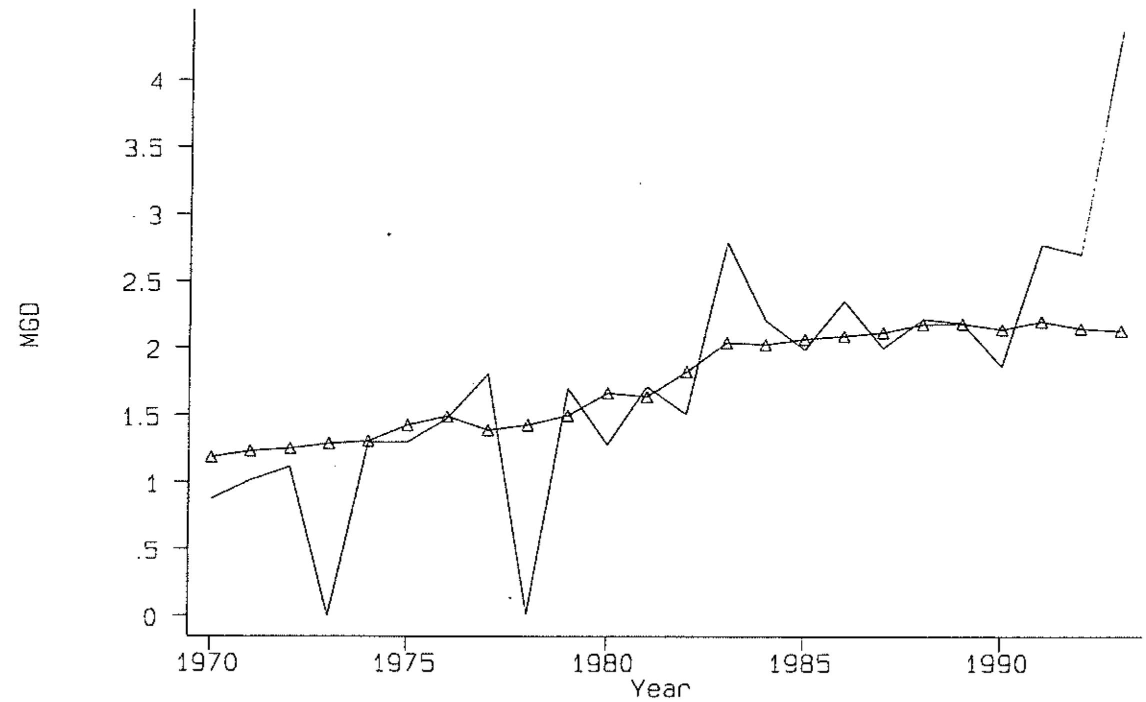


Figure 2h: Clark County, March Actual versus Predicted Use

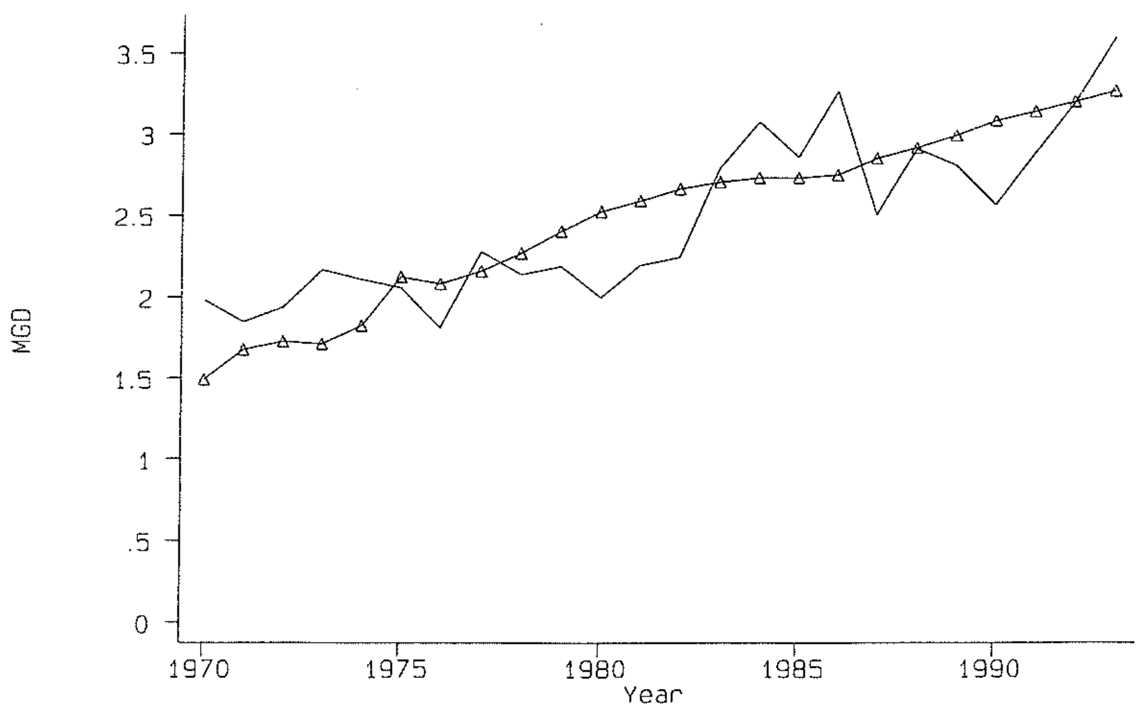


Figure 3a: Forecast March Demand, 2000, 2010, 2020, Base Model and High Growth

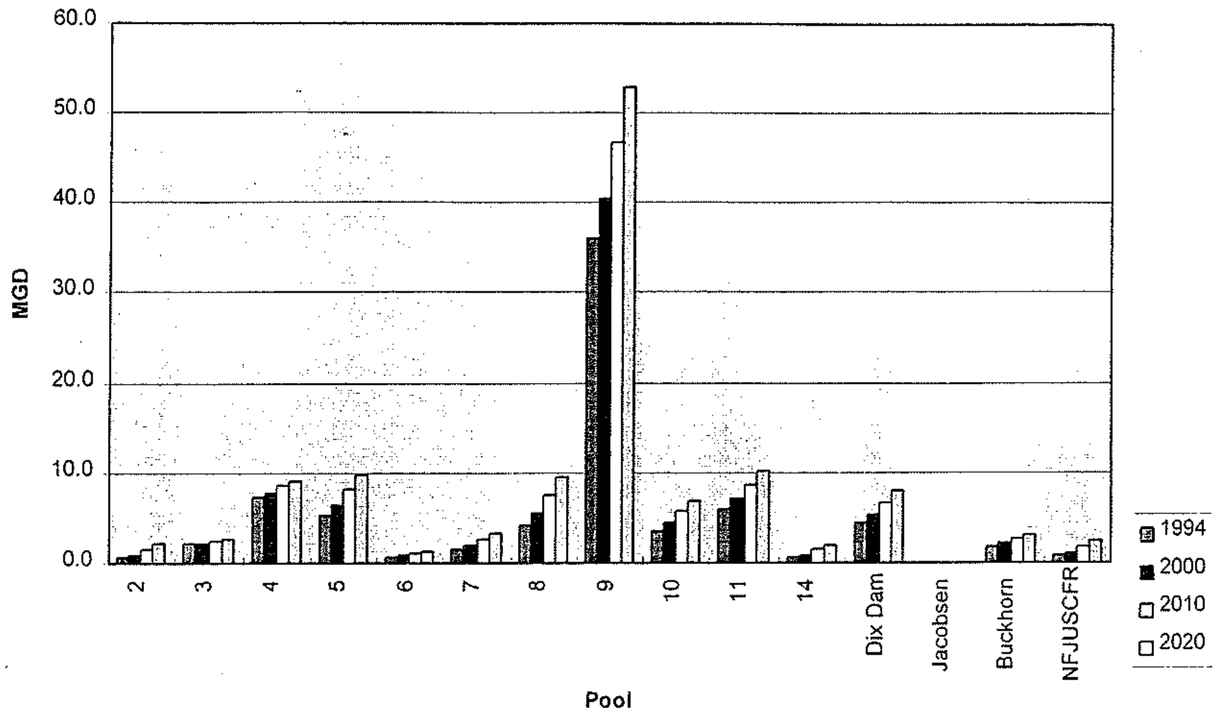


Figure 3b: Forecasted June Use, 2000, 2010, 2020, Base Model with High Growth

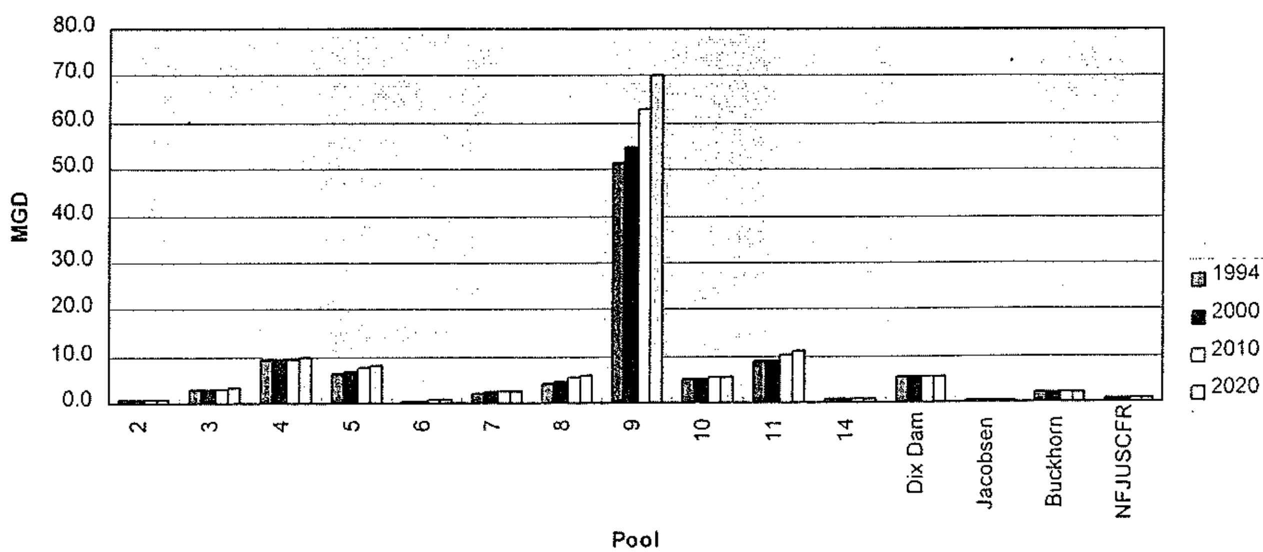


Figure 3c: Forecasted July Use, 2000, 2010, 2020, Base Model, High Growth

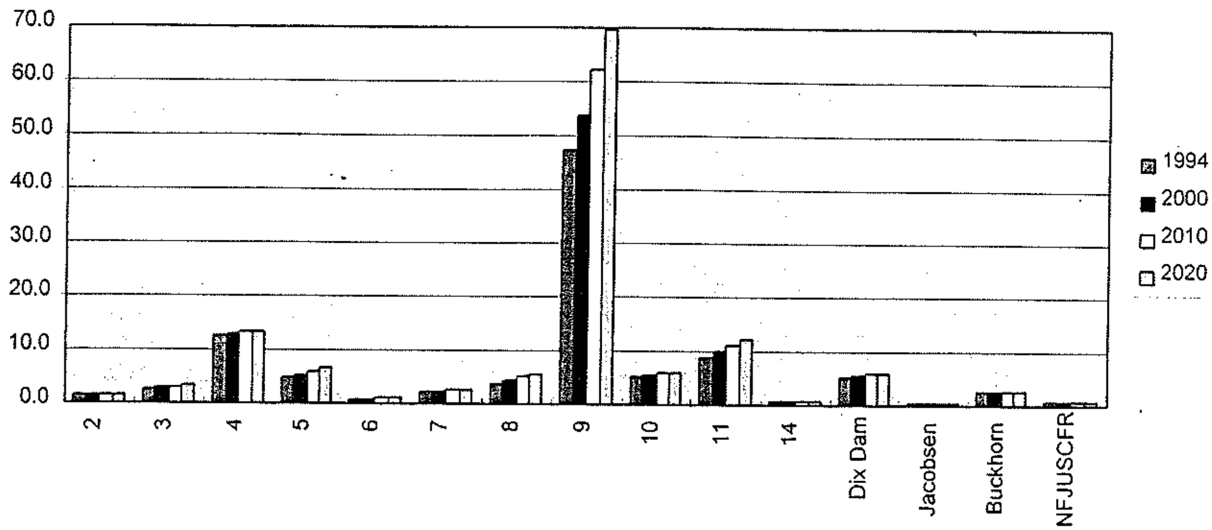


Figure 3d: Forecasted August Use, 2000, 2010, 2020, Base Model with High Growth

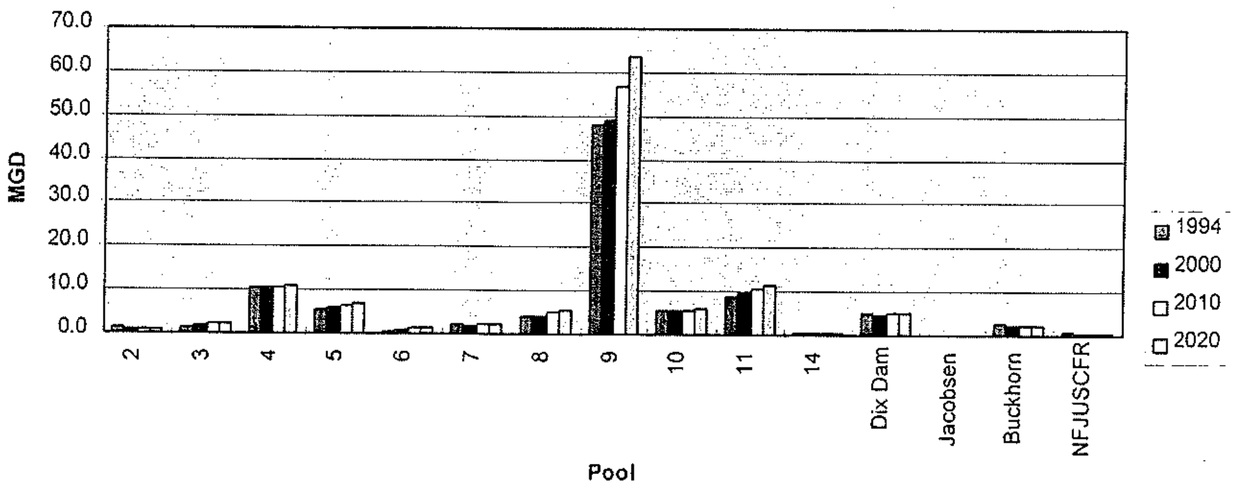


Figure 3e: Forecasted September Use, 2000, 2010, 2020, Base Model with High Growth

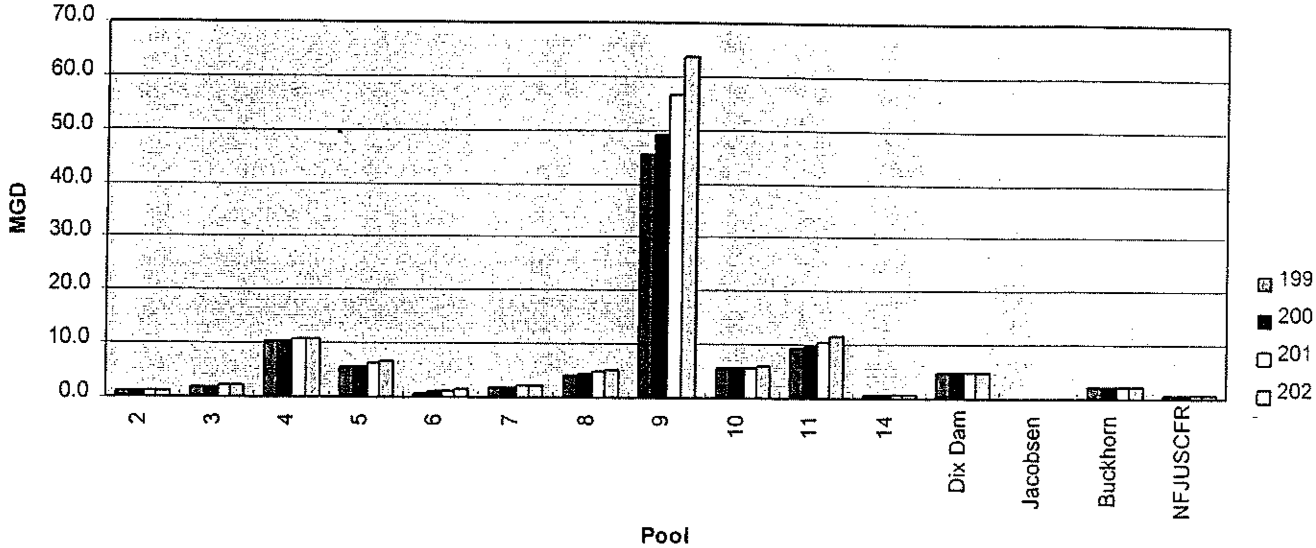


Figure 4a: Impact of Weather Conditions on June Use, By Pool for 1930, 1953, 1988 Weather Conditions

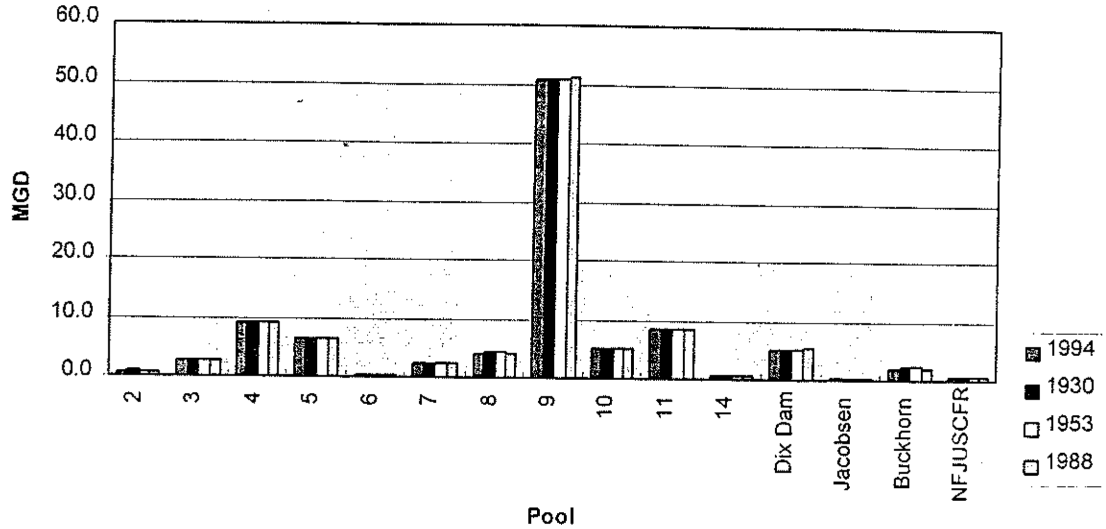


Figure 4b: Impact of Weather Conditions on July Use, By Pool for 1930, 1953, and 1988 Weather Conditions

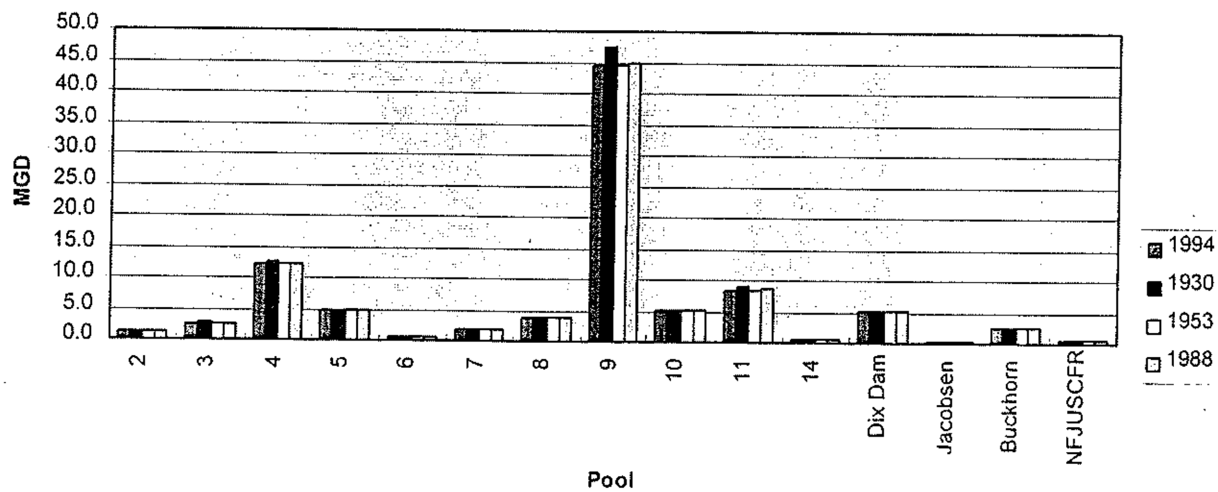


Figure 4c: Impact of Weather Conditions on August Use, By Pool for 1930, 1953, and 1988 Weather Conditions

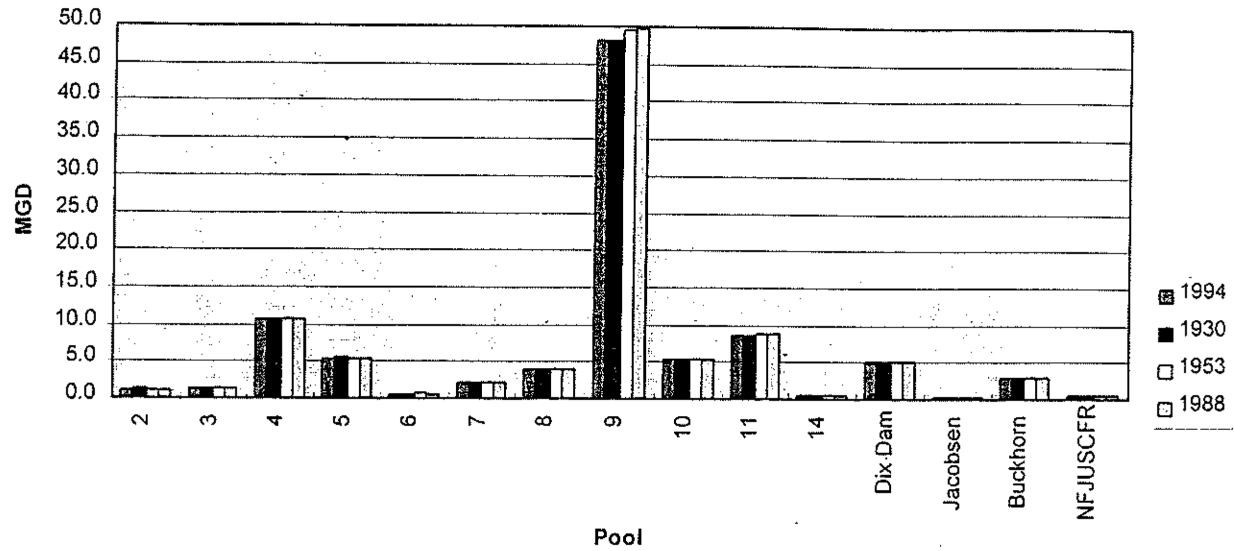


Figure 4d: Impact of Weather Conditions on August Use, By Pool for 1930, 1953, and 1988 Weather Conditions

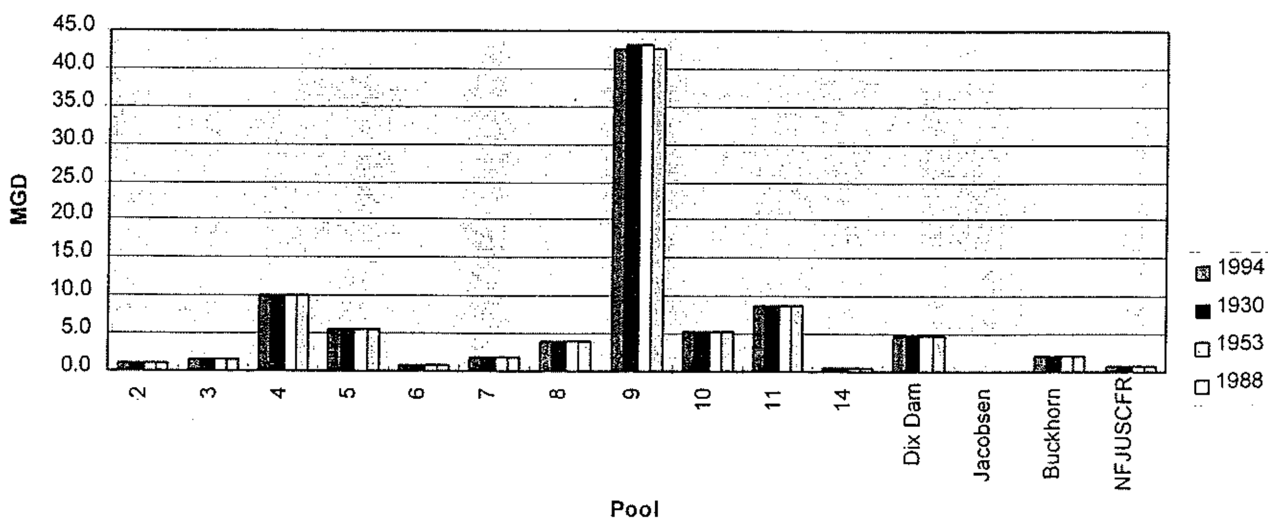


Figure 5: Forecast Use with 100% On-Line, By Pool