EVALUATION OF SAMPLING METHODS USED TO ESTIMATE IRRIGATION PUMPAGE IN CHASE, DUNDY, AND PERKINS COUNTIES, NEBRASKA

By Frederick J. Heimes, Richard R. Luckey, and Diane M. Stephens

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CONVERSION TABLE

For those readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply inch-pound units	By	To obtain metric units
inch	25.40	millimeter
acre-foot	1,233	cubic meter
gallons per minute (gal/min)	0.0631	liter per second

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Abstract

Combining estimates of applied irrigation water, determined for selected sample sites, with information on irrigated acreage provides one alternative for developing areal estimates of ground-water pumpage for irrigation. The reliability of this approach was evaluated by comparing estimated pumpage with metered pumpage for two years for a three-county area in southwestern Nebraska. Meters on all irrigation wells in the three counties provided a complete data set for evaluation of equipment and comparison with pumpage estimates.

Regression analyses were conducted on discharge, time-of-operation, and pumpage data collected at 52 irrigation sites in 1983 and at 57 irrigation sites in 1984 using data from inline flowmeters as the independent variable. The standard error of the estimate for regression analysis of discharge measurements made using a portable flowmeter was 6.8 percent of the mean discharge metered by inline flowmeters. Times of operation of the irrigation systems were determined from energy and hour meters and compared with times of operation determined from inline flowmeters. The standard error of the estimate for regression analysis of time of operation determined from electric meters was 8.1 percent of the mean time of operation determined from inline flowmeters. The standard error of estimate was 18.6 percent for gas meters and 15.1 percent for engine-hour meters. Sampled pumpage, calculated by multiplying the average discharge obtained from the portable flowmeter by the time of operation obtained from energy or hour meters, was compared with metered pumpage from inline flowmeters at sample sites. The standard error of the estimate for the regression analysis of sampled pumpage was 10.3 percent of the mean of the metered pumpage for 1983 and 1984 combined. The difference in the mean of the sampled pumpage and the mean of the metered pumpage was only 1.8 percent for 1983 and 2.3 percent for 1984.

Estimated pumpage, for each county and for the study area, was calculated by multiplying application (sampled pumpage divided by irrigated acreage at sample sites) by irrigated acreage compiled from Landsat (Land satellite) imagery. Estimated pumpage was compared with total metered pumpage for each county and the study area. Estimated pumpage by county varied from 9 percent less, to 20 percent more, than metered pumpage in 1983 and from 0 to 15 percent more than metered pumpage in 1984. Estimated pumpage for the study area was 11 percent more than metered pumpage in 1983 and 5 percent more than metered pumpage in 1984.

INTRODUCTION

The U.S. Geological Survey began a study of the High Plains aquifer (fig. 1) in 1978 as part of the Regional Aquifer-System Analysis (RASA) program. The purposes of the High Plains RASA were to: (1) Provide hydrologic information needed to evaluate the effects of continued ground-water development; and (2) develop computer models to predict aquifer response to changes in ground-water development. Estimates of the volume and areal distribution of ground-water pumpage were essential to meet the objectives of the High Plains study. Estimates of pumpage were derived by combining estimates of applied irrigation water, determined for selected sample sites, with Landsat mapped irrigated acreage for the 1980 growing season (Heimes and Luckey, 1983). Beginning in 1983, a second phase of the High Plains RASA was initiated to investigate relationships between irrigation pumpage and the volume of water removed from the aquifer, and to evaluate a sampling approach for estimating pumpage. The investigation of the relationships between irrigation pumpage and the volume of water removed from the aquifer is the subject of another report. This report describes the results of the evaluation of a sampling approach for estimating pumpage.

List of Terms

This section lists selected terms that are unique to this report.

Application: The annual **sampled pumpage**, totaled for all **sample sites** in a **county** or the **study area**, divided by the total irrigated acreage measured at those **sample sites**, expressed in inches. If there is no loss of water between the pump and the point where the water is applied to the field, this term represents the acreage weighted-average depth of applied irrigation water for all **sample sites** in the selected area.

Clampitron[1] discharge: The discharge measured **at a sample site** using a "Clampitron" portable flowmeter, expressed in gallons per minute.

County: Refers to the area of Chase or Perkins Counties or the area north of the Republican River in Dundy County, Nebr.

Estimated pumpage: An estimate of the annual volume of irrigation water pumped in a **county** or the **study area**, expressed in acre-feet. **Estimated pumpage** is calculated by multiplying the Landsat derived total irrigated acreage for a **county** or the **study area**, by the **application** computed from **sample site** data.

Metered discharge: The discharge at a **sample site** measured using a totalizing inline flowmeter, expressed in gallons per minute. **Metered discharge** is calculated by dividing the volume pumped, recorded by the inline flowmeter, by the time period during which the volume was recorded. **Metered discharge** was measured during each **sample site** visit if the irrigation pump was running, and was generally based on the volume pumped during a 10-15 minute period.

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[1]Any use of trade names is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

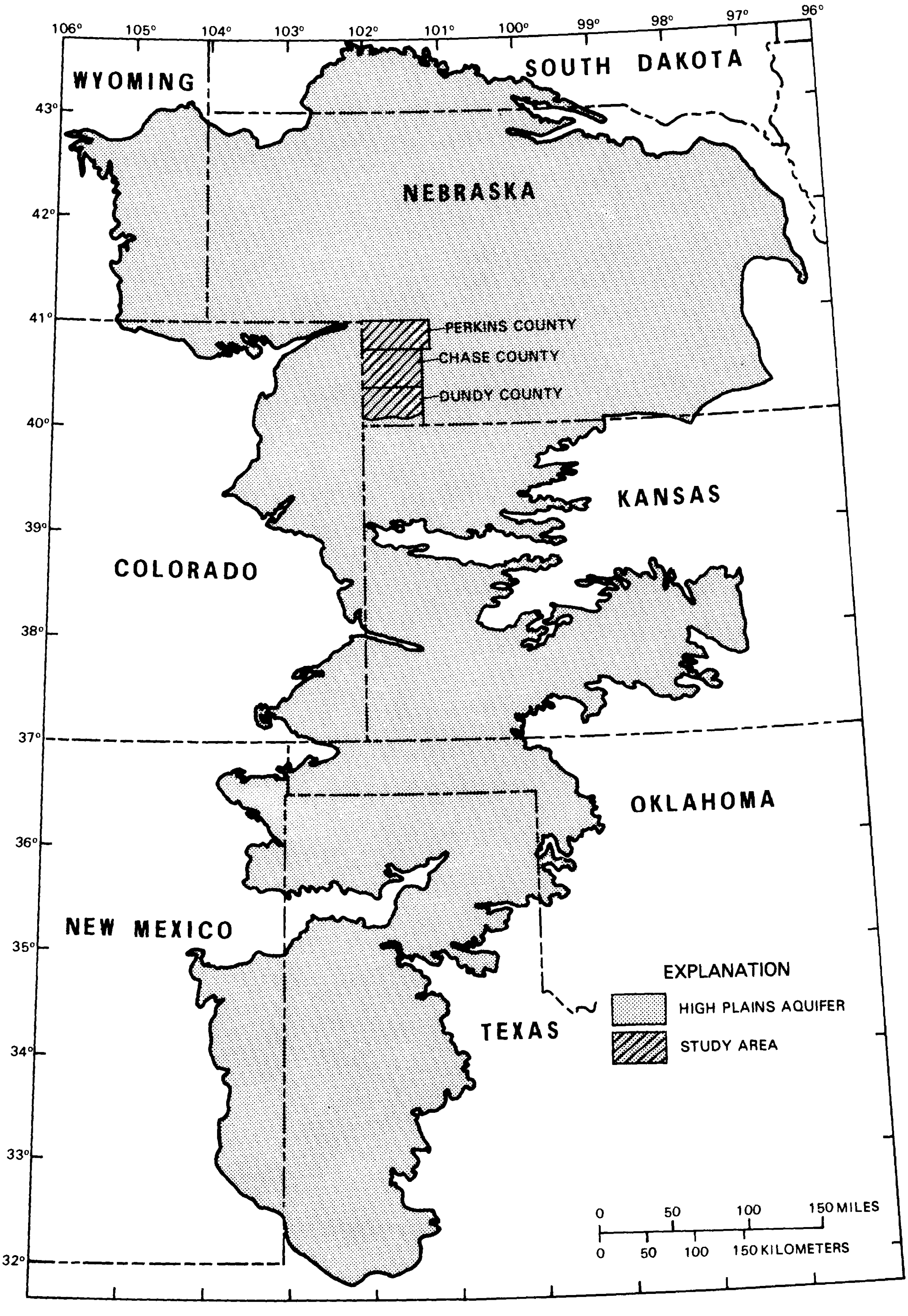

Figure 1.--Location of High Plains aquifer and study area.

Metered pumpage: The annual volume of irrigation water pumped that is recorded by totalizing inline flowmeters, expressed in acre-feet. The term **metered pumpage** may be used to refer to the volume of water pumped for a single **sample site**, the total volume pumped for all **sample sites** in a **county** or the **study area**, or the total volume pumped for all irrigation sites in a **county** or the **study area**.

Metered time: The time of operation of an irrigation pump at a **sample site**, expressed in hours. **Metered time** is calculated by dividing the volume pumped that is recorded by the inline flowmeter, for all or part of a growing season, by the mean **metered discharge** calculated from all measurements at the **sample site**.

Other time: The time of operation of an irrigation pump at a **sample site**, calculated using energy or hour meters and expressed in hours.

Sample site: An irrigation site selected for collection of comparative data to evaluate the sampling approach and equipment. The term irrigation site refers to an irrigation well or wells and the fields irrigated by the well(s).

Sampled pumpage: An estimate of the annual volume of irrigation water pumped at an individual **sample site** or for all **sample sites** in a **county** or the **study area**, expressed in acre-feet. **Sampled pumpage** is calculated by multiplying the average **Clampitron discharge** at an individual **sample site** by the **other time** for that site.

Study area: Refers to the area of Chase and Perkins Counties and the area north of the Republican River in Dundy County, Nebr.

Objectives

This study had two primary objectives:

(1) Compare data obtained using energy and hour meters, and portable flowmetering equipment with data obtained from inline flowmeters; and

(2) Compare sampled pumpage and estimated pumpage with metered pumpage.

Evaluations of equipment and a pumpage sampling approach were conducted during the first phase of the High Plains RASA, (Heimes and Luckey, 1980; Heimes and Luckey, 1983; and Luckey and others 1980). However, only a few wells used in the Phase I sampling program had calibrated inline flowmeters for comparison with sample data. Consequently, evaluations of equipment were made either in the laboratory or at a few sites that had inline flowmeters. Pumpage data from Phase I sample sites located in 15 High Plains counties were combined with irrigated acreage derived from Landsat data to estimate pumpage for all areas of the High Plains in 1980. However, the areal estimates of pumpage developed for the High Plains in 1980 could be compared only with reported information.

Consequently, to meet the objectives of this study, an area was needed in which a complete data set of metered pumpage was available. A three-county area in southwestern Nebraska (fig. 1) met these criteria and was selected for study.

Description of Study Area

The study area includes Chase and Perkins Counties, and the area north of the Republican River in Dundy County, Nebr. The area, which is in the High Plains section of the Great Plains physiographic province, consists of gently rolling uplands with many small flat areas. The southwestern part of the area contains sand hills and some small, inter-dune lakes and marshes. The area is drained by small eastward-flowing streams. Bottomlands along the streams comprise a small percentage of the study area.

Corn is the principal irrigated crop in the area and represents about 70 percent of the total irrigated acreage. Wheat is the second most commonly irrigated crop and represents about 16 percent of the total irrigated acreage in the area. Dry beans, sorghum, alfalfa, and other crops account for the remainder of the irrigated acreage in the study area.

About 2,800 wells supply nearly all of the irrigation water in the study area. Approximately 45 percent of these wells are in Chase County, 26 percent are in Dundy County, and 29 percent are in Perkins County. Most of the irrigation is done using center-pivot sprinklers.

The principal reason for selecting this study area is that all irrigation wells are required to have approved inline flowmeters. Chase, Dundy, and Perkins Counties (fig. 1) make up the Upper Republican Natural Resources District (NRD). In 1969, the State of Nebraska authorized the establishment of 24 NRD's that cover the State. The NRD's became effective on July 1, 1972. The Ground Water Management Act, LB577, enacted in 1975 gave the NRD's authority and responsibilities to establish management practices to conserve ground water for beneficial use. In 1977, the Upper Republican NRD, north of the Republican River (fig. 1), was designated a control area because of water-table declines. This required that measures be adopted to control ground-water withdrawal and use. As part of these control measures, the Upper Republican NRD requires all irrigation wells to be metered using approved in-line flowmeters. Irrigators are required to annually report the volume of water pumped from each irrigation well.

The metering requirement in the study area created an ideal situation for evaluating equipment, and comparing data collected using a sampling approach with metered data. Because pumpage from all wells in the study area must be metered and reported, estimated pumpage could be compared with metered pumpage for the area.

Approach

Seventy-five sample sites were randomly selected in the study area for possible use. Data were collected for about two-thirds of the sites during the 1983 and 1984 irrigation seasons (Stephens and others, 1984, and Stephens and others, 1985). Discharge, time-of-operation, crop-type, and crop-acreage data were collected at each sample site during the 1983 and 1984 growing seasons. Discharge measurements from a Clampitron portable flowmeter (Clampitron discharge) were compared with metered discharge obtained from in-line flowmeters at the sample sites. Time of operation calculated from electric, natural-gas, engine-hour meters (other time) was compared with time of operation calculated using inline flowmeters (metered time). Other time was multiplied by the average of Clampitron discharge obtained during multiple site visits to estimate sampled pumpage at each site. Sampled pumpage was compared with the metered pumpage at sample sites to evaluate the approach of estimating pumpage using discharge and time-of-operation data.

Estimated pumpage for 1983 and 1984 was calculated for each county and the study area by multiplying the average inches of water per acre pumped for sample sites in the county or the study area (application) by the total irrigated acreage for the corresponding area that was mapped from August Landsat data (excluding wheat acreage). Metered pumpage, aggregated for each county and the study area for 1983 and 1984, was compared with estimated pumpage for the same areas to evaluate the use of a sampling approach for estimating pumpage.

SAMPLE SITES

Of the initial 75 sample sites selected (fig. 2), 52 of the sites were actually sampled during the 1983 irrigation season (Stephens and others, 1984) and 57 of the sites were sampled during the 1984 irrigation season (Stephens and others, 1985). The remaining irrigation sites were either not used to irrigate crops during the irrigation season or were used to irrigate winter wheat. Obtaining measurements at the wheat sites was very difficult because of the short irrigation season and sporadic irrigation, so these sites were not used in the study. Winter wheat represents about 16 percent of the irrigated crops in the study area but only about 6 percent of the total water pumped. Because pumpage from sites used to irrigate wheat was systematically excluded from all aspects of the study, the exclusion did not affect comparisons of data used in the study.

Discharge

Discharge measurements were made using inline flowmeters and the Clampitron portable flowmeter. The accuracy of the Clampitron flowmeter was tested thoroughly under laboratory conditions (Luckey and others, 1980), and some field evaluations were made during the 1979 and 1980 irrigation seasons (Heimes and Luckey, 1980, and Heimes and Luckey, 1983). However, this study provided the opportunity for extensive field comparisons of Clampitron discharge with metered discharge.

The Clampitron discharge measurements were: (1) Used to determine whether a single discharge measurement was representative of the seasonal average discharge for a site; and (2) compared with metered discharge for various categories of inline flowmeters, irrigation system types, pipe materials, and pipe sizes.

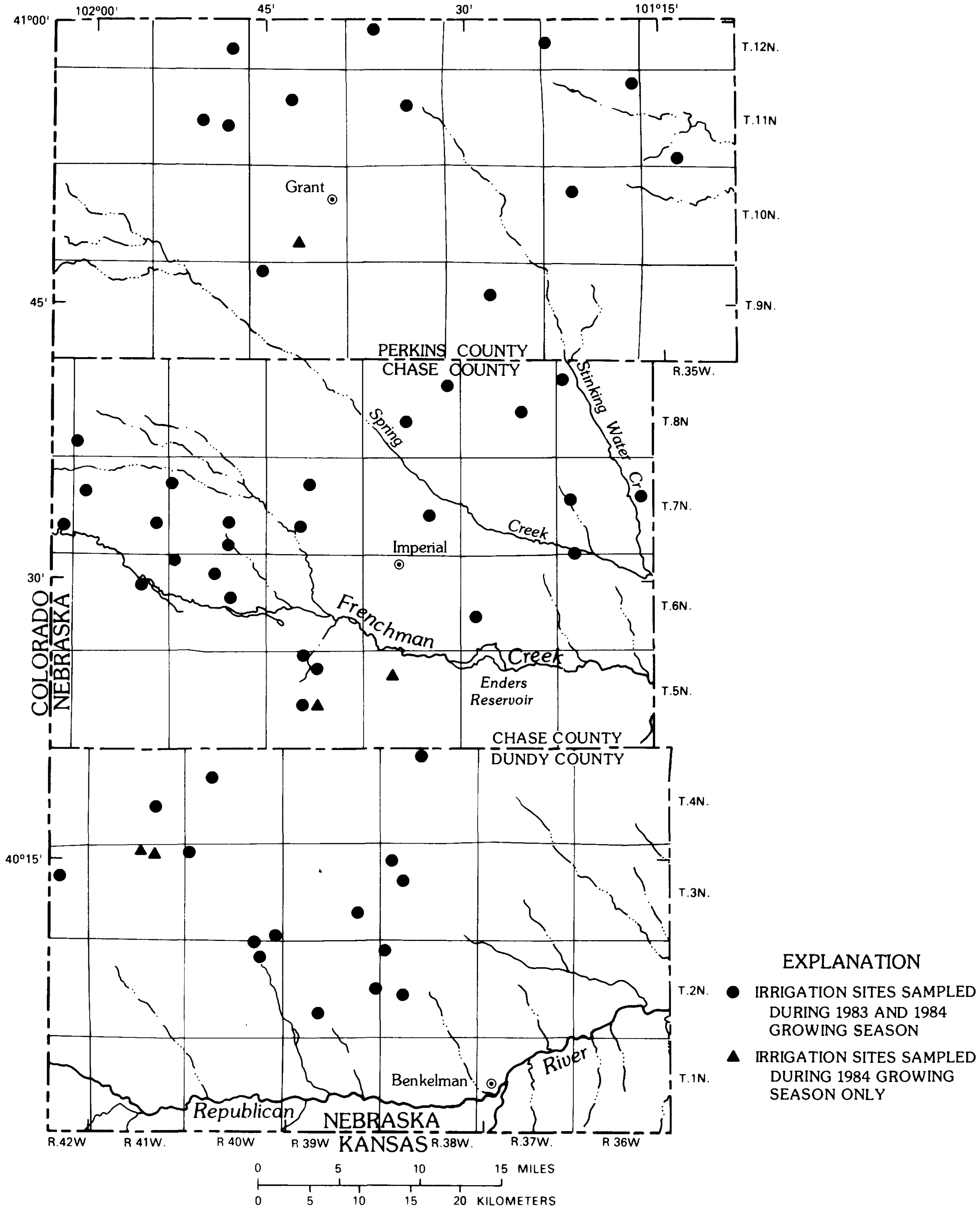

Figure 2.--Location of irrigation sites used for sampling.

In order to determine if discharge at individual sample sites remained relatively constant throughout the irrigation season, Clampitron discharge measurements were made four or more times during the 1983 irrigation season at four randomly selected sites (fig. 3). Care was taken to insure that pumps had been operating for a long enough time to insure that a representative discharge measurement was obtained. Although there is some fluctuation in discharge for a given site during the irrigation season there is no apparent trend with respect to time during the irrigation season. These data and data from previous studies (Heimes and Luckey, 1983) indicate that one or two discharge measurements during an irrigation season normally are sufficient to calculate the average discharge for the season. At most sites, two or more discharge measurements were made during both the 1983 and 1984 irrigation seasons.

Regression analyses were made to evaluate the differences in metered and Clampitron discharge. Figure 4 shows all 1983 and 1984 discharge measurements. The solid line represents equal discharge values; the dashed line represents the best fit to the data. In this example, the slope of the regression line is 1.03. The slope of the line of equal discharge is 1.00.

The coefficient of determination (the square of the correlation coefficient) is a statistical indicator of how well the data fit the regression line. The coefficient of determination represents the proportion of the total variation in the Clampitron discharge that is accounted for by the variation in the metered discharge. A coefficient of determination of 1.00 indicates that all the variation in Clampitron discharge is accounted for by the metered discharge. The coefficient of determination for the data in figure 4 is 0.97. This indicates that 97 percent of the variation in Clampitron discharge is accounted for by the metered discharge.

The standard error of the estimate is another measure of how well the data fit the regression line. The standard error of the estimate is a measure of the scatter of the data about the regression line. The standard error of the estimate is an estimate of the standard deviation of the data about the true regression line. The standard deviation has the property that two thirds of the data will fall within one standard deviation of the true regression line and 95 percent of the data will fall within two standard deviations of the true regression line. The standard error of the estimate, for the data in figure 4, is 65 gal/min or less than 7 percent of the mean of the metered discharge of 950 gal/min.

The slope of the regression line, the coefficient of determination, and the standard error of the estimate are the primary indicators of how well Clampitron discharge compares with metered discharge. In addition to the regression analysis conducted on the data shown in figure 4, regression analyses also were done for the following stratifications:

(1) Year;
(2) Irrigation system type;
(3) Inline flowmeter type;
(4) Pipe material; and
(5) Pipe size.

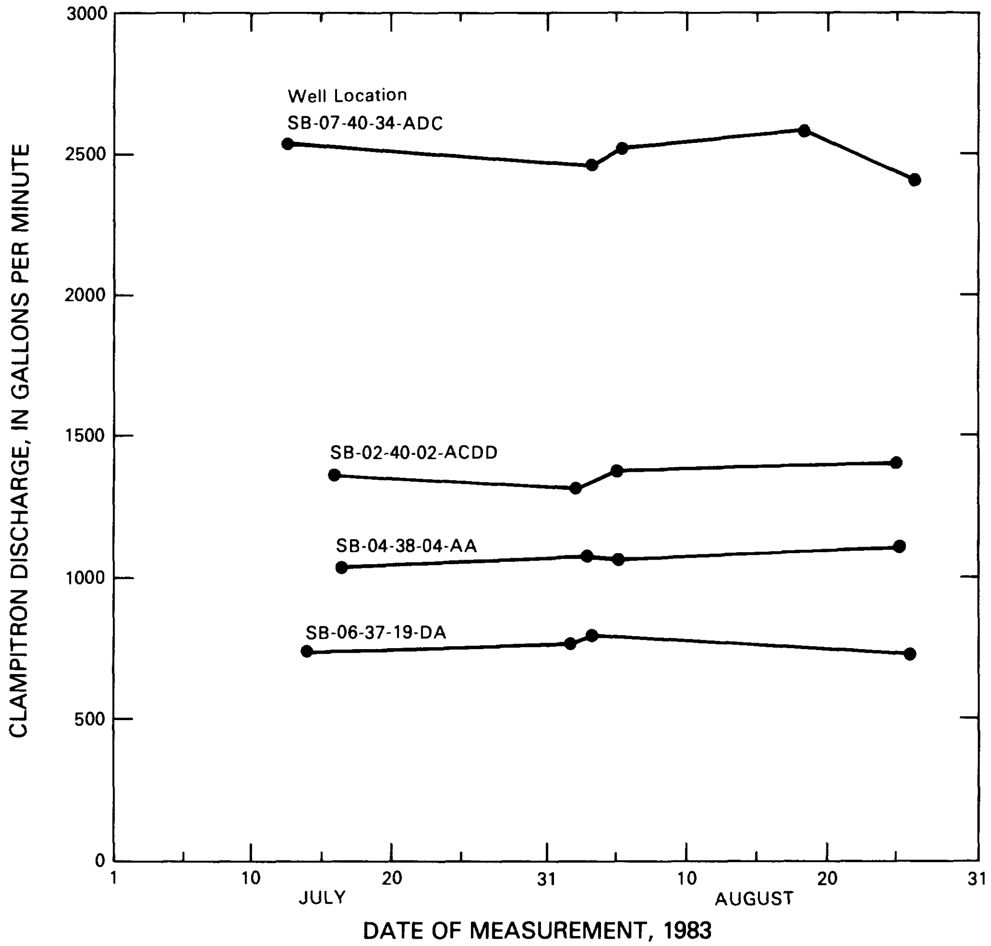

Figure 3.--Clampitron discharge measurements at four irrigation sites for various times during the growing season (data and well locations from Stephens and others, 1984).

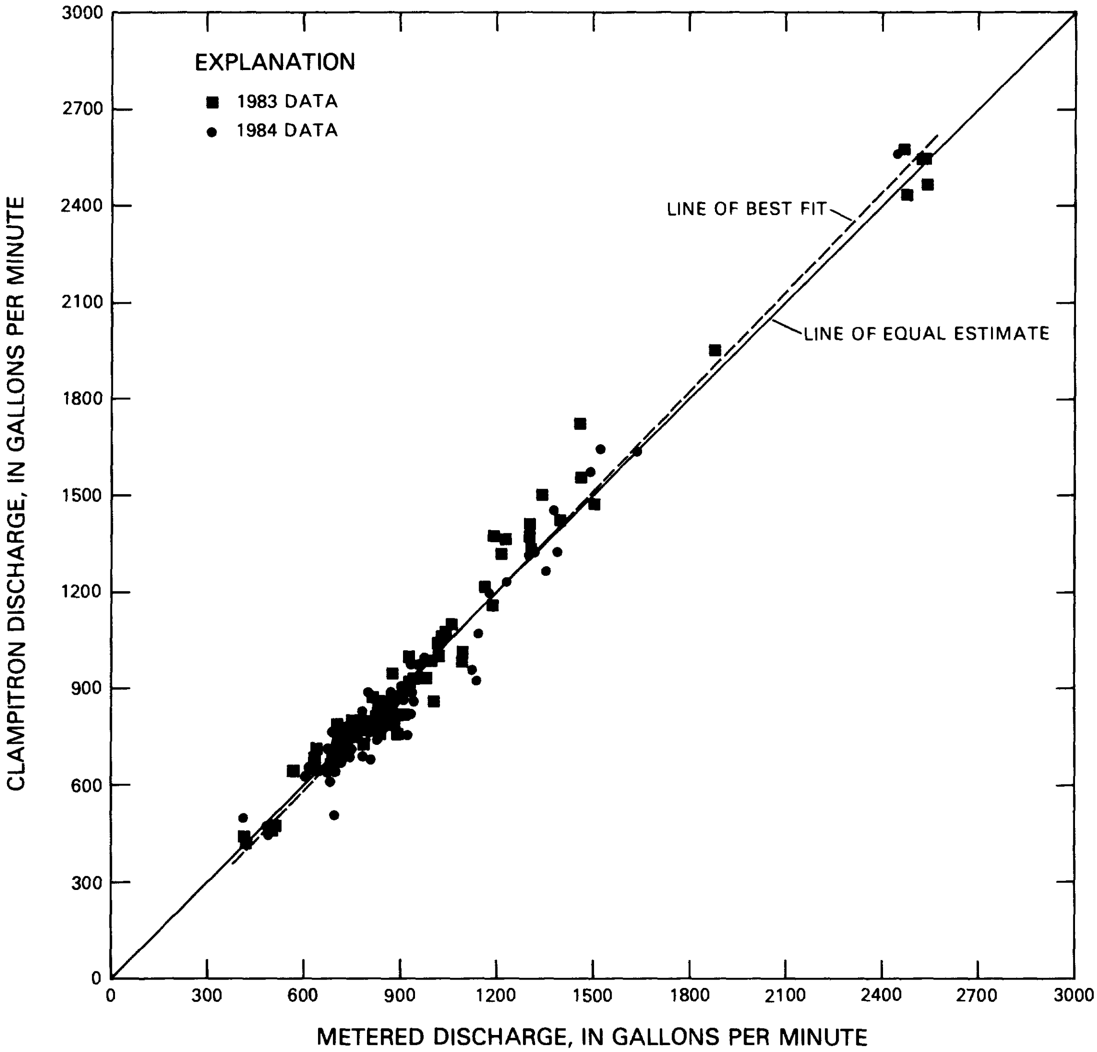

Figure 4.--Relation between Clampitron discharge and metered discharge at sample sites.

Table 1 summarizes the regression analyses. The metered discharge is the independent variable and the Clampitron discharge is the dependent variable in these analyses. The table shows: (1) The number of data points used in the analysis; (2) slope of the regression line; (3) the coefficient of determination; and (4) the standard error of the estimate, in gal/min and as a percent of the mean of the metered discharge. The standard errors of the estimate were tested to see if a significant difference existed between the 1983 and 1984 data and no significant difference was found at the 95 percent confidence level. Based on these results, discharge data were not stratified by year for the remaining regression analyses.

The slopes of the regression lines for the various stratifications were tested to see if they were significantly different than 1.00 (line of equal estimates) at the 95 percent confidence level. The only slope that was significantly different than 1.00 was the Water Specialities inline flowmeter strata (slope=1.24). A plot of these data is shown in figure 5. The solid line represents the line of equal estimate (slope=1.00) and the dashed line represents the line of best fit (slope=1.24). The discharge measurements between 650 and 950 gal/min (6 sites and 20 points) tend to be closely clustered about both the line of equal estimate and the line of best fit. However the discharge measurements greater than about 1,200 gal/min (2 sites and 9 points) tend to cluster above the line of equal estimate. The regression shows that metered discharge from the Water Specialities flowmeter tends to be 100 to 150 gal/min less than the Clampitron discharge for measurements greater than 1,200 gal/min. No discharge measurements were obtained below 650 gal/min, so it was not possible to determine if the line of best fit is representative of the relationship between metered and Clampitron discharge for less than 650 gal/min.

For the regression analyses of discharge stratified by irrigation-system type, the slope for flood systems was 1.24. However, this value was not significantly different from 1.0 at the 95 percent confidence level. This is because of the small number of data points (14) used in the regression and the scatter of the data.

The standard errors of the estimate were tested to see if they were significantly different from each other within the various strata. No significant differences were found at the 95 percent confidence level.

Time of Operation

Times of operation of irrigation systems were estimated using the inline flowmeters (metered time), and other methods including electric and natural-gas meters, and engine-hour meters (other time). Regression analyses were performed on various strata of the time-of-operation data. The metered time represented the independent variable in the analyses and the other time represented the dependent variable.

Figure 6 shows all 1983 and 1984 time-of-operation data. The solid line represents equal time-of-operation estimates and the dashed line represents the line of best fit to the data. The slope of the line of best fit is 1.02. The coefficient of determination of the data is 0.97 indicating that 97 percent of the variation in other time is accounted for by the metered time. The standard error of the estimate of the data about the regression line is 36 hours which is 11 percent of the mean of the metered time of 326 hours.

Table 1.--Results of the regression analyses of the discharge data collected at sample sites

[Independent variable: Metered discharge; Dependent variable: Clampitron discharge; gal/min = gallons per minute]

Explanation	Number of data points	Slope of the regression line	Coefficient of determination	Standard error of the estimate (gal/min)	Standard error of the estimate (percent of mean)
All data	167	1.03	0.97	65	6.8
Stratified by year					
1983	90	1.02	.98	64	6.4
1984	77	1.03	.96	62	6.9
Stratified by irrigation system type					
Pivot	150	1.01	.98	61	6.6
Flood	14	1.24	.89	74	5.6
Stratified by inline flowmeter type					
McCrometer	120	1.01	.98	57	5.8
Sparling	17	.91	.55	74	9.6
Water Specialties	29	1.24	.97	51	5.3
Stratified by pipe material					
Steel	141	1.01	.98	60	6.5
Aluminum	26	1.07	.95	78	7.0
Stratified by pipe size					
6.0 inch	11	1.11	.99	17	2.6
8.0 inch	118	1.03	.98	62	6.4
8.6 inch	26	.99	.97	48	4.9
10.0 inch	9	1.07	.95	81	6.9

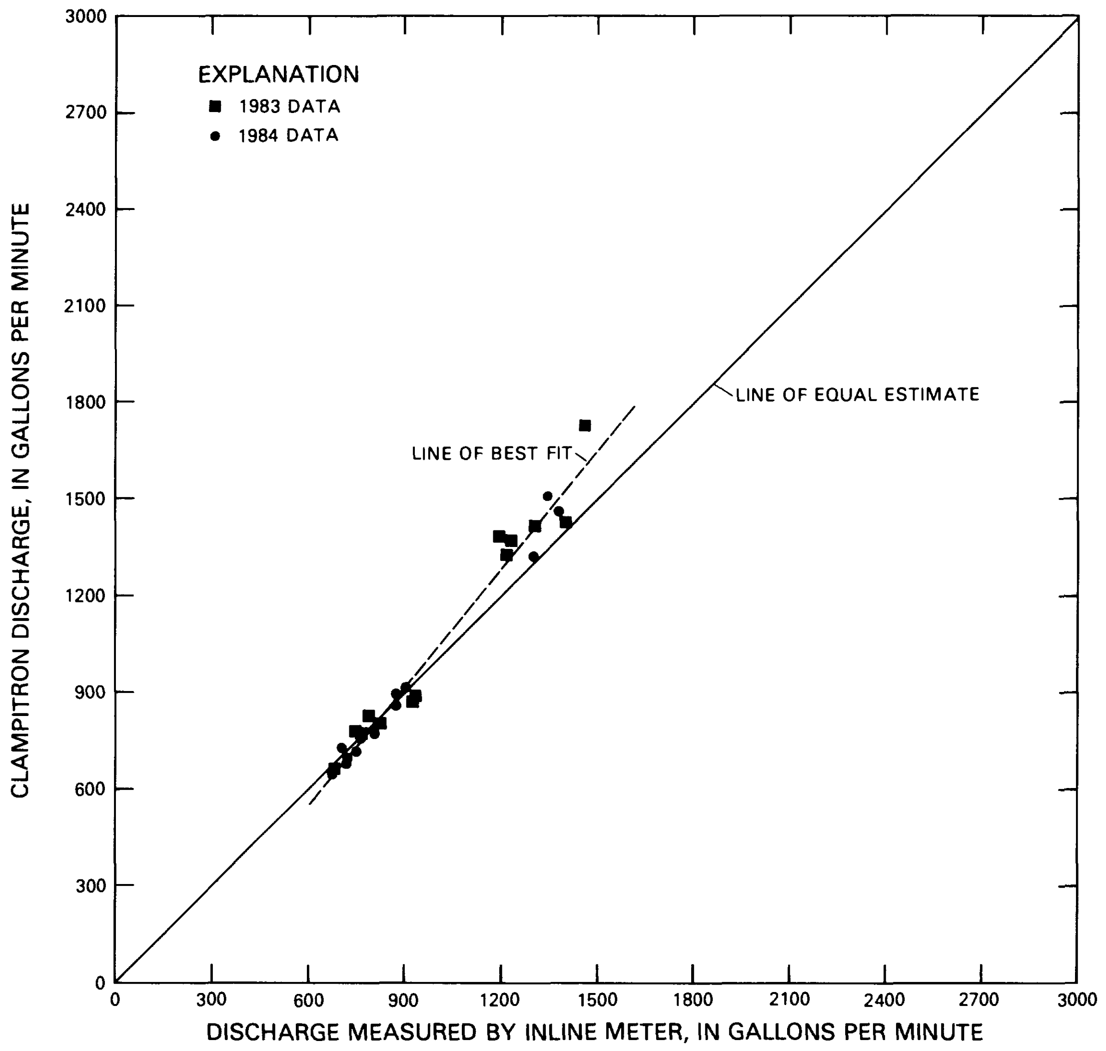

Figure 5.--Relation between Clampitron discharge and metered discharge from Water Specialties inline flowmeters at sample sites.

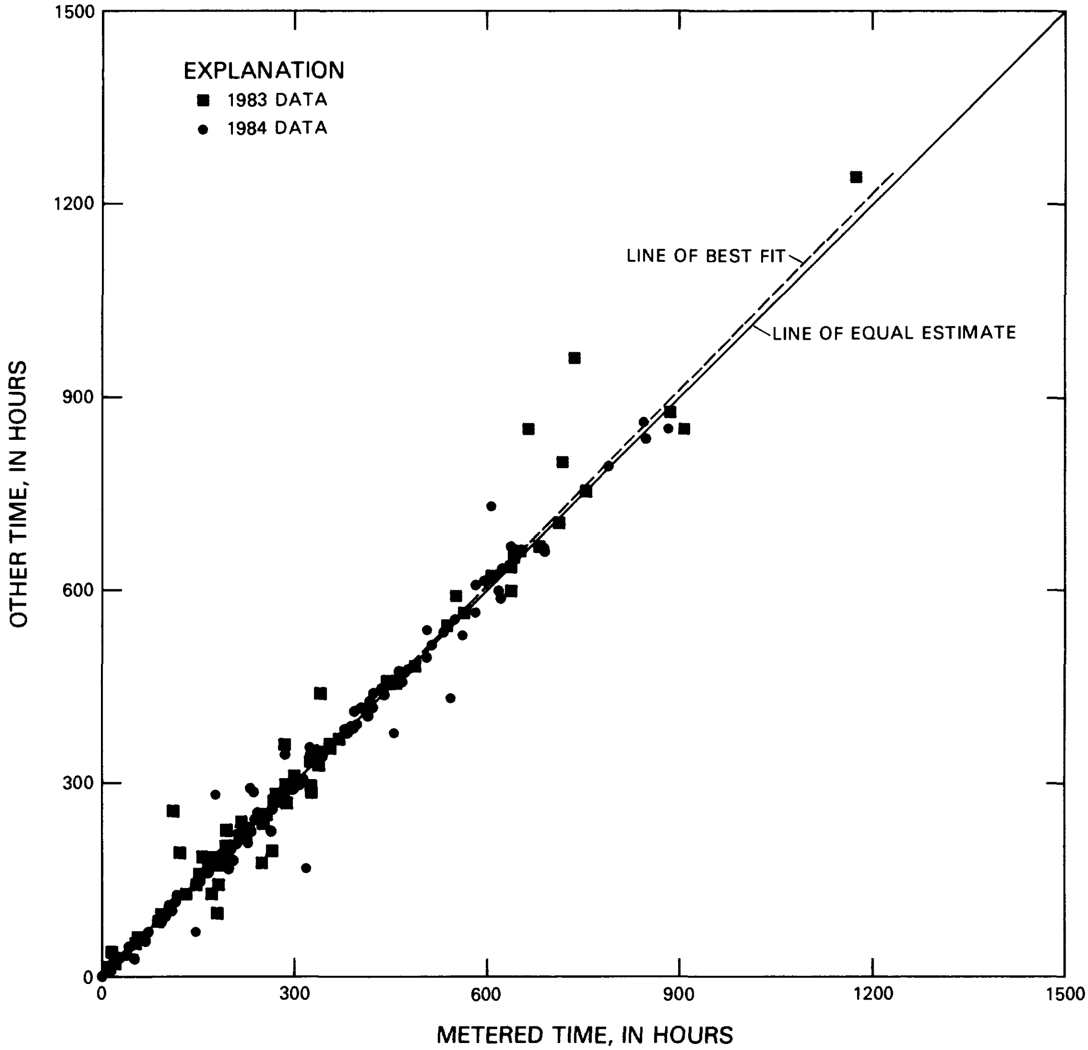

Figure 6.--Relation between other time (determined from energy or hour meters) and metered time (determined from inline flowmeters) at sample sites.

Regression analyses of time-of-operation data also were made for the following stratifications:

(1) Year;
(2) Year and inline flowmeter type; and
(3) Year and energy- or hour-meter type.

The results of these analyses are presented in table 2. The metered time is the independent variable in the regression analysis. The table shows: (1) The number of data points used in the analysis; (2) the slope of the regression line; (3) the coefficient of determination; and (4) the standard error of the estimate, both in hours and as a percent of the mean of the metered time.

Tests for significance were conducted for all time-of-operation data stratified by year. The slopes of the regression lines were not significantly different than 1.00 at the 95 percent confidence level for either year. However, the standard error of the estimate for the 1984 time-of-operation data (29 hours) was significantly less than the standard error of the estimate for the 1983 data (42 hours) at the 95 percent confidence level. This could be due to improved consistency in data-collection techniques in 1984. Because of the difference in the standard errors of the estimate for the 1983 and 1984 data, the regression analyses stratified by inline flowmeter type and by energy- or hour-meter type were further stratifed by year.

The slopes of the regression lines for the various stratifications were tested to see if they were significantly different from 1.00 (line of equal estimates) at the 95 percent confidence level. The slopes of the regression of the 1983 data for natural-gas meters (slope=1.25) and the 1984 data for Water Specialties inline meters (slope=0.97) were significantly different from 1.00 at the 95 percent confidence level. The time of operation for the 1983 natural-gas meters is based on 11 measurements at 4 sites and has a standard error of estimate of 18 percef the mean of the metered time of 324 hours. The time of operation for the 1984 Water Specialties inline flowmeter is based on 22 measurements at 6 sites and has a standard error of estimate of just over 3 percent of the mean of the metered time of 270 hours.

The standard errors of the estimate for time-of-operation data stratified by inline flowmeter type and by energy or hour meters also were tested for significance at the 95 percent confidence level. The standard error of the estimate for McCrometer inline flowmeters for the combined 1983 and 1984 data (40 hours) was significantly different from the standard error of the estimate for Sparling meters (20 hours) and Water Specialties meters (18 hours). The reason for these differences is unknown. The standard error of the estimate for electric meters for the combined 1983 and 1984 data (27 hours) was significantly different from the standard error of the estimate for either the natural-gas meters (57 hours) or engine-hour meters (49 hours). The difference between the time calculated from electric meters and natural-gas meters is not unexpected because electrically powered motors tend to use energy at a constant rate compared with the often variable rate of energy consumption of an internal combustion engine. Hence, electric meters are better clocks than natural-gas meters.

Table 2.--Results of the regression analyses of time-of-operation data collected at sample sites

[Independent variable: Metered time; Dependent variable: Other time]

Explanation	Number of data points	Slope of the regression line	Coefficient of determination	Standard error of the estimate (hours)	Standard error of the estimate (percent of mean)
All data-------------------	210	1.02	0.97	36	11.0
Stratified by year					
1983------------------	92	1.04	.97	42	13.1
1984------------------	118	1.00	.98	29	8.8
Stratified by year and inline flowmeter type					
1983					
McCrometer----------	69	1.04	.96	47	14.2
Sparling------------	5	1.01	1.00	6	1.8
Water Specialties---	18	1.04	.99	23	8.5
1984					
McCrometer----------	82	1.01	.97	33	10.3
Sparling------------	14	.99	.99	22	4.9
Water Specialties---	22	.97	1.00	9	3.3
1983 & 1984					
McCrometer----------	151	1.02	.97	40	12.4
Sparling------------	19	.99	.99	20	4.7
Water Specialties---	40	1.01	.99	18	6.7
Stratified by year and energy- or hour-meter type					
1983					
Electric Meter------	73	1.01	.99	29	9.2
Gas Meter-----------	11	1.25	.95	59	18.3
Engine Hour Meter---	8	1.04	.94	63	16.3
1984					
Electric Meter------	89	1.00	.99	24	7.2
Gas Meter-----------	14	.95	.92	42	14.2
Engine Hour Meter---	15	1.01	.98	35	12.1
1983 & 1984					
Electric Meter------	162	1.00	.99	27	8.1
Gas Meter-----------	25	1.13	.92	57	18.6
Engine Hour Meter---	23	1.03	.97	49	15.1

Pumpage

The mean Clampitron discharge (average of all Clampitron discharge measurements for the irrigation season) was multiplied by the total other time (time determined from the electric, natural-gas, or engine-hour meters for the year) to estimate the sampled pumpage, in acre-feet, at each site. Metered pumpage measured by inline flowmeters at each site was used to determine the reliability of sampled pumpage.

Of the 52 sites that were sampled during the 1983 irrigation season, 32 sites provided complete data sets that could be used for calculating both sampled and metered pumpage. For the 1984 irrigation season, 36 of the 57 sites sampled provided complete data sets for pumpage calculations. The loss of 20 sites in 1983 and 21 sites in 1984 resulted from a variety of factors including missing time-of-operation data, failure of an inline flowmeter, termination of irrigation early in the growing season because the crop was abandoned or destroyed, and inability to obtain a valid discharge measurement.

Regression analyses were performed on various stratifications of the pumpage data. The metered pumpage was the independent variable in the analyses and the sampled pumpage was the dependent variable. Figure 7 shows all 1983 and 1984 pumpage data. The solid line represents the line of equal pumpage measurements and the dashed line represents the line of best fit. The slope of the line of best fit is about 0.98. The coefficient of determination is 0.96. This indicates that 96 percent of the variation in sampled pumpage is accounted for by the variation in metered pumpage. The standard error of estimate is 19 acre-feet or about 10 percent of the mean of the metered pumpage of 187 acre-feet.

Regression analyses of pumpage data also were made for the following stratifications:

(1) Year;
(2) Inline flowmeter type; and
(3) Energy- or hour-meter type.

The results of the analyses are summarized in table 3. The table shows: (1) The number of data points used in the analyses; (2) the slope of the regression line; (3) the coefficient of determination; and (4) the standard error of the estimate, both in acre-feet and as a percent of the mean of the metered pumpage. The number of data points in this table is less than the number of data points in tables 1 or 2 because (1) individual discharge measurements at each site were averaged for the irrigation season, and (2) time-of-operation measurements at each site were summed for the irrigation season.

The slopes of the regression lines were tested to see if they were significantly different from 1.00 (line of equal estimates) at the 95 percent confidence level. The slope was significantly different from 1.00 for the Sparling meters (slope=0.65), based on nine data points collected at five sites. However, the range of the metered pumpage for Sparling meters is small, with eight of the nine points between 125 and 180 acre-feet.

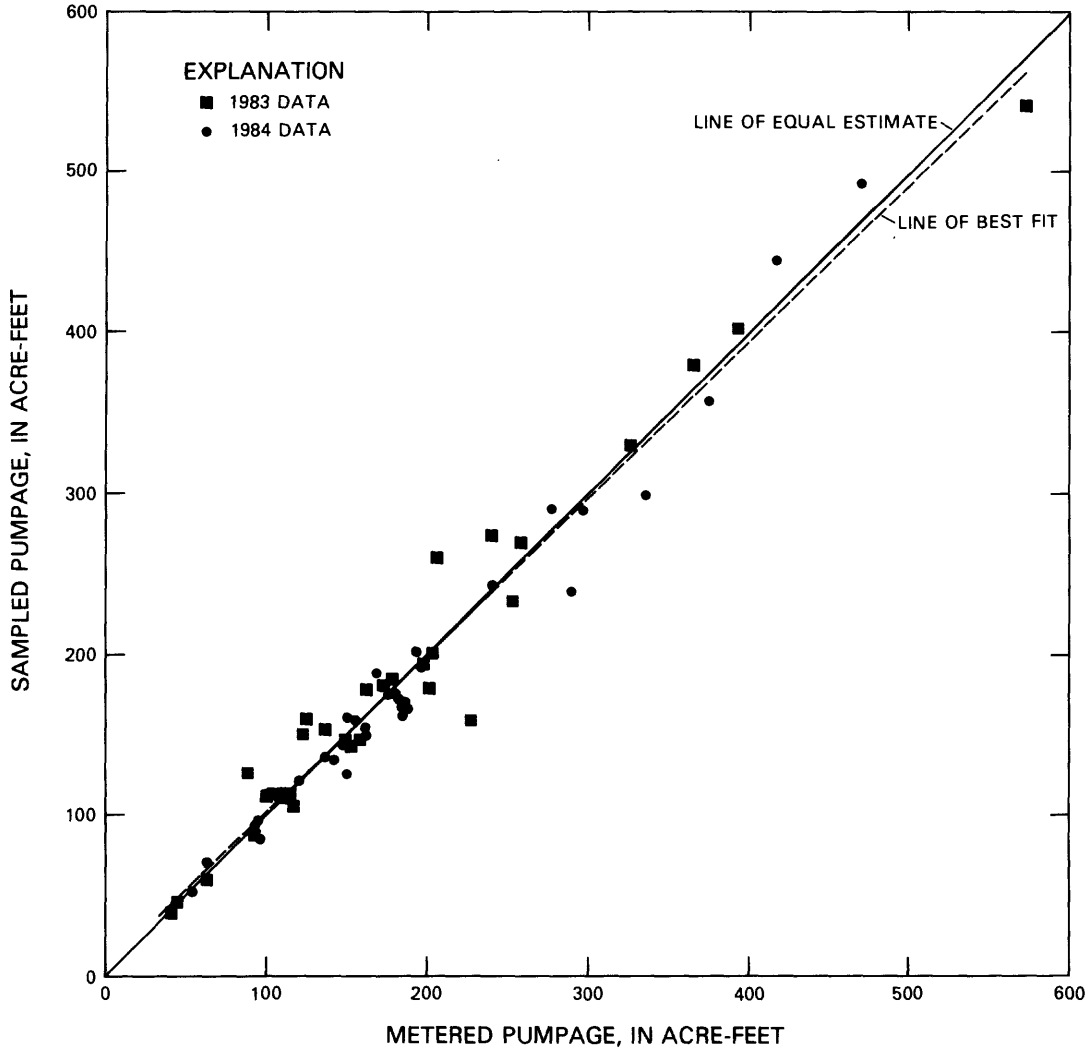

Figure 7.--Relation between sampled pumpage and metered pumpage at sample sites.

Table 3.--Results of the regression analyses of pumpage data collected at sample sites

Explanation	Number of data points	Slope of the regression line	Coefficient of determination	Standard error of estimate (acre-feet)	Standard error of estimate (percent of mean)
All data------------------	68	0.98	0.96	19	10.3
Stratified by year					
1983---------------	32	.96	.96	21	11.6
1984---------------	36	1.00	.97	16	8.5
Stratified by inline flowmeter type					
McCrometer---------	46	.99	.97	19	9.9
Sparling-----------	9	.65	.75	15	8.9
Water Specialties--	13	.94	.95	16	10.0
Stratified by energy- or hour-meter type					
Electric Meter-----	49	.97	.97	18	8.9
Gas Meter----------	8	1.01	.87	23	13.4
Engine Hour--------	11	1.05	.90	19	14.4

The standard errors of the estimate within each of the strata were tested to see if they were different from each other at the 95 percent confidence level. No significant differences were found. The standard error of the estimate for pumpage stratified by year is less for 1984 than for 1983. This difference also occurred in the time-of-operation data, but unlike the time-of-operation data, this difference is not significant at the 95 percent confidence level.

The mean of the metered pumpage for the 32 sites used in 1983 was 184.3 acre-feet compared to 181.0 acre-feet for the mean of the sampled pumpage. The difference of 3.3 acre-feet is 1.8 percent of the mean of the metered pumpage. For the 36 sites used in 1984, the mean of the metered pumpage was 187.0 acre-feet and the mean of the sampled pumpage was 191.3 acre-feet. The difference of 4.3 acre-feet is 2.3 percent of the mean of the metered pumpage. When both years are combined into a single data set with 68 points, the mean of the sampled pumpage is 186.5 acre-feet, only 0.8 acre-feet more than the mean of the metered pumpage. The difference is 0.4 percent of the mean of the metered pumpage. Although the difference in the means is small, the difference at individual sites can be large. The small difference between the mean of the metered pumpage and the mean of the sampled pumpage indicates that the total volume pumped for all sample sites can be estimated very closely. The errors that occur when extending the data from the sampled sites to estimate pumpage for the three-county area will be discussed in the next section.

STUDY AREA

Estimated Pumpage

Estimation of annual irrigation pumpage for each of the three counties and the study area included the following steps:

(1) Determine the acreage irrigated at each sample site;

(2) Divide the total volume of water pumped from all sample sites by the total irrigated acreage at those sites to obtain an average depth of pumped water (application);

(3) Estimate irrigated acreage for counties and the study area using Landsat data; and

(4) Multiply irrigated acreage estimates (from Step 3) by application (from Step 2) to calculate the estimated pumpage;

Crop-type and acreage data were collected for each sample site. Acreages were initially estimated in the field and were subsequently updated at the end of the irrigation season using detailed data from the U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service offices in each of the three counties. Crop-type data were used principally for scheduling site visits.

Application was calculated for each county and the study area by dividing the sum of the sampled pumpage by the sum of the acreage irrigated for all sample sites in the area. These applications are acreage weighted values which gave more weight to the pumpage for larger fields than for smaller ones. The number of sample sites, acreage irrigated at sample sites, sampled pumpage, and application for each county and the study area are shown in table 4.

There is larger variation in the application between counties for the 1983 irrigation season than for the 1984 irrigation season. This is most likely a result of precipitation patterns. The application for Perkins County is lower than the application for either Chase or Dundy Counties for both 1983 and 1984. Perkins County contains more fine-grained soils than either Chase or Dundy Counties. These fine-grained soils have a larger moisture holding capacity and a smaller percolation rate than coarse-grained soils, and generally require less water for each irrigation.

Landsat digital data for August 17, 1983, and August 27, 1984 (Scenes 40397-16540 and 50179-16545), were analyzed to provide maps and tabular estimates of irrigated acreage for each county and for the study area. A band ratioing analysis technique was used. Digital analysis of the Landsat data was conducted by personnel from the U.S. Geological Survey at Ames Research Center, Moffett Field, Calif. The procedures used for data analysis were the same as those used to map irrigated acreage for the High Plains in 1980 (Thelin and Heimes, in press).

Estimated pumpage was computed for each county and the study area for the 1983 and 1984 irrigation seasons. The appropriate application was multiplied by the corresponding irrigated acreage (compiled from Landsat) to calculate the estimated pumpage for the area. Because the Landsat data used to map irrigated acreage was for the month of August, wheat crops and crops abandoned or destroyed early in the growing season were not classified as irrigated. Table 5 shows the application, the irrigated acreage compiled from Landsat data, and the estimated pumpage for each of the three counties and the study area for 1983 and 1984. Both the acreage and the estimated pumpage for 1983 are about 25 percent less than for 1984. This primarily is a result of the Payment In Kind (PIK) program during 1983. The PIK program was established by the U.S. Department of Agriculture to provide producers compensation in the form of grain or other crop product in lieu of planting and harvesting the crop that year. This program resulted in substantially lower crop production in the study area during 1983.

Metered Pumpage

The Upper Republican NRD maintains records on the annual volume of water pumped for each irrigation well in the district. Individual well records were aggregated to provide totals of metered pumpage for each county and the study area for 1983 and 1984. Wells designated in the NRD records as irrigating winter wheat were excluded because these wells were not pumped during the summer irrigation season when the irrigated acreage was mapped from Landsat data. The metered pumpage for summer crops in each of the counties and the study area in 1983 and 1984 is summarized in table 6. The metered pumpage for the study area during 1983 is about 23 percent less than the metered pumpage for the study area during 1984, which is the result of the PIK program in 1983 as previously discussed.

Table 4.--Summary of acres irrigated, sampled pumpage, and application for sample sites

[Application = the sampled pumpage divided by acres irrigated]

Location	Number of sample sites		Acres irrigated		Sampled pumpage (acre-feet)		Application (inches)	
	1983	1984	1983	1984	1983	1984	1983	1984
Chase County	16	17	2,260	2,406	3,674	3,542	19.5	17.7
Dundy County	7	9	862	1,134	1,205	1,639	16.8	17.3
Perkins County	9	10	974	1,242	1018	1,552	12.5	15.0
Study area	32	36	4,096	4,782	5,896	6,733	17.3	16.9

Table 5.--Summary of application from sample sites, irrigated acreage, and estimated pumpage by county and study area

[Application from table 4; Irrigated acreage compiled from Landsat satellite data]

Location	Application (inches)		Irrigated[1] acreage		Estimated pumpage[1] (acre-feet)	
	1983	1984	1983	1984	1983	1984
Chase County	19.5	17.7	113,700	141,600	184,800	208,900
Dundy County	16.8	17.3	77,500	90,400	108,500	130,300
Perkins County	12.5	15.0	75,800	105,000	79,000	131,300
Study area	17.3	16.9	267,000	336,900	384,900	474,500

[1]Values rounded to nearest one hundred.

Table 6.--Comparison of estimated pumpage with metered pumpage by county and study area

[Percent difference = (Estimated pumpage - metered pumpage)/metered pumpage]

Location	Metered pumpage (acre-feet)		Estimated[1] pumpage (acre-feet)		Percent difference	
	1983	1984	1983	1984	1983	1984
Chase County	167,500	204,800	184,800	208,900	+10	+2
Dundy County	90,300	131,200	108,500	130,300	+20	0
Perkins County	87,100	114,400	79,000	131,300	-9	+15
Study area	344,900	450,400	384,900	474,500	+11	+5

[1]Values rounded to nearest one hundred.

Comparison of Estimated Pumpage with Metered Pumpage

Table 6 also shows the estimated pumpage (derived from sample data and irrigated acreage compiled from Landsat), and the percent difference between the estimated pumpage and metered pumpage. Estimated pumpage for the counties ranged from 9 percent less, to 20 percent more, than metered pumpage in 1983 and from 0 to 15 percent more than metered pumpage in 1984. Estimated pumpage for the study area was 11 percent more than metered pumpage in 1983 and 5 percent more than metered pumpage in 1984. Several potential sources of error can affect the accuracy of estimated pumpage. These include the standard deviation and size of the sample, the accuracy of irrigated acreage estimates, and the accuracy of the metered pumpage.

In this study the 1983 sampled pumpage has a larger standard deviation than the 1984 sampled pumpage. This means that if the standard deviation of the sample site data alone is considered, then there is a larger potential for error in the 1983 estimated pumpage than for the 1984 estimated pumpage. The smaller sample size in 1983 (32) compared with 1984 (36) also increases the potential for error but to a lesser degree than does the larger standard deviation. Another source of error in estimated pumpage may result from errors in irrigated acreage estimates determined from analyses of Landsat data. Errors in estimating irrigated acreage will result in errors in estimated pumpage. The third source of error in estimated pumpage is related to the accuracy of the NRD metered pumpage which also is not known. During the 1983 and 1984 growing seasons, about 5 percent of the inline flowmeters were found to be inoperable at the sample sites. If conditions at the sample sites were representative of all sites in the study area, then it is possible that metered pumpage for the counties and the study area is slightly lower than actual pumpage.

Even though the errors associated with the accuracy of irrigated acreage estimates and metered pumpage can not be quantified, they appear to have little affect on the results obtained in this study. Given the potential sources for error in both estimated pumpage and metered pumpage, the differences between the two for 1983 (11 percent) and 1984 (5 percent) are quite small.

SUMMARY AND CONCLUSIONS

The primary objectives of the study were to:

(1) Compare data obtained using energy and hour meters, and portable flowmetering equipment with data obtained from inline flowmeters; and
(2) Compare sampled pumpage and estimated pumpage with metered pumpage.

Regression analyses were conducted on discharge, time of operation, and pumpage data collected at 52 irrigation sites in 1983 and 57 irrigation sites in 1984 using data from inline flowmeters as the independent variable. The standard error of the estimate for regression analysis of all discharge measurements obtained using the Clampitron portable flowmeter was 6.8 percent of the mean metered discharge. This indicated that the Clampitron flowmeter could be used to successfully measure discharge for a variety of types and sizes of irrigation systems. Regression analyses of time-of-operation data obtained from energy and hour meters with time of operation determined from inline flowmeters indicated that electric meters provided the most accurate estimates of time of operation. The standard error of the estimate for time of operation from the electric meters was 6.8 percent of the mean time of operation determined from inline flowmeters. Regression analyses of time of operation data from gas and engine-hour meters showed that they were less accurate with standard errors of the estimate of 18.6 and 15.1 percent of the mean time of operation determined from inline flowmeters. However, there was no indication that the difference in accuracy between meter types affected the reliability of the estimates of sampled pumpage. Complete data for the comparison of sampled and metered pumpage was available for 32 sample sites in 1983 and 36 sample sites in 1984. The standard error of the estimate for the regression analysis of sampled pumpage was 10.3 percent of the mean of the metered pumpage for 1983 and 1984 combined. The difference in the mean of the sampled pumpage and the mean of the metered pumpage was 1.8 percent for 1983 and 2.3 percent for 1984. The small difference between the sampled pumpage and metered pumpage indicates that sampling techniques (portable flowmeters and energy and hour meters) can be used to provide reliable estimates of pumpage based on a sample of irrigation sites.

Estimated pumpage for each county and the study area was calculated by multiplying Landsat-derived irrigated acreage by the application determined from data collected at sample sites. Estimated pumpage was compared with metered pumpage obtained from the Upper Republican Natural Resources District data bases. Estimated pumpage for the counties varied from 9 percent less, to 20 percent more, than metered pumpage in 1983 and from 0 to 15 percent more than metered pumpage in 1984. Estimated pumpage for the study area was 11 percent more than metered pumpage for 1983 and 5 percent more than metered pumpage for 1984. The differences between metered and estimated pumpage for 1983 (11 percent) and 1984 (5 percent) are within the range that could be expected using a small sample size (32 and 36 sites).

Information on pumpage for irrigation is essential to the understanding of the problems associated with declining water levels and degrading water quality in many areas of the western United States. Based on the results obtained in this study, the authors believe that the sampling approaches and estimation techniques discussed in this report provide a method that can be used to successfully estimate irrigation pumpage. Refinements in sampling and analysis procedures could improve the accuracy of estimated pumpage.

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