EVALUATION OF THE METHOD TO COMPUTE VOLUMES OF WATER PUMPED FROM POWER RECORDS

by

Robert A. Longenbaugh
Assistant Research Engineer
Civil Engineering Department
Colorado State University
Fort Collins, Colorado

Prepared as a final report for
State Engineers Office
Division of Water Resources
State of Colorado

CER69-70RAL31

EVALUATION OF THE METHOD TO COMPUTE VOLUMES OF WATER PUMPED FROM POWER RECORDS

by

Robert A. Longenbaugh
Assistant Research Engineer
Civil Engineering Department
Colorado State University
Fort Collins, Colorado

Prepared as a final report for
State Engineers Office
Division of Water Resources
State of Colorado

CER69-70RAL31

COLORADO STATE UNIVERSITY

FORT COLLINS, COLORADO 80521

ENGINEERING RESEARCH CENTER, FOOTHILLS CAMPUS

April 3, 1970

Mr. Clarence J. Kuiper
State Engineer
Division of Water Resources
101 Columbine Building
1845 Sherman Street
Denver, Colorado 80203

Dear Mr. Kuiper:

This report entitled, "Evaluation of the Method to Compute Volumes of Water Pumped from Power Records," was prepared to satisfy your request of March 10, 1970 and the ensuing contract. The report describes the factors which would affect such calculations, the expected accuracies of the calculations, and includes cost estimates for obtaining the computed volumes pumped. Consideration is given to both electric motor and internal combustion engine powered pumping plants.

The report is based upon sound engineering principles and utilizes data collected by Colorado State University in a study of irrigation pumping plant efficiencies. That study was conducted in 1964 and 1965 and included collection of data on over 250 different wells in Eastern Colorado.

The purpose of this study was to evaluate the advantages, disadvantages, and costs of using power records to compute the volume of water pumped. This report could be used by you, your staff, or other interested parties to decide whether this method should be used to compute the volume of water pumped from individual wells. Recommendation on whether this method should be accepted or rejected are not included in this report.

I would be most happy to answer any questions which might arise from this report.

Sincerely yours,

Robert A. Longenbaugh

Robert A. Longenbaugh
Assistant Professor of
Civil Engineering
Project Leader

RAL/bh

INDEX

ACKNOWLEDGMENTS

Without the experience and data from the 1964-65 Pumping Plant Efficiency Study preparation of this report would have been impossible. Funding for the Efficiency Study was provided by Colorado Farm Power Council, Highline Electric Association, K-C Electric Association, Kansas Nebraska Gas Co., Plateau Natural Gas, and Y-W Electric Association.

Financial support for this study was provided by the Office of the State Engineer, Division of Water Resources, State of Colorado. Facilities at the Engineering Research Center, Colorado State University, Fort Collins, Colorado were used in the report preparation.

Introduction

The use of large capacity wells for irrigation began in Colorado as early as the 1920's with major increases occurring since 1945. Today there are over 12,000 wells in Colorado supplying water for irrigation. These wells range in size from those supplying less than 100 gpm to those in excess of 3,000 gpm. Most of these wells require a pump to deliver the water to the land surface, and both electric motors and internal combustion engines are used to drive the pumps.

The need to measure the amount of water pumped becomes more and more important so we can administer and manage our total water supplies to meet the ever increasing demand. To evaluate whether and how fast we are depleting our groundwater supplies requires a good estimate of the volume pumped. The conjunctive use of ground and surface water requires that the volumes pumped by wells and diverted by canals should be measured and administered to protect the water users rights.

There are several ways to measure or estimate the volume of water pumped from each well. One method would be to place individual flow meters on all the wells as has been done in other states. Another method would be to estimate the total volume of water pumped by knowing the discharge rate of the pump and the total period of operation. Somewhat analogous to this last method would be the approach of converting power used to volumes of water pumped. It is quite obvious there are advantages and disadvantages to any method used. Two points seem to be of primary concern:

1. How accurate will the estimates of the volume pumped by each well be?

2. What will the cost be for obtaining the necessary data and computing the volume pumped?

The State Engineer of Colorado who is responsible for administering the waters of the state is quite aware of the need to know how much water is being pumped. He has decided to evaluate the merits of the different methods for measuring or estimating the volumes pumped. This study was initiated upon his request to evaluate the advantages, disadvantages and cost of estimating the volume of water pumped from each well by converting power records to volumes pumped. This report will thus delineate the many factors affecting such estimates, evaluate the possible errors, and present an estimated cost.

Two different methods for converting power records to water pumped will be explored. The first method would utilize an average pumping plant efficiency and a total pumping head while the second method would require establishment of a conversion factor for computing volumes pumped directly from power consumption.

Factors in Converting Power Data to Water Pumped

This report will assume power data is available for each well although a later section of the report will discuss this assumption. Power data is recorded as kilowatt hours on a watt-hour meter or as cubic feet of natural gas through a gas meter. Data from both types of meters is a measure of the total energy that was supplied to pump the unknown volume of water to the land surface or to some other operational pressure. The problem then is to determine how we can convert this power data to volumes of water pumped.

Efficiency. Motors using electric energy or internal combustion engines using some types of fuel always require more input energy than they are able to convert to driveshaft horsepower. This is to say that the units are less than 100 per cent efficient. Loss in efficiency occurs because of friction losses, incomplete energy conversion, and other factors acting within the power plant. Similarly the pumps receive energy from the power plants by a series of gears and/or driveshafts and they will produce a certain water horsepower output. Here again the conversion is at some level less than 100 percent efficient. It is thus possible to define overall pumping plant efficiency as follows:

$$\text{Overall Pumping Plant Efficiency } (\%) = \frac{\text{Water Horsepower Output from Pump}}{\text{Input Energy to Power Plant}} \times 100 \qquad (1)$$

This assumes output horsepower and input energy are expressed in similar units.

Water horsepower output is defined as the volume of water pumped per unit of time multiplied by the total pumping head (total pumping head = pumping lift + friction loss in column pipe + operating head at the pump).

$$\text{Water Horsepower Output} = \frac{\overset{(gpm)}{\text{Volume Pumped}} \times \overset{(ft)}{\text{Pumping Head}}}{3960} \qquad (2)$$

Thus by combining Equations 1 and 2 and rearranging we have

$$\text{Volume Pumped} = C \times \frac{\text{Input Energy} \times \text{Overall Efficiency}}{\text{Pumping Head}} \qquad (3)$$

where Equation 3 will have some coefficient C which will make the equation dimensionally stable.

Equation 3 is the theoretical basis for computing the volume of water pumped from some known amount of energy used. In addition to knowing the amount of energy used it is necessary to have data on the overall pumping plant efficiency and total pumping head for each well. If the overall efficiency and pumping head were known exactly, then the computed volume of water pumped would be quite accurate. However, both the overall efficiency and pumping head vary throughout the year and thus some error in the computed volume pumped is expected. A discussion of expected variations in pumping head and overall efficiencies will follow.

Variations in pumping head. Pumping head as defined earlier is made up of three components: the distance water must be lifted in the well from its pumping level to the land surface, the friction head occurring in the pump and column pipe, and the operating head or pressure at the discharge side of the pump. Both the pumping lift and operational head may vary significantly in todays pumping plants.

Pumping lifts vary due to the raising or lowering of the pumping level in the well. As water is withdrawn from the aquifer the water level usually declines in the well. The rate at which this occurs is a function of the pumping rate, the length of time the pump operates, and the properties of the aquifer. Pumping levels in some wells have been observed to drop as much as 25 feet during a pumping season.

Variations in operational head are caused by the different methods by which water is delivered or applied to the crop. If the pump is discharging directly into a ditch or canal then the operational head will be nearly constant during a season. When the pump discharges into aluminum or underground pipe then the operating head will reflect the frictional loss in the pipe and difference between the elevation of the pump and the point of application. Friction head losses in the pipe have been observed to be as great as 15 to 20 feet. The widest variation in operational head occurs when the pump is used for open discharge part of the year and to pump water into a sprinkler system at some other time. Operating head variations of as much as 150 feet could result from this type of operation.

Due to variations in pumping levels and operation heads an average value for the total pumping head may be hard to obtain. It would be most desirable to use some average pumping head for any one pumping season and thus obtain a more accurate value for the volume of water pumped. One would expect that this average pumping head value would change from year to year as water levels varied and operating procedures changed. Data for each well on the changes in ground water levels and variations in the irrigation system would be needed in the calculations.

Variations in overall efficiency. There are many factors that affect the overall efficiency for a pumping plant. Each of the factors is discussed and a maximum expected efficiency given in the following paragraphs.

Vertical turbine pump. The maximum expected efficiency for the pump is specified by the pump manufacturer and usually ranges between 70 and 85 percent. Improper adjustment of pump impellers or their wear due to sand pumping or cavitation could reduce the expected efficiency quite significantly. If the pump is operated at less than its rated speed, this too will also reduce its expected efficiency. Each impeller is designed to be most efficient when pumping a particular volume of water against its designed pumping head. This pumping head, as described earlier, will also affect the overall efficiency. If the pumping head is either larger or smaller than the designed head then the pump efficiency will be less than the expected maximum. Pump curves supplied by the pump manufacturer indicate a difference of 5 feet head per stage could cause a 10 to 15% decline in efficiency. Since each pump has a different curve it is impossible to generalize this possible error.

Electric motor. The maximum expected efficiency for electric motors ranges from 85 to 92 percent[(6)*]. Forturately, electric motors maintain nearly constant efficiencies at various load factors and will either operate at near their maximum efficiency or not at all.

Internal combustion engines. Many pumping plants in Eastern Colorado are driven by internal combustion engines. The maximum efficiency for internal combustion engines measured during special tests[(3,5)] ranged between 25 and 29 percent with diesel operating plants being the highest. Factors affecting this efficiency include engine make, operating speed, fuel, temperature and altitude. Certainly the condition of the engine including wear, ignition system, carburetion, heat exchanger, and general maintenance has a most important influence on its efficiency. Reduction of efficiency to as little as 10 percent has been observed[(1)]. Overloaded engines usually are forced to operate at reduced speeds and thus lower efficiencies.

Gearheads and driveshafts. These devices are needed to connect internal combustion engines to the pump and operate between 95 and 98 percent efficient. Normally they will operate near this efficiency or not at all.

---

*Refers to reference number given in bibliography

Fuel ratings. There may be some variation in the BTU rating of natural gas and this should be accounted for in the input energy. Natural gas that is marketed through interstate commerce is required to have a fuel rating near 950 BTU/cubic foot. When natural gas is used from local oil fields it may have either a higher or lower energy content and should be considered in computing the volume of water pumped.

Maximum theoretical efficiencies. The above data can be used to compute a maximum theoretical efficiency as follows:

For electric powered plants:

Max. Theoretical Eff. (%) = 90% Motor x 85% Pump = 76.5%

For internal combustion engine powered plants:

Max. Theoretical Eff. (%) = 25% Engine x 85% Pump x 98% Driveshaft x 98% Gearhead = 20.3%

These values should serve as a guideline when converting power to water pumped in that few if any pumping plants will operate at this level of efficiency. These efficiencies can also be used with average observed efficiencies to evaluate a maximum probable error in the computed volumes of water pumped.

Observed efficiencies. During 1964 and 1965 Colorado State University conducted a research project in Eastern Colorado to determine overall pumping plant efficiencies and pumping costs. Over 250 individual wells were tested and those data [1] are summarized in this report. A brief summary of the work was published earlier by Miles and Longenbaugh [4].

Figure 1
Distribution of Measured Efficiencies
for 120 Electric Powered Plants

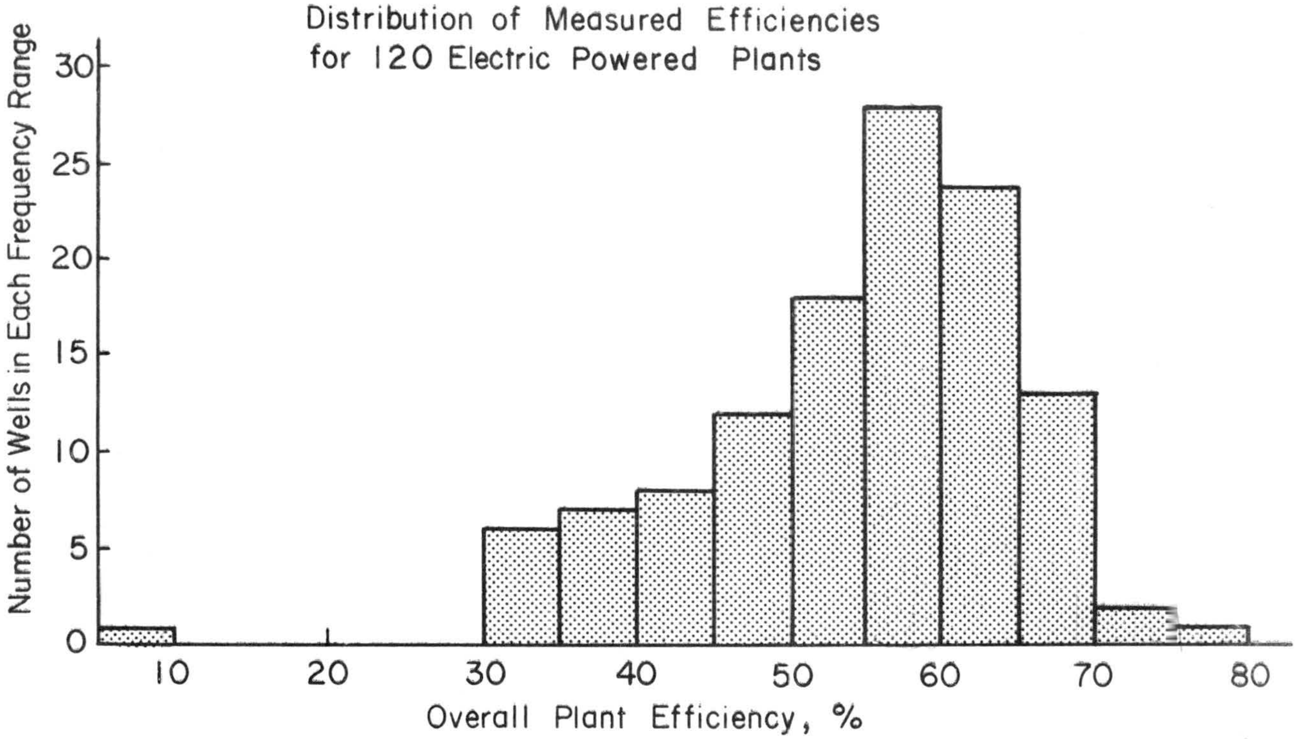

Figure 2
Distribution of Measured Efficiencies
for 127 Natural Gas Powered Plants

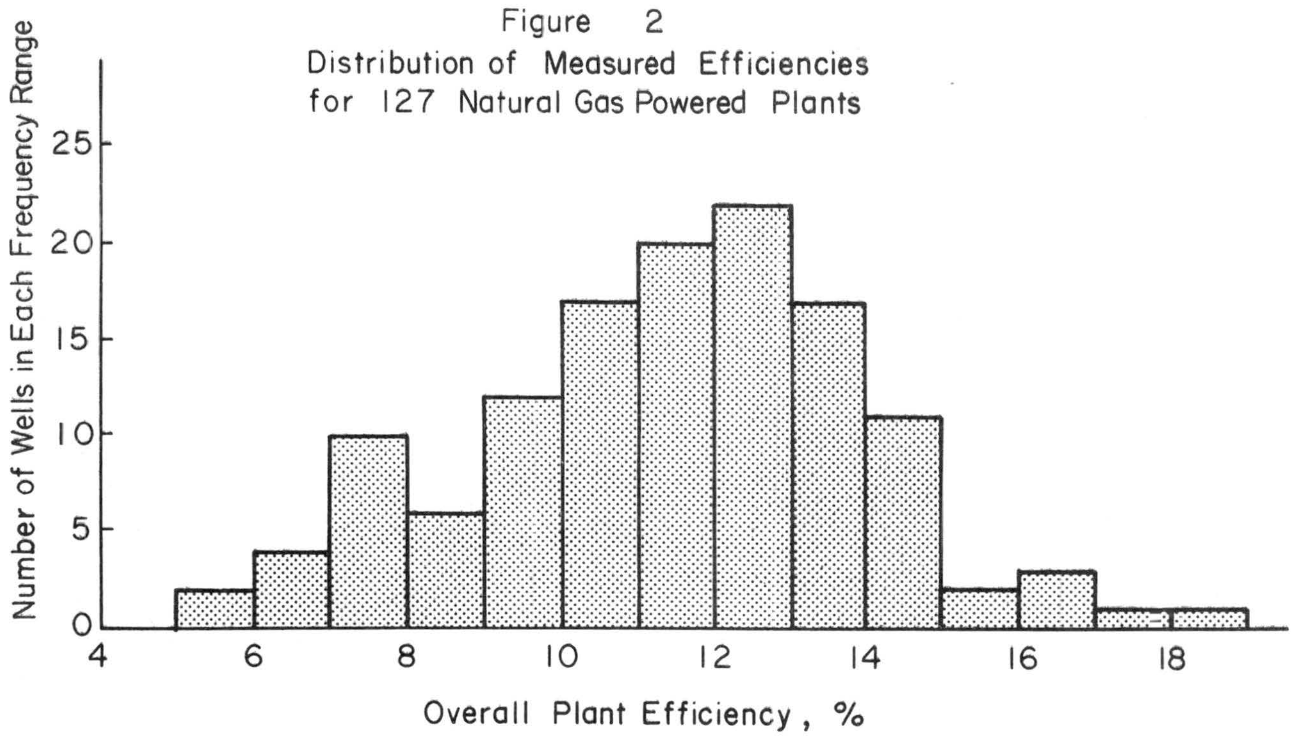

TABLE I. SUMMARY OF PUMPING PLANT EFFICIENCY DATA COLLECTED BY COLORADO STATE UNIVERSITY DURING 1964 AND 1965.

Location of wells (County)	Number Wells Tested	Overall Plant Efficiencies %				Range in Efficiencies for Following Confidence Limits*									
		Average	Standard Deviation	Observed Range		99%		95%		90%		75%		50%	
				Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
NATURAL GAS															
Kit Carson	57	11.66	2.00	16.6	7.9	16.81	6.51	15.58	7.74	14.95	8.37	13.96	9.36	13.01	10.31
Washington-Yuma Phillips-Sedgwick	17	14.12	2.17	18.5	10.1	19.71	8.53	18.37	9.87	17.69	10.55	16.62	11.62	15.58	12.66
Baca-Prowers	53	10.48	2.59	16.1	5.3	17.15	3.81	15.86	5.40	14.74	6.22	13.46	7.50	12.23	8.73
All Natural Gas	127	11.50	2.56	18.5	5.3	18.09	4.91	16.52	6.48	15.71	7.29	14.44	8.56	13.23	9.77
ELECTRIC															
Kit Carson	14	52.56	9.66	67.3	36.2	77.44	27.68	71.49	33.63	68.45	36.67	63.67	41.45	59.07	46.05
Washington-Yuma Phillips-Sedgwick	55	54.97	12.86	70.5	31.1	88.10	21.84	80.18	29.76	76.12	33.82	69.76	40.18	63.64	46.30
Prowers	8	52.56	13.36	78.0	36.0	86.98	18.14	78.75	26.37	74.54	30.58	67.92	37.20	61.56	43.56
Morgan-Weld Logan-Adams	45	53.30	11.80	71.7	9.1	83.70	22.90	76.43	30.17	72.71	33.89	66.87	39.73	61.25	45.35
All Electric	122	53.92	12.07	78.0	9.1	85.01	22.83	77.58	30.26	73.78	34.06	67.80	40.04	62.06	45.78

*A confidence limit of 99% would indicate that 99% of all wells would have efficiencies between the listed maximum and minimum values. Similarly a 50% confidence limit would indicate only 50% of the wells would have efficiencies between the listed maximum and minimum values. The other 50% of the wells would have efficiencies greater than the maximum or less than the minimum.

Figures 1 and 2 show the wide variation of efficiencies observed during the 1964-65 study. The data are also tabulated in Table I which gives a breakdown in the number of wells tested by counties. A further discussion of these data is included in a later section.

Method Using Average Efficiencies

This method is based upon Equation 3 which indicates that the volume of water pumped can be computed for each well if data are available on the total pumping head, the overall efficiency, and the amount of energy consumed. The energy consumption will be a known quantity for the pumping period being studied, but both the overall efficiency and pumping head can be expected to vary during that period. Due to the variation of these last two parameters it is necessary to assume some average value for them during the pumping period. The accuracy of the computed volume pumped will depend on how well these average values represent the real conditions.

One advantage of this technique is that one could compute the volume pumped for many different wells by assuming average overall efficiency and pumping head data based upon actual measurements from a much smaller number of wells. The question then arises as to how accurate is the estimated volumes pumped.

<u>Accuracy of computed volumes</u>. Data in Table I summarizing the 1964 and 1965 studies indicates the average, the standard deviation, the observed maximum and minimum values and some calculated confidence limits in overall efficiencies for both

electric and natural gas powered pumping plants. The range in average values for overall efficiencies is greater for natural gas plants than for electric but the variation in the standard deviation is greater for electric plants. This would indicate that an average efficiency of 53 percent for electric plants might be somewhat uniform over a wide area, however, the maximum probable error on any one plant could be very large.

Maximum probable error of the computed volume of water pumped from any one well due to errors in overall efficiencies can be calculated using the equation:

$$\text{Max. Probable Error}(\%) = \frac{\text{Max. Observed Eff.} - \text{Average Eff.}}{\text{Average Eff.}} \times 100 \qquad (4)$$

For electric plants the maximum probable error is 44.7 percent and similarly 60.8 percent for natural gas plants. These values can be interpreted as the computed volumes of water pumped were respectively 44.7 and 60.8 percent too low. Similarly a maximum probable error could be calculated using the minimum observed efficiencies and the average values but these errors would be even greater.

It should be noted that the above errors result from using an average value of overall efficiency for all wells. Variation of efficiencies within the pumping season on any one well would appear from data collected in 1964 and 1965 to be less than the wide variations between wells. It should be noted that the statistical analysis using confidence limits indicates that one could expect an even wider variation of overall efficiencies than what was observed in most counties.

One could conclude that for electric powered plants the maximum error in computing the volume of water pumped would be in the order of ±45% and similarly ±60% for natural gas plants.

The above error analysis assumed that the only error was in the overall efficiency values. However, there most certainly would be errors in the estimated pumping heads. If the estimated pumping heads were in error by ±20 feet, which seems like a reasonable maximum value, the error in computed volume of water for total pumping heads of less than 100 feet would be in the order of ±20%.

The errors due to using average values for overall efficiencies and estimated values for pumping head could be either additive or tend to cancel each other for any one pumping plant. Thus the errors in computed volumes pumped could be as great as ±65% for electric plants and ±80% for natural gas plants.

Cost of method. To estimate a cost of this method it is essential to specify the number of efficiency tests that should be conducted each year. It is assumed that efficiency tests will be conducted on 50 wells in the High Plains of Kit Carson, Washington, Yuma, Phillips and Sedgwick Counties; 200 wells in the South Platte River Valley and its tributaries; 100 wells in the Arkansas Valley; 20 wells in Baca and Prowers Counties and 100 wells in the San Luis Valley. This totals 470 efficiency tests per year and is considered to be a minimum number. The wells should be selected at random representing wells constructed by different drillers and having different makes of pumps, motors, and engines. Some statistical analyses of the data should be conducted yearly to see if a sufficient number of tests are conducted to truly represent all the wells.

If only 470 efficiency studies are to be made it is possible that two two-man teams working between April 15 and October 15 could accomplish this task. It is assumed that there would be 20 working days per month and that an average of two efficiency tests could be made in an eight hour day. Salary rates, per diem and mileage costs and equipment expenses were provided by the State Engineer.

Table II. Cost per Team to Make Efficiency Measurements

Personnel	
1 - Water Resource Engineer II (full year)	$11,683.00*
1 - Technician (6 months)	2,820.00
Per diem 120 days x $14.00/day x 2 people	3,360.00
Mileage	
Daily on job - 120 days x 75 miles/day x $ .10/mile	900.00
Weekend to Denver - 300 miles x 20 weeks x $ .10/mile	600.00
Equipment - yearly cost	750.00
Indirect and unexpected costs (25% contingency)	5,028.25
Total yearly cost per team	$25,141.25

* The entire yearly salary was used because the Engineer would be required to process data, repair equipment, and obtain water table fluctuation data during the rest of the year.

Assuming there are 12,000 irrigation wells in Colorado and the need for two teams to make the efficiency tests the cost would be about $4.20 per well per year. In addition it is assumed that there would be a $5.00 cost per well per year to obtain power records, estimate pumping head, select the overall efficiency, and compute the volume pumped. Total cost per well would then be about $9.20 per year.

Method Using Conversion Coefficient

One approach to overcome the large errors characteristic of the overall efficiency method would be to develop a conversion coefficient to compute volume pumped directly from consumed energy. To obtain such a coefficient would require one to measure the volume of water pumped from a well for a particular period of time while simultaneously recording the power used. This would allow one to immediately compute a coefficient which represents the units of energy required to pump a volume of water. The equation would be:

$$\text{Conversion Coefficient} = \frac{\text{Energy Input/Unit of Time}}{\text{Volume Pumped/Unit of Time}} \times C \quad (5)$$

where C would be some constant required to make the equation dimensionally stable. The conversion coefficient would have the units kilowatt-hours per acre foot pumped for electric plants, cubic feet of natural gas per acre foot pumped for natural gas plants, and gallons of fuel per acre foot pumped for diesel or propane powered pumps. To compute the volume of water pumped for each well one would have to take the total energy consumed in the selected time period and divide it by the conversion coefficient for that well. A conversion coefficient would be obtained by testing each well.

Accuracy of method. This technique would reduce the errors of the previous method caused by using average efficiencies and estimated pumping heads. Errors would occur, however, in the computed volumes pumped due to variations in pumping plant efficiencies and pumping heads during the pumping season. The conversion coefficient is truly valid only for the conditions that existed at the time the well was tested. If the test conditions represented the average operating conditions during the pumping season then the computed volume pumped would be most accurate. Considerable effort should be made to operate the pump at the averaging operating head during the test or else determine several conversion coefficients for different operating conditions and obtain a weighted average based upon the amount of time the pump is operated under each condition.

Data from the 1964-65 Efficiency Study, where tests were run at several operating conditions, indicated a 10.5 percent error in the conversion coefficient due to variations in engine speed on internal combustion engines. An error of 20.3 percent in the conversion coefficient was noted on one plant where a discharge measurement was made for open discharge versus another test where the water flowed through 1000 feet of eight inch aluminum pipe. Several tests were conducted before and after a pump impeller adjustment and an error in the coefficient of 14.7 percent was observed. The above three values for error in the conversion coefficient were the maximum values observed for their respective changes in operating criteria.

Data is not available to evaluate the effect of changes in pumping head during an irrigation season. Based upon analysis of manufacturers pump curves and due to the reduced yield of most wells as the water level declines it is estimated that the conversion coefficients could vary by as much as 25 percent in the pumping season for the same operating conditions.

In this method as well as in the method using overall efficiencies it is not clear how the errors due to changes in operating practices and due to variations in pumping head will affect each other. It is felt that they may tend to accumulate in the conversion coefficient method and thus maximum errors in estimating the volume of water pumped may approach 45 percent. If some care was taken during the tests on each well so that several operating conditions were checked and a good average coefficient was selected then I think this error could be reduced to a maximum of ±25 percent.

Cost of method. To develop a conversion coefficient for each well would require a test of each well involving a simultaneous discharge and power use measurement. This would require a two-man crew where one man should have engineering experience. The following cost analysis was prepared based upon salary, per diem, and mileage costs supplied by the State Engineer.

The cost data anticipates that the pumping period would be from April 15 to October 15 and the number of working days would average 20 per month. Measurement of six wells per day is reasonable in that when open discharge measurements are possible this number can be exceeded, however, to measure discharges for wells pumping into sprinklers, underground pipe, or long reaches of alluminum pipe will require considerable more time. It should also be noted that scheduling of the test with the individual farmers at their convenience is essential.

Table III. Cost per Team to Determine Conversion Coefficients

Personnel	
1 - Water Resource Engineer II (Full year)	$11,683 00*
1 - Technician (6 months)	2,820 00
Per diem 120 days x $14.00/day x 2 people	3,360 00
Mileage	
Daily on job 120 days x 50 miles/day x $ .10/mile	600 00
Weekend to Denver 200 miles x 24 weeks x $ .10/mile	480 00
Equipment - yearly cost	600 00
Indirect and unexpected costs (25% contingency)	4,880 75
Total yearly costs	$24,423 75

* The entire yearly salary of the Engineer was used because it was assumed he would spend the six months, when not in the field, working up field data, collecting power records and actually computing the volumes of water pumped.

Each team could measure about 720 wells per year resulting in a cost of about $33.90 per measurement. Due to the variation in pumping head and overall efficiency within a pumping season as well as between pumping seasons it is anticipated that it will be necessary to make an average of one measurement per well per year. In some areas the conversion coefficient will remain nearly constant but in others where the water table declines it may require several measurements per year to allow calculation of the volume pumped within the ±45 percent.

It is anticipated that there would be a cost of $2.00 per well to collect the yearly power data. The estimated total cost per well per year would be $35.90.

Availability of Power Data

Assuming that it would be possible to compute the volumes of water pumped from power data it appeared that the availability of such power records should be explored. With this in mind a questionnaire was sent to the 20 different electric and natural gas suppliers in the state. At the time of this printing 18 of the questionnaires have been returned and are summarized in Table IV. The companies receiving the questionnaires provide nearly all the electricity or natural gas used in pumping water for irrigation in the entire state. It should be noted that dealers supplying diesel fuel, gasoline, or liquid petroleum (propane) were not questioned. It is felt that it might be possible to obtain data for these different fuels by contacting the local dealers.

Summary of questionnaire. The numbers included in Table IV represent the accumulated total number of wells served by all the companies answering the question in a particular manner. Only three companies indicated they would not be willing to provide either yearly or monthly data on each well. Others had some degree of reservation which usually indicated they wanted to protect the rights of their customers and might in some cases require written approval from the pump user before releasing the records. It should be noted that all power suppliers of pumps located in the area known as the High Plains of Eastern Colorado expressed a willingness to cooperate if there was no objection from individual pumpers.

Table IV. Summary of Questionnaire Sent to Power Suppliers to Determine Availability of Power Records. Accumulated Number of Wells Appropriate to Each Answer.

How often are your meters read?

Monthly <u>9008</u> Bimonthly <u>835</u> Semiannual <u>647</u> Yearly <u>591</u>.

Could your firm supply <u>yearly</u> energy consumption for each well to the State Engineer?*

Yes <u>9040</u> No <u>1394</u> Position unknown <u>647</u> .

Could your firm supply <u>monthly</u> energy consumption for each well to the State Engineer?*

Yes <u>6598</u> No <u>2318</u> Position unknown <u>2165</u> .

Do you use a computer in your billing? Yes <u>5523</u> , No <u>5558</u> .

Do your records give a description of the location of the wells you serve? Yes <u>8822</u> , No <u>2259</u> .

Does each well have some type of identification number that would remain fixed throughout time? Yes <u>6676</u> , No <u>1405</u> .

* Assumed State Engineer would pay cost in obtaining records.

Other information obtained from the questionnaire indicated that all the meters were read by company representatives. Those companies indicating they could supply records would provide them in a tabulated form.

<u>Problems in using data</u>. Several difficulties in using the power data have become apparent. Probably the most serious problem is determining the power record on the tabulation sheet which corresponds to a particular well. Results from the questionnaire indicate most companies have records which would give the location of their meter, but often this can be obtained only by looking at the companies' map of the area they serve. This would require considerable time and effort by the water administrator to coordinate the power record to the proper well. Most Rural Electric Associations have a service number for each meter that gives its legal description.

Several companies (both electric and natural gas) allow more than one pump to be connected to a single meter. Power use by a single pump is thus not available. For example one natural gas company supplies 1471 wells with only 1258 meters. In addition many of the locations recorded for the natural gas meters will be near the main supply line, but the pump may be located some distance away (in some instances a mile or two).

In the case where power records are tabulated either by meter number, by the person receiving the billing, or by some company number other than one giving the legal description, additional problems can be expected that would have to be resolved. In the case where data is tabulated by meter number one can expect meter changes on the wells due to periodic repair and maintenance programs. The person receiving the power billing will also change with time due to change in ownership, tenantship or other reasons. In some instances one individual might receive billings for a large number of wells causing problems in differentiating the proper well for each billing. Some of the service identification numbers represent a particular meter route and are subject to change. Data from those companies that do not have a fixed identification number included on the data tabulation sheet would require considerable time in coordinating power data and well location.

Summary

The many different factors which influence the conversion of power records to volumes of water pumped have been briefly discussed. Data from the 1964-65 Efficiency Study indicates an expected average efficiency of 53 percent for electric powered plants and 11.5 percent for natural gas operated plants. Observed ranges in efficiencies and statistical analysis of the data both indicate that there would be a wide variation in efficiencies between individual wells.

For the method using an average overall efficiency and estimated pumping lifts it is expected that the probable error in computing the volume pumped could be off by as much as ±65 percent for electric powered plants and ±80 percent for internal combustion engine powered plants. The cost per well per year for computing volumes pumped would be $9.20 including making 470 efficiency tests.

For the method using a conversion coefficient the expected maximum error in computing volumes pumped would be less but still amount to ±45 percent. The cost of this method on an individual well basis would be about $35.90 per well per year Further study of the range in variation of the conversion coefficient during the pumping season due to changes in pumping lift and operating procedures is needed.

Bibliography

1. Groundwater Section Colorado State University. Unpublished records for over 250 pumping plant efficiency tests made in 1964 and 1965. Civil Engineering Department, Colorado State University, Fort Collins, Colorado.

2. Hicks, Tyler G., Pump Selection and Application. McGraw-Hill Book Co., 1957, 422 pp.

3. Implement and Tractor. Specifications on Liquid Cooled Engines for Tractors, Farm Machinery, and Industrial Applications. Implement and Tractor Red Book, Published by Intertec Publishing Corp., Kansas City, Mo., January 1969, pp. A-98 to A-122.

4. Miles, D. L. and R. Longenbaugh, Evaluation of Irrigation Pumping Plant Efficiencies and Costs in the High Plains of Eastern Colorado. Colorado State University Experiment Station, General Series 876, December 1968, 19 pp.

5. University of Nebraska. Nebraska Tractor Test Data 1970. University of Nebraska, Agricultural Engineering Department, Lincoln Nebraska, 1970, 61 pp.

6. Wheeler Economy Pumps. Pump Engineering Data. C. H. Wheeler Manufacturing Co., Philadelphia, Penn., 195[illegible], 420 pp.