EVALUATION OF HYDROLOGIC AND GEOLOGIC PARAMETERS FOR CONSIDERATION OF DESIGNATED GROUND WATER BASINS

by

H. R. Duke and R. A. Longenbaugh

CER66HD-RAL20

Rough Draft 3-2-66
CER66HD-RAL20

Mary - S

MASTER FILE COPY

EVALUATION OF HYDROLOGIC AND GEOLOGIC PARAMETERS FOR CONSIDERATION OF DESIGNATED GROUND WATER BASINS

by

H. R. Duke and R. A. Longenbaugh

INTRODUCTION

Purpose

The Forty-Fifth General Assembly of the Colorado State Legislature passed the 1965 Ground Water Laws amending Chapters 148-11 and 148-18, Colorado Revised Statutes, 1963, which became effective May 17, 1965. These laws allowed description of ground water aquifers meeting certain provisions as "designated ground water basins". Following designation of a ground water aquifer by the Colorado Ground Water Commission, the people of an area so designated may elect to form a "ground water management district", thus allowing local ground water administration and management.

This investigation was initiated primarily as a pilot project to establish a criteria and procedure for compiling the estimates required by law before consideration of a "designated ground water basin". To be included in this study was the evaluation of the required data for a selected Colorado ground water basin so that procedures could be initiated to implement this law should the area be deemed to qualify as a "designated ground water basin".

Basin Selection

Based upon consultation with the Colorado Water Conservation Board, Colorado State Engineer and Colorado Ground Water Commission, the Kiowa and Bijou Creek Basins were selected as the pilot study area. This site selection was based primarily upon the magnitude of previous studies in the area, the volume of data previously compiled, and upon the expected relative ease with which the law could be expedited. This area was not necessarily considered to be the most critical ground water area in the state.

Parameters Determined

The hydrologic and geologic parameters to be determined during the course of this study included the seven items specifically listed under paragraph 148-18-5 of the 1965 law. Procedures and the resulting estimates of these parameters are presented in a separate report by the authors. This report is primarily to provide guidelines for future investigators of similar areas, based upon the experience gained during this pilot study.

FIELD DATA COLLECTION

Type of Data Collected and Timing

During the summer of 1965, a field party from Colorado State University visited each well in the Kiowa-Bijou Basin, and interviewed every pump operator. Prior to the field data collection phase, all wells in the study area registered with the State Engineer were plotted on county highway maps. A thorough field search was conducted to locate and inventory those wells which were not registered.

Since this field inventory of wells was the initial step in the investigation, and it was not known what information might later be useful, as much information as possible was collected initially. The location of each well was established as closely as possible using the odometer of the field vehicle. This location is expected to be accurate to within .05 mile, considering the type of odometer installed on the vehicles used.

The name and address of the owner and tenant were recorded, as well as the use of the water, the type of pump, its size, kind of power used and size of motor or engine. In the case of electrically powered pumps, the power meter number was recorded. The static ground water level was measured in those wells not pumping at the time of inventory.

The above data were based upon personal observation of the field personnel, and with the exceptions of location and water level should be absolute. The expected accuracy of location was previously estimated. Although ground water levels were measured and recorded to the nearest .01 foot, the accuracy with which these measurements represent the actual static water level is expected to vary considerably. Neither the influence of pumping wells nearby nor the degree of recovery of the cone of depression in wells recently pumped was taken into account for correction. Water levels for a number of wells obviously not representing static water level were disregarded later in the analysis.

The remainder of the field inventory data was reported by the well operator, and probably varied considerably in accuracy with the person's judgment and memory. These data included the name and address of the driller, year well was drilled and depth of well. Reported yield of the well and the average number of days annual pumping completed the field data. It was noted that most operators were overly optimistic as to the yield of their wells. Based upon discharge measurements of 39 wells in the area, it was estimated that the average discharge of a well drilled during the early years of development has been approximately 70 percent of the initially reported discharge. Although the reported number of days annual pumping were considered to be 24-hour days in further analyses, the investigators felt that this might not be the case in many instances, therefore little confidence was placed on these reported figures. It was felt that an annual hourly use would be more useful and reliable for future studies.

Reasons for Collecting Field Data

The primary purpose of the field inventory was to determine the accuracy and completeness of the well registration records of the State Engineer. Colorado Water Conservation Board Basic Data Report No. 17 was used as a reference for the well registration records. It is realized that this record was 18 months out of date at the time of initiation of the study, and that a number of the wells recorded as "not registered" were, in fact, drilled after the January 1, 1964 compilation date of this report and were properly registered.

The field inventory revealed 62 wells (9%) in the study area were incorrectly located in the State Engineer's records. These errors ranged from less than one-quarter mile (error in quarter-quarter section location) to six miles (error in township location). A total of 86 wells (12 1/2%) were located during the field inventories which were not registered. Thirty-seven (37) wells previously registered were found to have been abandoned at the time of visitation.

Names and addresses of owner, tenant, and driller were recorded anticipating that personal correspondence might be required concerning certain individual wells. It was anticipated that the drilling date of a well be used to represent the date of first use for establishment of priorities. Depth of well was recorded to provide supplemental data for plotting bedrock contours if necessary. Data concerning the type and size of pump and motor and the reported yield and annual use were collected in anticipation of their use for refining computations of historic pumping.

The power meter number was recorded to allow matching of individual power records to field located wells for historic pumping calculations.

Justifiable Field Data Requirements

Although areas of more recent development than this study area would be expected to have a smaller percentage of abandoned and unregistered wells, the investigators feel that a field inventory of all wells should be conducted in future studies. It appears that such studies will be the basis for granting or denying permits for new well development, possibly on a well spacing basis. Errors in reported locations alone could result in serious long range consequences as development progresses.

In order to comply with item (h) under paragraph 148-18-5 of the law, this inventory should include a current record of the owner, date of first withdrawal (possibly the date of drilling will suffice), the use made of the water, and information to allow computation of the annual amount of water withdrawn.

For computation of the volume of water in storage and underflow rates, static ground water level measurements are necessary. The desired magnitude, accuracy, and timing of such measurements are discussed in a succeeding section of this report.

Additional desirable field investigations would include aquifer tests to determine permeabilities, specific capacities, and specific yield (drainable porosity) of the aquifers concerned. The extent of such needed tests will depend upon the amount of such work previously conducted in the area as well as upon the size, homogeneity, and other physical characteristics of the aquifer.

EVALUATION OF REQUIRED PARAMETERS

The Name or Names of the Water Bearing Geologic Member or Members of a Defined Formation

Data Available

To the best knowledge of the authors, the most recent geologic study of the entire state of Colorado is presented as a geologic contact map by the U. S. Geological Survey, circa 1935. Many local studies in more recent years have updated this investigation showing changes in location and areal extent of various formations, as well as changes in formation nomenclature.

U. S. Geological Survey Water Supply Paper 1378 was utilized in the lower reaches of the study area to refine the geologic data presented in the previously mentioned map. Such papers are the result of extensive investigation, and probably represent the best data feasibly obtainable for large areas.

Results of localized investigations by Colorado State University personnel and Woodward, Clyde, Sherard and Associates, Denver, were also utilized. Due to the small areal extent of these investigations, they were of primary value in determining the depth and thickness of defined formations, rather than in locating the contacts of the various formations.

Assumptions Necessitated by Lack of Data

Of primary concern to the geologic portion of this t study was the apparent lack of data concerning formation thickness. Since the irrigation wells in the study area are relatively shallow, and seismic exploration wells were seldom deeper than 150 feet, the only data concerning thickness of the lower formations were logs of the few deep well investigations in the area.

In determining the thickness of the lower formations, all formations were assumed to dip westward from their contacts at the rate of 6 feet per mile (as given in LWSP 1378). The resulting geologic cross sections were corrected where possible using deep well logs available. The investigators felt, however, that the resulting calculated depths and thicknesses of formations were very weak at best.

Depth of Earth's Surface Considered

Because of the limitation in minimum well sizes (i.e., discharge pipe diameter) considered in the law, only those formations considered capable of economic feasibility in pumping a significant quantity of water of usable quality were considered in this investigation. Although there is presently very little development of water in the Fox Hills sandstone aquifer, it is quite probable that this aquifer willl be developed in the future.

The necessity of including such an undeveloped aquifer, capable of future development, in an investigation of this nature is apparent when one conceives the possible interchange of water and/or contamination which could result from unrestricted development of a lower aquifer.

For this reason, the investigators feel that a management district, which may result from investigations of this type, should have authority to regulate drilling into all underlying formations. The fact that formations below the top of the Pierre shale were not considered significant waterbearing formations in this area should not exclude regulation of these formations as a part of the over all ground water management of the area.

Further Investigations Needed

It is not the position of the investigators to interpret the degree of accuracy required of future investigations, either by the sponsor of such investigations or by the courts. Although the accuracy attained in definition of thickness and depth of lower formations was not commensurate with the accuracy of other data used in this study, it is not felt that additional time and money spent in physical investigation is justifiable.

The Boundaries of Each Formation or Member Being Considered

Methods of Delineation

The areal extent, location, and non-coincidence of the various geologic formations caused considerable concern as to location of boundaries for the proposed "designated ground water basin". Since local control and management are provided, it was probably not the intent of this legislation that extremely large areas be included in the defined basins. Considering this and the authors recommendation that all formations below an area should be included in the designated ground water basin required that boundaries be drawn which would have little physical relation to some of the formations. Any boundary drawn to delineate the alluvium of the study area necessarily cuts the lower formations quite arbitrarily. It was felt that such a boundary was most satisfactory, since the major development is in the alluvial aquifers, and since movement of water in the lower aquifers is relatively slow.

This boundary delineating the alluvial aquifer was selected at the topographic or watershed boundaries. An alternate consideration was selection of the saturated alluvium boundary as a basin boundary. Since this is a transient boundary in an aquifer such as the study area, it was not considered a logical nor feasible boundary delineation. The topographic boundaries are stable, and such a boundary including the entire watershed will allow management of the over all water resources (through recharge, etc.).

Even though this method of boundary delineation would include landowners apparently not obtaining direct benefit of the ground water, the investigators feel that a "saturated alluvium" boundary would seriously effect the functioning of a management district. In the event of major development of underlying formations, such a boundary would be meaningless.

Special Considerations for Tributary Aquifers

Many aquifers in Colorado are, by strict definition, tributary to appropriated surface streams. The alluvium in the study area of this investigation is such an aquifer. The investigators considered the present ground water legislation as an attempt to apply a practical definition to evaluate the degree to which an aquifer is tributary. This investigation was based upon such an interpretation, realizing that well development in such an aquifer does reduce the volume of underflow, but probably not to the extent of beneficial use of the pumped water.

In such a tributary aquifer, special consideration must be given in delineating boundaries between the designated ground water basin and connected alluvial aquifers. Consideration was given to location of this boundary at the uppermost surface diversion ditch. The support for this method of boundary selection was that all land not lying within the proposed basin would be in an area served by surface water.

Further consideration of subsurface geology revealed that the deepest portion of the South Platte River alluvial channel would lie above such a boundary. In order to alleviate the problem of wells within the proposed basin capable of drawing water directly from the South Platte River, an alternate method of boundary selection was used. The lower basin boundary was defined by projecting the river elevation horizontally to its intercept with the bedrock. The locus of such points defined the lower basin boundary. This method of boundary selection assures that no well in the proposed basin can draw water directly from the South Platte River itself. The weakness in this reasoning is, of course, that these wells intercept water which might eventually reach the South Platte River as underflow.

This investigation pointed out the necessity for consideration of the physical characteristics of each individual area before deciding upon a method for locating a boundary separating one portion of a continuous aquifer from another.

The Estimated Quantity of Water Stored in Each Formation or Member

Aquifer Volume

Data available. Regardless of the type of waterbearing formations, either confined or water table aquifers, within a study area, the first step in evaluating the quantity of water stored is to define the limits of the aquifer.

For defining the bedrock underlying the alluvial aquifer, the primary source of data was seismic exploratory shot-hole logs. In many areas of considerable exploratory work, these logs were available at quarter mile increments around the periphery of each section. In the upper reaches of the study area, shot-hole exploration was much less dense, perhaps averaging one log for each 6 to 10 square miles. In general, these logs did not exceed 150 feet in depth. In the deeper portions of the alluvium, therefore, these logs were of little value.

A second source of depth-to-bedrock information was the reported depth of irrigation wells in the area. Such data is of questionable value in many instances, as will be discussed in the succeeding section.

In areas covered by U. S. Geological Survey Water Supply Paper 1378, the bedrock contour maps of this publication were utilized on this study. This investigation, being more localized than that covered by WSP 1378 required some refinement of these published maps, using the data compiled for the immediate study area.

Definition of the limits of lower aquifers was certainly less precise than that of the alluvium. With the exception of some 6 to 8 deep well logs available from Woodward, Clyde, Sherard and Associates, consulting engineers, the only data utilized in this study was the average dip from geologic contacts as given by the U. S. Geological Survey in WSP 1378 and 1658.

Accuracy of data. The accuracy of seismic shot-hole logs probably depended more upon interpretation of these logs by the investigator than upon the accuracy of the logs themselves. The ease of interpretation of these logs depended upon the formations encountered by the driller. In most instances, drilling passed abruptly from alluvial sand and/or gravel into a clay or shale member of a lower formation, thus easily establishing the depth to the bottom of the alluvium.

The accuracy of location of formation changes seemed to depend upon the individual driller. Some operators apparently logged to the nearest foot, while others logged only to the fearest five feet. Even the accuracy of recorded logging depths depends upon sample collection techniques used by the individual driller.

Irrigation well depths as a means of locating the bedrock were used quite cautiously. In the areas of greater aquifer thickness, wells (especially the older wells) may not completely penetrate the alluvium. Spot checks of wells in the more shallow areas where shot-hole investigations were less intense showed that most wells penetrated only one or two feet below the alluvium. In these areas, well depths were used with judgment in defining bedrock depth. In some areas, notably in the eastern portion of the study area where alluvium overlies poorly consolidated sandstone, both irrigation and shot-hole logs frequently failed to indicate the point of contact of the two formations.

As might be expected, the relative accuracy of defining aquifer volume varied with actual depth to bedrock and areal extent of the alluvial aquifer. In the lower portion of the basin, where depths of 100 feet and greater were encountered, and where the aquifer was relatively wide, it is expected that the accuracy attained approached 5 percent. On the other hand, in the upper regions where the aquifer was often only one-half mile or less in width and frequently very shallow, accuracy greater than 50 percent is not expected. Since these shallow areas comprise a very small portion of the total aquifer volume, however, it is felt that the accuracy of determination of aquifer volume for the entire area is quite acceptable.

The accuracy of determining the volume of lower formations was rather questionable. Comparison of cross sections drawn by using the reported average dip of the formations from their reported contacts showed considerable differences in formation thickness and depth along the length of the basin. The changes in thickness and depth indicated were not necessarily in a logical sequence considering surface topography and the general shape of the Denver Basin. The few deep well logs available indicated that errors of 50 to 100 percent in formation thickness were likely along the western portion of the study area. Therefore, if the contacts along the eastern portion of the area may be assumed accurately located, the best that could be expected would be 25 to 50% error.

Other data needed. In the lower portion of the study area, the data available for definition of the alluvial aquifer was more than sufficient. For the upper area, however, data was obviously quite sparce. Lack of logging information in these areas necessitated use of stereoscopic aerial photographs and the assumption that the alluvium was bounded by the relatively abrupt edge of the flood plain in the individual creeks.

In the extreme upper reaches of several creeks where alluvial wells are known to exist, the data was insufficient to even attempt definition of the extent of alluvium. Such areas are, however, very small and of little significance to the basin as a whole.

Any data whatsoever available for the lower formations would help to strengthen these estimates. Such data as might become available would probably require the services of a competent geologist for interpretation.

Justifiable accuracy of data. With the type data used in this portion of the investigation, the choice is one of volume of data to be used rather than accuracy of the data. The volume of data necessary for determination of bedrock contours will depend upon the physical characteristics of the aquifer, and may vary within a given study area. Logs at one mile intervals appeared to be sufficient in the lower portion of the study area while spacing of one-quarter mile or less in alluvial areas would have been desirable in the upper reaches.

Since the legislation for which similar investigations may be conducted provides for alteration of estimates as further data becomes available, the investigators feel that further field investigation in this area of a study is unwarranted. Two possible exceptions can be foreseen, however; these being the San Luis Valley and the Southern High Plains regions. These aquifers are very complex and little is known of their geology.

Volume of Water Stored

Data available. Calculation of the volume of water stored in an aquifer requires, in addition to establishment of aquifer limits, determination of static ground water levels for unconfined aquifers and selection of a representative porosity.

In 1929, Mr. W. E. Code of Colorado State University began semiannual monitoring of ground water levels in Colorado. Since that time, the Colorado State University ground water level observation well network has been expanded to include nearly 700 wells throughout the state east of the Continental Divide. The U. S. Geological Survey, Denver, Colorado, also maintains an extensive statewide observation well network.

These historic water level records were found invaluable for establishment of present ground water levels as well as historic ground water levels.

The intensity of this investigation necessitated monitoring of additional wells in the study area. Water level measurements were made in about 200 wells within the study area during summer 1965.

No actual aquifer tests were conducted in the study area by the investigators. Specific yields of the aquifer were estimated from aquifer tests conducted by the U. S. Geological Survey, reported in WSP 1378 and from personal judgment. Since the ground water law does not technically define the "quantity of water stored in each formation", calculations were performed based upon the volume of recoverable water.

Accuracy of data. Although ground water levels are measured and recorded to the nearest .01 foot, this does not necessarily reflect the accuracy with which static water levels are represented. Shallow, unconfined aquifers are often observed to have diurnal fluctuation of water levels of .1 to .2 foot or more. Water levels in confined aquifer wells may respond to changes in barometric pressure. Such fluctuations may well be .5 foot or more.

Even more important in determining static water levels is the time since pumping ceased. Timing of this investigation necessitated measuring ground water levels during the summer months. Weather conditions, however, resulted in much less than normal pumping in the area during 1965. The optimum time for ground water level measurements is late winter or early spring, depending upon the irrigation season in the particular area.

The accuracy of specific yield determinations, even with adequate aquifer tests, depends upon the physical characteristics of the aquifer and upon the judgment of the person analyzing these tests. U. S. Geological Survey aquifer tests indicated approximately 17% specific yield (in the alluvium) in the lower end of the study area. Considering the delayed drainage of the aquifer and probable lithology of the alluvial deposits, a figure of 20% was used in this study area.

Other data needed. Although the fringe areas of the aquifer in the study area seldom contribute sufficient water to maintain production of large wells, these areas (of less than 20 feet saturated thickness) contain a considerable volume of water due to their areal extent. Lack of sufficient observation wells in many of these areas made necessary the extrapolation of water table contours through these areas. Although the recharge influence of outlying areas was taken into account in these extrapolations, it is quite possible that errors as great as 10 feet may have resulted.

It is not expected that such errors in the relatively small areas of their occurrence seriously effected the total volume of water calculated for the basin. The most serious errors resulting would be in location of the limit of saturated thickness in the alluvium. Such errors could possibly be in the order of one-half to one mile in areas where the bedrock relief is extremely flat.

As previously discussed, the lack of sufficient aquifer tests necessitated the assumption of a uniform porosity throughout. Certainly, additional aquifer tests throughout the study area would have helped substantiate the specific yield used in this study.

Calculation of volume water in storage. Having prepared the bedrock and water table contour maps from data previously described, the investigators used a method of graphical subtraction to draw an areal map showing saturated thickness. In some areas of the upper reaches the topographic elevations could not be easily determined from available topographic maps. Here the depth of water in observation wells was used in conjunction with graphical subtraction to alleviate the problem of elevation errors. This saturated thickness map was used to calculate volumes of water stored in each township. The area of each 20 foot zone of saturation was determined by planimeter and converted to equivalent acreage. Assuming a linear transition between zones, the double-end-area method was used for calculating the volume of saturated alluvium. This volume multiplied by the estimated specific yield resulted in the estimated quantity of water stored in the alluvial aquifer.

For the underlying formations, geologic cross-sections were constructed as previously described, and similarly measured by planimeter. Calculation of volume water in storage was likewise accomplished by the double-end-area method and multiplying the resulting saturated volume by the estimated specific yield of the formation.

Justifiable data collection. The volume and accuracy of data justified for this type investigation will depend upon the physical characteristics of the area under study. For areas similar to the Kiowa-Bijou Basin, the investigators feel that measurement of observation wells at intervals less than one mile is unnecessary. In areas where the slope of the static water table can be expected to be relatively uniform, a spacing of two miles would probably be more justifiable.

These water level measurements should be made prior to the beginning of the pumping season, and one such current mass measurement should be sufficient. Although water levels to the nearest foot are as accurate as other data obtainable, the extra time to measure these levels to at least 0.1 foot is merely the time to record the data. The investigators find that an ordinary steel tape, marked with chalk, is the most efficient method for measurement in most wells. With such a tape, water levels are easily measured to 0.01 foot. Deep wells, wells with a leaky aquifer above the water table, and wells in which the water level cannot be estimated within 10 feet may be more easily measured with one of several electronic devices. The accuracy of such devices is frequently impaired by stretch in the cable, therefore recording water levels beyond .1 foot is probably meaningless.

The Estimated Annual Rate of Recharge

Data Available

Depending upon the method chosen for estimation of recharge, a considerable variety of data could be utilized. Precipitation, temperature, and evaporation records are available for many stations throughout the state, and can be analyzed by standard methods. Ground water levels as previously described are valuable for establishment of gradients and outflow areas. The Soil Conservation Service, USDA, has published recent soils maps which may be utilized for identifying areas of recharge as related to soil type.

Probably the most insufficient data for this area which would have been of value in calculating recharge is streamflow records along the major streams. Streamflow records were available for approximately four year periods on both the Kiowa and Bijou Creeks.

Methods of Estimation

Probably the most widely used method of estimating recharge to a ground water basin is to assume recharge equal to the underflow. This method can be acceptable in a developed area only if historic water levels and gradients before pumping began can be established. At best, this method gives a net recharge, not accounting for recharged water lost to evapotranspiration and seepage. Another possibility for this method is to add the estimated evapotranspiration from the water table and the difference between depletion by pumping and change in storage, to the underflow. However, the depletion by pumping, or conversely the percentage of pumped water returning to the water table, is equally as difficult to determine as recharge itself. A small percentage error in these relatively large figures could mean considerable error in the estimated recharge.

A second method preferred by some investigators is estimation of a fixed depth of water or fixed percentage of the precipitation being recharged in areas of similar climate. This method does not take into account differences in relief, geology, soil type, or cultural practices. In many instances, this is at best an arbitrary method of estimating recharge.

For this investigation, the authors compared several methods, and based the final estimate upon the combination of these methods. Historic water level records indicated little significant change in ground water levels above the Adams-Arapahoe county line, indicating that the underflow at this point has not been significantly altered by pumping development. Thus, the recharge in the drainage above this county line was considered equal to the underflow, or about 3.3 percent of the average annual precipitation. The remainder of the area, somewhat flatter and more conducive to recharge, was assumed to recharge 5 percent of the precipitation. Additional recharge was estimated for the area below the Adams-Arapahoe county line based upon the average volume of surface flow past that line. Kiowa Creek is reported to seldom flow from the area, thus its entire average flow assumed to infiltrate within the study area. Bijou Creek was estimated to infiltrate 1000 acre feet annually each 12 miles along its length.

Needed Research

This investigation again impressed upon the investigators the need for research to evaluate natural recharge. It is hoped that future investigations proposed by Colorado State University and others may develop techniques for accurate evaluation of natural recharge.

Thorough instrumentation of an area under consideration for at least a year would also aid future investigators in making accurate estimates.

The Estimated Use of Ground Water in the Area

Data Available

During the field inventories, a considerable amount of data was collected in anticipation of various methods for computing historic ground water use. These data applicable included the reported discharge of each well, its average annual use, the type and size of power plant, depth to water when well was not pumping, and the power meter number when applicable.

As previously discussed, historic ground water level measurements for most areas in eastern Colorado have been compiled by both Colorado State University Experiment Station and U. S. Geological Survey for a number of years. Colorado State University Experiment Station has also compiled records of power deliveries to irrigation pumping plants in Colorado supplied by the various electrical and natural gas distributors. These data are available in the offices of the authors.

Additional data collected for this investigation included individual power delivery records placed on microfilm. Records of Morgan County R. E. A. were microfilmed from 1944 through 1964, and those of Intermountain R. E. A. for 1964.

In conjunction with another study at Colorado State University, pumping plant efficiencies were tested during summer 1965 for 39 wells within the study area.

Aquifer permeability data, used for calculation of drawdown in individual wells, was taken from U. S. Geological Survey Water Supply Paper 1378.

Accuracy of Data

Certainly the most complete and most accurate data utilized in this study were the individual well records of electrical power delivery. These data were taken from individual account sheets, and included a month by month record of power delivery.

Accuracy of water level measurements in observation wells was previously discussed. For those wells in which water levels were not actually measured, topographic maps and the water table contour map were used to estimate water levels. The accuracy of these estimates depended largely upon the availability of accurate topographic maps, and errors for individual wells may be 10 feet or more, depending upon local topography. These errors should be somewhat compensating from well to well, with little expected effect upon total volume pumped in the study area.

Reported discharge and number of days pumped were of questionable value in determining annual pumping volumes. Most operators tended to be optimistic concerning well discharge, and reported the average pumping period in monthly increments, probably interpreted as length of pumping season. For these reasons, these reported data were not utilized in computation of pumping volumes for electrically powered wells. The validity of projecting measured efficiencies from the 39 wells studied to nearly 700 wells in the basin cannot be determined. An accurate projection would require knowledge of time and conditions under which the pump was installed, the operator's care in maintenance, and judgment exercised in initial selection of the proper unit, as well as changes in ground water condition since installation. The investigators do feel, however, that the studies conducted did give a representative efficiency for pumping plants in the study area.

Methods of Calculation

Perhaps the easiest method for calculation of pumping volumes is that using the average discharge and length of time well is pumped. As mentioned in the preceding section, this method is likely to result in calculated volumes considerably greater than actually occurred.

A second method, and that which the investigators would recommend to future investigators, utilizes the total power deliveries to the area in question and an area wide average for depth to water, efficiency, and drawdown. Although no absolute figure is obtainable for comparison, the authors feel this method is within limits of accuracy comparable to other information compiled concerning the basin.

The method of calculation used in this study was found to be extremely tedious, and was performed solely to determine its feasibility for future studies. Data from the microfilmed power records were transferred to IBM 1231 Optical Mark Reader sheets, one sheet per well per year. The location of each well was determined from the power companies' coded hookup designation, and specific information concerning capacity, water level, and basin location transferred from the field inventory sheets to the IBM sheets. A digital computer program was prepared to determine drawdown and total lift, to select a pumping plant efficiency, and to calculate directly from the IBM 1231 sheets the volume pumped annually by each individual well.

As power delivered to LP, gasoline, and diesel powered units would be very difficult, if not impossible to compile, water pumped by these units was estimated based upon reported capacity and number of days pumped. The error thus introduced in the total annual pumping estimate is believed small, since the volume pumped by these plants in 1964 was less than 5 percent of the total.

Recommended Methods

The authors recommend the use of total power deliveries and average values of lift and efficiency for future investigations. The method used in this investigation required approximately 50 man hours per year of data to transfer data for the study area from microfilm to IBM sheets. The results obtained from this method were within 10 percent of those obtained from the method recommended.

This detailed method will probably prove feasible for individual well analysis in more detailed investigations. Average annual volumes pumped for each well, as required under section (h), 148-18-5 of the legislation can probably be satisfactorily computed using the reported capacity - days pumped method.

The Estimated Projected Use of the Ground Water in the Succeeding Fifty Years at Ten Year Intervals

Factors Influencing

Projection of ground water usage as far in advance as fifty years presents a problem of considerable magnitude. Legal or legislative action might well alter use considerably. The passage of the very legislation under which this investigation was conducted may eventually pass the control of pumping to a local water conservation district, with the life span of the aquifer determined by judgment of the local people.

Even without implementation of such legislation, the logical management of ground water by individual users could effect the useful life of such an aquifer considerably. Of course, social and economic factors have been responsible for the development of ground water resources in these areas, and will continue to be major factors determining future use.

Of primary concern to the investigators were the physical characteristics of the study area. It is quite certain that water users in the areas of deeper saturation will be able to pump water long after wells in the less saturated areas have been abandoned. Such a phenomena is already history in parts of this study area. Technical inability to accurately detect and evaluate specific areas and amounts of recharge, local management practices in the future, and future well development patterns makes impossible the determination of exact areas which will be supplying water at a given date.

Methods of Estimating

The investigators' first approach to estimating projected pumping was to apply a water balance to the area. Depletions from storage were calculated, new water levels determined, and future volumes pumped based upon these calculations.

After consideration of the factors mentioned in the previous section, however, the results were felt to be meaningless. The final projection was based upon the realization that wells will be abandoned, replacement wells will probably be drilled, irrigation practices improved as water becomes more scarce, and most of all -- upon the judgment of the authors.

Expected Accuracy

It is the opinion of the authors that the accuracy of such a prediction, regardless of the method employed, can neither be rigorously supported nor justifiably rebutted. Only time can prove such a prediction. The authors do sincerely hope that their prediction will prove inaccurate and that technological advances in cropping methods, recharge and weather modification will allow a stable economy to be maintained in this area based upon ground water utilization.

List of Those Users Who Have Been Withdrawing Water in Excess of Fifteen Years, The Use Made of the Water, The Average Annual Quantity of Water Withdrawn, and the Year in Which the User Began to Withdraw Water

Source of Data

The data presented in this portion of the investigation was provided primarily by the State Engineer from his records of well registration. These data are presently published in Colorado Water Conservation Board Basic Data Report No. 17, current to January 1, 1964.

Based upon the field inventories conducted under this investigation, an addendum to this list was prepared. These inventories revealed a considerable percentage of the wells were incorrectly located, abandoned, or not legally registered at all.

The only factor to be calculated for this portion of the investigation was the average volume of water pumped. This was accomplished by the afore mentioned discharge - days pumped method.

Since much of the land has changed possession since the time at which watcr was first withdrawn, it was found that many of the present owners did not know when first use was made of the water. The investigators therefore considered the date of application as the date of first use. It is realized that many wells are constructed after the harvest season and may not be used until the succeeding calandar year.

Need for Field Investigations

The need for thorough field inventories of wells was impressed upon the investigators by the number of wells found to be inaccurately located, abandoned, or unregistered with the State Engineer's office.

Although not a specific requirement of this study, the complete and accurate location of existing wells is essential to effective administration of the present ground water legislation. A map showing such locations for the study area was presented to the State Engineer for his use in administration of the law.

ADDITIONAL FACTORS WARRANTING CONSIDERATION

Definition of "Designated Ground Water Basin"

Although the previous sections of this report have discussed all the specific facts to be ascertained in satisfaction of the law, the investigators feel that certain other information should be considered. The primary factor to be considered by the Ground Water Commission in designating a ground water basin is, apparently, support that the area under consideration complies with the definition set down in the legislation. This definition requires that the area not be adjacent to a continuously flowing natural stream or that the underground water contained therein not be required for fulfillment of surface water decrees, and that ground water has been the major source of water, use for a period exceeding fifteen years.

The investigators felt that the study area qualified unquestionably under the first portion of this definition, although some protest was expressed as to the technical definition of a natural stream. It was realized the ground water within the study area is certainly tributary to the South Platte River, therefore to a certain degree is required for satisfaction of surface rights along that river.

An attempt was made to show the relative importance of ground water underflow from the area compared to use of ground water within the proposed basin. Annual volumes of underflow and pumped water were compared, both at the present time and prior to extensive pumping development. Possible dispositions of underflow and the time lag prior to its emergence as surface water were also discussed.

Substantiation of the supposition that ground water has been the major source of water use for over 15 years was found to be more difficult than anticipated. Examination of the State Engineer's records revealed a tremendous volume of decreed surface rights within the study area. Although the surface streams are known to be intermittent and hearsay evidence indicates little surface water is diverted, there are no diversion records to prove or disprove the relative volumes of surface and ground water use.

Other Factors

Several other evaluations were found to be valuable for supporting the decisions of the investigators. These included evaluation of the irrigated acreage and area underlain by saturated alluvium as they relate to the entire area of the proposed basin. This material was used primarily for logical justification of proposed basin boundaries.

Such factors as aereal distribution of wells and stored ground water, and chronological development of pumping in the area were found to aid in the prediction of future pumping volumes. These evaluations should also be of considerable value to further investigations in these same areas.

PROBLEMS ENCOUNTERED IN THIS INVESTIGATION

Although this entire paper has been devoted considerably to specific problems encountered, this section will consider some of the more general problems worthy of consideration.

Volume of Data Used

Depending upon the parameters to be evaluated, the volume of data varied considerably. As an example, a tremendous amount of power records and, for part of the area, bedrock data (shot-hole logs) were compiled. On the other hand, streamflow records were so limited as to be of very little value to the investigation.

Although an attempt was made to evaluate each parameter as accurately as possible within feasible limitations, the investigators anticipate that future investigations will attempt to attain moderate accuracy of the same degree for each of the parameters evaluated. Thus, future investigations may well disperse with such large volumes of data as were used in evaluation of a few parameters in this study.

Lack of Basic Knowledge

Need for Research

As has been previously described, the lack of technically sound methods for evaluation of natural recharge and artificial recharge potential stifled the accuracy of recharge evaluation and pumping prediction. It is anticipated that future research developments may greatly assist the alert investigator in making such determinations more precise.

More accurate techniques for evaluation of crop water requirements and irrigation efficiency would make future predictions as well as recommended practices more meaningful.

Need for Data Collection

Geology. The investigators realize that a thorough geologic study requires considerable time and expense and that to delay such investigations as presented in this study pending geologic studies would considerably lessen the intent of the present ground water legislation. Although thorough knowledge of the geology in such an area is extremely helpful in making accurate estimates, the investigators feel, in the interest of expediting these investigations, that in most areas an intensive field geologic study is unwarranted.

Surface water resources. Though records of streamflow and surface water storage and diversion within such an area as the Kiowa-Bijou Basin may be relatively insignificant to administration of the water resources of the entire state, the lack of such records is sorely apparent in an investigation of this type. Of course, every area having possibilities as a "designated ground water basin" cannot be sufficiently instrumented. Even minimal instrumentation on watersheds to be analyzed in the near future would be of help to investigators.

Ground water levels. The many years of historic ground water fluctuation compiled by U. S. Geological Survey and Colorado State University were very valuable in this investigation. These respective observation well networks give fair representation in the major ground water areas of Colorado. It would be impossible to maintain, in anticipation of such studies as this, a sufficiently intense statewide observation as desired for these studies. It is relatively easy to correlate patterns of ground water fluctuation from these selected wells with intense water level measurements made during an investigation such as conducted by the authors. As with watershed instrumentation, the possibility exists for advance intensive water level studies in anticipation of this type of investigation. At the time of preparation of this report, such studies are being initiated in portions of the State.

Aquifer characteristics. The extent of previous investigations and need for furtuer aquifer tests has been discussed previously. Depending upon the desired accuracy, future investigators should anticipate the need for such tests during the course of their investigation.

Local Water Users

Education

Since this investigation was initiated immediately after passage of the present ground water legislation, the local water users had little idea of the purpose of the study or its possible effect upon them. During late summer, 1965, the authors, assisted by other state personnel, conducted a series of educational meetings throughout the study area. At these meetings the legislation in general, procedures for initiating a designated basin, and progress of the investigation were discussed.

It was found desirable to acquaint the field personnel somewhat with provisions of the law. It is these people who must present sufficient justification of the investigation's purpose to obtain the necessary field information from water users,

Cooperation

The investigators were pleased with the cooperation extended by all water users in the area. Although some were hesitant until contacting local leaders in the investigation, all water users, without exception, gave full cooperation to the field personnel.

With some educational program preceding initiation of field studies, the authors would expect good local cooperation in any similar area of the state. Of course, dissenting parties are expected in any area, and field investigation plans should be made accordingly.

PRESENTATION OF FINDINGS

To Ground Water Commission

As required under the legislation, the findings of this investigation were publically presented before the Colorado Ground Water Commission at a formal hearing. The authors testified under oath at Commission hearings in Fort Morgan, Colorado on November 4 and December 2, 1965. This testimony included presentation of findings and cross-examination by objectors. Since the study area was a pilot area under the new legislation, the authors do not anticipate that future investigations will require such detailed testimony.

The findings were presented at this hearing without benefit of the final report on the study, in order to expedite progress in initiating the new legislation. Such a presentation is not recommended to future investigators, as it is felt that a final report would add much strength to the presentation.

The State Engineer

The State Engineer, acting as interim administrator under the Ground Water Commission until such time as a local management district may be formed, requested certain preparations from the findings of this study. This request included maps at a useable scale (1 inch equals 1 mile) showing bedrock contours, saturated thicknesses, and, particularly, well locations. These maps were provided as inked tracings suitable for such reproductions as deemed desirable.

Report Requirements

The results of this investigation, being somewhat different from succeeding investigations, were submitted as two separate reports. The first report contained the findings of the authors' total water resource investigation in the area, and included those data required for satisfaction of the present ground water legislation. The second report, presented herein, was intended to serve as a guide for future investigators of similar basins, suggesting data requirements and problems which might be encountered.

SUGGESTIONS TO FUTURE INVESTIGATORS

Sources of Information

Though many helpful bits of information will likely come from varying sources as an investigation progresses, probably most used in this study were files and publications of the State Engineer, U. S. Geological Survey, Colorado Water Conservation Board, and Colorado State University. The appended bibliography lists specific publications used in making the evaluations. As much of this information is public property, it is available for inspection by anyone, the exceptions being confidential data loaned by private concerns.

Personnel Requirements

It is anticipated that subsequent investigations of similar areas will require less time and personnel than this study. Since the purpose of this study was multifold, considerably more work was involved than for only evaluation of the parameters required by law. The authors would estimate, for an area similar in size and characteristics, approximately six man months professional time and eight to ten man months from other personnel. The investigators utilized both graduate and undergraduate students at CSU for field inventories, data analysis, and drafting. These students proved quite satisfactory for this work, perhaps suggesting sources of personnel to future investigators.

Compilation of Data

The investigators found some repetition of work was caused by the order in which data were compiled and decisions made. Field investigations should begin immediately upon initiation of the study. Such a decision, however, resulted in collection of unnecessary field data, since the lower boundary of the study area was altered upstream after field studies were underway.

With careful initial organization, and, hopefully, with the knowledge of problems presented in this report future studies should progress more smoothly.

SUMMARY AND CONCLUSIONS

This investigation has led the authors to believe that the necessary data for future investigations are available for most areas of the State. The necessity for further data collection will be determined by the desired accuracy and refinement of evaluations. The problem of evaluating the required parameters is one of interpretation as well as collection and compilation of data, however, and should be supervised by competent technical personnel.

Though the authors feel that this study has contributed to expedition of future investigations, only these future investigators can make such an evaluation. If this report is of value in providing guidelines and preventing pitfalls in the future, this portion of the study may be considered worthwhile.

The adequacy of estimates made in this investigation is yet to be determined. A possibility exists that further legislation or court decisions may more specifically define the required extent and accuracy of these evaluations. Until such time, however, future investigators must proceed on the premise that the best estimates that judgment, time, and funds will allow will be sufficient.