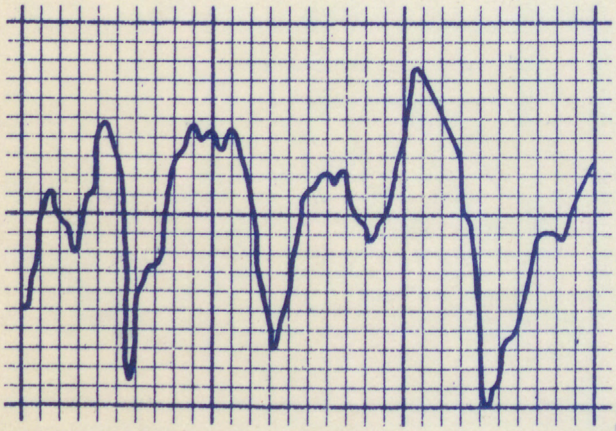
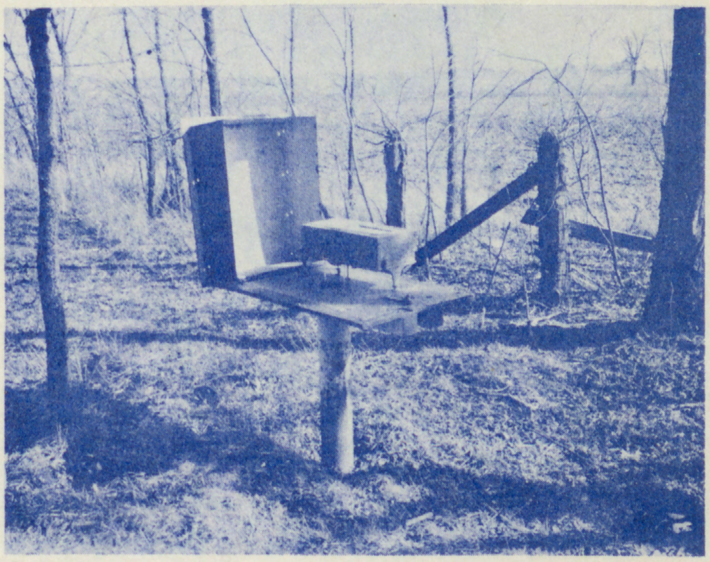
PRELIMINARY EVALUATION OF THE GROUND-WATER DATA NETWORK IN INDIANA





U.S. GEOLOGICAL SURVEY

Water-Resources Investigations

76-24

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle PRELIMINARY EVALUATION OF THE GROUND-WATER DATA NETWORK IN INDIANA			5. Report Date March 1976 6.
7. Author(s) James R. Marie			8. Performing Organization Rept. No. USGS/WRI 76-24
9. Performing Organization Name and Address U.S. Geological Survey Water Resources Division 1819 N. Meridian Street Indianapolis, Indiana 46202			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address U.S. Geological Survey Water Resources Division 1819 N. Meridian Street Indianapolis, Indiana 46202			13. Type of Report & Period Covered Final 14.

15. Supplementary Notes
Prepared in cooperation with the Indiana Department of Natural Resources, Division of Water

16. Abstracts

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17. Key Words and Document Analysis. 17a. Descriptors

*Observation wells, *Evaluation, *Planning, *Statistical methods, Indiana

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
No restriction on distribution	UNCLASSIFIED	50
	20. Security Class (This Page) UNCLASSIFIED	22. Price

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by James R. Marie

U.S. GEOLOGICAL SURVEY

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Indiana Department of Natural Resources

Division of Water

March 1976

UNITED STATES DEPARTMENT OF THE INTERIOR

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METRIC CONVERSION FACTORS

The following factors may be used to convert the English units published herein to the International System of Units (SI)

Multiply English units	By	To obtain SI units
feet (ft)	0.3048	metres (m)
miles (mi)	1.609	kilometres (km)
square miles (mi^2)	2.590	square kilometres (km^2)
million gallons per day (Mgal/d)	3.785	thousand cubic metres per day (tm^3/d)

PRELIMINARY EVALUATION OF THE GROUND-WATER DATA NETWORK IN INDIANA

by James R. Marie

ABSTRACT

The ground-water-data program, which was established in Indiana in 1935, has utilized 478 different wells located in every county in the State. Water-level data have been collected on a periodic basis from 468 of these wells. Continuous record is available from 199 wells located in 70 of the 92 counties. The length of record available for individual wells ranges from 1 to more than 38 years, and averages about 9 years. Water-quality data are available for 25 of the wells. Geologic logs and well-construction data are available for 82 wells, and yield and drawdown data are available for 27 wells. Water-level records of various types are published for selected wells, and hydrographs are kept in the files, but no data compilations are available. No in-depth study has been made of the network or the data. The main purpose of this study was to make a preliminary evaluation of the program and to suggest methods suitable for an in-depth study.

A water-well data-collection program of the type indicated for Indiana is based on five major considerations: (1) the purpose of the program is clearly defined, (2) the program goals are specified and attainable, (3) the methods used to attain the goals are appropriate, (4) periodic reevaluation is provided for, and (5) the cost of the program does not exceed the benefits. This report deals principally with the importance of the first four points.

A good ground-water data program provides the basic data needed to solve an anticipated water-related problem within the accuracy required at an acceptable cost. From a problem-anticipation point of view, the program at the present time (1974) should provide data to determine: (1) the quantity and quality of ground water in storage for each major aquifer of the State, (2) the long-term rate at which this quantity or quality is changing, (3) the stresses causing the changes, and (4) the aquifer characteristics and boundary conditions needed to make computations (predictions) of these changes with specified accuracy at specified places and times.

Once the purpose and objectives of the program have been defined, methods can be specified to obtain the data needed. The purpose of this study was to suggest appropriate data-collection methods; therefore, a detailed outline of procedures is presented for acquiring, processing, storing, and recalling both the raw data and the processed information.

To facilitate future study, tabulations and statistical summaries were made of most of the data available. Also, examples are given of analyses that were made; these analyses could be expanded to include the total network. The analyses indicate that methods can be developed to show what

data are needed from each site, when enough data have been collected, and what accuracy goals need to be set for various types of data. Examples used show that water levels can be estimated within a standard error of about 1 foot. Water-level estimates of this accuracy are adequate for most uses of this information.

The preliminary findings indicate the distinct possibility of accomplishing the stated purposes at a reasonable cost--a prospect that does not seem attainable with the present program. Consequently, an in-depth evaluation in the near future seems to be indicated.

INTRODUCTION

Objectives

The U.S. Geological Survey, in cooperation with the Indiana Department of Natural Resources and several communities throughout the State, has operated an observation-well network in Indiana since 1935. Ground-water data of many types have been collected from the 478 wells that have made up this network from 1935 to January 1974. Water-level records of various types are published for selected wells, and water-level hydrographs are kept in the files of the U.S. Geological Survey, but no data compilations are available. No in-depth study has been made regarding the adequacy of the network itself or of the data recorded.

The objectives of this study are twofold: first, to make a preliminary evaluation of the adequacy of the ground-water data program and to suggest changes in the program or its operation that are indicated by the evaluation; and second, to outline methods suitable for a detailed evaluation of the program and of the large amount of data derived from it. Consequently, this is a progress report describing the status of the existing program and presenting an outline of concepts and proposed methods that might be implemented to improve the future program.

The examples used in this report to illustrate the various methods deal with water-level data although the various types of ground-water previously gathered ought to be adequately considered in evaluating or redesigning the program.

MAJOR FACTORS TO BE CONSIDERED DURING EVALUATION

To properly evaluate a ground-water data-collection program of the size and type of that in Indiana, four major points need to be established: (1) the purpose of the program is clearly defined, (2) the goals are specified and their attainment is feasible, (3) the data-collection methods used are adequate, and (4) the cost of the program does not exceed the benefits.

One additional point must be made: An evaluation is not a one-time study. An effectively operating program is in a continual state of reevaluation and modification, because the data provided are those needed to solve both present and future problems. Obviously, if future problems are significantly different from those anticipated, new or different data may be required for solution. If these points are duly considered during any evaluation, the resulting program can provide the desired data at the required time and at an acceptable cost.

The Purpose of a Ground-Water Data Program

Knowledge of the water level or its fluctuation with time will not ordinarily be sufficient for solving water problems or for formulating prudent plans for ground-water use. Water-level information is only part of the basic-data output needed for a comprehensive ground-water program--much in the same way that stream-stage data are only one part of the data needed from a comprehensive streamflow network. Design of a program needs to be based on current or anticipated problems. Data collected need to materially aid in answering questions such as: How much water is or will be available? Where and when is it or will it be available? What is the quality or what will be the quality of the available water? How will the quantity and quality vary with time and place? What factors cause this variation? What is the use of water, and how will changes in use of the water influence the amount and quality of water available? Answers to these questions, as well as many others, can be supplied only by using data derived from an effective ground-water data-collection program. In other words, a data-collection network is meaningful only within a problem-solving context. Data acquisition, of itself, is not an acceptable purpose within the context of this discussion; that is, collection of data for use in answering unspecified problems, on the assumption that the data will prove useful, is speculative at best and runs a high risk of failure.

The purpose of a ground-water data network, therefore, is to provide the basic data anticipated to be needed for solving hydrologic problems, within the accuracy required, and at an acceptable cost. More precisely, and strictly from a hydrologic point of view, the network for Indiana could be designed to provide the data needed to determine: (1) the amount and quality of ground water in storage in the spring of each year for each major aquifer of the state, (2) the rate at which the amount or the quality of the water is changing, (3) the stresses causing the changes taking place,

and (4) the aquifer parameters and boundary conditions used to permit calculations (predictions) of the changes that may occur, within specified accuracy limits at specified places and times.

Characteristics of an Ideal Ground-Water Data Program

An ideal ground-water data program would: (1) be comprehensive, (2) be coordinated, (3) be constituted so that it can be systematically reviewed and evaluated, (4) provide data for all significant ground-water environments, and (5) provide the needed data at the required time and at acceptable cost.

A comprehensive program denotes one that is effectively and accurately collecting and processing data required to solve a particular current or anticipated problem (definition of the natural ground-water system within specified accuracies is included). This program would compile all data needed to relate natural or man-made stresses to observed water-level and water-quality changes; such data allow prediction, within specified accuracies, of future changes resulting from specified stresses. To assure that the program is comprehensive, decision makers specify what problems will need solutions, and then decide: (1) what data are needed, (2) how much data of each type are needed, (3) what precision or quality of data are needed, and (4) what accuracies are required for various problem solutions or natural flow-system definitions.

A coordinated program is one in which the data collected from each well, along with all additional data necessary to define water-level and water-quality changes, are available when they are needed and that these data are stored in a system from which they can be retrieved and used efficiently. In short, the program would specify when data will be needed and in what form they will be provided. Benefits of a comprehensive and coordinated network are that the collection of superfluous data at a given time is avoided, that reasonable decisions can be made in specific cases as to when enough data have been collected, and that data are not misplaced or inadvertently destroyed.

The program is constituted to provide for systematic review and reevaluation; that is, specific provisions are established in the program for a periodic review, so that if the water problems change with time in ways not anticipated, the program is periodically revised to reflect the new needs. The benefits of this flexibility are: first, data do not continue to be collected long after the problem for which they were being collected to solve has changed; second, data are not collected in excess of that needed to solve a particular problem; and third, few major problems will appear without warning for which needed data have not been collected.

The program provides data on all significant factors that define each ground-water environment. This is a very subjective criterion. Because data needs are predicated on problem solving and because most ground-water data are not directly transferable from one area to another, the hydrologist needs information on all hydrologic factors involved in solving anticipated

problems. To solve complex problems, the hydrologist needs to understand the individual ground-water systems well enough to determine complex cause and effect relations and what data are needed to solve those problems in each aquifer or hydrologic system.

The key word is "understanding". This understanding of the ground-water system will be more complete in some environments than in others. The completeness of understanding is based on a need-to-know priority. The question to be answered is: How critical are the problems arising or that might arise in the near future within each different hydrologic system? This question needs to be answered in evaluating how many data of each type are needed and when they are needed. Some problems can be solved with very little data, whereas others require a concerted effort in data collection. The hydrologist must have at least a working knowledge of all environments that he works with in order to solve simple problems in these environments and to plan future data-collection programs to solve the more complex problems that are anticipated. At a minimum he needs enough data to determine how each system operates under natural or undeveloped (unstressed) conditions.

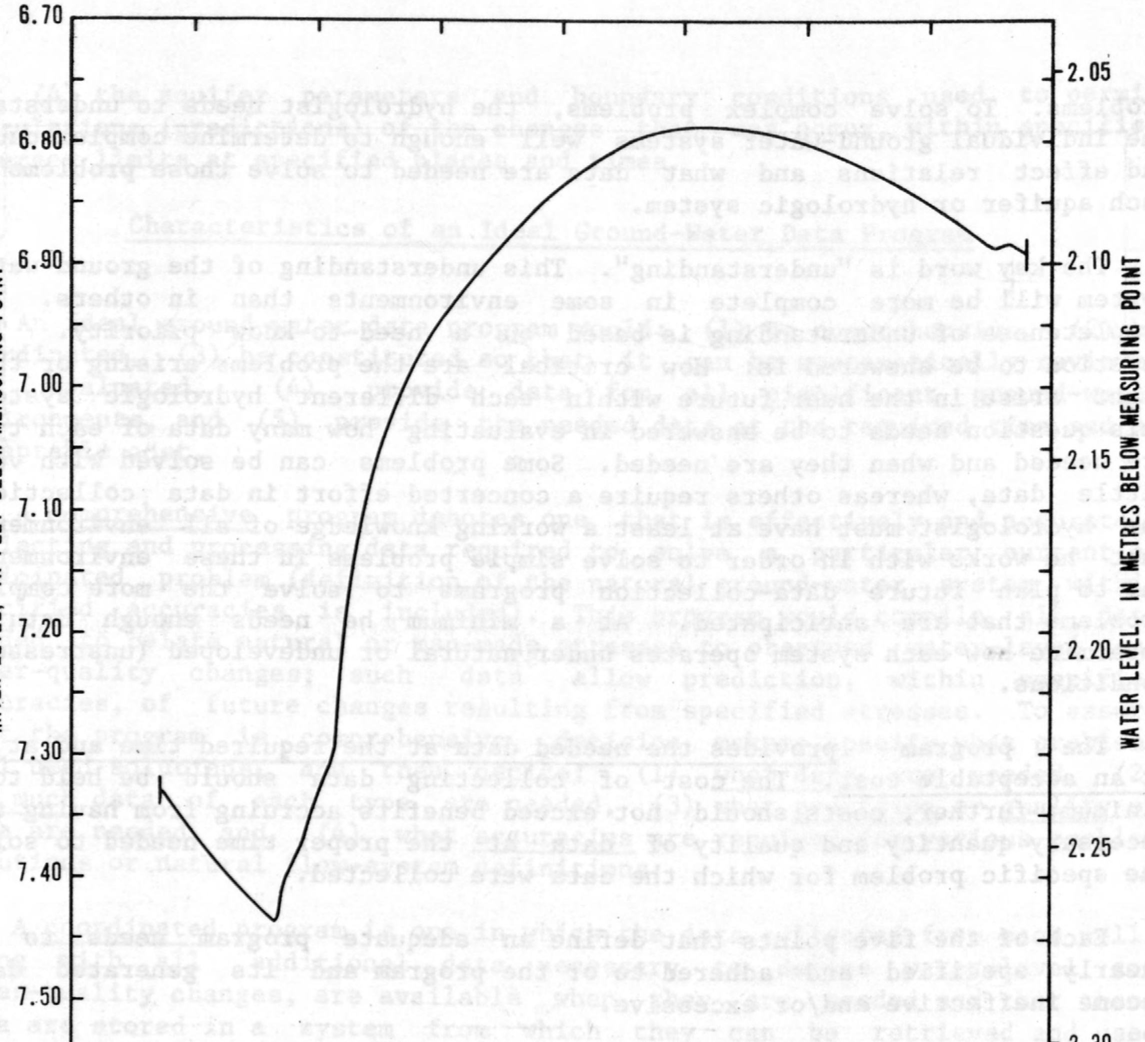
The program provides the needed data at the required time and at an at an acceptable cost. The cost of collecting data should be held to a minimum; further, costs should not exceed benefits accruing from having the necessary quantity and quality of data at the proper time needed to solve the specific problem for which the data were collected.

Each of the five points that define an adequate program needs to be clearly specified and adhered to or the program and its generated data become ineffective and/or excessive.

Factors Influencing Water-Level Fluctuations

Ground-water levels are almost constantly fluctuating. These fluctuations are caused by short-term and seasonal variations in such factors as: recharge from precipitation (fig. 1), evapotranspiration (fig. 2), natural discharge to streams (fig. 3) and springs, and withdrawals from wells (fig. 3). These short-term and seasonal variations are in turn superimposed on long-term fluctuations caused by alternating series of wet and dry years. Representative long-term fluctuations of water levels in various areas of Indiana are shown on figure 4. Water-level fluctuations are also influenced by changes in atmospheric pressure (fig. 5), stream stage (fig. 3) and water levels in lakes. Earthtides can also influence ground-water levels, as can earthquakes (fig. 6). All the above factors can and sometimes do act simultaneously (fig. 7) to influence the water levels observed in wells. As can be seen from the list of factors above, fluctuations of water levels indicate changes in amount of water stored within an aquifer, hydrostatic head, and hydraulic gradient.

In heavily pumped areas, changes in water levels caused by pumping are superimposed on the short-term (seasonal) and long-term fluctuations that



Modified from Indiana Department of Conservation, 1956

Figure 1.-- Water-level response in well Adams 3 to a 0.75 inch rainfall, May 6 and 7, 1948.

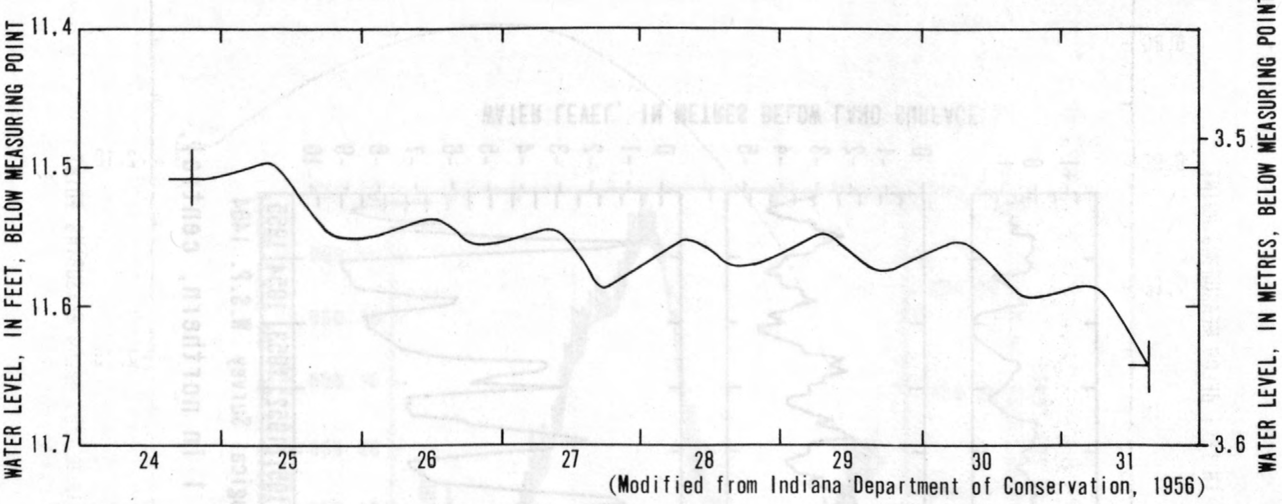


Figure 2.-- Water-level response to evapotranspiration in well Montgomery 4, near Waveland, Indiana, July 1948.

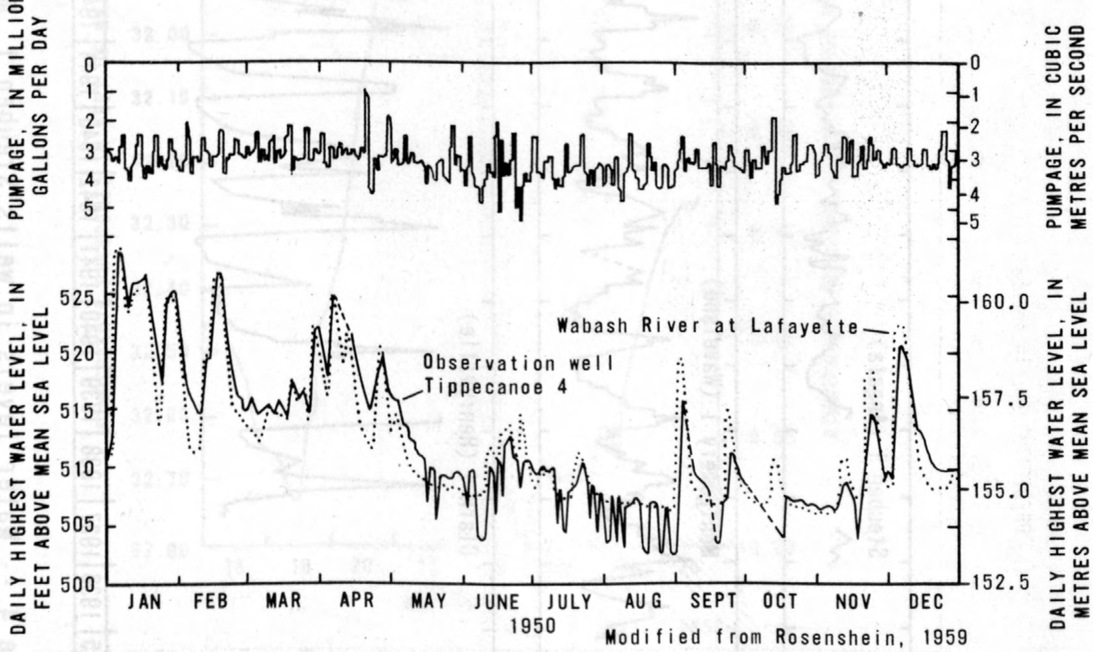


Figure 3.-- Water-level fluctuations recorded in observation well Tippecanoe 4 illustrate how ground-water levels respond to changes in stage of nearby stream and to local ground-water withdrawals.

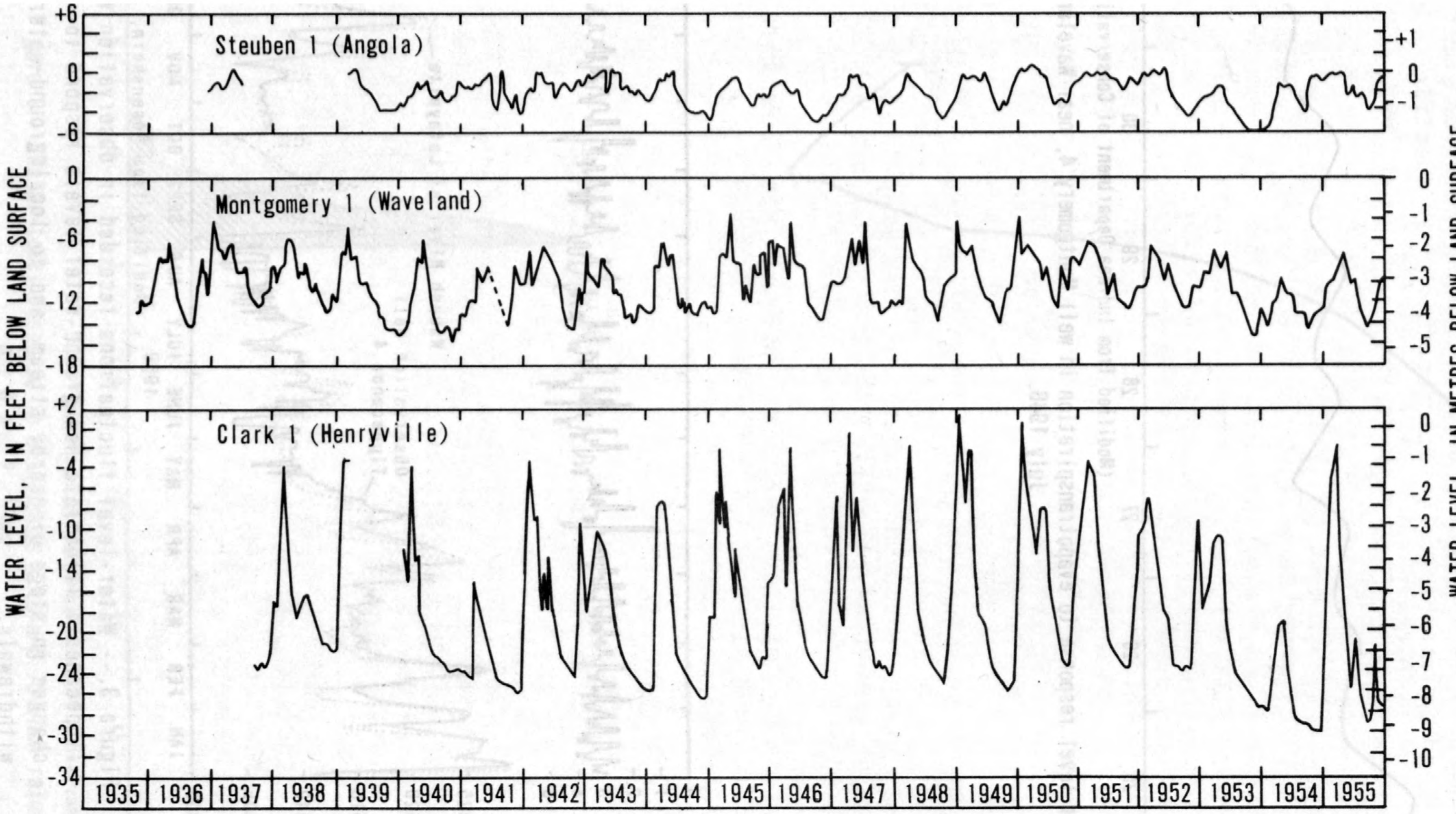


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Figure 4.-- Water levels in wells Steuben 1, Montgomery 1, and Clark 1 in northern, central, and southern Indiana, 1935 through 1955.

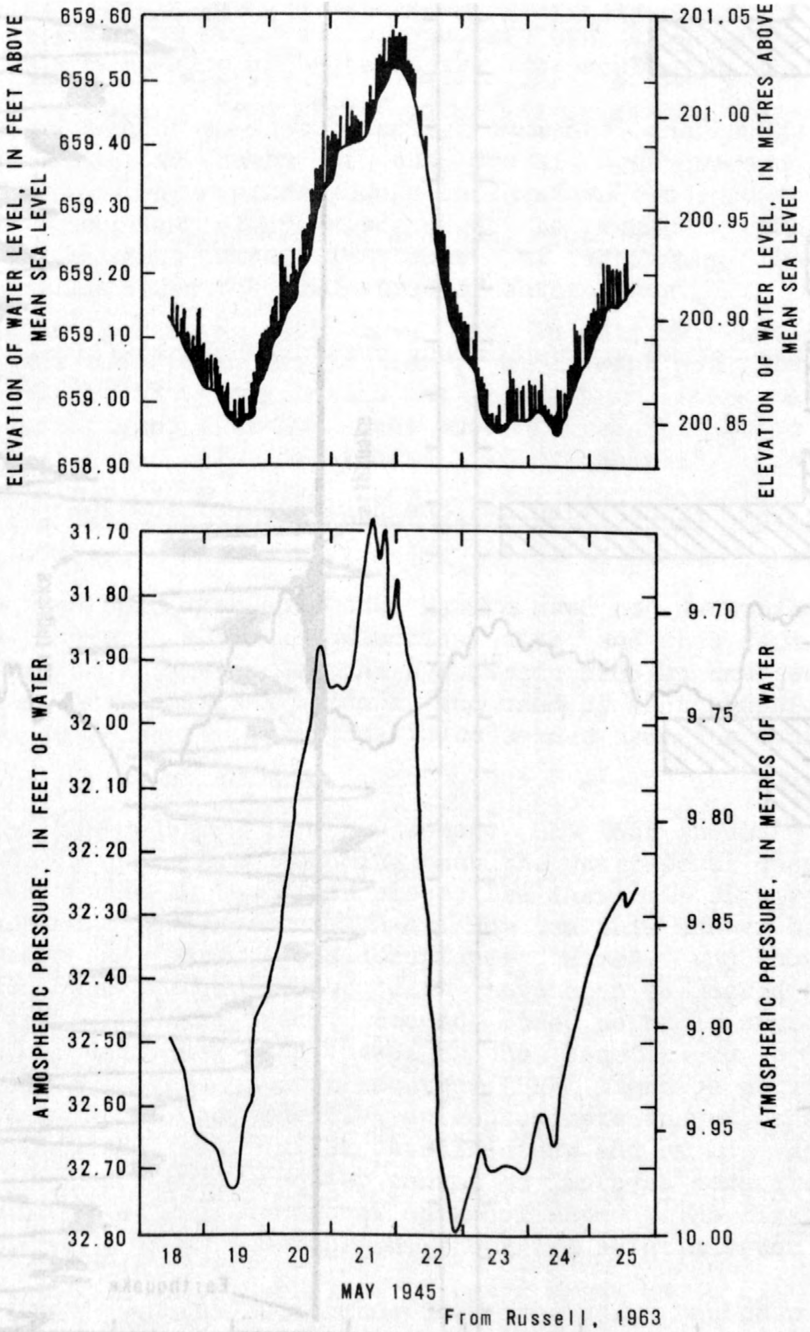


Figure 5.-- Water-level fluctuations in observation well caused by atmospheric-pressure changes.

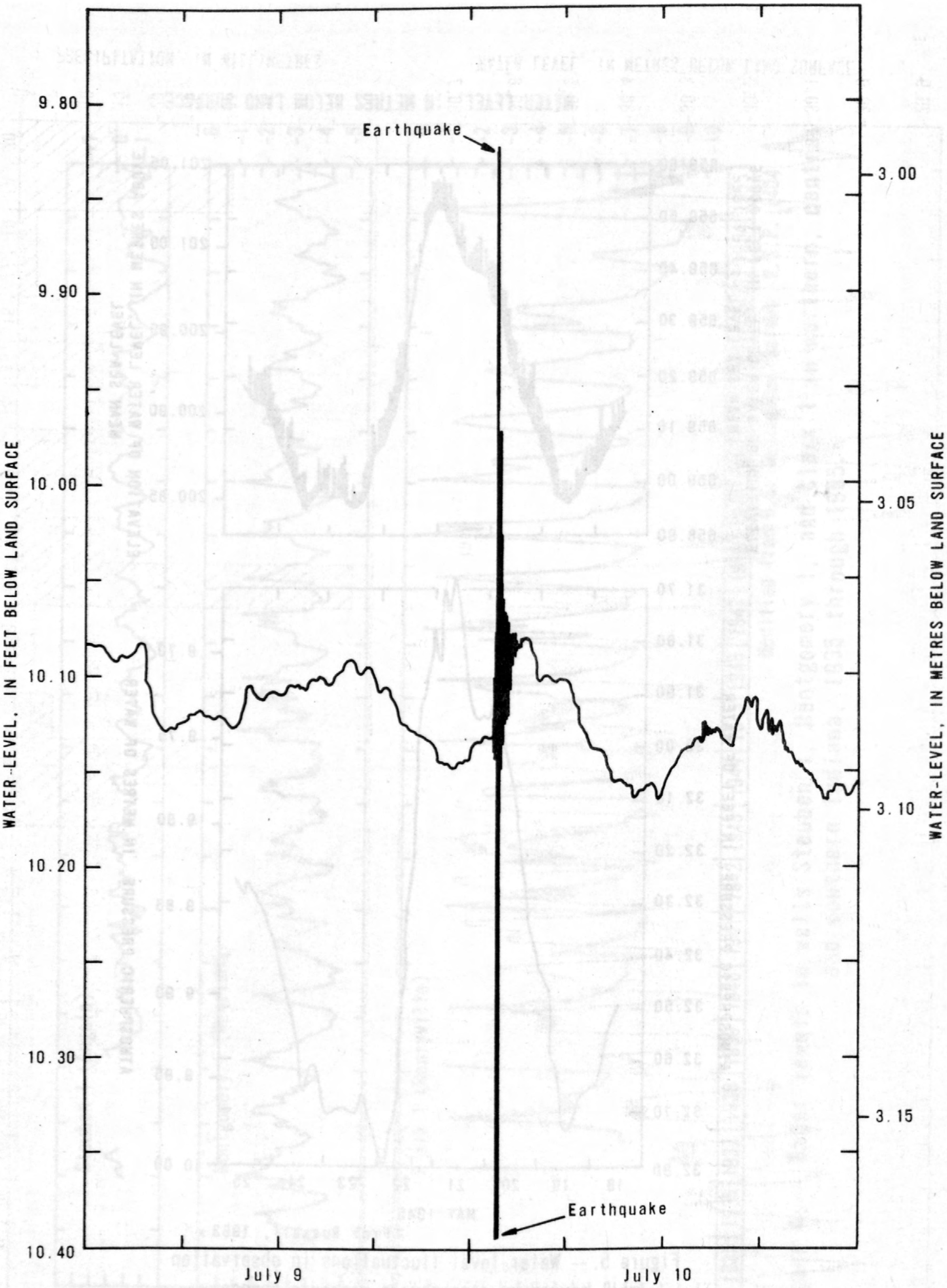


Figure 6.-- Water-level fluctuations in well Pulaski 6 caused by an earthquake, Richter Magnitude 7.9, in Southeastern Alaska, July 10, 1958.

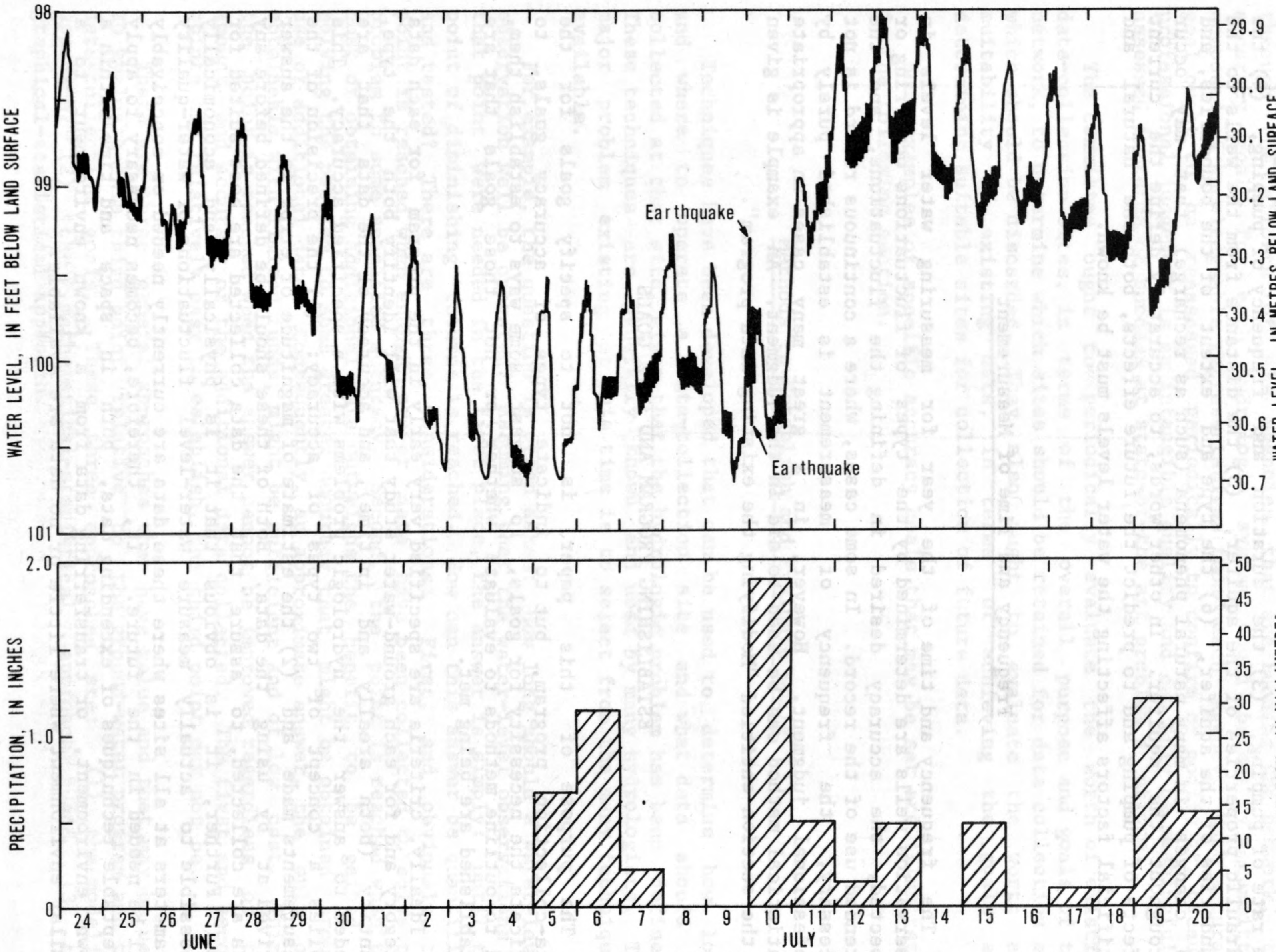


Figure 7.-- Water-level fluctuations in well Marion 31 caused by precipitation, evapotranspiration, local pumping, and an earthquake, 1958.

are caused by natural phenomena. (See fig. 3.) The amplitude of fluctuation (rate of water-level change) observed in a pumped area depends on: (1) the distance from the observation well to the pumping well, (2) the rate of pumping, (3) the duration and frequency of pumping, (4) the hydraulic properties of the aquifer, (5) the distance from the wells to the boundaries of the aquifer, (6) the type and extent of the boundaries, and (7) changes in many natural phenomena (such as recharge) that may occur throughout the aquifer. In other words, to accurately define the current effects of pumping and to predict the future effects, both the natural and artificial factors affecting the water levels must be known.

Frequency and Time of Measurement

The frequency and time of the year for measuring water levels in observation wells are determined by the types of fluctuations occurring or expected, the accuracy desired in defining the fluctuations, and the intended use of the record. In some cases, where a continuous record is not necessary, the frequency of measurement is established purely by professional judgment. However, in a great many cases an appropriate statistical method can be used to aid in the judgment. An example is given in the section entitled "Modifying the existing data program".

ESTABLISHING PROGRAM AND DATA GOALS

The purpose of this paper is not to specify goals for the data-collection program, but to indicate types of accuracy goals, to indicate the necessity for goals, to suggest some ways to establish them, and to outline methods to evaluate whether or not those goals that are established are being met.

Ideally, criteria are specified very early in the program for each data category and for each ground-water study that will identify both the type, quantity (both areally and in time), and accuracy of the data that are needed to answer the hydrologic problems with a specified accuracy. This implies a concept of two types of accuracy: (1) the precision of the measurements made and (2) the estimate of magnitude of error in the answer arrived at by using the data. Both of these should be defined before any data are collected, to assure that the data collected are best suited for use. Further, it is obvious that it is physically and economically impossible to actually measure water-level fluctuations or water-quality parameters at all sites where these data are currently needed or conceivably will be needed in the future. It, therefore, becomes necessary to apply acceptable techniques of extending data, both in space and time within a known environment, or transferring data from a known environment to a similar environment where little or no data are available.

Definition of accuracy goals is still controversial at present. However, because it is believed that the Indiana program will be improved through the efforts of all agencies that are funding the network, the accuracy goals for each hydrologic system could be set by a committee composed of knowledgeable representatives from each agency. Each accuracy goal ought to be reassessed periodically to confirm or modify it, because professional judgement is an intangible quality and can only be meaningfully assessed in terms of success at state-of-the art problem solutions.

The committee ought to periodically evaluate the worth of existing data-collection sites, in terms of the overall purpose and goals of the network, to determine which sites should be retained for data collection and which should be discarded. They also ought to evaluate the worth and suitability of existing data, in terms of achieving the goals and determining suitable sites for collection of future data.

Some examples of specific accuracy goals that may be set are illustrated in the following section.

Methods to Establish and Evaluate Goals

Techniques have been developed that can be used to determine how long and where to operate a data-collection site and what data should be collected at that site, given that the hydrologic problem has been defined. These techniques are generally known and used by many hydrologists. The major problem existing at this time is to select from the many techniques available.

For example, the question is often asked: How long should a water-level observation well be operated? Assuming that the water-level observations at that point were needed in the first place, the answer is simply: until the point of diminishing returns is reached. How can this answer be quantified and tested? There are three considerations: First, and obviously, the point is reached when enough proper data have been collected to solve the problem to some specified accuracy. Second, the point is reached when the cost of obtaining additional data outweighs the benefit to be gained by solving the problem to some greater accuracy that might be obtained through use of additional data. Consequently, an approximate answer, the only one obtainable with limited funds, might be sufficient and of low cost. Third, the point is reached when the answer cannot be improved regardless of the amount and accuracy of the additional data collected. The first and second points are relatively easy to establish, the third point may not be.

There are three general approaches that have value and that may be used to evaluate this third point relative to the ground-water program and the data-collection goals. These three approaches are: (1) the modeling approach, (2) the mathematical-statistical approach, and (3) the graphical-statistical approach.

The modeling approach may be used in all areas, whether affected or unaffected by pumping. It is probably the most effective of the methods; however, its greatest utility to date has been primarily in areas where pumping is a major influence on water-level fluctuations. The approach may involve the use of either numerical or electrical-analog models of the system.

The accuracy goal suggested for the modeling approach is to be able to predict water-level departures from any known starting water level to within 20 percent, using all available influencing parameters as input to the model. Fluctuations predicted are checked by measuring water-level changes in suitable observation wells. As long as the accuracy goal is being met, data from long-term trend well(s) will be sufficient as the pumping continues to confirm the water-level predictions made by the model.

An example of this technique is included in the section "Examples and results of selected methods".

The mathematical-statistical approach can be used very effectively in analyzing an unpumped aquifer system. It also has utility for analyzing pumping effects in uncomplicated or low-stress aquifer systems.

The mathematical-statistical approach includes use of either correlation or regression techniques.

Correlation techniques may be used effectively to relate ground-water levels observed in a well to observed precipitation records, stream stages, water levels in other wells, and other observations. The technique may be used then to either extrapolate or transfer data in time and space.

The analysis will produce an equation relating observed water levels in a particular well to the other observed parameter; an indication of the closeness of fit for an estimated water level at the same or at another site lacking observations also can be obtained. In other words, by computing statistical accuracies using standard techniques, the accuracy goals set for the estimation of water levels throughout the system of nonobservation sites may be evaluated.

How good must the correlation be? The accuracy goal suggested for all correlation techniques applied to the ungaged sites in the natural-flow system is to be able to compute water-level changes there from any known water level within 20 percent of the mean-annual fluctuation that would be observed if measurements were actually made at the site. Thus, eventually, if a precipitation record, stream hydrograph, or other appropriate data are available, a usable well hydrograph can be compiled at many sites without benefit of additional water-level measurements.

When this accuracy goal is met for any observation well, water levels are continued at that site through correlation. Time between measurements can be lengthened, and the recorder can be moved to another well; the new record is continued there until the accuracy goal is met and this process can be continued indefinitely. This allows broader estimated records, both in time and space, that will aid in reaching one of the stated purposes of

the network--ability to estimate water levels at any place and time within specified accuracies and at significant savings in dollars.

A multiple-regression technique, as described by Benson (1962) and used by Marie and Swisshelm (1970) in their evaluation of the Indiana surface-water data program, could be used to evaluate the possibility of predicting ground-water levels at any place within Indiana. This technique consists of relating each of a group of water-level characteristics to hydraulic, geologic, and climatic characteristics through equations developed using the technique. The equation has the form:

$$Y = aG^{b_1}H^{b_2}T^{b_3}$$

where Y is a statistical water-level characteristic; G, H, and T are geologic, hydraulic or climatic characteristics; a is the regression constant; and b , b , and b are exponents obtained by regression. A computer program is used to calculate the regression equation, the standard error of estimate, and the significance of each hydraulic parameter.

The following ground-water level characteristics are suggested for this regression evaluation:

1. Mean annual water level (M)
2. Mean annual low water level (ML)
3. Annual low water levels with 5-year, 10-year, and 20-year recurrence intervals (L_5), (L_{10}), and (L_{20})
4. Mean annual high water level (H)
5. Annual high water level with 5-year, 10-year, and 20-year recurrence intervals (H_5), (H_{10}), and (H_{20})
6. Mean annual water-level fluctuation (MF)
7. Annual water-level fluctuation with 5-year, 10-year, and 20-year recurrence intervals (F_5), (F_{10}), and (F_{20}).

The following hydraulic, geologic, and climatic characteristics are suggested for this evaluation:

1. Transmissivity of aquifer at site of observation well (T).
2. Storage coefficient of aquifer at site of observation well (S).
3. Depth to top of aquifer (D).
4. Depth to mean annual water level (DM).
5. Distance to discharge stream of flow system (r).
6. Hydraulic head measured from mean annual water level to mean stream stage of discharge stream at point r (HH).
7. Average annual discharge of stream (Q).
8. Drainage area of control basin at point used to determine annual discharge (A).
9. Geologic index (Marie and Swisshelm, 1970) for control basin (G).
10. Soil index (Marie and Swisshelm, 1970) for control basin (SI).
11. Average annual precipitation at observation well site (P).
12. Maximum positive single-year departure from normal precipitation observed at nearest National Weather Service station (PP).

13. Maximum negative single-year departure from normal precipitation observed at nearest station (NP).
14. Average difference between average October through December precipitation and February through April precipitation at closest station (AOD) and (AFA).

The regression equations developed through this analysis will define the water-level characteristics and indicate how good the definition is, based on the hydraulic, geologic, and climatic characteristics. This technique may allow estimation of the water-level characteristics throughout the State. Accuracy goals for water-level characteristics are suggested as the accuracy equivalent of an arbitrary number of years (about 10) of record.

The graphical-statistical approach is a simpler graphical method that may be used to analyze most of the techniques suggested under the mathematical-statistical section discussed above. In this method, median and quartile deviations and standard error are used as measures of central tendency and dispersion instead of the mean and standard deviation as in the mathematical approach. Accuracy goals are established by judgment, as in the mathematical approach.

In summary, when water-level fluctuations can be predicted within the accuracy goals set for a particular site, enough data have been collected at that site.

APPRAISING THE EXISTING PROGRAM

The question now becomes: Are we measuring all the significant factors affecting water-level fluctuations and water quality in the proper combinations at each well to accurately assess their influence on the ground-water system? Further, and more importantly, are we able to provide reasonable answers to hydrologic questions or to reasonably predict changes in the ground-water system based on the information provided by the basic-data program? If not, what factors do we need to be measuring, where should they be measured, with what accuracies should they be measured, and with what priorities should they be measured? The answers to these questions, which cannot properly be given here, will define the type, number, and distribution of all data-collection sites needed at any time. In short, once the purpose, objectives, and accuracy goals of the program have been clearly defined, a network can be designed to produce the desired data in a timely fashion.

The first steps in appraising the existing observation-well network are to evaluate and classify each active well in the network. These steps accomplish two purposes: (1) they assure that each well is suitable for yielding the desired data, and (2) that the data being collected are needed. The evaluation of each well includes a written purpose for that well, an estimate of the length and frequency of water-level and water-quality records to satisfy the purpose, all supporting data needed to

assess the information, the required accuracy of all data, and an evaluation of each site to insure that it is capable of providing the needed data. A file is compiled detailing well-construction information and all geohydrologic data available. Guidelines are established that specify the minimum requirements for this file data.

Second, the types and amounts of data now being collected are defined. A preliminary tabulation of selected types of data has been made for all wells used to date in the Indiana network. These tabulations include:

1. Well -- by name and number
2. Classification
3. Status
4. Period of record available
5. Type of record -- recorder and/or hand taped
6. Geohydrologic data available
7. Well-construction data available
8. Geophysical logs available
9. Pumping-test data available
10. Summary of water-level fluctuations observed
11. Quality-of-water data available

Third, all collection sites and available data are evaluated to assure that they are in accord with the stated objectives of the program.

Results of Preliminary Tabulation and Evaluation

Some preliminary results of the network tabulations indicate the amount and type of data collected thus far. There are seven classifications for observation wells used for the Indiana network: (1) key unaffected - KU, (2) key affected - KA, (3) special purpose - SP, (4) project unaffected - PU, (5) project affected - PA, (6) support unaffected - SU, (7) support affected - SA. In addition to these, all wells are classified as to whether they are completed in rock or in glacial deposits.

Ground-water data have been collected from 478 different wells that have made up the network from 1935 to January 1974 (fig. 19). At least one well has been established in each of the 92 counties in the State. More than half the counties have had four or more active wells, while Marion County has had the most: 32 wells. One of the original wells (Marion 3), established in 1935, is still in use.

Water-level data have been collected on a periodic basis from 468 of the 478 wells; however, some water-level data are available from all the wells. The length of periodic water-level record available for individual wells ranges from 1 year to more than 38 years, with an average length of record of more than 9 years. About 200 of the wells have been equipped with continuous water-level recorders (fig. 20). Some continuous-recorder records exceed 35 years in length. A total of over 4,500 years of

water-level data are available. Of this total, over 1,250 years of continuous-recorder record are available, with the bulk of the rest of the data as either weekly or semi-monthly measurements.

The observation wells in operation in Indiana as of January 1974 are shown in figure 21 and listed in table 1.

Quality-of-water data are available for 25 of the 478 wells used to date. Most of these data consist of one or two parameters measured only once. No samples have been collected from wells in the network for water-quality determinations since 1969. Geologic logs and well-construction data are available for 82 of the wells. Yield and drawdown data are available for 27 wells. Currently (January 1974), 54 wells in the network are being measured. Thirty two of these are equipped with continuous water-level recorders; the remaining 22 are scheduled to be measured by hand twice each year. Quality-of-water data are available for 22 of these wells, geologic logs and construction data for 41 wells, and pumping data for 19 wells.

Statistics have been generated outlining both the maximum annual water-level fluctuations and the maximum fluctuations of record for all wells.

Maximum annual fluctuations

1. Range: 4 to 63 ft (1 to 19 m)
2. Mean: 8 ft (2 m)
3. Bimodal at 5 and 12 ft (2 and 4 m)
4. Ten percentile: 5 ft (2 m)
5. Sixty-six percentile: 11.5 ft (3.5 m)
6. Ninety percentile: 17 ft (5 m)

Maximum fluctuation of record

1. Range: 5 to 80 ft (2 to 24 m)
2. Mean: 11 ft (3 m)
3. Mode: 7 ft (2 m)
4. Ten percentile: 10 ft (3 m)
5. Sixty-six percentile: 13.5 ft (4 m)
6. Ninety percentile: 28 ft (8 m)

To date, aside from water-level records of various types (ranging from daily high or low readings from recorders to semi-annual measurements) published for selected wells, no data compilations are available. No in-depth study has been made of either the network or the data produced by the network.

Examples and Results of Selected Methods

Water-level data from Pulaski 6 observation well were selected to be used as the primary input for a number of selected techniques to be illustrated here. Pulaski 6 was chosen because the two indices of extreme fluctuation for this well were larger than these same indices for two-thirds of all other wells measured; and if acceptable correlations can be made using Pulaski 6, then it is suggested that wells having less extreme fluctuations can be correlated with similar or better results. These indices are:

	All wells	Pulaski 6
Maximum annual fluctuation:	11.50 ft (3.5 m)	12.79 ft (3.9 m)
Maximum fluctuation of record:	13.50 ft (4.1 m)	14.48 ft (4.4 m)

Pulaski 6 is located in southwestern Pulaski County just north of Francesville. The well is 663 ft (202 m) deep and is completed as an open hole in limestone from 11 to 663 ft (3 to 202 m). A recorder was installed in July 1956 and is still in operation. Figure 8 shows the general relationships between water levels in Pulaski 6, precipitation at Winamac, and flow in Big Monon Creek near Francesville.

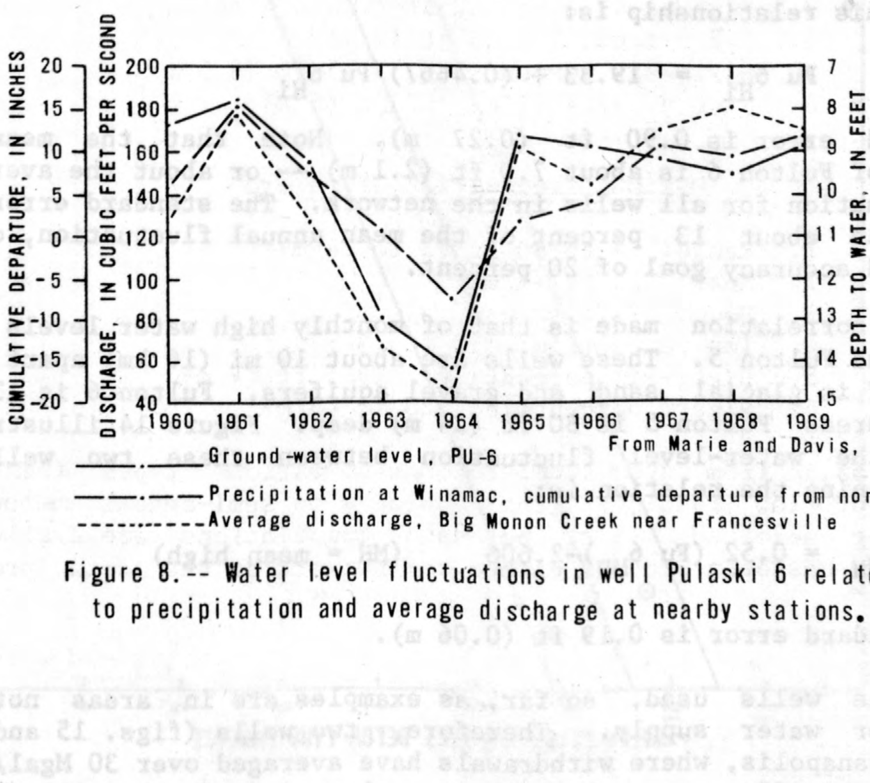


Figure 8.-- Water level fluctuations in well Pulaski 6 related to precipitation and average discharge at nearby stations.

Water-level data from Pulaski 6 were correlated with departures from normal precipitation at the National Weather Service's Winamac station, which is about 16 mi (26 km) northeast of Pulaski 6. Figures 9 through 12 illustrate the results of four correlations of these data. The graphical method of curve fitting is used, but it is a practical and expedient way of defining the line for this report. The best results were obtained using 2-year intervals to compute departures from normal (figs. 9 and 10). The equation for the annual high water level is:

ANNUAL HIGH = 6.32 + (-0.206) departure from normal.

The standard error is 0.76 ft (0.23 m). The equation for the annual low is:

ANNUAL LOW = 15.67 + (-0.147) departure from normal.

The standard error is 0.83 ft (0.25 m).

Figures 11 and 12 show the relations of annual high and low water levels to cumulative departure of precipitation from normal. Figures 9-12 indicate that the annual high and low water levels can be estimated within a range of about 1 foot, which is suitable for most uses.

Three different combinations of well-to-well correlations are used to illustrate this technique. First, Pulaski 6 is correlated with Fulton 6. Fulton 6, about 25 mi (40 km) east of Pulaski 6, is 133 ft (40 m) deep and completed in a glacial sand and gravel aquifer -- Pulaski 6 is 663 ft (202 m) deep in limestone. Figure 13 illustrates the relation of monthly high water levels between these two wells during 1962-66. The equation expressing this relationship is:

$$\text{Fu } 6_{Hi} = 19.33 + (0.4667) \text{ Pu } 6_{Hi}$$

The standard error is 0.90 ft (0.27 m). Note that the mean annual fluctuation of Fulton 6 is about 7.0 ft (2.1 m) -- or about the average mean annual fluctuation for all wells in the network. The standard error of 0.90 ft (0.27 m) is about 13 percent of the mean annual fluctuation, or within the suggested accuracy goal of 20 percent.

The next correlation made is that of monthly high water levels in wells Fulton 6 and Fulton 5. These wells are about 10 mi (16 km) apart and both are completed in glacial sand and gravel aquifers. Fulton 6 is 133 ft (40 m) deep, whereas Fulton 5 is 80 ft (24 m) deep. Figure 14 illustrates the relation of the water-level fluctuation between these two wells. The equation defining the relation is:

$$\text{Fu } 5_{MH} = 0.52\ (\text{Fu } 6_{MH}) - 2.606 \qquad (\text{MH = mean high})$$

Here the standard error is 0.19 ft (0.06 m).

All three wells used, so far, as examples are in areas not highly developed for water supply. Therefore, two wells (figs. 15 and 16) in downtown Indianapolis, where withdrawals have averaged over 30 Mgal/d (114 + m^3/d) for about 30 years, have been selected to further illustrate the

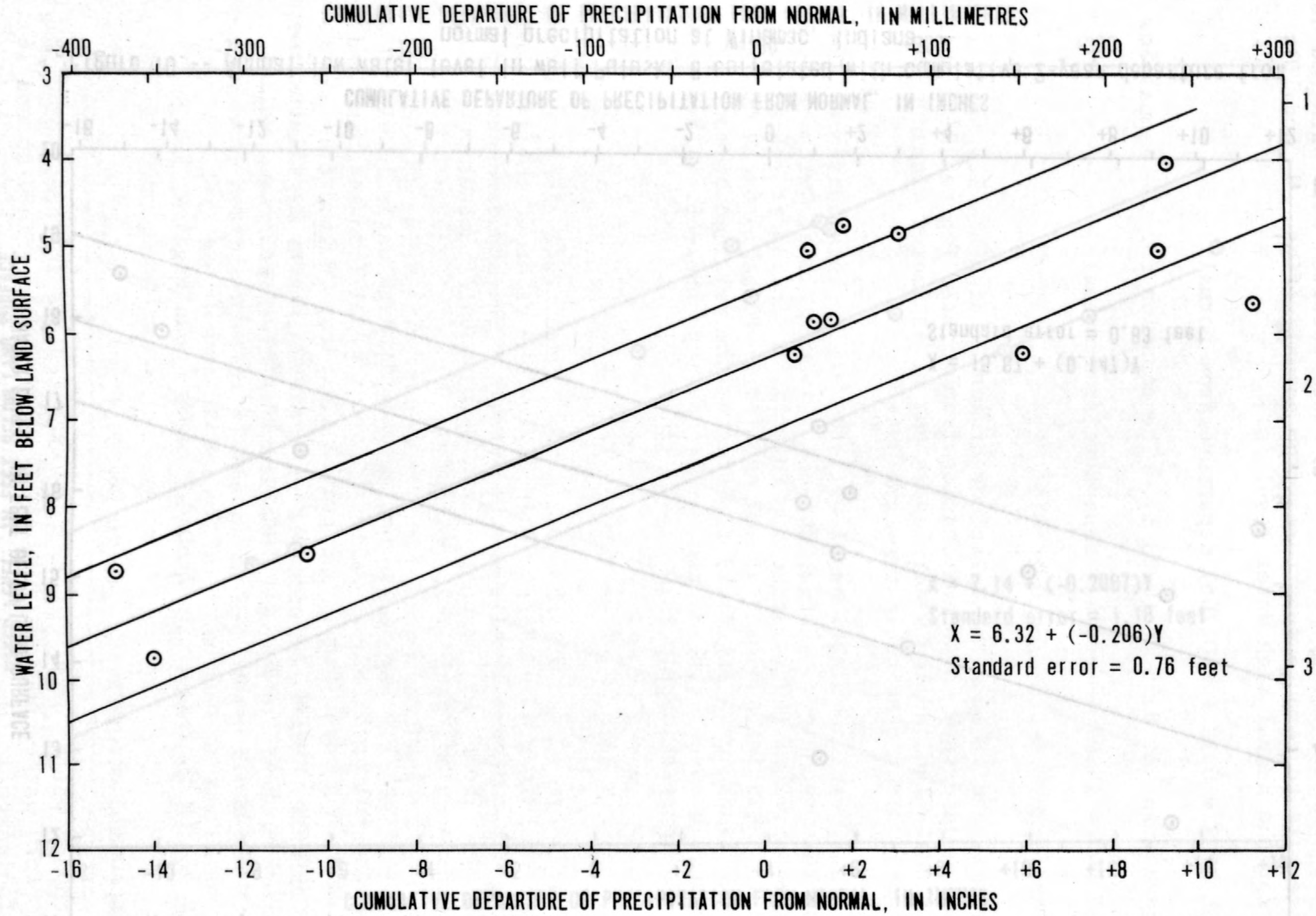


Figure 9.-- Annual high water level in well Pulaski 6 correlated with cumulative 2-year departure from normal precipitation at Winamac, Indiana

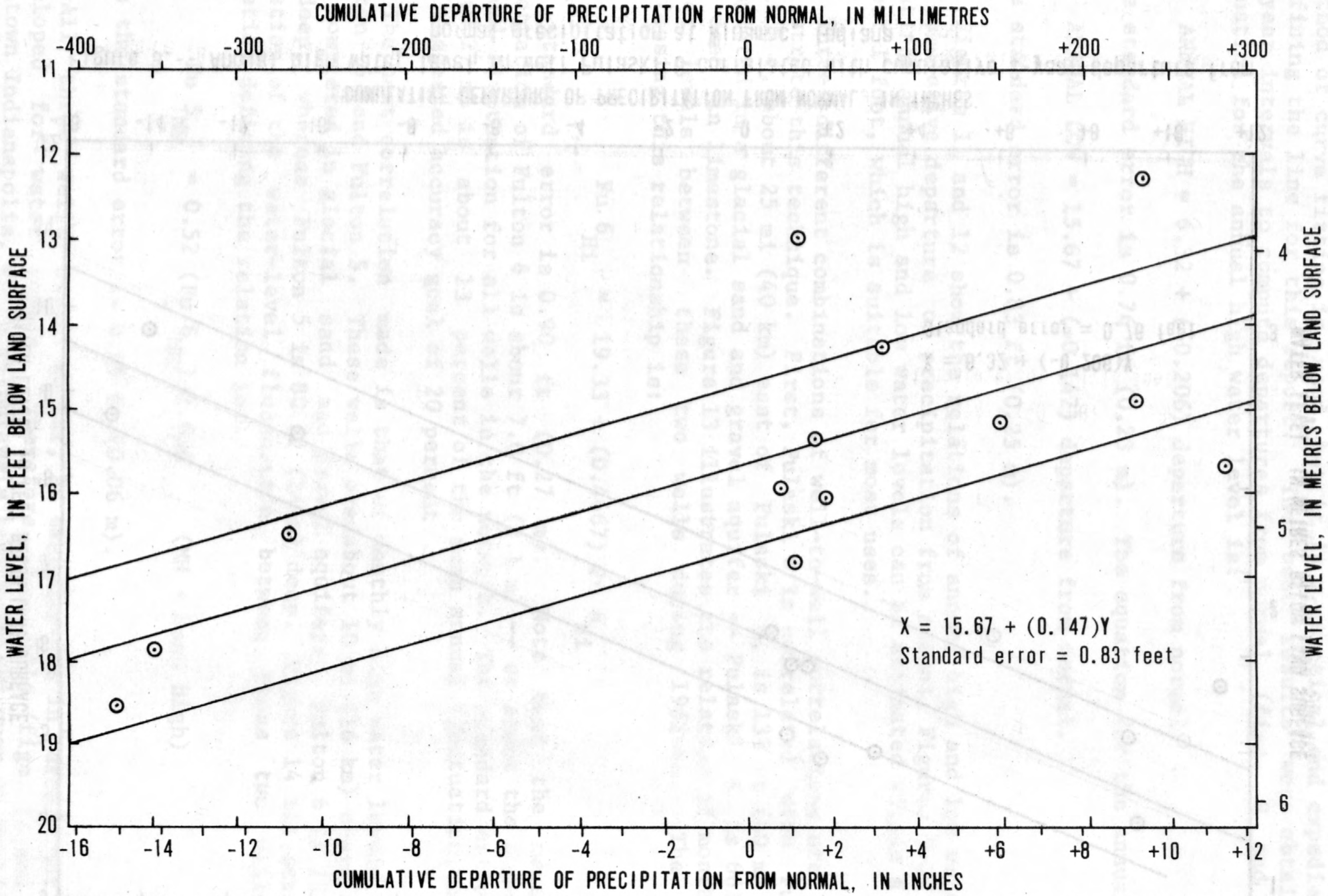


Figure 10.-- Annual low water level in well Pulaski 6 correlated with cumulative 2-year departure from normal precipitation at Winamac, Indiana

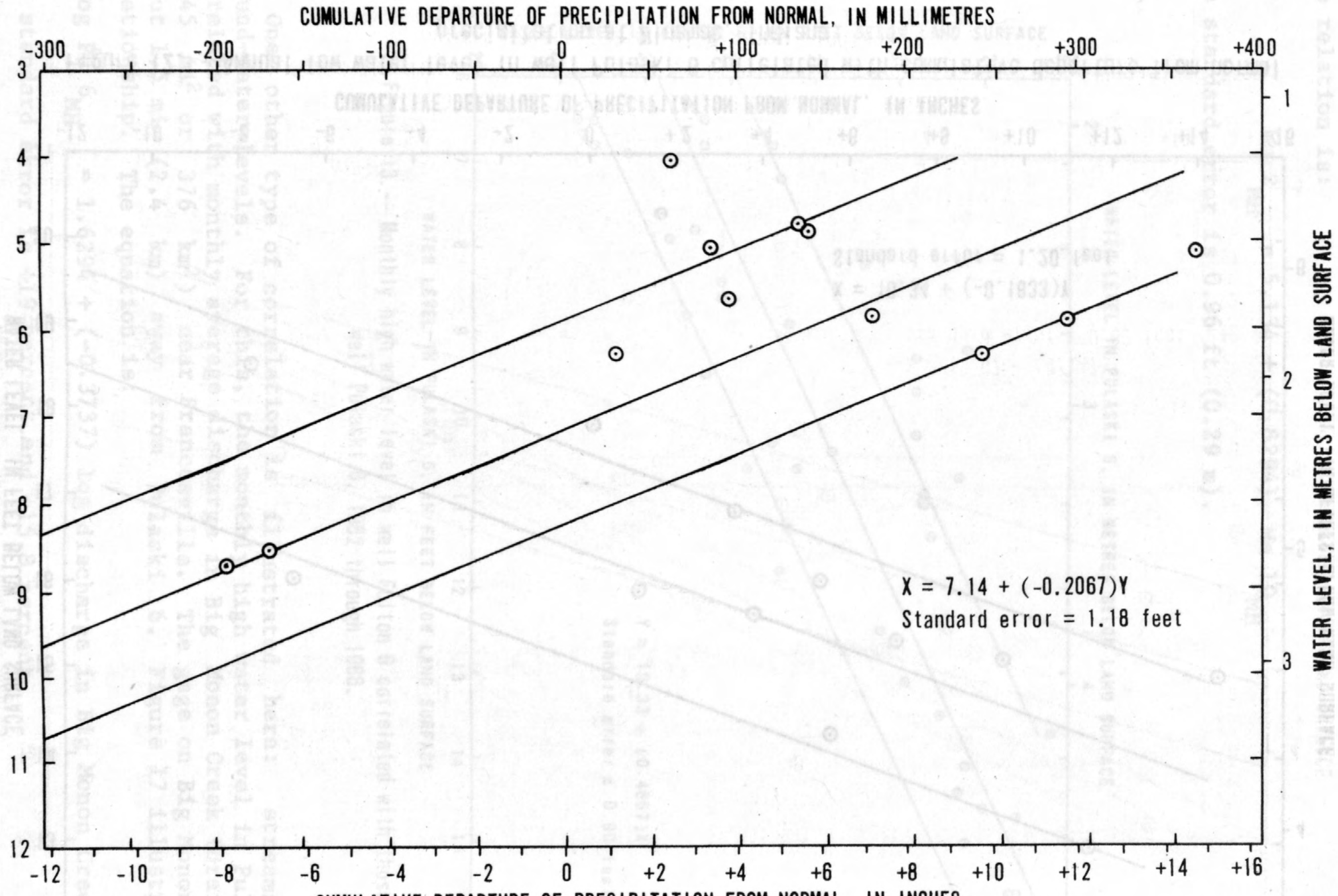


Figure 11.-- Annual high water level in well Pulaski 6 correlated with cumulative departure from normal precipitation at Winamac, Indiana

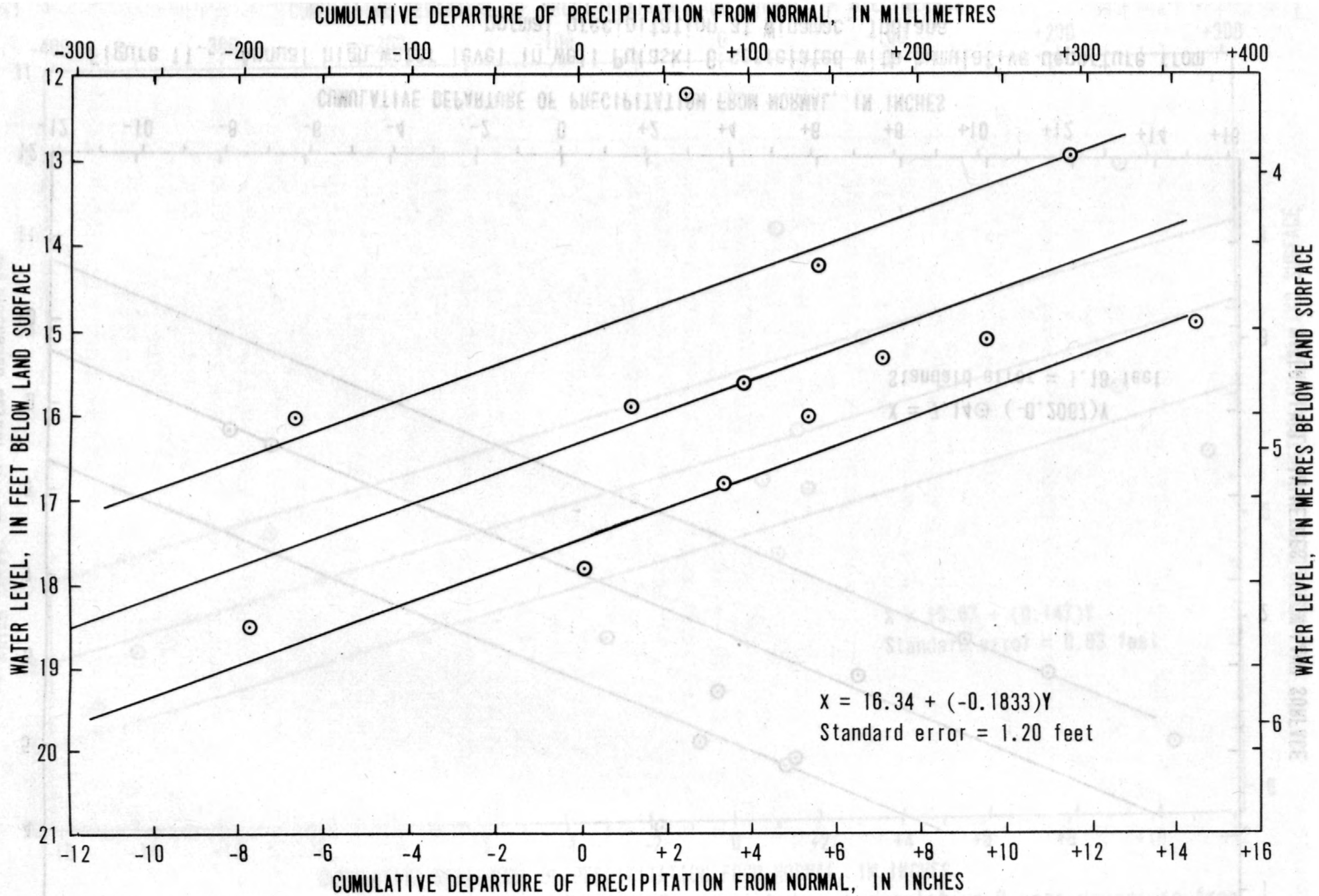


Figure 12.-- Annual low water level in well Pulaski 6 correlated with cumulative departure from normal precipitation at Winamac, Indiana

technique. Figure 16 shows the relation between monthly high water levels in Marion 2 and Marion 10. These wells are 0.25 m (0.4 km) apart. Marion 2 is 90 ft (27 m) deep and completed in a sand and gravel aquifer; Marion 10 is 304 ft (93 m) deep and completed in limestone. The equation expressing the relation is:

$$\text{Ma } 2_{MH} = 5.134 + (0.8294) \text{ Ma } 10_{MH}$$

The standard error is 0.96 ft (0.29 m).

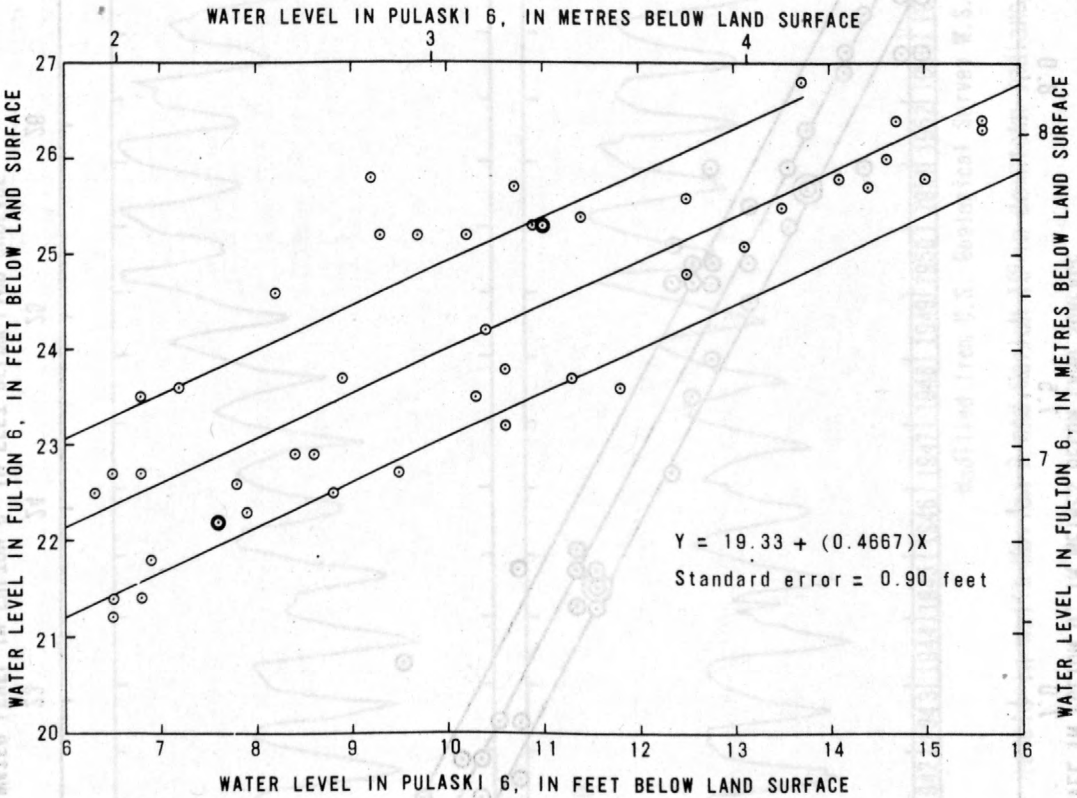


Figure 13.-- Monthly high water level in well Fulton 6 correlated with those in well Pulaski 6, 1962 through 1966.

One other type of correlation is illustrated here: streamflow with ground-water levels. For this, the monthly high water level in Pulaski 6 is correlated with monthly average discharge in Big Monon Creek (drainage area = 145 mi^2 or 376 km^2) near Francesville. The gage on Big Monon Creek is about 1.5 mi (2.4 km) away from Pulaski 6. Figure 17 illustrates this relationship. The equation is:

$$\log \text{Pu } 6_{MH} = 1.6294 + (-0.3737) \log \text{discharge in Big Monon Creek } (ft^3/s)$$

The standard error is +19 percent and −15.8 percent.

Figure 18 shows an example of the modeling technique applied to water-level definition in an area of pumping. This figure shows both

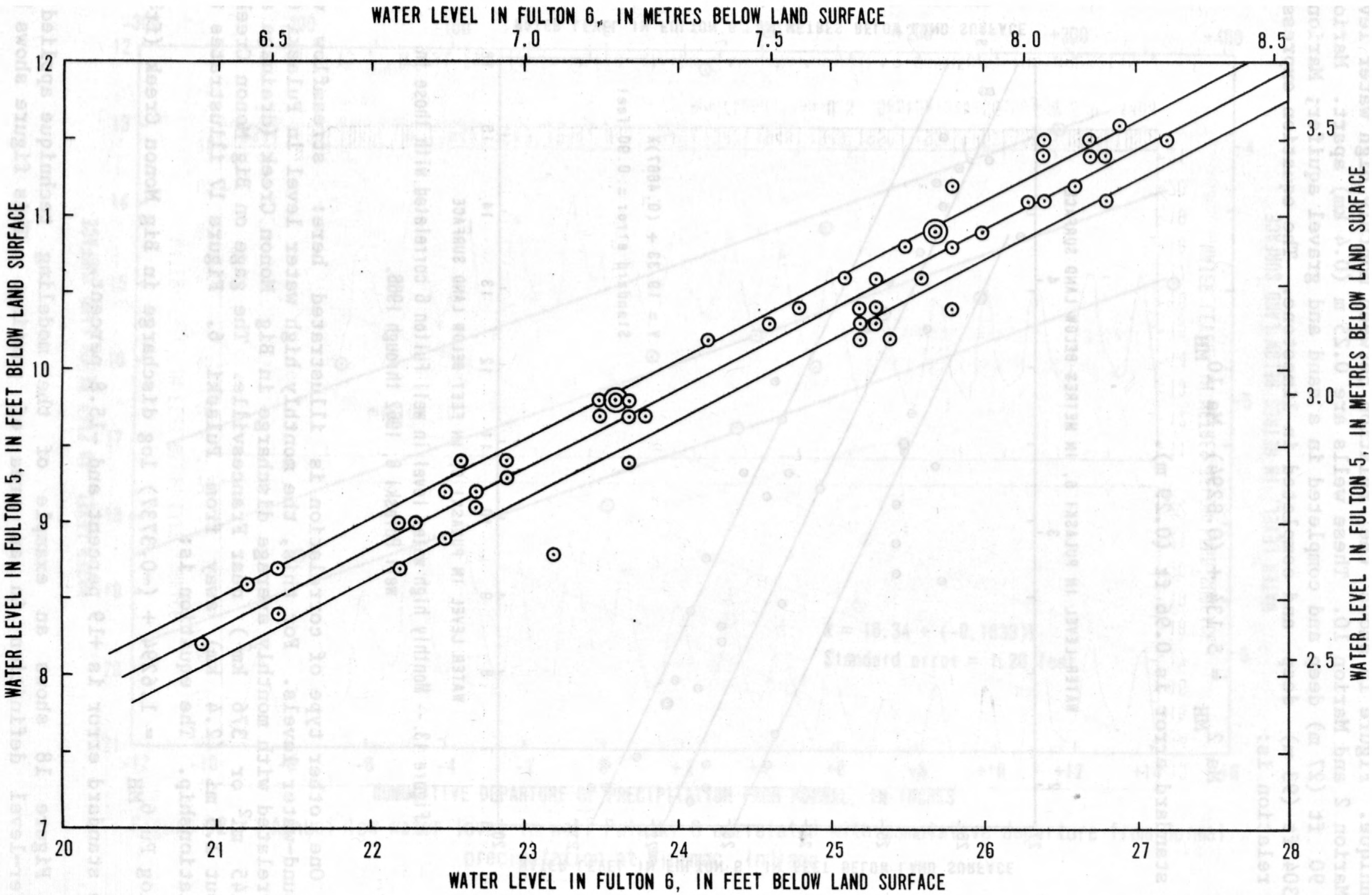
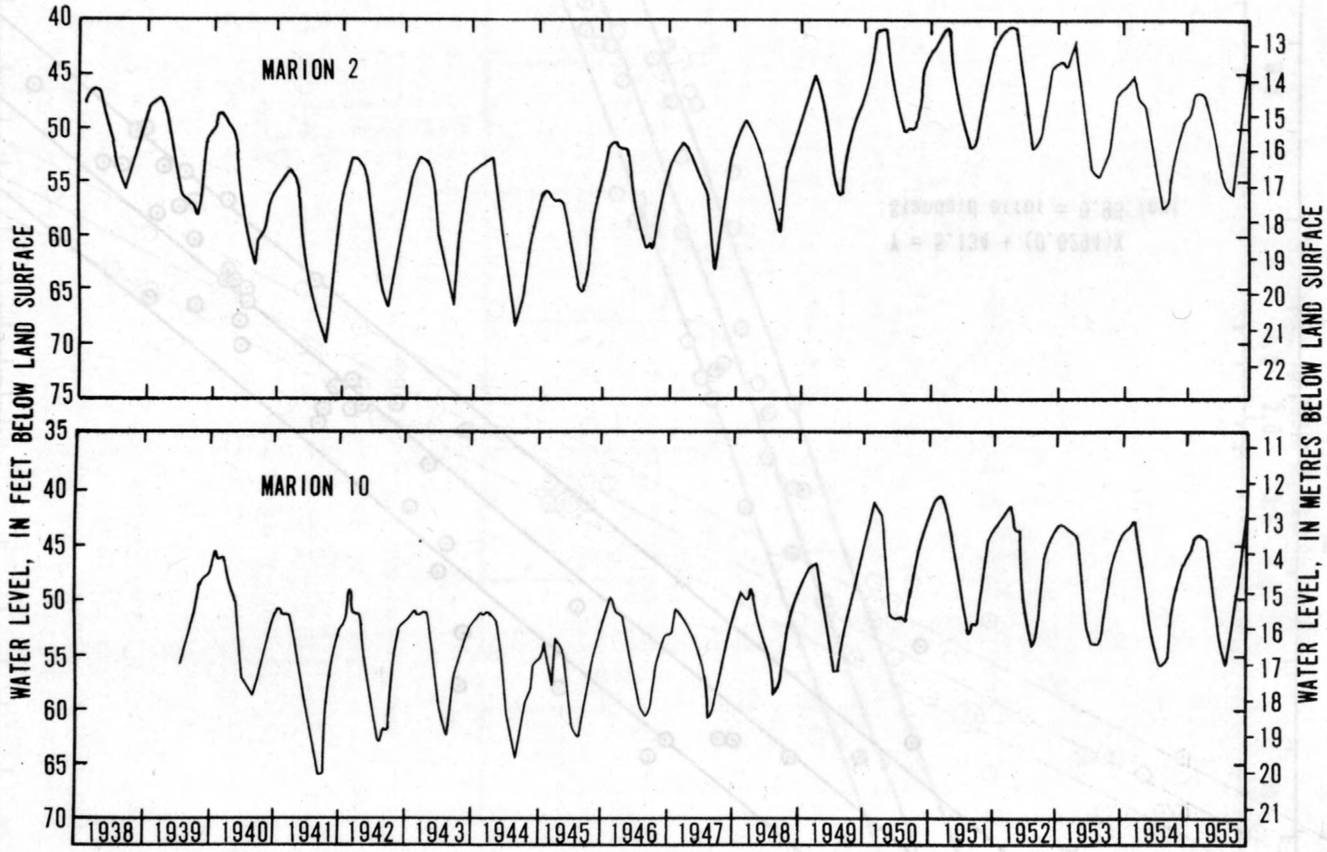


Figure 14.-- Monthly high water levels in well Fulton 5 correlated with those in well Fulton 6, 1962 through 1966.



Modified from U.S. Geological Survey W.S.P. 1404

Figure 15.-- Water levels in wells Marion 2 and Marion 10 in downtown Indianapolis.

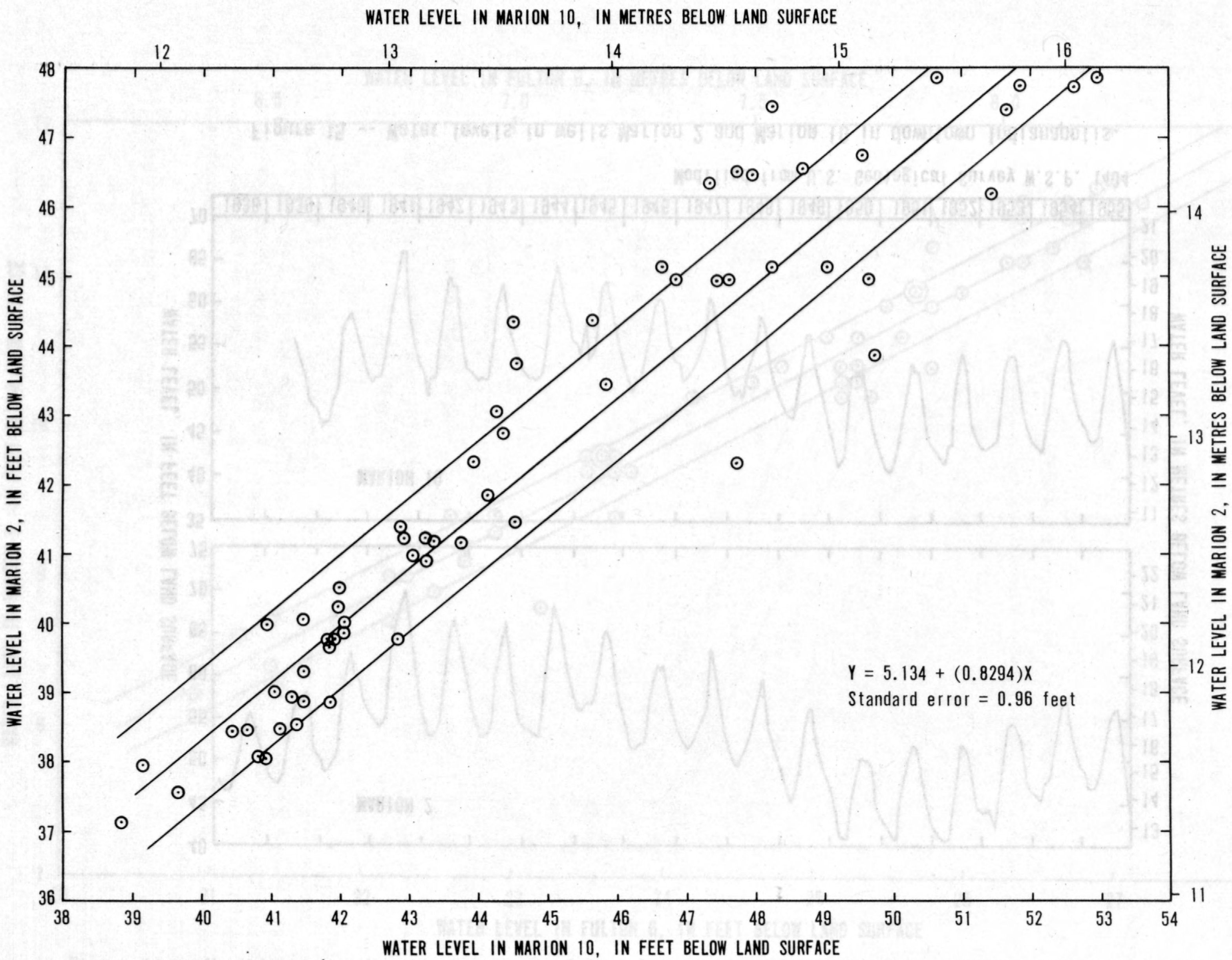


Figure 16.-- Monthly high water levels in well Marion 2 correlated with those in well Marion 10, 1958 through 1962

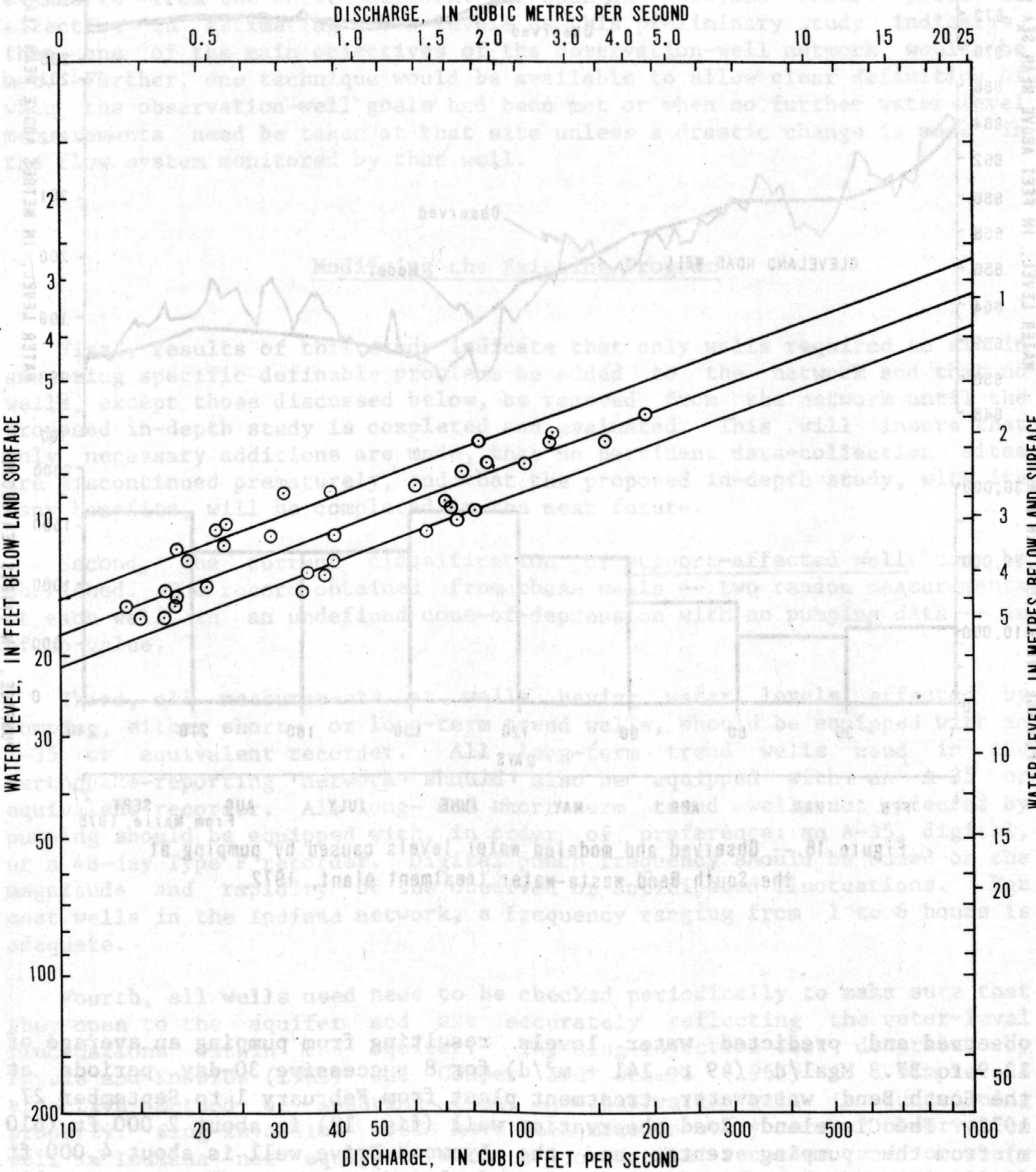


Figure 17.-- Monthly high water level in well Pulaski 6 correlated with average monthly discharge at Big Monon Creek near Francesville, Indiana.

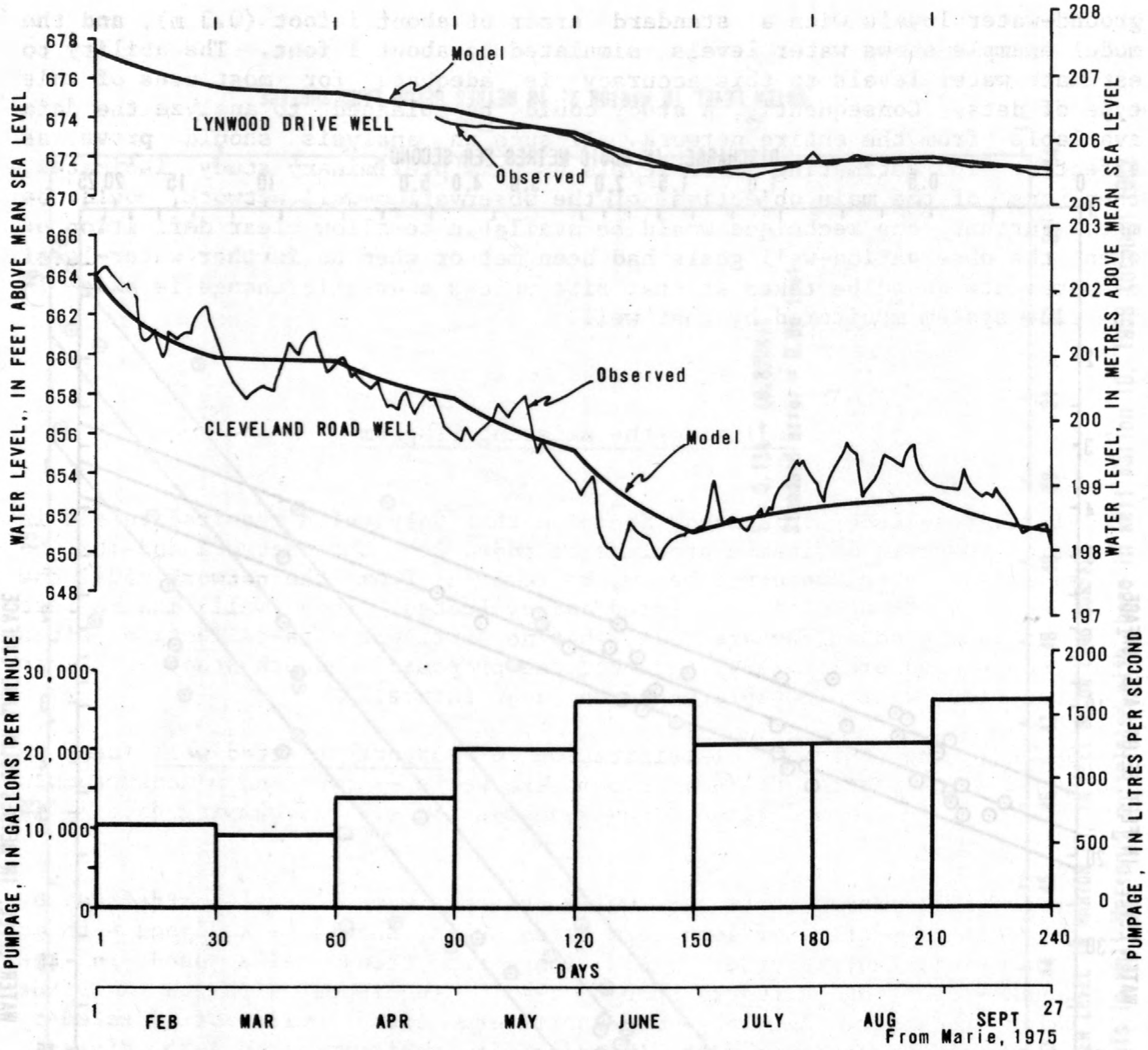


Figure 18.-- Observed and modeled water levels caused by pumping at the South Bend waste-water treatment plant, 1972.

observed and predicted water levels resulting from pumping an average of 12.9 to 37.3 Mgal/d (49 to 141 + m^3/d) for 8 successive 30-day periods at the South Bend wastewater treatment plant from February 1 to September 27, 1972. The Cleveland Road observation well (fig. 18) is about 2,000 ft (610 m) from the pumping center and the Lynwood Drive well is about 4,000 ft (1,220 m) away. The digital-model-simulated water levels are generally within 1 foot (0.3 m) of those observed in the wells at the end of each successive 30-day simulation period and within the suggested accuracy goal of 20 percent at the end of the 240-day pumping period.

All examples of correlation techniques shown above allow estimation of ground-water levels with a standard error of about 1 foot (0.3 m), and the model example shows water levels simulated to about 1 foot. The ability to estimate water levels to this accuracy is adequate for most uses of this type of data. Consequently, a study could be planned to analyze the data available from the entire network. If such an analysis should prove as effective in estimating water levels as this preliminary study indicates, then one of the main objectives of the observation-well network would be met. Further, one technique would be available to allow clear definition of when the observation-well goals had been met or when no further water-level measurements need be taken at that site unless a drastic change is made in the flow system monitored by that well.

Modifying the Existing Program

First, results of this study indicate that only wells required to aid in answering specific definable problems be added to the network and that no wells, except those discussed below, be removed from the network until the proposed in-depth study is completed and evaluated. This will insure that only necessary additions are made, that no pertinent data-collection sites are discontinued prematurely, and that the proposed in-depth study, with its many benefits, will be completed in the near future.

Second, the current classification of support-affected well can be abolished. The record obtained from these wells -- two random measurements at each well in an undefined cone-of-depression with no pumping data -- is of no value.

Third, all measurements at wells having water levels affected by pumping, either short- or long-term trend wells, should be equipped with an A-35 or equivalent recorder. All long-term trend wells used in the earthquake-reporting network should also be equipped with an A-35 or equivalent recorder. All long- and short-term trend wells not affected by pumping should be equipped with, in order of preference: an A-35, digital, or a 48-day Type F recorder. Digital punch frequency should be based on the magnitude and rapidity of the observed or anticipated fluctuations. For most wells in the Indiana network, a frequency ranging from 1 to 6 hours is adequate.

Fourth, all wells used need to be checked periodically to make sure that they open to the aquifer and are accurately reflecting the water-level fluctuations within the aquifer. The slug-injection test described by Ferris and Knowles (1963) and Cooper and others (1967) is a simple and effective method of assuring that an observation well is functioning properly. Slug-injection tests have been made on every current observation well in Indiana not equipped with a continuous recorder and on every recorder well in which a change in the characteristics of the water-level fluctuations were noted. Slug-injection tests need to be made on all wells on a periodic basis and the results compared with those of earlier tests.

Results of this preliminary evaluation indicate that tests be made on non-recorder wells every 2 to 3 years and on recorder-equipped wells every 5 to 6 years or whenever the characteristics of the record change. Slug tests were last made during 1968 and 1969; consequently, it is indicated that a periodic schedule for testing be defined and adopted and that tests be made on each well in the near future.

In Indiana, the wells classified as "support affected" and "support unaffected" are designed to provide data on the annual low and high water levels. As a routine practice, these measurements were taken twice-a-year -- on or about October 1st and then again on or about April 1st. During the early stages of this study, a simple frequency distribution of low and high water levels was made using all available continuous-recorder data. It was found that the annual low water level occurred significantly more frequently between December 30th and January 3rd than during any other period of the year, and that the annual high water level occurred more frequently during the period of April 15th to 19th. Further, the low water level generally had an average duration of less than 20 days, while the high had an average duration of less than 35 days. With these facts in hand, the time of measurement of the semi-annual wells was changed to correspond to these periods.

THE PROPOSED DATA SYSTEM

With the purpose and objectives of the program defined, a system can be devised that will specify the procedures for acquiring, processing, storing, and recalling data that will meet the objectives. It is clearly beyond the scope of this paper to define this system in detail; however, a brief outline of such a system is included to give a point-of-departure for future study.

First, each well that has been used, is being used, or is proposed for the future will be classified within a system designed to provide all desired data. Seven well classifications are proposed for this system:

1) Long-term trend,
2) Support long-term trend,
3) Short-term unaffected,
4) Short-term affected,
5) Project,
6) Current-purpose, and
7) Currently unneeded wells.

The proposed classification system is designed to provide a maximum amount of easily accessible and necessary information that can be collected in a timely manner and at an acceptable cost. Each well is classified to meet a specific purpose, and the data collected from each well, or in conjunction with it, will meet specified requirements. The purpose for each classification is given in detail below, but only an outline of the other requirements is given, because their exact definition should properly be a product of the proposed future study.

The first requirement is the demonstrable need for data from a particular well. The second requirement is that the water-level and water-quality data obtained from the well accurately define these parameters within the aquifer at that point. The last requirement is that the water-level fluctuations and water-quality changes observed must be both qualitatively and quantitatively attributable to specific influencing factors. If these individual well requirements are not met, the data have the possibility of being superfluous and/or inaccurate.

1. Long-term trend wells. Wells in this category provide a record of long-term natural and artificial changes in water levels and in the quality of ground water throughout the State. Data collection at, or in conjunction with these wells, is continued indefinitely at the frequency specified. Multiple-well installations may be necessary at some sites to adequately define the hydrology in a multi-aquifer or complex flow system. Water-level records collected from wells affected by pumping are correlated with the record from at least one unaffected well, so that an estimate of the influence of the artificial stress can be made. All water-level data collected from affected wells in this and the following categories are augmented by pumping information. These data will be sufficient, in conjunction with aquifer information, to allow acceptable prediction of future water-level response. Quality-of-water analyses are made of water from each well included in this category. Frequency of water analysis will be established, based on estimated or determined rates of change in the water quality.

2. Support long-term trend wells. These wells provide extensive areal coverage of the same types of data collected by category 1, but at a much reduced cost. Data collections from wells in this category are to be continued indefinitely. However, water levels are measured periodically, for example, twice-a-year, and water levels in all wells that are to be measured at the same frequency are measured at essentially the same time. Quality-of-water analyses are made of samples collected from all wells in this category. The frequency of sampling is determined as in category 1.

3. Short-term unaffected wells. Wells in this category provide a record of natural water-level fluctuations and periodic water-quality data in hydrologically complex areas. These data are used to supplement and provide more areal coverage through correlation with data collected from wells in categories 1 and 2. Wells in this category are maintained until adequate correlation (defined later) with a long-term trend well(s) is accomplished. When correlation is accomplished, the recorders are moved to another site so that the desired statewide areal distribution can be fulfilled. Once areal coverage is accomplished, this category will be discontinued. Until then, a specified number of wells (about 25) are operated.

4. Short-term affected wells. Wells in the category aid in defining the shape and extent of the cones of depression in areas where large quantities of water are being withdrawn. These data can be used to adequately estimate the effects of using the water resource both now and in the future. These wells may be either equipped with continuous recorders or measured by the wetted-tape method, depending upon local conditions and

expected water-level responses. These water-level measurements are continued in areas where large cones exist and are expected to enlarge, until water-level response to the pumping and, thus, the hydrologic effects of water use can be adequately predicted by one of the modeling techniques. Quality-of-water data for these wells may be desirable in certain situations.

5. Project wells. Wells in this category are installed and maintained to provide data to satisfy specific project goals or objectives. For example, seven wells were installed to provide data that will allow development of a model to predict dewatering effects at a construction site in northern Indiana. The project was designed to provide the National Park Service with specific information. Once this information is provided, the wells can be discontinued unless they can be legitimately reclassified. Wells in this category may be equipped with continuous recorders or measured by the wetted-tape method, and water-quality data may be obtained depending upon data requirements.

6. Current-purpose wells. Wells in this category are installed and maintained in situations where real-time data must be collected to meet a specified objective; for example, if an aquifer test is planned. These wells would be discontinued when their purpose is satisfied unless they can be legitimately reclassified. An example of reclassification would be if a well field requiring monitoring were developed in the area of the pumping test.

7. Currently unneeded wells. This category assures that a file is maintained for each well that has been in the network. Wells are moved from an active status into this category when (1) the well has accomplished the purpose for which it was established or (2) it is determined, through the periodic well evaluation, that the well has become unsuitable for a data-collection site and consequently, should be discontinued.

All wells proposed as additions to the network will also be classified within this system. Provision will be made to collect all supplemental data needed for complete evaluation when the well is included in the network.

In addition to the system necessary to collect the data, methods and requirements are specified for processing, storing, and recovering the data. Data should be stored in both its original form, so that any currently unforeseen use may be made of the data at any time in the future, and in a processed form, so that current informational needs are satisfied.

The first type of data storage is fairly straightforward, the second is considerably less so. Again, instead of specifying current informational needs in detail, a general outline is given for a point of departure for future consideration. Three general types of informational displays will provide for most of the current needs: (1) data plots can be made of each type of data collected at each well--for example, water-level hydrographs; (2) maps can be compiled for each type of data--for example, water-level change maps for specific time periods; and (3) statistical summaries of the various data collected can be compiled for each well--for example, summaries of water-level data.

Statistical summaries of water-level data would include:

1. mean annual water level,
2. mean annual high-water level,
3. mean annual low-water level,
4. mean annual water-level fluctuation,
5. average annual duration of high-water level,
6. average annual duration of low-water level, and
7. average annual duration within X feet of mean annual water level, where X equals one-third of the mean annual water-level fluctuation.

Data processing to produce informational displays of these three types provides good insight into two different facets of the data program. First, through the integrated display of information available from individual sites and from the total network, the hydrologist can have good insight into how the ground-water system is functioning in specific areas or throughout the State. Second, a display of this type will allow preliminary evaluations of the network to be made at almost any time by indicating needs for additional data at certain sites and indicating other sites where enough data have been collected. Both facets are provided for in the processing procedures of all ground-water data programs.

SUMMARY AND CONCLUSIONS

The ground-water data program, which was established in Indiana in 1935, has utilized 478 different wells located in every county in the State. More than half the counties have had more than four active wells, and one county has had 32. Water-level data have been collected on a periodic basis from 468 of these wells. The length of record available for individual wells ranges from 1 year to more than 38 years, with an average length of record of more than 9 years.

To date, aside from water-level records of various types published for selected wells and the hydrographs kept in the files of the U.S. Geological Survey (copies of the hydrographs are furnished to the cooperator), no data compilations are available. No in-depth study has been made of either the network or the data produced by it. In fact, very little has been done to evaluate the data or to insure that it is preserved in a readily accessable and usable form. No attempt has been made to establish accuracy goals for the data or to suggest when enough record has been collected from an individual well. The main purpose of this study was to address these problems by making a preliminary evaluation of the network and to suggest methods suitable for a future in-depth study.

To properly evaluate a ground-water data program, five major points need to be considered. The first four are: (1) the purpose of the program is clearly defined, (2) the goals are specified and feasible, (3) the methods used to attain these goals are adequate, and (4) the cost of the program does not exceed the benefits. The fifth is: if the program is to operate

effectively, it must be in a continual state of reevaluation and modification to insure that the data gathered are those needed to solve both present and future water problems. This report deals with all but the fourth point -- cost versus benefits.

The purpose of a ground-water data program is to provide the basic data as needed to solve any water-related problem within the accuracy required and at an acceptable cost. More precisely, and strictly from a hydrologic point of view, the program would provide the data needed to determine: (1) the amount and quality of ground water in storage at any time and place, (2) the rate at which the amount or the quality of the water is changing, (3) why this change is taking place, and, possibly most importantly, (4) to allow prediction of these changes within specified accuracy limits at any place, any time, and due to any cause.

The observation-well classification system described requires that a clear statement of the purpose for each well and companion data-collection site be made at the time each is included in the program. The system also specifies that accuracy requirements will be set for each type of data to be collected. In addition to this data-collection system, an outline of methods and requirements is given for processing, storing, and recovering the data as a point of departure for the future study.

An approach is outlined and examples given that may be used to evaluate the entire network to determine how long and where to operate a data-collection site and what data should be collected at that site. The approach consists of three methods: (1) modeling, (2) mathematical-statistical, and (3) graphical-statistical techniques. All examples shown of statistical techniques allow estimation of ground-water levels with a standard error of about 1 foot; the example of modeling shows water levels simulated to within 1 foot. The ability to estimate water levels to this accuracy are adequate for most uses. Consequently, it is indicated that an in-depth study of the type outlined be undertaken in the near future to evaluate the network.

Further, it is specifically indicated that no changes except those outlined above be made in the current program until the future study is completed and evaluated.

In summary, the preliminary findings of this study indicate the distinct possibility of accomplishing the stated purpose of a data program within the framework outlined above, in time and at a reasonable cost -- a prospect that does not seem attainable with the present program.

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NETWORK DATA

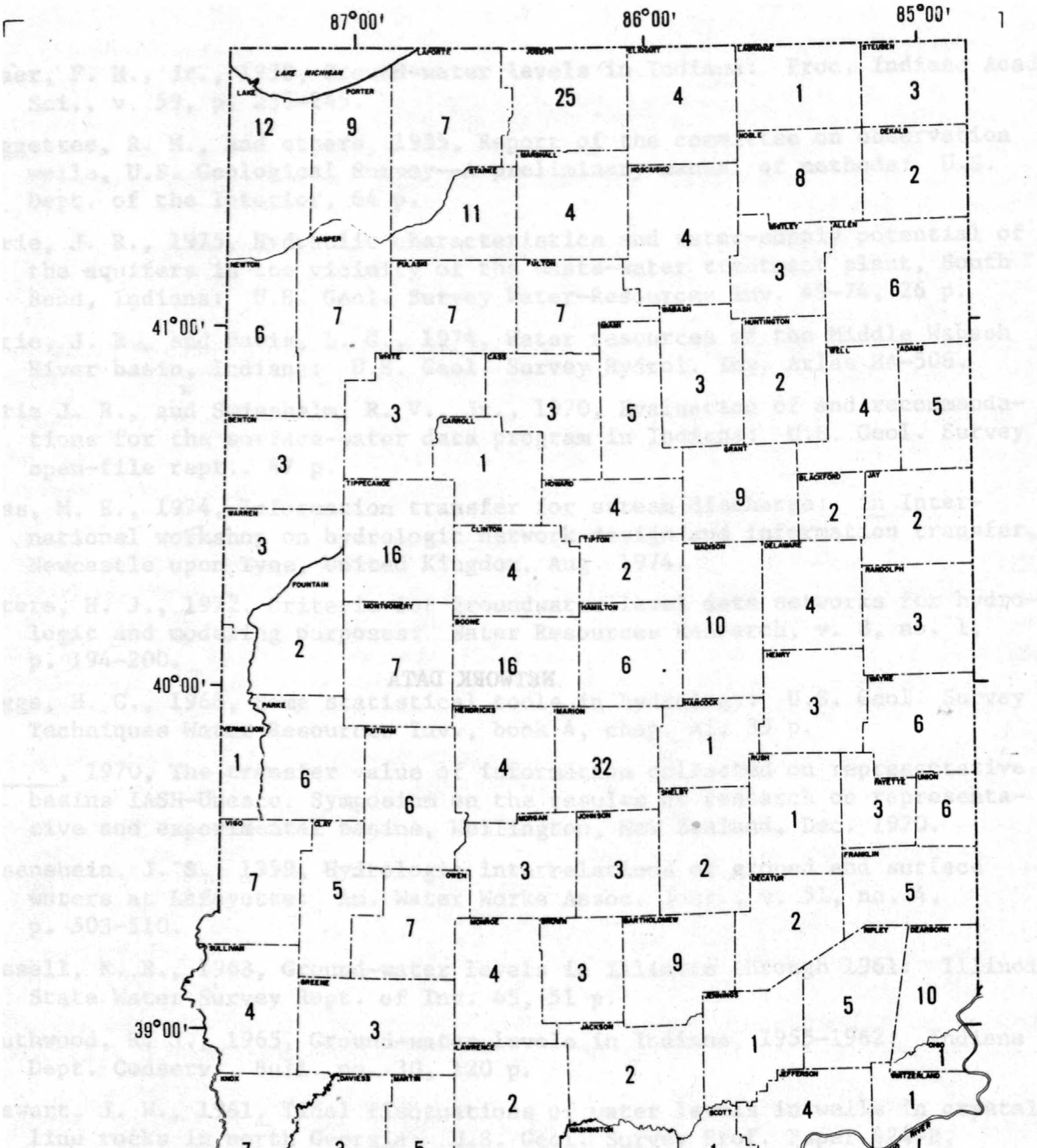

Figure 19.—Distribution by county of the 478 wells used in the network from 1935 through 1973.

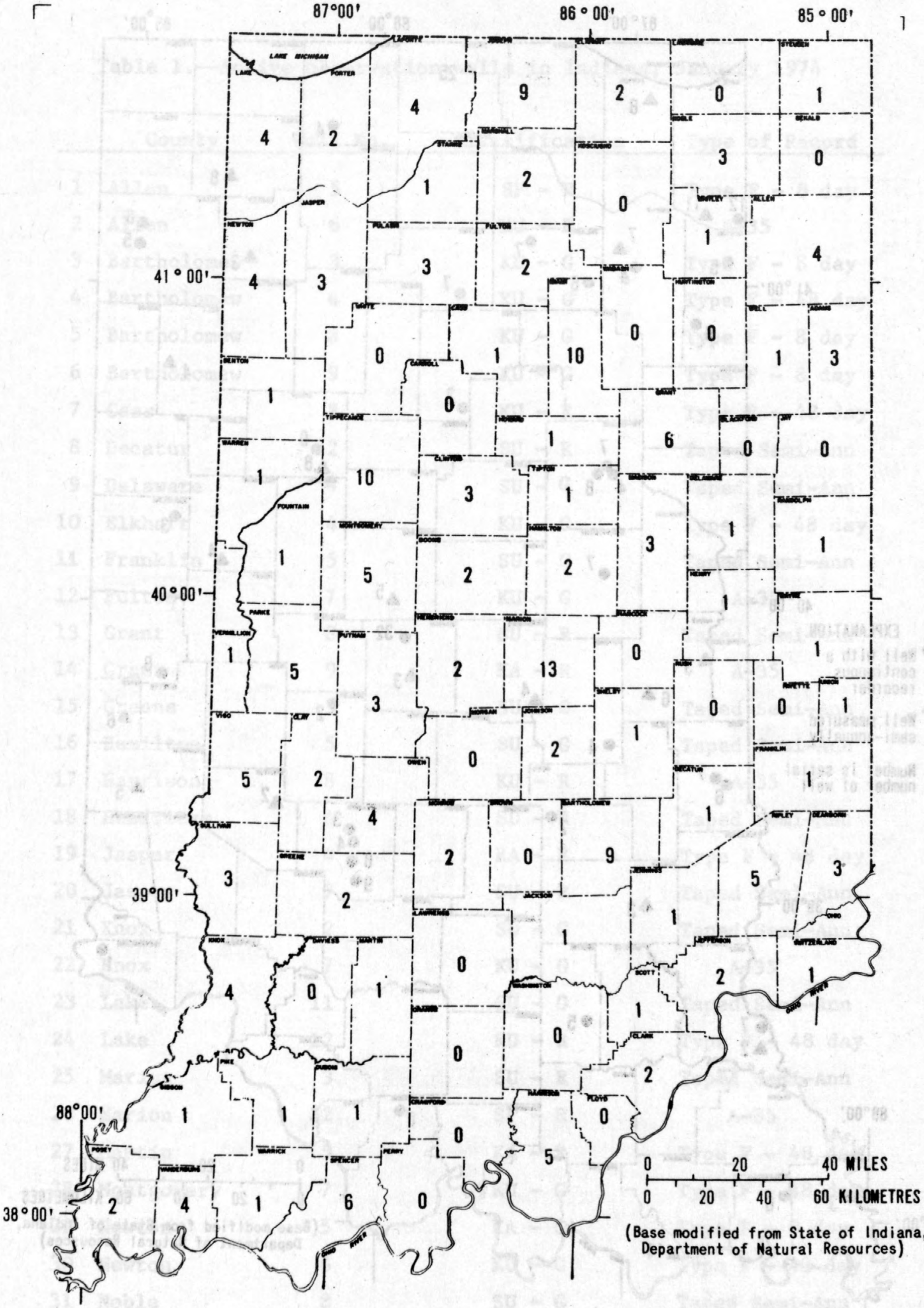

Figure 20.-- Distribution by county of the 199 continuous-recorder equipped wells used in the network from 1935 through 1973.

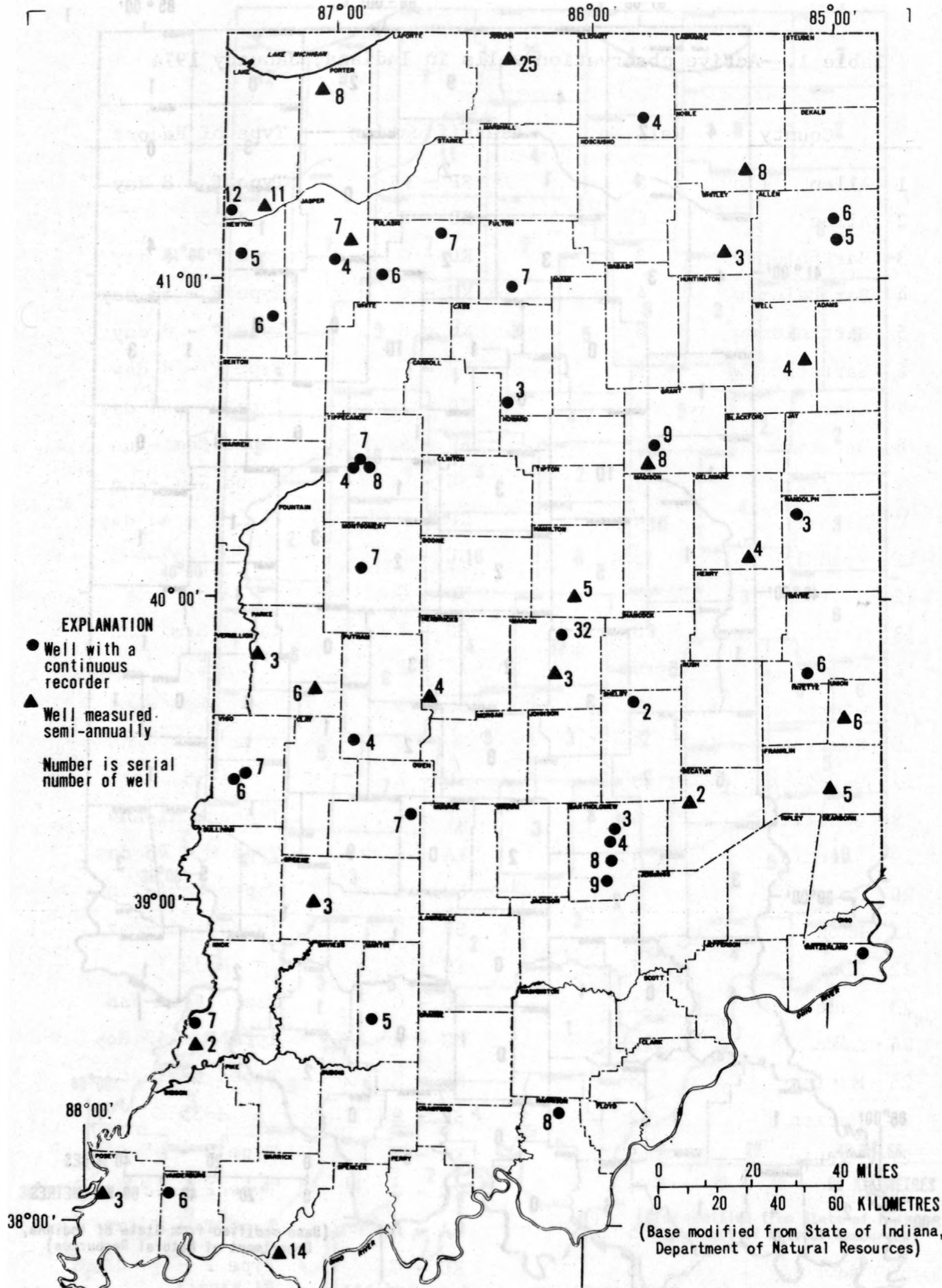

Figure 21.-- Location of active observation wells in Indiana, January, 1974.

Table 1.--Active observation wells in Indiana, January 1974

	County	Well No.	Classification	Type of Record
1	Allen	5	SP - R	Type F - 8 day
2	Allen	6	KU - R	A-35
3	Bartholomew	3	KU - G	Type F - 8 day
4	Bartholomew	4	KU - G	Type F - 48 day
5	Bartholomew	8	KU - G	Type F - 8 day
6	Bartholomew	9	KU - G	Type F - 8 day
7	Cass	3	KU - R	Type F - 48 day
8	Decatur	2	SU - R	Taped Semi-Ann
9	Delaware	4	SU - G	Taped Semi-Ann
10	Elkhart	4	KU - G	Type F - 48 day
11	Franklin	5	SU - G	Taped Semi-Ann
12	Fulton	7	KU - G	A-35
13	Grant	8	SU - R	Taped Semi-Ann
14	Grant	9	KA - R	A-35
15	Greene	3	SU - G	Taped Semi-Ann
16	Hamilton	5	SU - G	Taped Semi-Ann
17	Harrison	8	KU - R	A-35
18	Hendricks	4	SU - R	Taped Semi-Ann
19	Jasper	4	KA - R	Type F - 48 day
20	Jasper	7	SU - R	Taped Semi-Ann
21	Knox	2	SU - G	Taped Semi-Ann
22	Knox	7	KU - G	A-35
23	Lake	11	SU - G	Taped Semi-Ann
24	Lake	12	KU - R	Type F - 48 day
25	Marion	3	SU - R	Taped Semi-Ann
26	Marion	32	SP - R	A-35
27	Martin	5	KA - R	Type F - 48 day
28	Montgomery	7	KU - G	Type F - 48 day
29	Newton	5	KA - G	Type F - 8 day
30	Newton	6	KU - G	Type F - 48 day
31	Noble	8	SU - G	Taped Semi-Ann
32	Owen	7	KU - R	Type F - 48 day

Table 1.--Active observation wells in Indiana, January 1974--Continued

	County	Well No.	Classification	Type of Record
33	Parke	3	SU - G	Taped Semi-Ann
34	Parke	6	SU - R	Taped Semi-Ann
35	Porter	8	SU - G	Taped Semi-Ann
36	Posey	3	SU - G	Taped Semi-Ann
37	Pulaski	6	SP - R	A-35
38	Pulaski	7	KU - G	Taped Semi-Ann
39	Putnam	4	KA - G	Type F - 48 day
40	Randolph	3	KU - R	A-35
41	St. Joseph	25	SU - G	Taped Semi-Ann
42	Shelby	2	KU - R	A-35
43	Spencer	14	SU - G	Taped Semi-Ann
44	Switzerland	1	KU - R	A-35
45	Tippecanoe	4	KA - G	Type F - 8 day
46	Tippecanoe	7	KU - G	Type F - 8 day
47	Tippecanoe	8	KA - G	Type F - 8 day
48	Union	6	SU - R	Taped Semi-Ann
49	Vanderburgh	6	KU - R	Type F - 48 day
50	Vigo	6	KA - G	Type F - 48 day
51	Vigo	7	KA - G	Type F - 48 day
52	Wayne	6	KU - G	A-35
53	Wells	4	SU - R	Taped Semi-Ann
54	Whitley	3	SU - G	Taped Semi-Ann

CLASSIFICATION KEY

KU - Key Unaffected
KA - Key Affected
SP - Special Purpose
PU - Project Unaffected
PA - Project Affected
SU - Support Unaffected
SA - Support Affected
G - Glacial
R - Rock

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Table 1.--Active observation wells in Indiana, January 1974--Continued

	County	Well No.	Classification	Type of Record
33	Parke	3	SU - G	Taped Semi-Ann
34	Parke	6	SU - R	Taped Semi-Ann
35	Porter	8	SU - G	Taped Semi-Ann
36	Posey	3	KU - G	Taped Semi-Ann
37	Pulaski	6	SP - R	A-35
38	Pulaski	7	KU - G	Taped Semi-Ann
39	Putnam	4	KA - G	Type F - 48 day
40	Randolph	3	KU - R	A-35
41	St. Joseph	25	KU - G	Taped Semi-Ann
42	Shelby	2	KU - R	A-35
43	Spencer	14	SU - G	Taped Semi-Ann
44	Switzerland	1	KU - R	A-35
45	Tippecanoe	4	KA - G	Type F - 8 day
46	Tippecanoe	7	KU - G	Type F - 8 day
47	Tippecanoe	8	KA - G	Type F - 8 day
48	Union	8	SU - R	Taped Semi-Ann
49	Vanderburgh	6	KU - R	Type F - 48 day
50	Vigo	6	KA - G	Type F - 48 day
51	Vigo	7	KA - G	Type F - 48 day
52	Wayne	6	KU - G	A-35
53	Wells	4	SU - R	Taped Semi-Ann
54	Whitley	3	SU - G	Taped Semi-Ann

CLASSIFICATION KEY

KU - Key Unaffected
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