Circular 98

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION

Cost of Municipal and Industrial Wells in Illinois, 1964-1966

by J. P. GIBB and E. W. SANDERSON

ILLINOIS STATE WATER SURVEY
URBANA
1969

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Printed by authority of the State of Illinois—Ch. 127, IRS, Par. 58.29

COST OF MUNICIPAL AND INDUSTRIAL WELLS IN ILLINOIS, 1964-1966

by J. P. Gibb and E. W. Sanderson

ABSTRACT

This study of the cost of water wells and pumps is based on information obtained for 143 municipal and industrial water-supply wells drilled in Illinois during 1964, 1965, and 1966. Regression analyses using the method of least squares show that the cost of wells is directly related to depth and the cost of pumps is directly related to capacity. A series of cost-depth relationships which plot as straight lines on log-log graph paper are developed for wells tapping sand and gravel aquifers; shallow sandstone, limestone, or dolomite aquifers; and deep sandstone aquifers. Similar graphs relating pump cost to capacity are also presented for various operating heads.

Use of the materials presented in this circular should provide reasonable estimates of the initial investments involved in constructing and equipping water wells of given sizes and types in the primary aquifers of the state. Sample cost estimates have been given for each type of well and pump discussed in the report. These data are intended to establish orders of magnitude for comparison purposes and do not substitute for more detailed engineering estimates.

INTRODUCTION

The recently published report *Water for Illinois, a Plan for Action (1967)* has inventoried the known water resources and estimated the water needs through the year 2020 for the state of Illinois. As noted in that report, Illinois has an abundant supply of water, but it is unevenly distributed throughout the state. Therefore, advanced planning on a regional basis will be necessary to satisfy the state's future water demands and to optimize utilization of its total water resource.

The decisions involved in formulating plans of this magnitude are indeed difficult and large in number. Knowledge of available resources, proposed uses, possible treatment criteria, and finally the cost of providing water for specific uses is required to develop a working solution to the problem of regional water allocation. Studies have been made or are currently under way at the Illinois State Water Survey on the cost of various elements of water resources development. The results have been published briefly as technical letters, the five issued covering subjects as follows: Technical Letter 7, Water Transmission Costs, October 1967; Technical Letter 8, *Cost of Reservoirs in Illinois*, April 1968; Technical Letter 9, Cost of Pumping Water, July 1968; Technical Letter 10, Costs of Wells and Pumps, July 1968; Technical Letter 11, Cost of Water Treatment in Illinois, October 1968. In addition, Cost of Reservoirs in Illinois was published as Circular 96. Other studies in progress include cost of reconditioning water, sewage treatment, and waste disposal.

This report summarizes a cost study of municipal and industrial wells recently completed in Illinois. It was prepared under the general supervision of William C. Ackermann, Chief of the Illinois State Water Survey, and Harman F. Smith, Head of the Hydrology Section. William H. Walker reviewed the final manuscript and provided guidance from the beginning of the project. Computer analysis of all data was accomplished with the assistance of Robert A. Sinclair. Mrs. Dorothy Woller handled the mass mailing of the questionnaires, and John W. Brother, Jr., prepared the illustrations. The authors wish to express their gratitude to all those who contributed cost information for this project.

COST DATA

This report presents a summary of data on the initial cost of 143 municipal and industrial wells constructed throughout Illinois during 1965, 1965, and 1966. These data were obtained primarily from questionnaires voluntarily returned by 78 consulting engineers, 48 water-well contractors, 38 industries, and 30 municipalities. Multiple reportings on individual installations from these various sources furnished adequate and complete data for the wells studied. The excellent correlations obtained from the data collected attests to their dependability and accuracy. The statewide distribution of the assembled well-cost data is illustrated in figure 1.

Data Adjustments

All cost data were adjusted to a common 1966 level by increasing the 1964 and 1965 cost figures 10 and 5 percent, respectively. This simplified correction technique was proven reasonable according to both the Engineering News-Record Cost Indexes (1967) and the Handy-Whitman Index of Water Utility Construction Costs (1966).

After correcting the reported cost information to the 1966 economic level, well and pump data were separated to facilitate further analysis. In many cases, separate contracts for the well and pump had been awarded, and it was not uncommon to have two different contractors involved in a single project. Therefore, isolating the well and pump costs proved to be a simple task and appeared a natural step to a more refined analysis.

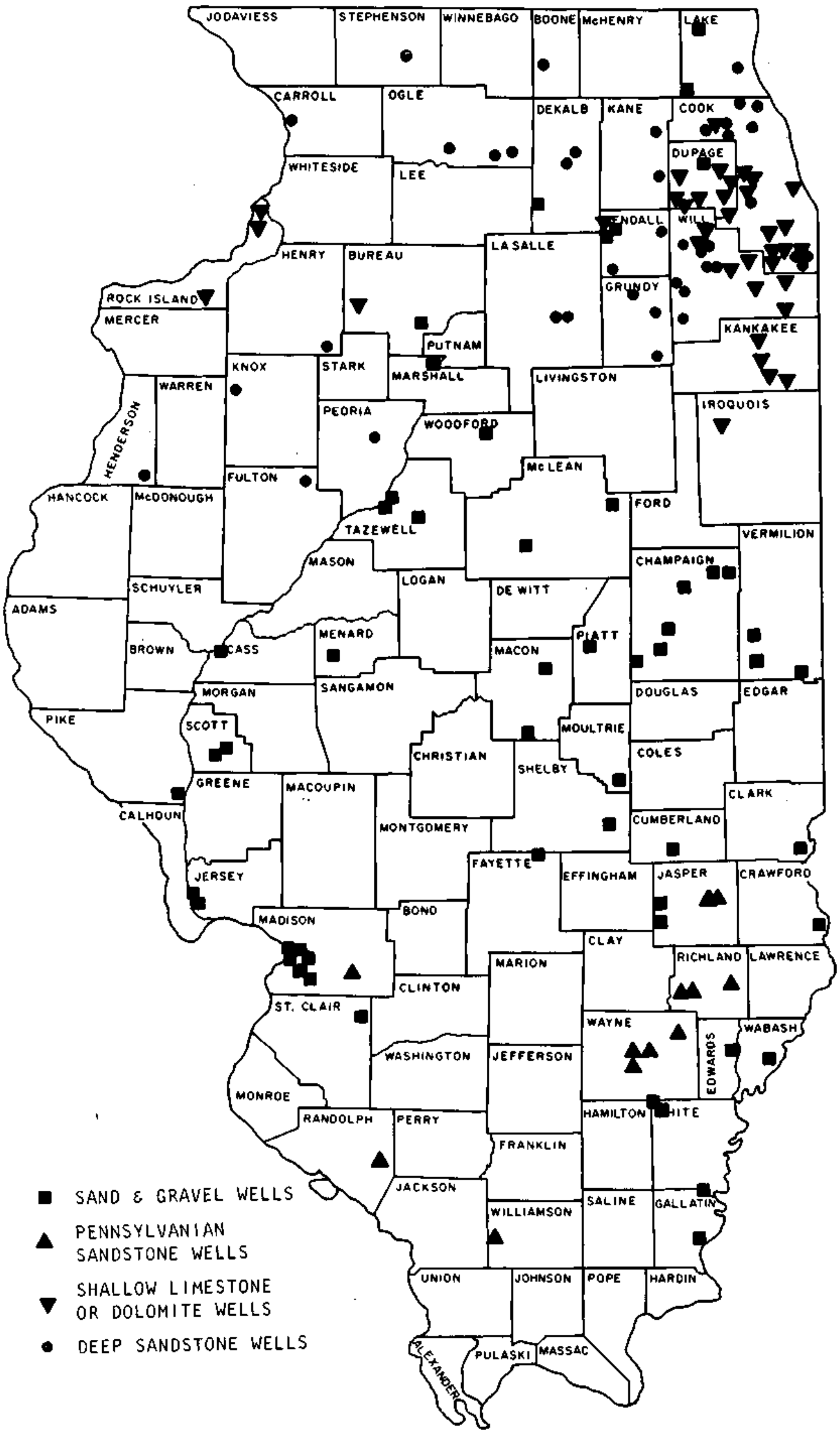


Figure 1. Distribution of wells for which completed cost data were obtained

Well cost data were divided into three categories according to the aquifers tapped: 1) sand and gravel, 2) shallow bedrock, and 3) deep sandstone. Tubular type and artificially gravel-packed wells finished in the glacial materials above bedrock were considered separately in the 'sand and gravel' category. Wells tapping Pennsylvanian, Mississippian, and Devonian sandstone or limestone, and those tapping Silurian or upper Ordovician dolomite aquifers have similar construction-depth features and were therefore combined in a 'shallow bedrock' grouping. All wells tapping water-bearing sandstone units of the Cambrian-Ordovician or Mt. Simon rocks were considered in a 'deep sandstone' category.

After separating all well data into their respective groupings, each set of cost information was examined to establish a relative standard for acceptable data. Cost figures for wells having unusual construction features or obvious inconsistencies in pricing were immediately omitted from further analysis. Information for wells where the exact cost components of the reported lump sum bids could not be separated were also discarded from the final analysis. Data from joint-bid prices for two or more wells were deleted because in all cases of this type the resulting individual well costs were much below normal.

Additional information omitted from the analysis of sand and gravel wells included that pertaining to wells equipped with slotted pipe rather than commercially made screens and that for gravel-packed wells with a gravel-pack annulus greater than 10 inches in thickness. Data for bedrock wells with unusual or unnecessary casing configurations were also dropped from the final analysis.

The finally sorted sets of data that were used represent the material and labor costs of the following as applicable: 1) setting up and removing the drilling equipment, 2) drilling the well (test drilling not included), 3) all casings and liners including construction casings, 4) grouting and sealing the annular spaces between casings and between casings and the bore hole, 5) well screens and fittings, 6) gravel-pack materials and placing, 7) developing the well, excluding blasting (shooting) of deep sandstone wells, and 8) conducting one 8-hour pumping test.

Data obtained during this study indicate that the current practice of constructing wells of a given diameter for a specified pumping capacity is essentially the same as outlined by Smith (1961). Well diameters are usually determined by the probable pump required and the minimum clearance requirements to facilitate removal of the pumping system for inspection and repairs. Some variations in the pump sizes for a given rated capacity were noted when comparing pumping installations dealing with contrastingly small and large pumping lifts. These variations coupled with the rapid changes in pump technology and design prohibit setting forth a definite scheme relating minimum well diameters to the proposed pumping capacities. Table 1 presents typical well diameters used in Illinois (Smith, 1961).

Pump cost data were divided into two categories according to the type of pumping installation: 1) vertical turbine pumps, and 2) submersible turbine pumps. Each piece of pump cost data was examined to achieve a common base for comparison purposes. Detailed investigations into individual cases revealed that unusually low pump costs could normally be attributed to the installation of used pumps or materials. Excessively high pump costs normally resulted from the inclusion of sophisticated control systems, and in some cases, the inclusion of the pump house in the reported installed pump costs. All data that deviated greatly from the norm were therefore investigated more thoroughly, and each was included or excluded from the final analysis on its own merit.

These sorted sets of data represent the direct expenses involved in furnishing and installing a basic pumping plant of a given size and type. The costs of well houses and control systems are not included in the installed pump costs.

Table 1. Well Diameters Used in Illinois

Pumping rate *(gpm)*	Diameter of well *(inches)*
125	6
300	8
600	10
1200	12
2000	14
3000	16

Method of Analysis

The method of least squares as applied in exponential curve fitting (Miller and Freund, 1965) was used in the final analyses for all sets of selected well and pump cost data. This type of analysis permitted the development of equations for a series of lines determined from the data points relating well cost to well depth for given diameter ranges and types of wells, and installed pump costs to the design pumping rate at various increments of total operating head. Equations relating well cost to depth for various diameter groupings and types of wells are of the form

$$W.C. = K d^n$$

where

$W.C.$ = well cost, in 1966 dollars
K = a constant
d = depth of the well, in feet
n = slope of the best fit line

Equations relating pump cost to the design pumping rate at various operating heads are of the form

$$P.C. = K\,Q^{n}H^{m}$$

where

$P.C.$ = installed pump cost, in 1966 dollars
K = a constant
Q = capacity of the pump, in gallons per minute (gpm)
n = slope of the best fit line at a given operating head
H = operating head of the pump, in feet
m = slope of the best fit line at a given pump capacity

Correlation coefficients ranging from 0.803 to 0.988 and averaging 0.942 attest to the validity of the chosen relationships. In this regard, the average correlation coefficient obtained indicates that $100(0.942)^2$ or about 87 percent of the adjusted well or pump cost can be attributed to the depth of well or capacity of pump.

To present a reasonable range of cost values for estimating purposes, 80 percent confidence limits were derived for all well cost data sets in the study. As the term confidence limits implies, these lines envelop a range of cost values which should be expected 80 percent of the time for a given depth, size, and type of well. It should be noted that the range of cost values defined by the confidence limit lines increases as the well depth deviates from the mean depth. In those segments of the graphs containing most of the data points, a narrower range of cost values can be expected at the same confidence level. The limits of prediction, or range of cost values, become increasingly wide outside the area of observed data, and for this reason, extrapolation into these areas should be done with utmost caution and good judgment.

COST OF WELLS

Cost of Sand and Gravel Wells

Sand and gravel aquifers of the glacial drift deposits are a primary source of groundwater supplies throughout much of Illinois. Wells tapping these aquifers are generally of the 'tubular' or 'gravel-packed' types.

Tubular wells are normally designed to retain from 30 to 60 percent of the coarser aquifer materials immediately adjacent to the well by using a properly sized screen; the finer-grained materials from this part of the aquifer are removed during development by surging, bailing, and pumping so that a 'natural' coarse-grained envelope is formed around and along the entire screen length. A gravel-packed well is formed by placing a 6- to 9"inch thick envelope of coarse-grained gravel material around the outside of the screen during construction to retain the fine-grained aquifer materials. The gravel pack grain size is normally about 5 times as large as the average grain size of the aquifer materials. The well-screen slot opening size in this type of well is selected to retain only the gravel-pack material.

Completed cost data were collected for 54 sand and gravel wells constructed in Illinois during the 1964-1966 study period. Of this total, 38 percent were tubular wells and the remainder were gravel-packed wells. Geographic distribution of these wells and diagrams showing typical well-construct ion features of the two types are included in figures 2 and 4. Because of appreciable differences in the depth-cost relationships for the two types of wells, the data have been treated separately in the discussion which follows.

Tubular Wells. Completed cost data were secured for 21 tubular sand and gravel wells (figure 2). Adjusted and selected data for 17 of these wells were used in the final analysis. The depths of the 17 selected wells vary from 37 to 238 feet, screen diameters from 6 to 12 inches, screen lengths from 10 to 30 feet, and installed pump capacities from 20 to 450 gpm. All wells are equipped with commercially made well screens and are constructed similar to the typical tubular sand and gravel well illustrated in figure 2.

Regression analysis based on the method of least squares was used with the selected data to develop the depth-cost relationships illustrated in figure 3. Correlation coefficients of 0.957 and 0.976 were obtained for the 6- to 10-inch diameter and 12- to 15-inch diameter ranges, respectively. Screen diameters were considered to be identical to the bottom bore hole diameters for this type of well. A sample cost estimate for a typical tubular sand and gravel well is given in figure 3. In this, as in all well cost estimates given in the report, the well diameter was obtained from table 1 using the desired pumping rate expected from the completed well.

Gravel-Packed Wells. Completed cost information for 33 gravel-packed sand and gravel wells were obtained (figure 4). Adjusted and selected data for 18 of the wells of this type were used in the final analysis. These wells vary in depth from 36 to 310 feet, have screen diameters from 6 to 26 inches, screen lengths from 10 to 100 feet, bottom bore hole diameters from 16 to 42 inches, and installed pump capacities from 110 to 3500 gpm. All of these artificially placed gravel-packed wells are equipped with commercially made well screens and are constructed similar to the typical gravel-packed well illustrated in figure 4.

The depth-cost relationships illustrated in figure 5 were developed from the selected data by the methodology previously noted. Correlation coefficients of 0.979, 0.920, and 0.988 were obtained for the 16- to 20-inch, 24- to 34-inch, and 36- to 42-inch diameter ranges, respectively. Bottom bore hole diameters were used to separate the data into the various diameter ranges for this type of well. In general, the bottom bore hole diameter will range from 12 to 20 inches larger than the screen diameter for a given well.

A sample cost estimate of a typical gravel-packed well finished in fine sand is given in figure 5. The bore hole diameter for the 200 gpm sample well

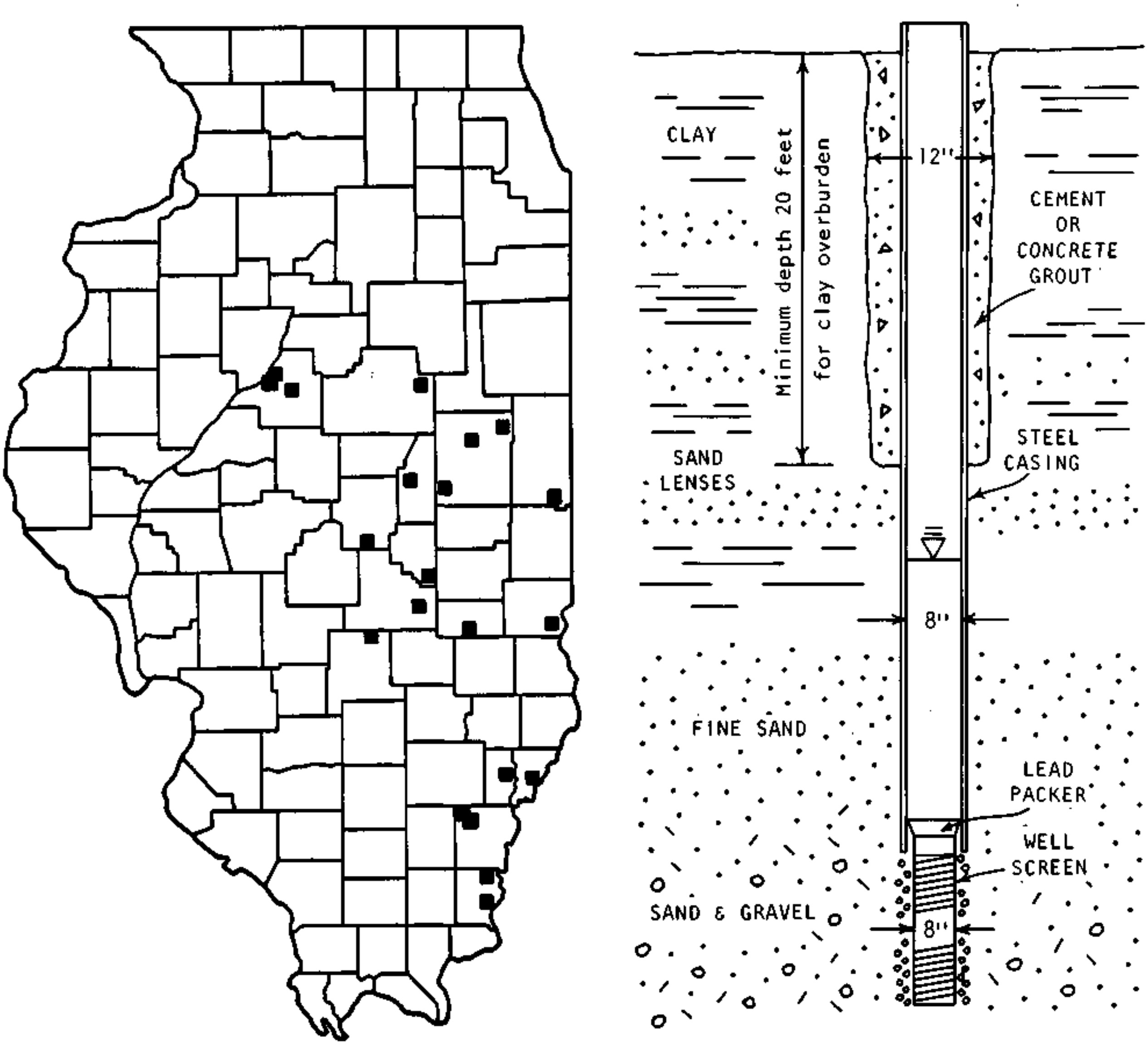


Figure 2. Distribution of data points and a typical tubular well finished in sand and gravel

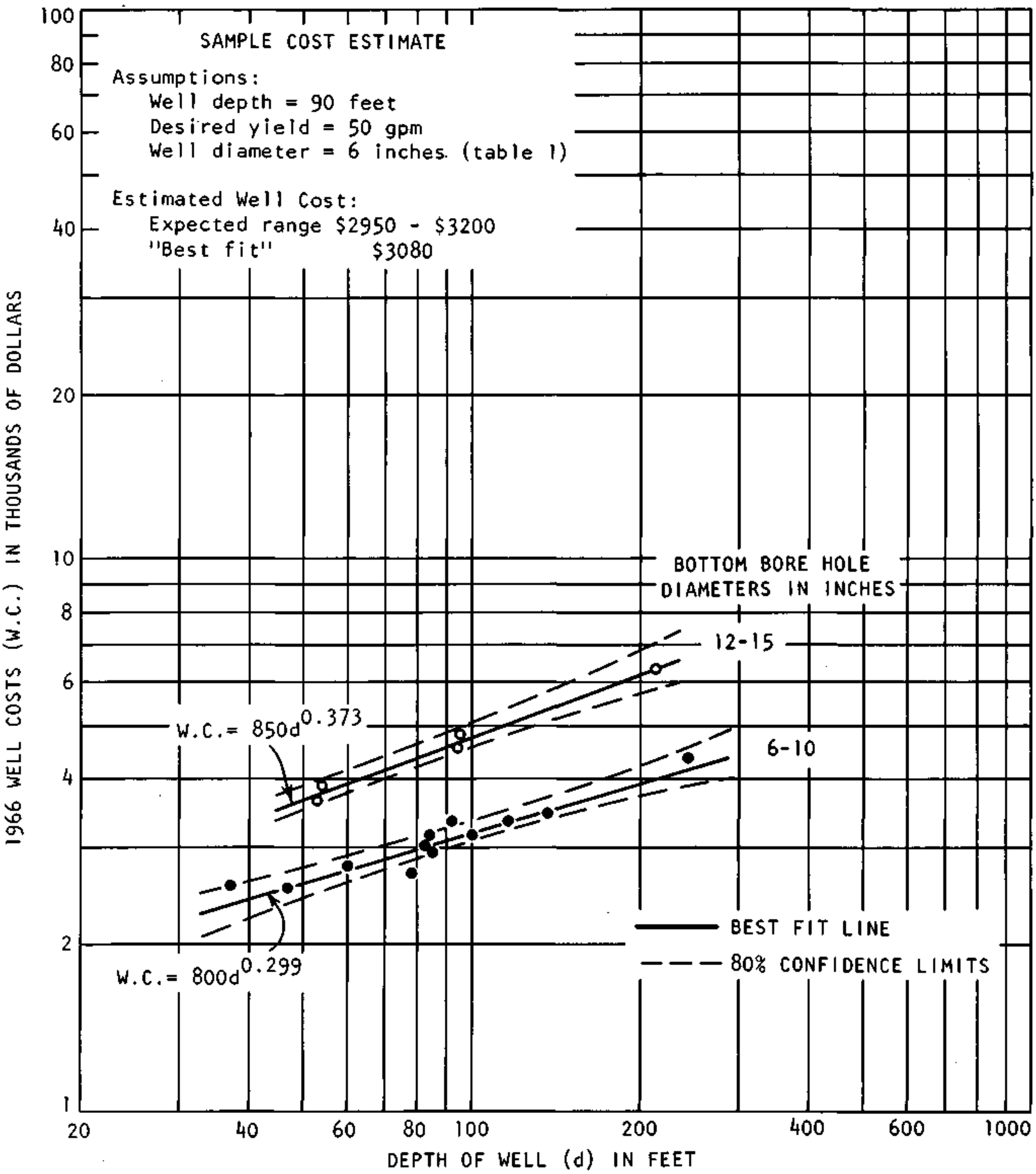


Figure 3. Cost of tubular wells finished in sand and gravel

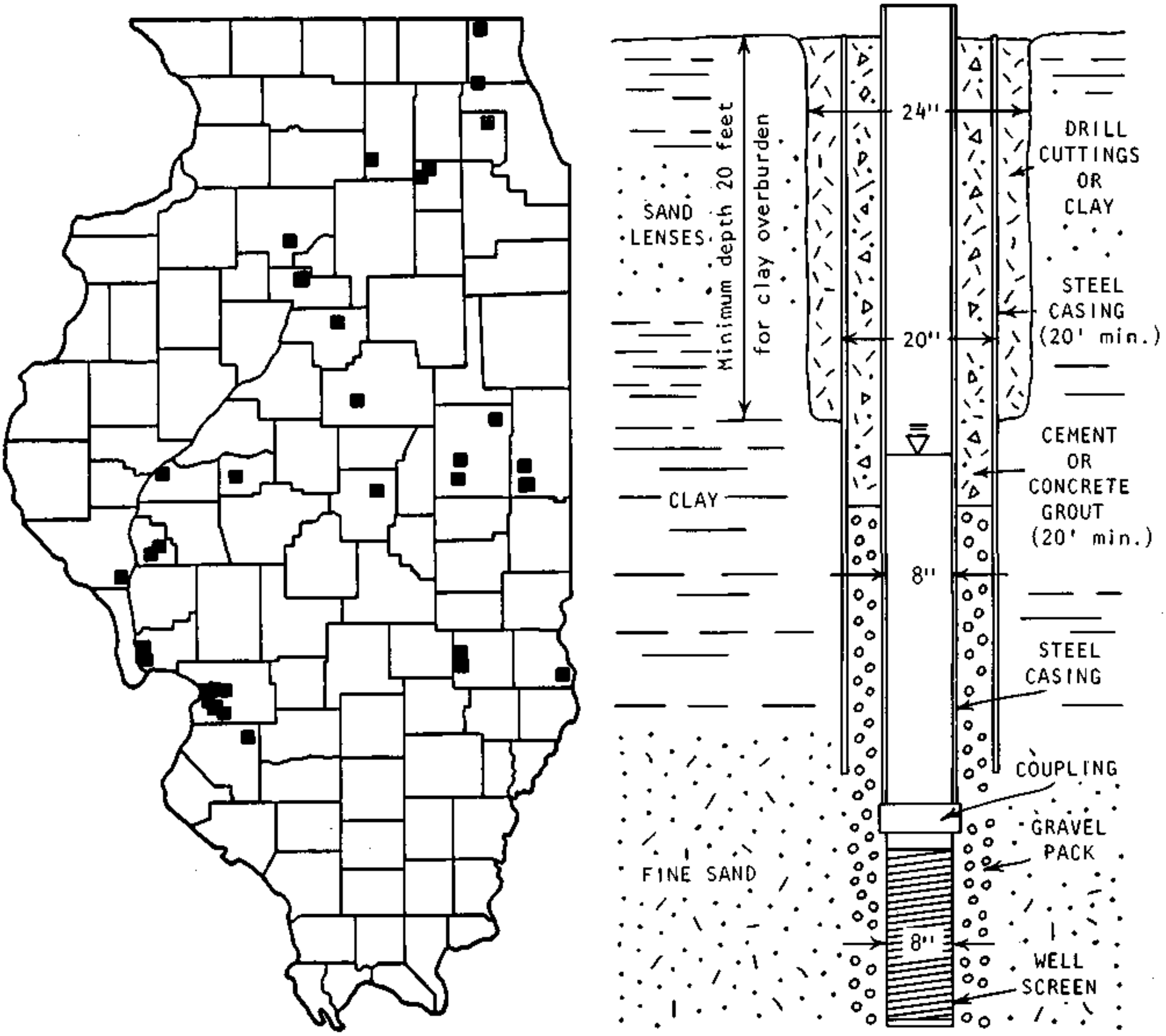


Figure 4. Distribution of data points and a typical gravel-packed well finished in sand

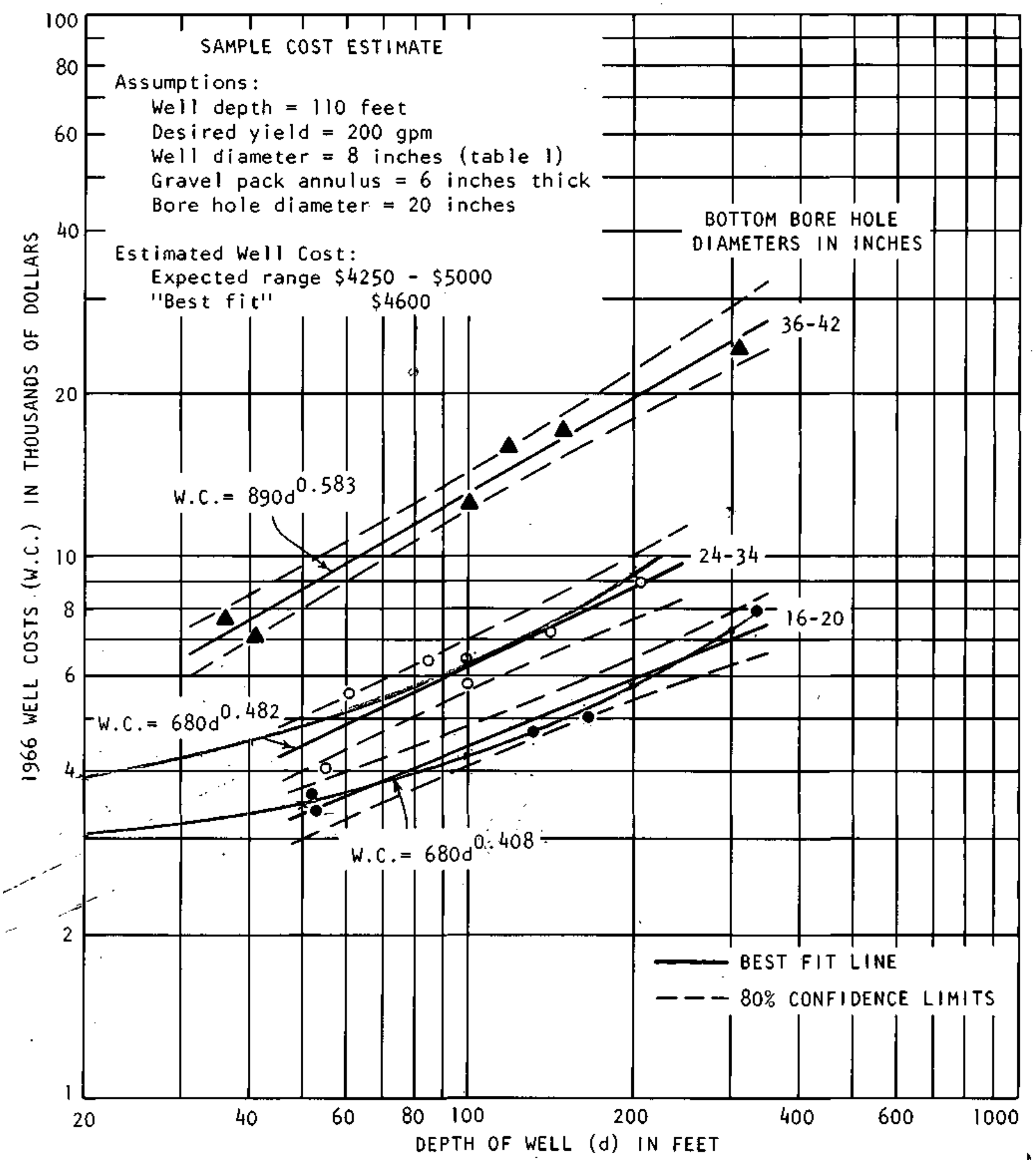


Figure 5. Cost of gravel-packed wells finished in sand and gravel

was determined by using table 1 to find the well or screen diameter required for this pumping rate and adding 12 inches to provide a 6-inch thick gravel annulus around the screen.

Comparison of cost data for tubular and gravel-packed sand and gravel wells (figures 3 and 5) shows that, for any given well diameter and depth, the cost of a gravel-packed well is generally significantly higher than that of a comparable tubular well. Much of this differential can be attributed to the additional cost of drilling the larger diameter hole, plus material and placement costs of the coarse-grained envelope required for the gravel-pack type of well.

In addition to obtaining cost information for the various types of wells, the initial questionnaire used in this study asked for the estimated life span of these wells. A 25-year median service life was determined from the reported data for all wells tapping the unconsolidated materials above bedrock. This estimate is identical to that presented by Hudson and Geils (1952) in a more comprehensive study of the life span of wells.

Cost of Shallow Bedrock Wells

Wells tapping Pennsylvanian , Mississippian, and Devonian sandstone or limestone and those tapping Silurian or upper Ordovician dolomite aquifers were combined into a single category for this study. This was possible because of similar depth and construction features. Completed cost data for 48 wells of this type were collected (figure 6) . Adjusted and selected data for 34 of the initial 48 wells were used in the final analysis. Selected wells tapping Pennsylvanian or Mississippian age sandstone formations range in depth from 137 to 310 feet, have bottom bore hole diameters from 6 to 8 inches, and have installed pump capacities from 5 to 100 gpm. Selected wells finished in Mississippian, Devonian, Silurian, and Ordovician age limestone or dolomite formations range in depth from 161 to 575 feet, have bottom bore hole diameters from 6 to 24 inches, and have installed pump capacities from 20 to 2000 gpm. The construction features of the selected wells are comparable to those of the typical well illustrated in figure 6.

Again, regression analysis based on the method of least squares was used to develop the depth-cost relationships illustrated in figure 7. Correlation coefficients of 0.933, 0.938, and 0.967 were obtained for the 6-inch, 8- to 12-inch, and 15- to 24-inch diameter ranges, respectively. Bottom bore hole diameters were used for grouping purposes except in cases where the bottom bore hole diameter extended for a length less than 10 percent of the total depth of the well. In these instances, the next larger bore hole diameter was used. A sample cost estimate for a typical dolomite well is given in figure 7.

Median service lives of 20 years for the sandstone wells and 40 years for the limestone or dolomite wells were determined from the reported data. Hudson and Geils (1952) tabulated median service lives of 18.3 years for Pennsylvanian sandstone wells, 11.8 years for Mississippian sandstone wells, and 60+ years for the dolomite wells.

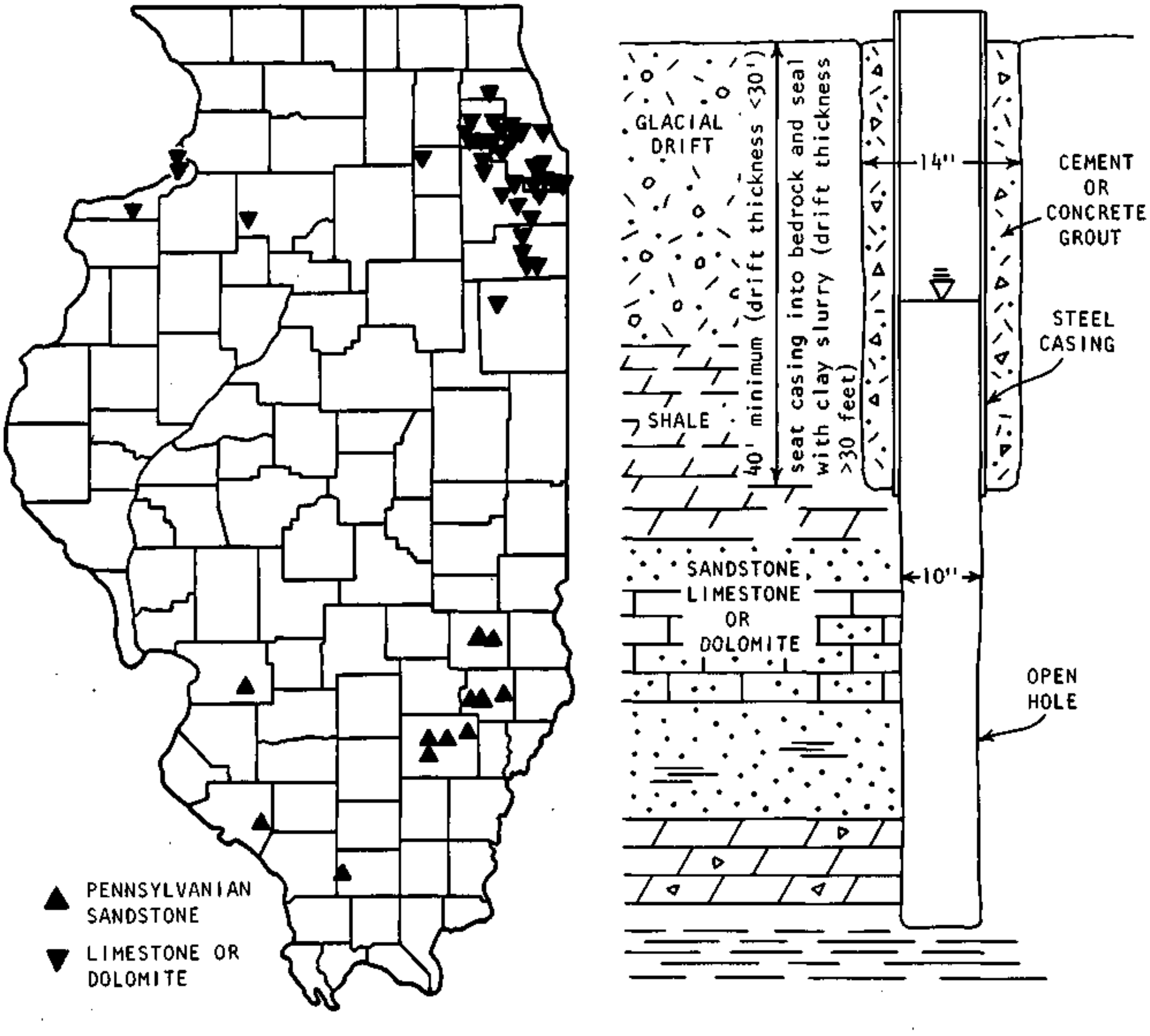


Figure 6. Distribution of data points and a typical well finished in shallow sandstone, limestone, or dolomite bedrock

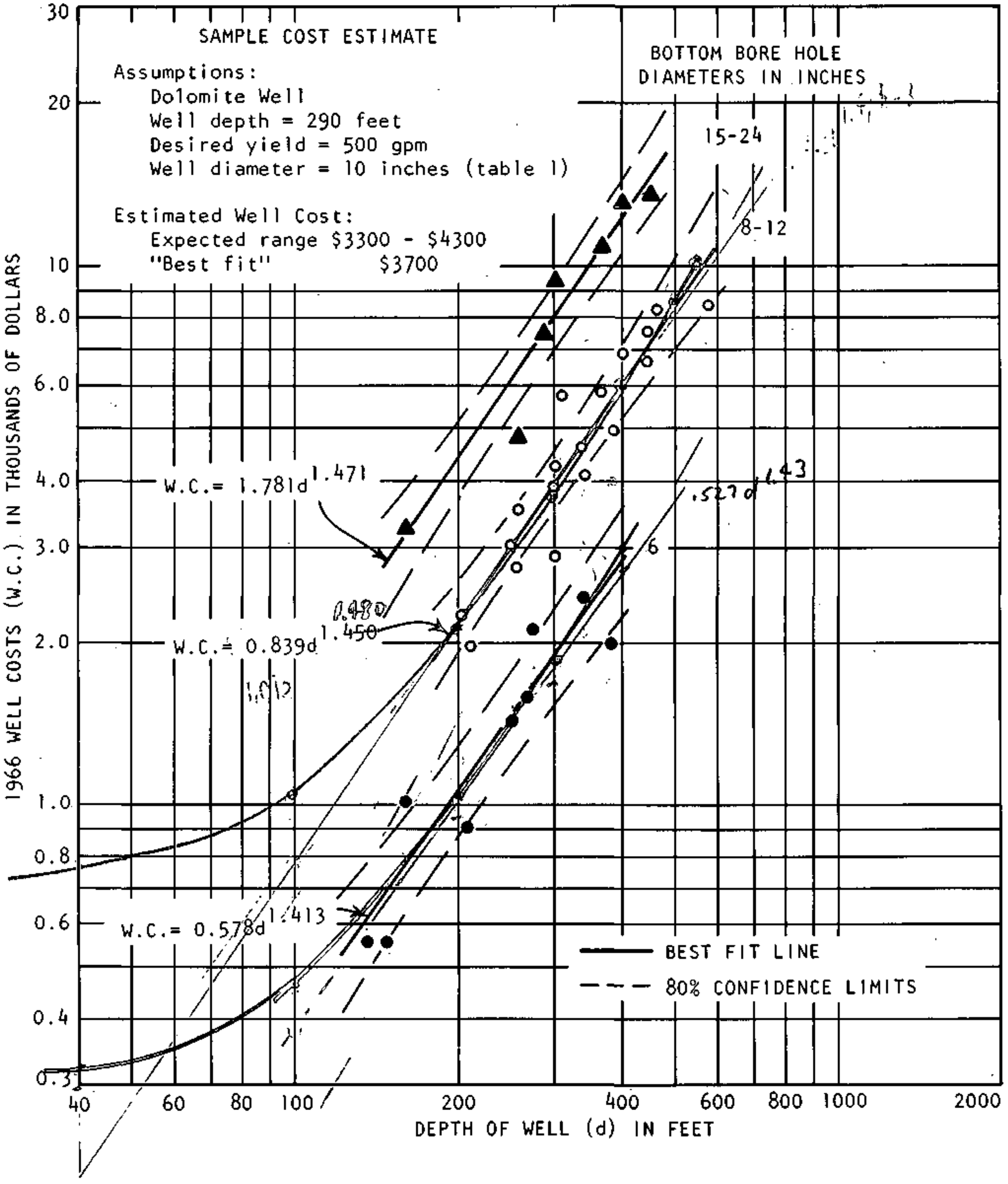


Figure 7. Cost of shallow sandstone, limestone, or dolomite bedrock wells

Cost of Deep Sandstone Wells

Completed cost data were obtained for 41 wells tapping Cambrian-Ordovician and deeper lying sandstone aquifers of northern Illinois (figure 8). Adjusted and selected data for 33 of the total 39 wells of this type were used in the final analysis. The depths of these wells vary from 650 to 2501 feet, bottom bore hole diameters from 8 to 19 inches, and installed pump capacities from 50 to 1500 gpm. A generalized graphic log and construction features of a typical deep sandstone well are given in figure 8.

The regression analysis previously noted was used to develop the depth-cost (blasting costs not included) relationships illustrated in figure/9 for the deep sandstone wells. Correlation coefficients of 0.963 and 0.803 were obtained for the 8- to 12-inch and 15- to 19-inch diameter ranges, respectively. Bottom bore hole diameters were used for grouping purposes with the same exception as applied to the shallow bedrock wells. In cases where the bottom bore hole diameter extended for a length less than 10 percent of the total well depth, the next larger bore diameter was used.

A sample cost estimate of a typical deep sandstone well is given in figure 9. Previous studies by the Water Survey have established the existence of declining water levels in the deeper lying aquifers of northeastern Illinois. This phenomenon has influenced the current trend in well construction in these aquifers toward larger bottom hole diameters to permit the installation of larger pumps at deeper settings. It may therefore be desirable to use larger diameters than those given in table 1 to insure continued operation in the future.

Data obtained during this study indicated such a wide range in the blasting and cleaning expenses of some deep sandstone wells that it proved impractical to include these costs in the final analysis. Completed cost information for 15 wells reported shooting and cleaning costs apart from the total well costs. Figure 10 illustrates the relative costs of the wells which were blasted in comparison with those developed by other methods. The average cost of the wells including blasting and cleaning is noted to be some $35,000 higher than the average for the other wells.

In a report by Walton and Csallany (1962) which includes the effects of blasting deep sandstone wells, it is suggested that in most cases well yields are increased by blasting because 1) the hole is enlarged and 2) fine materials deposited on the well face and in the well wall during drilling are removed. According to that report, enlarging the effective diameter of the well bore by blasting results in an average increase in specific capacity of a well of about 10 percent. The yield of a newly completed well is on the average increased about 20 percent by removing fine materials from the well face and wall.

Seven of the 15 wells for which blasting costs were reported had increased costs greater than 30 percent of the construction cost, and there is no evidence of any unusually large increases in the yields of those wells. Five of the 15 wells for which blasting costs were reported had shooting and cleaning costs in

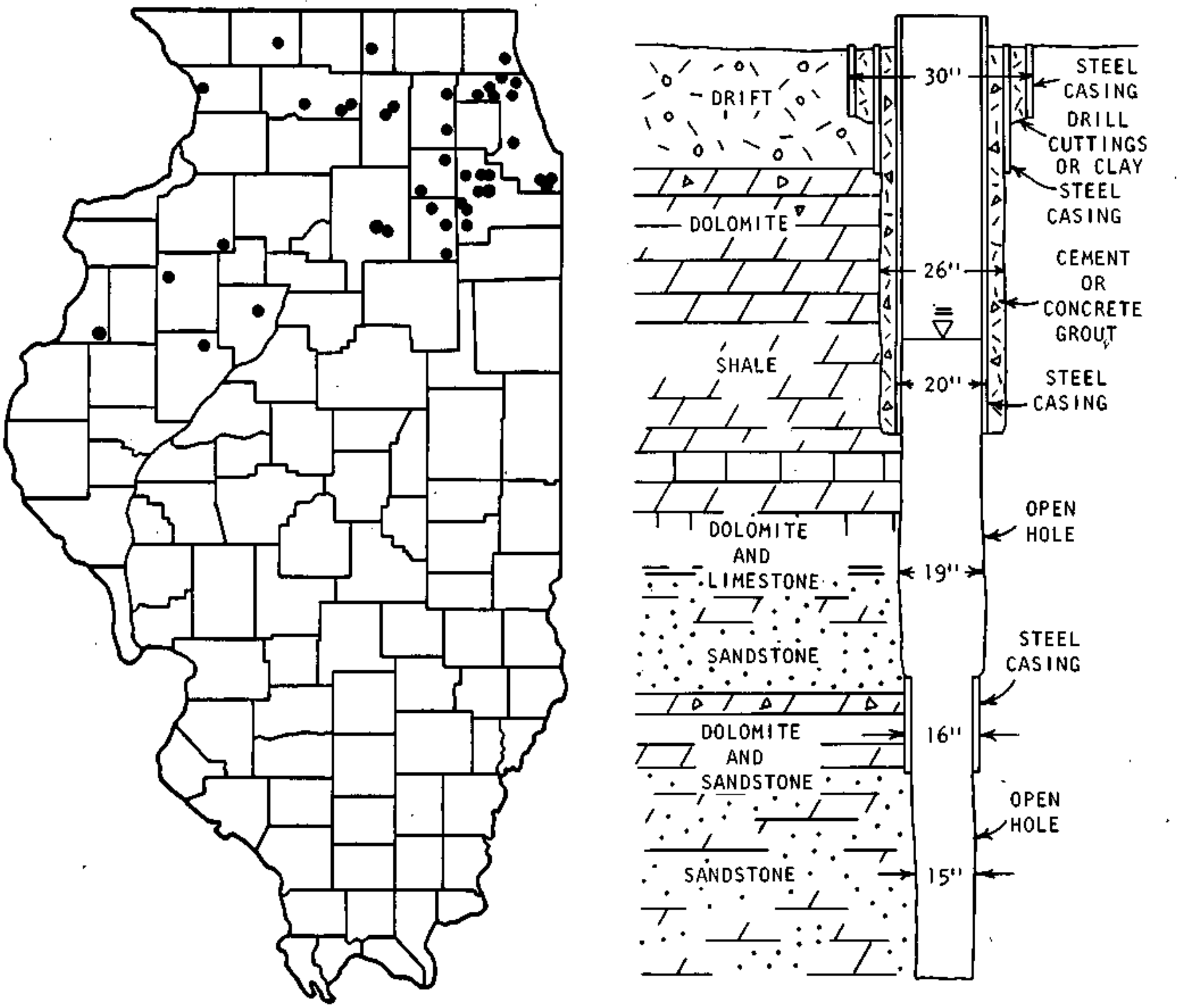
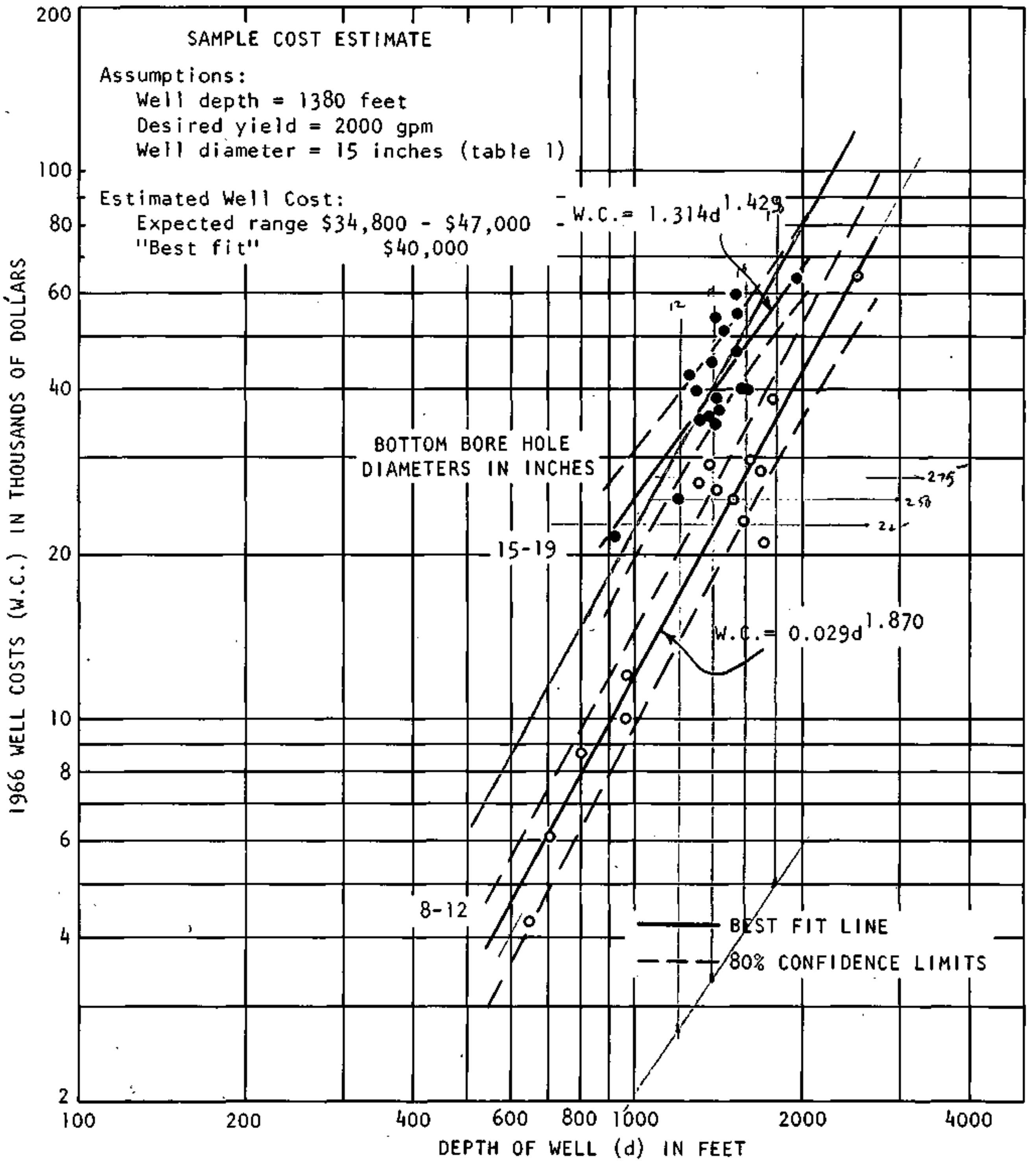


Figure 8. Distribution of data points and a typical deep sandstone well



SAMPLE COST ESTIMATE

Assumptions:
Well depth = 1380 feet
Desired yield = 2000 gpm
Well diameter = 15 inches (table 1)

Estimated Well Cost:
Expected range $34,800 - $47,000
"Best fit" $40,000

Figure 9. Cost of deep sandstone wells

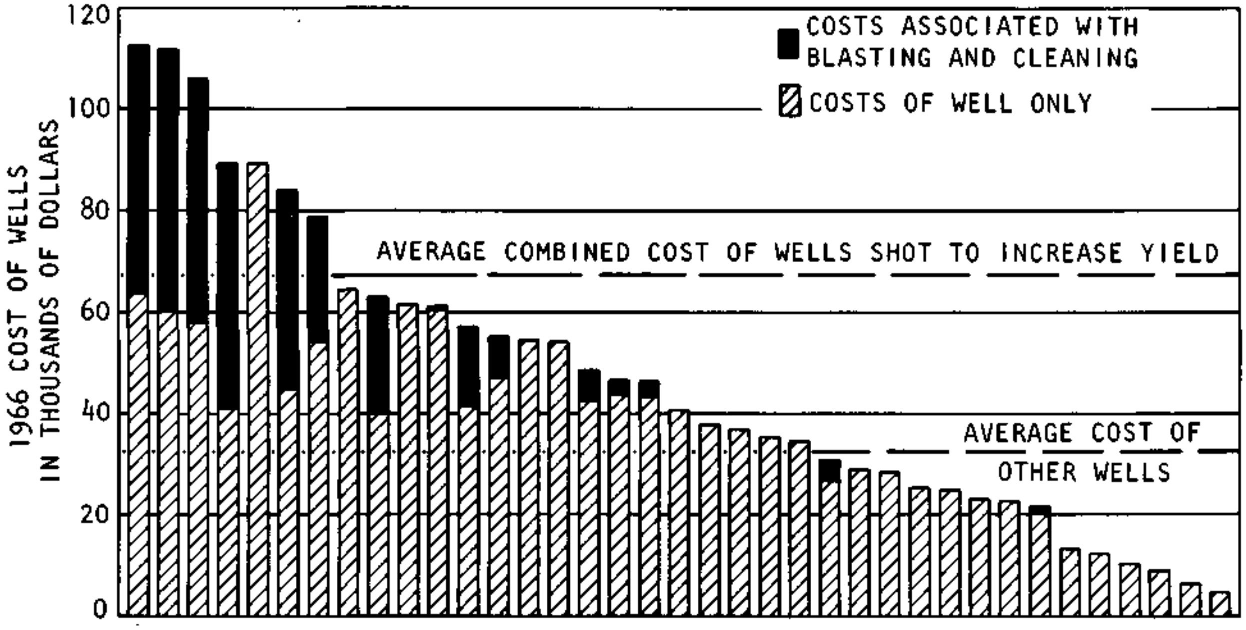


Figure 10. Cost of blasting deep sandstone wells

excess of 100 percent of the original construction cost. In these cases, a second well of the same size and type could have been constructed which theoretically would have increased the yield of the system 100 percent. For these reasons, it appears that a closer look should be given to the expenses involved in shooting and cleaning a well prior to the undertaking of this type of well development.

A median service life of 45 years was calculated from reported data for the deep sandstone wells. Hudson and Geils (1952) reported median service lives of 41.8 years and 60+ years for wells finished in the Ordovician and Cambrian age sandstones, respectively.

COST OF PUMPS

Adequate detailed cost information for 108 pumping plants installed in the wells just studied was reported. Of this total, about 45 percent were vertical turbine pumps and the remainder were of the submersible turbine type. Because of the marked difference in the cost-pump capacity relationships for various heads for the two types of pumps, the data have been treated separately in the discussion which follows.

Vertical Turbine Pumps

Completed cost data for 49 vertical turbine pumps were initially collected. Adjusted and selected data for 39 of these were used in the final analysis. The reported capacities of the pumps vary from 40 to 3500 gpm operating against total heads from 30 to 915 feet.

Regression analysis based on the method of least squares was used to develop the installed cost-pump capacity relationship for various heads illustrated in figure 11. A correlation coefficient of 0.909 was obtained for the tested relationship. A sample cost estimate for a vertical turbine pump to be installed in a sand and gravel well is given in figure 11.

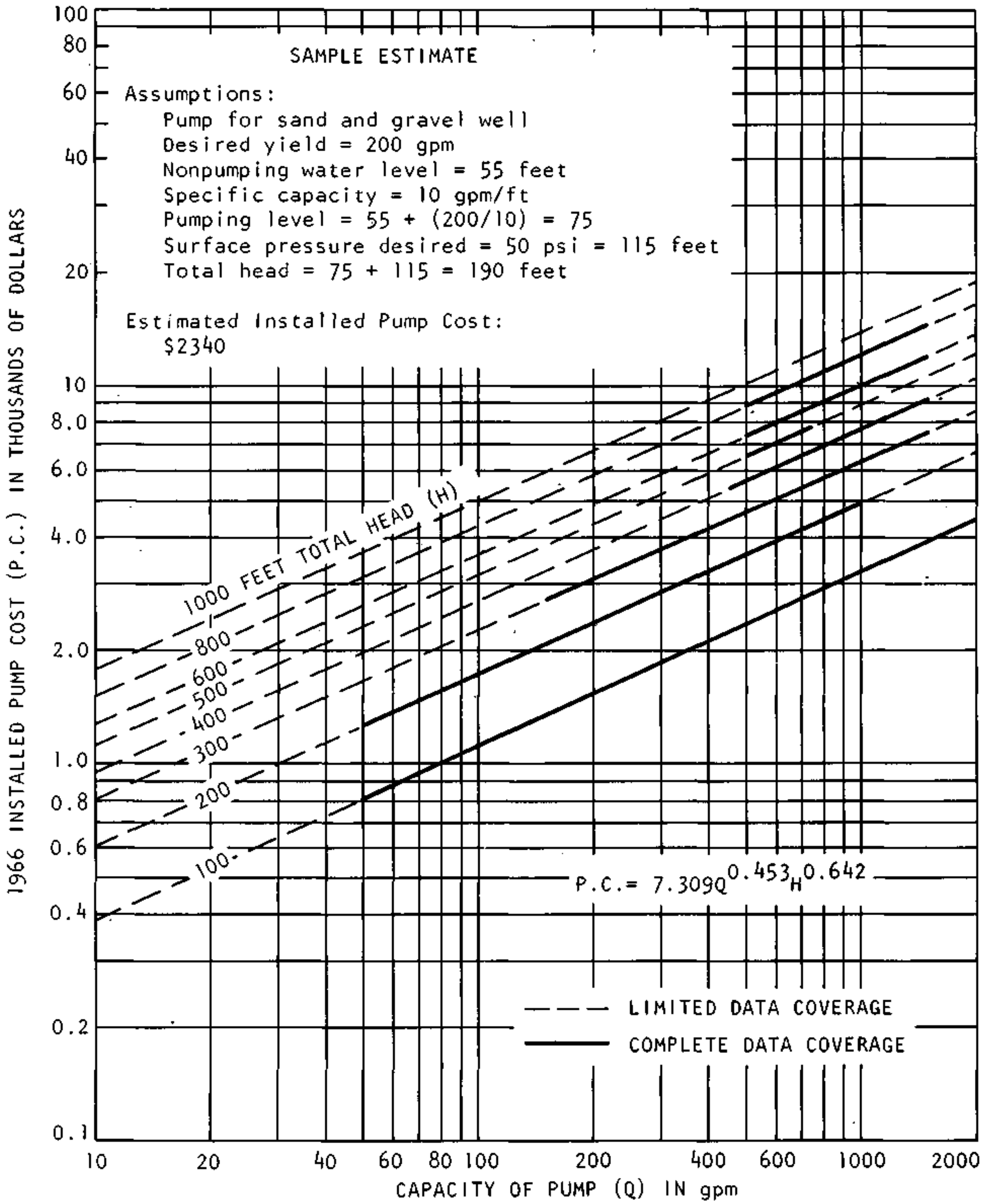
Submersible Turbine Pumps

Completed cost data for 59 submersible turbine type pumps were initially obtained. Adjusted and selected data for 47 of these were used in the final analysis. The reported capacities of pumps vary from 10 to 2000 gpm operating against total heads from 40 to 870 feet.

Again, regression analysis based on the method of least squares was used to develop the installed cost-pump capacity relationship for various heads illustrated in figure 12. A correlation coefficient of 0.976 was obtained for the tested relationship.

A sample cost estimate for a submersible turbine pump to be installed in a deep sandstone well in an area influenced by declining water levels is given in figure 12. In this example, a design period of five years was used since that is usually the expected maintenance-free life of pumps in these formations. Present practice normally consists of designing the proposed pumping installation to deliver the desired quantity of water from the anticipated depth at the end of the expected maintenance-free period of the pump. At that time the pump is usually pulled, repaired, and lowered commensurate with the rate of water-level decline and anticipated maintenance-free life of the repaired pump.

The original questionnaire used in this study asked for the estimated total life span of pumps. In reporting these estimates, our contributors made no apparent attempt to delineate between types of pumps nor to indicate the intended usage of the pumps. Estimated life spans for all pumps, regardless of type or the type of well in which it was installed, ranged from 5 to 30 years. The mean estimated life span was approximately 13 years. However, the validity of this approach may be somewhat questionable. Available information suggests that the maintenance-free life of pumps in the capacity ranges of the data collected is only 4 to 5 years. If the pump is properly maintained, and if no unusual conditions in pumping occur, it is quite possible that the component parts of the pump itself may last almost indefinitely. It may therefore be more practical to speak of the maintenance-free life of a pump rather than total life span, particularly as a concept for planning purposes. In any event our brief survey on this subject demonstrates the need for further concentrated study to determine more useful and practical concepts to be used in economic studies of water pumping facilities.



SAMPLE ESTIMATE

Assumptions:
Pump for sand and gravel well
Desired yield = 200 gpm
Nonpumping water level = 55 feet
Specific capacity = 10 gpm/ft
Pumping level = 55 + (200/10) = 75
Surface pressure desired = 50 psi = 115 feet
Total head = 75 + 115 = 190 feet

Estimated Installed Pump Cost:
$2340

Figure 11. Cost of vertical turbine pumps

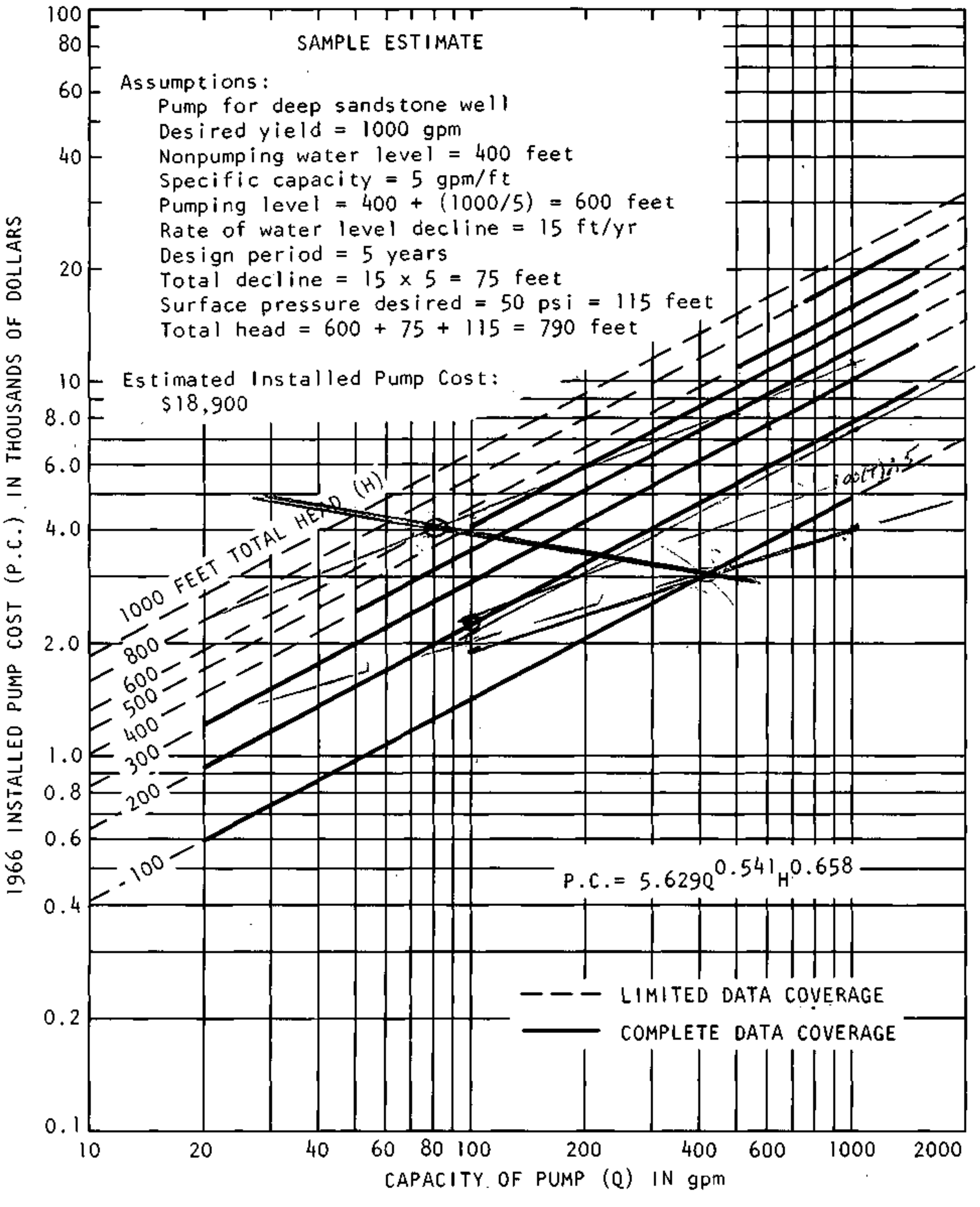


Figure 12. Cost of submersible turbine pumps

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