Illinois State Water Survey

WATER RESOURCES BUILDING • MAIL: BOX 232, URBANA, ILLINOIS 61801 • AREA CODE 217
605 E. SPRINGFIELD, CHAMPAIGN PHONE 333-2210

WILLIAM C. ACKERMANN. CHIEF

Subject: Technical Letter 9 July 1968
Cost of Pumping Water

This information on the cost of pumping water represents one product of research currently under way at the Illinois State Water Survey on the cost of water resource development. Technical Letters 7 and 8 have treated water transmission costs and reservoir costs, respectively. Parallel studies are going forward on cost of water treatment plants, cost of wells, and head loss determination for transmission lines.

Use of this material will assist in the determination of cost of pumping water, given the quantity of flow required, the total pumping head, the wire-to-water efficiency, and the unit cost of power.

A table of conversions is presented to aid in reducing theoretical equations to simplified equations, and a figure is provided for graphical solutions of the equations.

Power Requirements

The basic formula for theoretical horsepower is

$$hp = Qwh/550$$

where

hp = theoretical horsepower (unit of work expressed as 1 hp = 550 ft-lb/sec)
Q = flow in cubic feet per second (cfs)
w = weight of water at 60°F = 62.37 pounds per cubic foot (lb/cu ft)
h = total pumping head in feet (ft)

This can be converted to kilowatt hours as follows:

$$kw = [Qwh\ (0.7457\ \text{kw/hp})]/550$$

$$kw\text{-}hr = [Qwht\ (0.7457\ \text{kw/hp})]/550$$

where

$$t = \text{time in hours}$$

$$kw\text{-}hr = [2.228 \times 10^{-3} \text{ cfs/gal/min}) \ (Q_1 \text{ gal/min}) \ (0.7457 \text{ kw/hp}) \ (62.37 \text{ lb/cu ft}) \ (h \text{ ft}) \ (t \text{ hr})]/550 \text{ ft-lb/sec/hp}$$

Actual power required in kilowatt-hours is

$$kw\text{-}hr = 1.88 \times 10^{-4} \ Q_1 h \ t/E_O$$

where

Q_1 = flow in gallons per minute (gpm)
E_O = wire-to-water efficiency in percent
h = total pumping head in ft
t = time in hours

As an example, the power requirements to pump 1000 gallons at a rate of 1000 gallons per minute at a 100-foot head for the various wire-to-water efficiencies would be as follows:

$$kw\text{-}hr = \frac{1.88 \times 10^{-4} \times 10^3 \text{gpm} \times 10^2 \text{ft} \times 1/60\text{hr}}{E_O}$$

$$kw\text{-}hr = 31.40083/E_O$$

A graphic representation of this expression is shown in figure 1. The cost of pumping a given quantity of water is illustrated as follows:

Quantity desired	=	1000 gallons
Cost of electrical energy	=	$0.01 per kw-hr
Total head pump against	=	100 ft
Wire-to-water efficiency	=	50 percent

Cost of pumping 1000 gallons = value from figure 1 for E_O of 50% times cost/kw-hr times total head/100 ft times quantity desired/1000 gpm
= (0.628) (0.01) x 100/100 x 1000/1000
= $0.00628

The cost of pumping at any desired rate for a time period of minute, hour, day, week, 30-day month, and 365-day year can be determined given the rate of pumping in gpm, the cost of electric energy in $/kw-hr, the total pumping head in ft, and the wire-to-water efficiency in percent, with the following time factor constants:

Time factor	Constants
minute	1
hour	6×10
day	1.44×10^3
week	1.008×10^4
month	4.320×10^4
year	5.256×10^5

Example:

Rate of pumping	=	500 gpm
Cost of electric energy	=	\$0.01/kw-hr
Total head pumped against	=	200 ft
Wire-to-water efficiency	=	50 percent

\$ per minute	=	0.628 x 0.01 x 200/100 x 500/1000 x 1.0	=	\$0.00628
hour	=	$0.00628 \times 6.0\times10$	=	0.37680
day	=	$0.00628 \times 1.44\times10^3$	=	9.04320
week	=	$0.00628 \times 1.008\times10^4$	=	63.30240
month	=	$0.00628 \times 4.320\times10^4$	=	271.29600
year	=	$0.00628 \times 5.256\times10^5$	=	3300.76800

Conversions

cfs x	0.64317	=	mgd
mgd x	1.54723	=	cfs
cfs x	448.831	=	gpm
gpm x	2.228×10^{-3}	=	cfs
1 gal water x	8.3453	=	lb of water
1 cu ft of water at 60°F x	62.37	=	lb/cu ft of water
ft-lb/min x	3.030×10^{-5}	=	hp
ft-lb/min x	2.260×10^{-5}	=	kw
hp x	33000.0	=	ft-lb/min
hp x	550.0	=	ft-lb/sec
ft-lb/sec x	.001812	=	hp
hp-hr x	1.98×10^6	=	ft-lb
kw x	737.6	=	ft-lb/sec
hp x	0.7457	=	kw
kw x	1.341	=	hp

We hope this information will be useful to you.

Very truly yours,

William C. Ackermann

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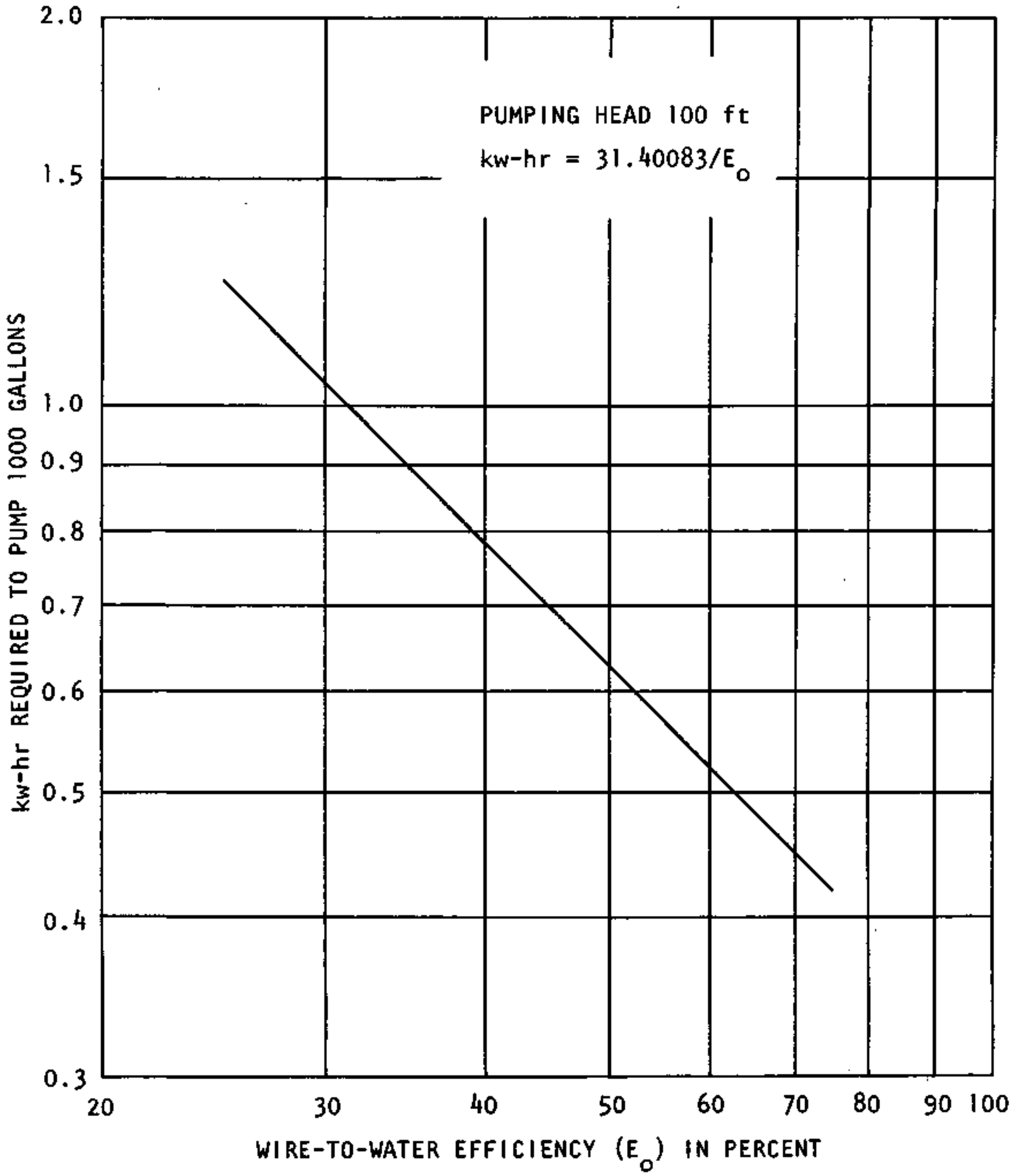
PUMPING HEAD 100 ft
kw-hr = 31.40083/E0
kw-hr REQUIRED TO PUMP 1000 GALLONS
2.0
1.5
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
20
30
40
50
60
70
80
90
100
WIRE-TO-WATER EFFICIENCY (E0) IN PERCENT

Figure 1

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BOS E. SPRINGFIELD, CHAMPAIGN PHONE 333-2210

WILLIAM C. ACKERMANN. CHIEF

Subject: Technical Letter 10 July 1968
Costs of Wells and Pumps

This letter concerning the cost of wells and pumps represents one product of research currently under way at the Illinois State Water Survey on the cost of water resources development. Parallel studies are going forward on the cost of water treatment, reconditioning water, sewage treatment, and waste disposal.

Previous technical letters issued have covered subjects as follows: Technical Letter 7, Water Transmission Costs; Technical Letter 8, Cost of Reservoirs in Illinois; and Technical Letter 9, Cost of Pumping Water.

The use of this material will give an estimate of the well and pump costs for projects requiring a given capacity. This is intended only as an instrument for establishing orders of magnitude as a basis for comparisons, and of course does not substitute for detailed engineering studies.

This study is based on information obtained from 142 municipal and industrial water supply wells drilled in Illinois during 1964, 1965, and 1966. All cost data were adjusted to a common 1966 cost 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 and the Handy-Whitman Index of Water Utility Cost.

Well cost data were analyzed for three categories according to the aquifer tapped: sand and gravel, shallow bedrock, and deep sandstone. In the sand and gravel category, tubular and gravel packed wells finished in the glacial materials above bedrock were considered separately.

The following are well diameters that have been used in Illinois for wells in unconsolidated formations (H. F. Smith, 1961, Modern Water Well Design and Construction Procedures, Illinois State Water Survey mimeo report):

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

Cost of Wells

A depth-cost relationship for tubular wells finished in sand and gravel is illustrated in figure 1. The mean line and a line representing the mean plus one standard deviation is shown for each group of bottom bore hole diameters in inches. Use of the line representing the mean plus one standard deviation gives an estimate that can be expected to be exceeded only 16 percent of the time.

Making an estimate of cost requires knowing the desired yield and depth of well to be constructed. When the desired yield is known, the diameter of well in inches is determined from the table above. As an example, for a desired yield of 100 gpm the well diameter would be 6 inches. If the desired water bearing aquifer were 100 feet from the surface, the well cost (*W.C.*) would be computed as follows:

$$W.C. = 845\, d^{0.299}$$

$$W.C. = \$3,360$$

where

$W.C.$ = well cost in dollars
d = depth of well in feet

This same value can be read directly from the appropriate line on figure 1.

Figures 2, 3, and 4 give the well costs for gravel-packed wells finished in sand and gravel; shallow sandstone, limestone, or dolomite bedrock wells; and deep sandstone wells, respectively.

Costs of Pumps

Detailed pump costs were studied for 108 of the pumping plants installed in the 142 municipal and industrial water supply wells. Of this total about 45 percent were vertical turbine pumps and the remainder of the submersible turbine type. Pump costs include the normal costs of well houses and control systems but do not include sophisticated automatic control systems.

Vertical Turbine Pumps. Selected data were analyzed for 39 vertical turbine pumps with reported capacities of 40 to 3,500 gpm and heads of 30 to 915 feet. The installed pump cost-pump capacity relationship developed for vertical turbine pumps is shown in figure 5. The pump cost *(P.C.)* can be computed as follows:

$$P.C. = 7.309\ Q^{0.453}\ H^{0.642}$$

where

$P.C.$ = pump cost in dollars
Q = pump capacity in gallons per minute (gpm)
H = total head = depth to nonpumping water level plus drawdown depth plus surface pressure desired, expressed in feet of head

Figure 5 illustrates the general solution for the above equation.

An example estimate follows for the cost of a pump required for a sand and gravel well, given these requirements:

Desired yield = 200 gpm
Nonpumping water level = 55 feet
Specific capacity of aquifer = 10 gpm/ft
Surface pressure desired = 50 psi

The total head is calculated by:

Drawdown = pumping rate/specific capacity
= 200 gpm/10 gpm/ft = 20 feet
Surface pressure = 50 psi = 50 psi (2.307 ft/psi) = 115 feet
Total head = 55 + 20 + 115 = 190 feet

Then, the estimated cost of the vertical turbine pump is:

$$P.C. = 7.309\ Q^{0.453}\ H^{0.642} = 7.309\ (200)^{0.453}\ (190)^{0.642}$$

$$= (7.309)\ (11.02)\ (29.2)$$

$$P.C. = \$2,350$$

Figure 6 illustrates the general solution for the equation for installed pump costs of submersible turbine pumps which is:

$$P.C. = 5.629\ Q^{0.541}\ H^{0.658}$$

A more detailed explanation of the development of these empirical expressions is given in State Water Survey Circular 98. We hope this information will be useful to you.

Very truly yours,

William C. Ackermann

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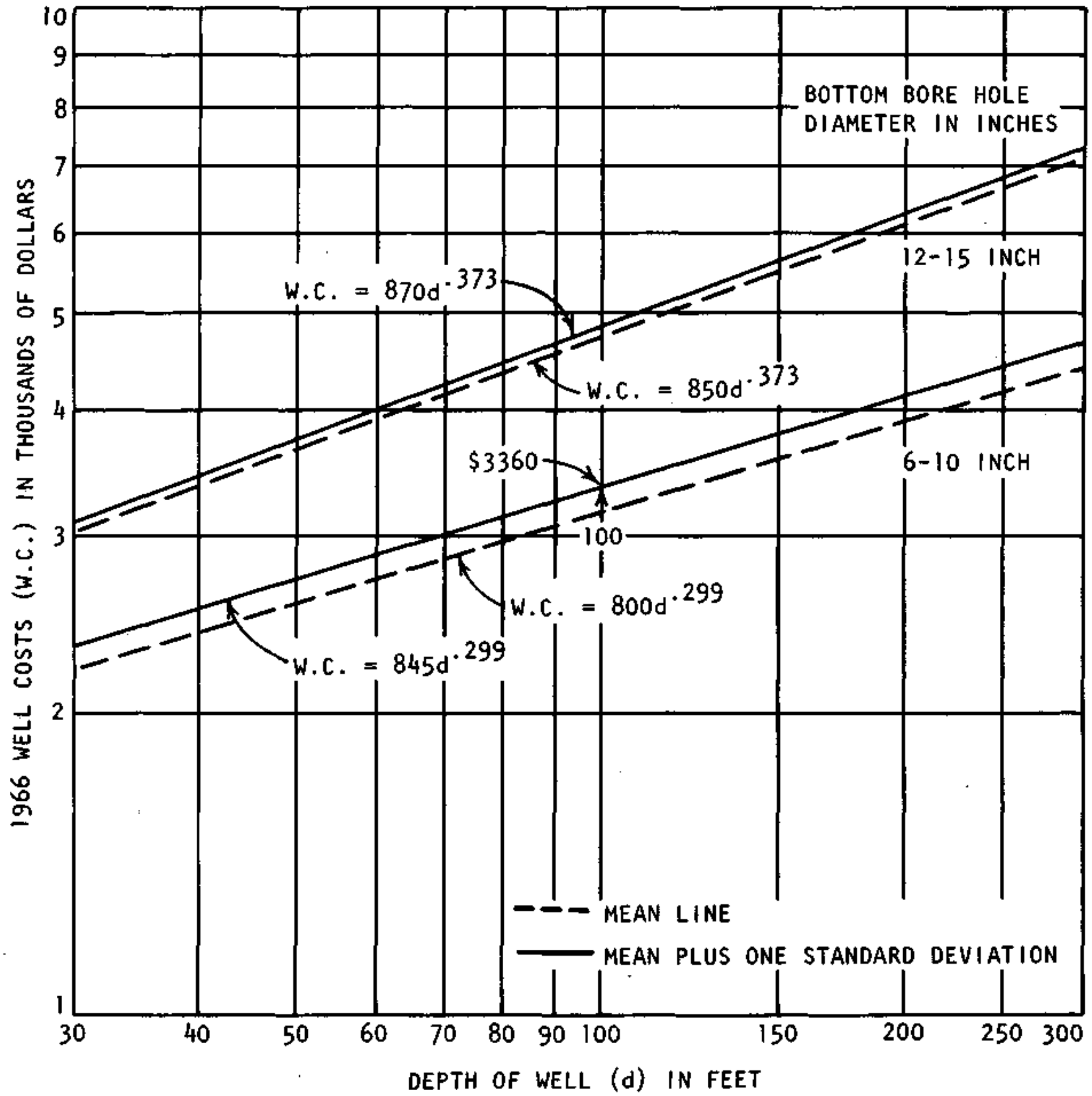

Figure 1. Cost of tubular wells finished in sand and gravel

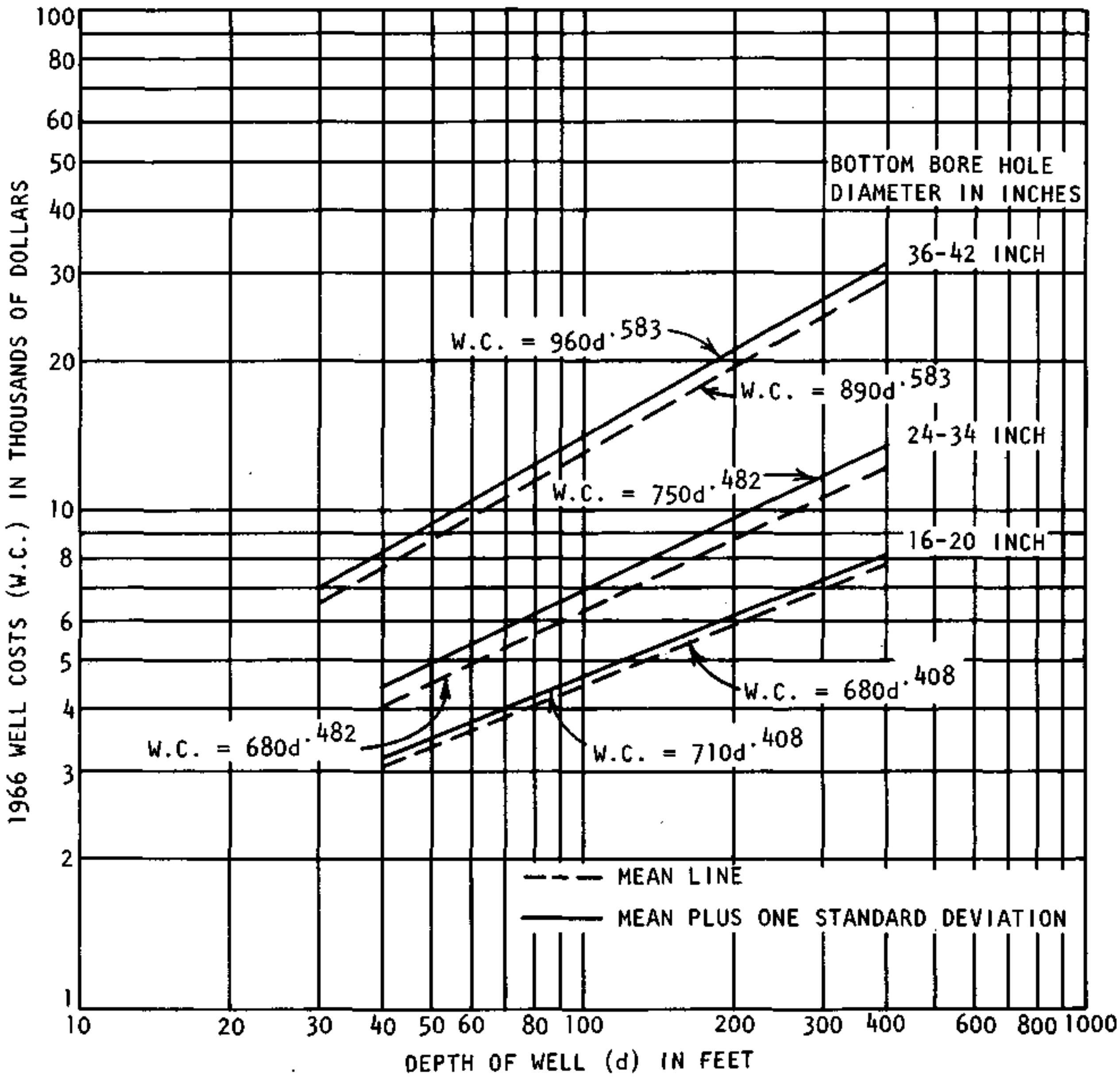

Figure 2. Cost of gravel-packed wells finished in sand and gravel

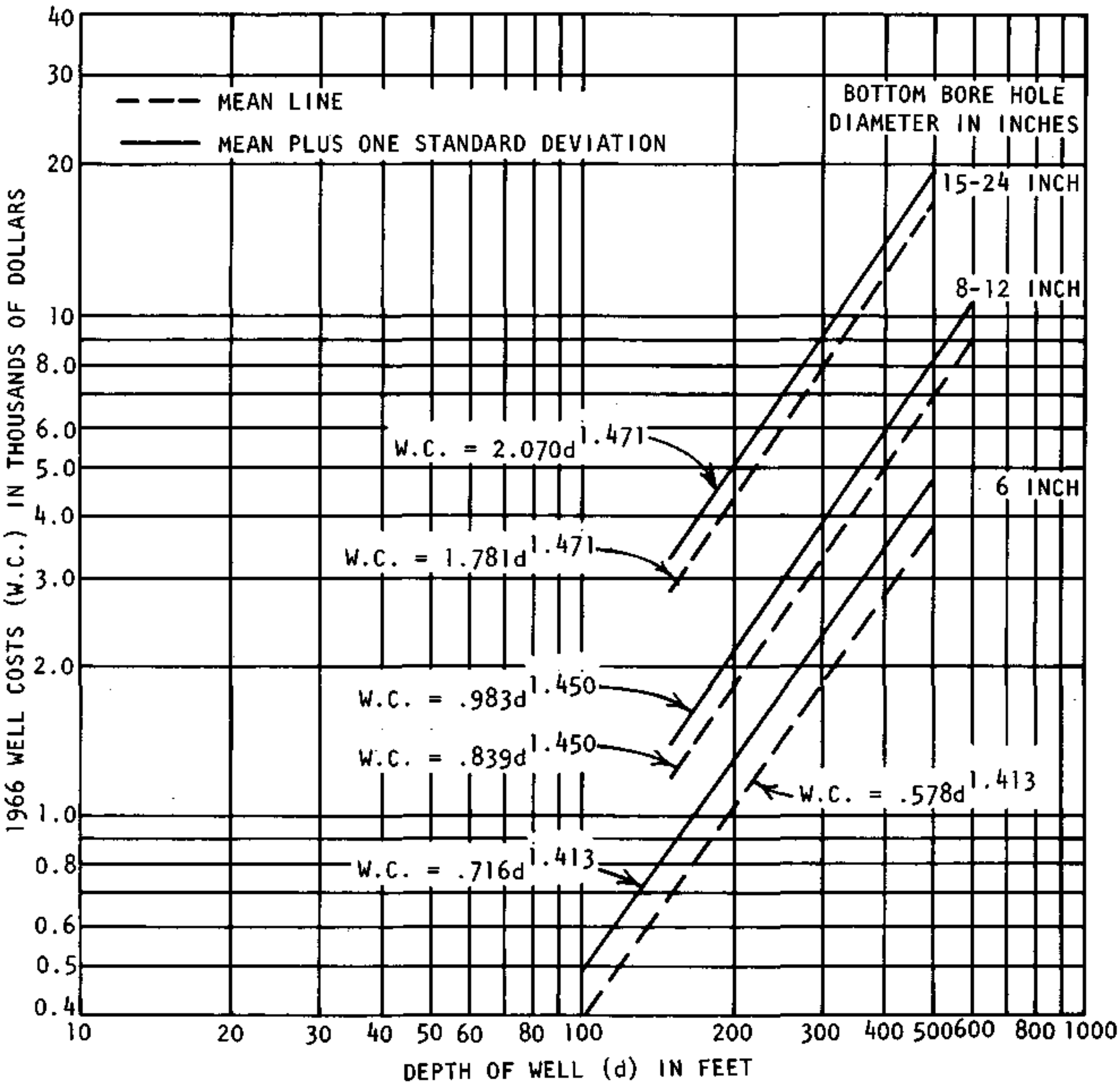

Figure 3. Cost of shallow sandstone, limestone, or dolomite bedrock wells

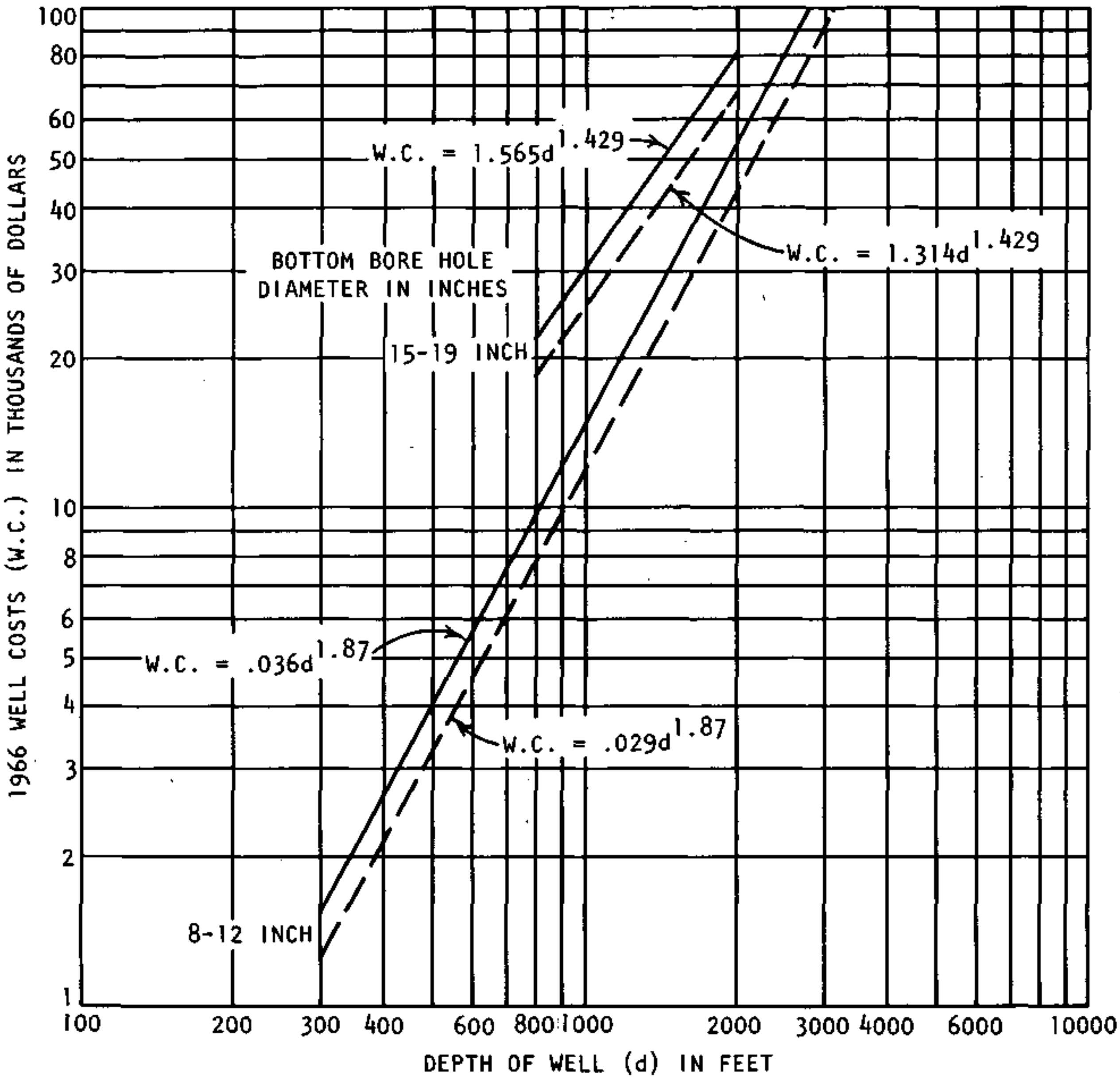

Figure 4. Cost of deep sandstone wells

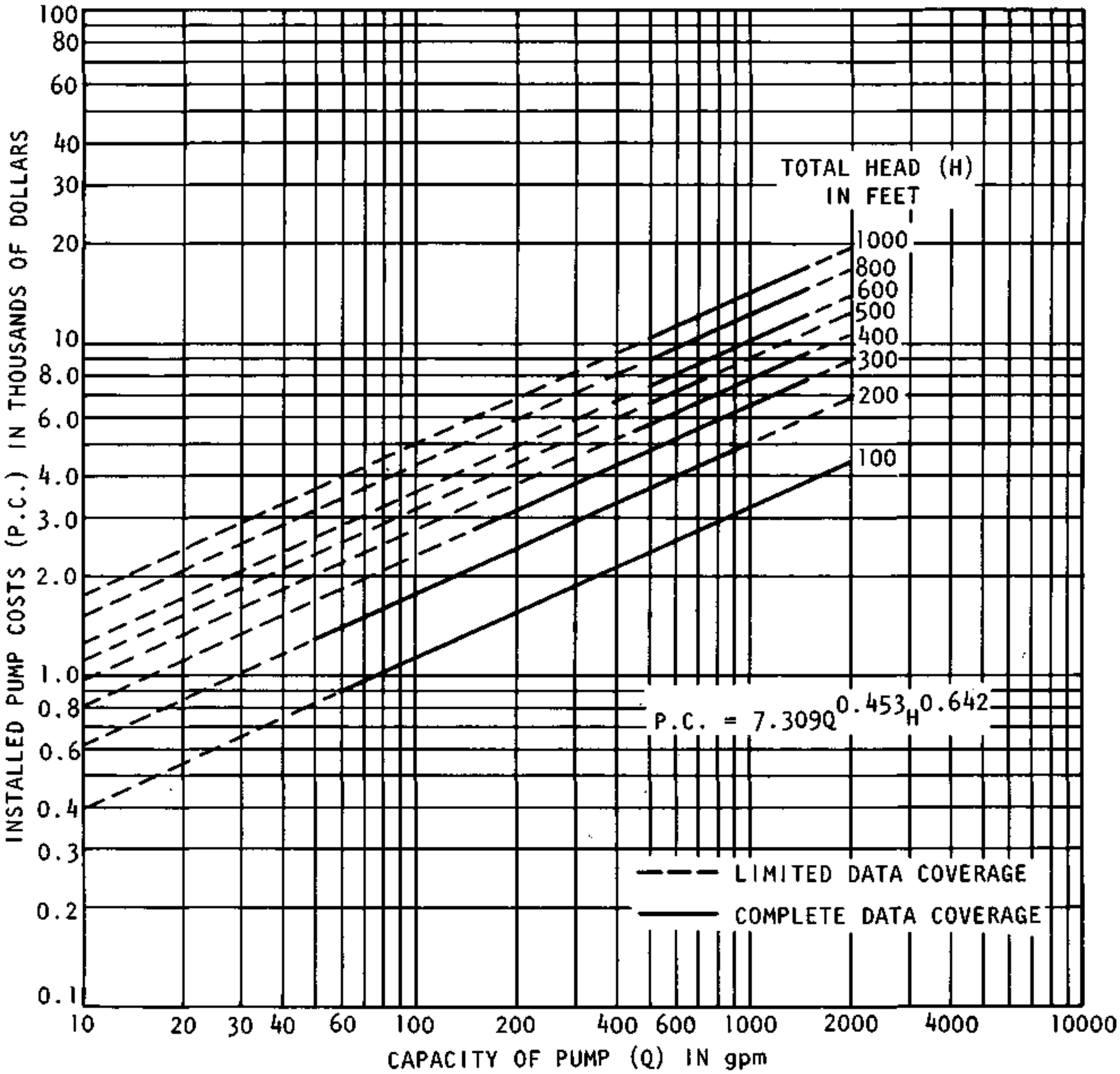

Figure 5. Costs of vertical turbine pumps

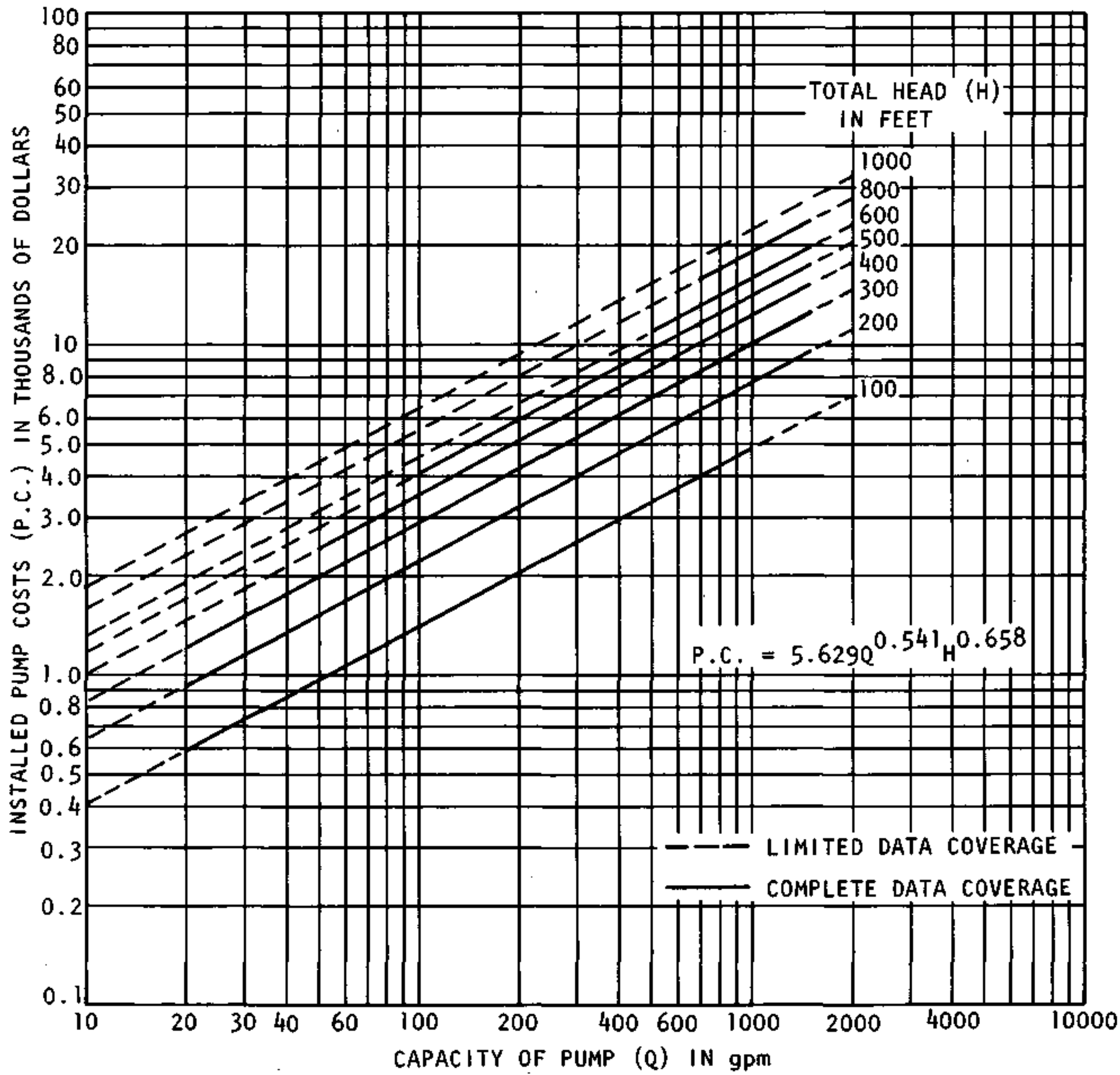

Figure 6. Costs of submersible turbine pumps