Heads and Gradients

The depth to the water table has an important effect on use of the land surface and on the development of water supplies from unconfined aquifers. Where the water table is at a shallow depth, the land may become "waterlogged" during wet weather and unsuitable for residential and many other uses. Where the water table is at great depth, the cost of constructing wells and pumping water for domestic needs may be prohibitively expensive.

The direction of the slope of the water table is also important because it indicates the direction of ground-water movement. The position and the slope of the water table (or of the potentiometric surface of a confined aquifer) is determined by measuring the position of the water level in wells from a fixed point (a measuring point). To utilize these measurements to determine the slope of the water table, the position of the water table at each well must be determined relative to a *datum plane* that is common to all the wells. The datum plane most widely used is the National Geodetic Vertical Datum of 1929 (also commonly referred to as "sea level").

If the depth to water in a nonflowing well is subtracted from the altitude of the measuring point, the result is the *total head* at the well. Total head, as defined in fluid mechanics, is composed of *elevation head, pressure head,* and *velocity head.* Because ground water moves relatively slowly, velocity head can be ignored. Therefore, the total head at an observation well involves only two components: elevation head and pressure head. Ground water moves in the direction of decreasing total head, which may or may not be in the direction of decreasing pressure head.

The equation for total head (h_t) is

$$h_t = z + h_p \qquad (5)$$

where z is elevation head and is the distance from the datum plane to the point where the pressure head h_p is determined.

All other factors being constant, the rate of ground-water movement depends on the *hydraulic gradient.* The hydraulic gradient is the change in head per unit of distance in a given direction. If the direction is not specified, it is understood to be in the direction in which the maximum rate of decrease in head occurs. Ex. A

If the movement of ground water is assumed to be in the plane of Figure 9—in other words, if it moves from well 1 to well 2—the hydraulic gradient can be calculated from the information given on the drawing. The hydraulic gradient is h_L/L, where h_L is the head loss between wells 1 and 2 and L is the horizontal distance between them, or

$$\frac{h_L}{L} = \frac{(100\text{ m} - 15\text{ m}) - (98\text{ m} - 18\text{ m})}{780\text{ m}} = \frac{85\text{ m} - 80\text{ m}}{780\text{ m}} = \frac{5\text{ m}}{780\text{ m}}$$

≈ 0.0064

When the hydraulic gradient is expressed in consistent units, as it is in the above example in which both the numerator and the denominator are in meters, any

Source: USEPA Groundwater Handbook

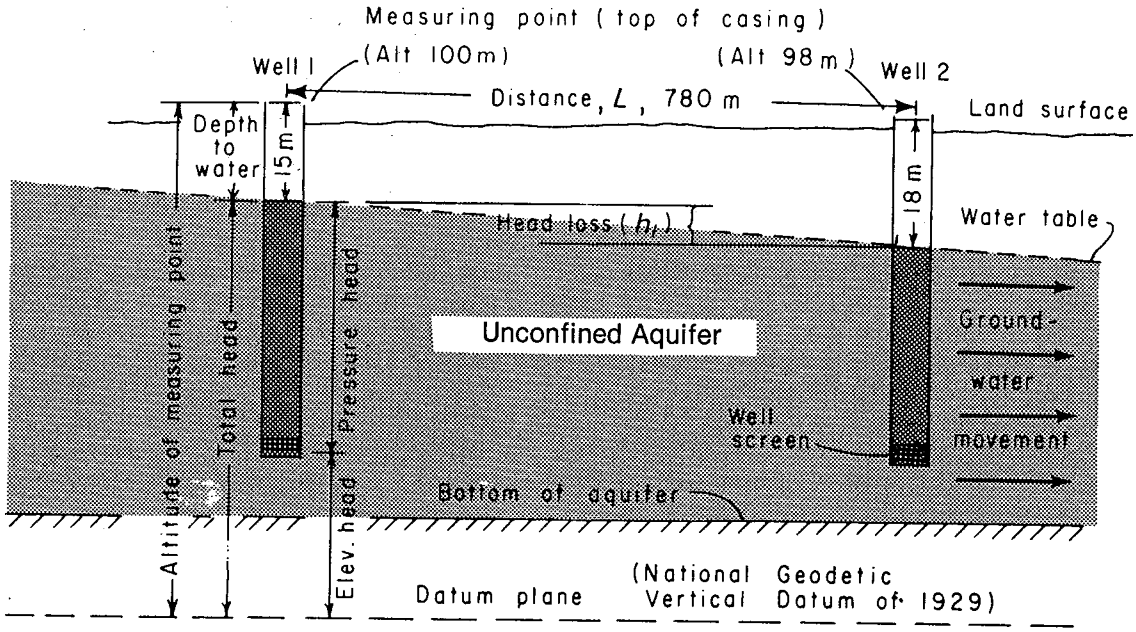


Figure 9. Gradient is Determined By the Difference in Head Between Two Wells.

Ex. B.

other consistent units of length can be substituted without changing the value of the gradient. Thus, a gradient of 5 ft/780 ft is the same as a gradient of 5m/780 m. It is also relatively common to express hydraulic gradients in inconsistent units such as meters per kilometer or feet per mile. A gradient of 5 m/780 m can be converted to meters per kilometer as follows:

$$\left(\frac{5\text{ m}}{780\text{ m}}\right) \times \left(\frac{1{,}000\text{ m}}{\text{km}}\right) = 6.4\text{ m km}^{-1}$$

Both the direction of ground-water movement and the hydraulic gradient can be determined if the following data are available for three wells located in any triangular arrangement such as that shown in Figure 10:

1. The relative geographic position of the wells.
2. The distance between the wells.
3. The total head at each well.

Figure 11 illustrates the following steps in the solution.

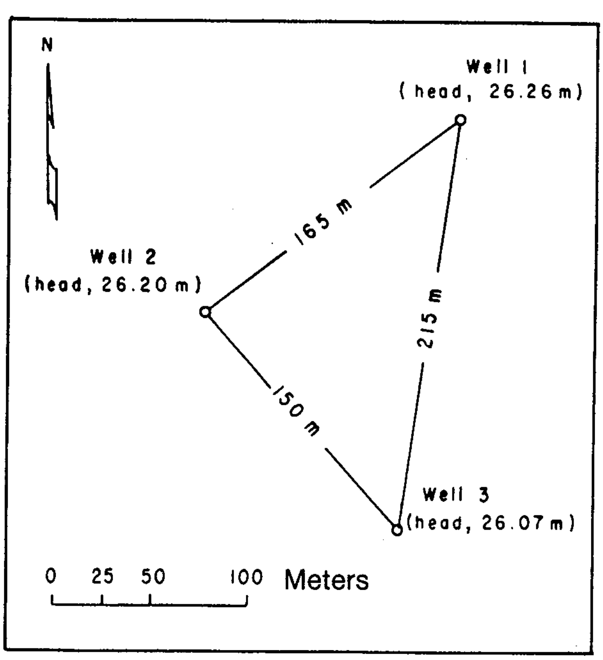


Figure 10. Triangular Arrangement of Wells

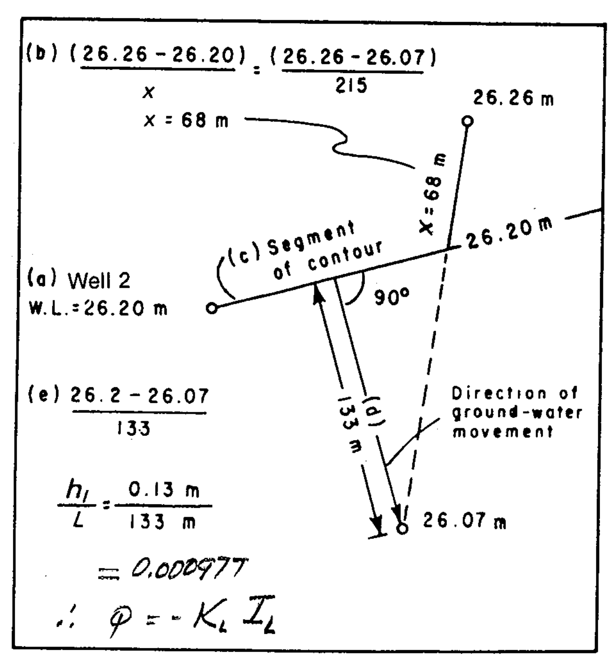
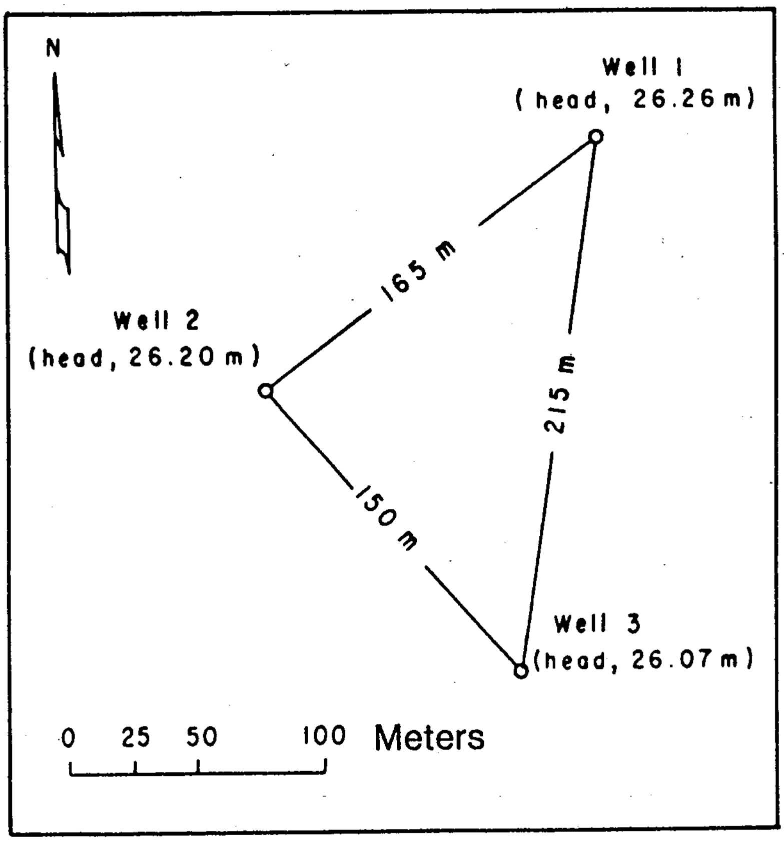
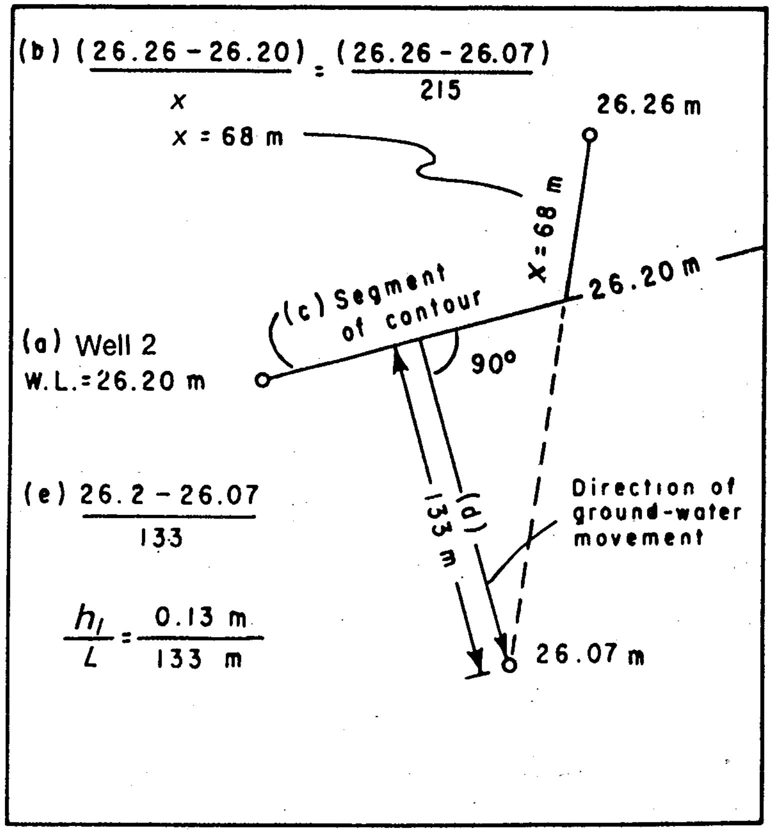


Figure 11. Determining the Direction of Ground-Water Movement and the Hydraulic Gradient for a Triangular Arrangement of Wells

May use trigonometry: $\alpha + \beta + \mu = 180°$
Law of Sines $a : b : c = \sin\alpha : \sin\beta : \sin\mu$
Law of Cosines $a^2 = b^2 + c^2 - 2bc\cos\alpha$



N
Well 1
(head, 26.26 m)
165 m
215 m
Well 2
(head, 26.20 m)
150 m
Well 3
(head, 26.07 m)
0 25 50 100 Meters


(b) $\frac{(26.26-26.20)}{x} = \frac{(26.26-26.07)}{215}$
$x = 68$ m
26.26 m
x = 68 m
26.20 m
(c) Segment of contour
(a) Well 2
W.L.=26.20 m
90°
(e) $\frac{26.2-26.07}{133}$
(d) 133 m
Direction of ground-water movement
$\frac{h_l}{L} = \frac{0.13\ \text{m}}{133\ \text{m}}$
26.07 m