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Lecture (6)

Water table and potentiometric surface maps

Lines drawn joining points of equal groundwater head, or groundwater potential, are termed equipotential lines. Lines perpendicular to the equipotential lines are flow lines and can be used in the construction of a flow net.

In an unconfined aquifer, the potentiometric surface is a map of the water table, where the groundwater is by definition at atmospheric pressure. In a confined aquifer the potentiometric surface predicts the position that the water level would rise to in a borehole that penetrates the buried aquifer.

Flow nets and the tangent law

The construction of a flow net, for example, a water table or potentiometric surface map, and the interpretation of groundwater flow lines, requires the implicit assumption that flow is perpendicular to the lines of the equal hydraulic head (i.e. the porous material is isotropic), with the flow in the direction of decreasing head.

All flow nets, however simple or advanced, can be drawn using a set of basic rules. When attempting to draw a two-dimensional flow net for isotropic porous material by trial and error, the following rules must be observed (Fig.1):

1. Flow lines and equipotential lines should intersect at right angles throughout the groundwater flow system;

2. Equipotential lines should meet an impermeable boundary at right angles resulting in groundwater flow parallel to the boundary;

3. Equipotential lines should be parallel to a boundary that has a constant hydraulic head resulting in groundwater flow perpendicular to the boundary;

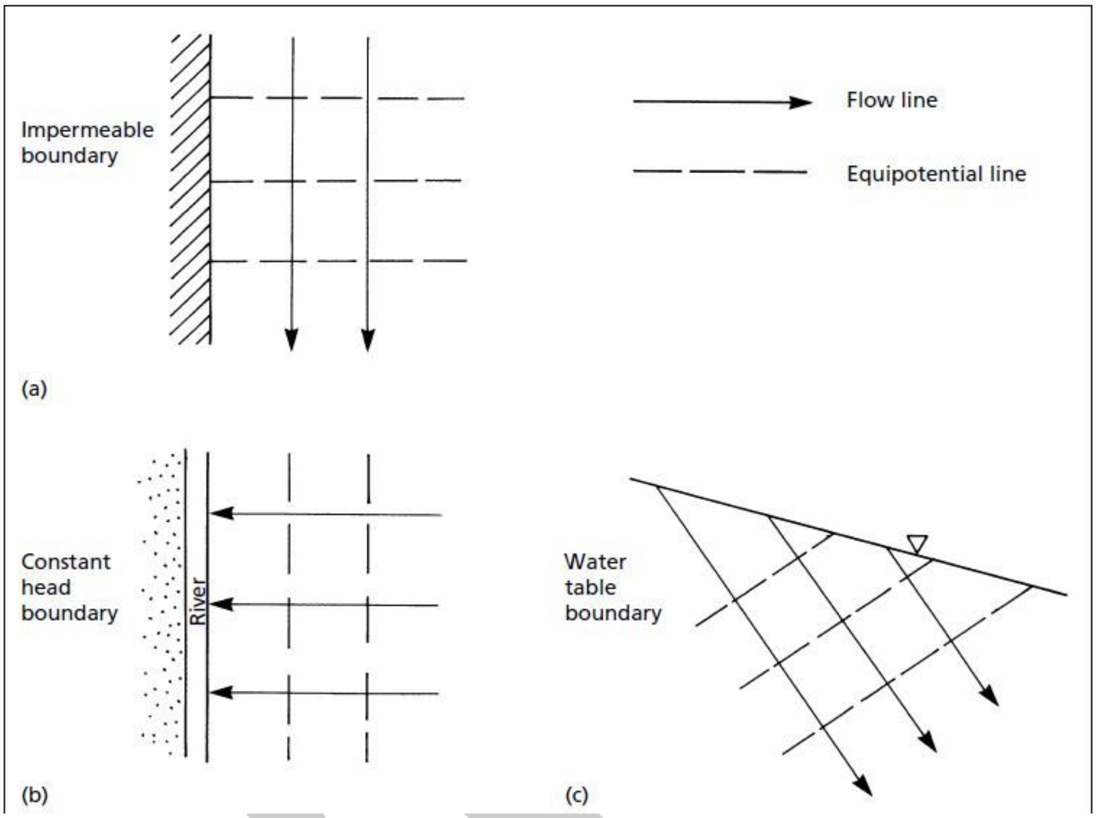
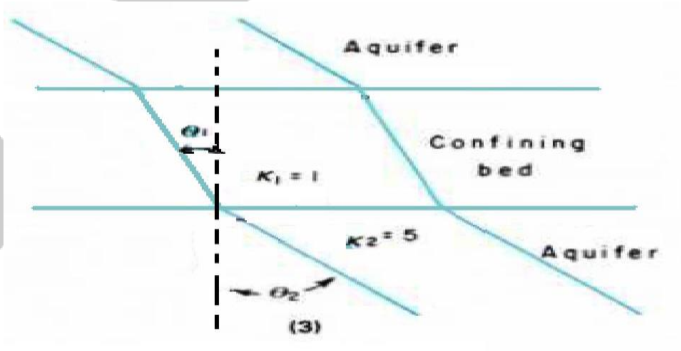


Fig.1: Simple rules for flow net construction for the cases of (a) an impermeable boundary, (b) a constant head boundary (here shown as a river), and (c) a water table boundary.

4. In a layered, heterogeneous groundwater flow system, the tangent law must be satisfied at geological boundaries; Fig. 2.



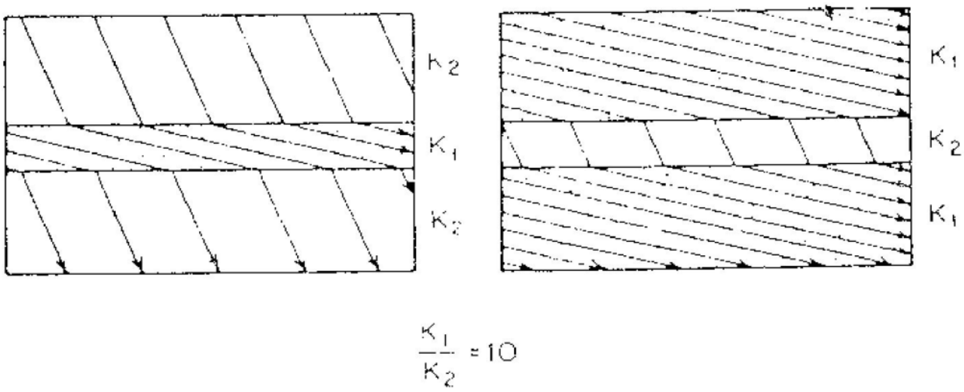


Figure 2: shows the behavior of the flow lines in the case where it is K_1/K_2=10. (I.e. the breakdown of flow lines in layered systems)

5. If squares are created in one portion of one formation, then squares must exist throughout that formation and throughout all formations with the same hydraulic conductivity with the possible exception of partial stream tubes at the edge. Rectangles will be created in formations with different hydraulic conductivity.

In Fig. 3, a flow net is constructed for groundwater flow beneath a dam structure that is partially buried in an isotropic and homogeneous sand aquifer. To calculate the flow beneath the dam, consider the mass balance for box ABCD for an incompressible fluid.

Under steady-state conditions, and assuming unit depth into the page, the flow into the box across face AB with width, Δw, will equal the flow out of the box across face DC. From Darcy's Law the best estimate of flow through box ABCD, ΔQ, is equal to:

$$\Delta Q = \Delta w . K \frac{\Delta h}{\Delta l} \text{------------------------} 1$$

or, on rearrangement:

$$\Delta Q = K . \Delta h \frac{\Delta w}{\Delta l} \text{------------------------} 2$$

If the flow net is equi-dimensional (curvilinear squares), then Δw/Δl is about equal to unity and eq. 2 becomes:

$$\Delta Q = K.\Delta h \text{---------------------------} 3$$

Δh is found from the total head drop ($h_1 – h_2$) along the stream tube divided by the number of head divisions, n, in the flow net:

$$\Delta h = \frac{h_1 - h_2}{n} \text{----------------------------} 4$$

If the number of stream tubes in the region of flow is m, then the total flow below the dam is:

$$Q = \frac{m}{n}\ .K\ (h_1 - h_2) \text{-----------------} 5$$

For the example of flow beneath a dam shown in Fig. 3, m = 5, n = 13 and (h_1 - h_2) =26 m. If the hydraulic conductivity, K, is 20 m day^{-1}, then the total flow is found from:

$Q = \frac{5}{13}\ X\ 20\ X\ 26$ = 200 m^3 day^{-1}.

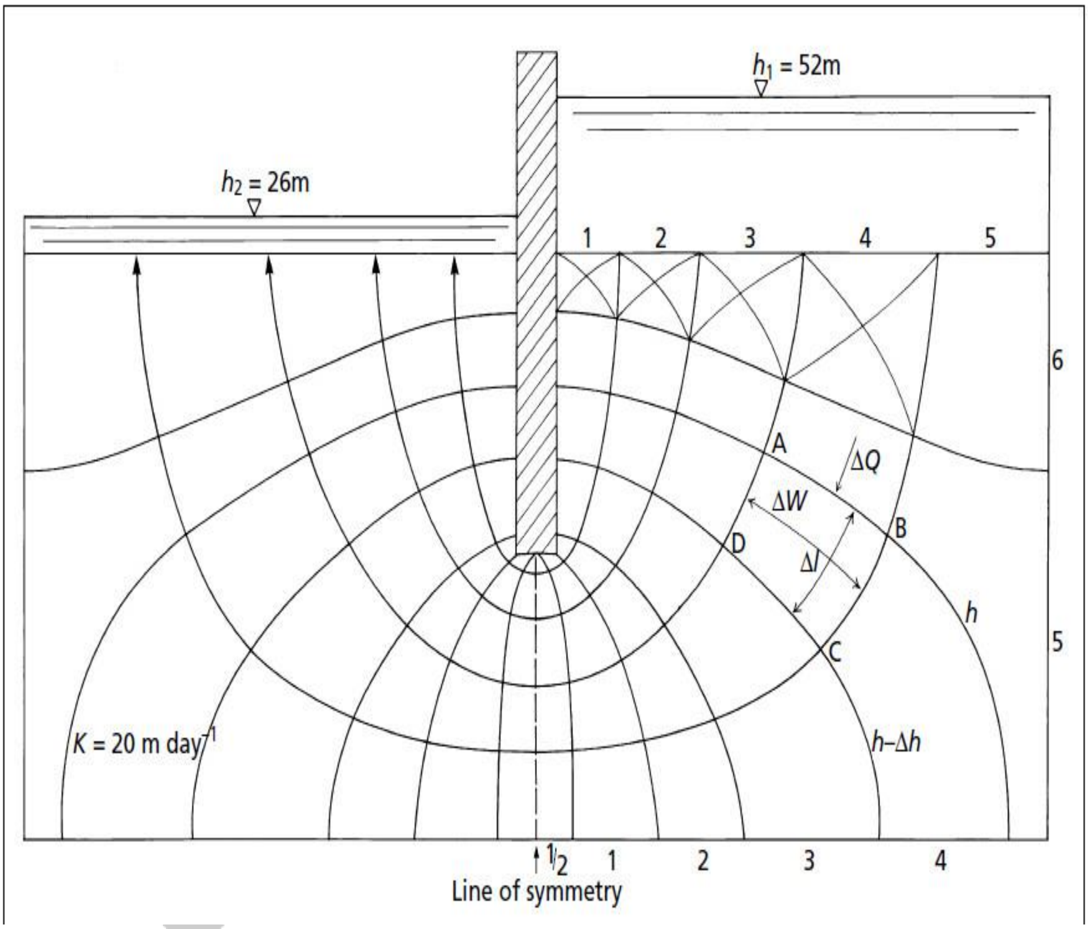
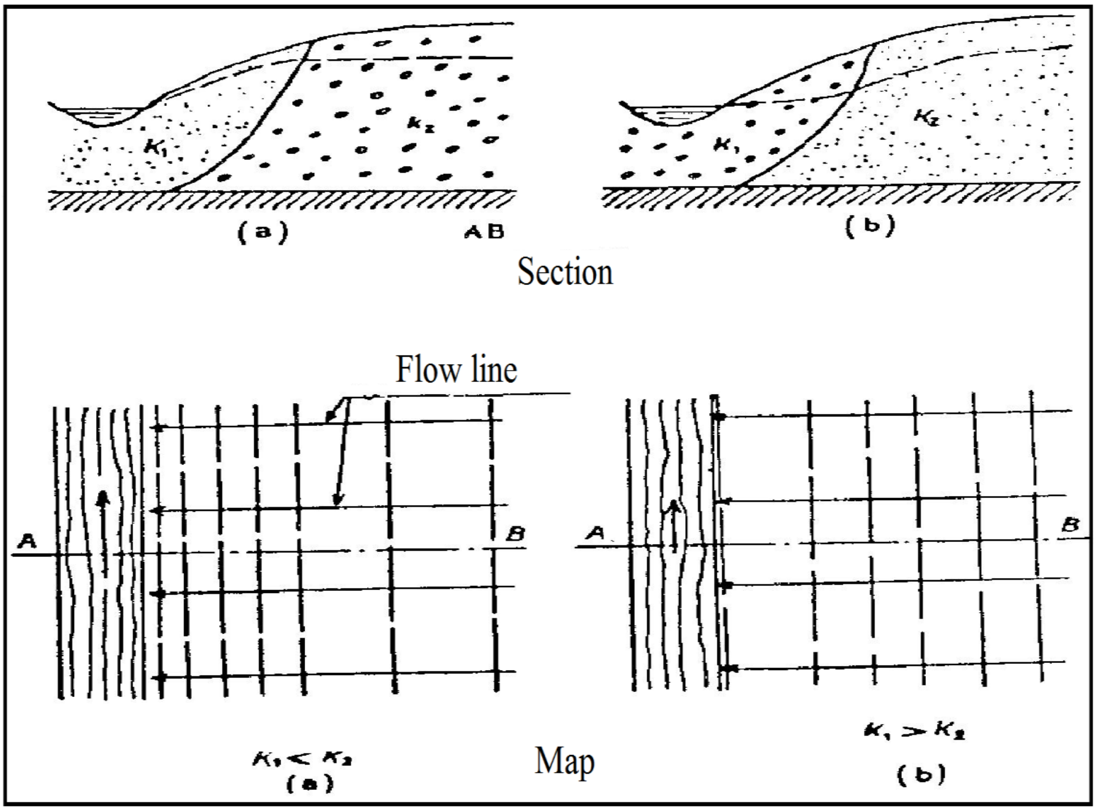


Fig. 3: Flow net constructed for groundwater flow beneath a dam in a homogeneous, isotropic aquifer.

Interpretation lines equal to water levels (potentiometric surface):

The shape and intensity of water level lines on the map give an idea of flow. Obviously, whenever it is the shorter the distance between the lines of water levels, the hydraulic gradient the larger and vice versa. The spacing between the lines of water levels indicates increased permeability, thus increasing the discharge of the region and vice versa.



A map of the potentiometric surface of the Chalk aquifer below the London Basin is shown in Fig. 4 and illustrates a number of the above points. Areas of high groundwater levels in excess of 50 m above sea level are present in unconfined areas where the Chalk is exposed on the northern and southern rims of the synclinal basin. Here, the Chiltern Hills and North Downs are the recharge areas for the London Basin, respectively.

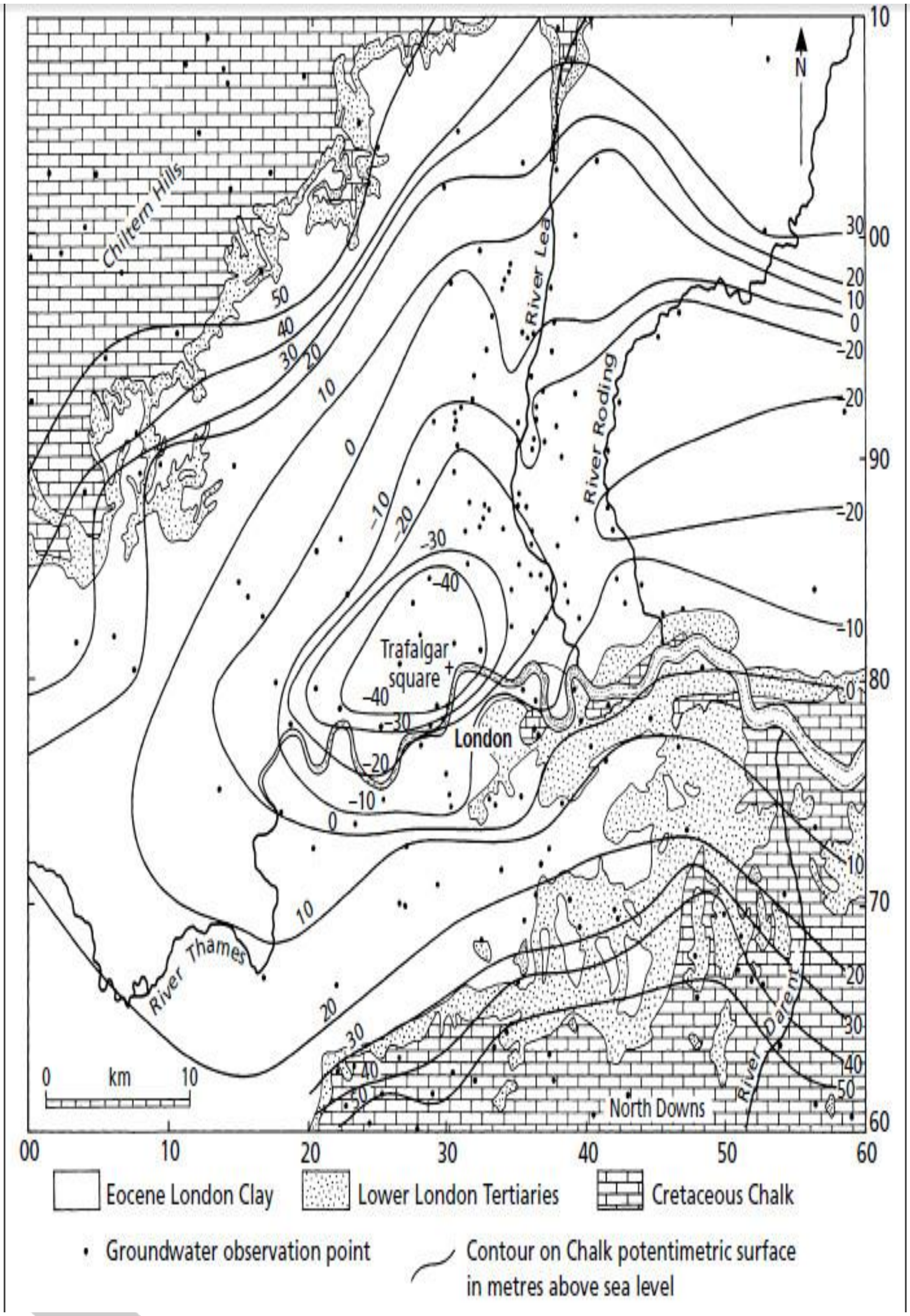
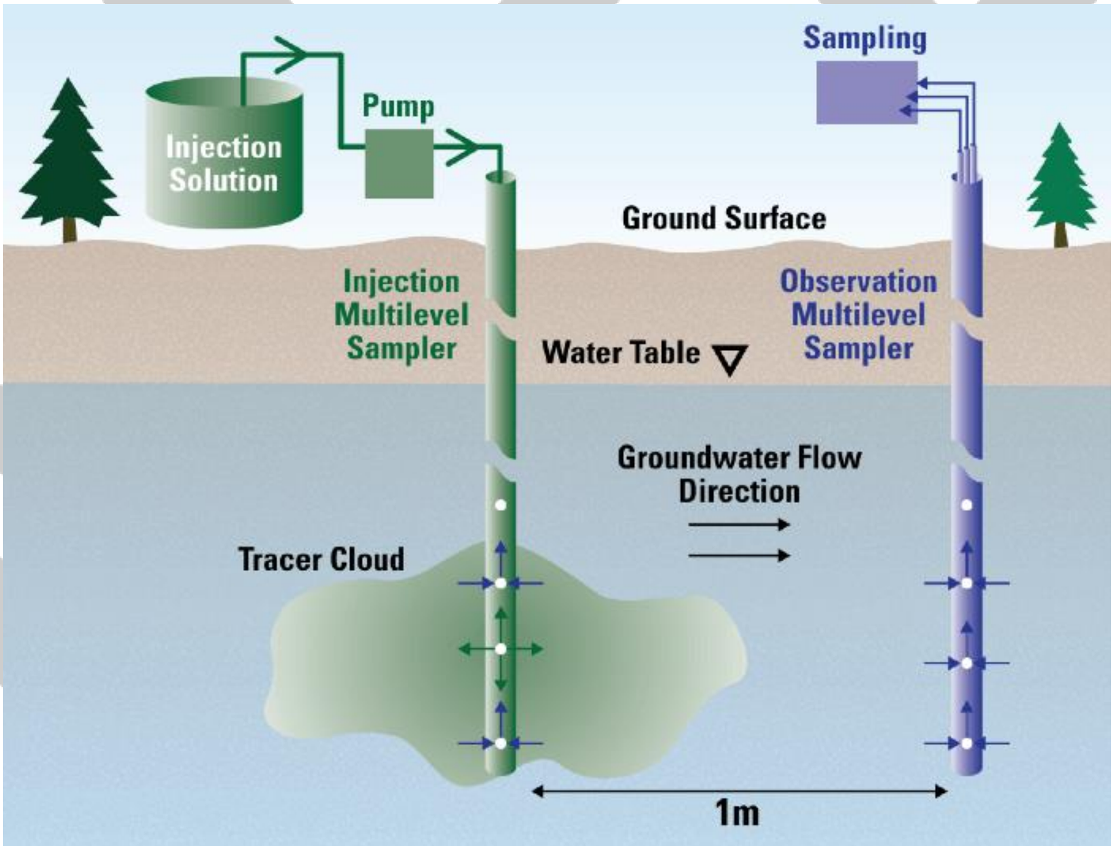


Fig.4: Map of the potentiometric surface of the Chalk aquifer underlying the London Basin drawn from observations made in January 1994. (Adapted from Lucas and Robinson 1995)

Tracing groundwater movement

The direction and velocity of groundwater movement in aquifers can be determined in several ways the most important is the use of colors or salts. Where the observation wells are drilled at a certain distance from the optional well if the direction of the current is detected, the observation wells are drilled in the direction of the current after the well, If the direction of the current is unknown, the observation wells are drilled in a circular manner:

- A distance (1 – 1.5) m in the case of aquifers composed of coarse sand.
- A distance (0.5 – 1) m in the case of water layers consisting of fine and medium sand.



A salt solution is then injected into the optional well with chlorine concentration increasing by 2000 times for its concentration in groundwater. It then determines the time required for chlorides to reach the observation wells; knowing the time of injection of salt into the optional well and measuring chloride content in observation wells, where water samples are taken every 10 minutes. The well in which the salt appears before others is located in the direction of the groundwater flow. The velocity of groundwater movement can be determined by the following equation:

$$V = \frac{l}{t}$$

Where; l: The distance between the optional well and the observation well in the direction of current in meters. t: Time from the beginning injected of the saline solution in the well until it appears in the observation well.

To determine t can be draw curve diagram, showing the relationship between the chloride content in groundwater and the time that has passed since the beginning of the experiment. The time (t) is taken equal to the value of the horizontal coordinate located opposite A, some sources recommend taking value up to the maximum point B.

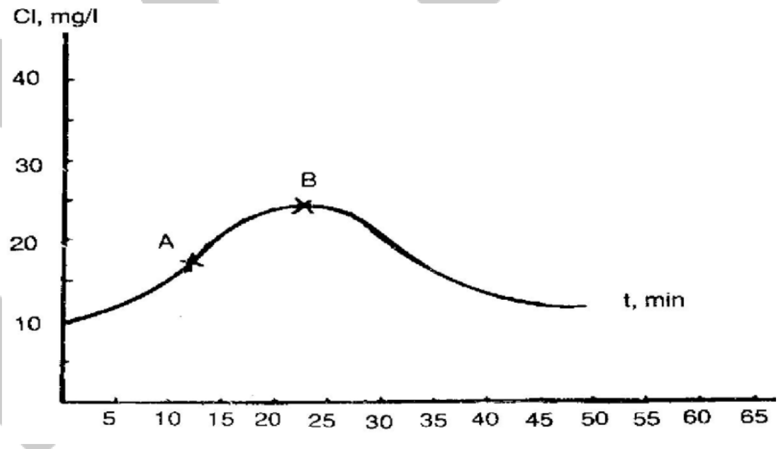


Fig. --: The spread of chlorine when determining the velocity of groundwater movement

The velocity of groundwater movement in highly saline aquifers, especially those with more than 500 – 600 mg/l chlorine content. We cannot be determining it by salts, organic dyes are used instead of salt.

Fluorescent Dyes

Fluorescent dyes are some of the oldest groundwater tracers known and have been used successfully for more than 100 years. Fluorescent dyes are now the most commonly used groundwater tracers because they fulfill the following criteria for optimal artificial tracers:

1. they are readily soluble in water;
2. adequately conservative (they don't react with water or soil/rock);
3. inexpensively detectable at very small concentrations;
4. readily available and relatively inexpensive; and, most importantly
5. low in toxicity thereby posing no significant health or environmental hazard (except for pink or green fingers).

Figure --: Uranine dye moving downstream in Fisher Creek during a 2003 injection to trace the destination of the water disappearing at Fisher Creek.

In *acidic groundwater*, Methylene blue is added instead of Fluorescent Dyes. The table below gives an idea of some of the tracers used to detect groundwater movement:

TABLE Classification by Method of Detection of Substances Which May Be Useful as Ground Water Tracers

Colorimetry	Chemical Determination
Organic dyes and stains, water soluble	Soluble chloride salts
Soluble chromate salts	Boron, borax, and boric acid
Amaranth dye	Copper sulfate
Basic fuchsin	Dextrose
Congo red	Ethanethiol
Eosine	Sodium glyceral phosphate
Magenta	Sodium iodide
Methylene blue	
Sodium fluorescein	
Mass Spectrography	**Nuclear Radiation**
Helium	Bromine 82
Hydrogen 2	Calcium 45
Oxygen 18	Cobalt 60
	Hydrogen 3 (Tritium)
	Iodine 131
	Phosphorus 32
	Rubidium 86
Flame Spectrophotometry	**Electrical Conductivity**
Soluble lithium salts[a]	Any strong electrolyte

References:

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- **Analysis and Evaluation of Pumping Test Data**, Kruseman, G. P., and de Ridder, N. A. 1994.
- **Hydrogeology Principles and Practice**, Second Edition, Kevin M. Hiscock and Victor F. Bense.
- **Watershed management**, Prof. T I Eldho, Department of Civil Engineering, IIT Bombay.
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