ILHAM-EC

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Intoduction to groundwater resources exploration and exploitation

Prof. Konstantinos Mattas

Dr. Christos Mattas

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GROUNDWATER RESOURCES

<u>Groundwater as a water source can offer various advantages such as:</u>

- reduced seasonal fluctuation of supply to the point of use
- reduced evaporation losses
- reduced sedimentation/bacteriological treatment needs

GROUNDWATER EXPLORATION

The following methodologies are critical to the successful groundwater resources exploration:

- **Evaluation of Groundwater Supply Potential**
- **Geologic and Structural Mapping**
- **Geographic Information Systems (GIS) Mapping and Analysis**
- **Remote Sensing and Image Interpretation**
- **Hydrogeologic and Recharge Investigations**
- **Water supply Contaminant Threats Mapping and Evaluation**

http://www.groundwaterresources.com/groundwaterexploration.html

GROUNDWATER RESOURCE EVALUATION

Evaluation of exisiting or under development water resources include the following steps:

- **Pumping Test Planning and Design**
- **Pumping Test Supervision**
- **Water Supply Safe Yield Analysis**
- **Water Quality Testing and Analysis**
- **Hydrogeologic and Groundwater Modeling**
- **Long Term Water Supply Monitoring and Protection**

EVALUATION OF GROUNDWATER SUPPLY POTENTIAL

DESK STUDY

During desk study all the available data from the competent authorities, management bodies, free lancers (e.g. geological companies), research institutes or from internet are collected.

This step is prior to the field work. Field work will provide updated data. The main topics of interest for a hydrogeologist or a relavant scientist (e.g. engineers, geoscientist, environmental scientists etc) include the following:

- ✓ Maps: geological, topographical, hydrogeological
- ✓ Lithological sections of the boreholes and boreholes reports
- ✓ Meteorological data: rainfall, temperature etc
- ✓ River flow data

https://books.google.gr/books?id=hK1RDgAAQBAJ&pg=PT55&lpg=PT55&dq=desk+study+in+hydrogeology&source=bl&ots=k4l_BX03Nq&sig=A5QyI9eOwT6Qy0Q1PJ9vMGfaHnw&hl=el&sa=X&ved=0ahUKEwjBqP39hLnYAhXQ16QKHff3AMgQ6AEIZTAJ#v=onepage&q=desk%20study%20in%20hydrogeology&f=false

EVALUATION OF GROUNDWATER SUPPLY POTENTIAL

FIELD WORK

An adequate groundwater resources exploration should at least include the following actions:

- ✓ Inventory of all the water abstraction points (using GPS)
- ✓ Recording of the boreholes characteristics. A well inventory form should be used.
- ✓ Potential pollution sources must be detected.
- ✓ Groundwater level and discharge rate measurements in wells and boreholes.
- ✓ Water sampling and water quality in situ measurements (pH, EC, temperature, dissolved oxygen etc).

Shishaye HA, Abdi S (2016) Groundwater Exploration for Water Well Site Locations Using Geophysical Survey Methods. Hydrol Current Res 7:226. doi:10.4172/2157-7587.1000226

EVALUATION OF GROUNDWATER SUPPLY POTENTIAL

FIELD WORK

- ✓ Soil sampling.
- ✓ Geological, hydrogeological mapping.
- ✓ Drilling of new boreholes, logging in the boreholes, geophysical investigations, use of tracers, isotopes.
- ✓ Pumping tests
- ✓ Installation of monitoring systems (rainfall, temperature, groundwater level, river flow, borehole discharge)
- ✓ Taking photos in the field is a very good practise.

GEOLOGIC AND STRUCTURAL MAPPING

Structural mapping is the identification and characterization of structural expression. Structures include faults, folds, synclines and anticlines and lineaments

The geological formations have different hydrogeological behavior. They are classified in three main categories:

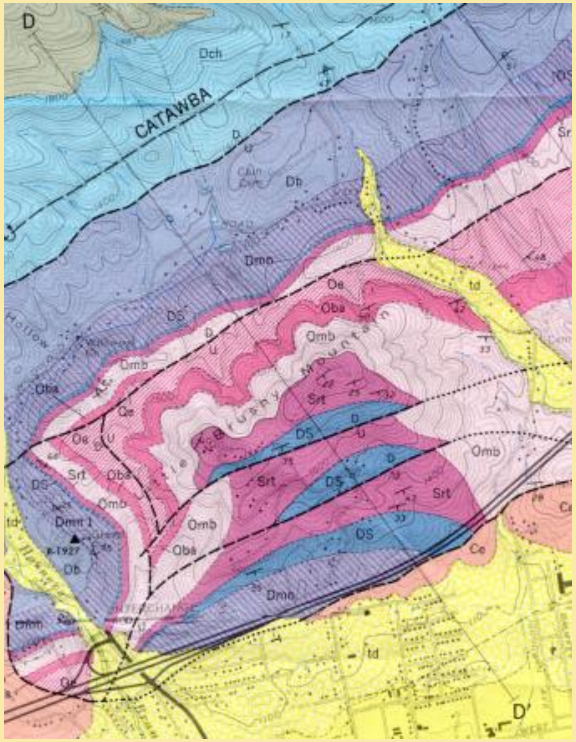
- ✓ Permeable
- ✓ Impermeable
- ✓ Semi-permeable

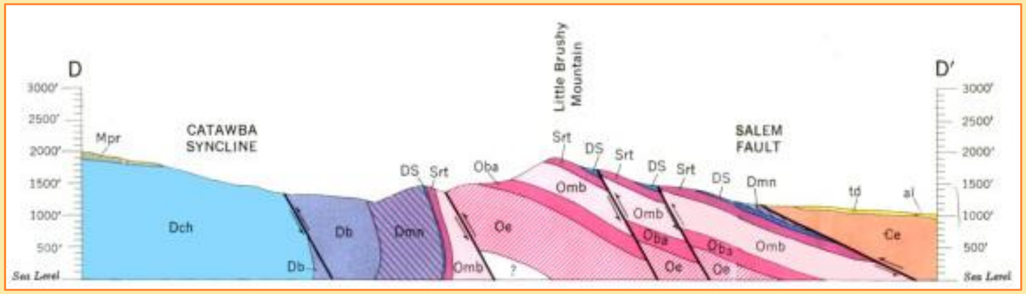
<u>Structures can indicate potential locations of aquifers by characterizing the underlying subsurface geometry of rock units.</u>

The assessment of the obtained geological information regarding the type of the soil or rock formations, their structural/stratigraphic position, the geometry of the formations (depth, thickness, inclination etc) can be used for a preliminary aquifers classification.

http://www.nrcan.gc.ca/node/9345

GEOLOGIC AND STRUCTURAL MAPPING

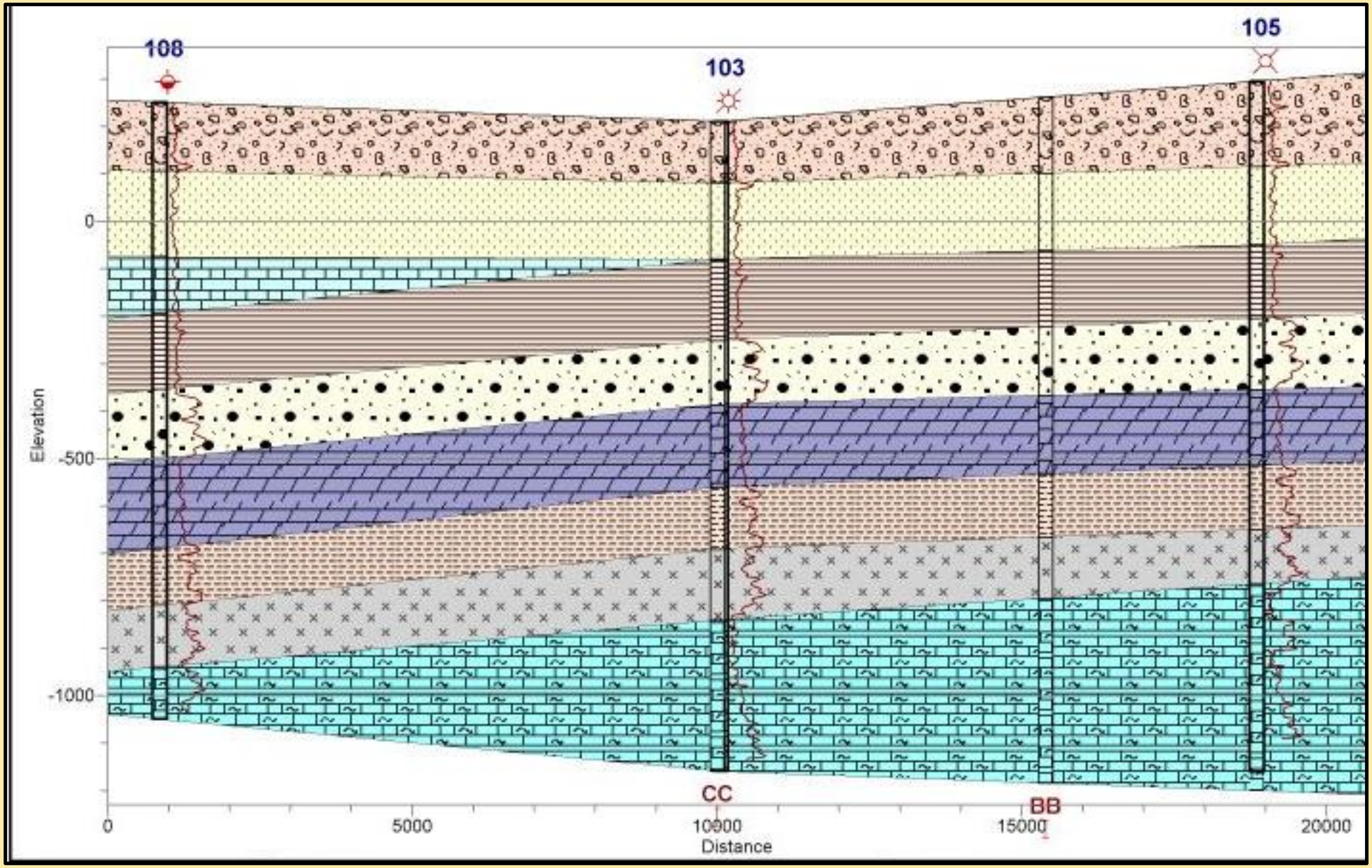




https://www.radford.edu/jtso/GeologyofVirginia/Structures/GeologyOfVAStructures4-3b.html

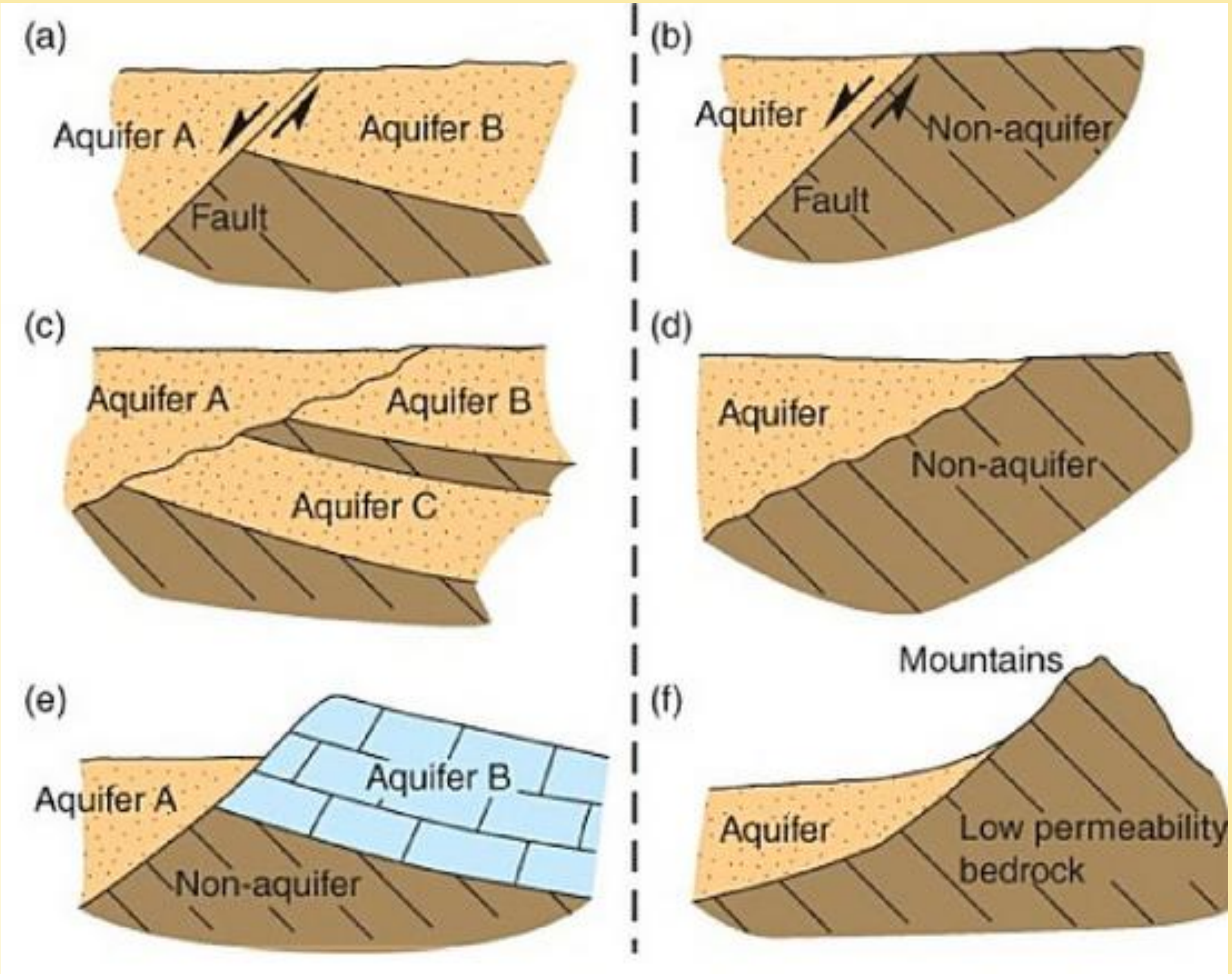
GEOLOGIC AND STRUCTURAL MAPPING

Boreholes lithological sections are also extremely useful tools towards this direction. Boreholes are always the most reliable source of information.



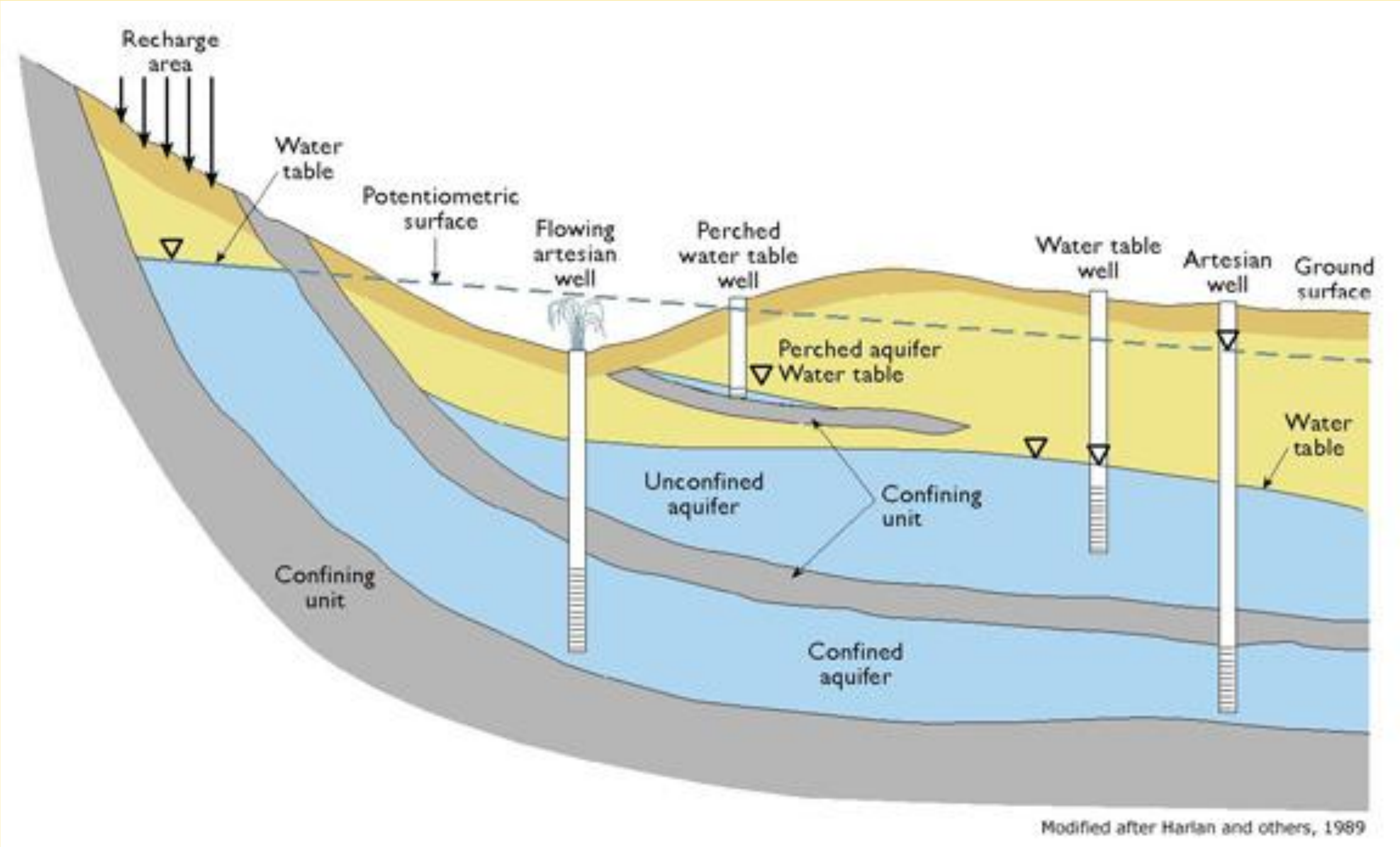
https://gaea.ca/proddetail.php?prod=3021

HYDROGEOLOGIC AND RECHARGE INVESTIGATIONS



https://books.google.gr/books?id=hK1RDgAAQBAJ&pg=PT55&lpg=PT55&dq=desk+study+in+hydrogeology&source=bl&ots=k4l_BX03Nq&sig=A5QyI9eOwT6Qy0Q1PJ9vMGfaHnw&hl=el&sa=X&ved=0ahUKEwjBqP39hLnYAhXQ16QKHff3AMgQ6AEIZTAJ#v=onepage&q=desk%20study%20in%20hydrogeology&f=false

HYDROGEOLOGIC AND RECHARGE INVESTIGATION



http://butane.chem.uiuc.edu/pshapley/environmental/l23/3.html

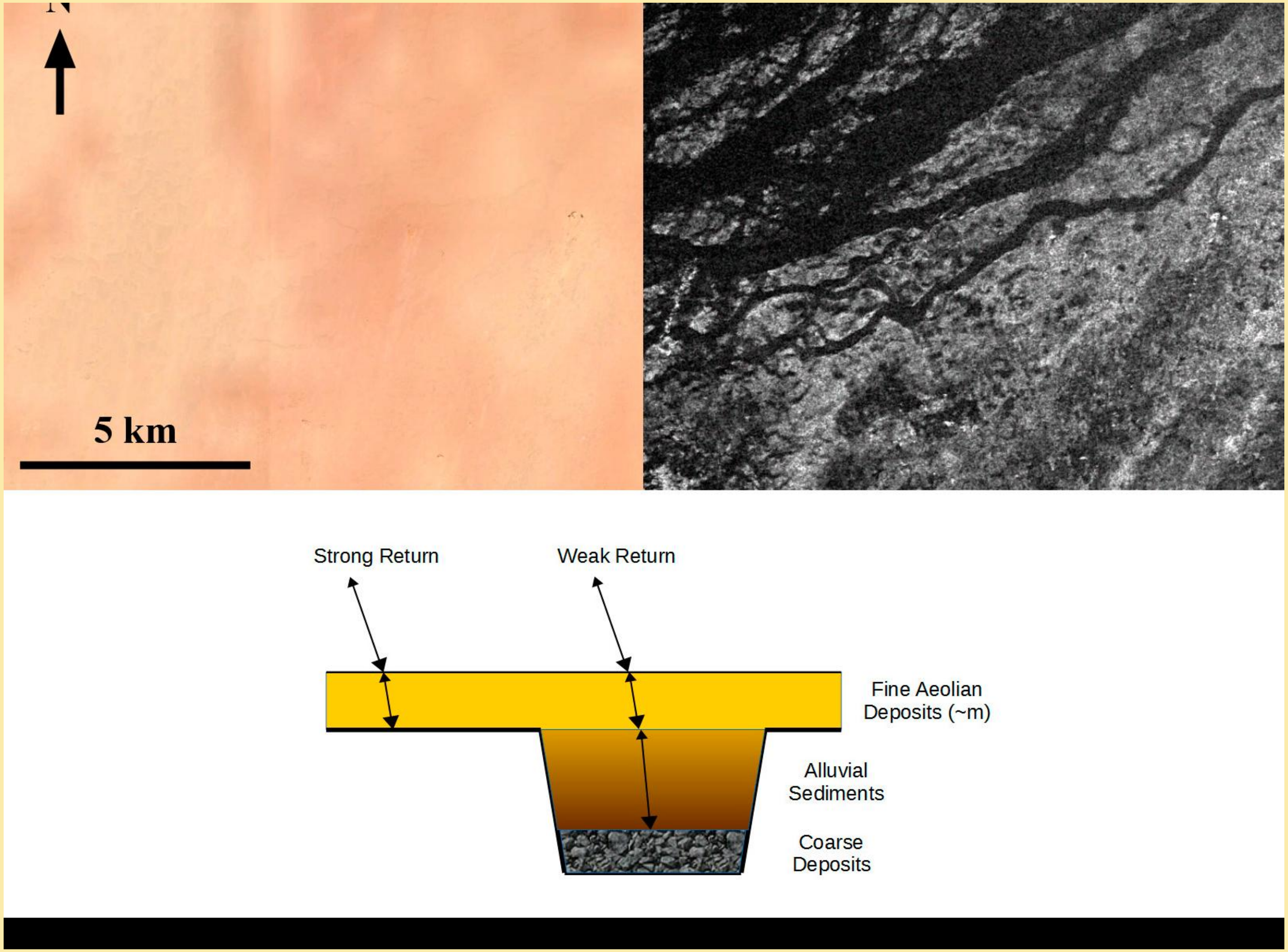
REMOTE SENSING

Remote sensing is used more often during the last years and offers a synoptic regional scale of view and allows a geologist to examine different type of data simultaneously (that is not possible from the point ground observation).

Remotely sensed data are nowadays commonly used for monitoring of hydrological parameters (soil moisture, rainfall, water levels, flood extent) or for monitoring changes such as land use change, forest and vegetation changes, urban extent, soil cover.

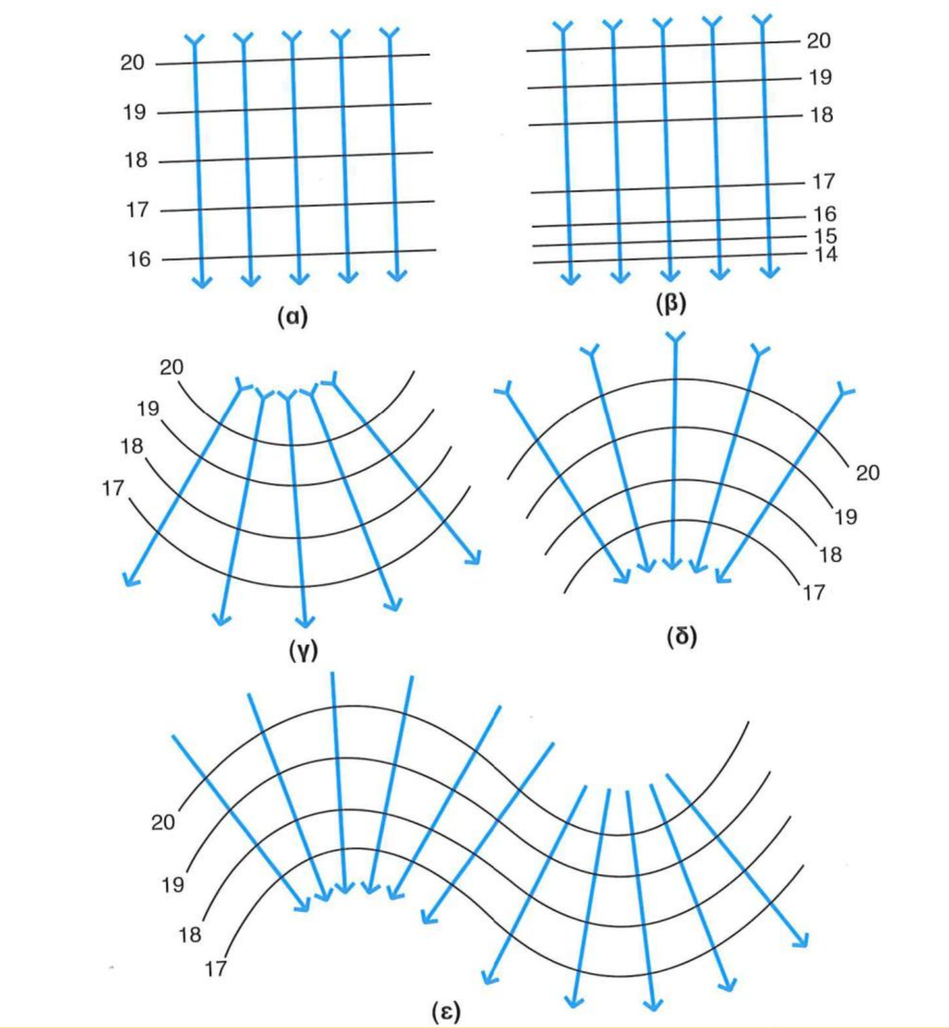
The remote sensing techniques include radar, microwave, infrared, and visible sensors.

REMOTE SENSING



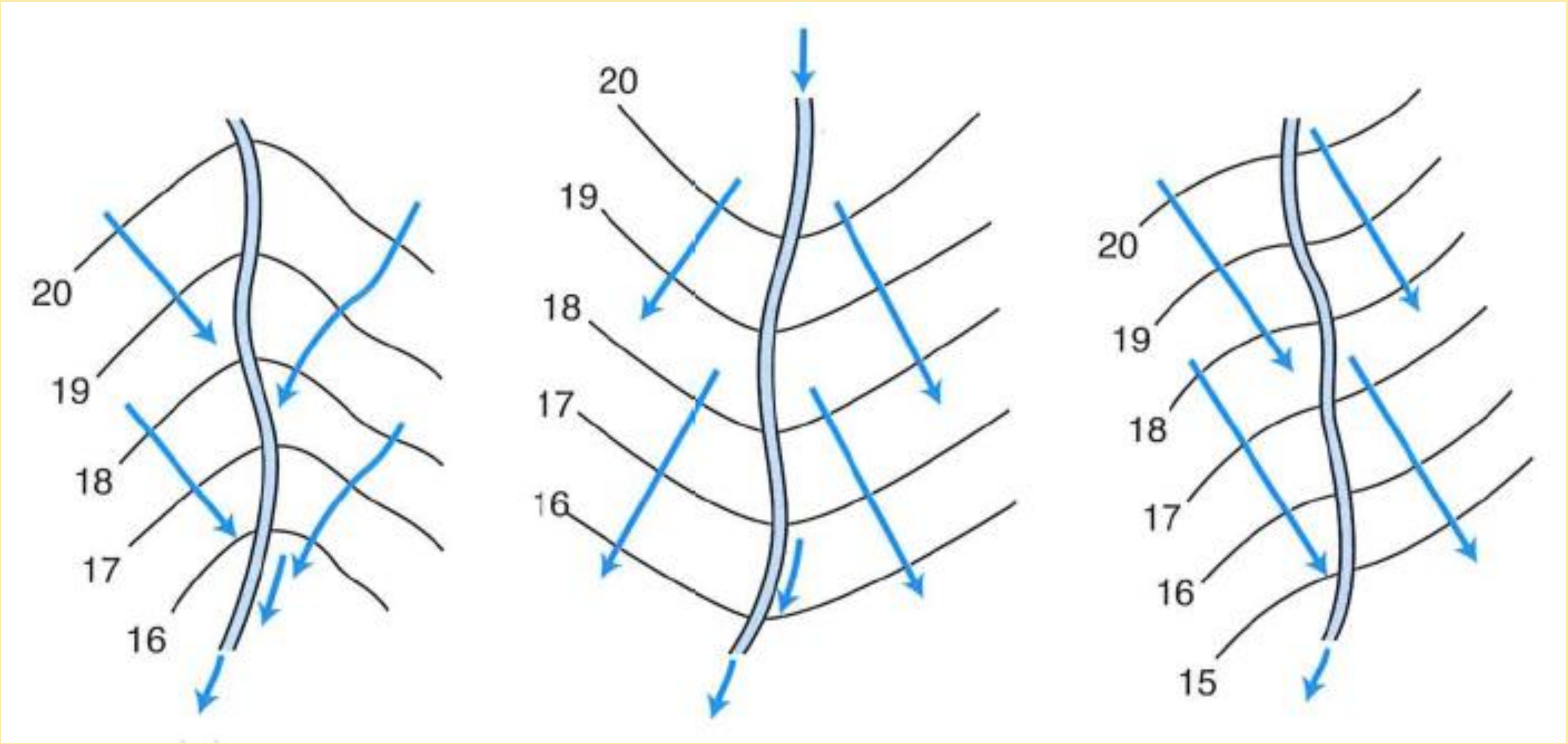
Philippe Paillou (2017). Mapping Palaeohydrography in Deserts: Contribution from Space-Borne Imaging Radar. Water , 9, 194; doi:10.3390/w9030194

HYDROGEOLOGIC AND RECHARGE INVESTIGATIONS

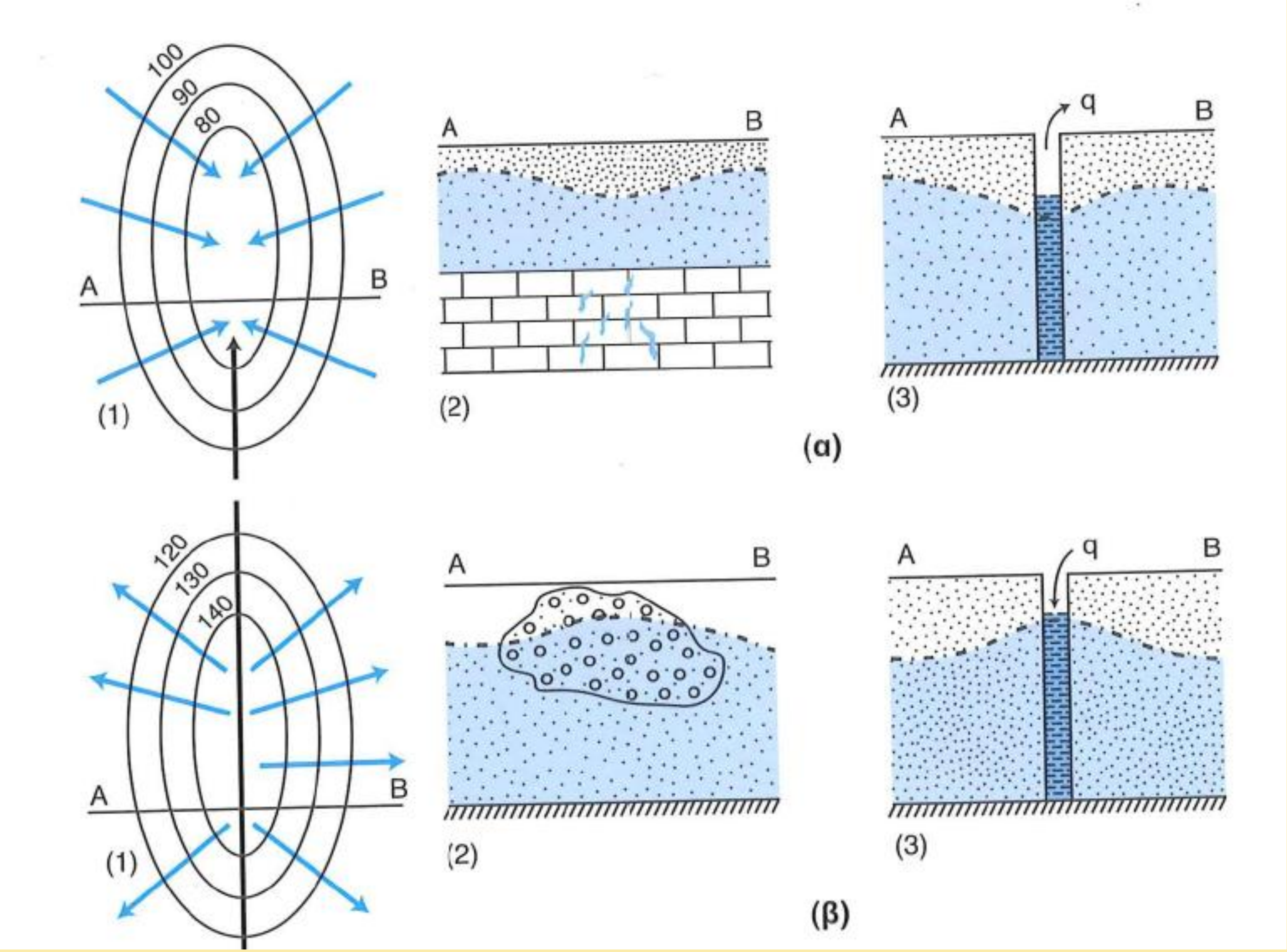


Kostas Voudouris (2015). Groundwater exploitation and management. Tziolas publications, ISBN 978-960-418-469-9 (in greek)

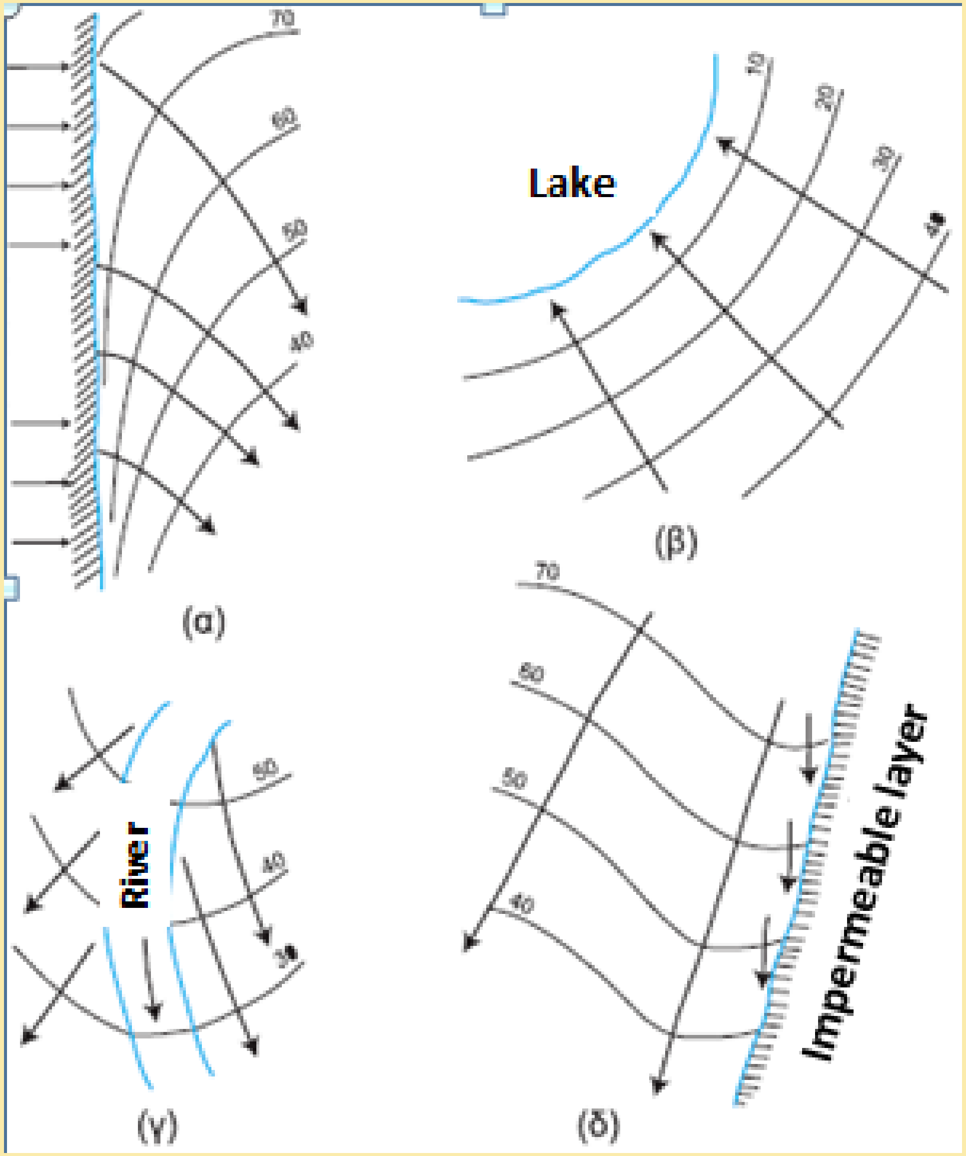
HYDROGEOLOGIC AND RECHARGE INVESTIGATIONS



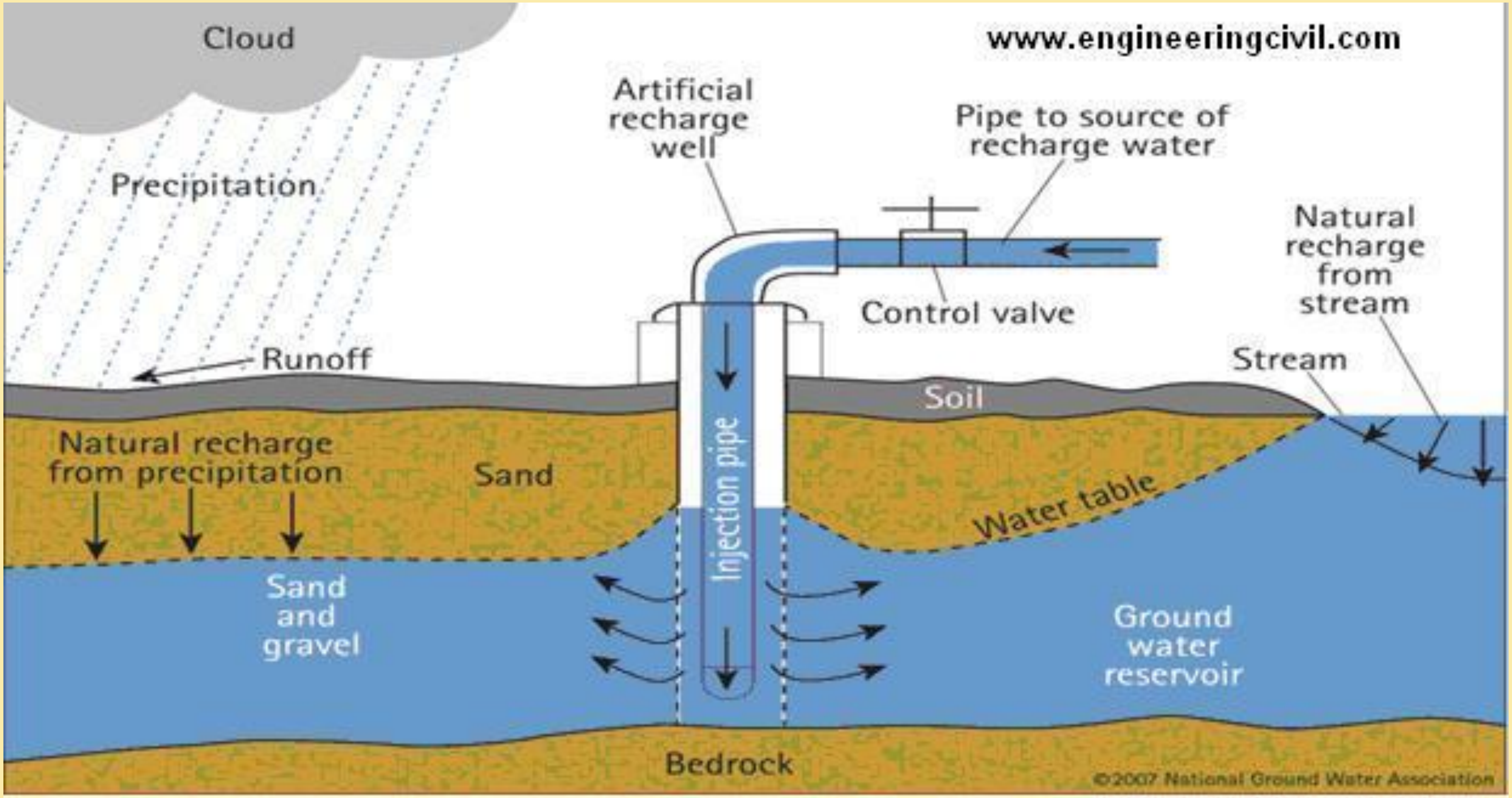
HYDROGEOLOGIC AND RECHARGE INVESTIGATIONS



HYDROGEOLOGIC AND RECHARGE INVESTIGATIONS



HYDROGEOLOGIC AND RECHARGE INVESTIGATIONS



The main recharge sources are precipitation or surface water bodies

http://www.engineeringcivil.com/groundwater-recharge-by-waste-water.html

WATER SUPPLY CONTAMINANT THREATS MAPPING AND EVALUATION

During the field observation all the potential pollution sources are mapped.

In situ measurements and water sampling and laboratory analysis are conducted.

The location of these pollution sources is marked using a GIS and photos must be taken.

Details regarding the type of the source are recorded (point or surface, sesonal or continuous), the kind of the pollutant , the amount etc.

WATER SUPPLY CONTAMINANT THREATS MAPPING AND EVALUATION

After the mapping of the possible threats the hydrogeological data are evaluated. A number of indicative parameters that are evaluated are presented in the following lines:

- ✓ The type of the aquifer (confined/unconfined)
- ✓ The water abstraction works (type and characteristics of boreholes)
- ✓ The water use in the vicinity of the pollution source (regarding the use there are different threats)
- ✓ Groundwater flow (direction), groundwater flow velocity
- ✓ Soil/rock properties

ISOTOPES

Isotopes in hydrogeology can be used in order to :

- Detect the elevation of aquifers recharge zone
- Detect the mixture of water from different aquifers or between aquifers and surface water
- Seawater intrusion
- Evapotranspiration of surface water

TRACERS

Tracers can be used for:

- The monitoring of groundwater flow
- Calculation of the flow velocity
- Detection of the recharge zone
- Detection of the groundwater flow towards a well/borehole
- Detection of a pollutant flow and delimitation of a polluted area
- Interaction between different aquifers

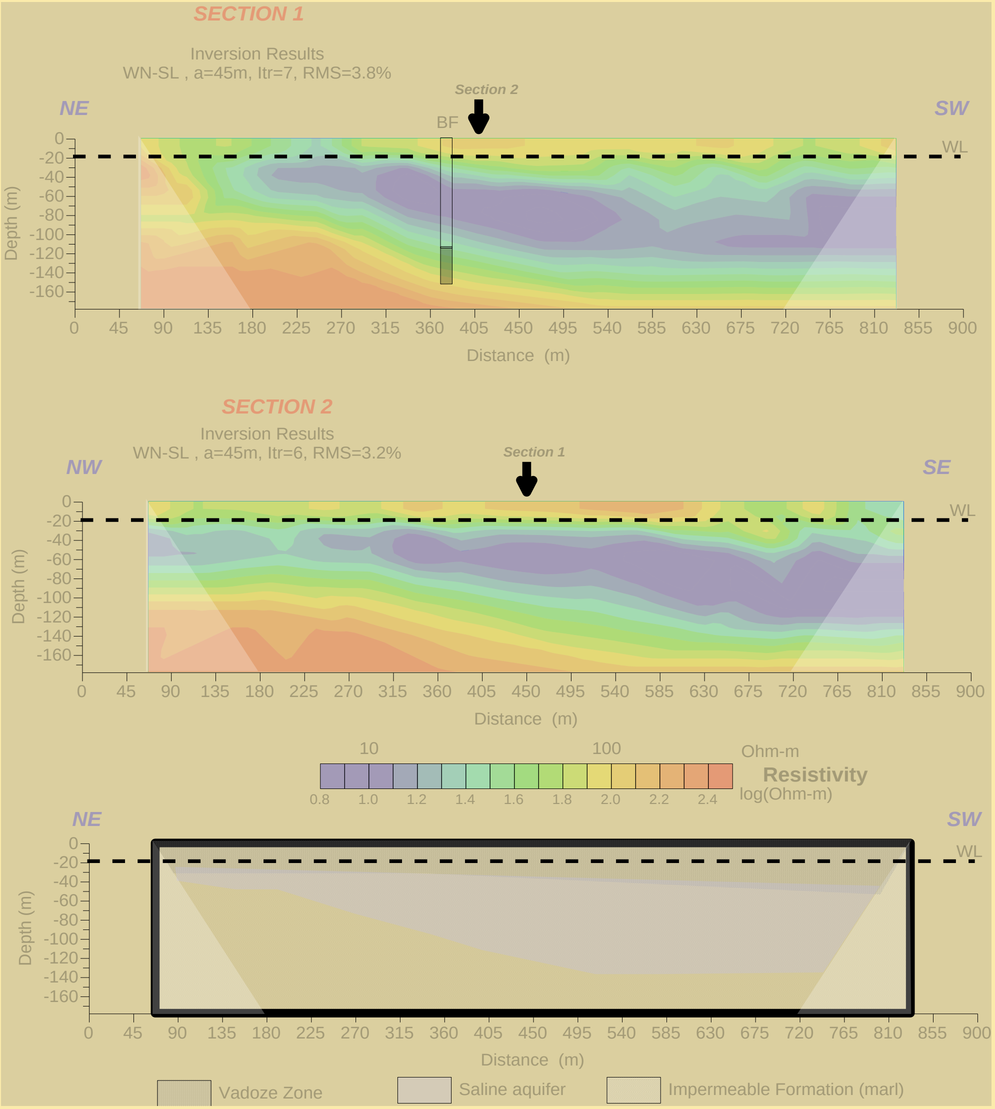
GEOPHYSICAL INVESTIGATIONS

Geophysical methods are used in order to solve or to predict an environmental problem.

The fields of application mainly regard:

- the monitoring of a pollutant (it is a prerequisite that the pollutant has a parameter that differs from the surrounding environment)
- the investigation of the geological structure of an area
- the detection and mapping of an aquifer

GEOPHYSICAL INVESTIGATIONS



SAFE YIELD

Safe yield is the rate of pumping from one aquifer without causing unwanted effects. This rate depends on the hydraulic characteristics of the aquifer, location of wells pumping, environmental and economic criteria, etc.

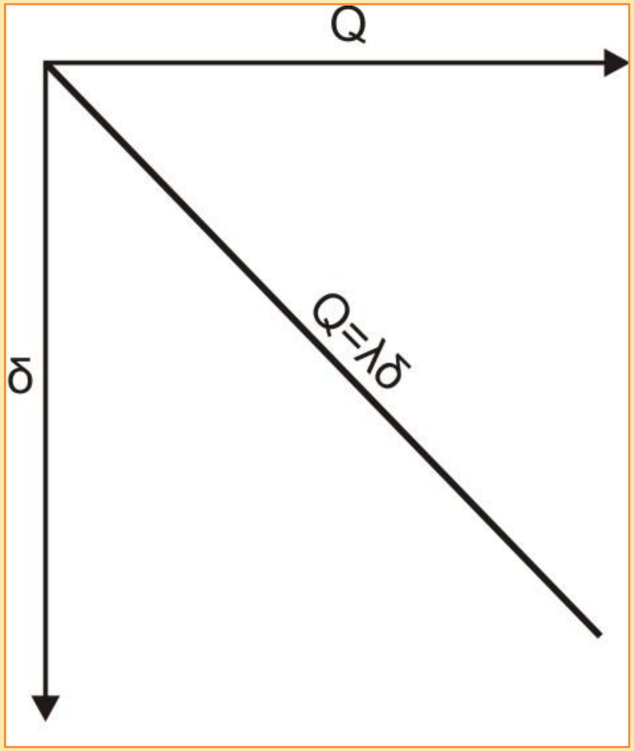
Undesired effects can manifest as:

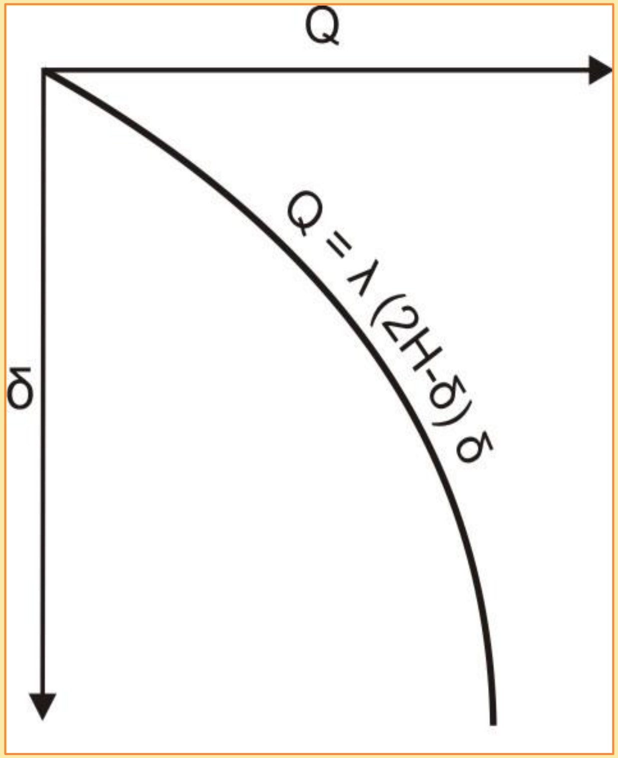
- Reduced discharge of groundwater to surface water features
- Reduction in ecological base flows
- Overlapping of drawdown cones
- Depletion of reserves
- Land subsidence due to pore pressure reduction

http://www.watereducation.org/aquapedia/safe-yield
https://albertawater.com/groundwater/age-trends-and-yield/what-is-safe-groundwater-yield

STEP DRAWDOWN PUMPING TEST

A step-drawdown test is a single-well test in which the well is pumped at a low constant- discharge rate until the drawdown within the well stabilizes. The pumping rate is then increased to a higher constant-discharge rate and the well is pumped until the draw- down stabilizes once more. This process is repeated through at least three steps, which should all be of equal duration (from 30 minutes to 2 hours each).





http://www2.alterra.wur.nl/Internet/webdocs/ilri-publicaties/publicaties/Pub47/Pub47-h14.pdf

ASSUMPTIONS MADE FOR ANALYZING FLOW TO WELLS

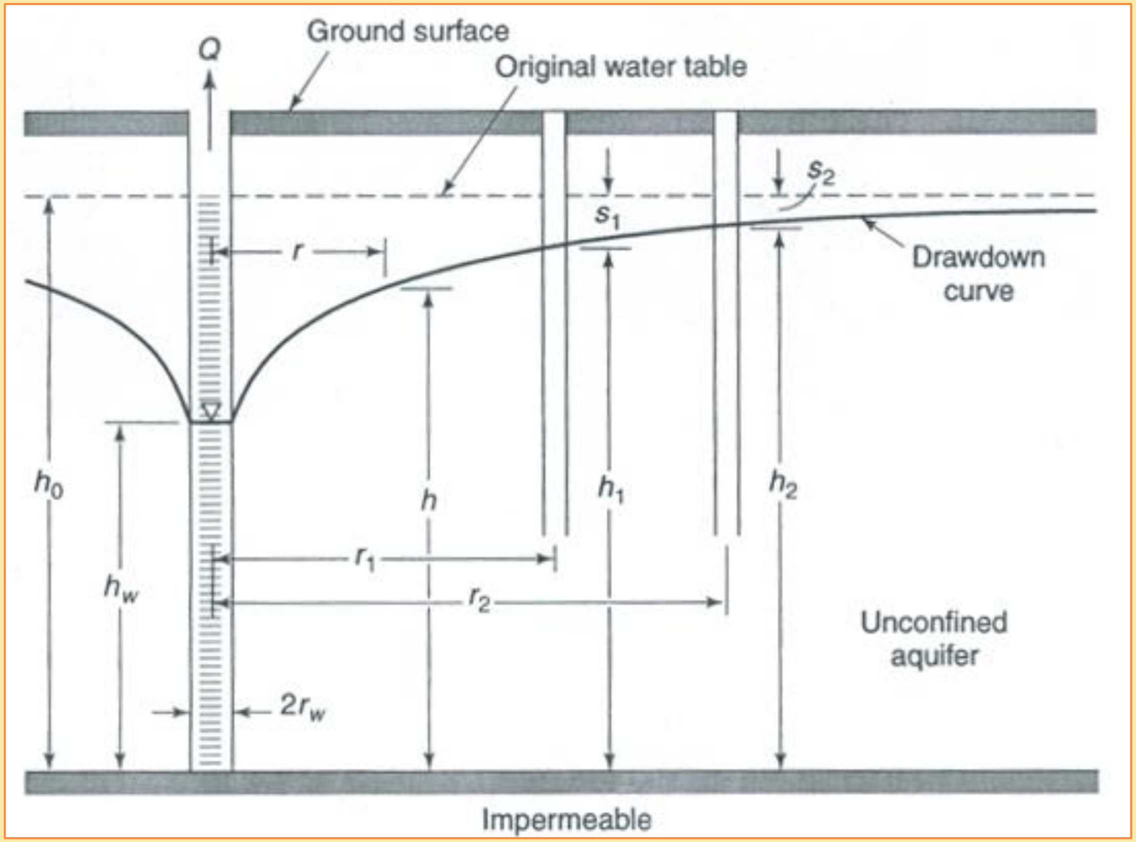
- The aquifer is bounded on the bottom by a confining layer.
- The groundwater level of the aquifer is horizontal and not changing with time prior to the start of pumping.
- All changes in the position of the groundwater level are due to the effect of the pumping well alone.
- All geologic formations are horizontal and of infinite horizontal extent.
- The aquifer is homogeneous and isotropic.
- All flow is radial towards the well.
- Groundwater flow is horizontal.
- Darcy's law is valid.
- The pumping well and the observation wells are fully penetrating.

http://ecoursesonline.iasri.res.in/mod/page/view.php?id=124673

ASSUMPTIONS MADE FOR ANALYZING FLOW TO WELLS

- The pumping well has an infinitesimal diameter (i.e., negligible storage) and is 100% efficient (i.e., no well losses).
- Groundwater has a constant density and viscosity.

STEADY STATE FLOW IN AN UNCONFINED AQUIFER

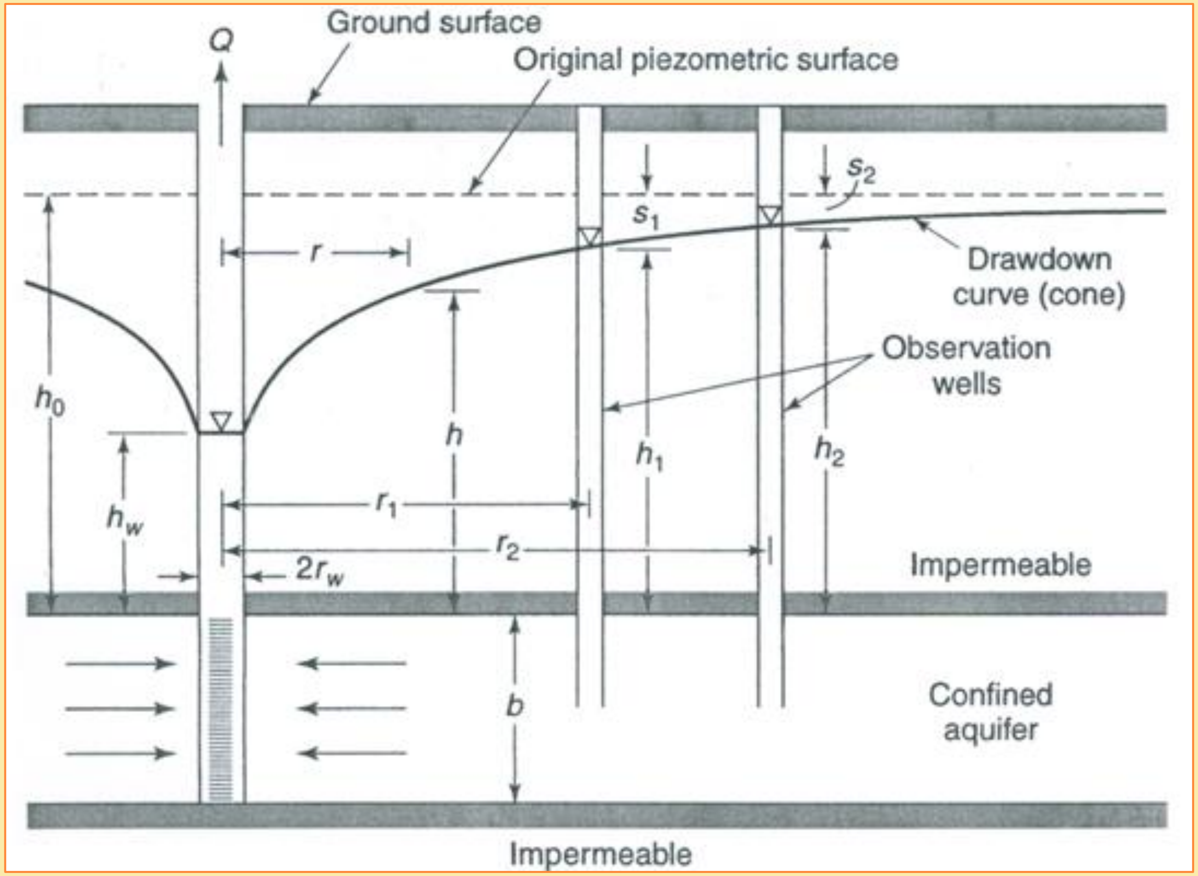


$$T = \frac{Q}{1.366(h_1 + h_2)(s_1 - s_2)} \log \frac{r_2}{r_1}$$

- The aquifer is unconfined and underlain by a horizontal confining layer
- The well is pumped at a constant rate
- The Dupuit-Forchheimer assumptions are valid

http://ecoursesonline.iasri.res.in/mod/page/view.php?id=124673

STEADY STATE FLOW IN A CONFINED AQUIFER



$$T = \frac{Q}{2.73(s_1 - s_2)} \log \frac{r_2}{r_1}$$

- The aquifer is bounded on the top and bottom by impervious confining layers
- The well is pumped at a constant rate.

http://ecoursesonline.iasri.res.in/mod/page/view.php?id=124673

UNSTEADY STATE FLOW-THEIS SOLUTION

Assumptions made:

- aquifer has infinite areal extent
- aquifer is homogeneous and of uniform thickness
- control well is fully or partially penetrating
- flow to control well is horizontal when control well is fully penetrating
- aquifer is nonleaky confined
- flow is unsteady pumped by constant rate
- water is released instantaneously from storage with decline of hydraulic head
- diameter of a pumping well is very small so that storage in the well can be neglected

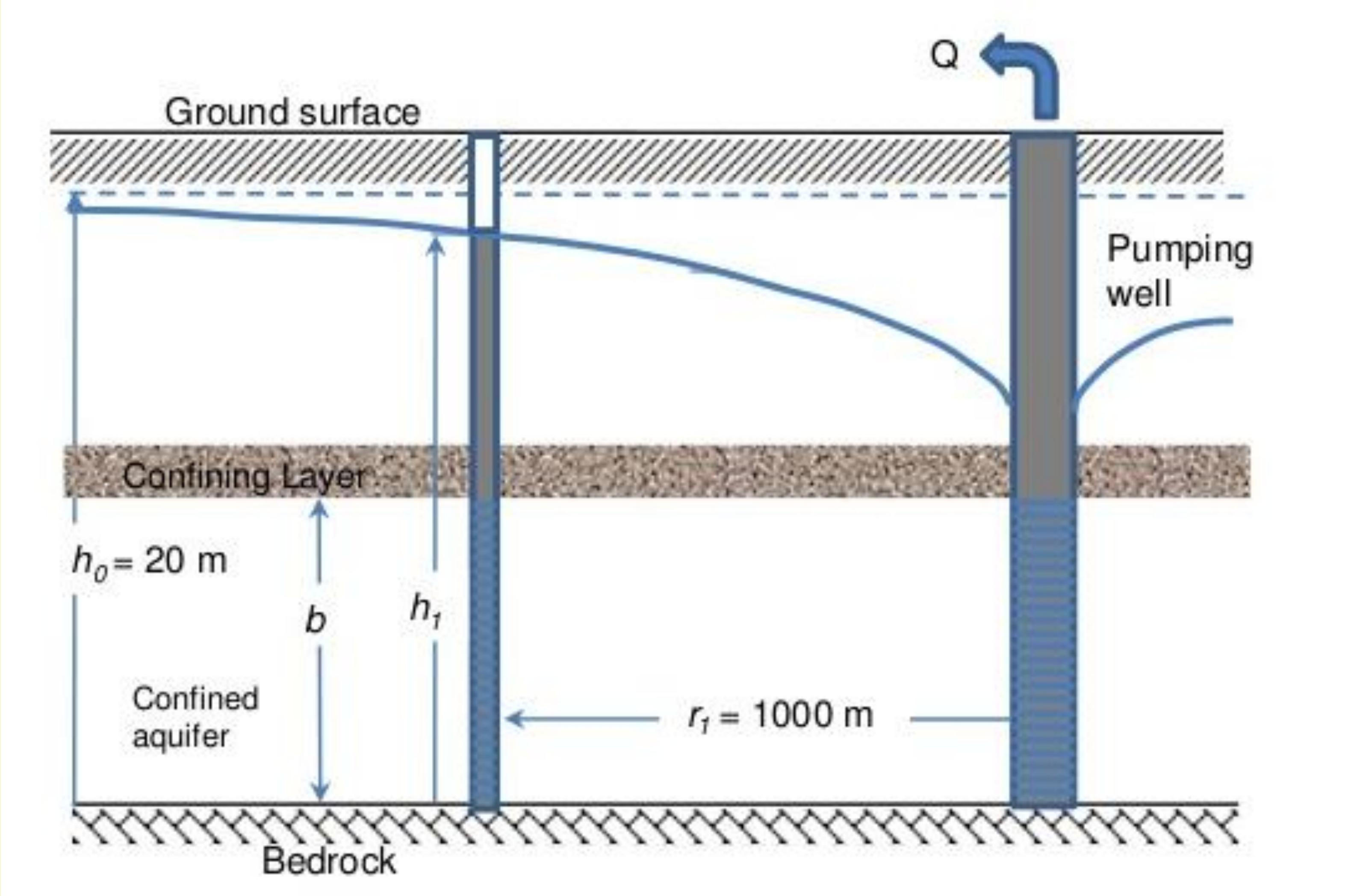
UNSTEADY STATE FLOW-THEIS SOLUTION

DATA REQUIREMENTS

- pumping and observation wells locations
- pumping rate
- observation well measurements (time and displacement)

http://www.aqtesolv.com/theis.htm#Theis_Type_Curve

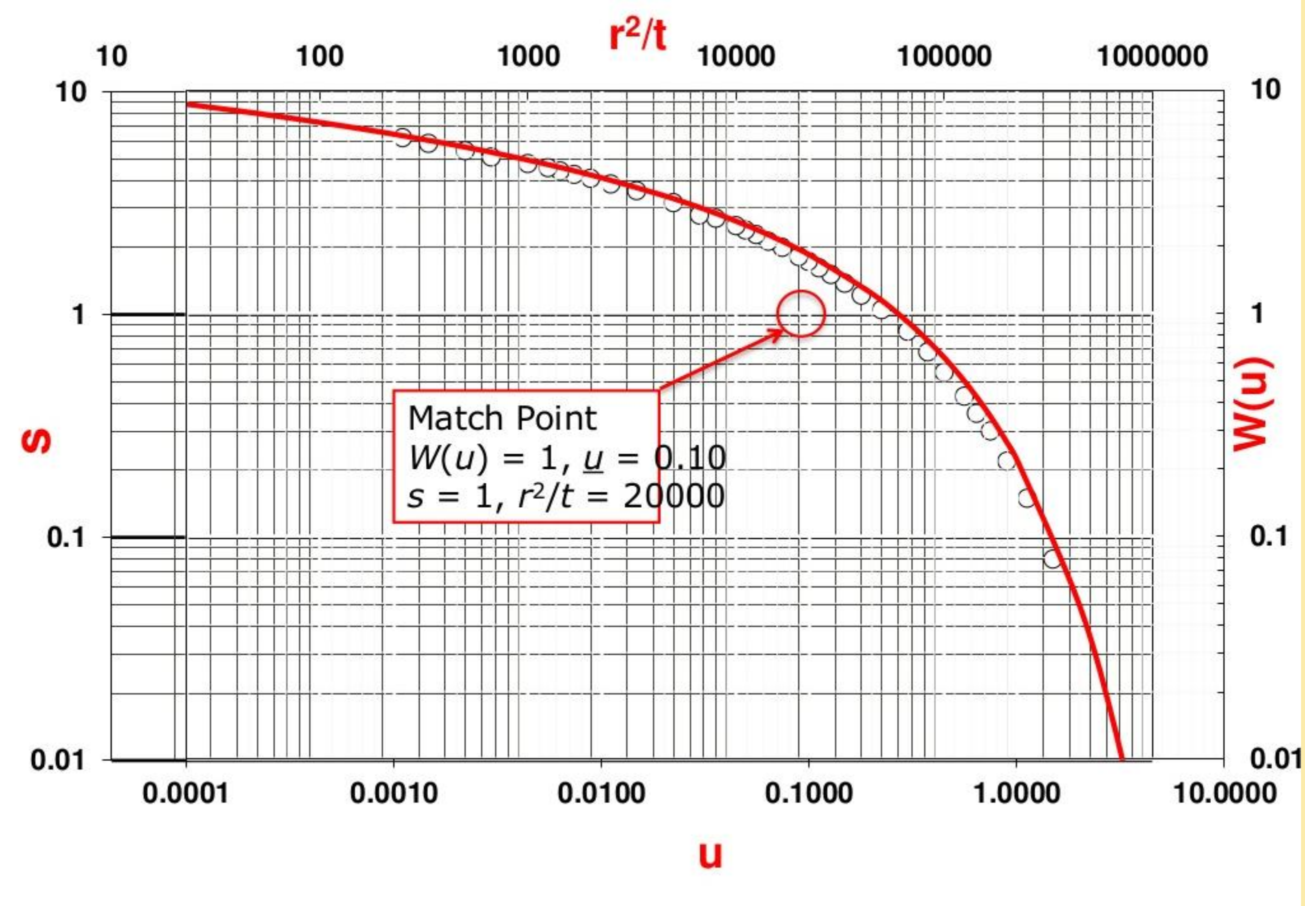
UNSTEADY STATE FLOW-THEIS SOLUTION



https://www.slideshare.net/tynAa0910/radial-flow-pumping-test

Bear, J., Hydraulics of groundwater, McGraw and Hill, 1979

UNSTEADY STATE FLOW-THEIS SOLUTION



$$W(u) = -0.5722 - \ln u + u - \frac{u^2}{2 \cdot 2!} + \frac{u^3}{3 \cdot 3!} - \frac{u^4}{4 \cdot 4!} + \dots$$

$$u = \frac{r^2 S}{4Tt}$$

$$s = \frac{Q}{4\pi T} W(u)$$

http://quebec.hwr.arizona.edu/classes/hwr431/2006/Lab6.pdf
https://www.slideshare.net/tynAa0910/radial-flow-pumping-test

UNSTEADY STATE FLOW-JACOB SOLUTION

Two approximations:

1) One pumping-one observation well
   - Time versus drawdown method

2) One pumping well at least three observation wells
   - Drawdown versus distance method

UNSTEADY STATE FLOW-JACOB SOLUTION

Cooper-Jacob I: Time-Drawdown Method

Drawdown versus time is plotted as a straight line on semi-logarithmic paper.

t_0 = 8 min

s_2 = 5 m

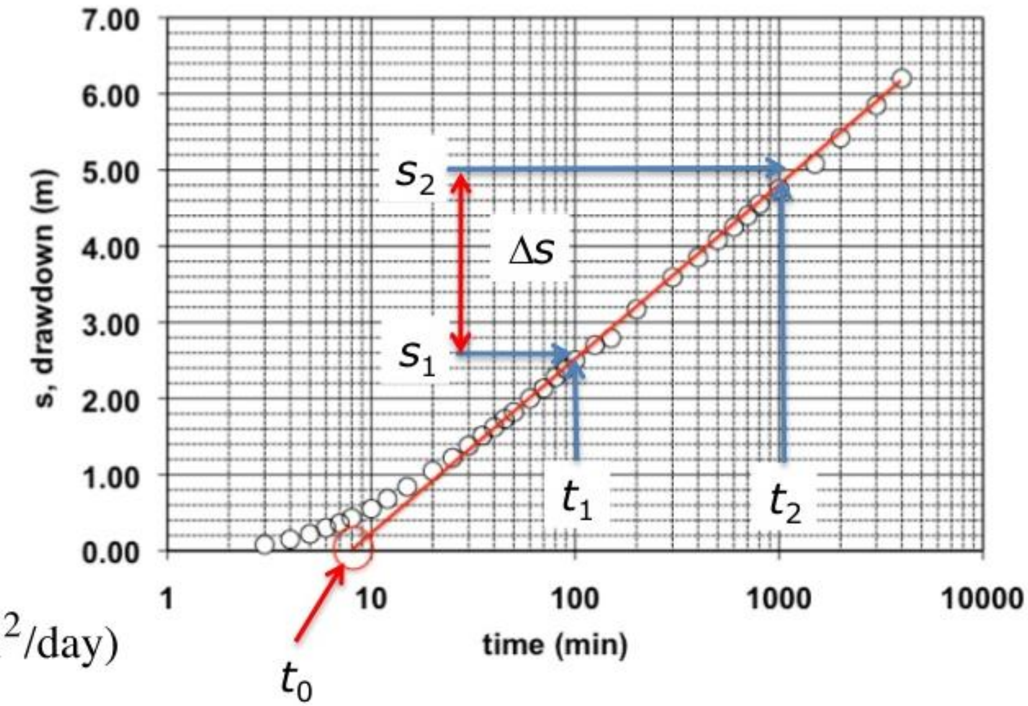
s_1 = 2.6 m

Δs = 2.4 m

$$T = \frac{2.3Q}{4\pi\Delta s}$$

$$= \frac{2.3(1000 \text{ m}^3/\text{hr})}{4\pi(2.4 \text{ m})}$$

$$= 76.26 \text{ m}^2/\text{hr} \;\; (1830 \text{ m}^2/\text{day})$$



$$S = \frac{2.25Tt_0}{r^2} = \frac{2.25(76.26 \text{ m}^2/\text{hr})(8 \text{ min}*1 \text{ hr}/60 \text{ min})}{(1000 \text{ m})^2}$$

$$= 2.29x10^{\;\;5}$$

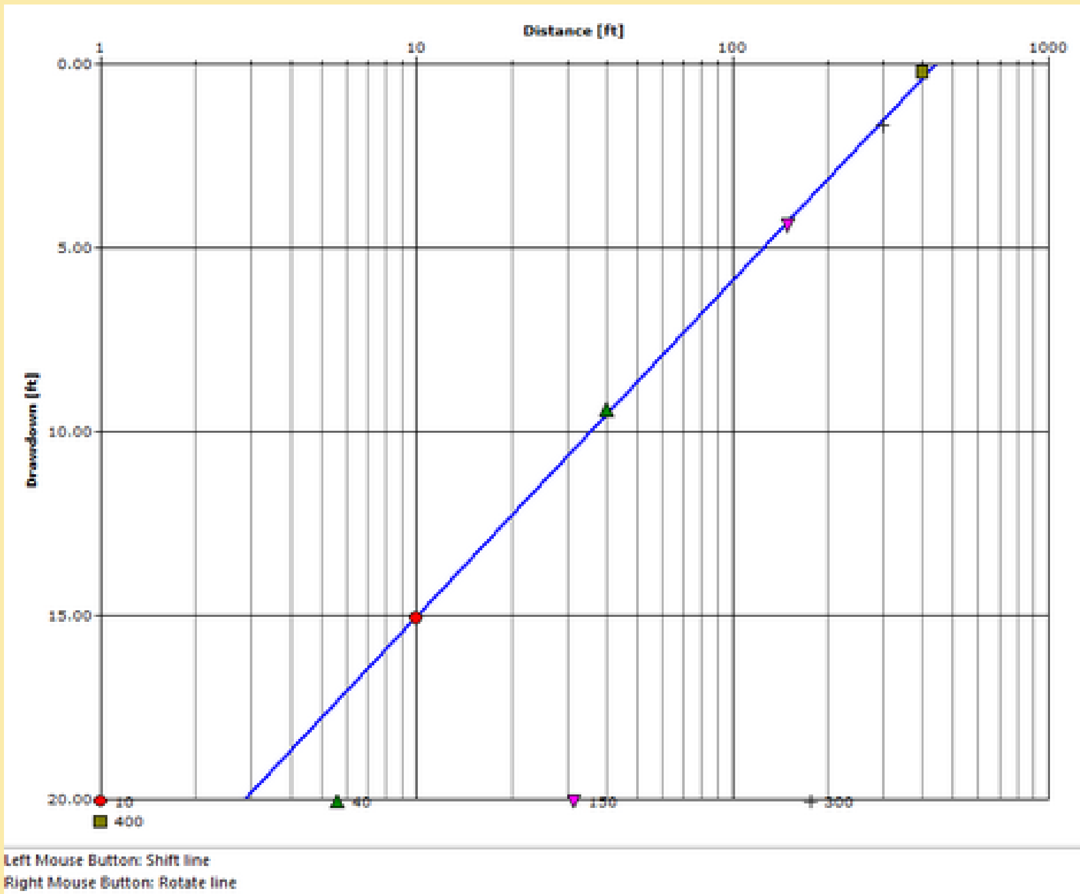
r= distance between pumping and observation wells

https://www.slideshare.net/tynAa0910/radial-flow-pumping-test

UNSTEADY STATE FLOW-JACOB SOLUTION

Cooper-Jacob I: Distance-Drawdown Method

Drawdown versus distance of the pumping and observation wells is plotted as a straight line on semi-logarithmic paper.



$$T = \frac{2.3Q}{2\pi\Delta s}$$

$$S = \frac{2.25Tt_0}{r_0^{\,2}}$$

t_o= the pumping time at the moment of measurement

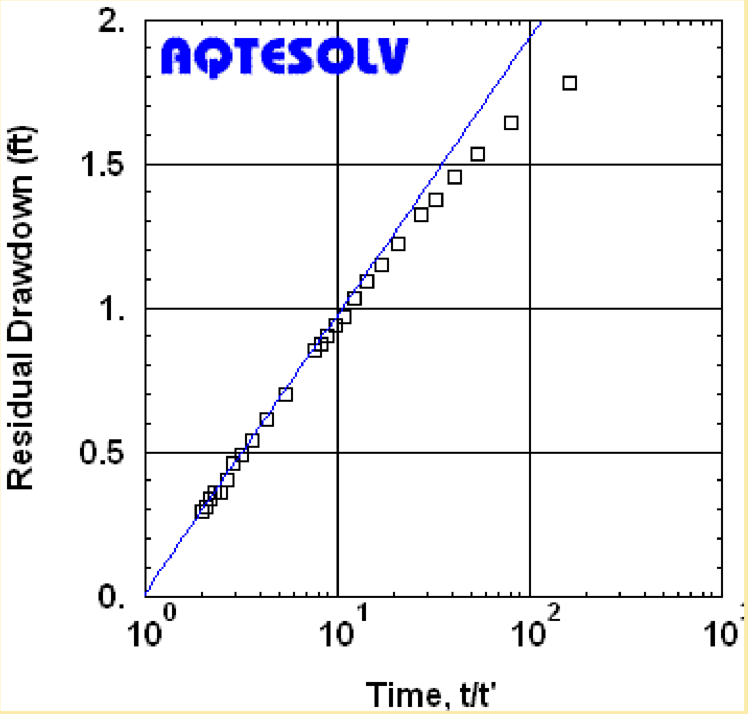
r_o= the distance defined by the intercept of the zero-drawdown and the straight-line though the data points

http://www.novametrixgm.com/help/aquifertest/index.html?_cooper_jacob_method_confined_.htm

UNSTEADY STATE FLOW-RECOVERY TEST

When pumping is stopped, water level rise towards it pre-pumping level.

Residual drawdown vs t-t' are plotted as a straight line in a semi-logarithmic paper



$T = (2.303Q)/4\pi\Delta s'$

t= is time since pumping started

t'= is time since pumping stopped

The method of recovery analysis does not allow calculation of S. This is obvious from the absence of S in basic equations of this method.

http://www.unibuc.ro/prof/scradeanu_d/docs/2016/noi/28_18_05_02Pumping_TesRAMALLAHt.pdf

STUDENTS TRAINING

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