UNIVERSITÉ DE NEUCHÂTEL

CHYN
Centre d'hydrogéologie et de géothermie

CHYN TRAINING COURSE FOR

UNHCR WASH STAFF

APPLIED HYDROGEOLOGY

from field investigation towards sustainable water resources management

June 1 to June 6, 2014

UNHCR
The UN Refugee Agency

Introduction to hydrogeology II

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Agency for Development and Cooperation SDC

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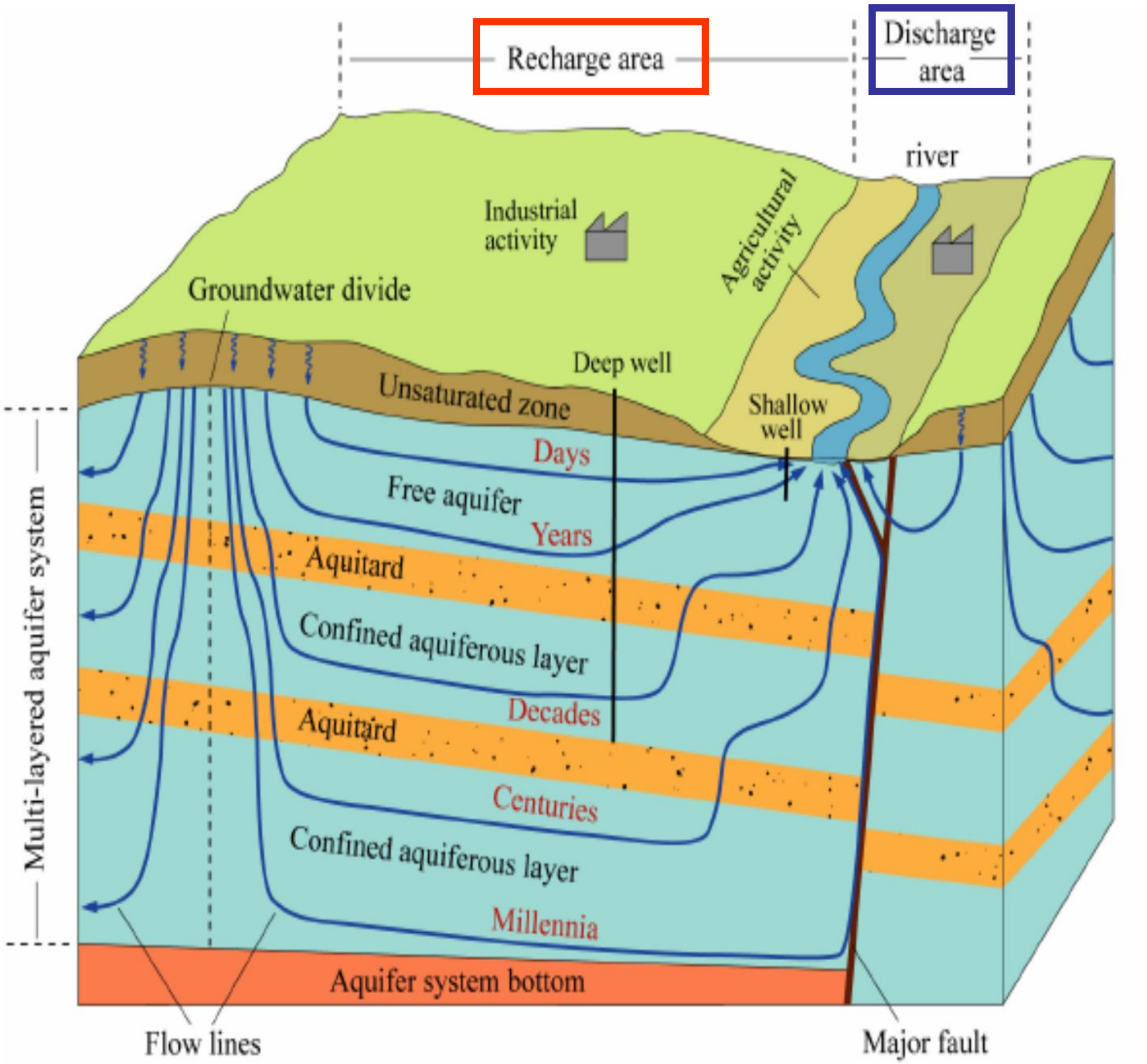
Groundwater dynamics



Groundwater circulation requires ‘input’ and ‘output’

Recharge areas:

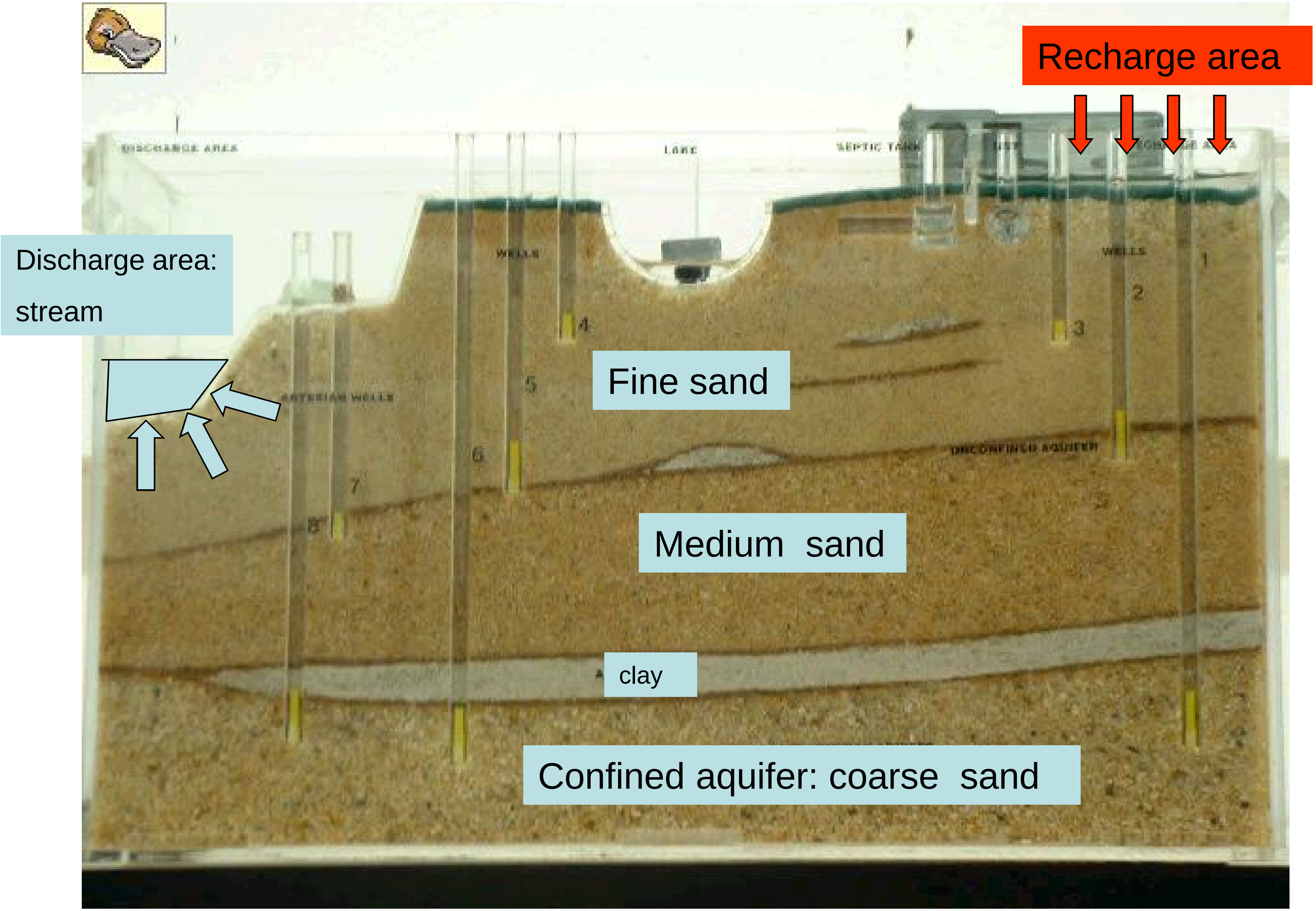
→Infiltration into the aquifer from rainfall or surface water bodies. Water table below land surface.

Discharge areas:

→ Exfiltration from the aquifer to springs or to surface water bodies. Pumping wells.

Superimposed groundwater flow systems

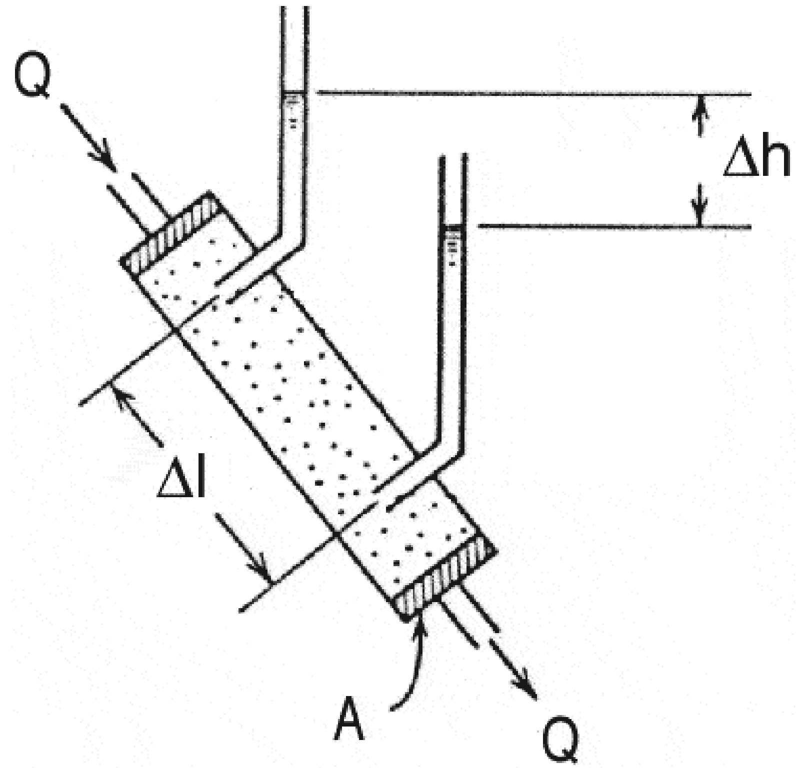
Sand box experiment



What are the driving forces of groundwater flow?

The porosity only tells us how much water can be stored in a rock or soil but does not tell us how water moves within the body – **hydraulic conductivity** is the measure (resistance) that governs groundwater flow, and the **hydraulic head gradient** is the **driving force**!

Darcy's experiment:



$$q = \frac{Q}{A} = K \times \frac{\Delta H}{\Delta L}$$

K = hydraulic conductivity [m/s]

q = specific flux [m/s]

Q = discharge rate [m^3/s]

A = cross sectional area of the filter [m^2]

ΔH = difference of piezometric levels [m]

ΔL= Distance between piezometric level measurements [m]

Quantifying groundwater flow under field conditions

→ The first step towards sustainable groundwater management

$$Q = \boxed{A} \times \boxed{K} \times \boxed{\frac{\Delta H}{\Delta L}}$$

Aquifer geomtery

→ borehole logs and geophysics

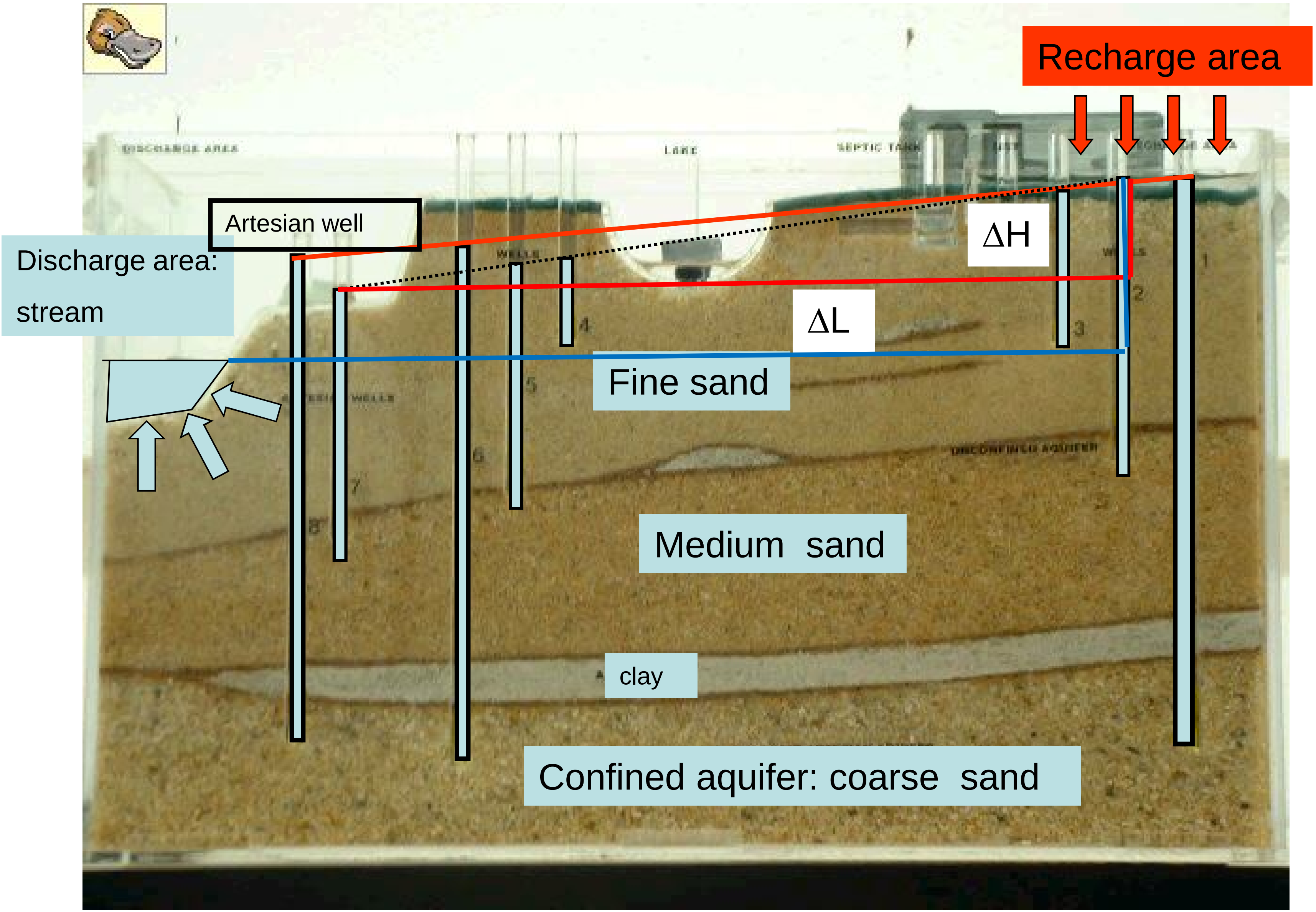
Hydraulic gradient

→Piezometry

Hydraulic conductivity

→Pumping tests, literature values

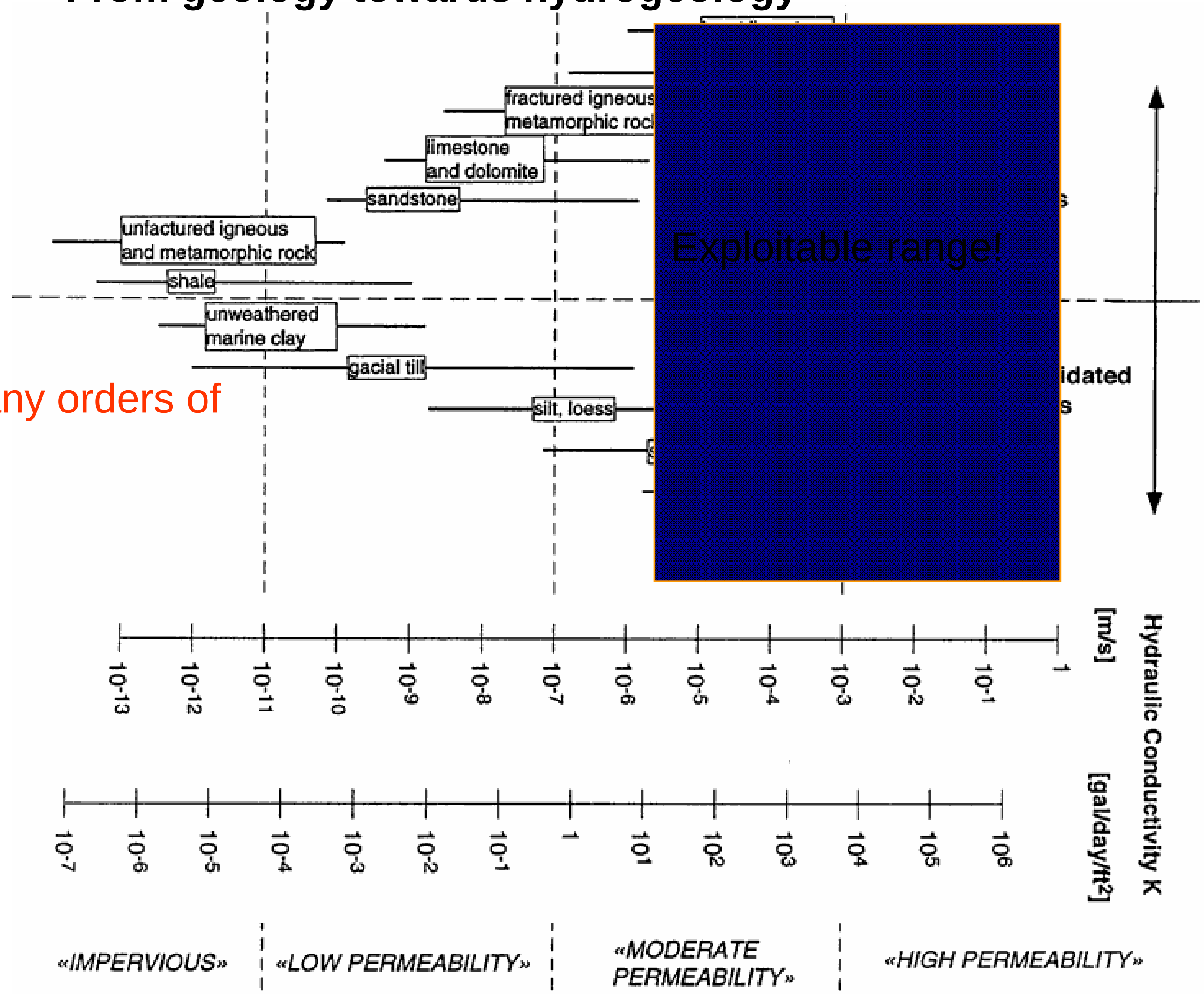
Hydraulic gradient: how is it identified?



Hydraulic conductivities for different soil/rock types

From geology towards hydrogeology

Variability over many orders of magnitude!



Regional groundwater flux estimation

→Example of application of Darcy's law to field conditions

Let's assume:

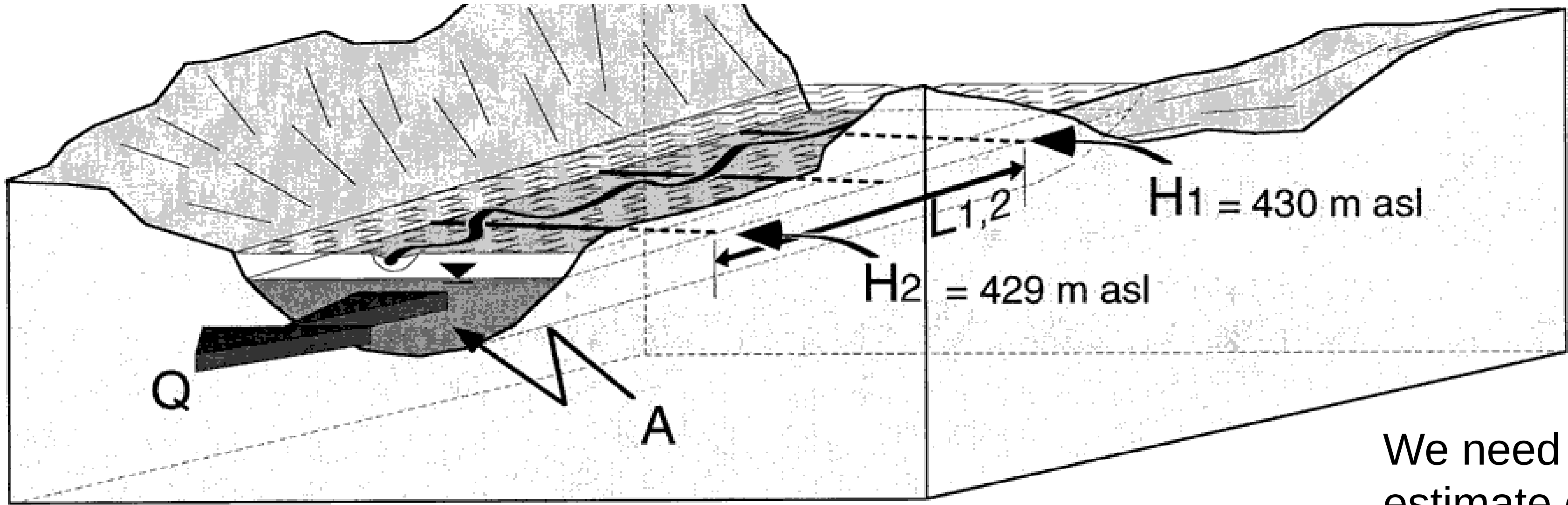
A = 20m * 500m = 10'000m²

K (sandy, loamy gravel) = 10^{-4} m/s

$\Delta H/\Delta L$= (430-429)/1000=10^{-3} [-]

$$Q = A \times K \times \frac{\Delta H}{\Delta l}$$

Q=? [m³/d]



Axial groundwater flow (m³/s): $Q = A \times K \times \frac{\Delta H}{\Delta L}$

We need to estimate or measure K! AND the regional gradient $\Delta H/\Delta L$

How do we map the ‘driving force’ of groundwater flow in the field?

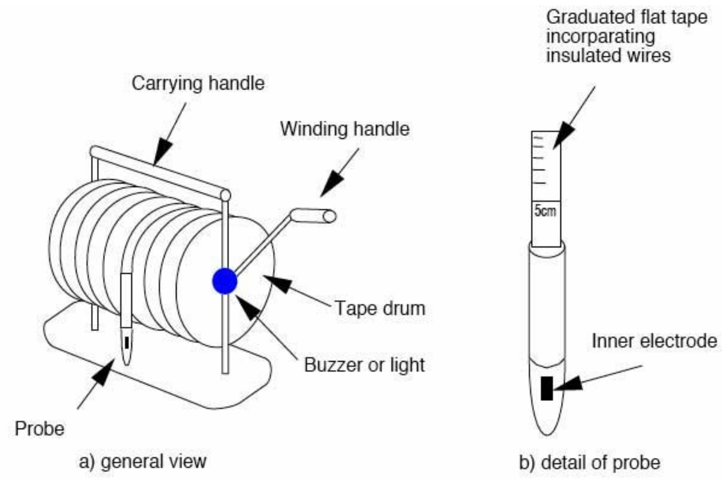
Piezometric maps

Measuring at a moment in time the water level in many different places yields a map of the ‘topography’ of the groundwater body

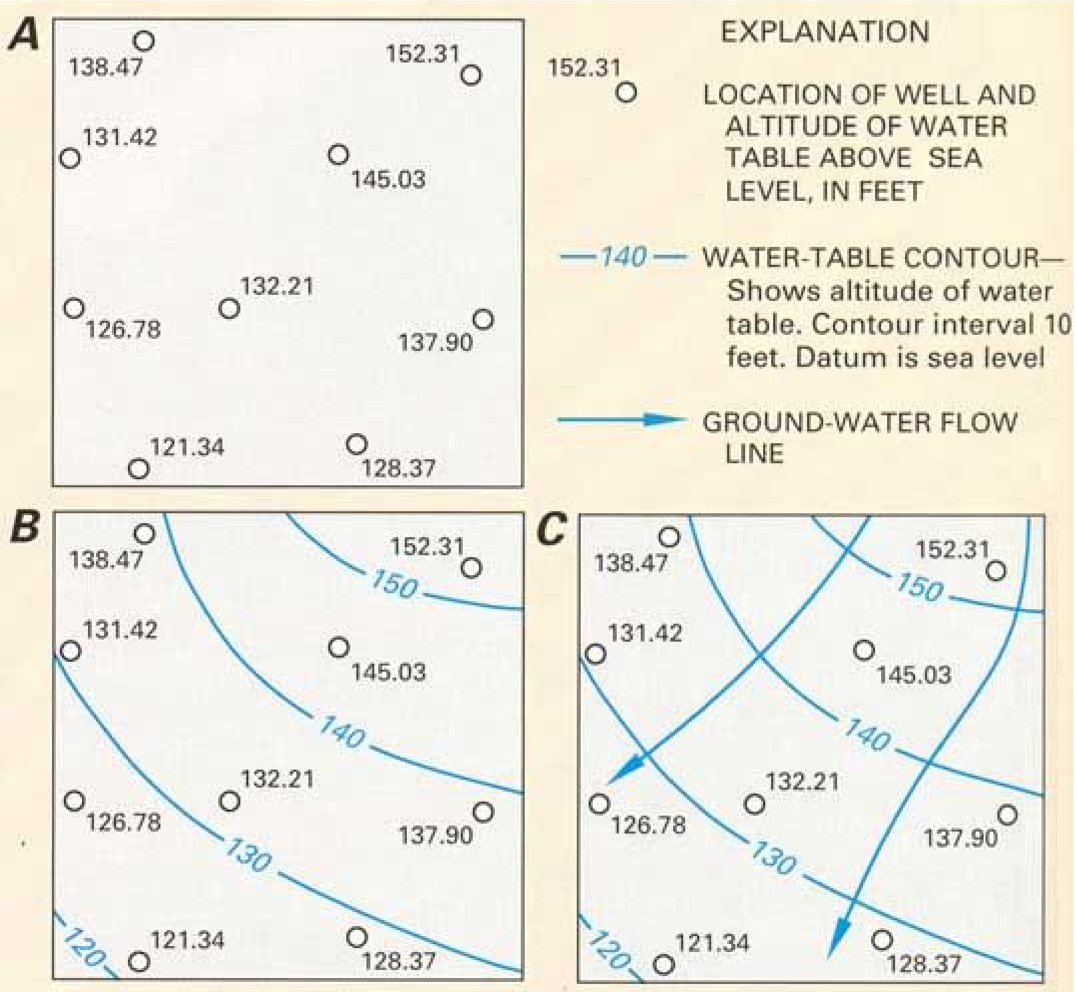
What do water level maps tell us?

- Flow direction (important for **contamination** issues and **well/spring protection**)
- Interaction of groundwater and surface water
- Interaction of wells and springs
- Allows estimation of groundwater fluxes

Water level probe: equipment used to measure the water table



Hydraulic head distribution (piezometric map), 2D horizontal example

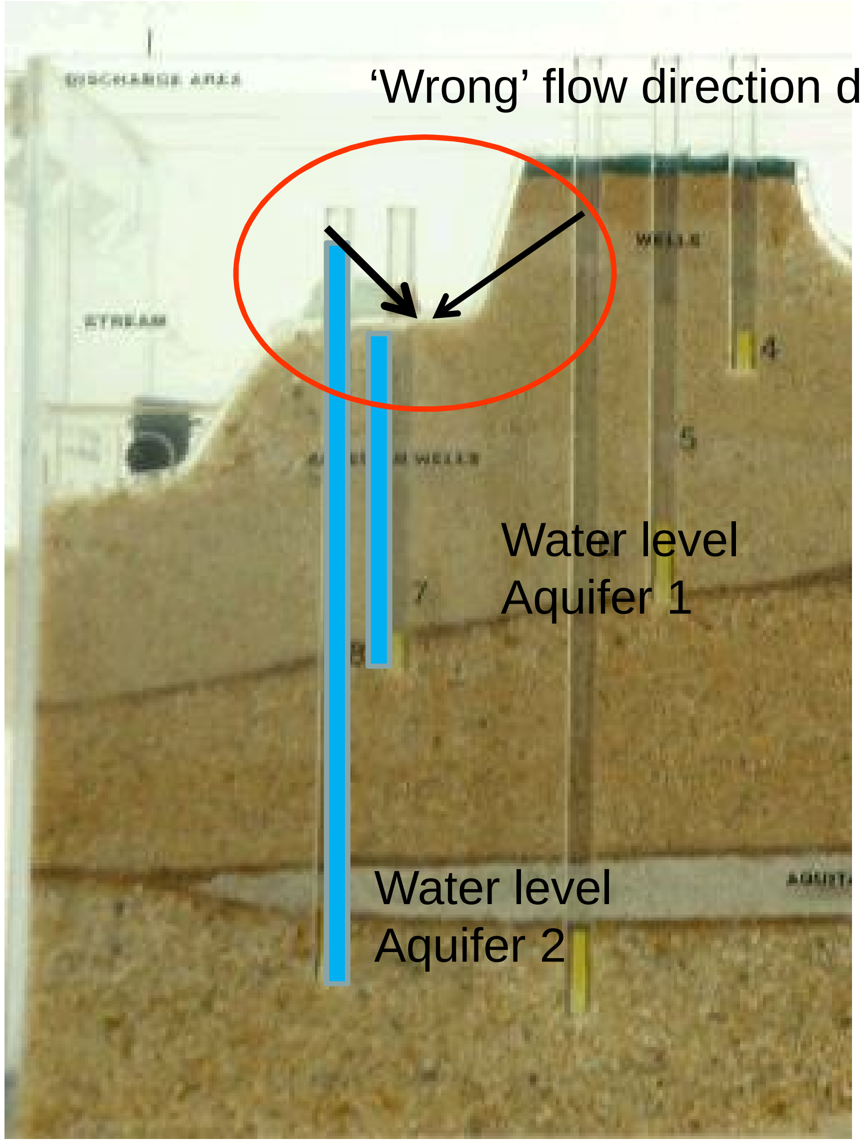


→ **Flow** is always **perpendicular to the iso-contours of water table elevation** – a water table map is like a topographical map - water will always flow in the direction where the slope is steepest (= direction of hydraulic gradient)

Such maps vary in time!!!

Flow fields and piezometric distribution (2D vertical example)

‘Wrong’ flow direction due to vertical movement

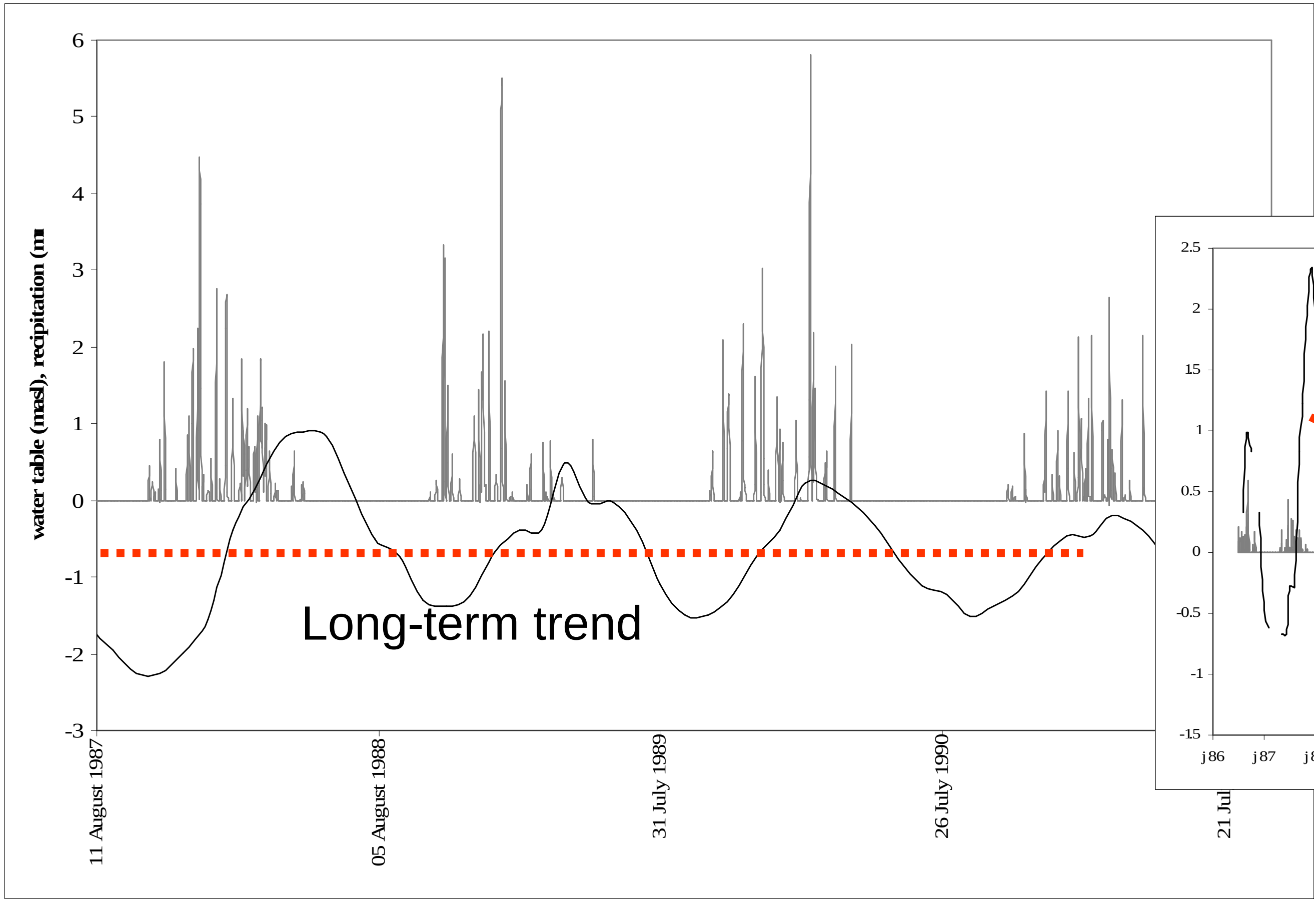


→ **Piezometric maps** have to be done for **separate aquifers**: using piezometric measurements of different aquifers may lead to oposite flow directions!

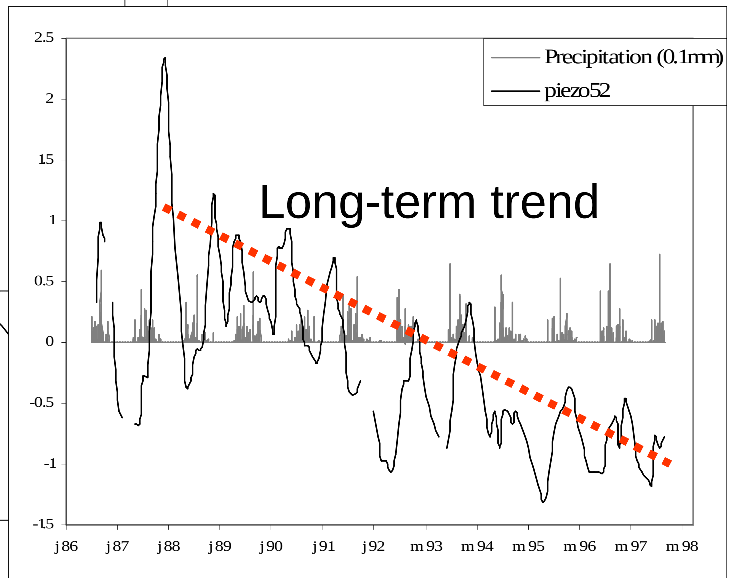
→If confronted with water level measurements which indicate ‘unlogical’ flow directions, this may be due to **different aquifer compartments**

Seasonal variations of water table

Typical porous aquifer reaction: fluctuations caused by seasonal variation of recharge! Long-term behaviour in equilibrium



In case of drought OR overexploitation: long-term behaviour leads to a decrease of the water levels!!!



In Springs: the water level does not change with time (unless they dry up), BUT the discharge rate varies in time!!!

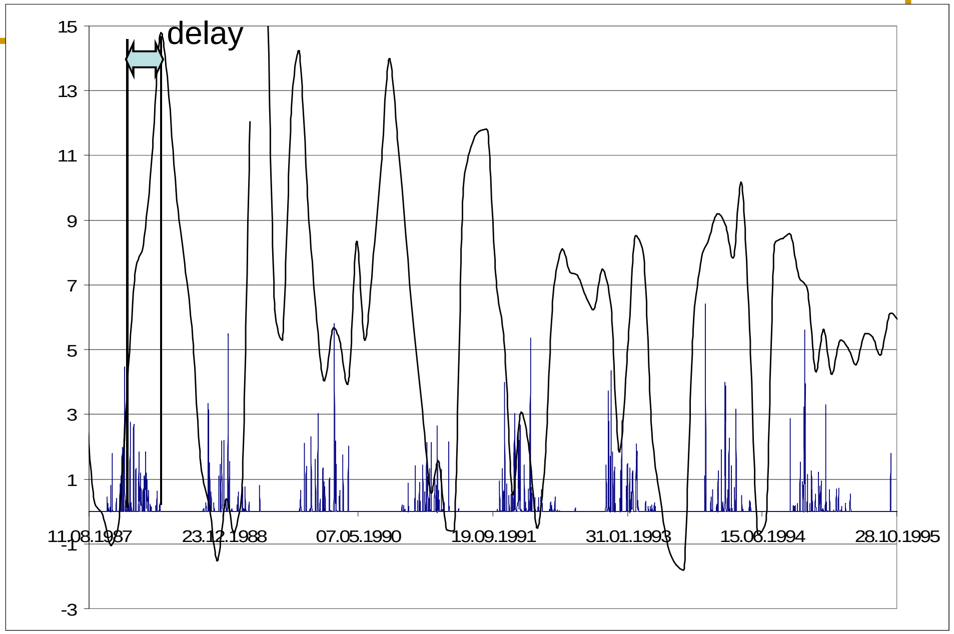
Identification of aquifer type from seasonal fluctuations of water table

Depending on the delay of the reaction of the groundwater level with respect to precipitation (or surface runoff events) we can identify if it is a porous, fractured or a Karst aquifer!!!

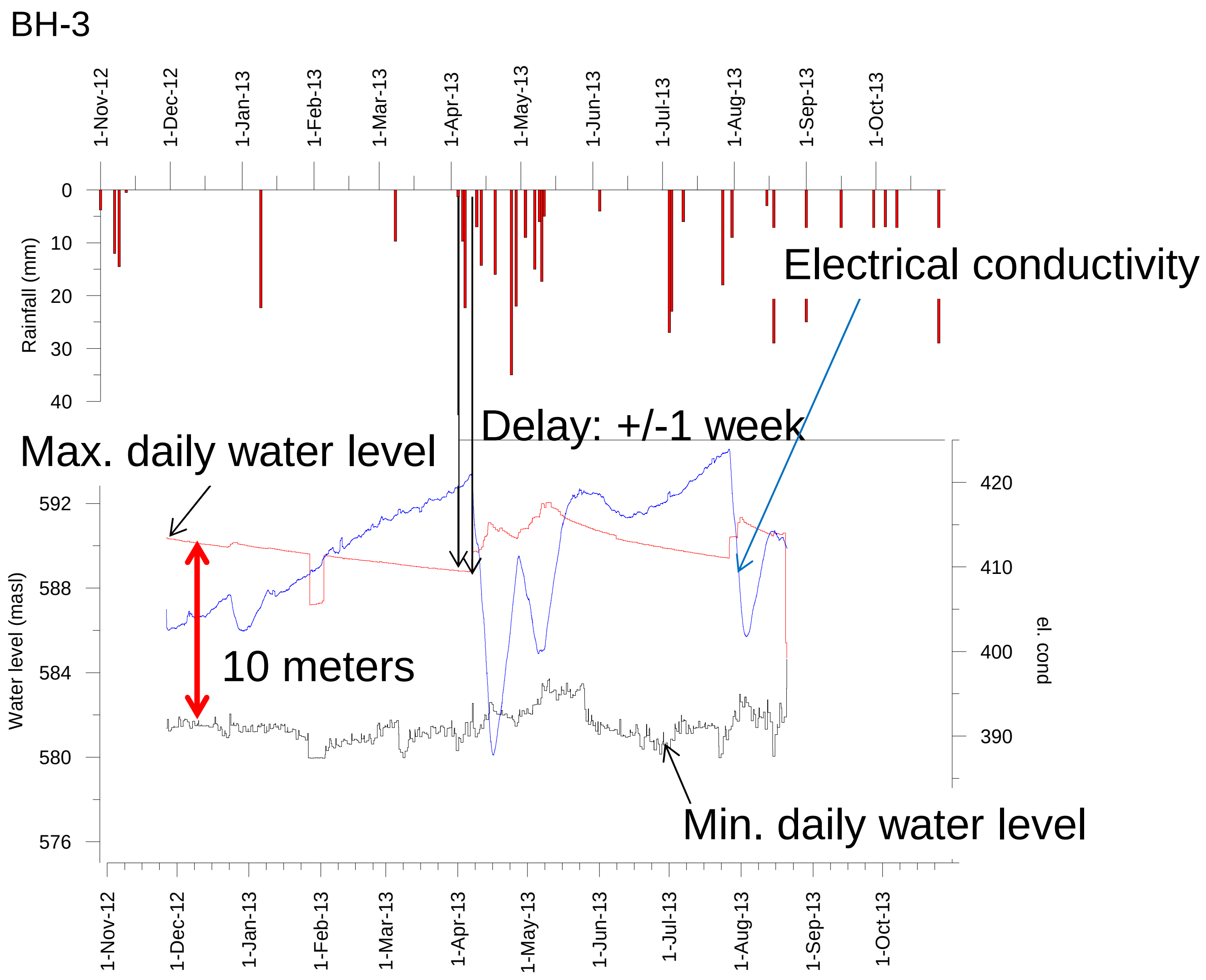
Porous aquifer: fluctuations are usually delayed by approximately weeks to months with respect to rainfall (depending on thickness of unsaturated zone and confined or non-confined) → water table fluctuations max. 1-3 meters– under confined conditions up to 10 meters

Fractured aquifers: usually delayed by months, water table fluctuations are much higher (small porosity!)→ up to several tens of meters!

Karst aquifers: delayed by only few hours to days, water table fluctuations are mostly synchronous with precipitation/runoff events → high fluctuations possible!

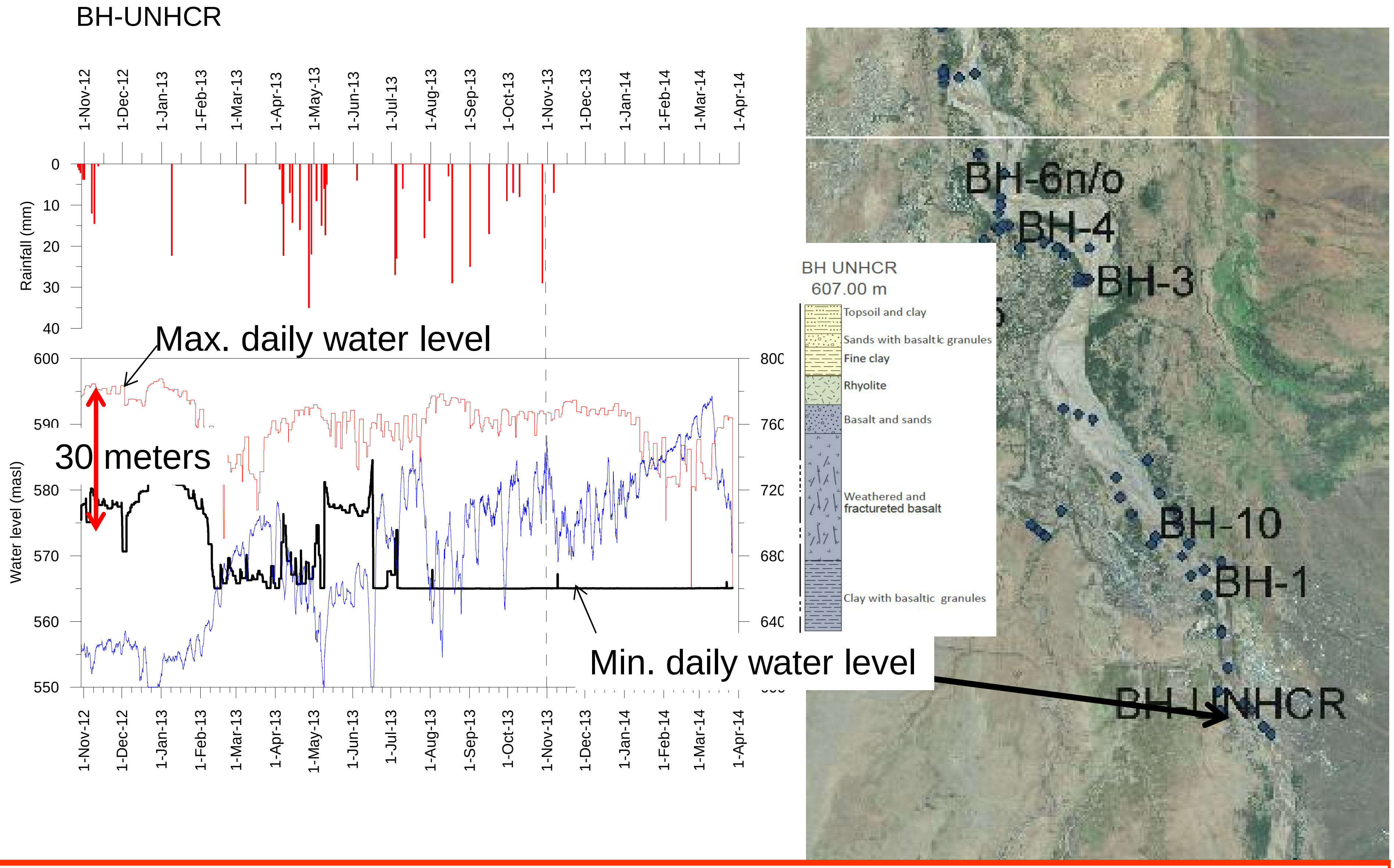


Example from Kakuma: porous aquifer



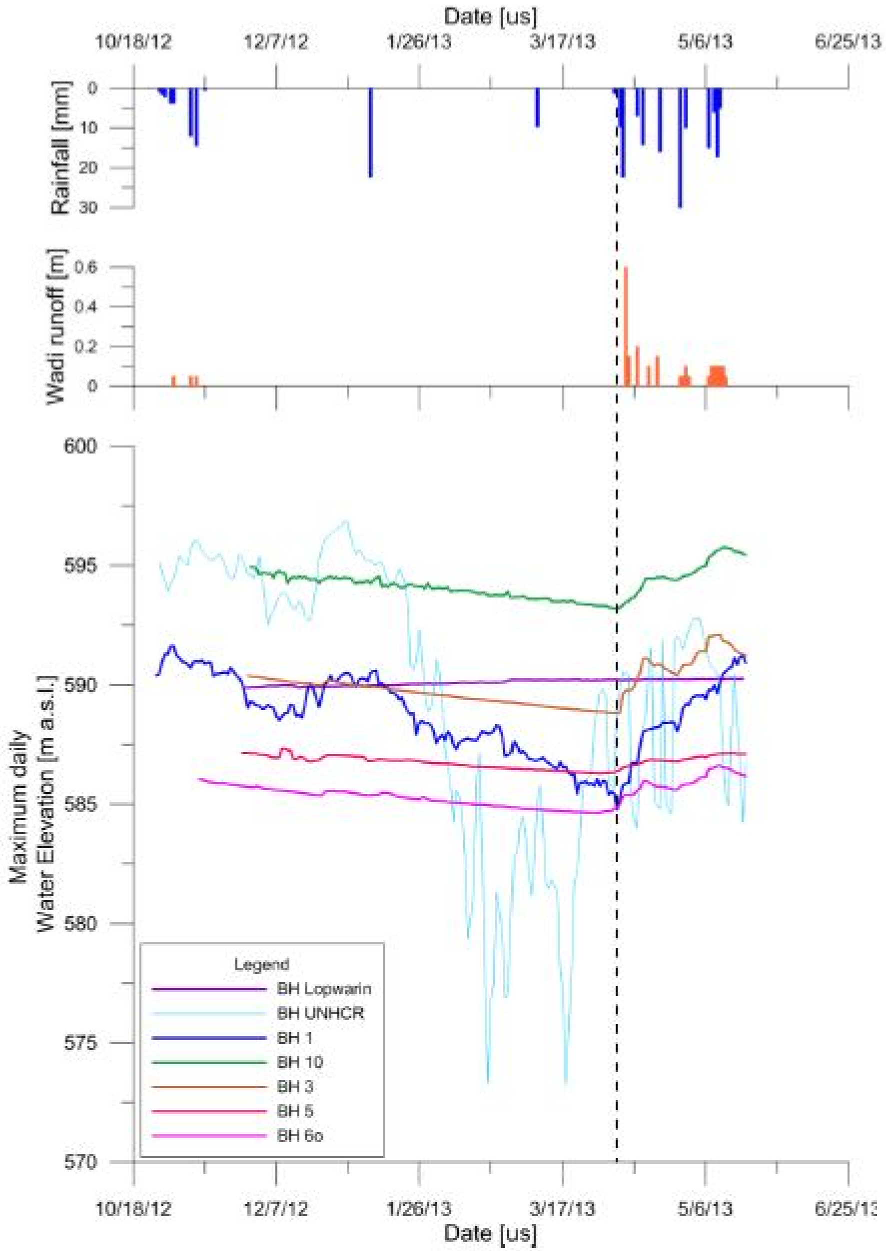
Porous aquifer: fluctuations are usually delayed by approximately weeks to months with respect to rainfall (depending on thickness of unsaturated zone and confined or non-confined) → water table fluctuations max. 1-3 meters– under confined conditions up to 10 meters

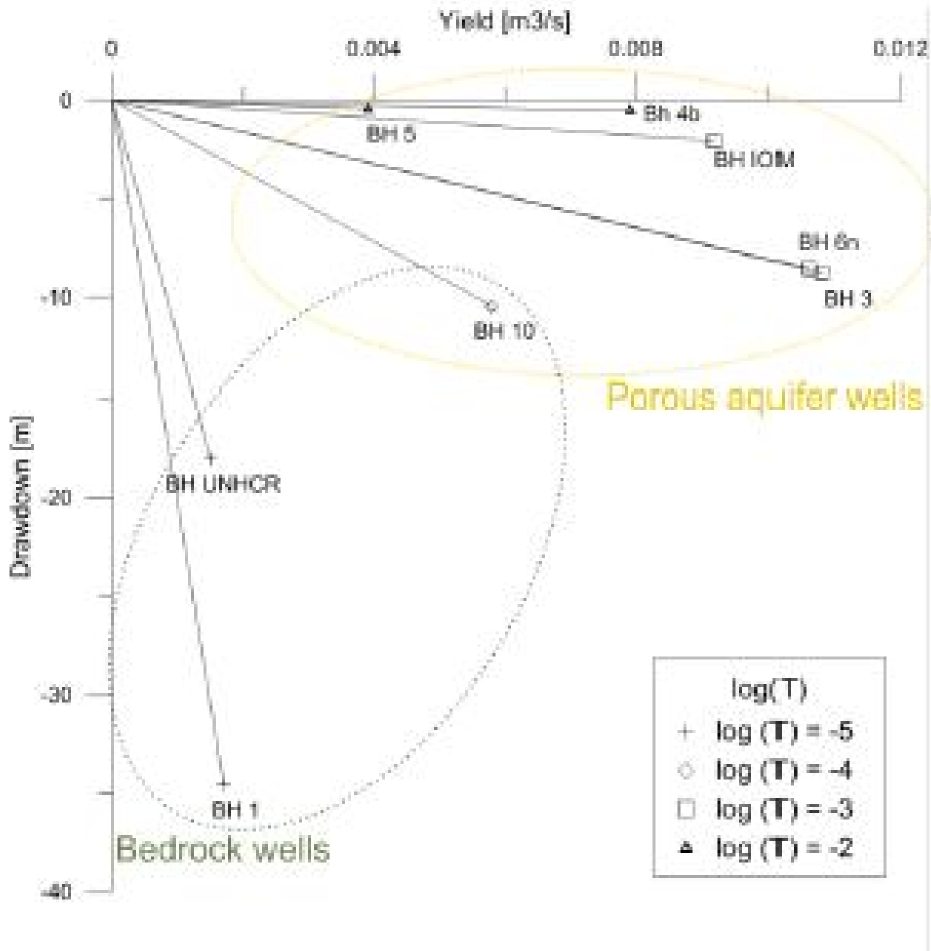
Example from Kakuma: fractured aquifer



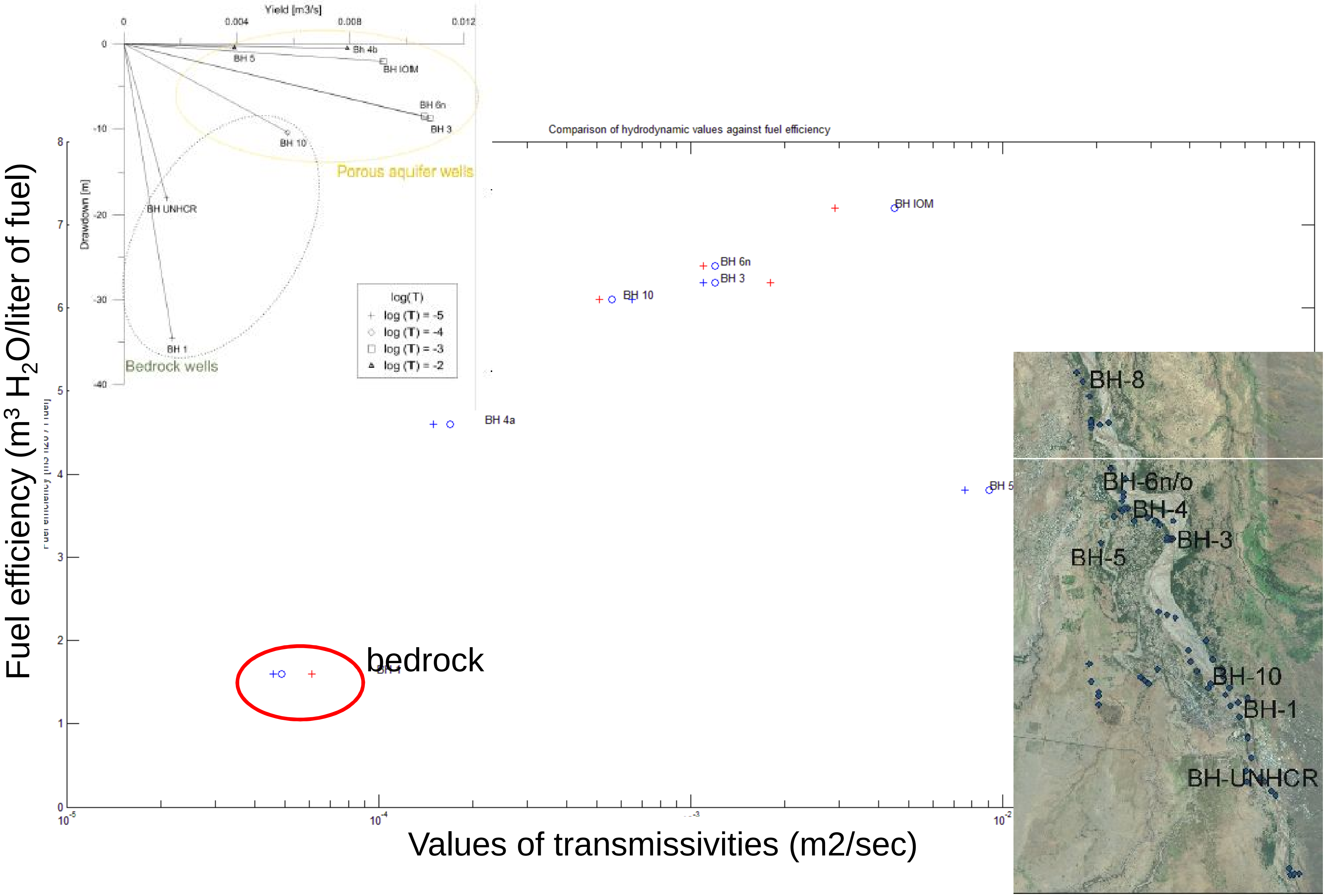
→**Fractured aquifer**: delayed and not distinct reaction to rainfall and runoff events, water table fluctuations are much higher (small porosity!)→ up to several tens of meters!

Which wells are more efficient and productive? Porous or fractured?





Which wells are more productive?



Importance of monitoring of water levels (in space and time)

→Spatial water table measurements allow identification of flow directions and flow systems: important to protect water supply wells

→Seasonal monitoring of water levels allows identification of aquifer type and reservoir behaviour in response to recharge (e.g. important for sustainable management): Knowing the aquifer type allows estimation of capacity and of reaction to groundwater contamination

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APPLIED HYDROGEOLOGY

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June 1 to June 6, 2014

Introduction to the training course

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Confederazione Svizzera
Confederaziun svizra

Swiss Agency for Development and Cooperation SDC

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Objectives of the training course

- Introduction to basic geological and hydrogeological concepts relevant and applicable to any site where groundwater is exploited in humanitarian contexts for water supply: water balance, aquifer characterisation, resource evaluation, groundwater flow dynamics and systems, groundwater protection and sustainable exploitation

- Introduction to the major hydrogeological assessment and interpretation methods: pumping tests, groundwater quality, groundwater exploration/exploitation, groundwater monitoring

- Developing skills in critical evaluation of hydrogeological assessments: e.g. has a pumping test been carried out according to the defined standards and TORs? ; or, is well rehabilitation necessary and how can aging of wells be monitored?,;or, has a hydrogeological investigation based its answers to specific hydrogeological questions on sound investigations strategies?; or, is the aquifer exploited sustainably?

Course timetable

Sunday 01/06/14

Time		*Unit title*	*Speaker*	*Place*
09:30-10:30	(01:00)	Welcome and introduction of participants	DP/CP & EM/MP	CHYN
10:30-11:00	(00:30)	Coffee break		CHYN
11:00-14:00	(03:00)	Transfer to field site (Hotel La Couronne, Beurnevésin) and lunch at Café du Soleil (Saignelégier)		
14:00-15:00	(01:00)	WASH in UNHCR (strategical orientation, WMS, tools, what we do, roles & responsibility, monitoring, quality control)	DP/CP	Hotel
15:00-15:30	(00:30)	Coffee break		Hotel
15:30-16:00	(00:30)	Introduction to the training course	EM/MP	Hotel
16:00-17:30	(01:30)	Introduction to applied hydrogeology I	MP	Hotel
17:30-17:45	(00:15)	Break		Hotel
17:45-19:15	(01:30)	Introduction to applied hydrogeology II	EM	Hotel
20:00		Dinner		Hotel

Monday 02/06/14

Time		*Unit title*	*Speaker*	*Place*
07:00-07:45	(00:45)	Breakfast		Hotel
08:00-12:30	(04:30)	Site visit/field work: Basics of groundwater management: Piezometry of the aquifer →Picnic on site and transfer to hotel	Three separate groups	Buix site
12:30-15:00	(02:30)	Workshop: Elaboration of piezometric map of Buix, resource calculation and water balance, flow direction and velocity	Animated group work (EM/MP)	Hotel
15:00-15:30	(00:30)	Coffee break		
15:30-16:30	(01:00)	Basic concepts of groundwater exploration: geophysical investigations	EM	Hotel
16:45-17:45	(01:00)	Basic concepts of sustainable groundwater exploitation and protection	MP	Hotel
18:00-19:00	(01:00)	Basics of water quality- chemical and bacteriological analyses	CV	Hotel
19:30		Dinner		Hotel

Course timetable

Tuesday 03/06/14

Time		*Unit title*	*Speaker*	*Place*
07:00-07:45	(00:45)	Breakfast		Hotel
08:00-14:00	(06:00)	Rotating field work: a) Simple geoelectrical survey & interpretation directly in the field – critical discussion of results and implications for such surveys b) Water quality analysis (incl. bacteriology) of all water points: springs, surface water, wells and piezometers c) Vulnerability mapping and groundwater protection zones, pollution risk, monitoring → Picnic on site	CV/MP/EM three groups with changing activity after 2.0 hours	Buix site
14:00-14:45	(00:45)	Transfer to hotel and coffee break		Hotel
14:45-19:15	(04:30)	Rotating workshops: a) Interpretation of geophysical investigation b) Bacteriological analysis c) Google earth mapping and elaboration of a groundwater protection map	CV/MP/EM three groups with changing activity 1.5 hours	Hotel
19:15-19.45	(00:30)	Wrap-up and discussion of the day's work		Hotel
20:00		Dinner		Hotel

Wednesday 04/06/14

Time		*Unit title*	*Speaker*	*Place*
07:00-07:45	(00:45)	Breakfast		Hotel
08:00-09:00	(01:00)	Interpretation of bacteriological analysis	CV	Hotel
09:15-11:45	(02:30)	Concepts of well construction and rehabilitation	Frank Gugger	Hotel
12:00-12:30	(00:30)	Introduction to pumping tests	EM	Hotel
12:45-13:00	(00:15)	Transfer to Buix site		
13:00-19:00	(06:00)	Rotating field work: a) Step draw-down pumping test b) Constant rate pumping test c) Electrical resistivity tomography → Picnic on site	MP/EM/PP three groups with changing activity 2 hours	Buix site
20:00		Dinner		Hotel

Course timetable

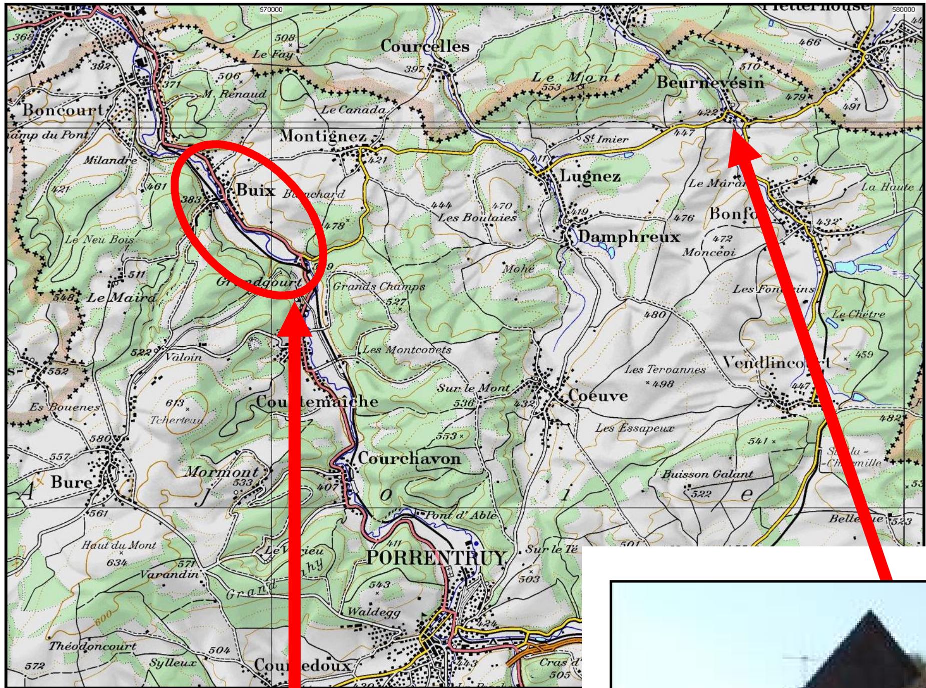
Thursday 05/06/14

Time		*Unit title*	*Speaker*	*Place*
07:15-08:00	(00:45)	Breakfast		Hotel
08:15-10:00	(01:45)	Workshop: Interpretation of pumping tests: - Safe yield - Well performance - Aquifer characteristics	Animated group work (MP/EM/PP)	Hotel
10:00-10:30	(00:30)	Coffee break		Hotel
10:30-12:15	(01:45)	Workshop: Interpretation of pumping tests: - Safe yield - Well performance - Aquifer characteristics	Animated group work (MP/EM/PP)	Hotel
12:30-13:30	(01:00)	Lunch		Hotel
13:45-15:45	(02:00)	Workshop: Case study Kakuma: - Hydrogeological investigation: geophysics, pumping tests and resource evaluation	Group work	Hotel
15:45-16:15	(00:30)	Coffee break		Hotel
16:15-18:15	(02:00)	Group presentations of case studies	Group work	Hotel
18:30-19:30	(01:00)	Recap and discussion on field sessions Synthesis of main 'take-home-messages'	DP/CP & EM/MP	Hotel
20:00		Dinner		Hotel

Friday 06/06/14

Time		*Unit title*	*Speaker*	*Place*
07:00-07:45	(00:45)	Breakfast		Hotel
08:00-10:00	(02:00)	Transfer to Neuchâtel, CHYN		
10:00-10:30	(00:30)	Coffee break		CHYN
10:30-11:30	(01:00)	Example of monitoring groundwater resources in the private sector	C. Egger, NW	CHYN
11:45-13:00	(01:15)	Monitoring in humanitarian operations: case study Dadaab/Kakuma	EM/LB	CHYN
13:00-14:00	(01:00)	Lunch		UNINE
14:30-15:30	(01:00)	Roundtable discussion		CHYN
15:30-16:30	(01:00)	Recap, closure, course evaluation and wrap-up discussion	DP/ BMD & EM/MP	CHYN
18:30		Dinner at Hotel Alpes et Lac		Hotel

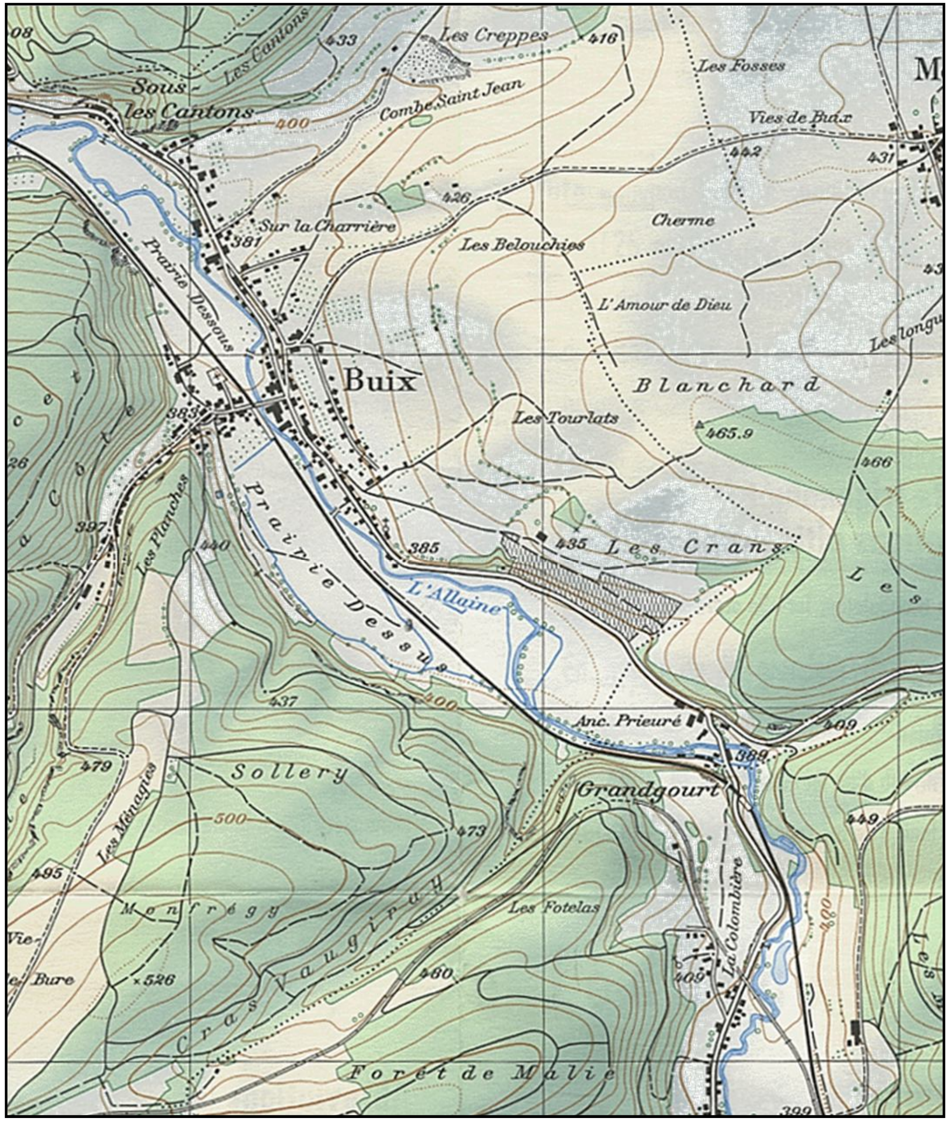
The Buix plain – geographical situation



the Buix plain

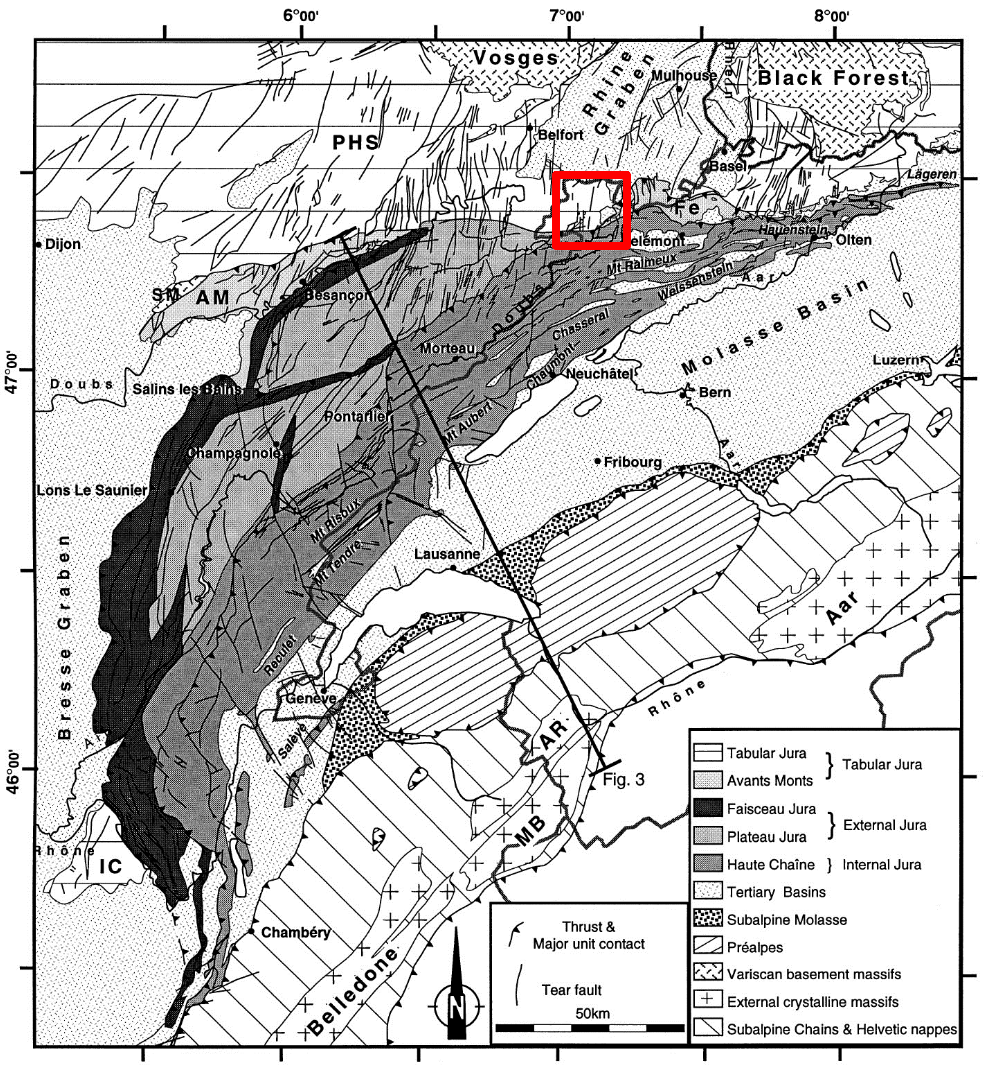
Hôtel-Restaurant La Couronne

Geographical situation



- **mean annual precipitation: 1100 mm/y**
- **alluvial plain: about 0.4 km^2**

Geological setting



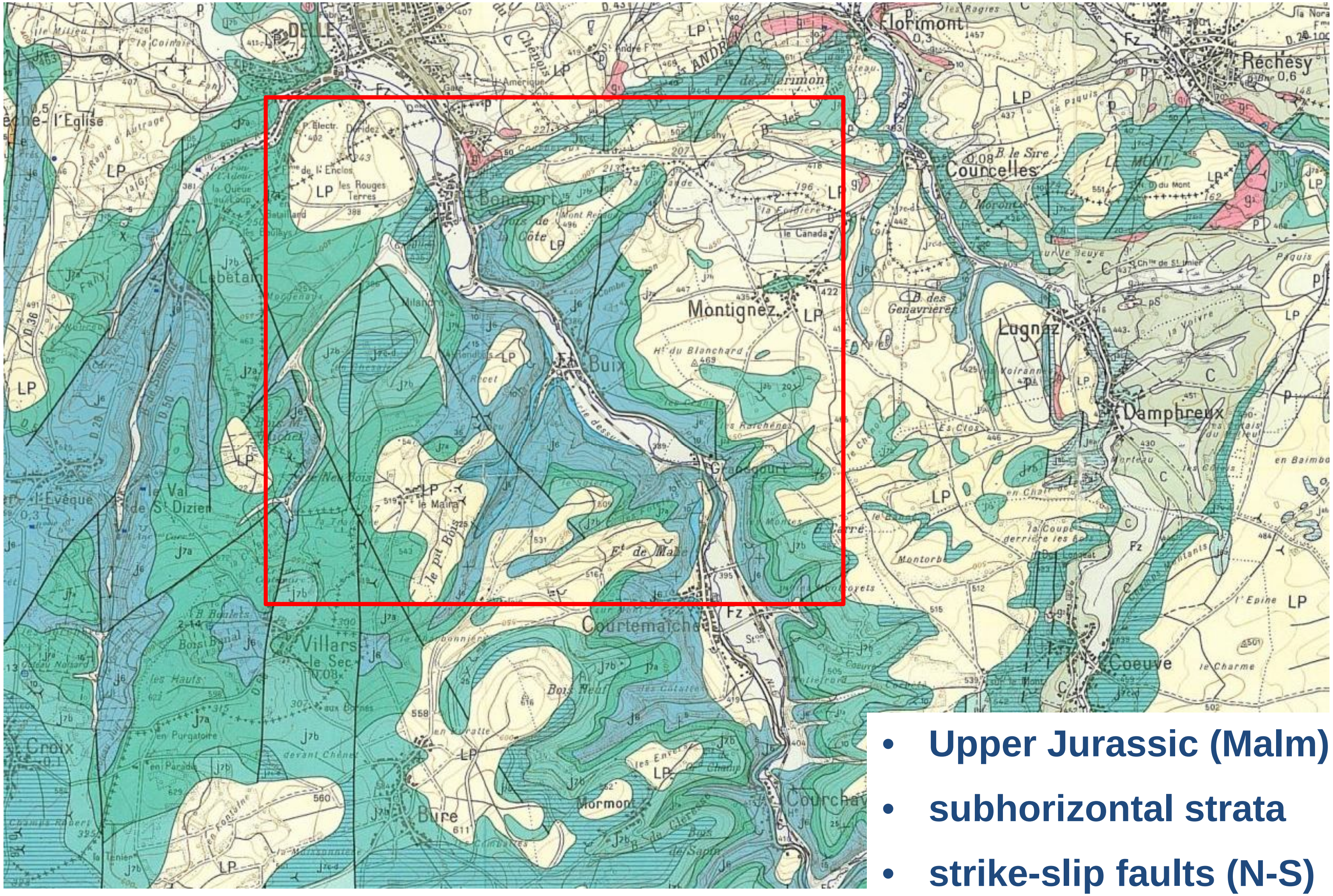
Tabular Jura

Folded Jura Mountains

Swiss Plateau

Alps

Geological setting



- **Upper Jurassic (Malm)**
- **subhorizontal strata**
- **strike-slip faults (N-S)**

Geological setting - stratigraphy

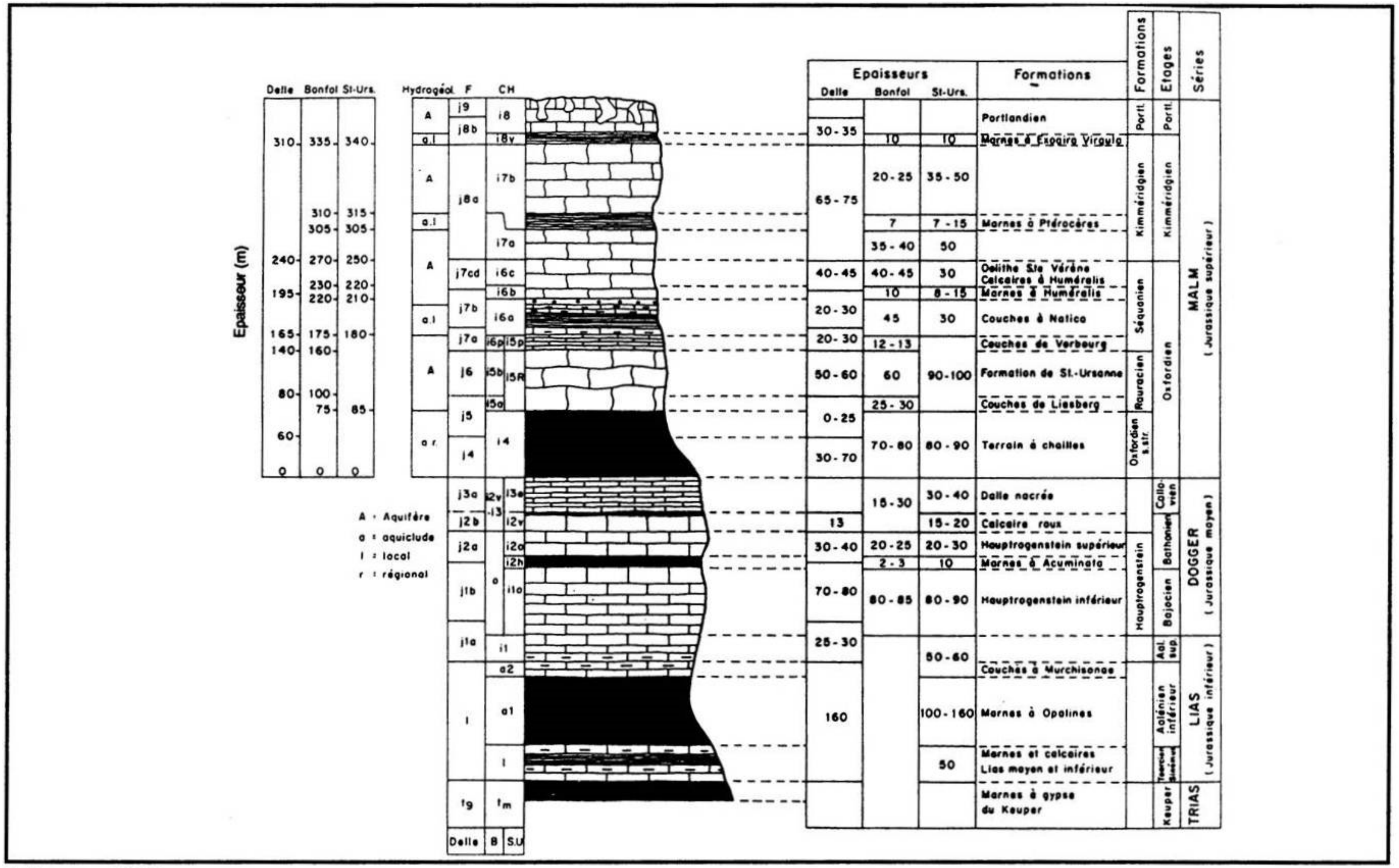
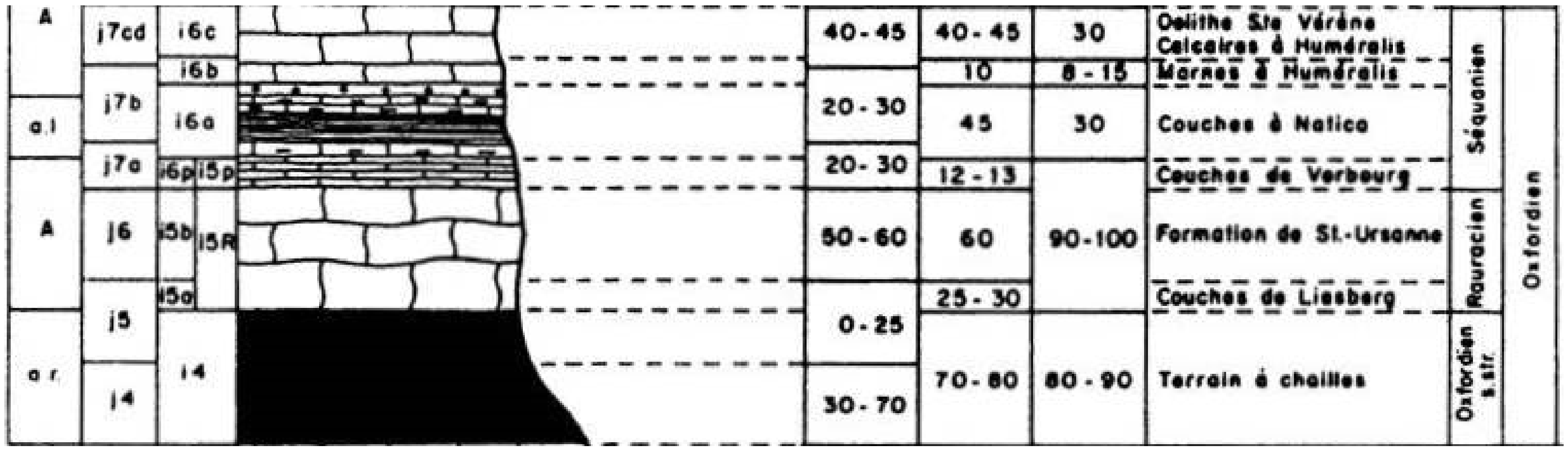


Figure B.6

Log stratigraphique de l'Ajoie basé sur les cartes géologiques suisses (Bonfol et St-Ursanne) et française (Delle). Essai de synthèse.

Geological setting - stratigraphy

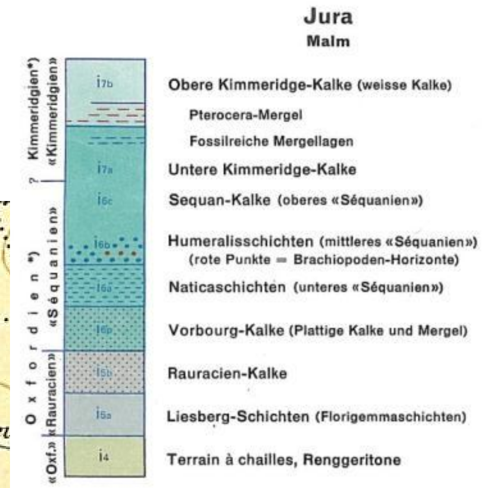


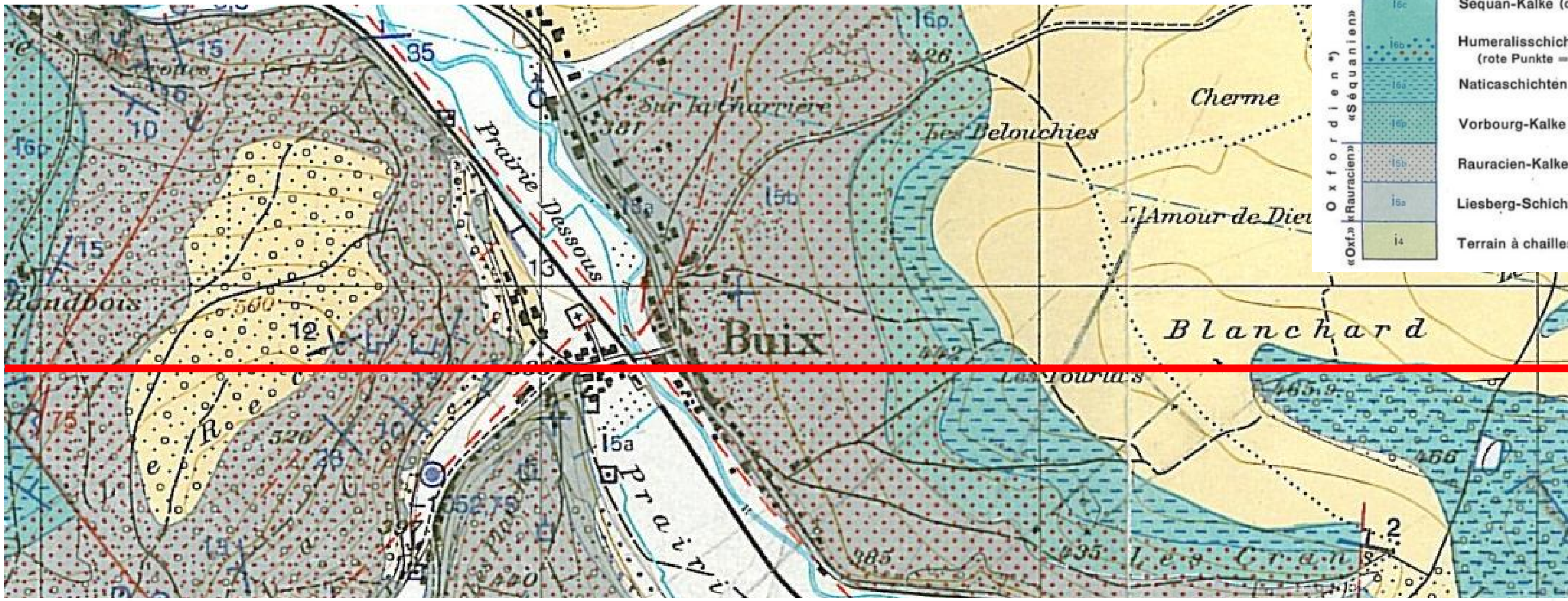
Local stratigraphy:

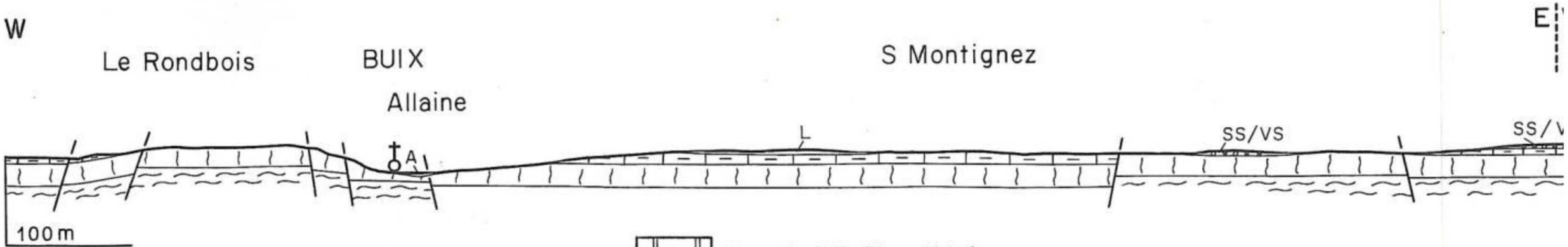
multi-layer karst aquifer: limestone and marls (Rauracian, Sequanian, Kimmeridgian)

regional aquiclude : Oxfordian marls

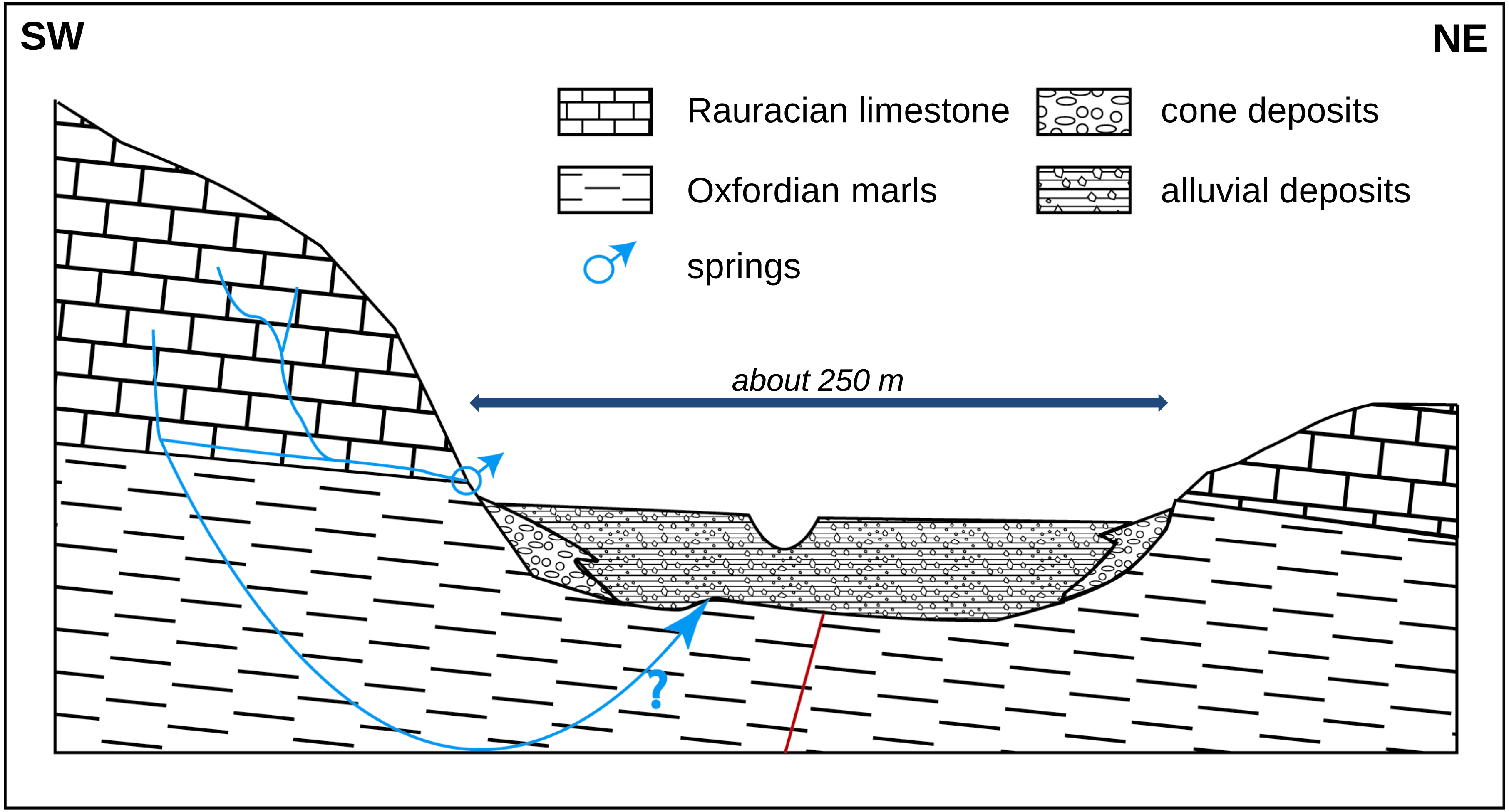
Detailed geology of the Buix plain



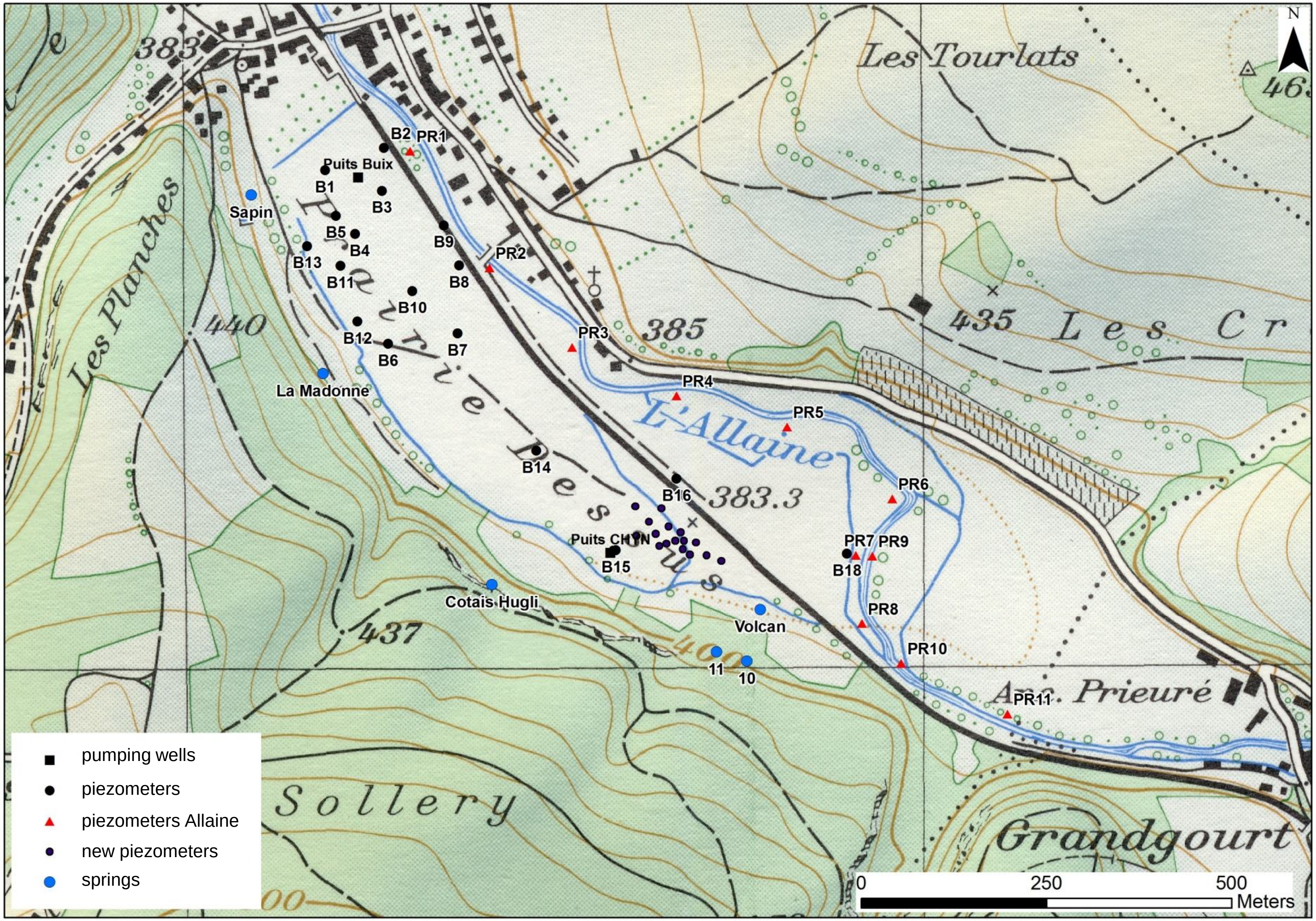




Geological cross-section of the Buix plain



Infrastructure of the Buix plain

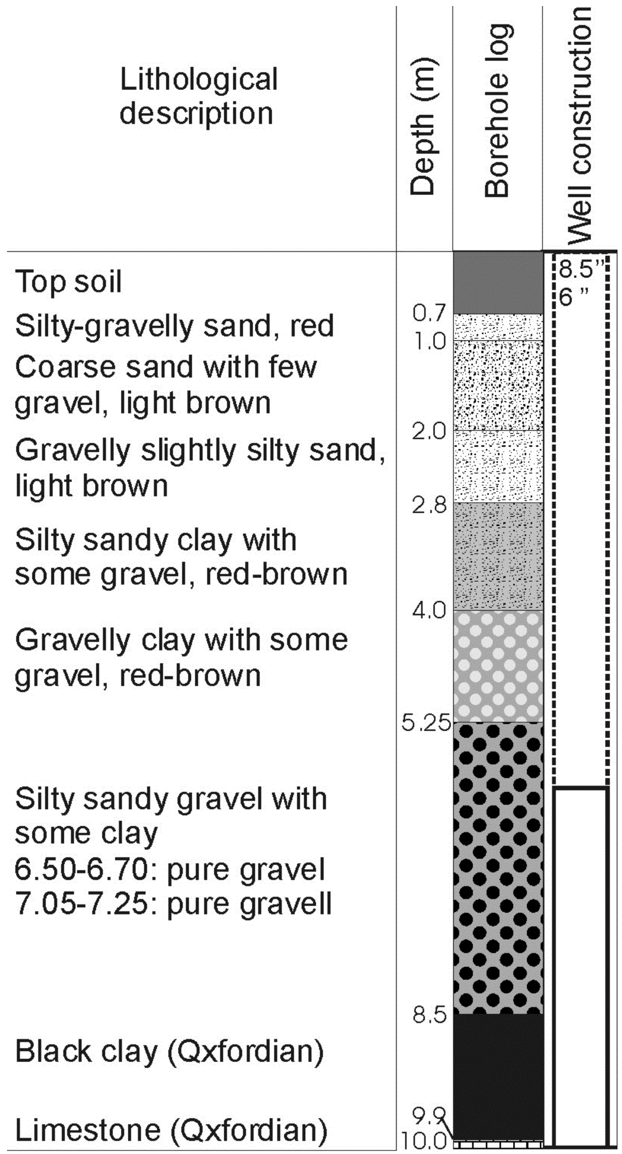


Buix pumping well

Buix pumping well (1982)

- **used for drinking water supply of the village of Buix**
- **approximately 400 m^3/d**

CHYN pumping well



Piezometers

- 18 piezometers distributed throughout the plain (B1-B18)
- 16 new piezometers (B19-B34)
- 11 new piezometers along the Allaine river (PR1-PR11)

Springs

5 karst springs on the Buix plain

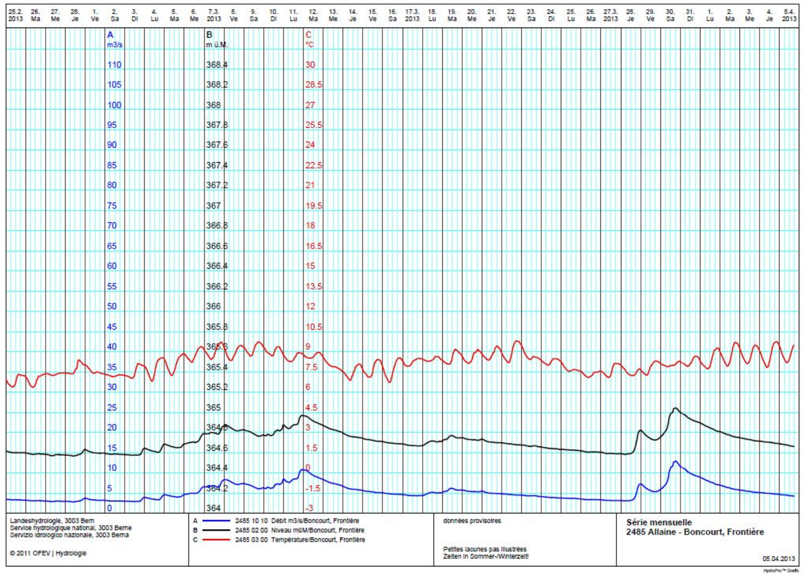
	mean annual discharge
La Madonne spring	0.5 L/s
Côtais Hügli spring	0.9 L/s
S10 spring	0.4 L/s
S11 spring	0.3 L/s
Volcan spring	0.8 L/s

Volcan spring

La Madonne spring

Allaine river

- **affluent of the Doubs and the Rhône**
- **catchment: about 200 km^2**
- **mean alt. of the catchment: 560 m**
- **mean annual discharge: 2.8 m^3/s**
- **maximum monitored discharge: 72.4 m^3/s**



http://www.hydrodaten.admin.ch

What and who is the CHYN?

Centre for Hydrogeology and Geothermics CHYN

University of Neuchâtel

01 June 2014

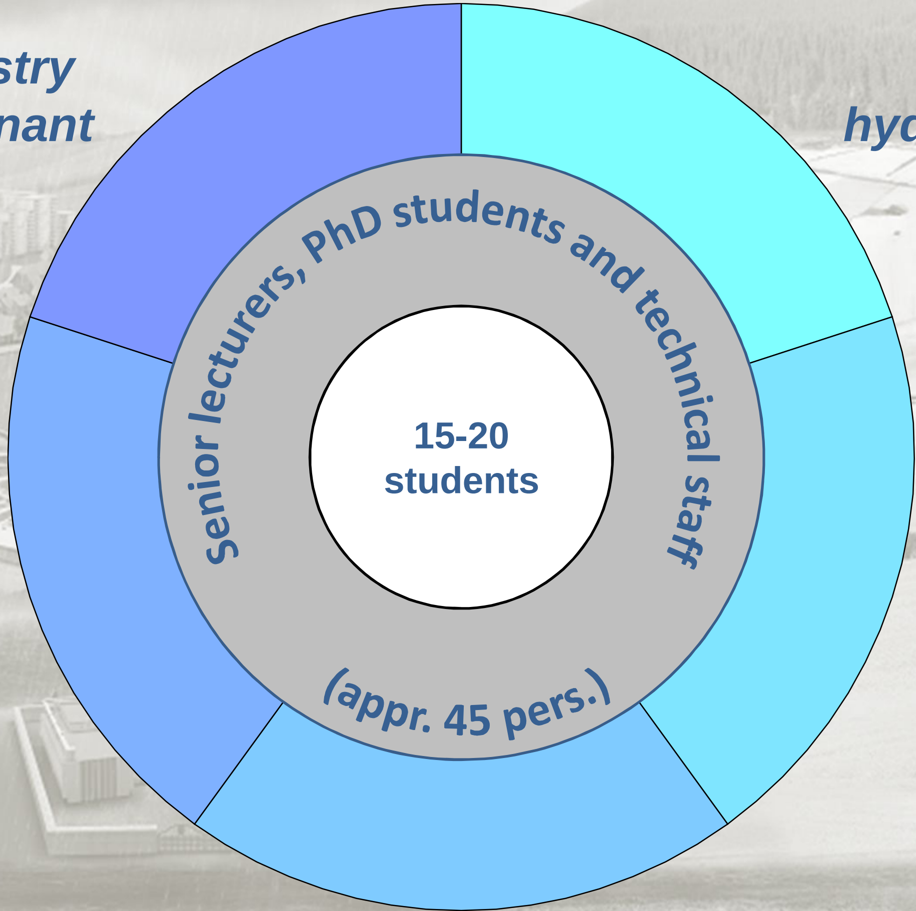
BRIEF HISTORY

- **Founded in 1963, offering a postgraduate course in hydrogeology**
- **Until 1999: one full professor**
- **Since 2009: 5 professors and appr. 45 collaborators**
- **Since 2009: Master in hydrogeology and geothermics**

STRUCTURE OF THE CHYN

D. Hunkeler
Hydrochemistry and contaminant hydrology

P. Brunner
General hydrogeology

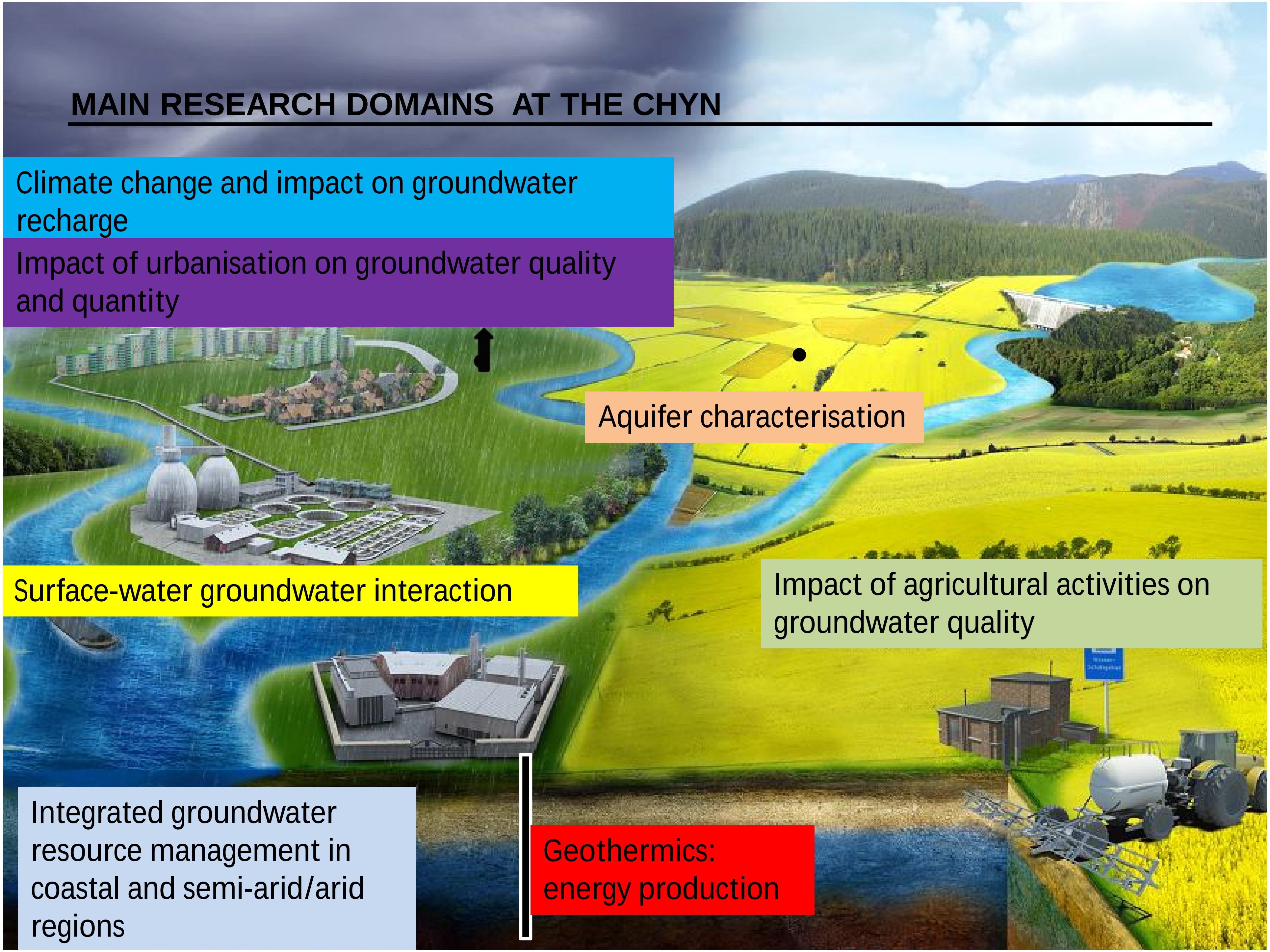


S. Miller
Geothermics

P. Perrochet
Quantitative hydrogeology

P. Renard
Stochastical hydrogeology

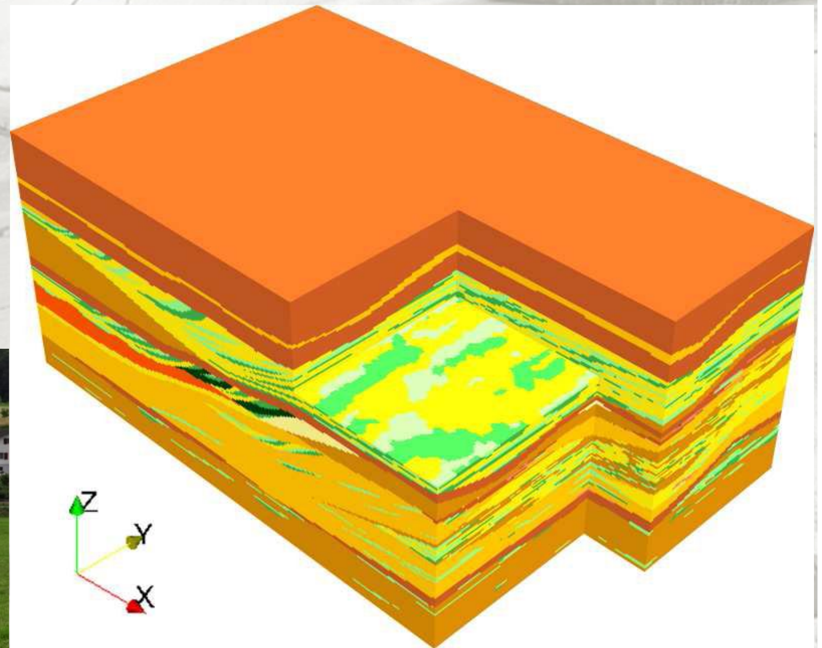
MAIN RESEARCH DOMAINS AT THE CHYN



AQUIFER CHARACTERISATION

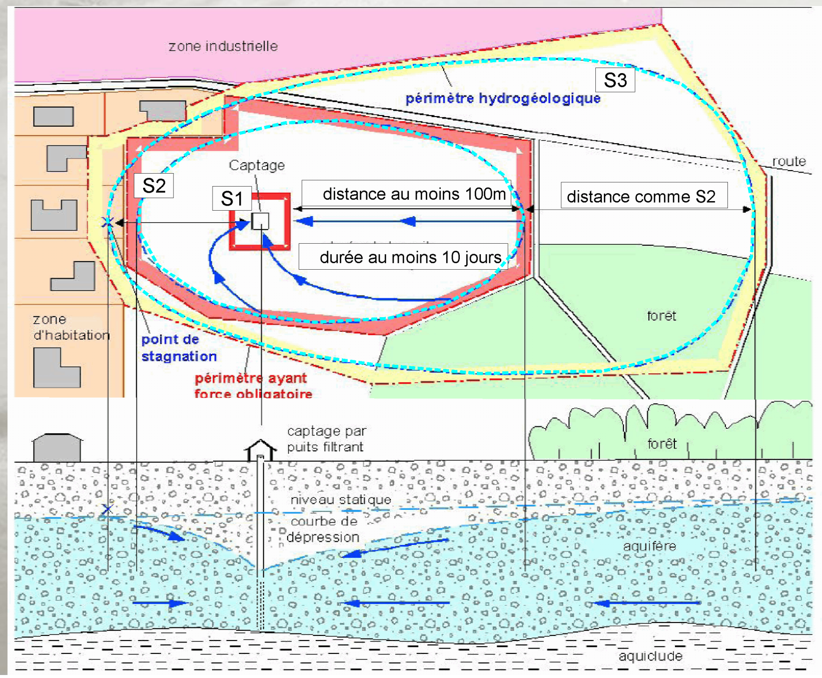
- Characterisation of different aquifer types using multiple field methods in order to understand groundwater dynamics: geophysics, tracer tests, pumping tests, hydrogeological/geological mapping

- Geological and numerical modelling



IMPACT OF URBANISATION ON GROUNDWATER QUALITY AND QUANTITY

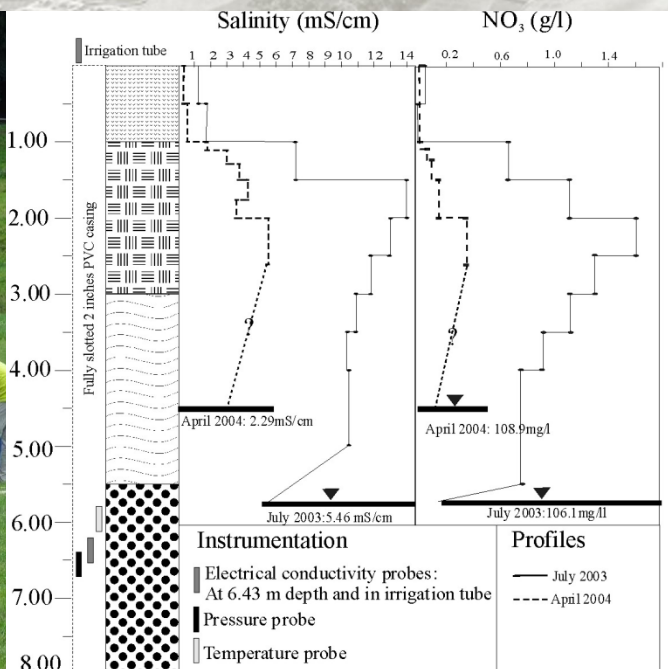
- Impact of waste disposal sites on groundwater quality and development of remediation techniques
- Protection zones and vulnerability mapping
- Investigation of processes involving chemical and biological contaminants in groundwater systems



IMPACT OF AGRICULTURAL ACTIVITY ON GROUNDWATER QUALITY AND QUANTITY

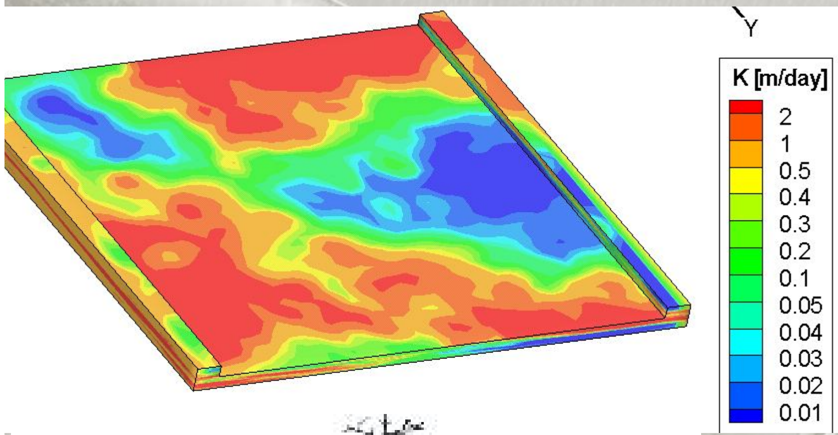
- Transport processes and degradation of nutrients and pesticides and their impact on groundwater quality using laboratory and field methods

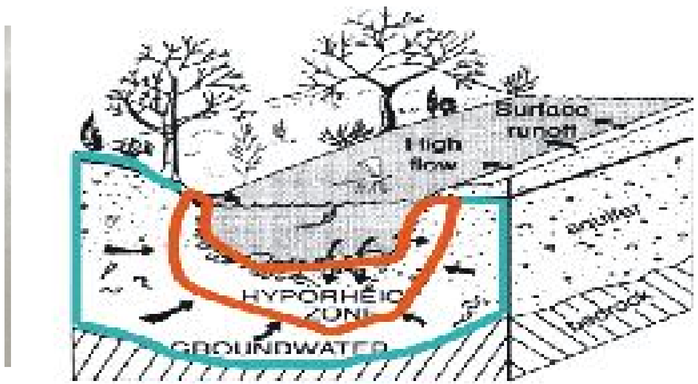
- Investigations on impact of irrigation on groundwater quality and quantity by means of field investigations and modelling

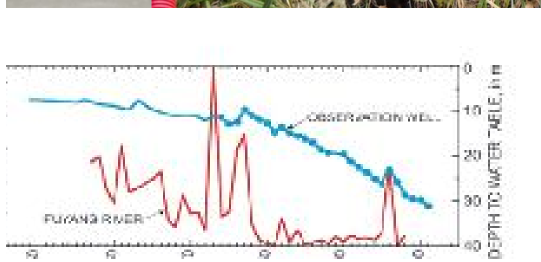


SURFACE-WATER GROUNDWATER INTERACTIONS

- Impact of groundwater exploitation on surface water bodies
- Impact of surface water quality on groundwater quality
- Role of groundwater for ecosystems

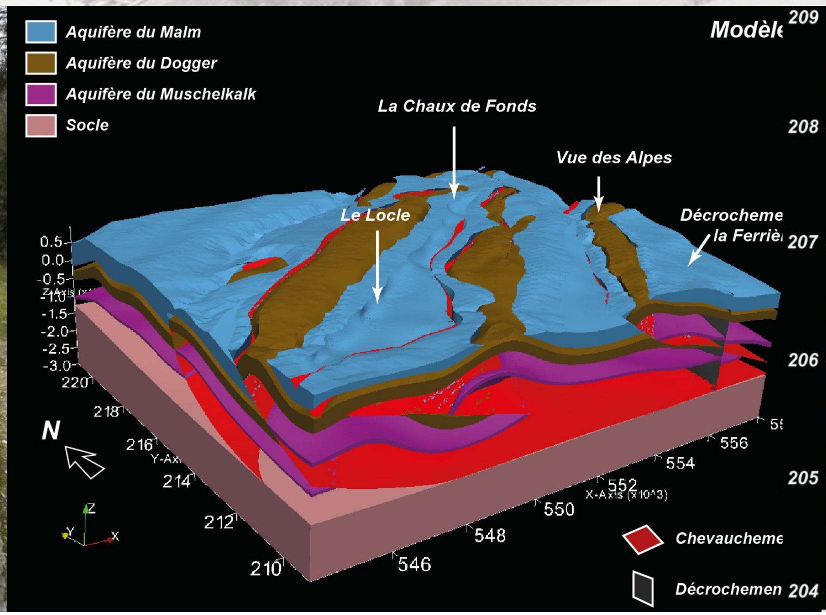


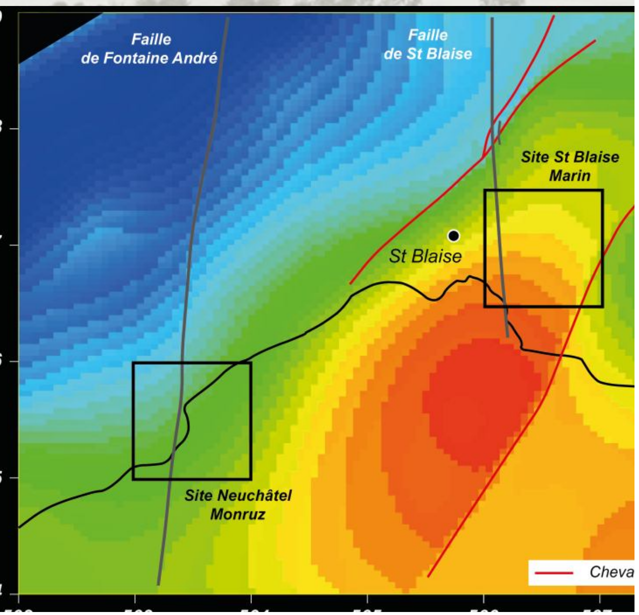




GEOTHERMICS

- Defining geothermic potential at regional scales for energy production
- Development of field methods for exploration of deep geothermal resources
- Geochemical modelling of geothermal fluids
- Geological and thermic modelling of deep reservoirs
- Dimensioning of groundwater heat pump systems



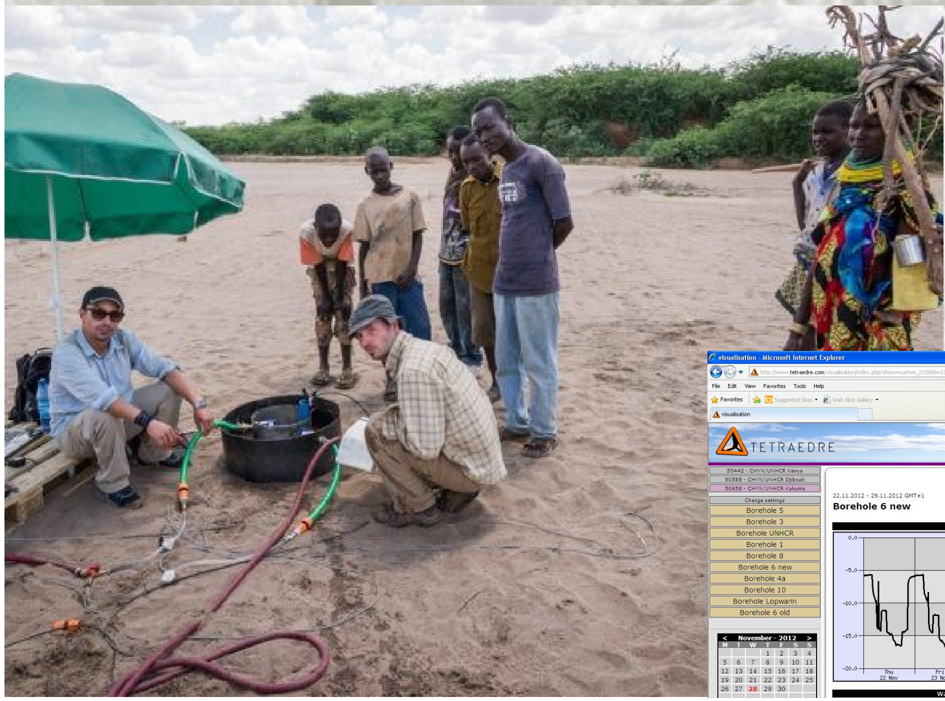


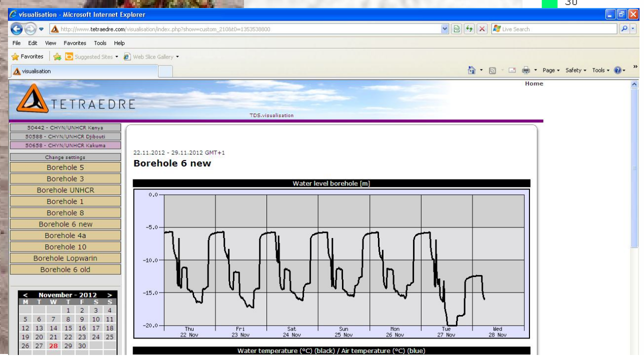
CLIMATE CHANGE AND IMPACT ON GROUNDWATER RECHARGE

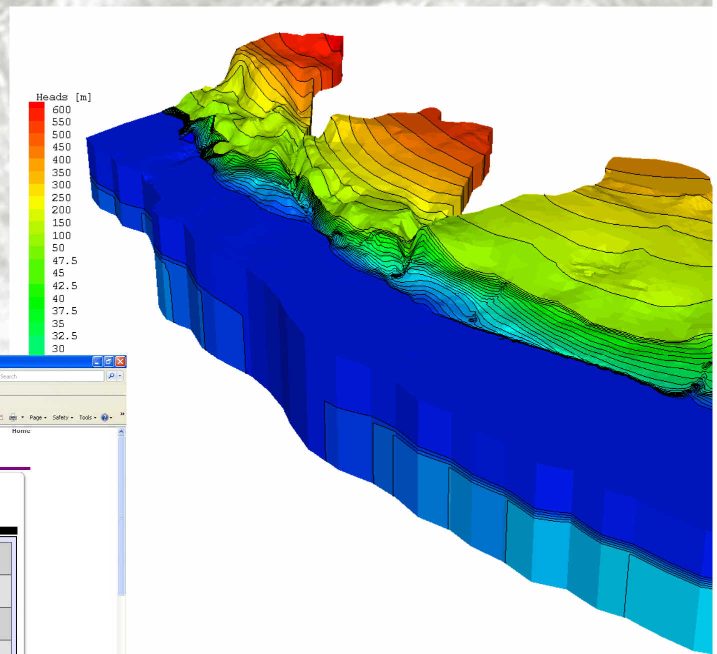
- Impact of snow cover on groundwater recharge processes (climate change)
- Quantification of groundwater recharge in different climatic conditions
- Interaction of surface-water groundwater during droughts

INTEGRATED GROUNDWATER RESOURCE MANAGEMENT IN COASTAL AND SEMI-ARID/ARID CONTEXTS

- Seawater intrusion in coastal areas: development of management tools
- Quantification of groundwater recharge in arid and semi-arid conditions by field methods, remote sensing and modelling
- Development of novel monitoring techniques in humanitarian contexts







UNIVERSITÉ DE NEUCHÂTEL

CHYN
Centre d'hydrogéologie et de géothermie

CHYN TRAINING COURSE FOR

UNHCR WASH STAFF

UNHCR
The UN Refugee Agency

APPLIED HYDROGEOLOGY

from field investigation towards sustainable water resources management

June 1 to June 6, 2014

Introduction to hydrogeology I

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Agency for Development and Cooperation SDC

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Main questions to be addressed today

- What is hydrogeology and why is groundwater a precious resource?
- The water cycle and water sheds: how much water is available in average and where?
- What is an aquifer and what different types exist?
- What are the driving forces of groundwater flow?
- How do we ‘measure’ groundwater flow – identification of groundwater flow systems

What is hydrogeology?

The discipline that studies the movement of groundwater, its origins, quantity and quality

What is groundwater and where do we encounter it in the everyday life?

hydro = the liquid which moves underground
geology = the vessel in which the liquid moves

Why is groundwater a valuable resource?

- generally of good (or better) quality (than surface water)
- is far more constant in time: when the rivers run dry there is still groundwater

Surface water *vs.* groundwater

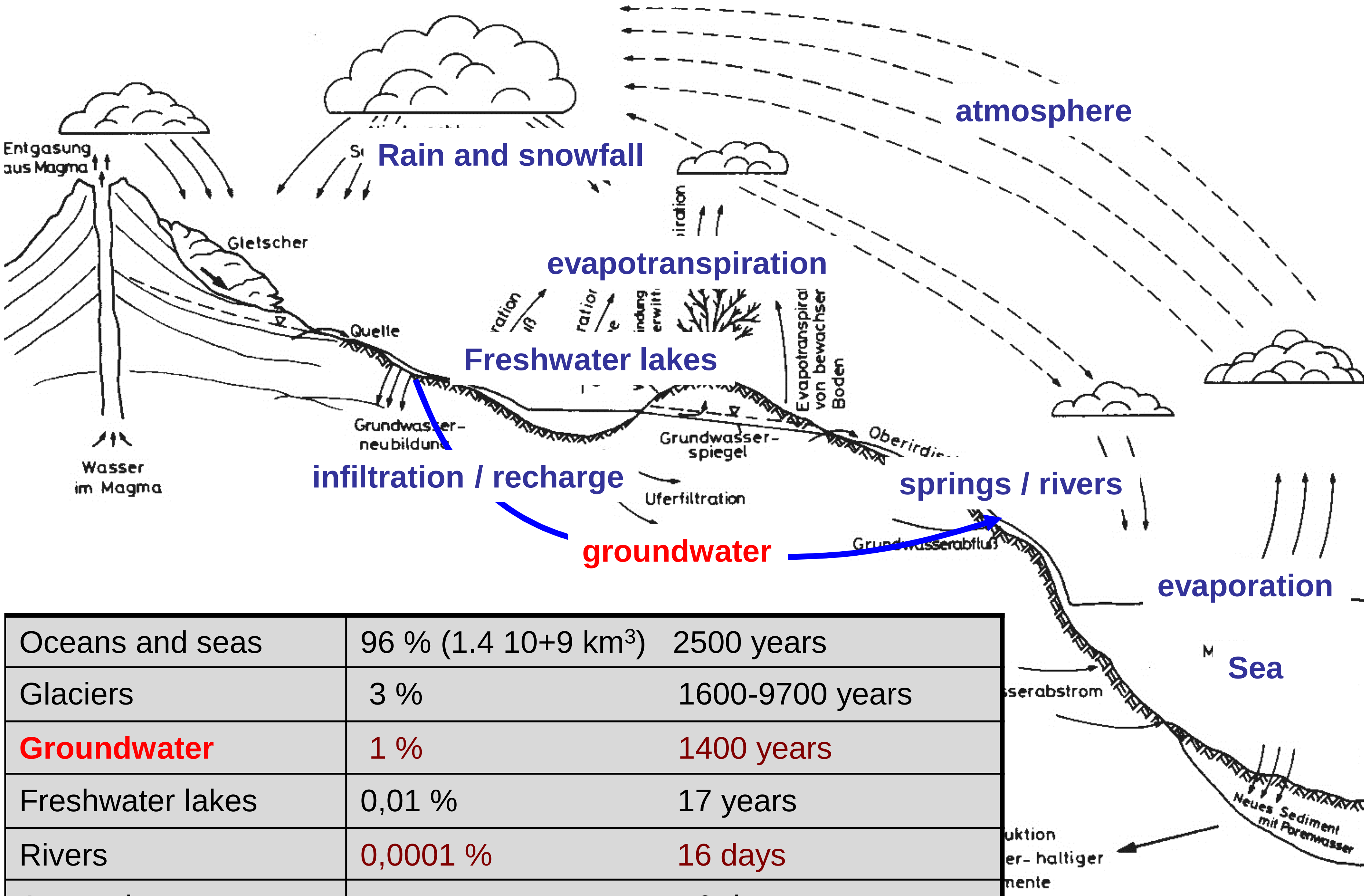
Surface water

- ***always has to be assumed to be affected by faecal contamination***

Groundwater

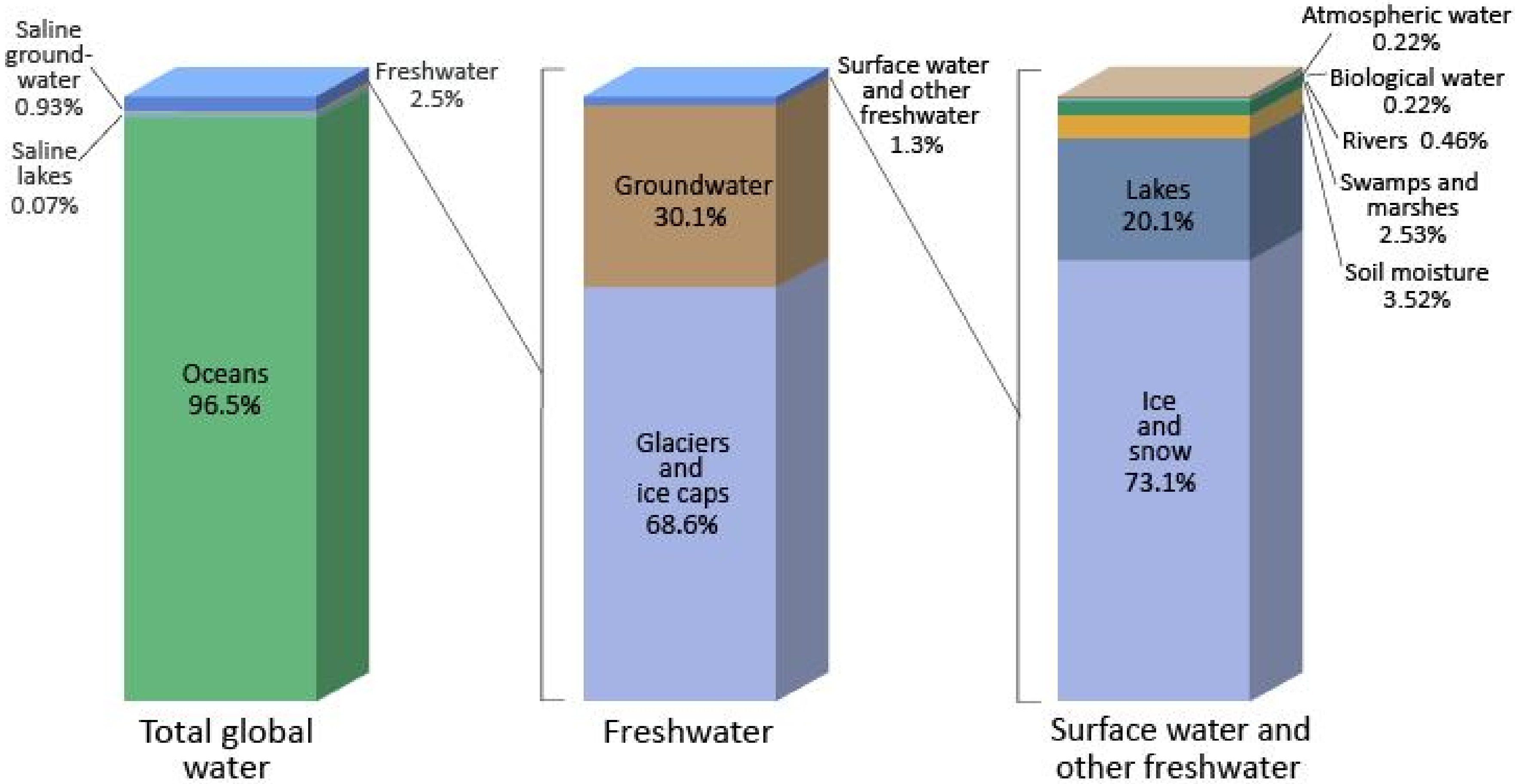
- natural filtration occurs
  - eliminates microorganisms
  - eliminates also some chemical compounds
- may still contain some faecal contamination depending on how well the pumping well or the spring is protected
- karst springs and other springs that react strongly on precipitation events:
  - strong link with surface via caves or other preferential pathways
  - ***likely affected by faecal contamination in particularly during flood events***

How is it embedded in the global water cycle?



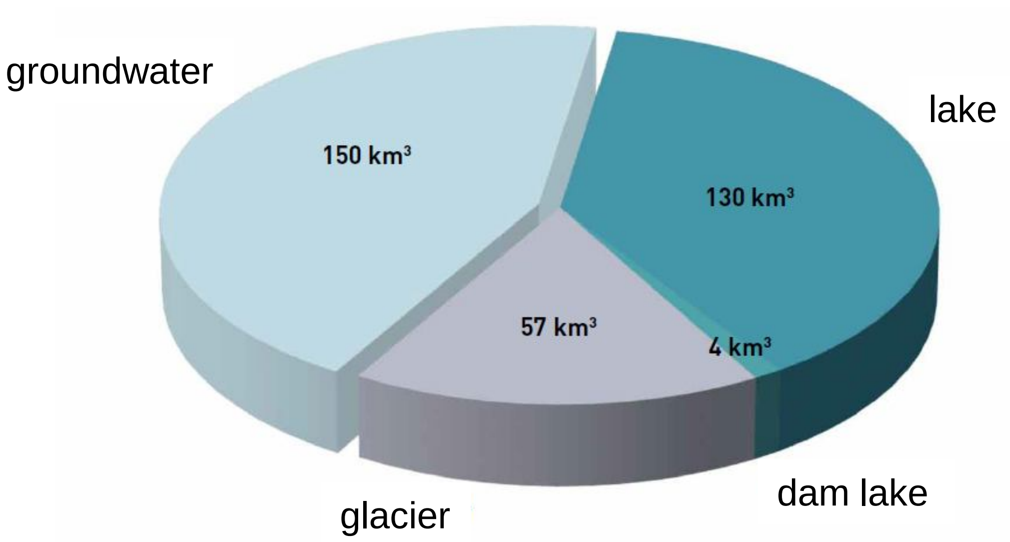
Oceans and seas	96 % (1.4 10+9 km^3)	2500 years
Glaciers	3 %	1600-9700 years
Groundwater	1 %	1400 years
Freshwater lakes	0,01 %	17 years
Rivers	0,0001 %	16 days
Atmosphere	-	8 days

Distribution of earth's water



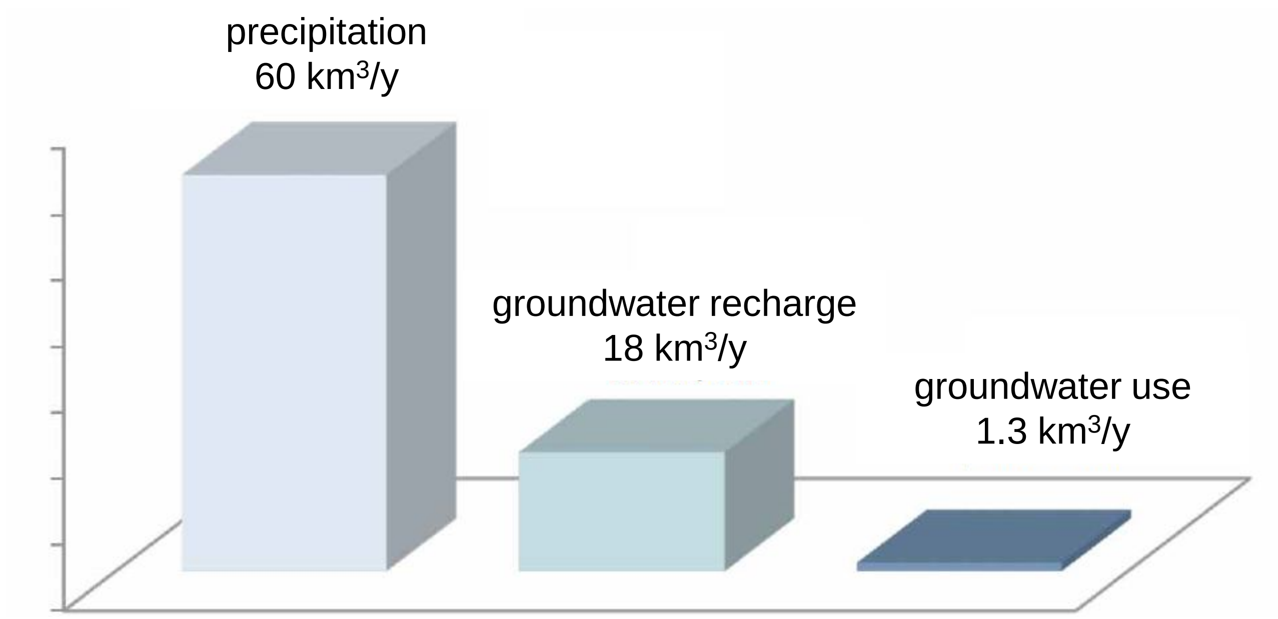
Source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources.

Distribution of water in Switzerland



Water reserves in Switzerland

Precipitation, groundwater recharge and groundwater use in Switzerland

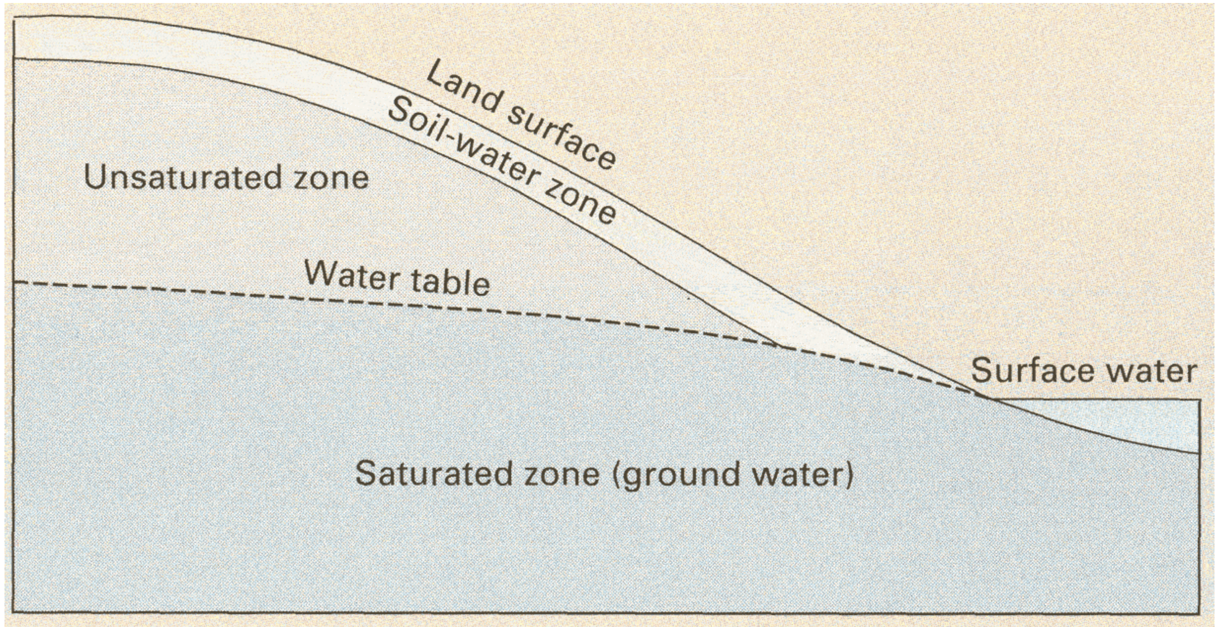


Major difficulty with groundwater

We hardly ever see it – only in some places: springs, wells and boreholes are the only places where we can SEE the groundwater

The main features of groundwater

Unsaturated (vadose) zone: the pore spaces in the soil contain both water and air – it may be humid but water cannot be pumped- plants can use this water



Saturated zone: the pores are completely filled with water. Pressure is above atmospheric pressure.
Water table: interface between the two zones – this is what we can measure

What is an aquifer?

- **aquifer**: a rock formation made up of permeable materials that can store, transmit and yield economically significant amounts of water e.g. sands, gravel, sandstones, limestones

- **aquifuge**: impermeable rock that is incapable of absorbing or transmitting significant amounts of water e.g. unfractured granites

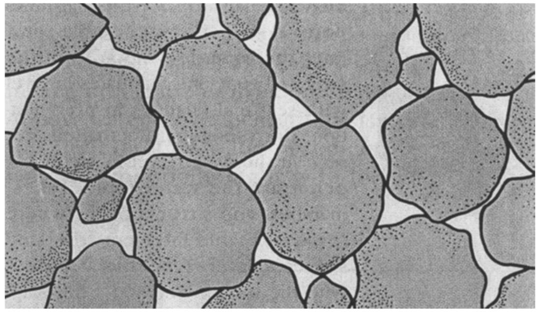
- **aquiclude**: rocks that may absorb large amounts of water, but when saturated are unable to transmit it in significant amounts e.g. clays, marls

- **aquitard**: a relatively less permeable bed in an otherwise highly permeable sequence e.g. a calcareous sandstone in a karstified limestone

The main aquifer types
primary *vs.* secondary porosity

Porous aquifers –
unconsolidated deposits
as found in river valleys

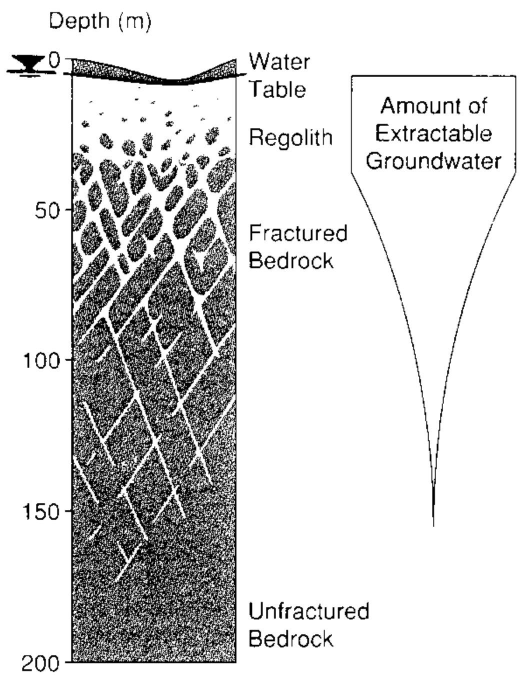
primary porosity
(during sedimentation)



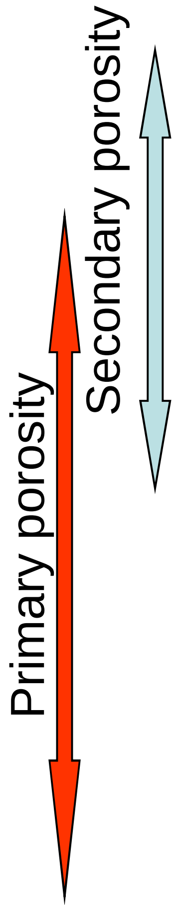
Fractured aquifers –
crystalline: sedimentary,
igneous, volcanic and
metamorphic rocks

Karst aquifers –
Limestone / dolomite with
highly dissolved fracture
systems forming caves –
subsurface rivers and
lakes

secondary porosity
(tectonics, karstification)



Typical porosities of different rock types



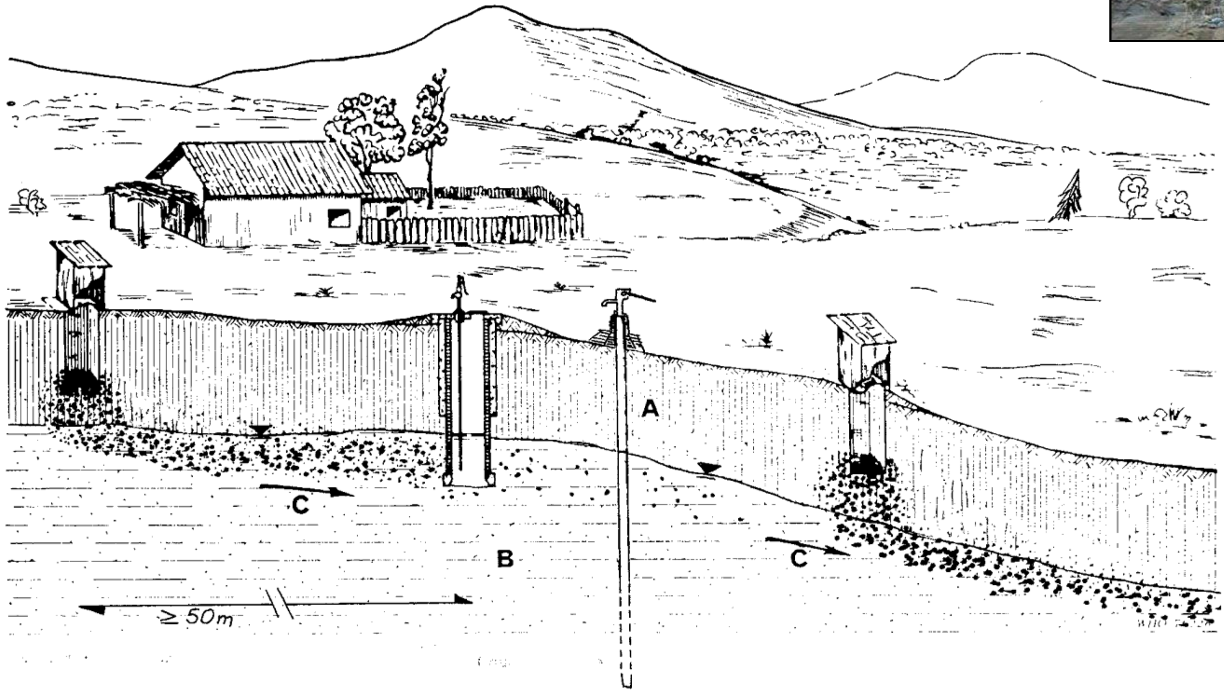
	Type of pore space	Total porosity	Efficient porosity
Granite and crystalline bedrock	Joints and fractures	Low	0.1 - 5%
Limestone	Solution cavities	Low to high	**0.1 - 20%**
Basalt	Vesicles and fractures	High	**5 - 30 %**
Cemented Sandstone	Between grains	Moderate to high	**2 - 15%**
Cemented Conglomerate	Between grains	Moderate to high	**2 - 20%**
Shales	Joints, fractures and clay minerals	Low	0.1 - 10%
Unconsolidated Sand	Between grains	Moderate	**15 - 25%**
Unconsolidated Gravel	Between grains	Moderate	**10 - 20%**
Silt	Between grains	High	0.1 - 2%
Clay	Clay minerals	High	0.1 - 1%

The **efficient porosity** n_e is defined the ratio of the volume of the “gravity mobile” water by the total volume of a sample:

$$n_e = \frac{V_{mob.water}}{V_{total}}$$

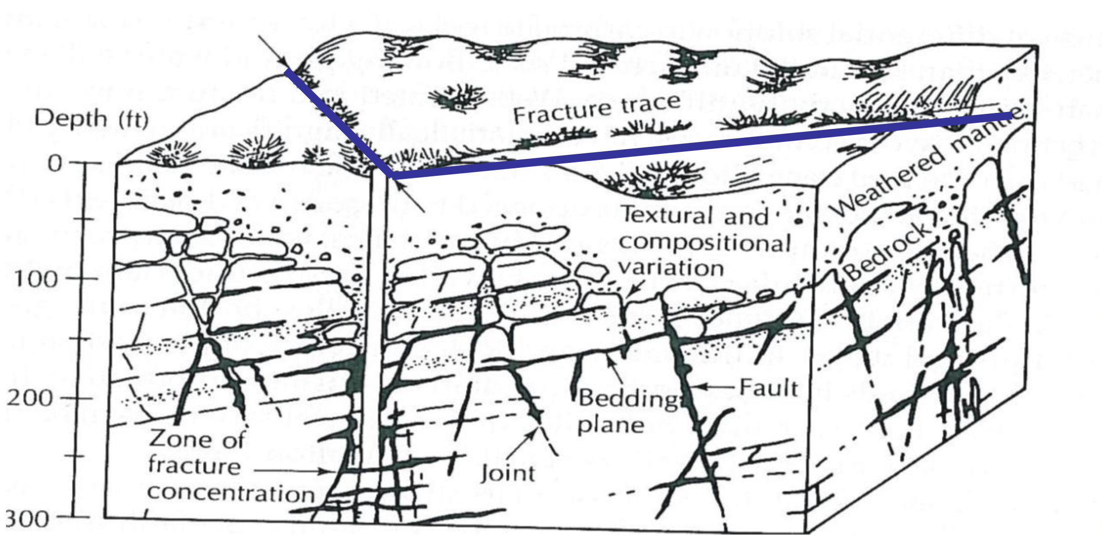
Porous aquifers – unconsolidated sands & gravels

- highly productive aquifers
- good degree of filtration in general but
- may be vulnerable to surface contamination by infiltration if it is too shallow

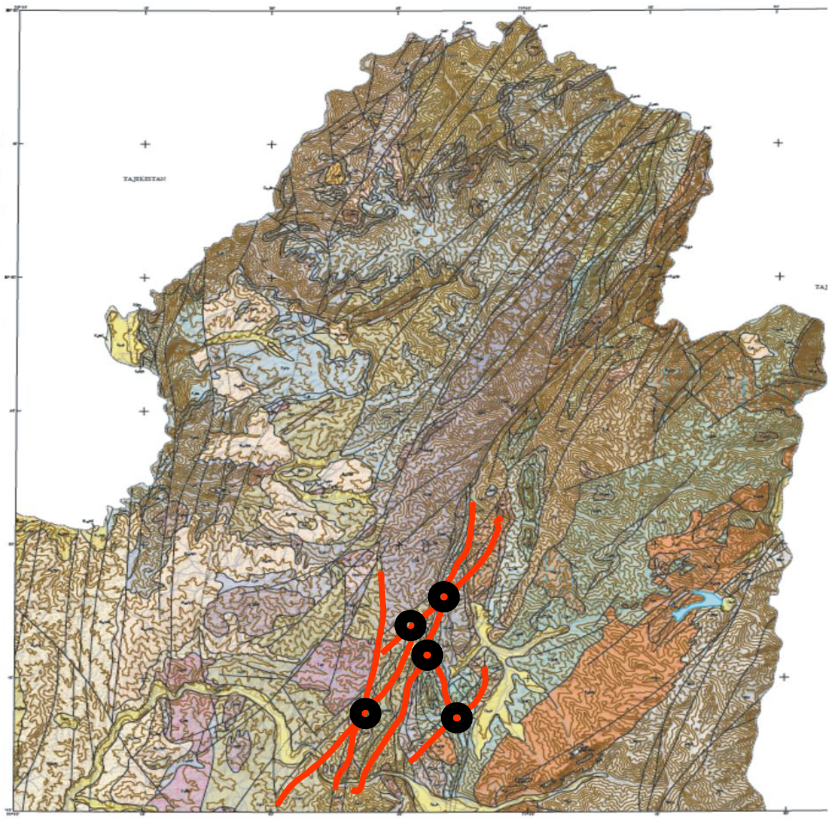


Fractured aquifers – lithified rocks

- Water flows mainly in millimetric fractures or on fault zones (heavily crushed areas)
- Highest permeability in places where several faults meet
- The bulk of the rock has a very low porosity and permeability
- Fractures can be difficult to find



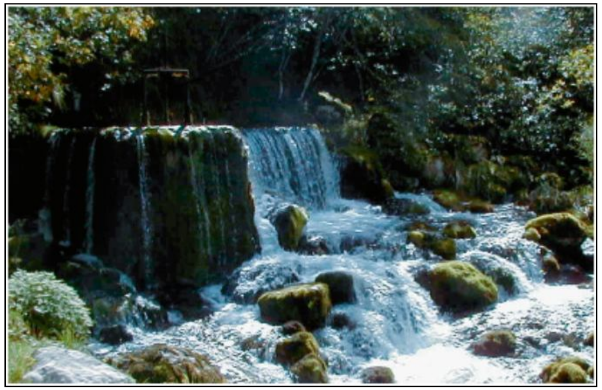
Fractures and fault zones are zones of weakness: often they form dominant features in the topography (e.g. valleys, lineaments)



example of intersecting faults in Afghanistan

Karst aquifers – limestone / dolomite

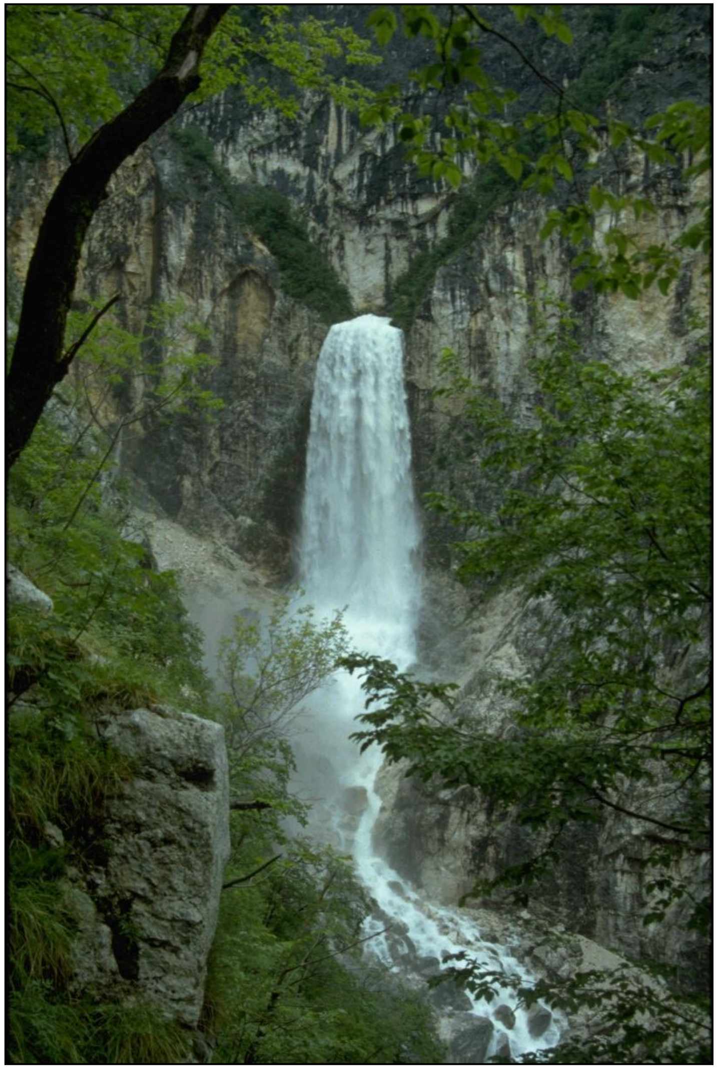
- large areas often without surface drainage
- streams from adjacent non-karst areas often sink underground via swallow holes
- residence times much smaller than in usual aquifers
- only few springs per surface area, but with high discharge, often > 10 m^3/s (sometimes > 100 m^3/s; e.g. Fontaine de Vaucluse)
- in response to hydrologic events (rainfall, snowmelt), karst springs often show rapid and strong variations of discharge, physico-chemical and microbiological parameters
- extremely vulnerable to contamination



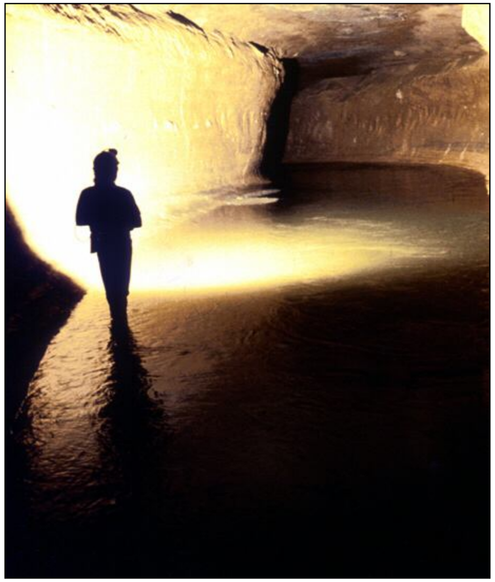
Source de la Lionne (Vallée de Joux, Switzerland) during low- (above) and high-flow conditions (below)

$$CaCO_3 + CO_2 + H_2O = Ca^{2+} + HCO_3^- + HCO_3^-$$

Typical karst features



Boca spring, Slovenia



Mammoth Cave System, USA

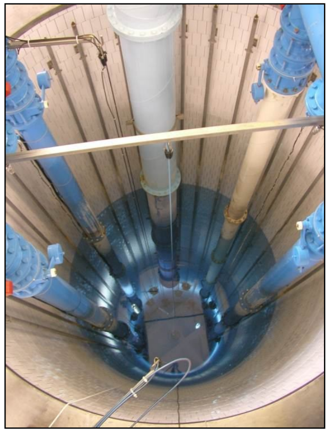
Milandre Cave System, Switzerland

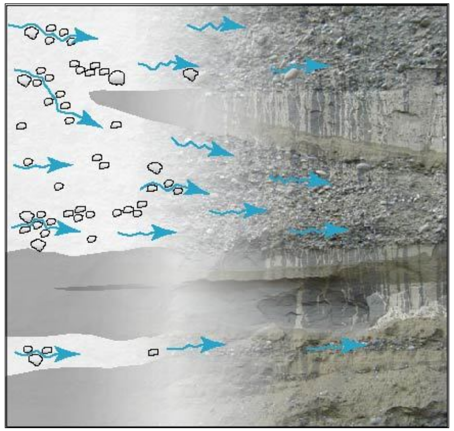
Sinkhole Plain, USA

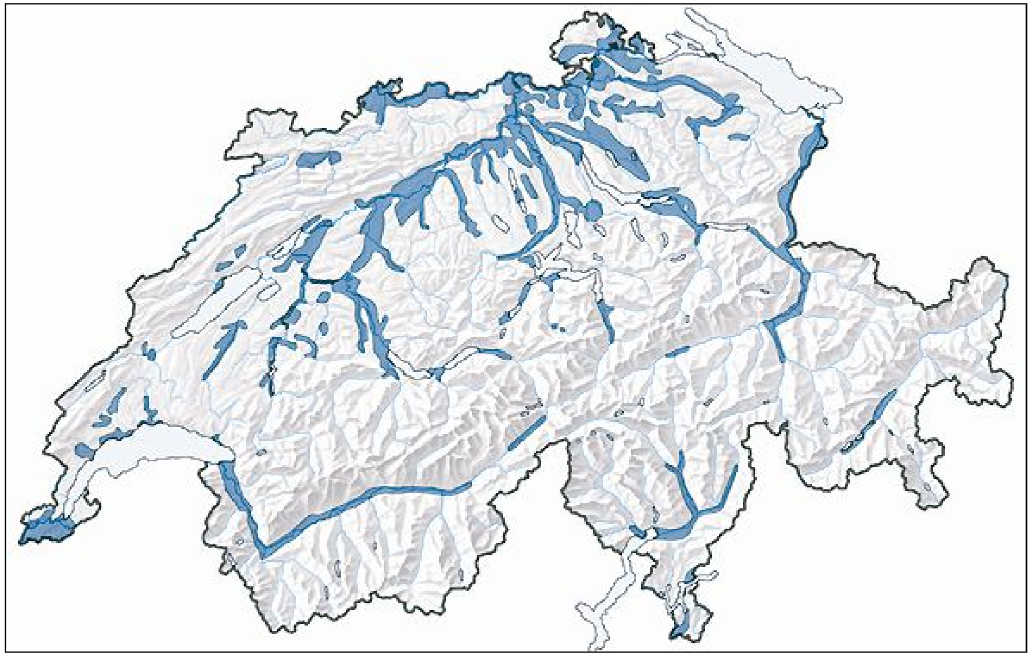
Main aquifer types in Switzerland

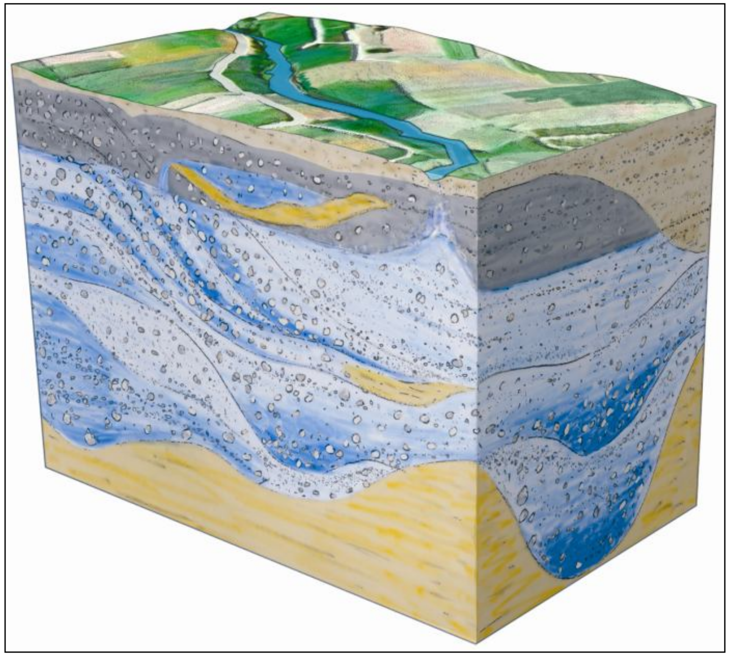
Porous aquifers:

- cover about 6 % of Switzerland
- contributes to about 35 % of the drinking water supply







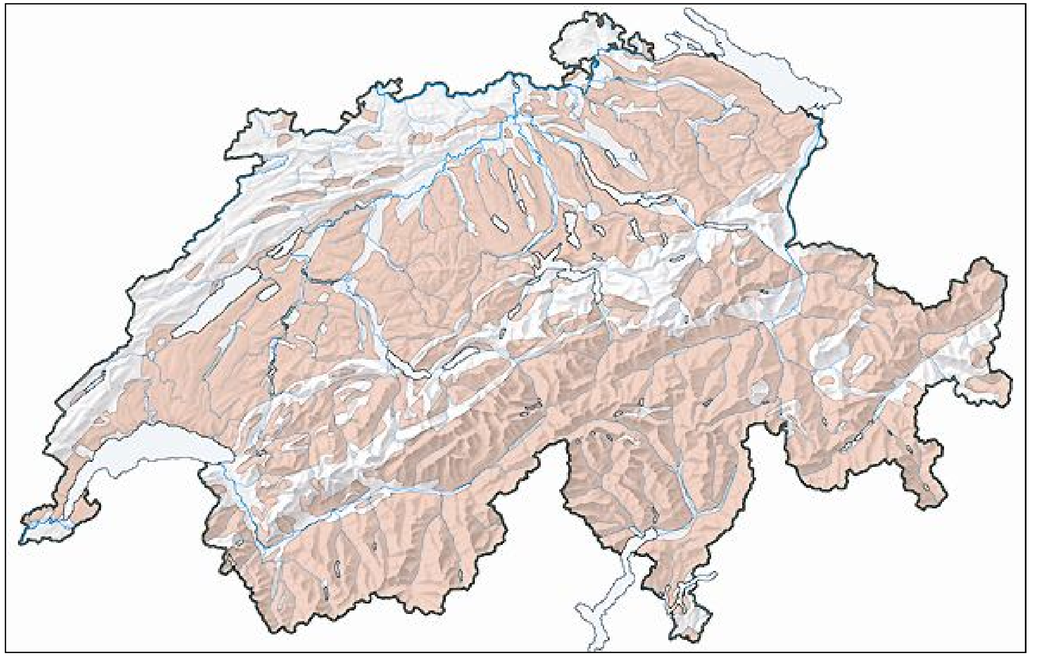


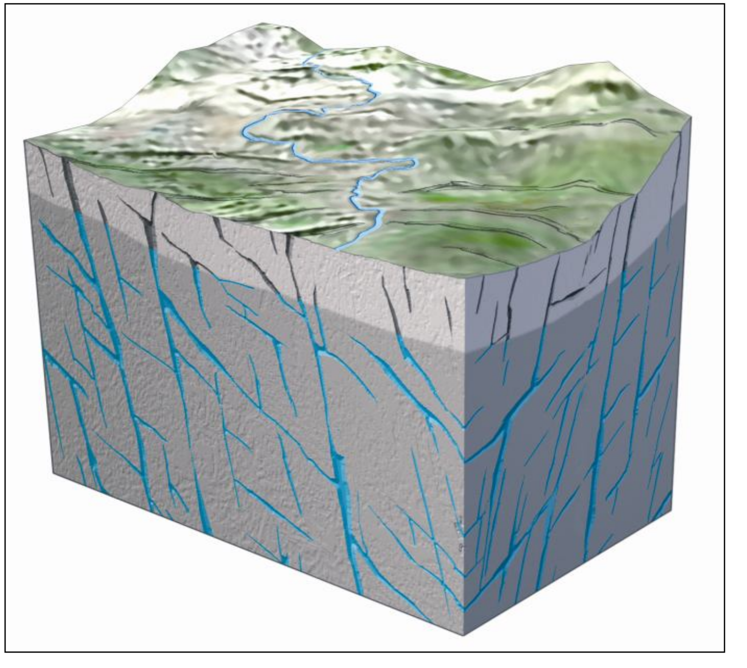
all figures: *FOEN / BAFU / OFEV*

Main aquifer types in Switzerland

Fractured aquifers:

- cover about 78 % of Switzerland
- contributes to about 30 % of the drinking water supply





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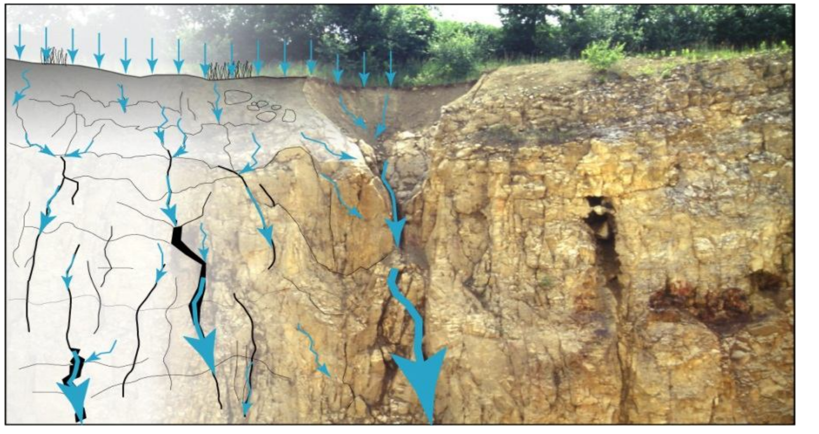
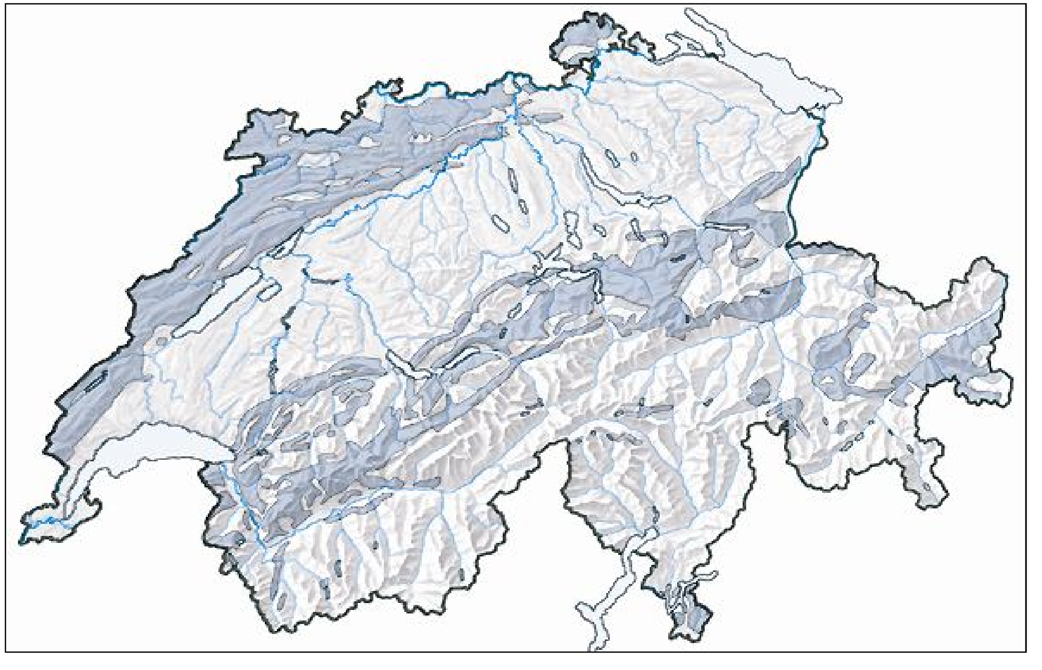
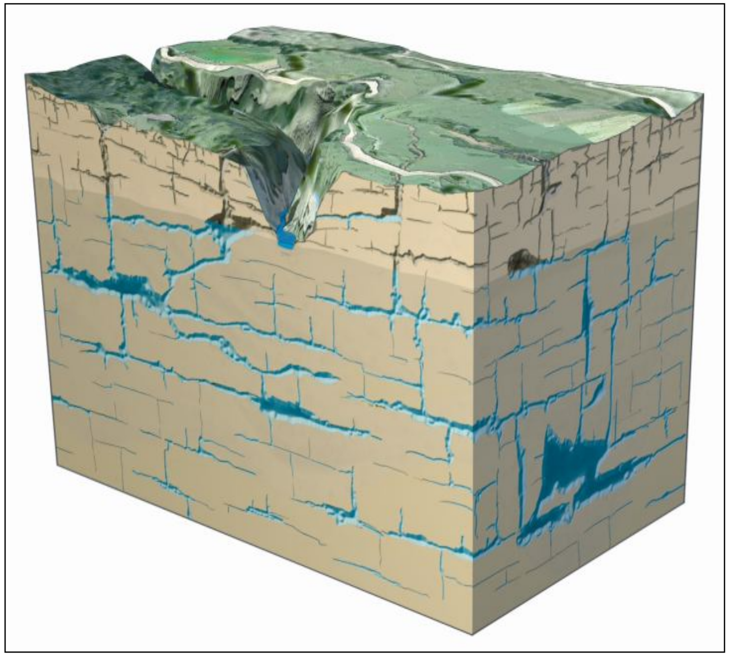
Main aquifer types in Switzerland

Karst aquifers:

- cover about 16 % of Switzerland
- contributes to ca. 18 % of the drinking water supply







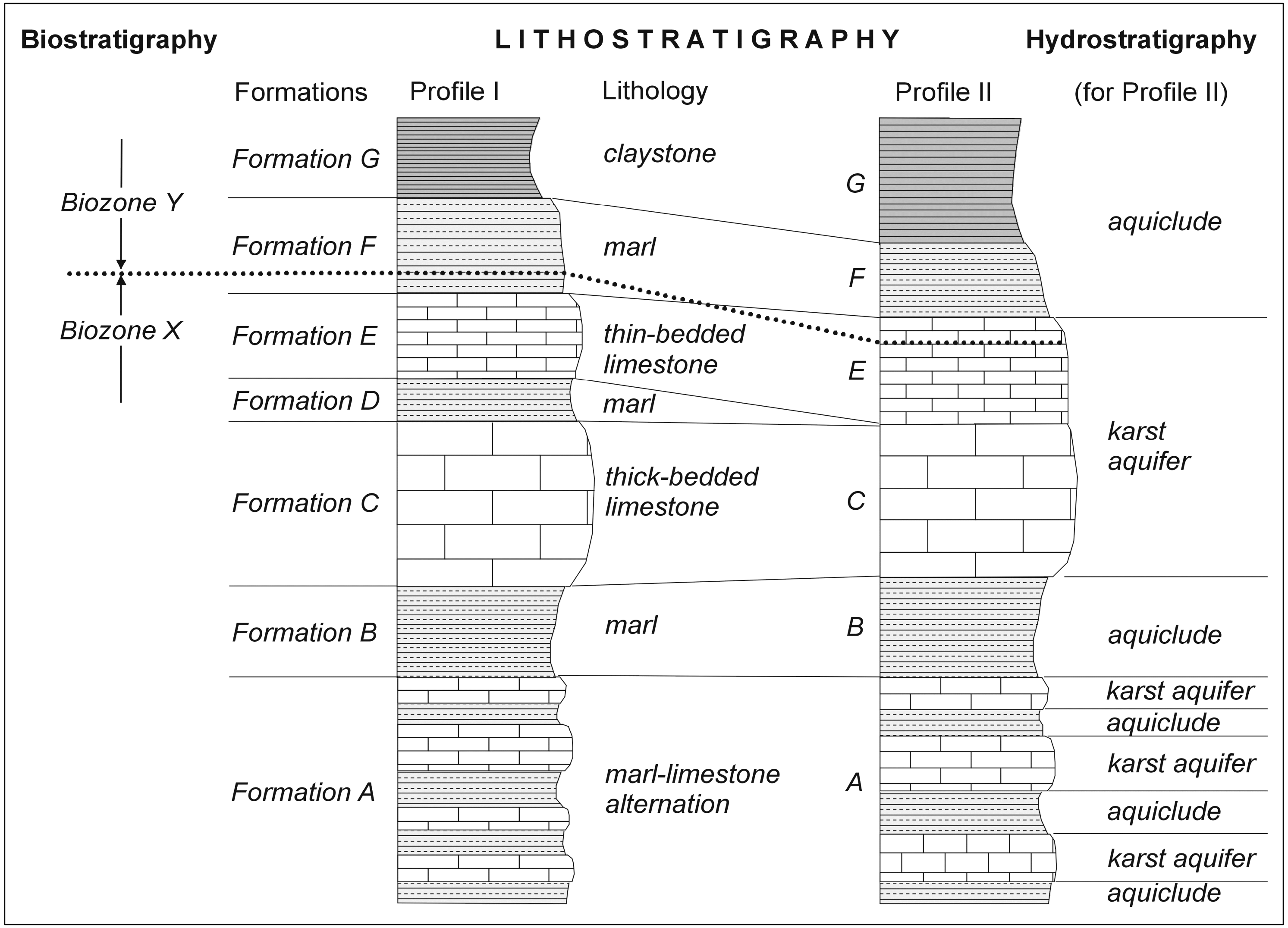
all figures: *FOEN / BAFU / OFEV*

From geology towards hydrogeology

- Translation of lithostratigraphy into hydrostratigraphy: hydraulic characterisation of the geological formations, identification of potential aquifers & aquicludes
- Characterisation of tectonic joints and bedding planes
- Influence of fault tectonics (normal, thrust and strike-slip faults) upon the hydrogeological system
- Influence of fold tectonics (anticlines, synclines, axial depressions and culminations) upon the hydrogeological system
- Landscape history and development of the system during geological time

➡ *(hydro)geological analysis is always a **3D + time** problem*

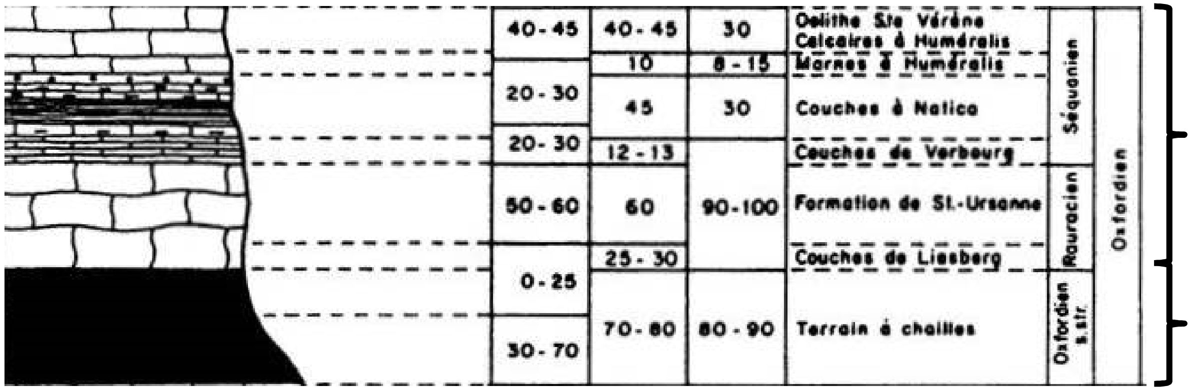
From lithostratigraphy to hydrostratigraphy



Goldscheider & Drew 2007

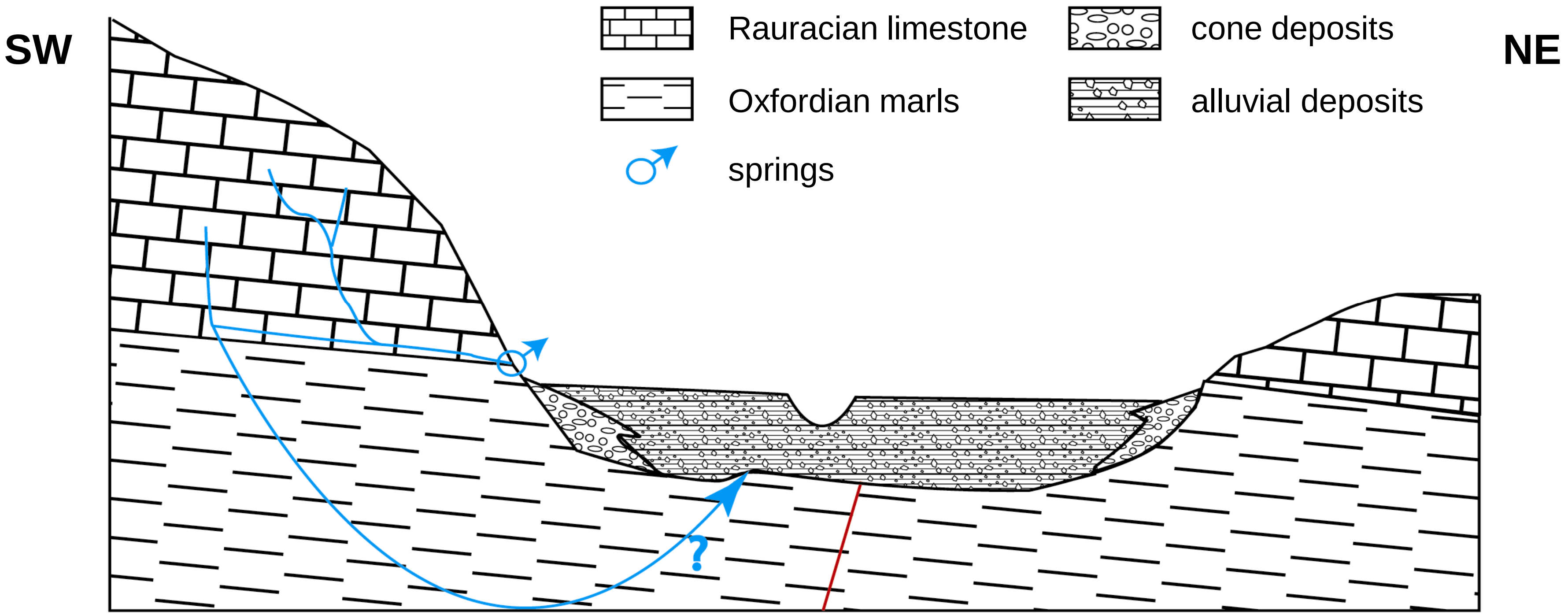
From lithostratigraphy to hydrostratigraphy

example of our Buix site

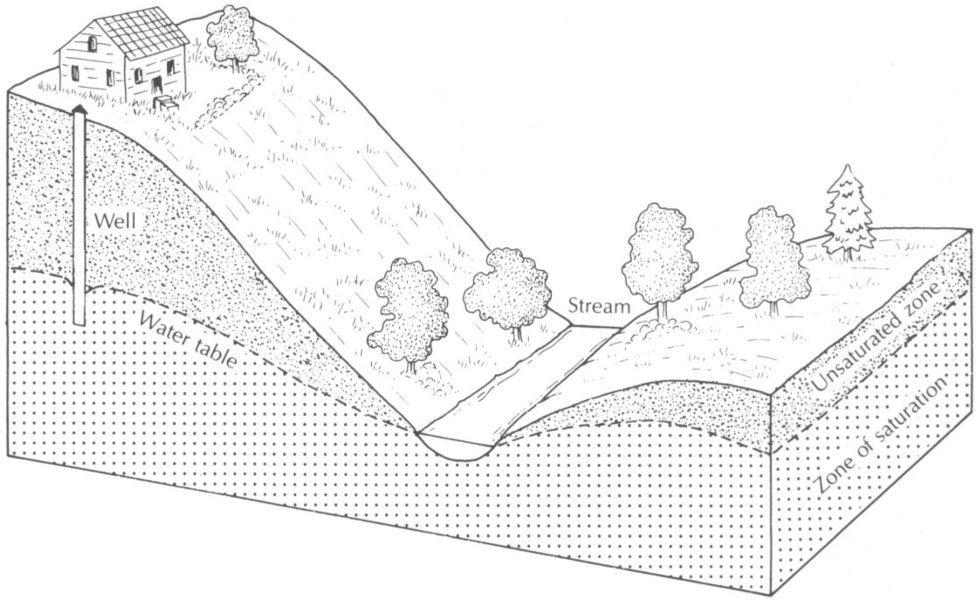


multi-layer karst aquifer: limestone and marls (Rauracian, Sequanian, Kimmeridgian)

regional aquiclude : Oxfordian marls

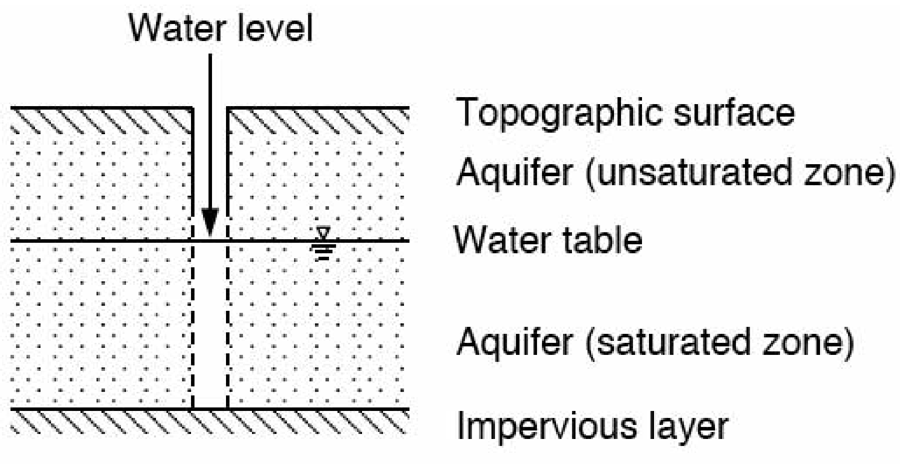


Typical unconfined groundwater conditions

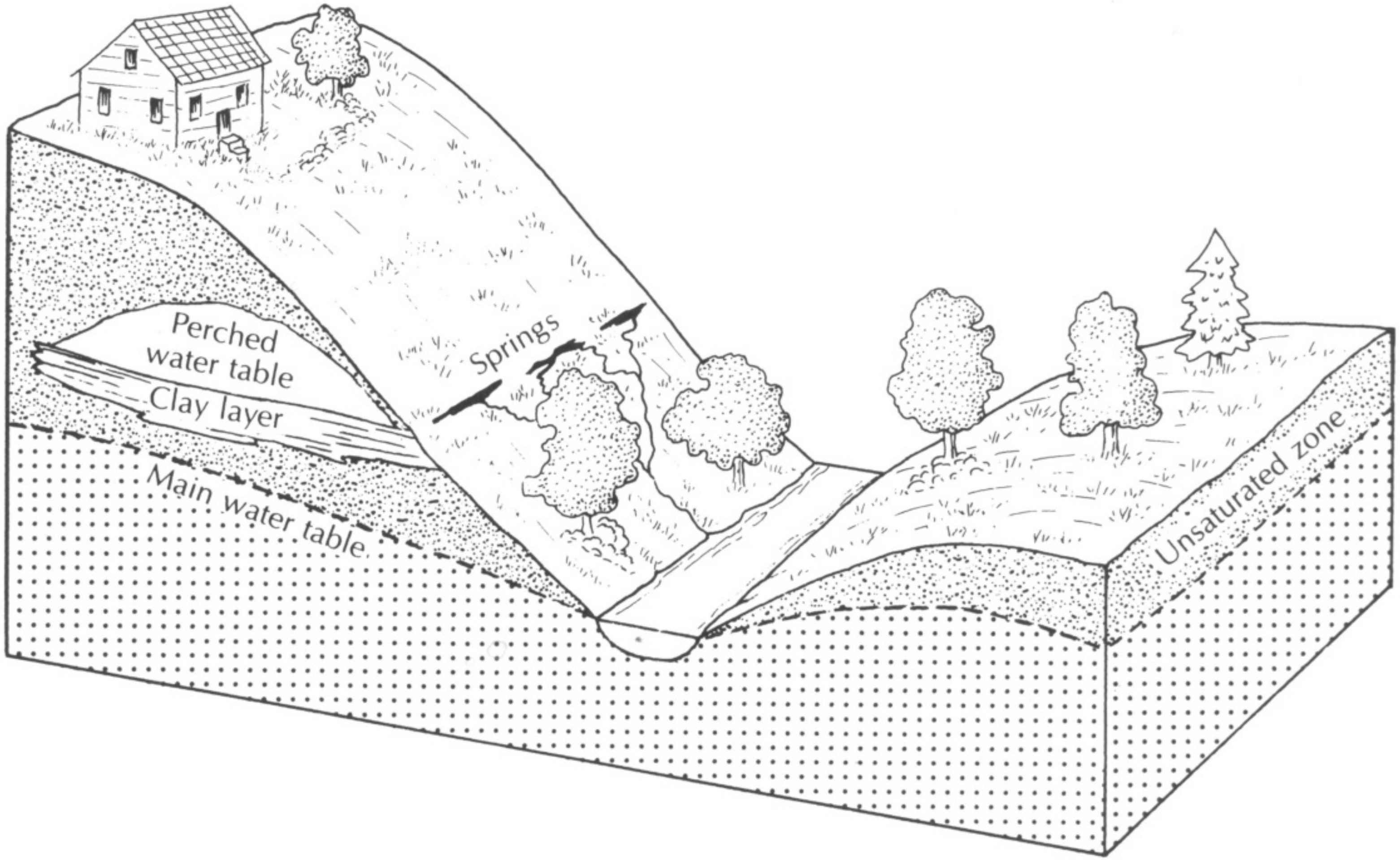


Unconfined aquifer
Only a part of the aquifer is saturated.
The top of the aquifer is the water table.

Typically, if you drill you will find the water at the depth of the saturated zone: the groundwater is not pressurised



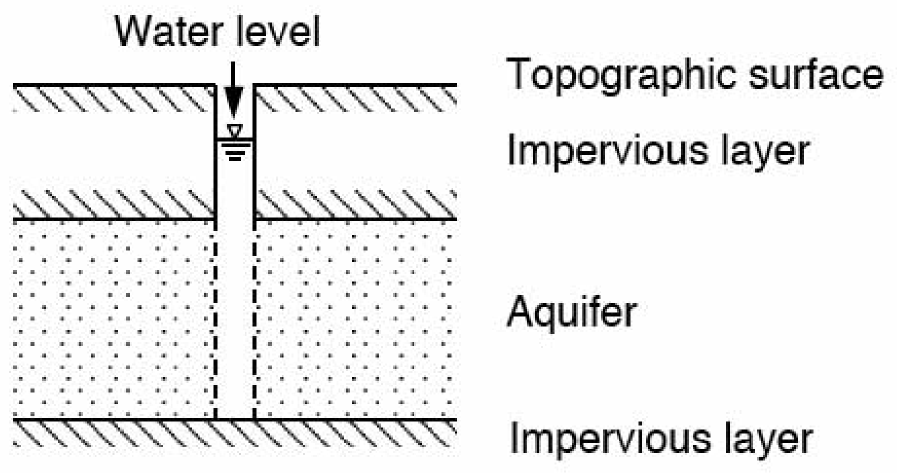
Typical unconfined groundwater conditions

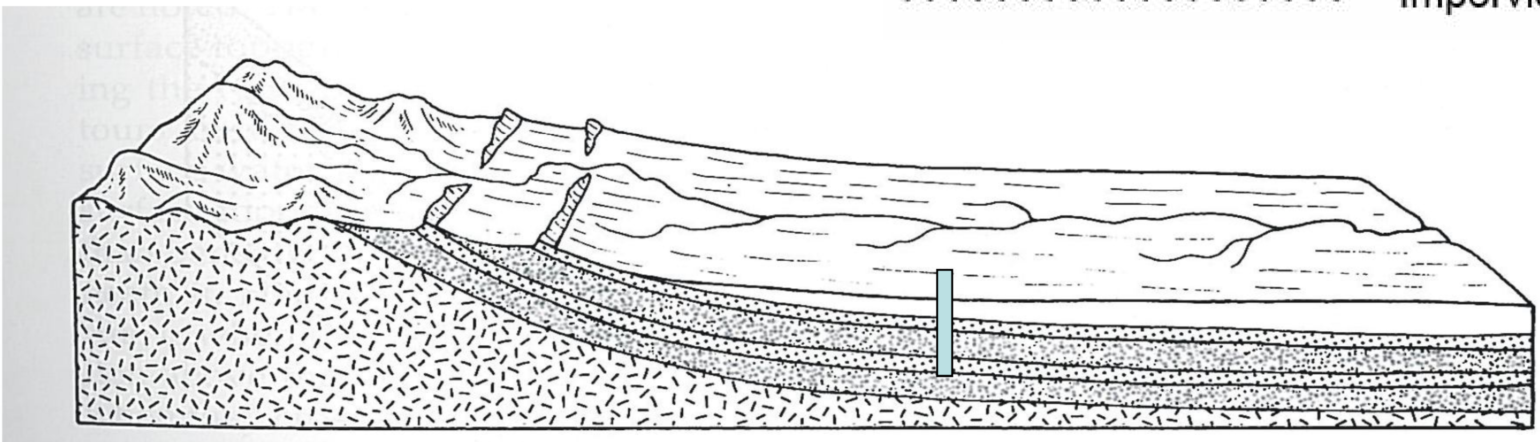


Typical confined groundwater conditions

Confined aquifer

The whole thickness of the geological formation is saturated. The top of the aquifer is a geological boundary with an aquitard. Water is pressurized.

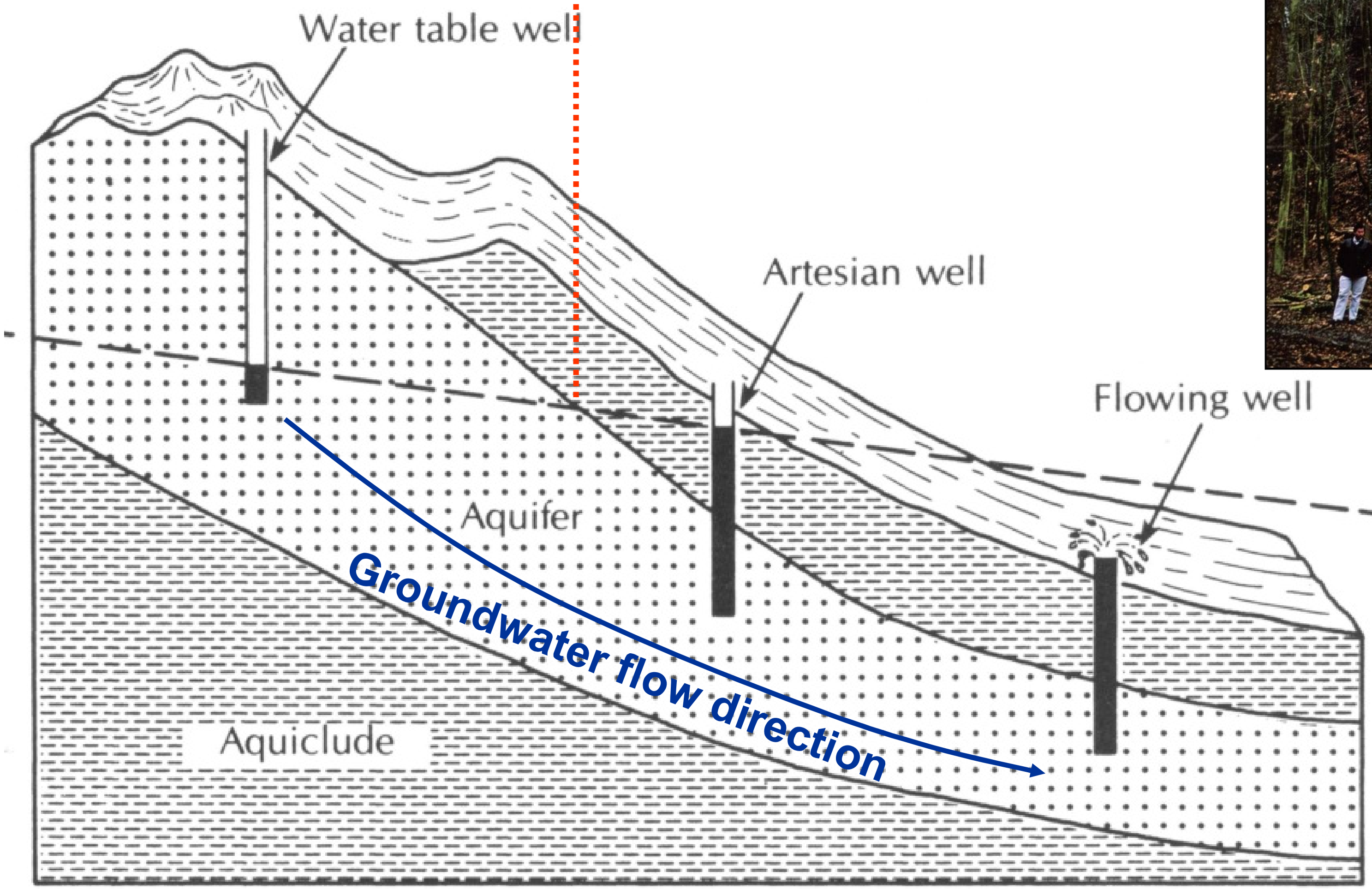




Confined aquifer created by upwarping of beds by intrusions.

Typically, if you drill you will find the water at a deeper depth than the water level which you will measure (i.e. pressurised)

Transition from unconfined to confined aquifer



Fetter 2001

Water balance

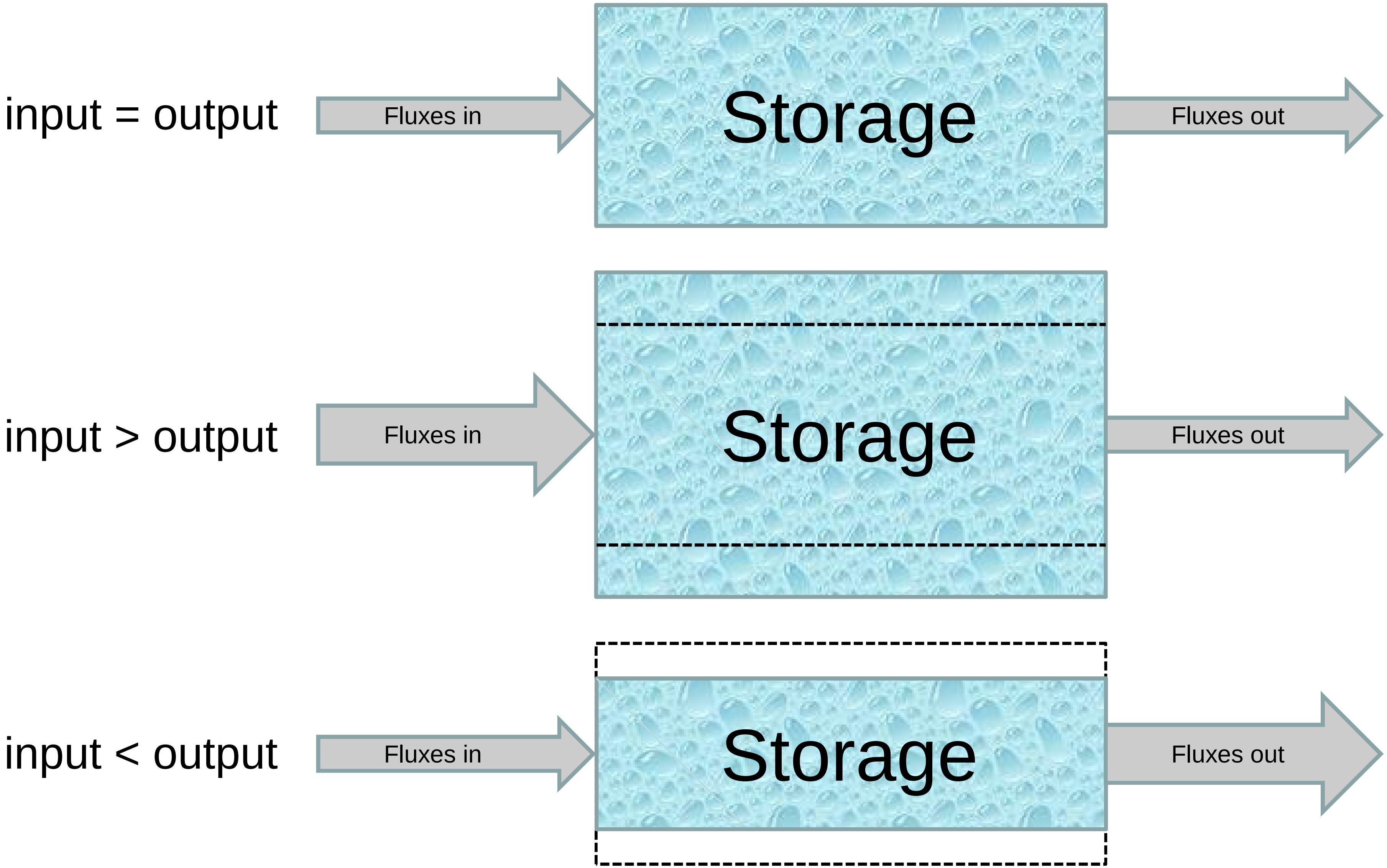
Balancing: an important tool for any kind of management

- a water balance links recharge and discharge to changes in storage

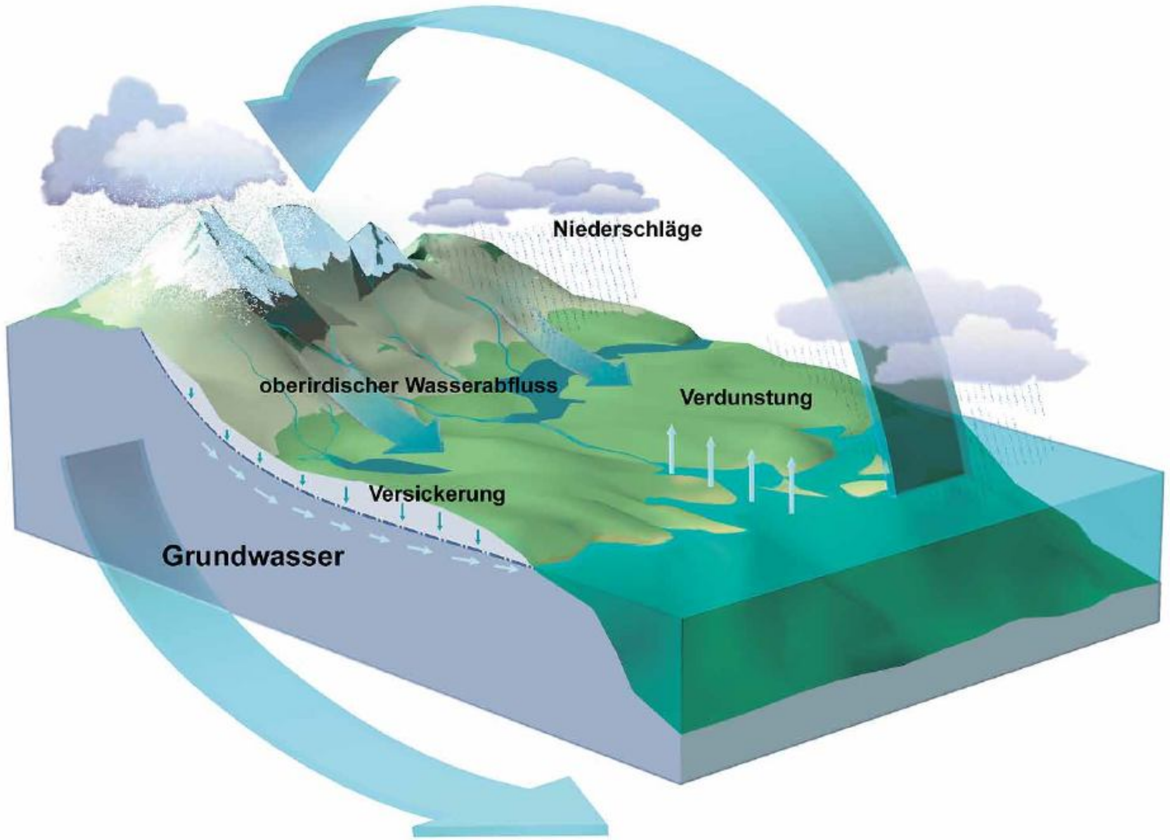
- a balance can be written as a mass or volume change in time Δt

- better: a time rate of change of mass or volume dM/dt or dV/dt

Water balance



Water balance



Niederschläge = precipitation P

Verdunstung = evapotranspiration ETP

oberirdischer Wasserabfluss = runoff R

Versickerung = recharge I

Grundwasser = groundwater ΔS

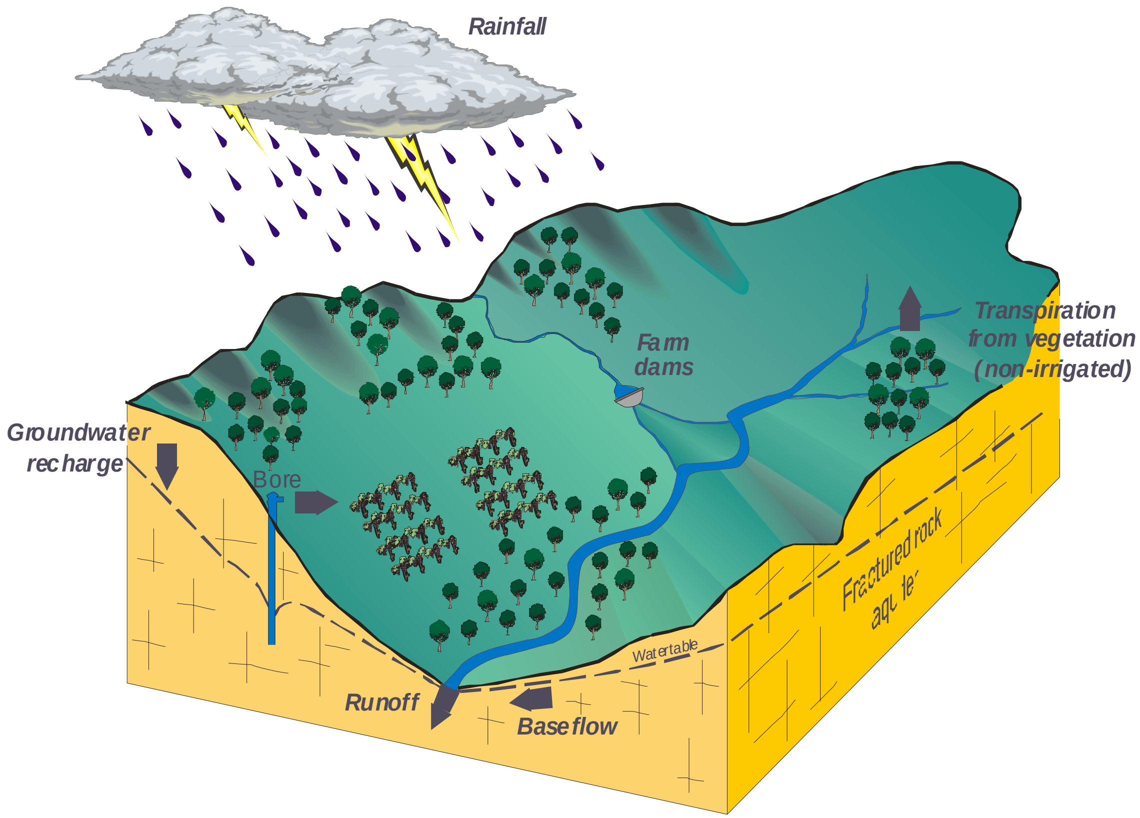
Water budget for a water shed (m^3):

$$I * A = (P - ETP - R - \Delta S) * A$$

ΔS: water table change / A: surface area of water shed

Recharge of groundwater

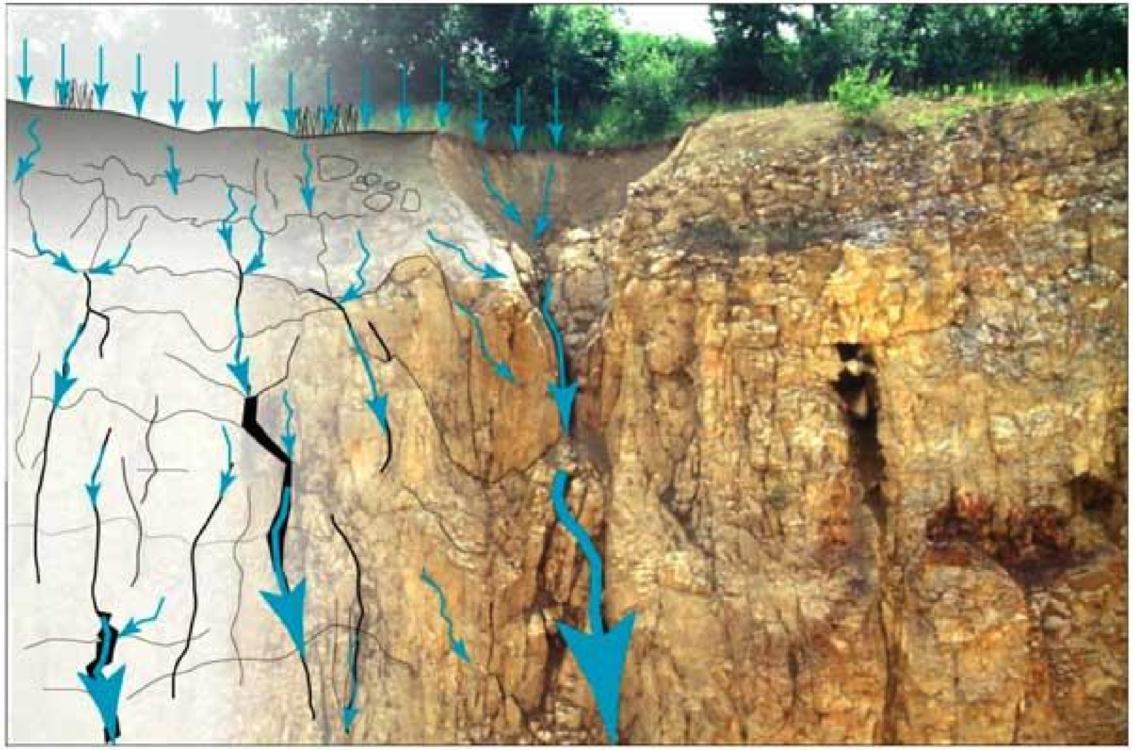
the process by which water enters the groundwater system or, more precisely, enters the phreatic zone



Recharge of groundwater
a/ infiltration of rainwater into the pores of the ground

primary porosity

pores between grains



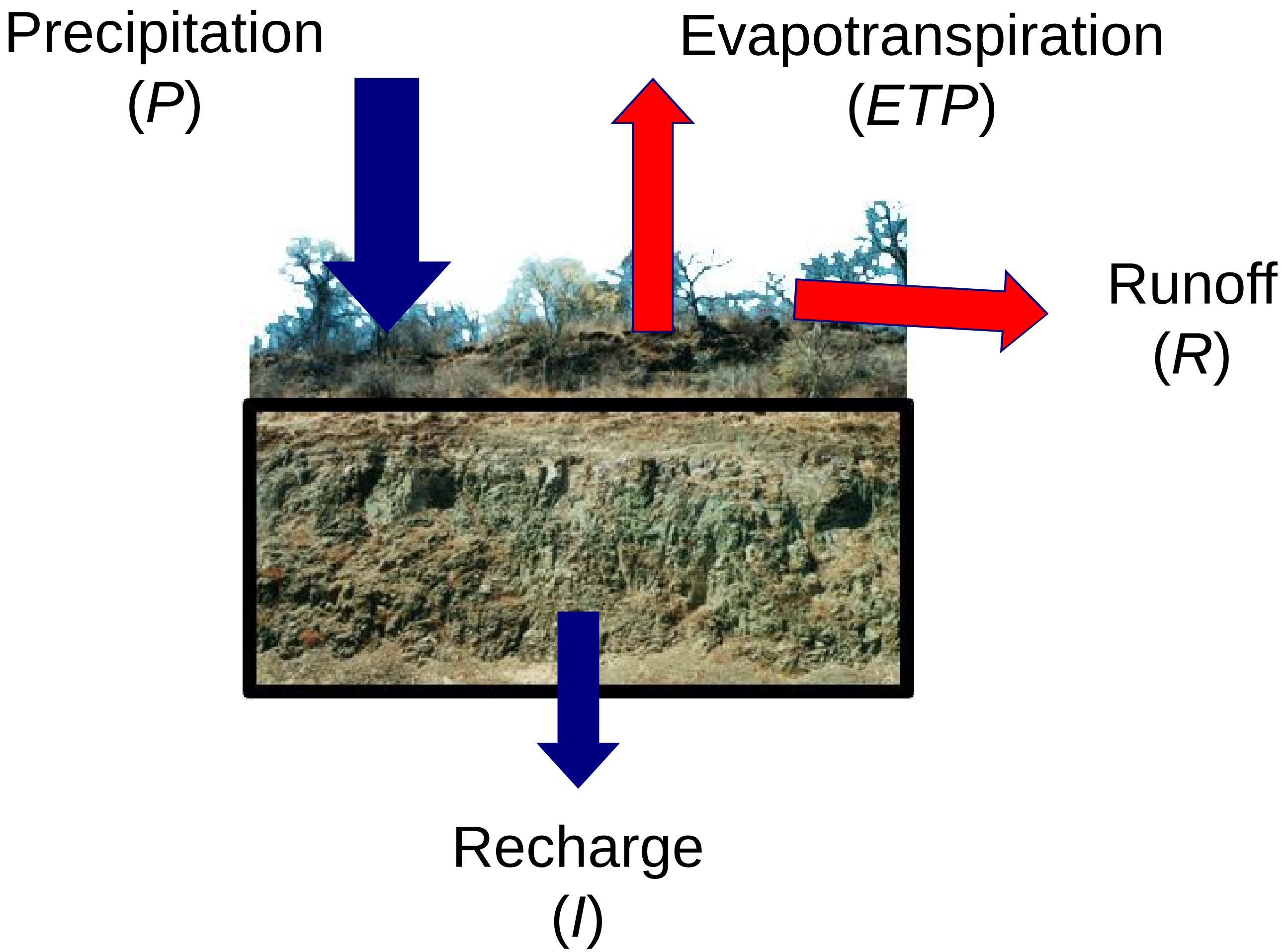
secondary porosity

fractures and dissolved channels

Recharge of groundwater

How is groundwater recharge quantified?

Simple water balance: $I = P – ETP - R$



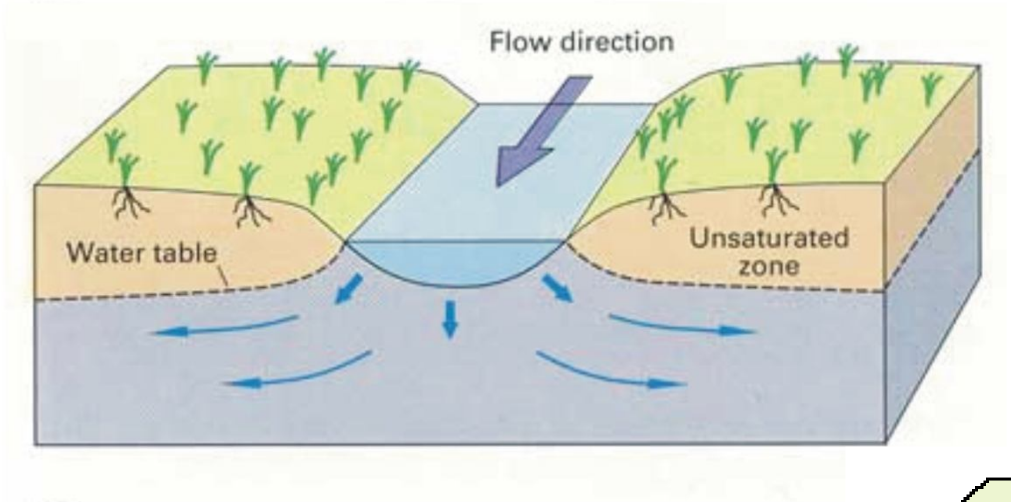
Recharge of groundwater

Rough estimates for different climatic conditions

		Temperate climate		**Semi-arid climate**		**Arid climate**	
		%	mm	%	mm	%	mm
P	Total precipitation	100	500 – 1500	100	200 - 500	100	0 - 200
ETP	Real evapotranspiration	~ 33	167 – 500	~ 50	100 - 250	~ 70	0 - 140
I	Groundwater recharge	**~ 33**	167 – 500	**~ 20**	40 - 100	**~ 1**	0 - 2
R	Surface runoff	~ 33	167 – 500	~ 30	60 - 150	~ 29	0 - 58

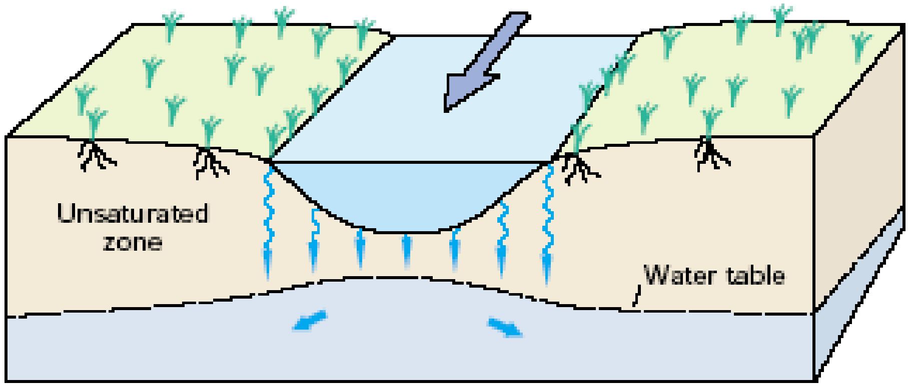
Recharge of groundwater
b/ infiltration of surface water (river, lake)

If the water table is lower than the surface water elevation, surface water will infiltrate and recharge the groundwater



losing river

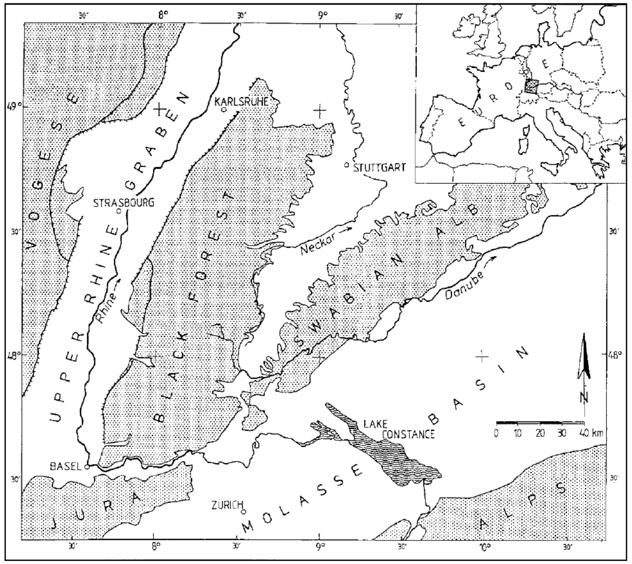
losing, disconnected river



Difficult to measure!

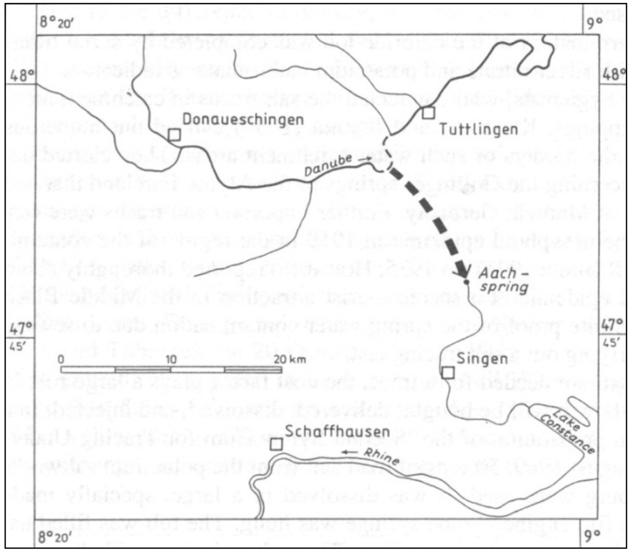
(USGS 1998)

Recharge of groundwater
b/ infiltration of surface water (river, lake)



Hötzl 1996

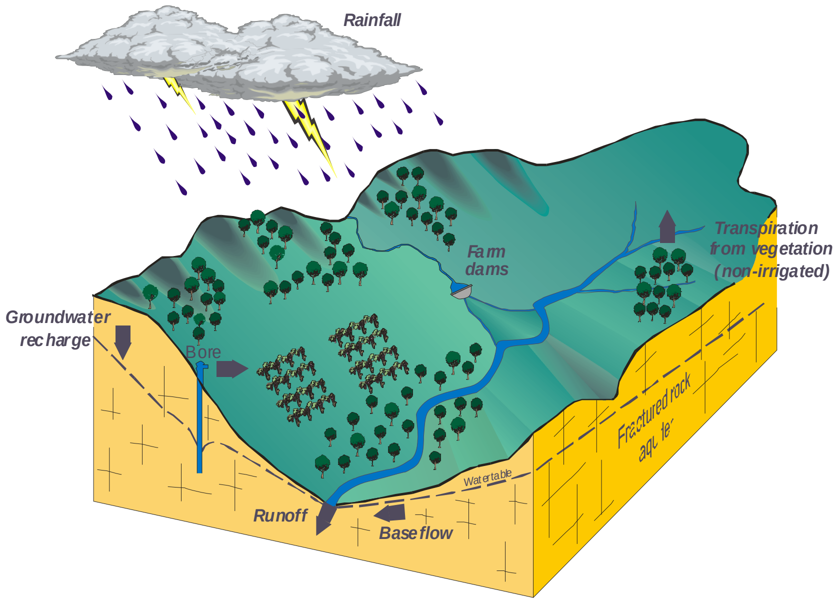
River Danube near Immendingen (upstream) September 2011



Käss 2007

River Danube near Immendingen (downstream) September 2011

Discharge of groundwater



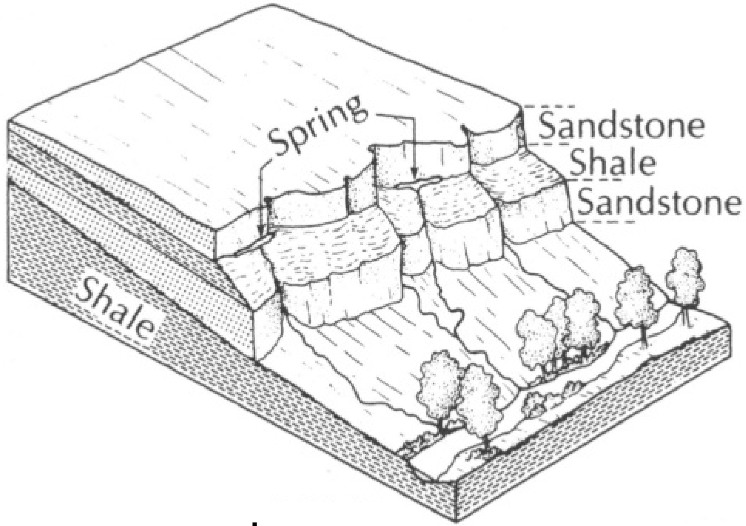
- the volumetric flow rate [m^3/s] of a stream, spring, or groundwater system; or

- the water leaving a groundwater system by flow to surface water, to the land surface, or to the atmosphere.

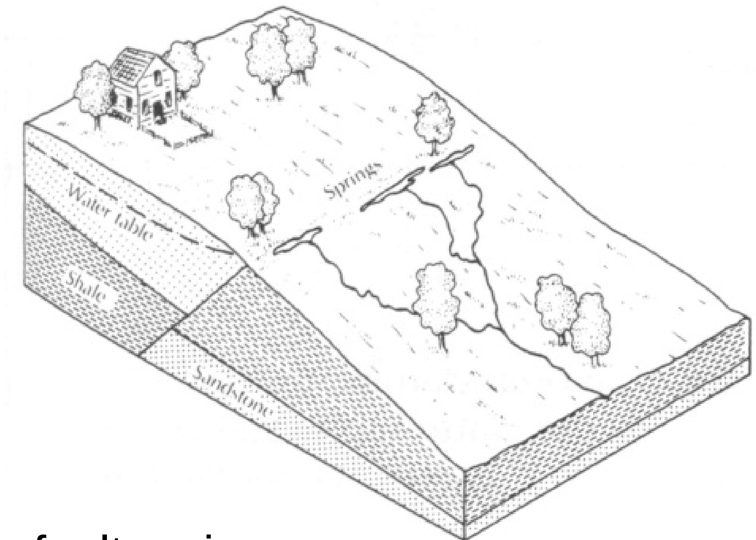
Discharge of groundwater
a/ discharge to springs

Springs develop where the water table and the topography intersect!

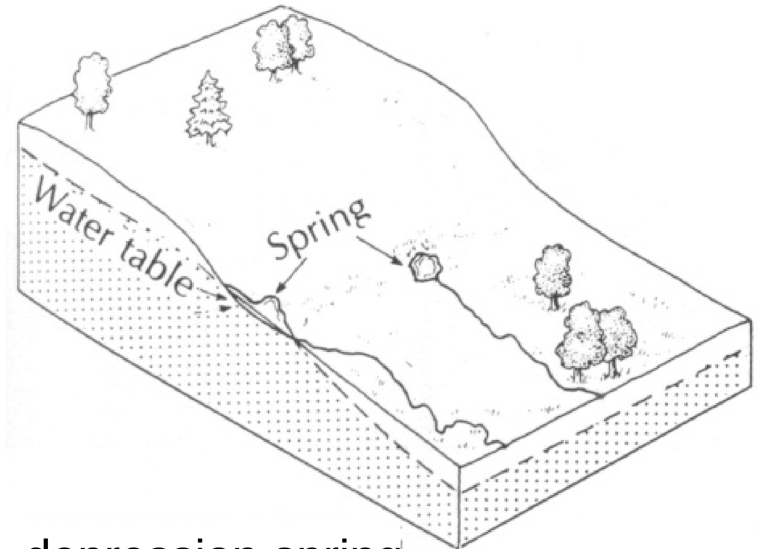
Measuring spring discharges for water balance!



contact spring



fault spring



depression spring

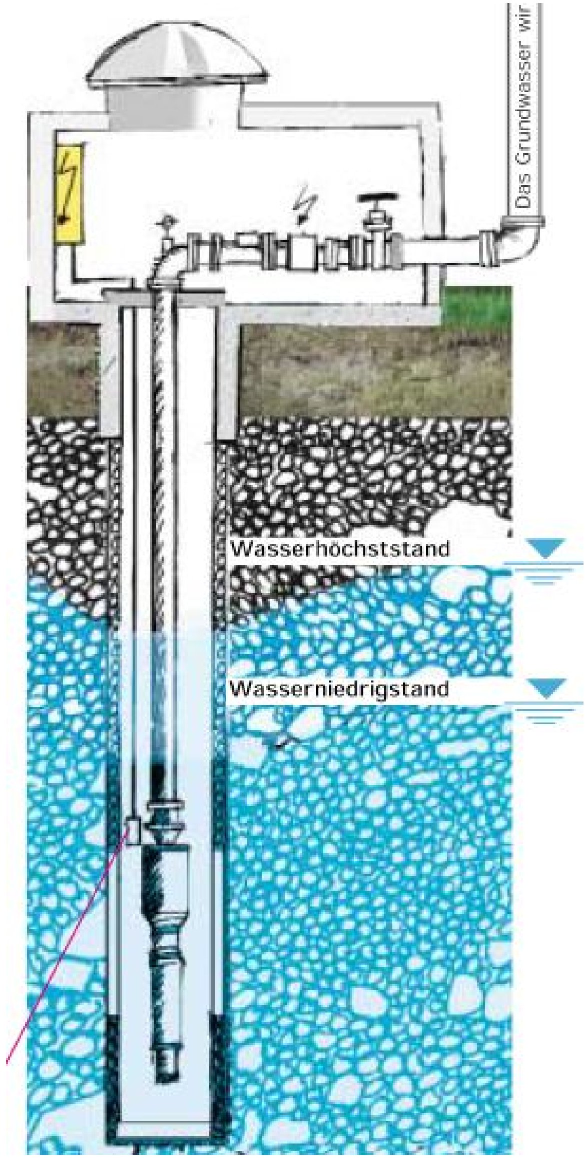
Discharge of groundwater
b/ wells and boreholes

Pumping well

- drinking water supply

Measuring pumping rates for water balance!

Typical pump-house in Switzerland

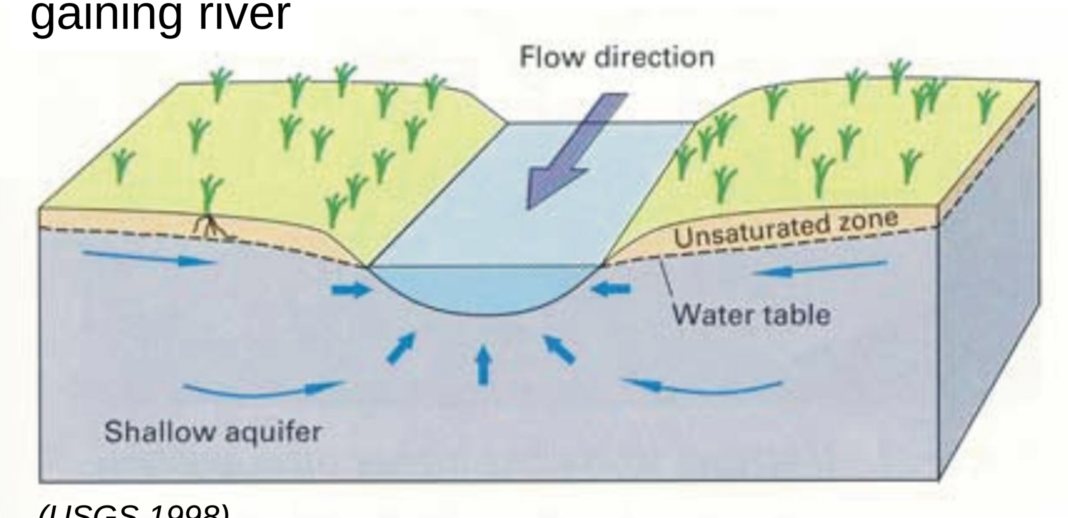


Discharge of groundwater
c/ discharge to surface water bodies (river, lake, sea)

If the water table elevation is higher than the surface water elevation, groundwater will **discharge** to the surface water

Important for
- rivers (baseflow)
- wetlands, groundwater dependent ecosystems…

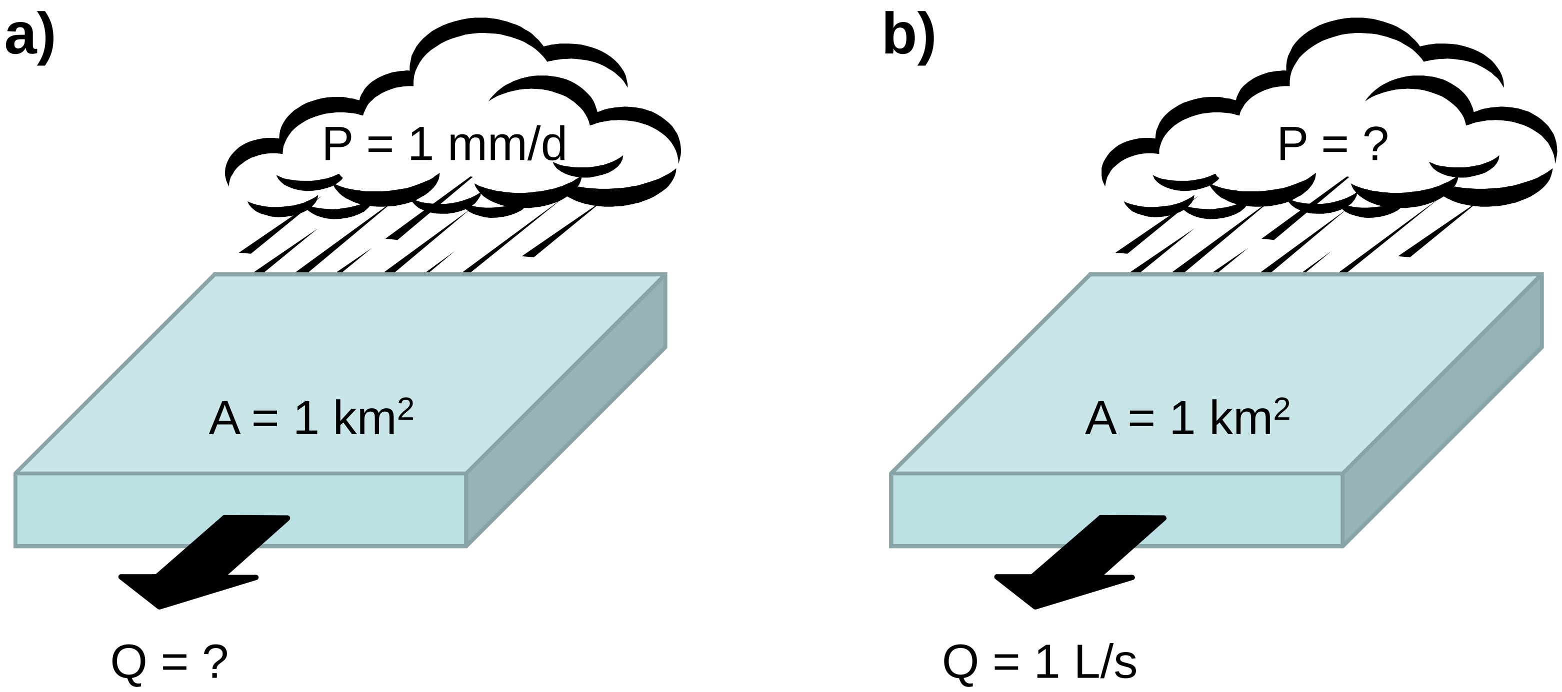
gaining river



(USGS 1998)

Difficult to measure!

Recharge, surface area & spring discharge
exercice



Considering a semi-arid climate:

a) calculate the mean annual discharge of the spring [L/s]

b) calculate the daily groundwater recharge [mm/d]

UNIVERSITÉ DE NEUCHÂTEL

CHYN Centre d'hydrogéologie et de géothermie

CHYN TRAINING COURSE FOR

UNHCR WASH STAFF

APPLIED HYDROGEOLOGY

from field investigation towards sustainable water resources management

June 1 to June 6, 2014

UNHCR The UN Refugee Agency

Basic concepts of groundwater exploration: geophysics

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Agency for Development and Cooperation SDC

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From groundwater exploration to groundwater exploitation

- The aim of this session:

→ Present the basic hydrogeological approaches used in groundwater exploration in order to elaborate terms of reference for consultants and to evaluate hydrogeological reports

- Basic concepts of groundwater exploration: how does one look for new water sources?
  - Presentation of the most frequently used geophysical method (cf. field excercise): geoelectrics
- Basic concepts of pumping tests:
  - Step-draw-down tests (definition of well-yield)
  - Constant rate pumping tests and the most frequent interpretation method

First steps in groundwater exploration

- Surveying water points and groundwater levels
- Compiling existing geological and hydrogeological information
- Identifying potential aquifers and elaborate a water balance
- Identify potential groundwater pollution sources associated with the aquifers

→ Based on such an analysis, more localised investigations, such as geophysics, can be proposed for well implementation

The most commonly used geophysical investigation techniques for groundwater exploration

For well siting in porous or layered aquifers:

- **Resistivity techniques**: geoelectrical surveys, electrical imaging
- Ground penetrating radar

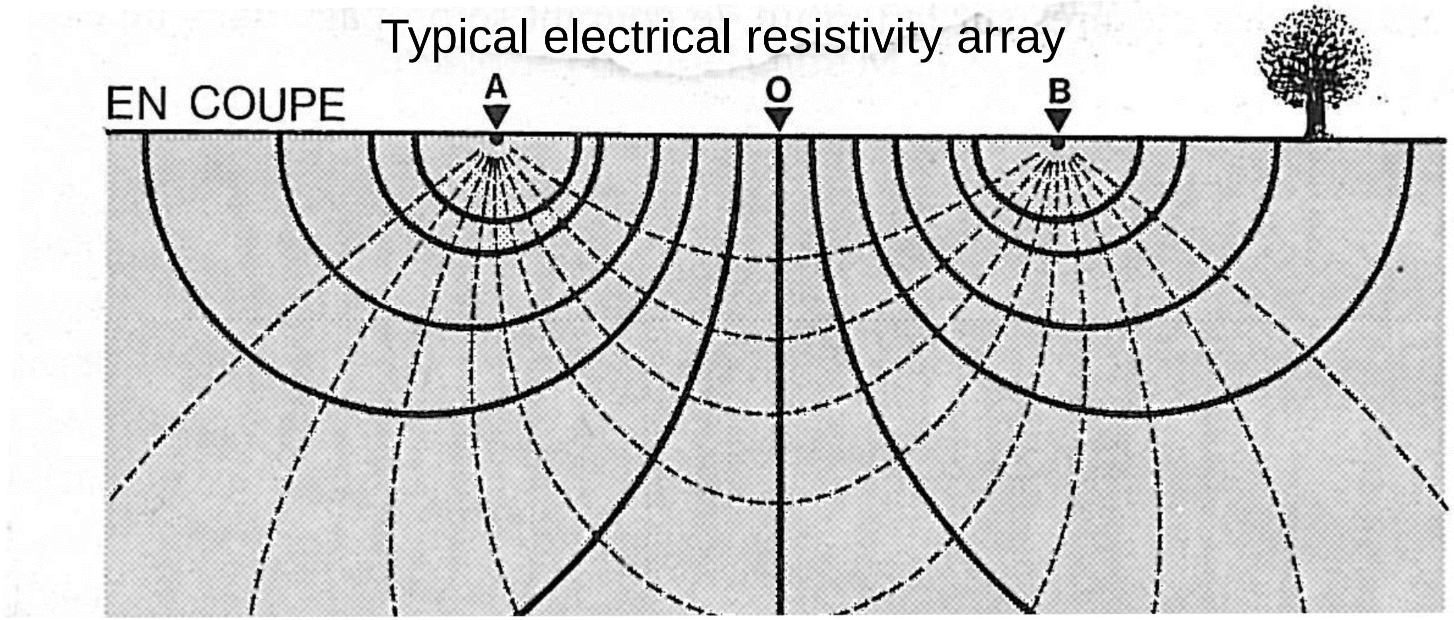
For well siting in fractured aquifers:

- Very low frequency electro-magnetic surveys (VLF)

Resistivity techniques

They are based on the response of the earth to the flow of electrical current. The **resistivity** (inverse of conductivity) of the subsurface depends primarily upon the **amount of water** in the rock, the salinity of the water and the distribution of the water in the voids. Therefore, measurement of resistivity is a combined measure of water saturation and connectivity of pore space and the electrical properties of the soil (→major difficulty!).

Typical electrical resistivity array



Two current electrodes A and B with the current lines (dashed) being perpendicular to the voltage equipotentials (bold lines), measured between to potential electrodes close to O.

Definition and units of resistivity: Ohms Law (applied to a cylinder)

$$R = \rho \frac{L}{A}$$

R : resistance [ohm]

ρ : resistivity [ohm m] – characteristic of the material, analogue to permeability K)

L : length [m]

A : cross-section [m^2]

According to Ohm's law, the resistance *R* is related to the potential difference *ΔV* [volt] and the currant *I* [A] through the resistance, as follows:

$$R = \frac{\Delta V}{I}$$

$$\rho = \frac{A}{L}\frac{\Delta V}{I}$$

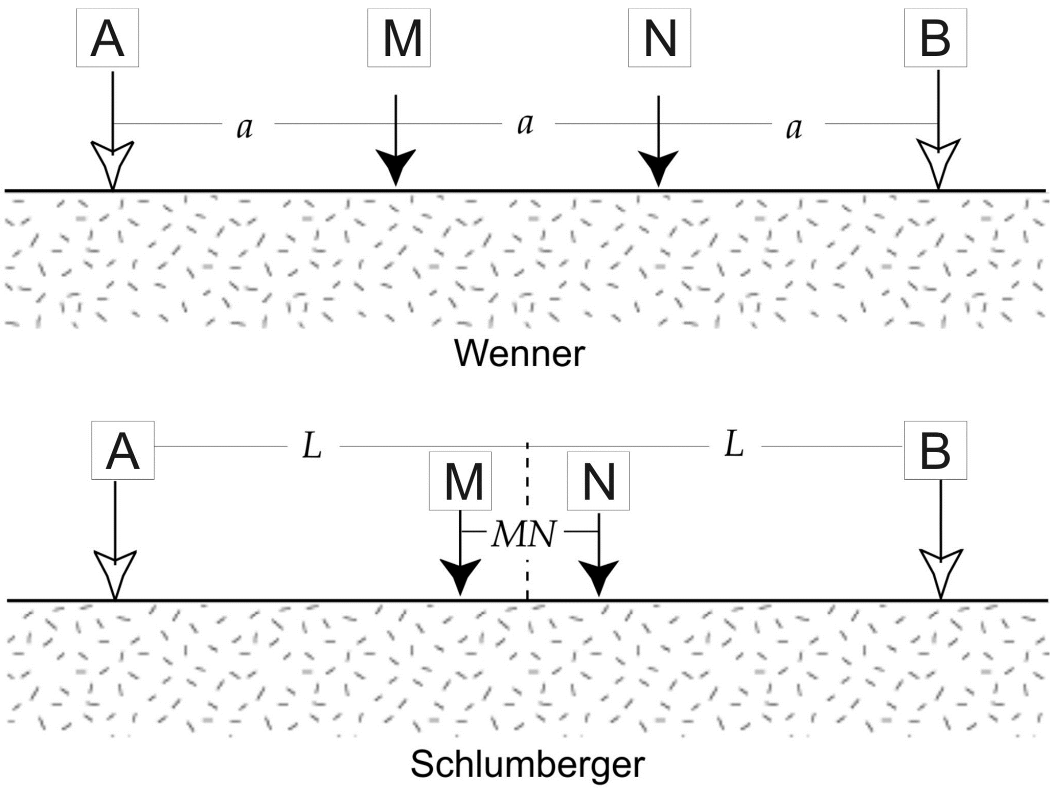
This is measured in the field!!!

Geometric factor- depends on layout used for sounding

The resistivity is a bulk measure of both the rock framework (and different types of rocks) and of the water in the pores. Therefore, the measured resistivity is called **apparent resistivity ρ_a.**

Different layouts for electrical resistivity soundings

Simple geometrical electrode layouts, such as the Wenner or Schlumberger arrays yield simple geometrical factors **K**.



$$\rho_a = \frac{A}{L}\frac{\Delta V}{I} = KR_{app}$$

For Wenner array,
geometrical factor: K =2πa

$$\rho_a = 2\pi a R_a = 2\pi a \frac{\Delta V}{I}$$

a= Electrode spacing

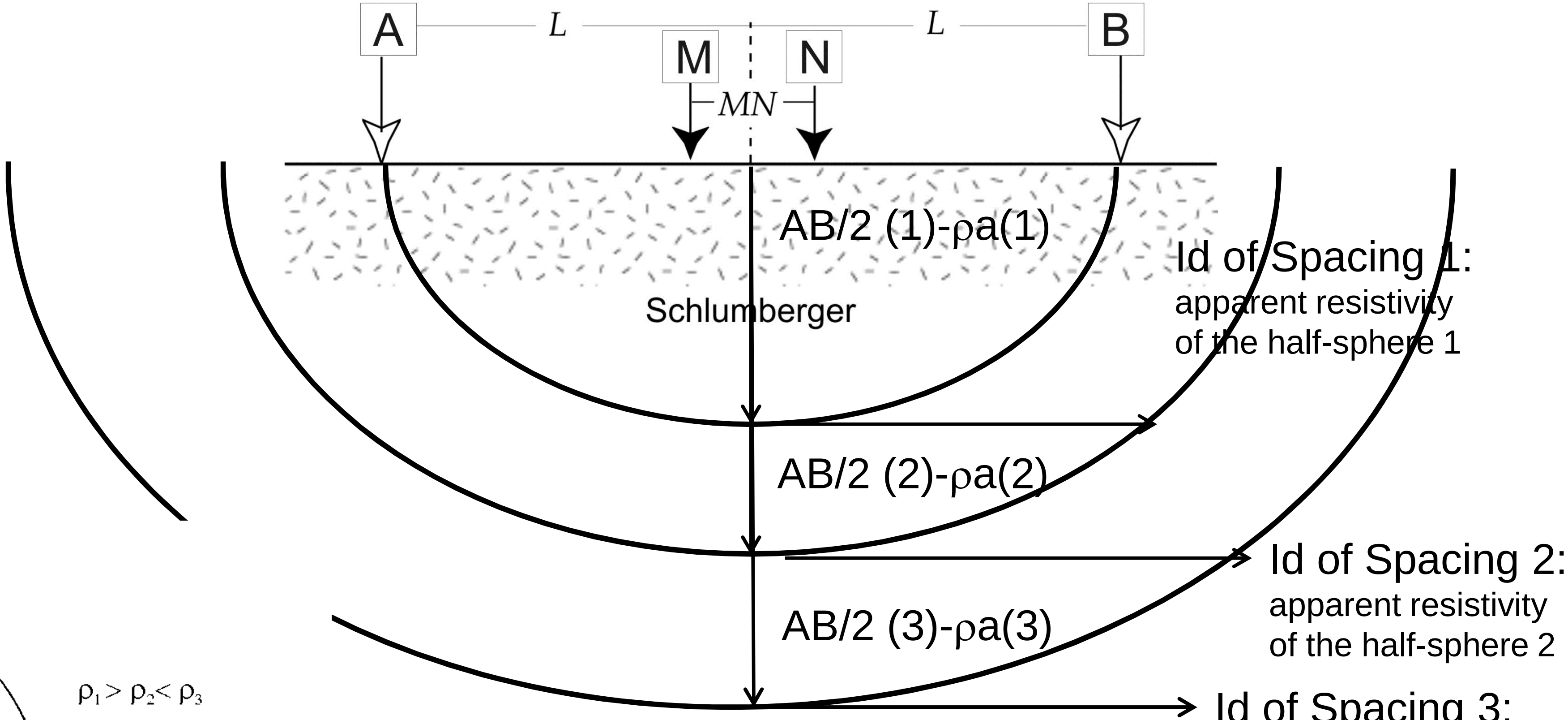
I= injected current [A]

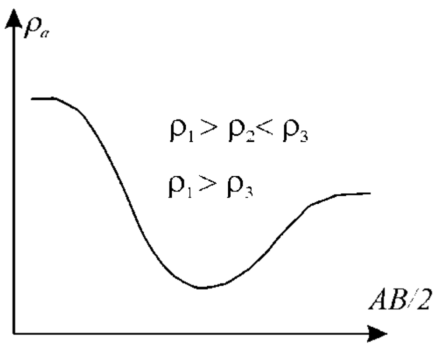
ΔV = measured potential difference [V]

The bigger the electrode spacing is, the deeper the investigation depth

VES (vertical electrical soundings): investigation depth (Id)

→A VES is carried out by increasing the distance between the injection electrodes, thereby investigating an increasingly large half-sphere in the subsurface.





Investigation depth of a VES is 20-50% of the maximum electrode spacing AP

Typical resistivity values of different earth materials

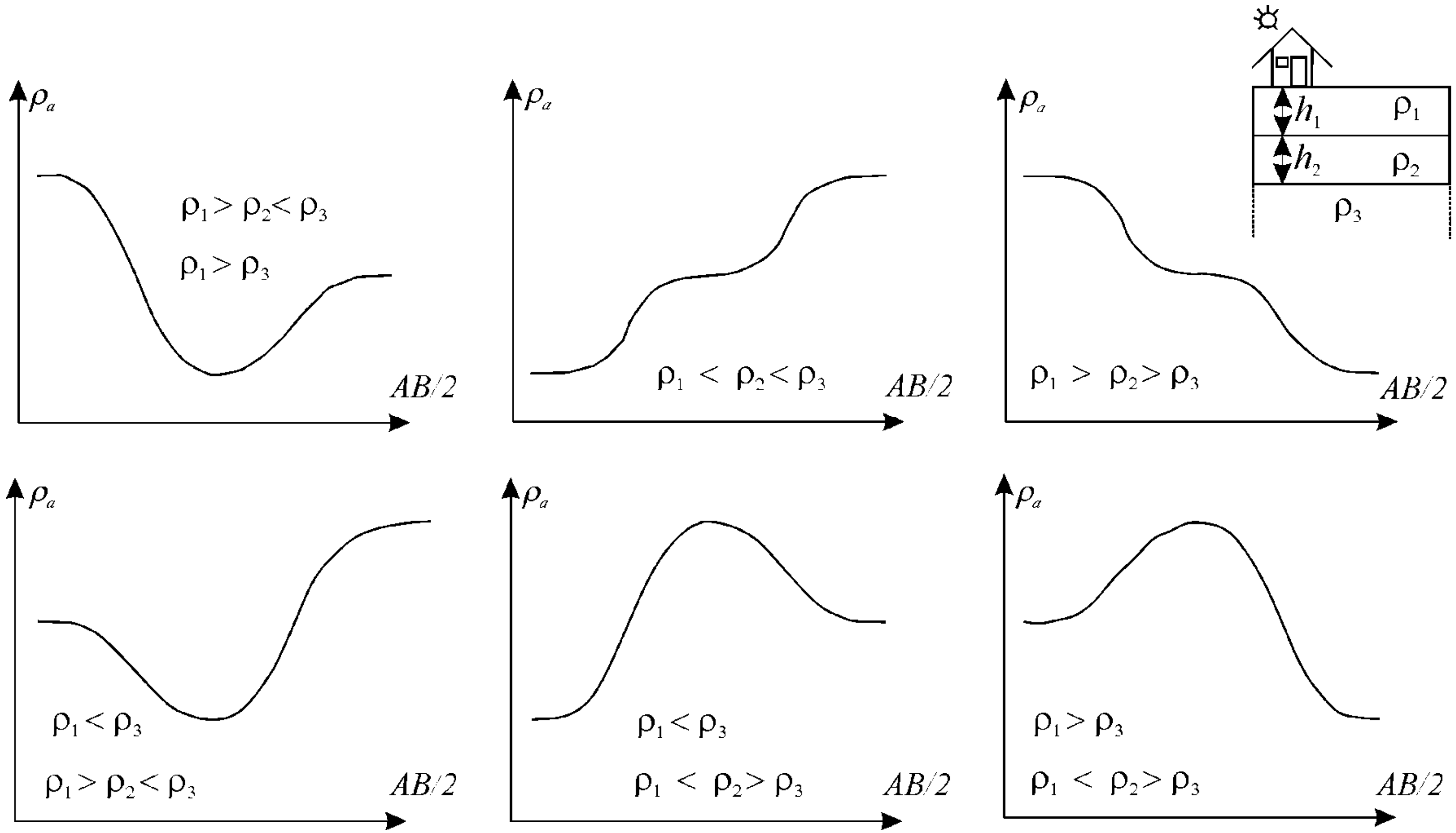
Resistivity values overlap! Correlation between permeability and resistivity – but not always unambiguous

Earth material	Resistivity [ohm m]
Clay (marls) (**AQUICLUDE**)	10-70 (30)
Sand (**AQUIFER**)	**50-400 (100)**
Gravel (**AQUIFER**)	**150-500 (200)**
Schist	10-10 000 (3000)
Granites and basalt	10-50 000 (5000, 3000)
Limestone and dolomite	100-10 000 (2000)
Seawater	**< 1**
Surface and groundwater	**10-300**
Brackish water	**0.05-10**

Qualitative interpretation of geoelectrical soundings

The apparent resistivities measured as a function of the electrode spacing between A or B and the mid-point O (OA=AB/2) yield different curves.

Qualitative interpretation: using the type curves one can interpret the succession of more or less resistive layers



Quantitative interpretation of geoelectrical soundings

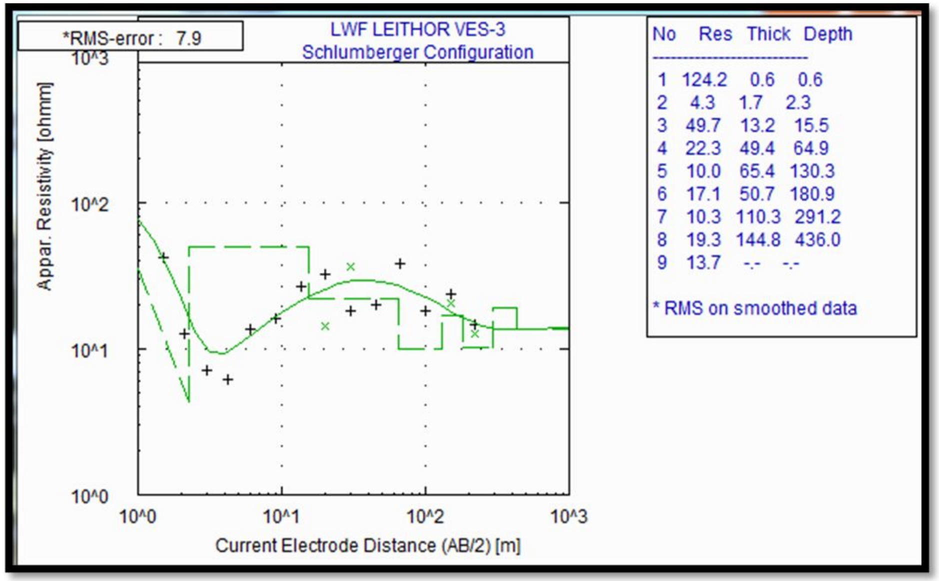
Quantitative interpretation: inversion of the curves!
Most delicate step for non-specialists AND for specialists!

How can a non-specialist evaluate if a geoelectrical inversion is useful or ‘geopoetic’?

Main hypothesis of VES interpretation is**:**

→ **PERFECTLY HORIZONTALLY LAYERED SUBSURFACE CONDITIONS (→ NO LATERAL CHANGES IN GEOLOGICAL CONDITIONS)!!!**

Geoelectrical curve of VES-3 with tables showing interpretation



Example VES: Kakuma

What are the comments?

a) How many measuring points vs. How many layers?
b) How many layers according to the type curves?
c) How is the fit?
d) How do the resistivities correspond to literature values?

Layer No.	ρ (Ohm-m)	Thickness (m)	Depth (m)	Expected Lithology
1	124.2	0.6	0.6	Top covered black Cotton soil
2	4.3	1.7	2.3	Moist silty soil (probable upper aquifer)
3	49.7	13.2	15.5	Drier fine grained sand
4	22.3	49.4	64.9	Medium to Coarse grained sand (alluvial deposit)
5	10	65.4	130.3	Moist medium to coarse grained sand (probable lower aquifer)
6	17.1	50.7	180.9	Medium to Coarse grained moist sand with silty soil (probable lower aquifer)
7	10.3	110.3	291.2	Medium to coarse grained moist sand(probable dipper aquifer)
8	19.3	144.8	436	Medium to coarse grained moist sand(probable deeper aquifer)
9	13.7	---	---	Alluvial formation

Interpretation of Leitchor VES-3 and the recommended drilling depth is 120m ± 30m

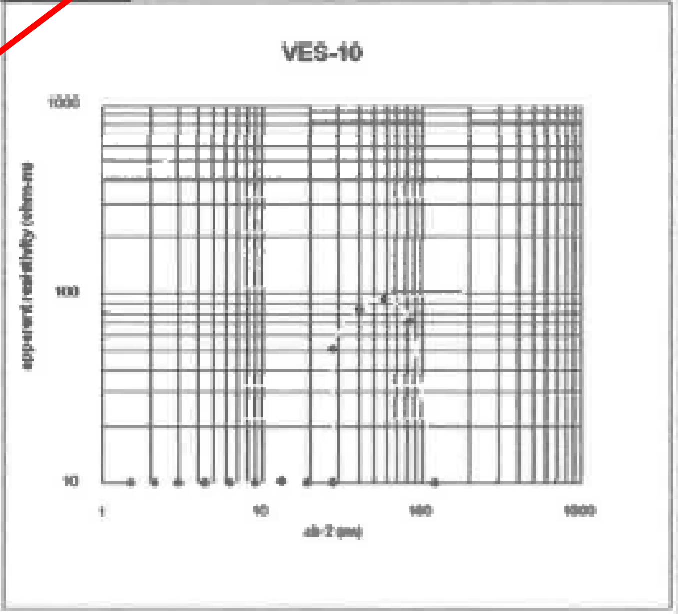
Results from the geophysical exploration in the Kakuma area

Zero resistivity????
Any comments???

Location:	Nyumanzi	County:	East Moyo
Parish:	Adjugopi	District:	Adjuman
Sub-county:	Dzaip i	Date:	20.02.2014

Grid E:383445 Grid N:383833 Altitude:660m

ab/2(m)	resistance (ohm)	mn/2	k-factor	apparent resistivity(ohm-m)
1.5	0.000	0.5	6.280	0.000
2.1	0.000	0.5	13.062	0.000
3.0	0.000	0.5	27.475	0.000
4.4	0.000	0.5	60.005	0.000
6.3	0.000	0.5	123.842	0.000
9.1	0.000	0.5	259.238	0.000
13.2	0.000	0.5	546.328	0.000
13.2	0.000	5.0	46.861	0.000
19.0	0.000	0.5	1132.755	0.000
19.0	0.000	5.0	105.504	0.000
27.5	0.000	0.5	2373.840	0.000
27.5	0.229	5.0	225.613	51.665
40.0	0.169	5.0	494.550	83.579
58.0	0.090	5.0	1046.446	94.150
83.0	0.034	5.0	2155.298	72.849
120.0	0.000	5.0	4516.000	0.000



Expected formation

Loam top soil + Laterites + Quarts + Granite gneiss

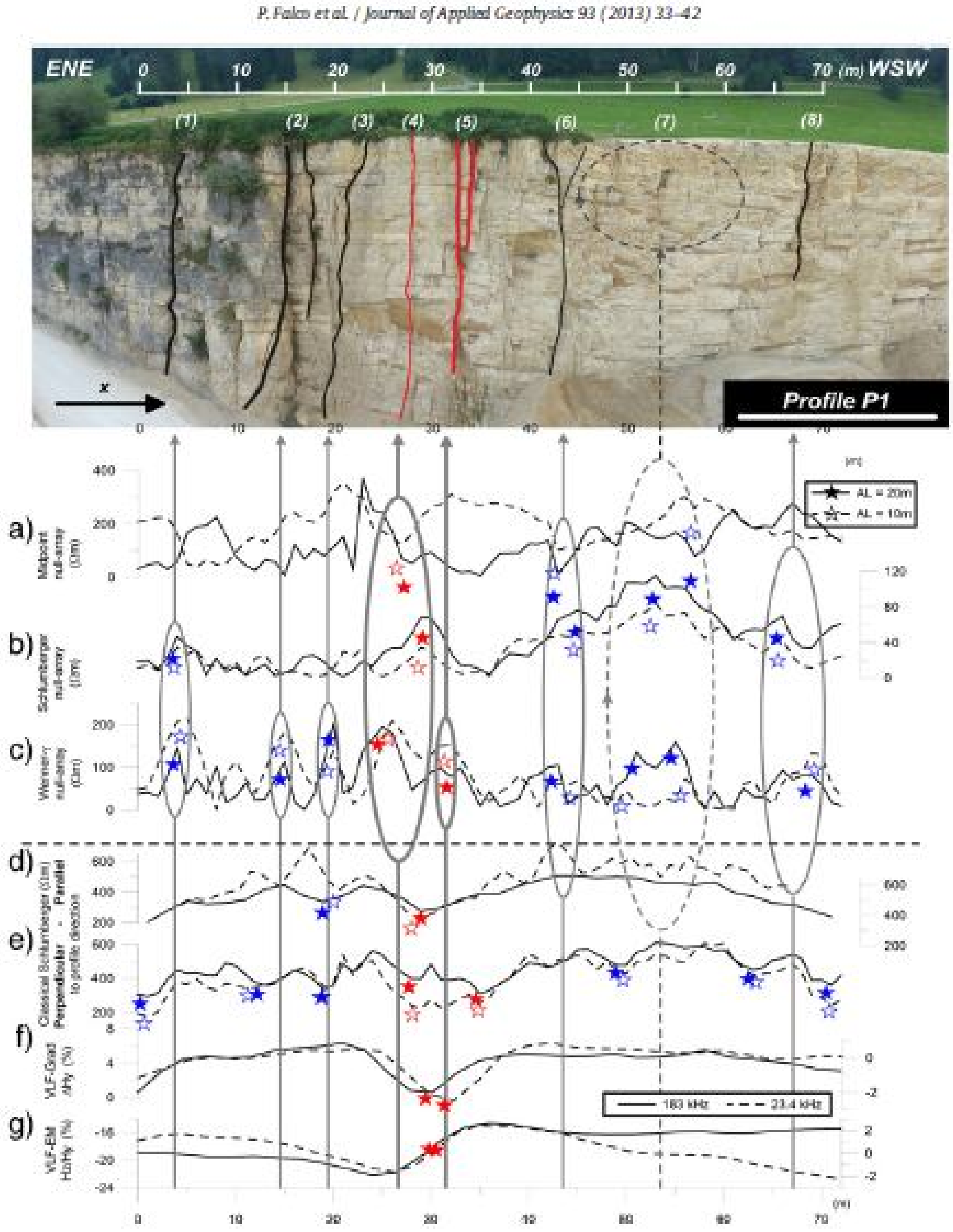
Weathered/fractured + Fresh granite

Expected bedrock depth:20-25m
Expected aquifer zones:40-60m
Expected drilling depth:50-65m
Good

Geoelectrical profiling

- Is used to identify lateral changes in electrical resistivities

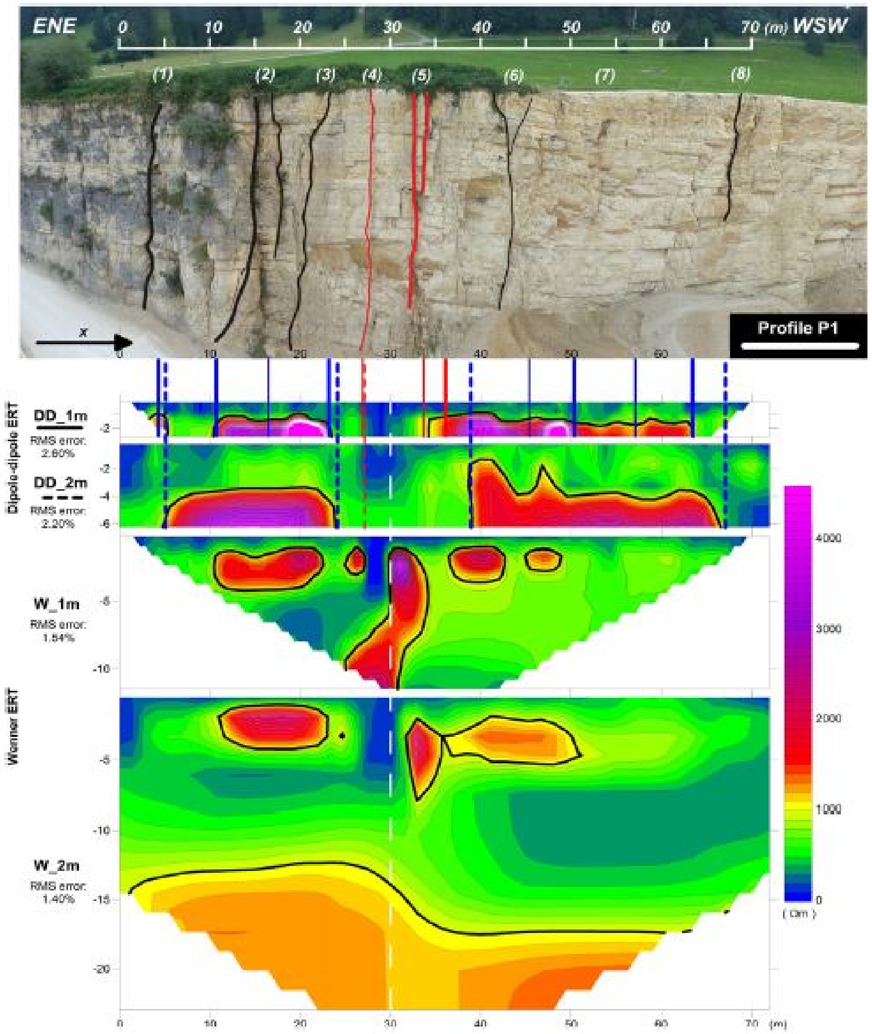
→Adapted to places where the subsurface is NOT PERFECTLY HORIZONTALLY LAYERED SUBSURFACE CONDITIONS: Identification of faults and structures



Geoelectrical profiling

Falco P. et al., (2013)

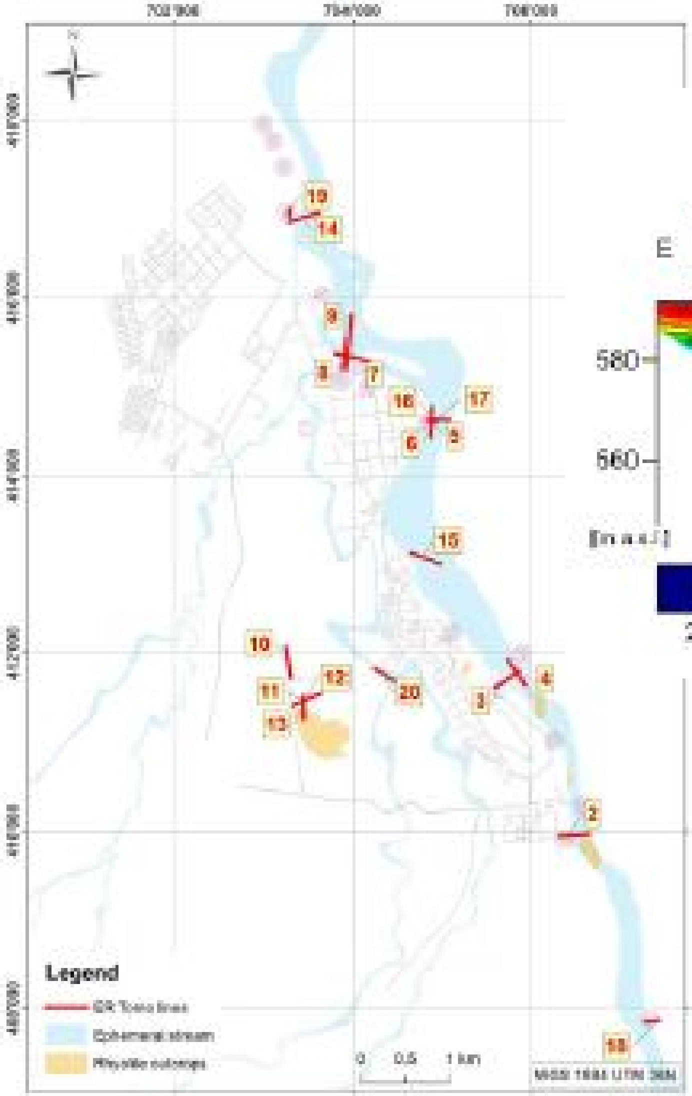
Electrical resistivity tomography (ERT)



A combination of vertical electrical sounding and profiling

Falco P. et al., (2013)

Electrical resistivity tomography (ERT): Example Kakuma



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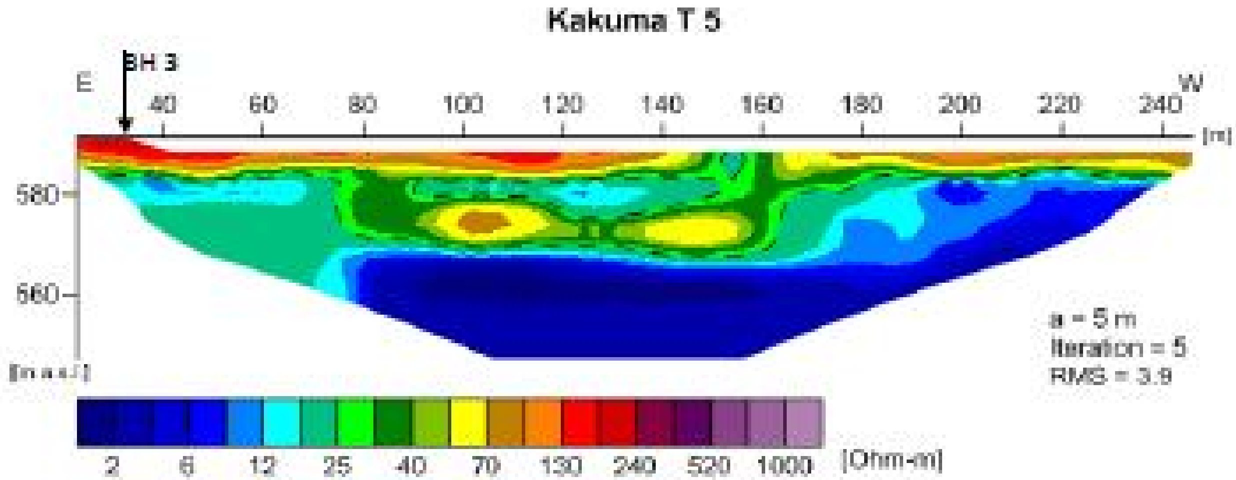
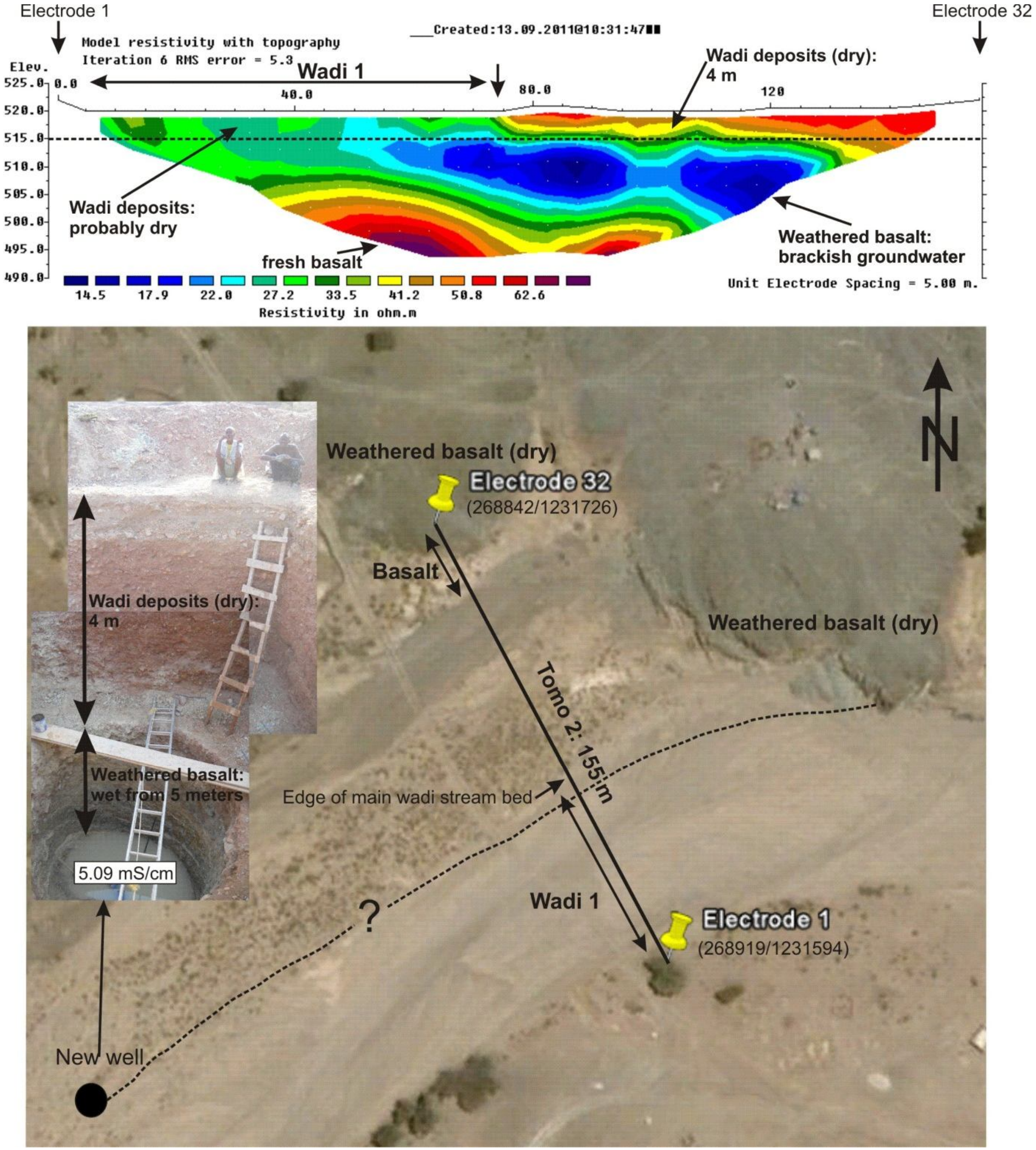


Electrical resistivity tomography (ERT). Example Djibouti



TORs for geophysical investigation should explain

- Which method is used: why, where with which expected outcome? (e.g. what kind of geophysical signal is expected for the ‘aquifer horizon’?)

- Which equipment and which interpretation methods are used?

- All raw data has to be contained in the reports (this is what the client has actually paid for!)

Let’s try it ourselves in the field now !!!!

University of Applied Sciences and Arts of Southern Switzerland
Water, Sanitation and Hygiene Competence Centre

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SUPSI

Bacteriological Analysis of Water

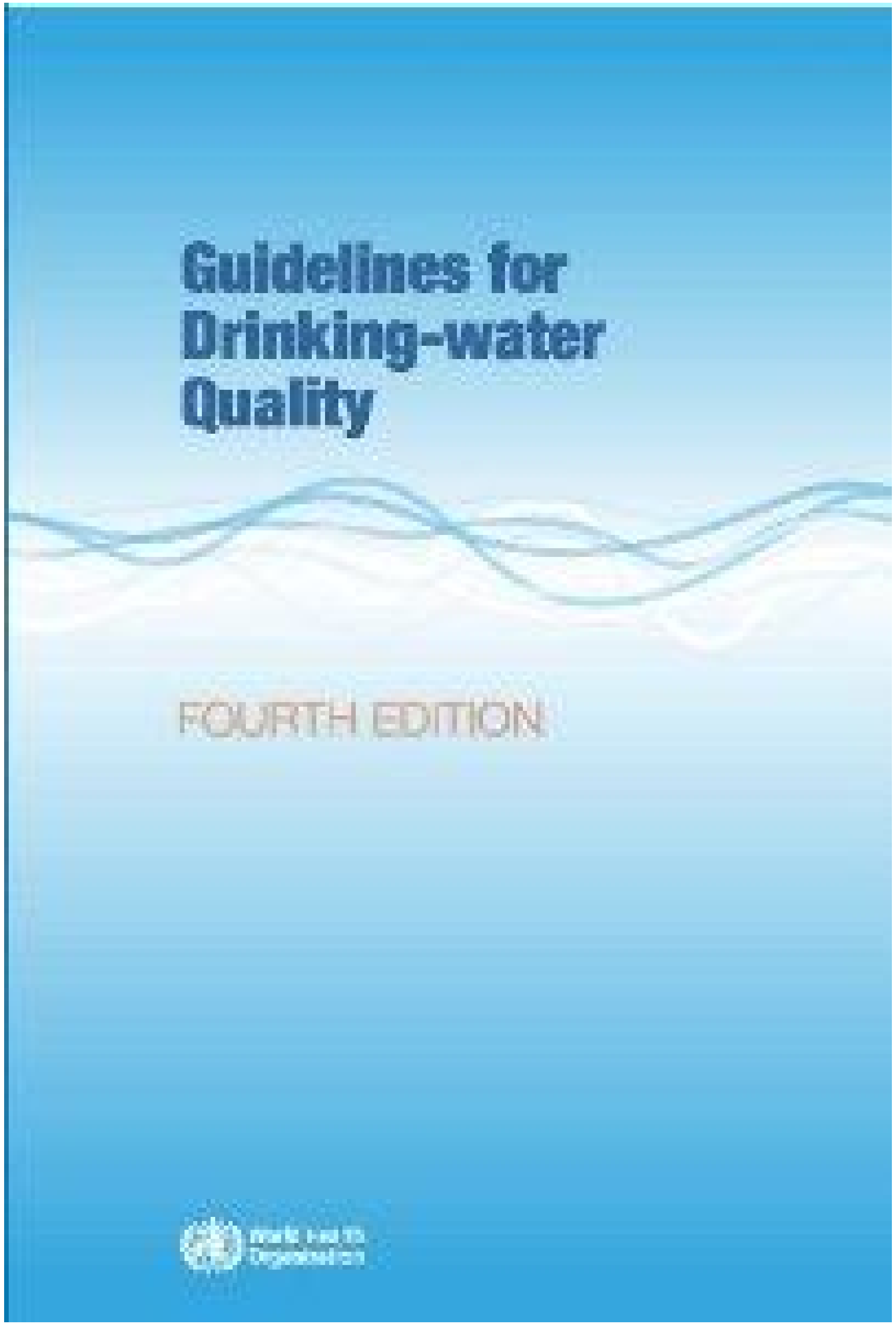
UNHCR Applied Hydrogeology training (SDC-CHYN-UNHCR)

June 1 to 6, 2014

Claudio Valsangiacomo (www.supsi.ch/go/wash)

World Health Organization

1. Introduction
2. A conceptual framework for implementing the Guidelines
3. Health-based targets
4. Water safety plans
5. Surveillance
6. Application of the Guidelines in specific circumstances
7. Microbial aspects
8. Chemical aspects
9. Radiological aspects
10. Acceptability aspects: Taste, odour and appearance
11. Microbial fact sheets
12. Chemical fact sheets
13. Annexes



Types of portable laboratories

Del agua kit for water testing

- Only turbidity, free residual chlorine and coliforms.
- More difficult to use than SHA water lab (preparation of sterile artificial media.

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SHA kit for water testing

Intruments and equipment for **sampligns** and **oganoleptic, physical** analyses

Intruments and equipment for the **bacteriological** analyses

Instruments and equipment for the **chemical** analyses

Main analysis parameters during emergency

Analysis	**Analyte**	**Sample**	**Result**	**Requirements (WHO)**
Bacteriological analysis with Compact Dry EC	*E. coli* as indicator of fecal contamination	100 ml water (sterile sample collection, analyze within 24 h, no thermal shocks, use thiosulfate soln. if chlorine treated).	CFU/100 ml (Colony Forming Units in 100 ml)	0 CFU/100 ml
Free residual chlorine	Free residual chlorine (FRC)	Just fill the vial as required (analyse on the spot, no sterile conditions required)	ppm (parts per million) or mg/L	> 0.5 ppm (for humanitarian situations > 0.2 ppm (BUT: Turbidity requirements satisfied)
Turbidity	Turbidity	Just fill the turbidimeter (analyse on the spot, no sterile conditions required)	NTU (Nephelometric Turbidity Units)	< 5 NTU (for humanitarian situations < 10 NTU)

Free residual chlorine (FRC) and Turbidity

FRC and turbidity

If

A. Free Residual Chlorine > 0.5 ppm (> 0.2 ppm for humanitarian situations)

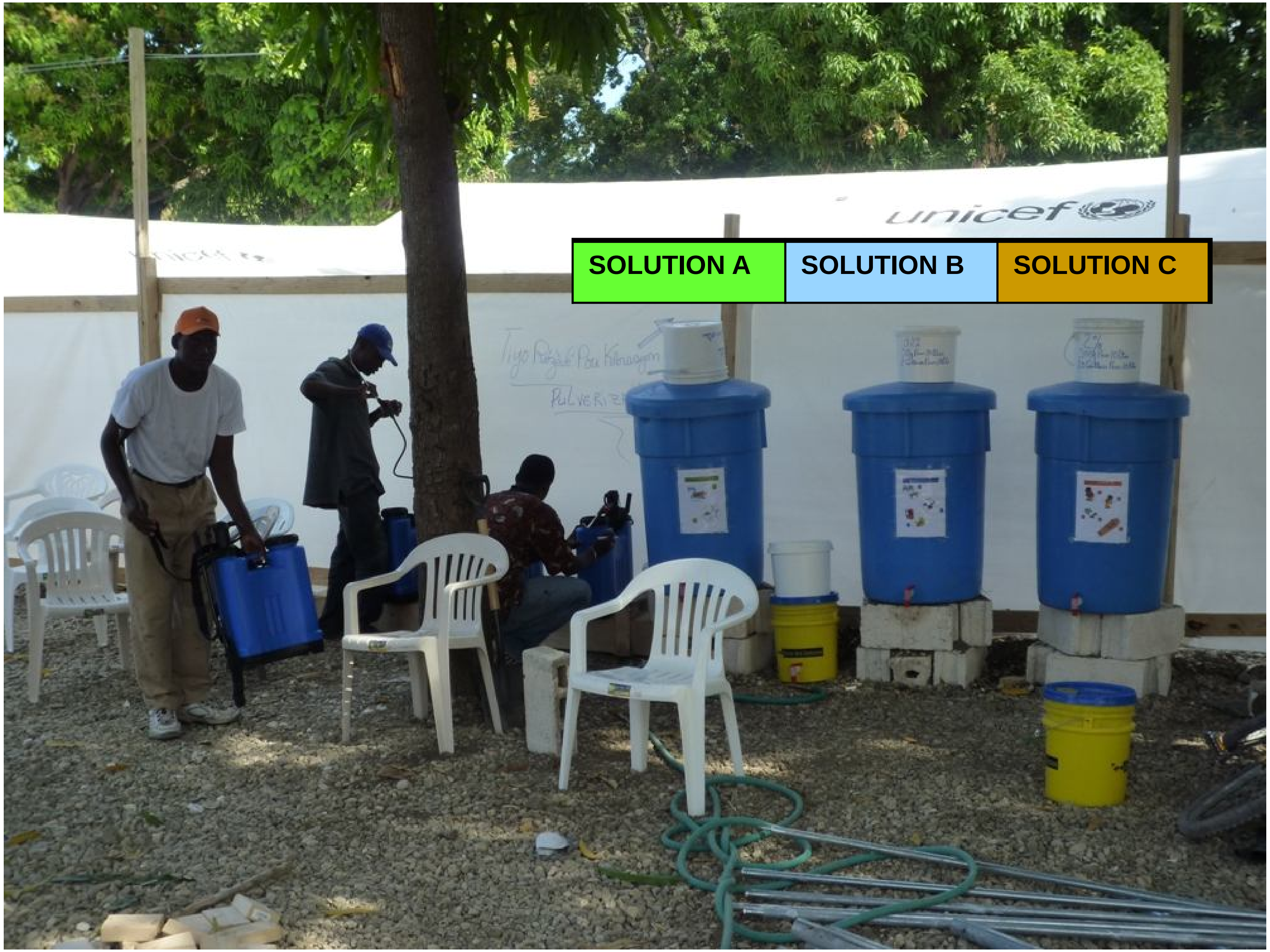
and

B. Turbidity < 5 NTU (< 10 NTU for humanitarian situations)

Then: No need for bacteriological water testing

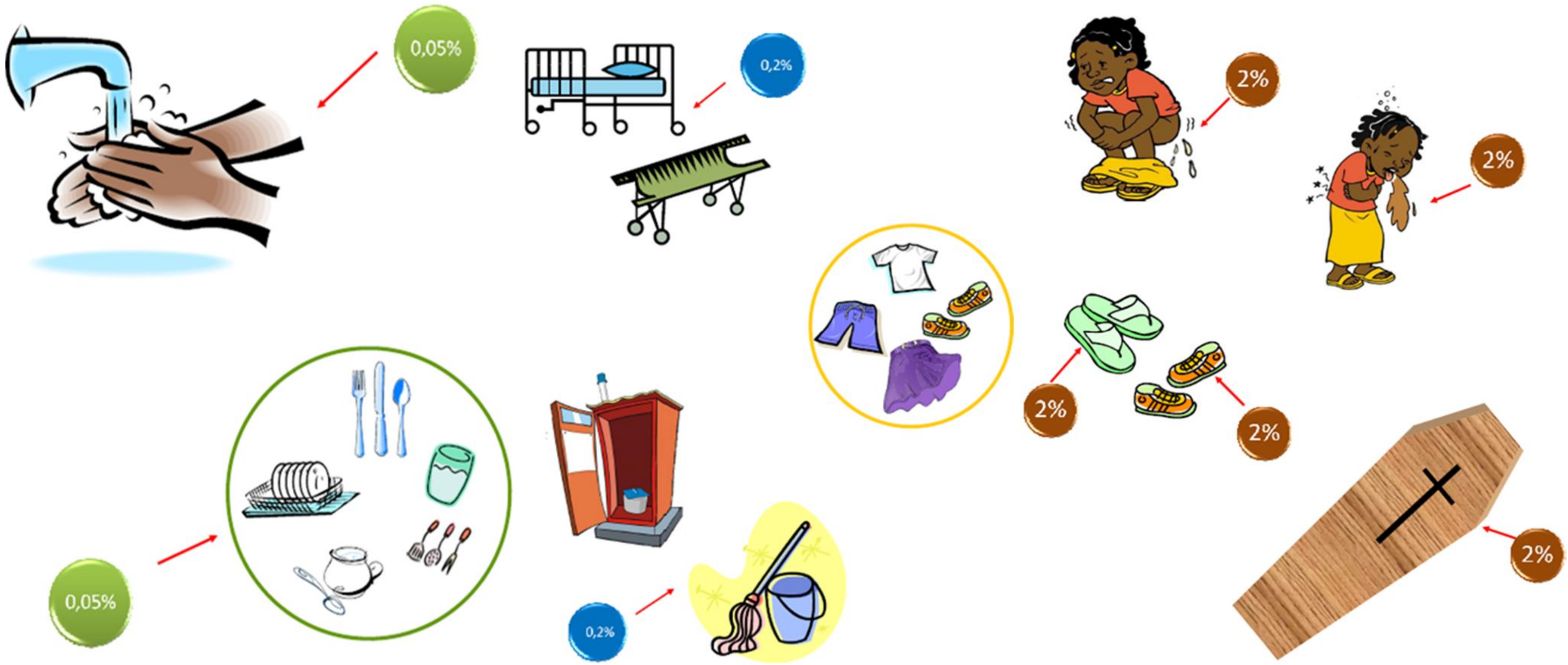
P.S. Be sure the pH is within the ideal range 6.5 – 8.5

FRC and turbidity

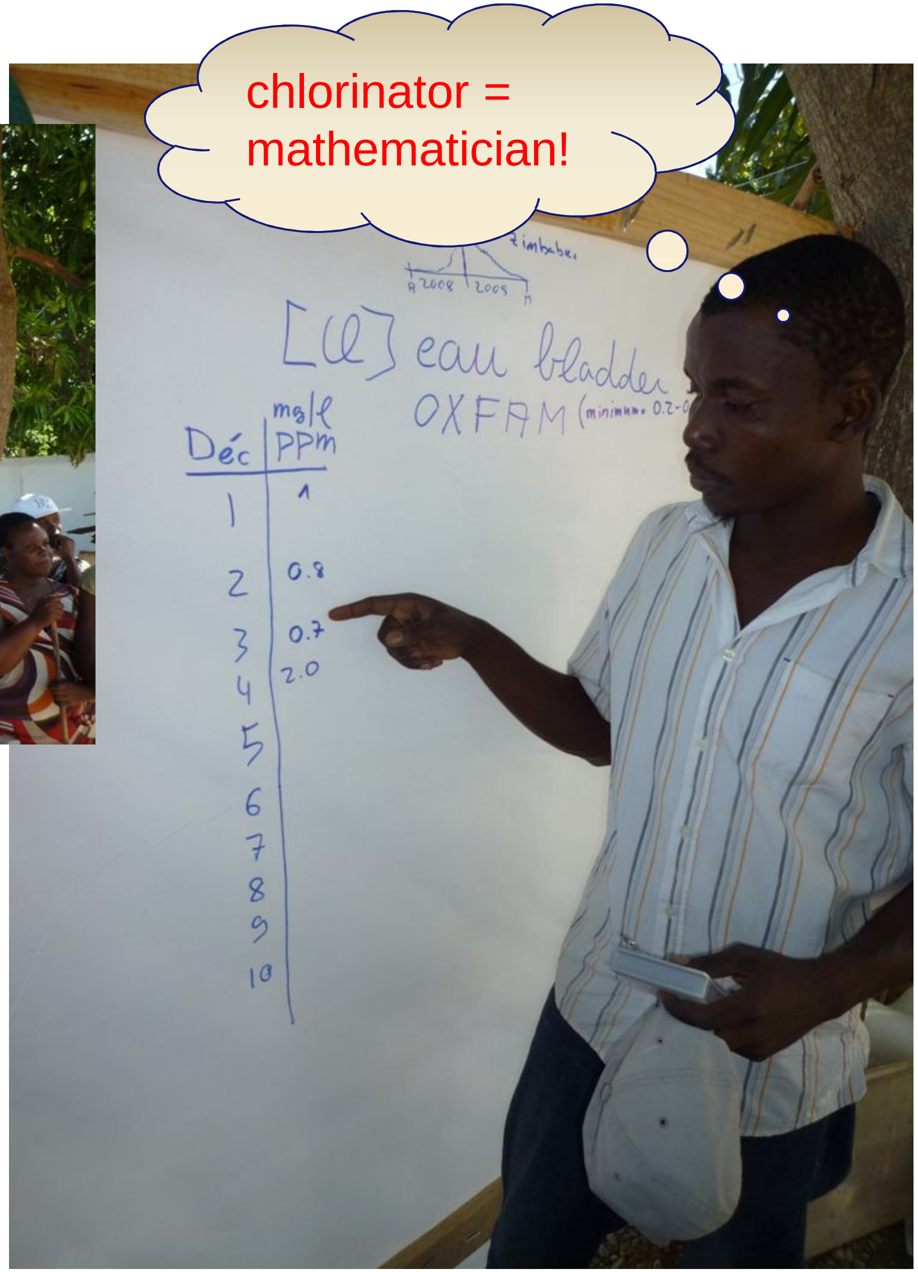


Chlorine stock solutions in a Cholera Treatment Centre

SOLUTION A	SOLUTION B	SOLUTION C



Main, peau, vaisselle	**Sols, vêtements, literie, latrines**	**Excreta, pédiluves, cadavres**
Ajouter 1 cuillère à soupe dans 20L d'eau	Ajouter 1 cuillère à soupe dans 5L d'eau	Ajouter 2 cuillère à soupe dans 1L d'eau



Daily check of FRC in drinking water at CTC

FRC and turbidity

Figure 1: Sample Turbidities (Howard, 2001)

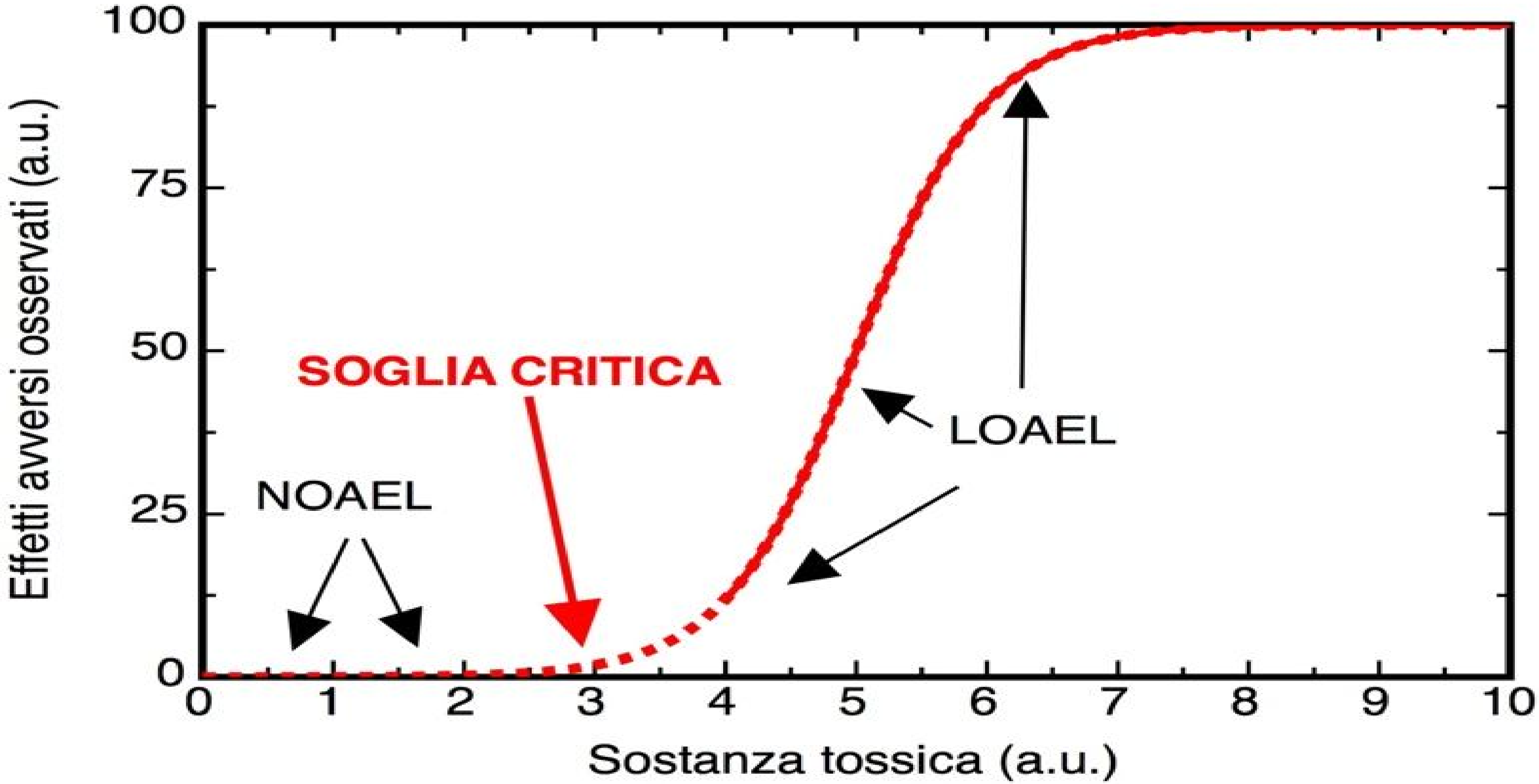
Chemical versus Bacteriological contamination

Chemical versus Bacteriological contamination

1. Presence of *E. coli* means presence of fecal contamination, during Cholera or other diarrheal epidemics the risk to get sick is high
2. Presence of total coliforms indicates bad disinfection practice of water (**only *Escherichia coli* accurately indicates fecal contamination!**).
3. Presence of chemical contamination has a variety of different meanings. Usually risk to get sick is very low (if consumption only for short period)

Reference values for chemical contamination: basics of toxicology

With experiments on animals LOAEL (Lowest observed adverse effect level) and NOAEL (No observed adverse effect level) are determined. The animals are fed for the whole life with a specific concentration of the substance.



Extrapolation of reference value from experimental toxicology – Example for Hg residues in water

10 mg/kg

- Critical treshold for animals NOAEL

1 mg/kg

- Critical treshold for human beings

0.1 mg/kg

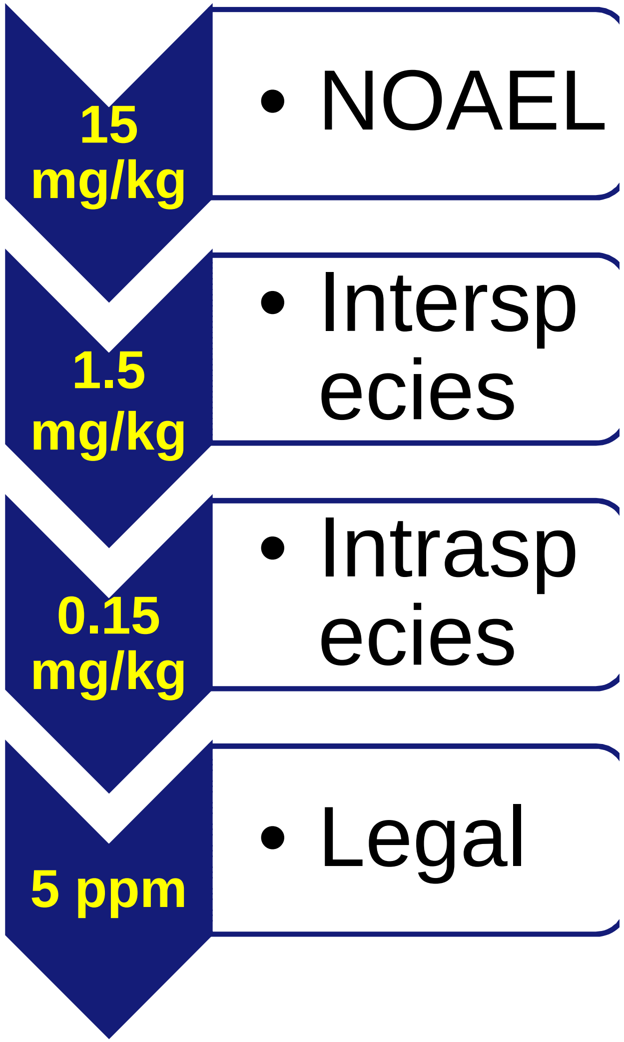
- Critical treshold for particularly susceptible human beings (intraspecific susceptibility)

0.01 mg/kg

- Legal reference value

Guideline value for chlorine in water

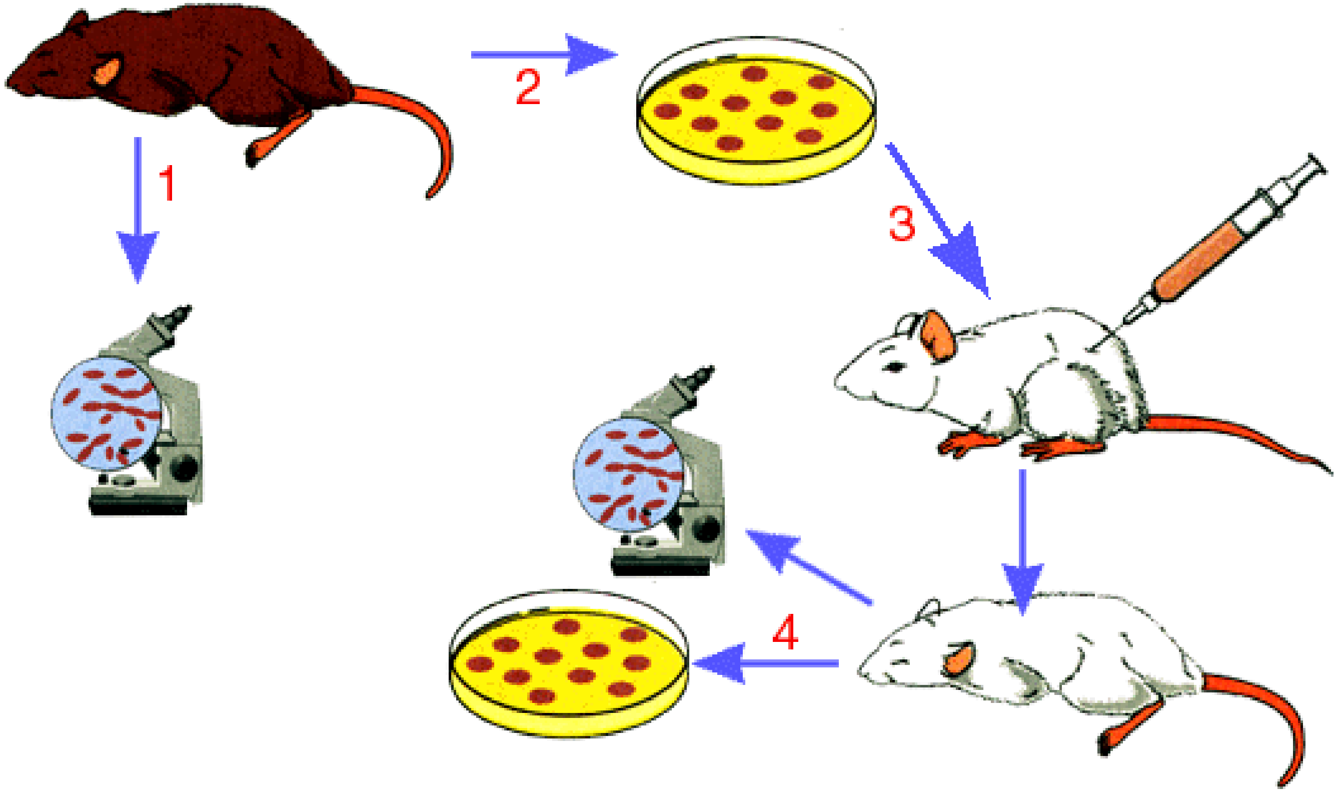
- Guideline values are derived for many chemical constituents of drinking-water and normally represent the concentration of a constituent that does not result in **any significant risk to health over a lifetime of consumption**.
- The guideline value for free residual chlorine in drinking-water is derived from a NOAEL of 15 mg/kg of body weight per day, based on the absence of toxicity in rodents that received chlorine as hypochlorite in drinking-water for up to 2 years. Application of an uncertainty factor of 100 (for inter- and intraspecies variation) to this NOAEL gives a TDI of 150 µg/kg of body weight. With an allocation of 100% of the TDI to drinking-water, the guideline value is 5 mg/litre (**5 ppm**).
- It should be noted, however, that this value is conservative, as no adverse effect level was identified in this study.
- Most individuals are able to taste chlorine or its by-products (e.g. chloramines) at concentrations below 5 mg/litre, and some at levels as low as 0.3 mg/litre.



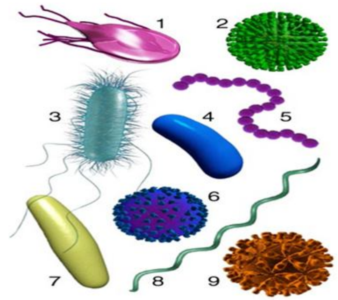
Extrapolation of reference value for microbiological agents

Koch postulates:

1. Microorganism in the sick host
2. Grow the microorganism
3. Inoculate the microorganism in a healthy host and observe symptoms
4. Isolate the microorganism again



Bacteriological analysis, fecal indicators

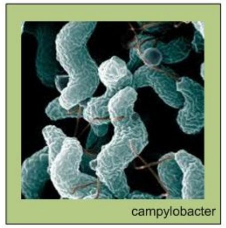


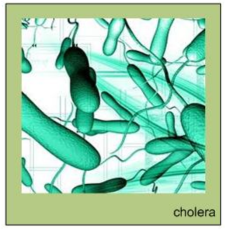
Why we do not measure pathogens

- Numerous water borne pathogens
- Individual pathogen numbers may be too low to detect in a reasonable sized water sample
- Isolation and detection of some pathogens can take several days, weeks, or months
- Absence of one particular pathogen does not rule out the presence of another

Infections

Infection		Pathogenic agent
Diarrhoeas and Dysenteries	*Campylobacter enteritis*	Bacterium
	Cholera	Bacterium
	E. coli diarrhoea	Bacterium
	Salmonellosis	Bacterium
	Shigellosis (bacillary dysentery)	Bacterium
	Yersiniosis	Bacterium
	Rotavirus diarrhoea	Virus
	Giardiasis	Protozoon
	Amoebic dysentery	Protozoon
	Balantidiasis	Protozoon
Enteric fevers	Typhoid	Bacterium
	Paratyphoid	Bacterium
Poliomyelitis		Virus
Hepatitis A		Virus
Leptospirosis		Spirochaete
Ascariasis		Helminth
Trichuriasis		Helminth


campylobacter

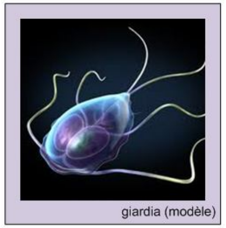

cholera


salmonella

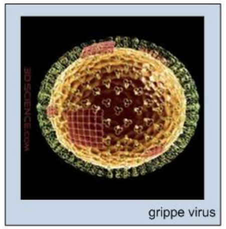

protozoaire

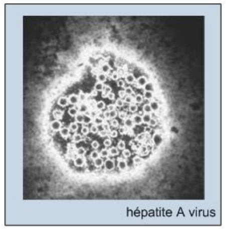

amoeba


crysporodium


giardia (modèle)


entérite virus


grippe virus


hépatite A virus

Sanitary and water diseases

Insufficient Quantity → Lack of hygiene

Bad microbiological Quality
- Faecal pollution
- Urines (some mammals)
- Larvas of Guinea worm

Problems limited to certain regions

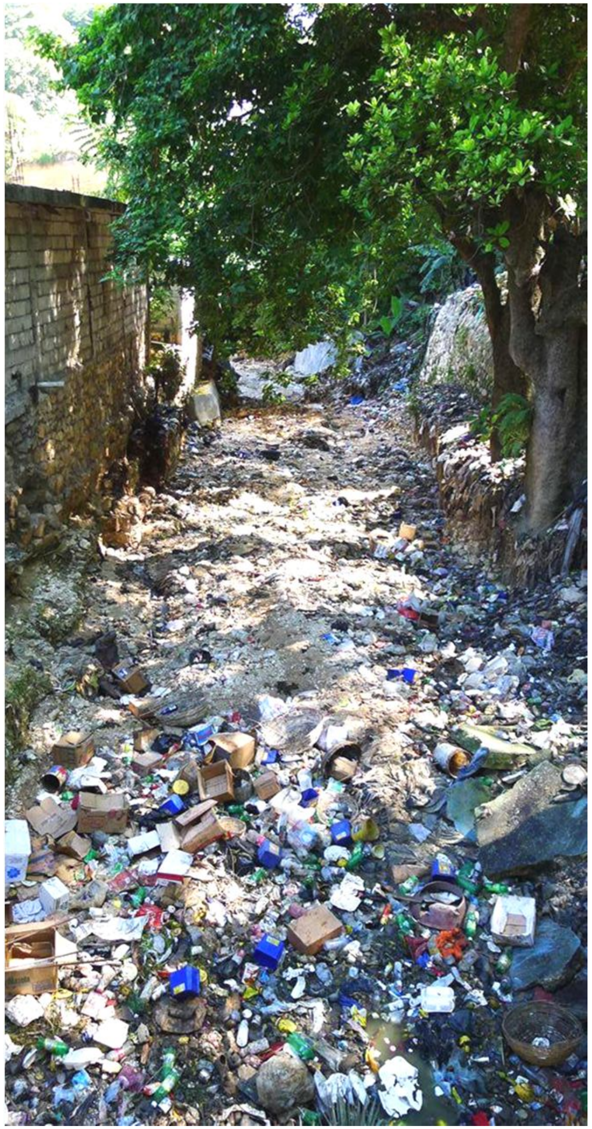
Bad chemical Quality

Water as vectors shelter

diseases

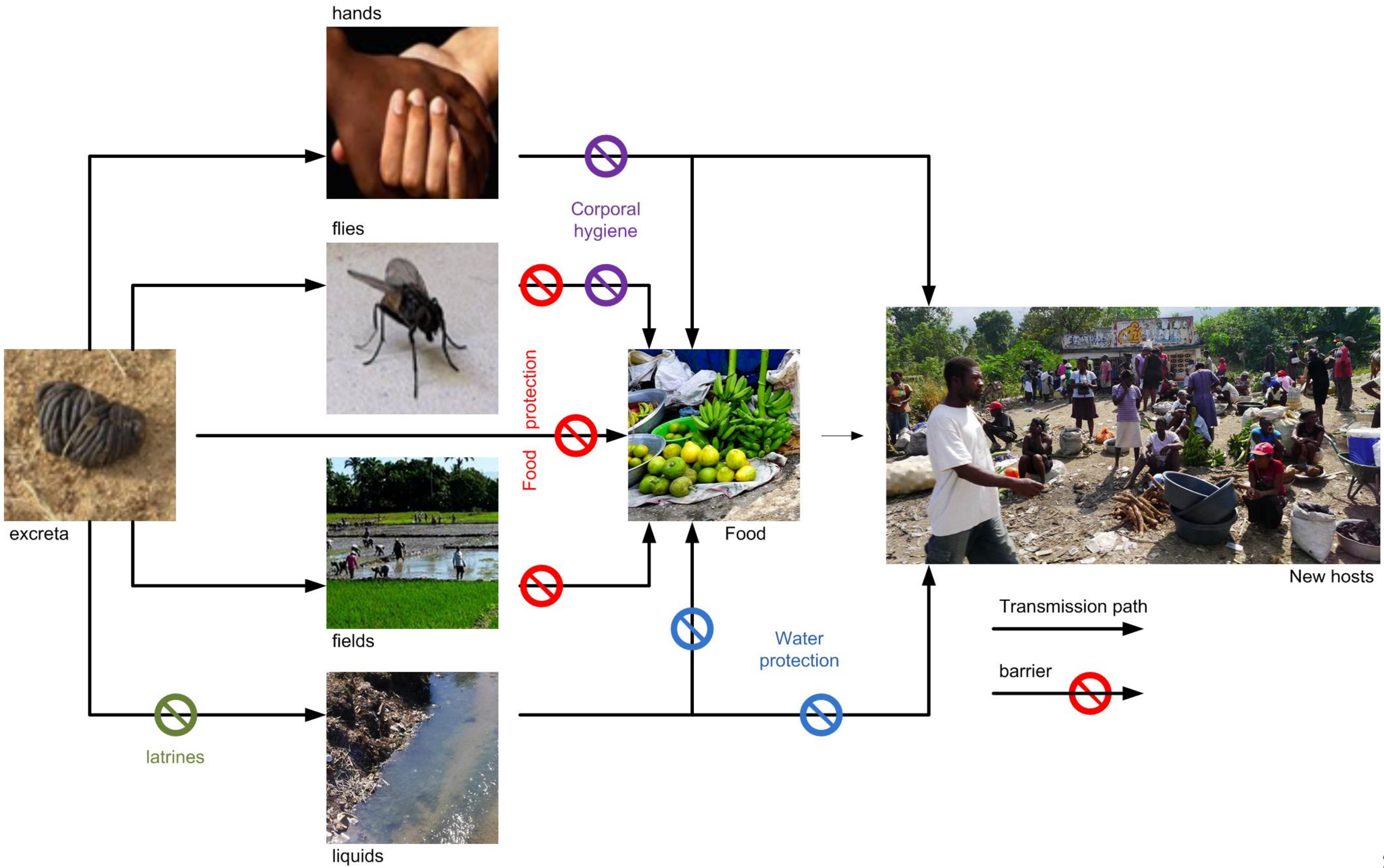
- **Dermatological** (manges, mycoses) and **ophtalmological** diseases (conjonctivites, trachomes,…)
- **Louses** → Recurring fever
- **Faecal-oral** transmitted diseases (diarrhea, typhoïd, cholera, polio, Hep. A,…)
- **Bilharzioses**
- **Leptospiroses**
- **Dracunculose** (Guinea worm)
- **Poisonings**
- **Malaria, yellow fever, dengue, onchocercose,...**

Problèmes sanitaires liés à l'eau (source : MSF)



Transmission routes and barriers

Simple and effective interventions at each stage of transmission



Sources of contamination

Sources and impacts of contamination

→ Human origin sources or after a natural disaster

→ Non-exhaustive list

Cities, villages
- Sanitation infrastructure (latrines, septic tank, sewage,…)
- Wastes,…

Agriculture
- Animal dung
- Agricultural chemicals products

Industries
- Chemicals flows and sludges
- Tanks
- Sewage systems

Energies and transportation
- Fuels storage
- Management of the waste

Pathogenic agents (virus, bacteria, protozoons)

Nitrates

Pesticides

Heavy metals

Organic contaminants

Drinking water and intense pesticide uses : risks of pollution

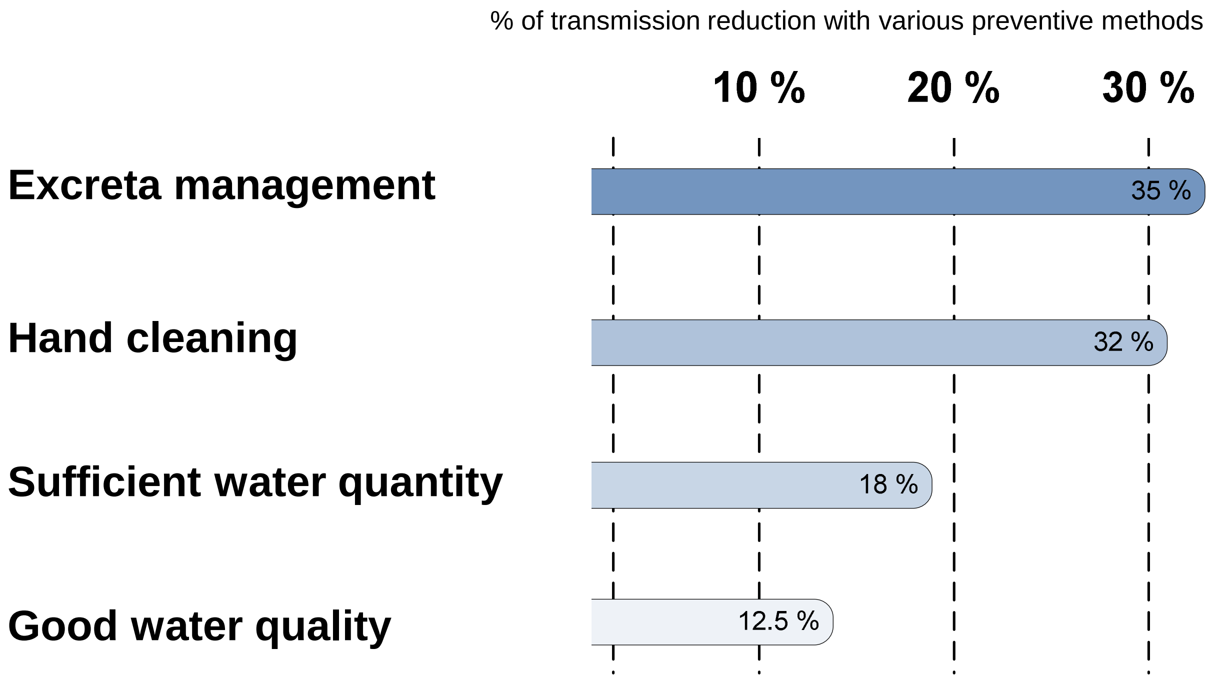
Controlling transmission

Preventative measures

→ High efficiency

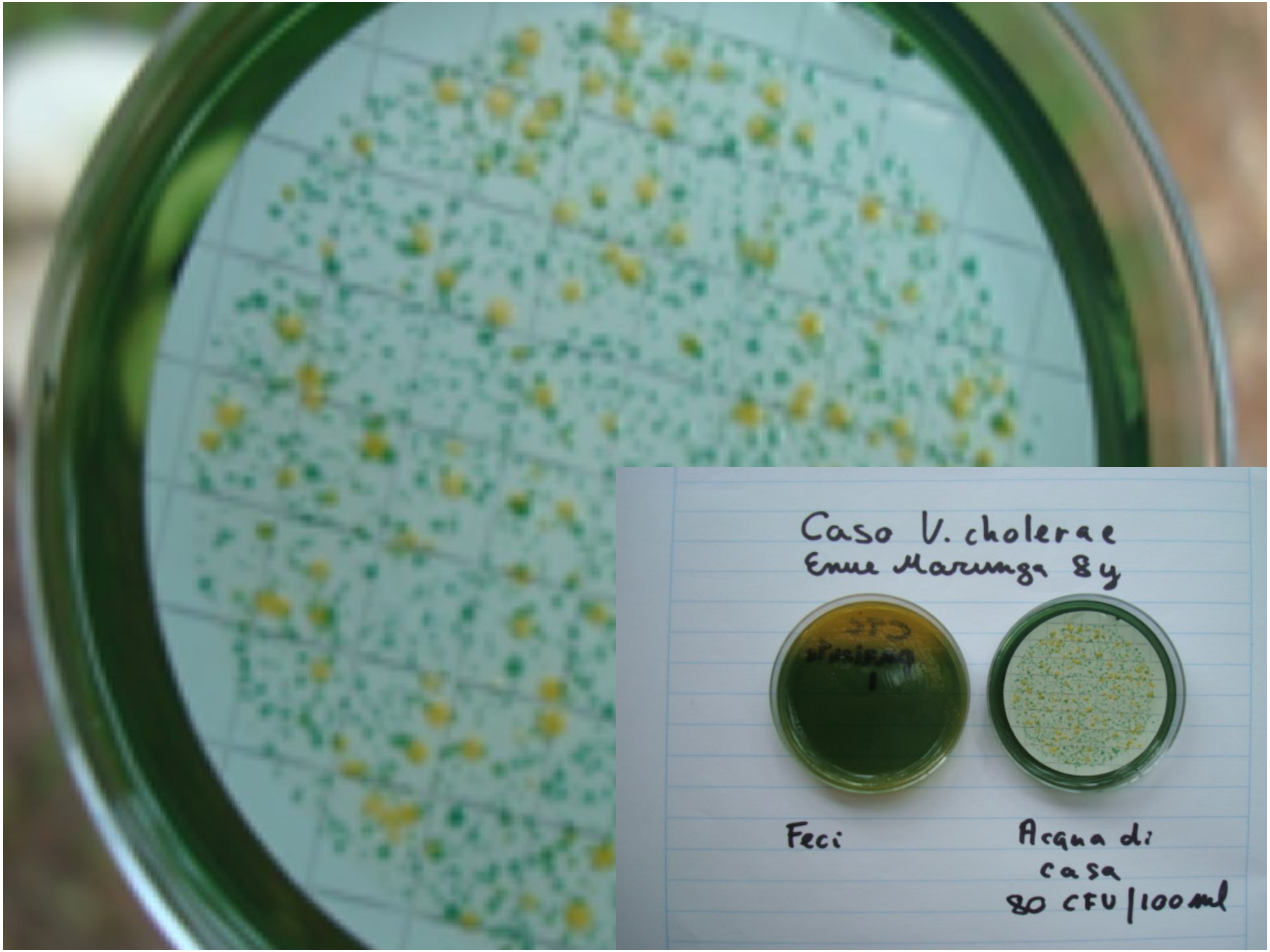
→ Simple and low-cost actions

→ Prioritize large quantity of water (medium quality) over low quantity of water (high quality)



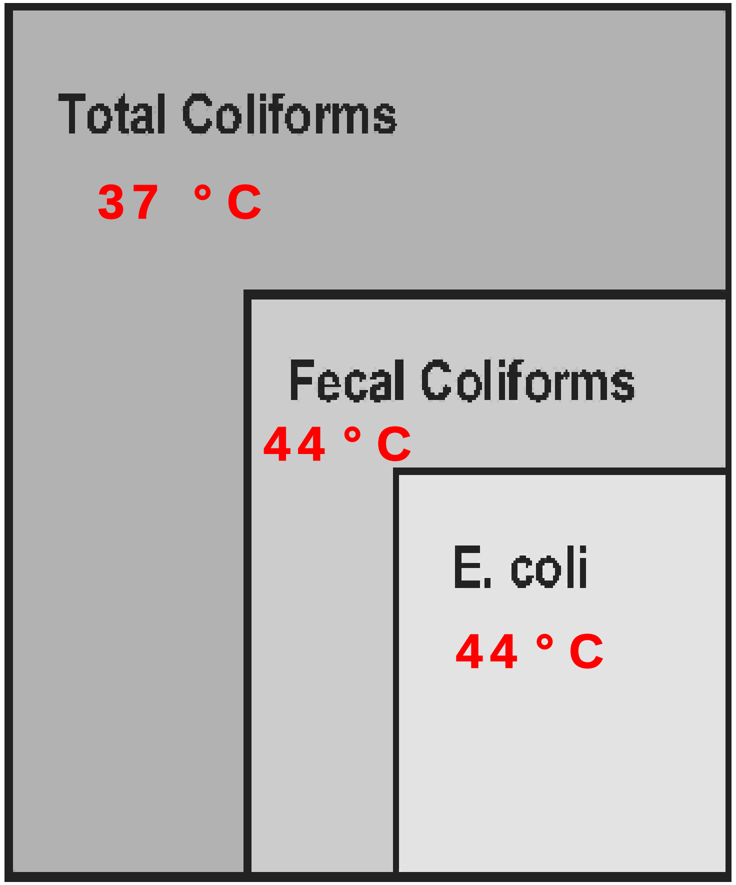
Indicator Organism Concept

- Correlated to the presence of pathogens
- Population large enough to isolate in small water samples (100 mL)
- Rapid
- Inexpensive
- Safety, not culturing pathogens



Caso V. cholerae
Feci
Acqua di casa
80 CFU/100ml

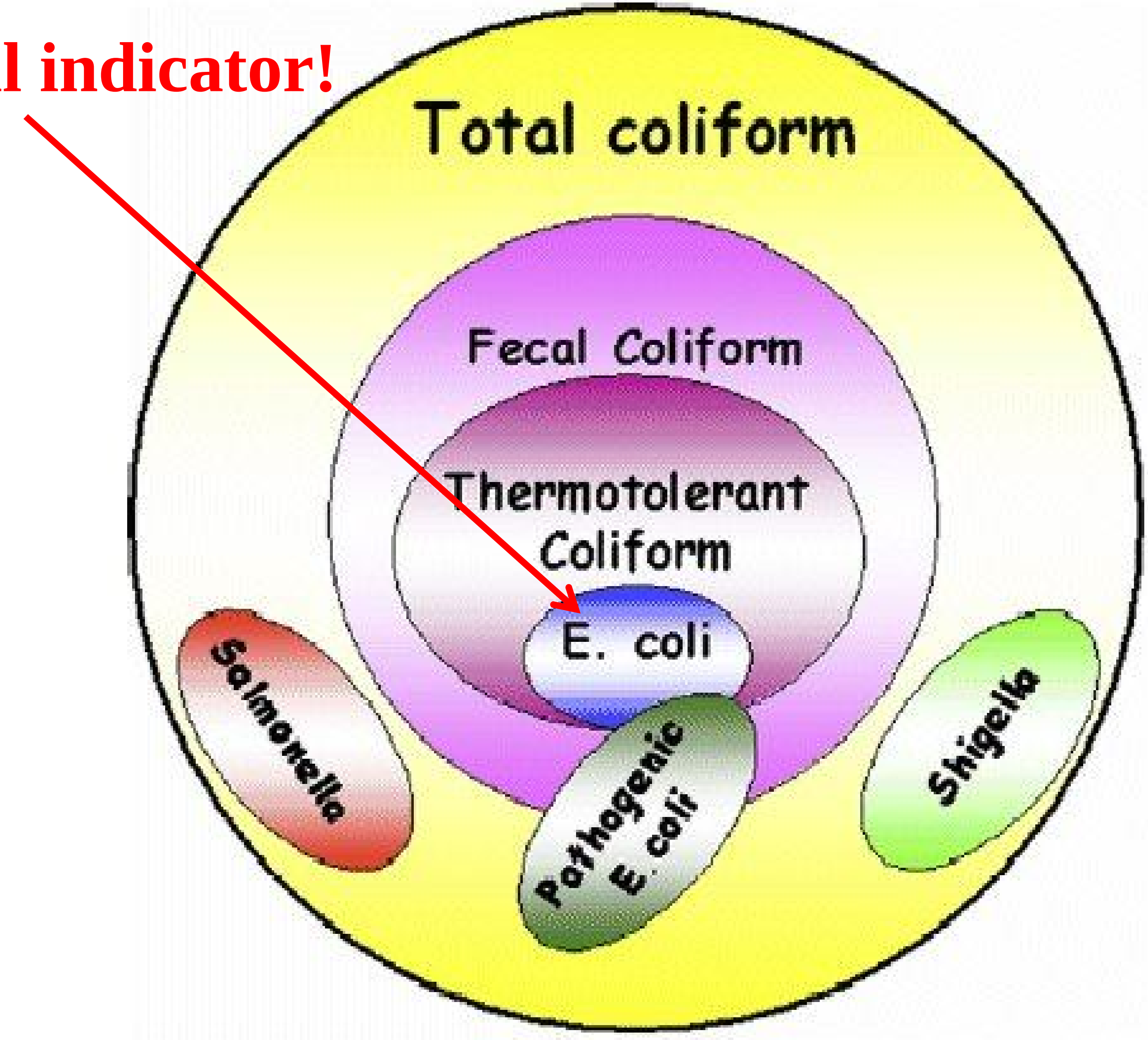
Fecal indicators in water



Total coliforms: ca. 10% of bacteria found in human and animal intestinal wastes. Some coliforms may grow in decaying organic matter, unreliable indicator of fecal contamination.
Fecal coliforms: the subset includes *E. coli* but can also include other bacteria that grow at this temperature. Some of these are not necessarily associated with fecal contamination.
Generic *E. coli:* in the intestines of animals and humans. The presence of generic *E. coli* provides the best evidence of fecal contamination.

- Human feces: 1 g = 12×10^9 bacteria
- Bacteriological water analysis is expressed as CFU/100ml

Best fecal indicator!

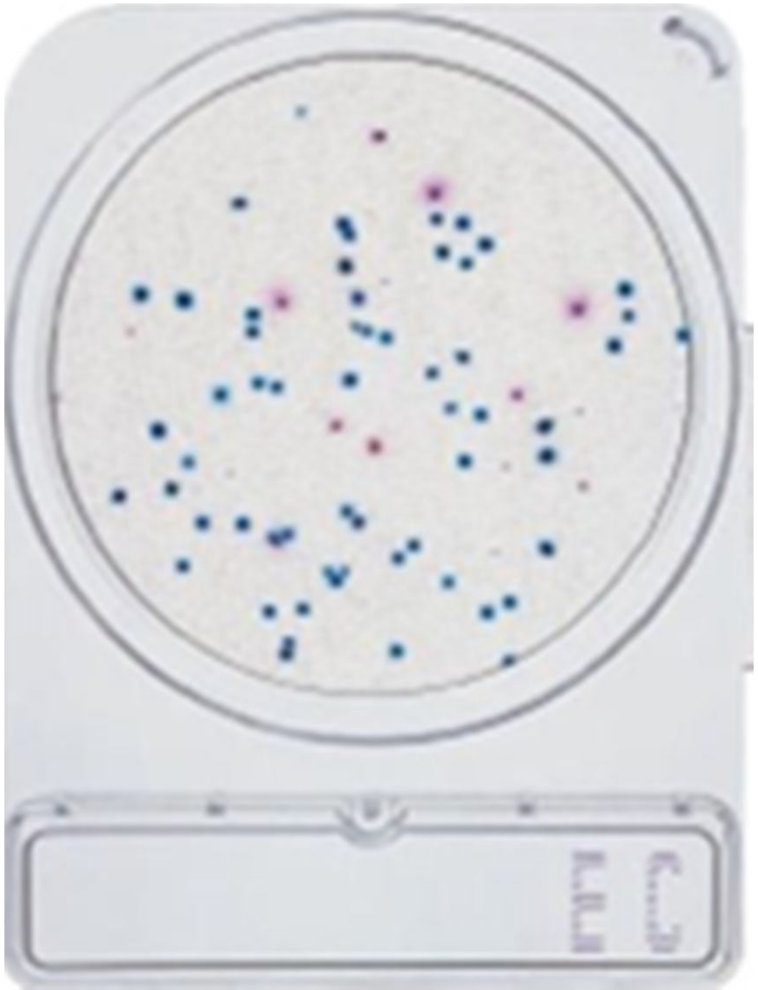


Standard operating procedure for bacteriological analysis of water

Analysis of E.coli and Coliforms

Enzyme Substrate or Chromogenic Substrate Method

- Coliforms have the enzyme
  - β-D-galactosidase
  - Can be detected with Magenta-Gal artificial sugar: Pink
- *E. coli* has the enzyme
  - β-glucuronidase
  - Can be detected with X-Gluc artificial sugar: Blue



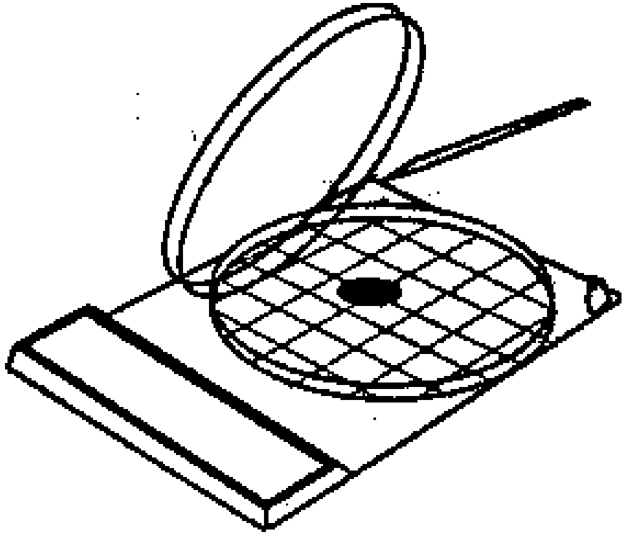
Membrane Filter Method

- Rehydrate plate with 1 ml sample water
- Filter 100 ml water through a 0.45 µM membrane filter
- Place membrane filter on selective media
- Close lid and incubate up-side down at

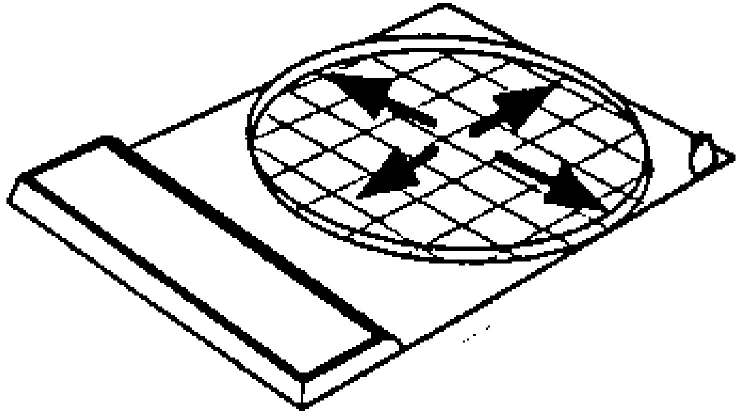
  37.0 °C – 44.5 °C depending on which indicator you want to test (total coliforms or E. coli)
- Count pink and blue colonies and express result in CFU/100 ml (Colony Forming Units in 100 ml of water)
- In your samples always put a positive (fecal contaminated) and negative sample (mineral water from the bottle).

Rehydration

Lift the lid and drop 1 ml of water sample in the centre.



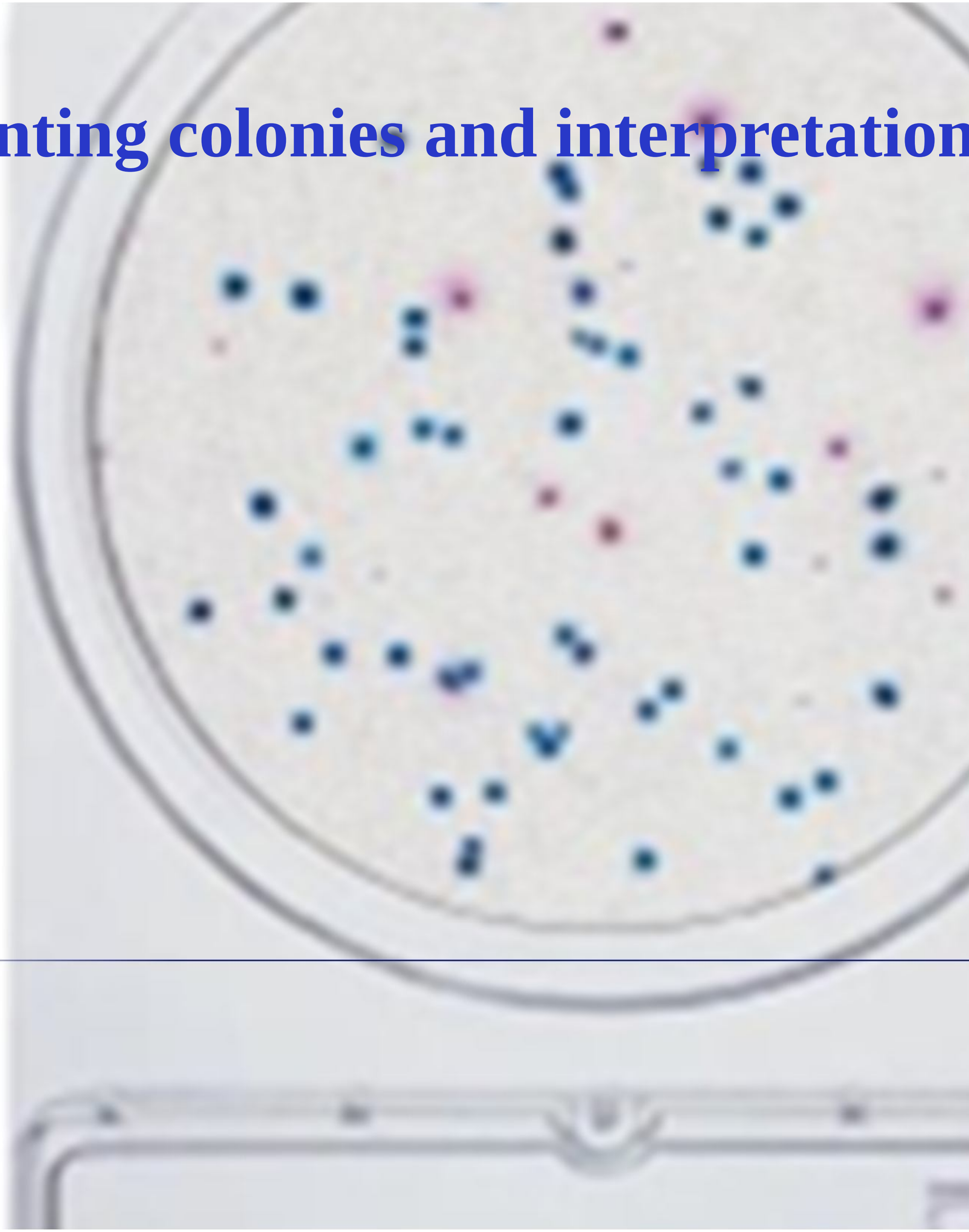
Let diffuse water over the surface of ca 20 cm^2

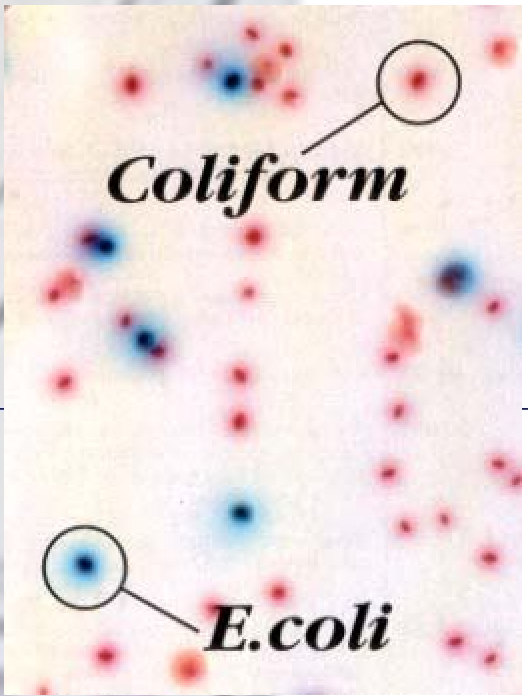


Filtration: 0.45 μm

Incubation for 24 h (at least 18 h) at 37 °C

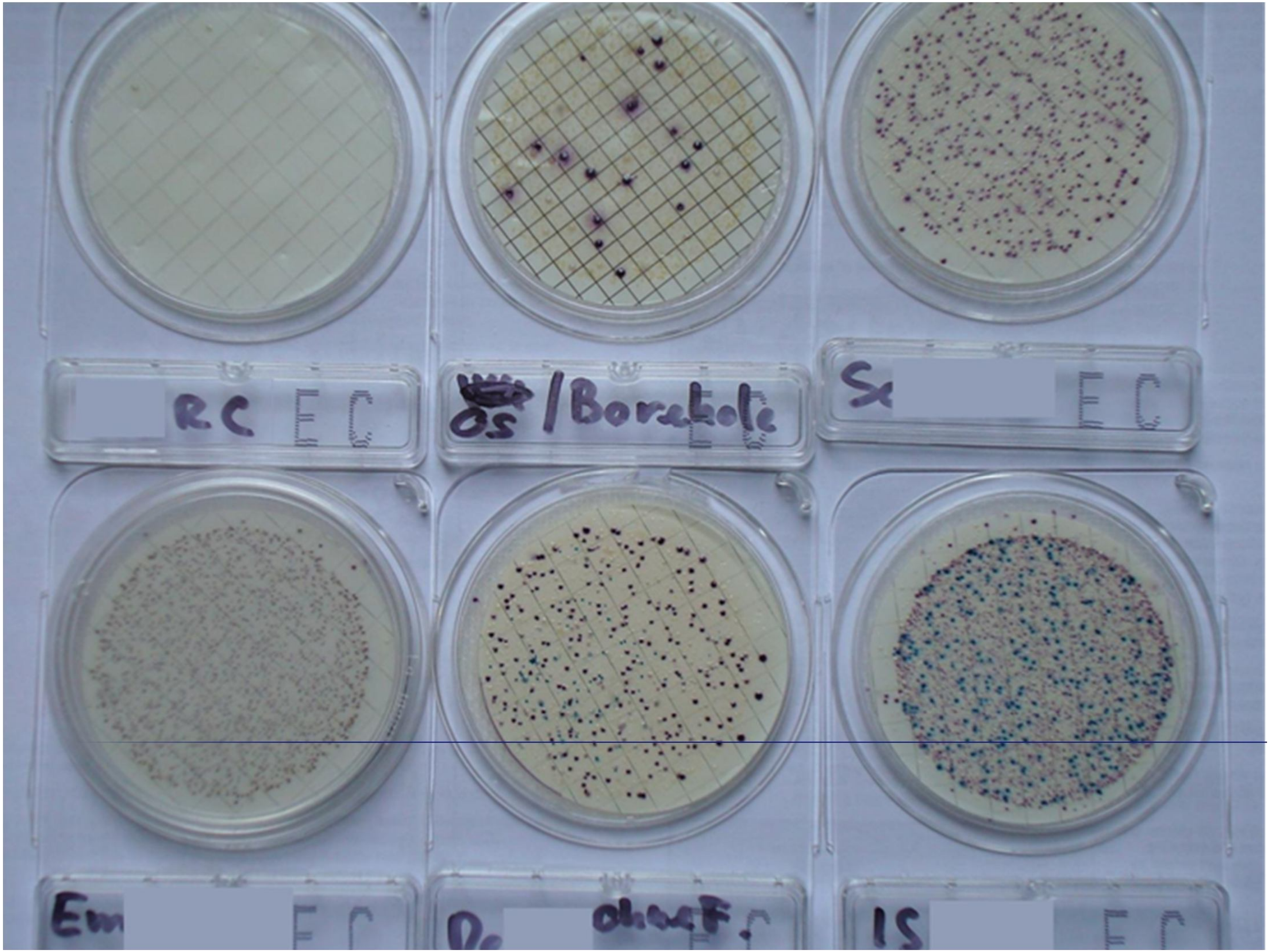
Counting colonies and interpretation of results

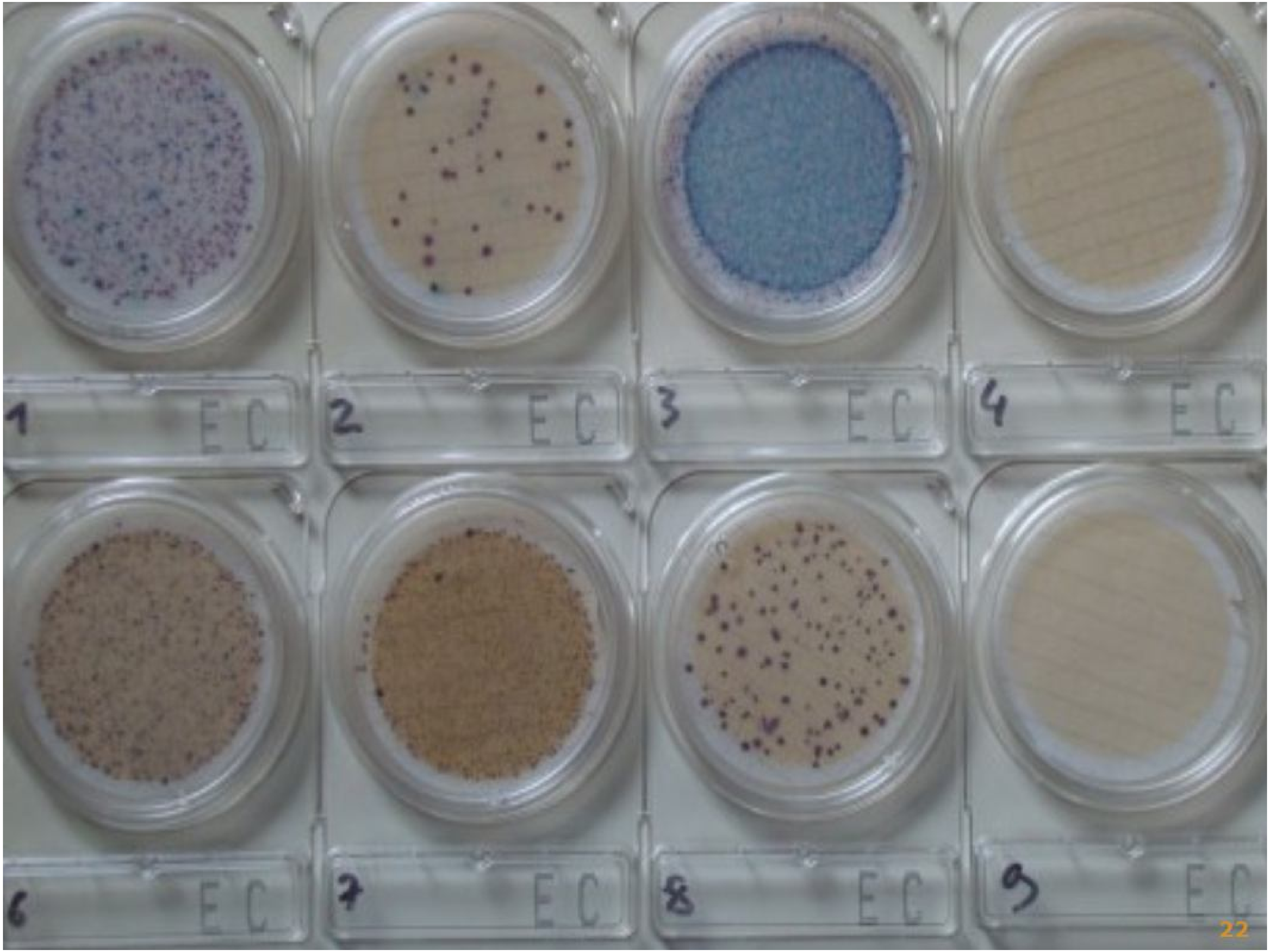




Count Colony Forming Units (CFU)

Maximum 100 CFU, if more than TNTC (too numerous to count)


RC EC
Os /Borekole
EC
EC
EC


1 EC
2 EC
3 EC
4 EC
6 EC
7 EC
8 EC
9 EC


14 Jan 2009
Hotel H2O
before treatment
E.coli 100 CFU/100 ml
after treatment
0 CFU/100 ml
MICROPUR®
FORTE
KATADYN®
MAKING WATER DRINKING WATER
MF 1T | DCCNa
Zur Wasserdesinfektion & Konservierung auf Reisen
For Water Disinfection & Conservation when Travelling
Le plus efficace des comprimés désinfectants; conservation de l'eau purifiée jusqu'à 6 mois
Voor ontsmetting & conservering van water op reis
Per la disinfezione e la conservazione dell'acqua in viaggio
100 tab./compr.
Natriumdichlorisocyanurat
Dichloroisocyanurate de sodium
DCCNa 4,5 mg
Silberionen/silver ions/ions d'argent/zilverionen/ioni argento
Ag+ 0,1 mg

… water is a symbol of purification…

why should we purify it?

why do we pollute it?

UNIVERSITÉ DE NEUCHÂTEL

CHYN
Centre d'hydrogéologie et de géothermie

UNHCR
The UN Refugee Agency

CHYN TRAINING COURSE FOR

UNHCR WASH STAFF

APPLIED HYDROGEOLOGY

from field investigation towards sustainable water resources management

June 1 to June 6, 2014

Basic concepts of groundwater protection

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Agency for Development and Cooperation SDC

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Main questions to be addressed today

- Why do we need groundwater protection?
- How do we define groundwater protection zones?
- Why is groundwater monitoring important?

- Delineate groundwater protection zones and design a monitoring scheme for our Buix site

Prologue

THE GLOBE AND MAIL

CANADA'S NATIONAL NEWSPAPER • FOUNDED 1844 • FRIDAY, MAY 26, 2000

'This could have been prevented'

Accusations fly that Walkerton's tainted water supply was covered up for five days; death toll continues to climb

ESTANISLAO OZIEWICZ
CAROLINE ALPHONSO
PETER CHENEY
The Globe and Mail, Walkerton, Ont.

Police are investigating the worst public-sanitation scandal in Canadian memory amid accusations that public officials covered up a water-supply contamination here that has left at least five dead and hundreds wretchedly ill.

The regional health chief charged yesterday that utility employees withheld information for five days and insisted that Walkerton tap water was safe when they had a lab report showing bacteria. Even before that, they knew that a chlorination system intended to kill germs was not working properly, he said.

"People have died. People may die yet," said Murray McQuigge, medical officer of health for Grey-Bruce. "This could have been prevented."

Yesterday, air ambulances were again flying to London, carrying victims to that city's major hospitals. Four children were in critical condition on dialysis machines, their kidneys overcome by the infection.

The dead include a two-year-old child, at least two women, aged 66 and 82, and an 89-year-old man. The number made ill passed 700 yesterday as the Ontario Provincial Police were handed the job of figuring out how it happened.

"The local policing services have asked us to take over and investigate," Sergeant Dave Beam of the nearby Mount Forest OPP said last night. "What they're doing is looking for an independent investigation."

At the centre of the storm is the Walkerton Public Utilities Commission, a nine-employee municipal water-and-power company, and its general manager, Stan Koebel, who was nowhere to be seen yesterday, although his pickup truck was parked outside the PUC office.

The utility, overseen by a part-time board, serves a town population of about 5,000. Its chairman, Jim Kieffer, who runs a formal-rental shop, said employees did not

A young girl suffering from E. coli infection lies with her teddy bear as she is taken to an evacuation helicopter at a medical centre in Walkerton, Ont., yesterday.

THE WHISTLE-BLOWER

'They received that fax [showing bacterial contamination] on the Thursday, May 18. They did not tell us this on Thursday, nor did they tell us this on Friday or Saturday when we phoned asking if the water supply was safe and secure.'

— Dr. Murray McQuigge

THE DOCTOR

'There are children in intensive care who are not getting better, they are getting worse. I cannot say there won't be more deaths . . . in fact, I worry that there will be more deaths.'

— Dr. Douglas Matsell

Desperately ill children stream into hospital

CAROLYN ABRAHAM
KEN KILPATRICK
The Globe and Mail, London, Ont.

For at least the sixth time in the past 72 hours, the whirring blades of the air ambulance arriving from Walkerton, Ont., flattened

INSIDE

Grief: "I remember her always being there. She was mom." **A7**

Timeline: How the tainted-water tragedy unfolded. **A8**

since died, one of them a child.

"I've never lost a child to this before," Dr. Matsell said, not in the 12 years he has been practising medicine. And he has treated many children with E. coli in those years.

"I'm coping with it," he said, his

The Globe and Mail (Canada's national newspaper), May 26, 2000

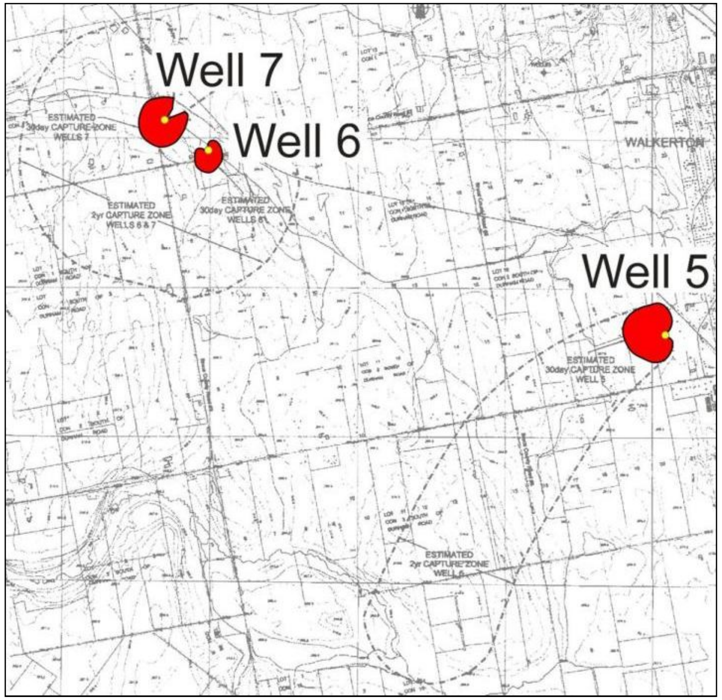
The « **Walkerton-tragedy** »:

- Walkerton (Ontario, Canada): ca. 5000 people
- May 2000: 2300 people became ill and 7 died as a result of microbial contamination of the water supply
- principal pathogens: *E. coli O157:H7* and *Campylobacter jejuni*

Reason: grossly inappropriate protection zones. The nature of karst had been totally ignored and inappropriate investigative methods were used.

Prologue

- aquifer at Walkerton: about 70 m of flat-bedded Paleozoic limestones & dolostones, overlain by 3 to 30 m of till
- the area is rural, with cattle & dairy farms
- hydrogeologists measured hydraulic properties of the aquifer & derived the 30-day protection zones by modelling
- protection zones: no more than 300 m in Ø & no bacterial contamination sources within any of them!



Monitoring of microbial parameters (June – August 2000):

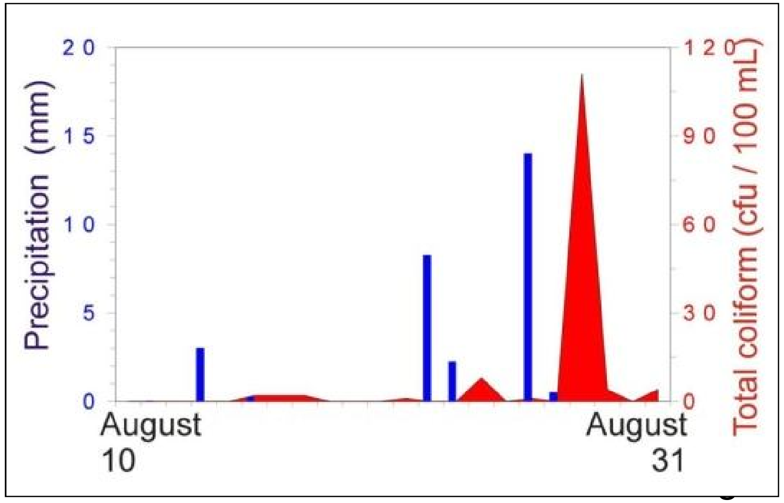
- well 5: heavily contaminated by indicator bacteria
- wells 6 & 7: 34 % & 10 % of samples positive for total coliforms

Photos & figures from this example:
D. Ford (conference Giulin 2009)

Prologue

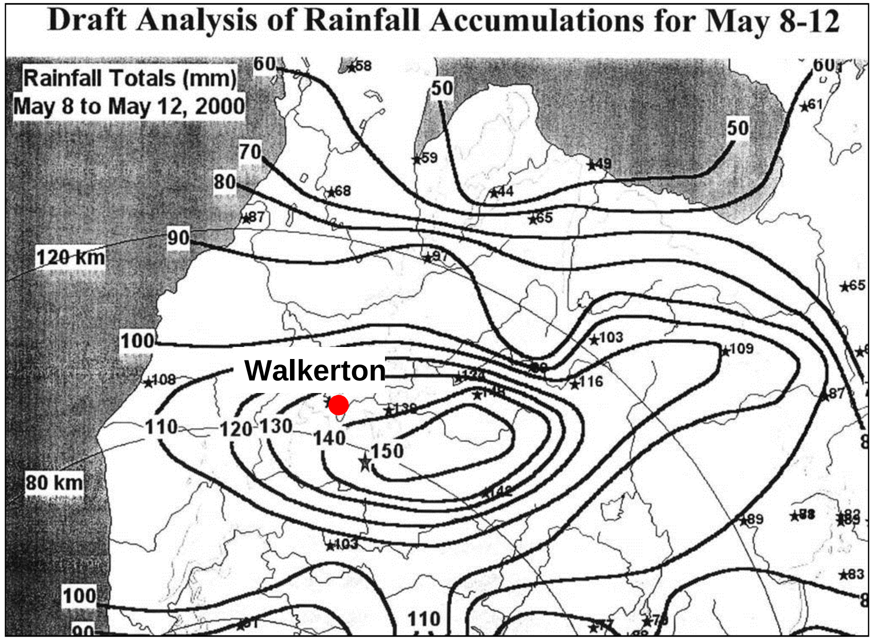
Subsequent investigations found that there were many indications that the aquifer is karstic:

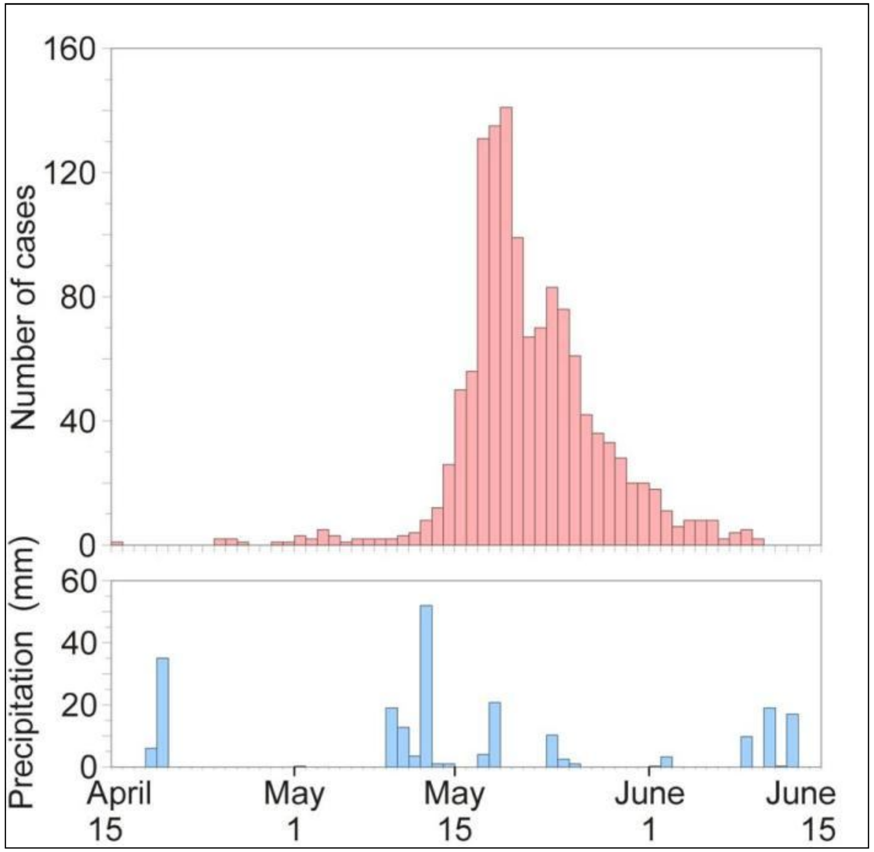
- correlation between bacterial contamination in wells and antecedent rain ➡ rapid recharge and flow to wells;



Prologue

130 mm of rain fell over four days when the chlorination system was not working properly





Prologue

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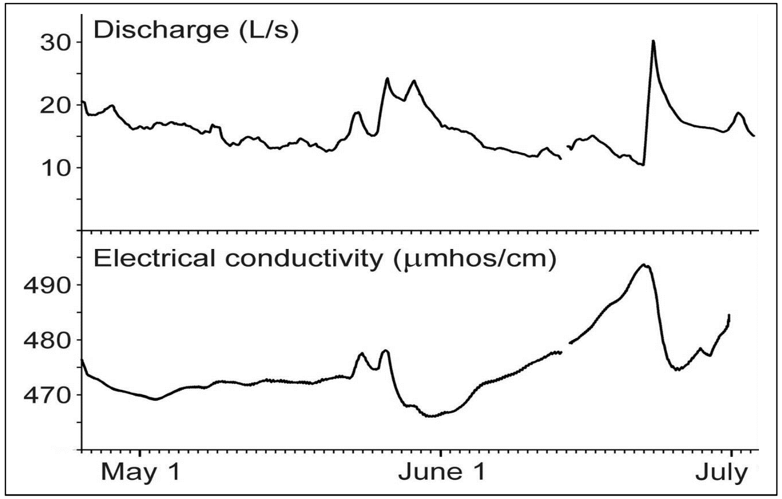
- localised inflows to wells which video images showed to be solutionally-enlarged openings on bedding planes;

Prologue

Subsequent investigations found that there were many indications that the aquifer is karstic:

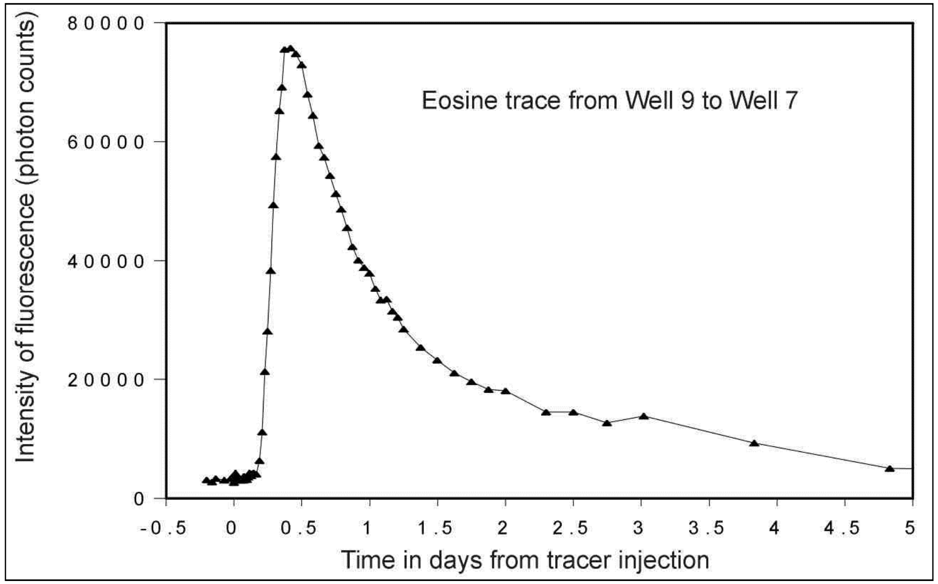
- correlation between bacterial contamination in wells and antecedent rain ➡ rapid recharge and flow to wells;
- localised inflows to wells which video images showed to be solutionally-enlarged openings on bedding planes;
- presence of springs with discharges up to 40 L/s;
- rapid changes in discharge & chemistry at these springs following rain;

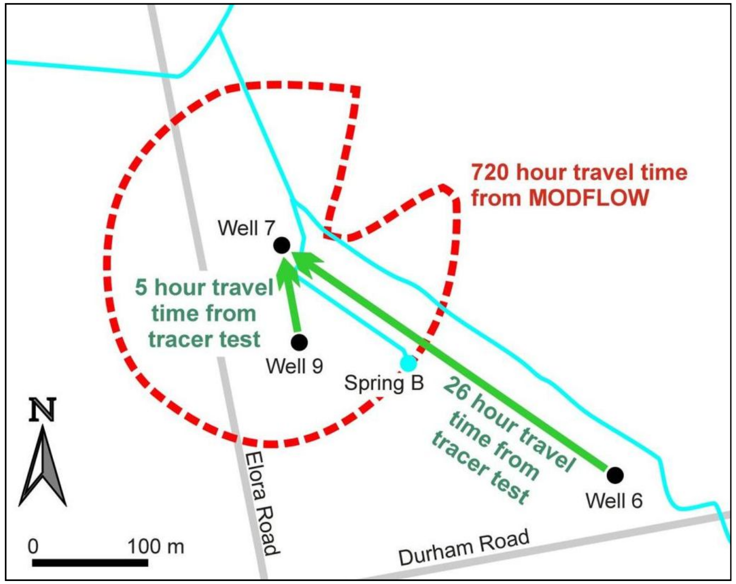


Prologue

- … tracer tests gave groundwater flow velocities about one hundred times faster than the modelling results

➡ source for the pathogenic bacteria could have been much further from tHe wells than the earlier modelling had indicated





What can be learned from this example…

regarding…

- groundwater protection?

- groundwater monitoring?

Few words about groundwater monitoring

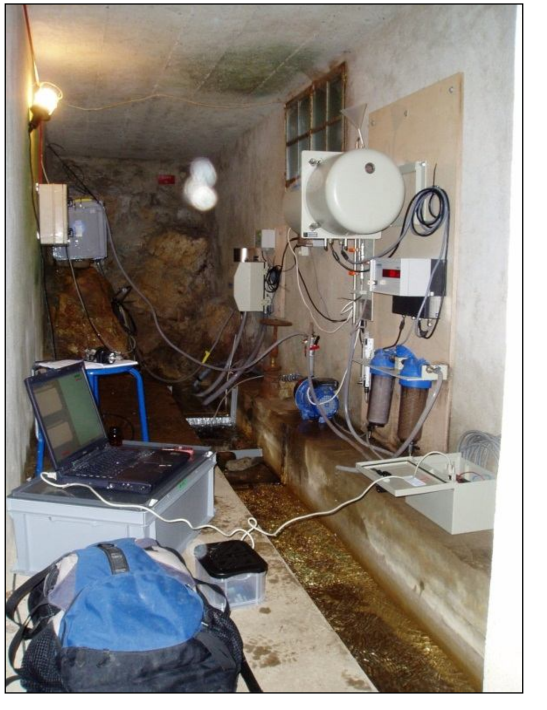
- discharge / water level
- temperature
- electrical conductivity

} standard hydrogeological parameters

- turbidity (or better PSD)
- organic carbon (DOC/TOC)

} idem for dynamic hydrogeological systems

- major ions
- stable isotopes
- chemical contaminants (pesticides, chlorinated solvants,…)
- radon / CO_2
- water quality indicator bacteria *(E. coli*, enterococci, mesophilic aerobic bacteria)
- microbiological contaminants (pathogenic bacteria, viruses, protozoa)



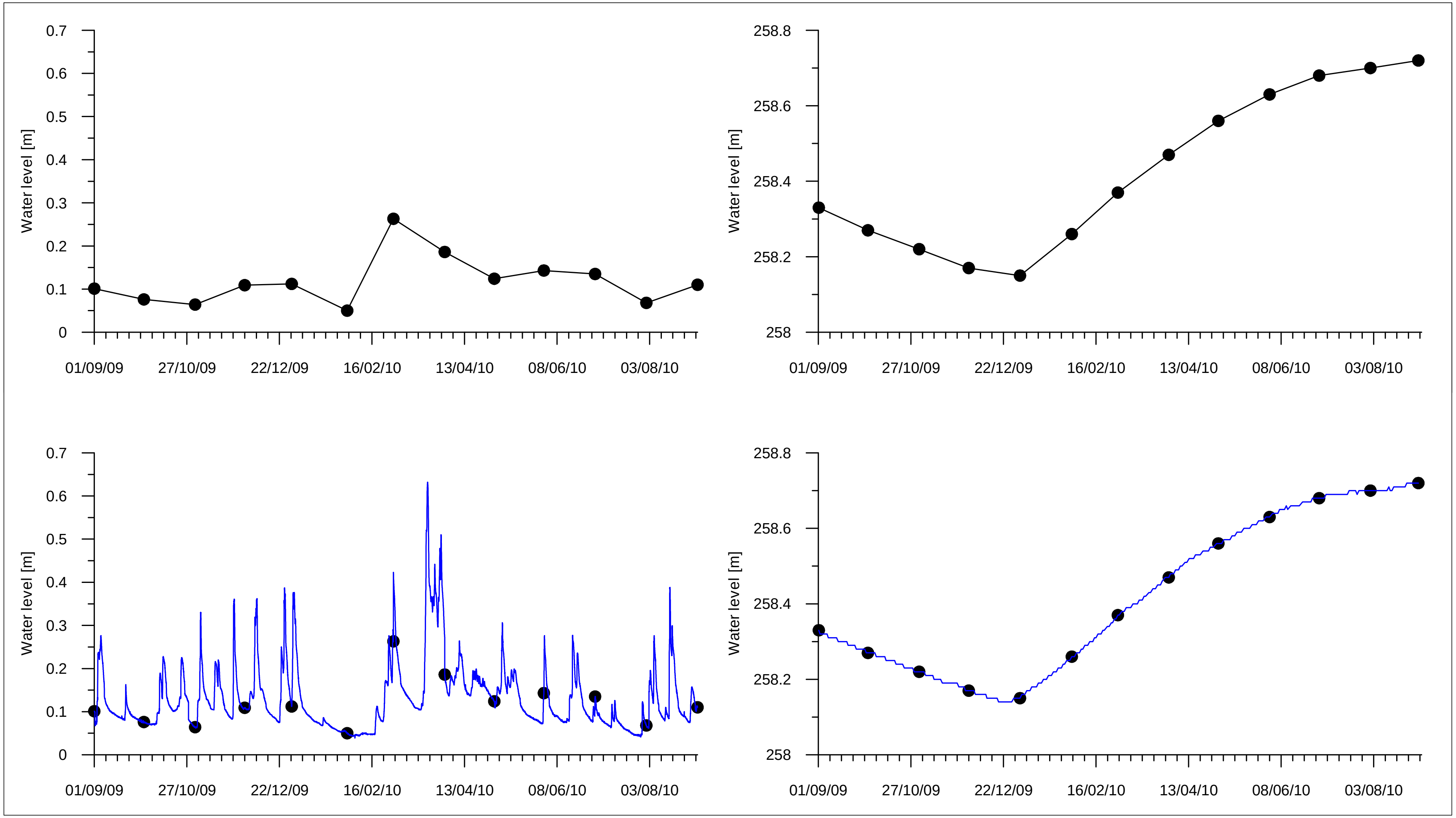
View of the monitoring equipment installed at a karst spring (Yverdon-les-Bains, Switzerland)

Few words about groundwater monitoring

«Imagine trying to understand a Beethoven symphony if one could only hear one note every minute or two! That is what we are trying to do when we infer the hydrochemical functioning of a catchment from weekly or monthly grab samples. Or imagine trying to understand a symphony from a high-fidelity recording of just one of its crashing crescendos. That is what we are trying to do when we analyse high-frequency samples of an individual storm event. Continuous high-frequency monitoring of catchment hydrochemistry will require significant resources and tenacity. In our view, however, what we stand to learn is well worth the effort. If we want to understand the full symphony of catchment hydrochemical behaviour, then we need to be able to hear every note.»

(Kirchner *et al*. 2004)

Manual *vs.* continuous measurements



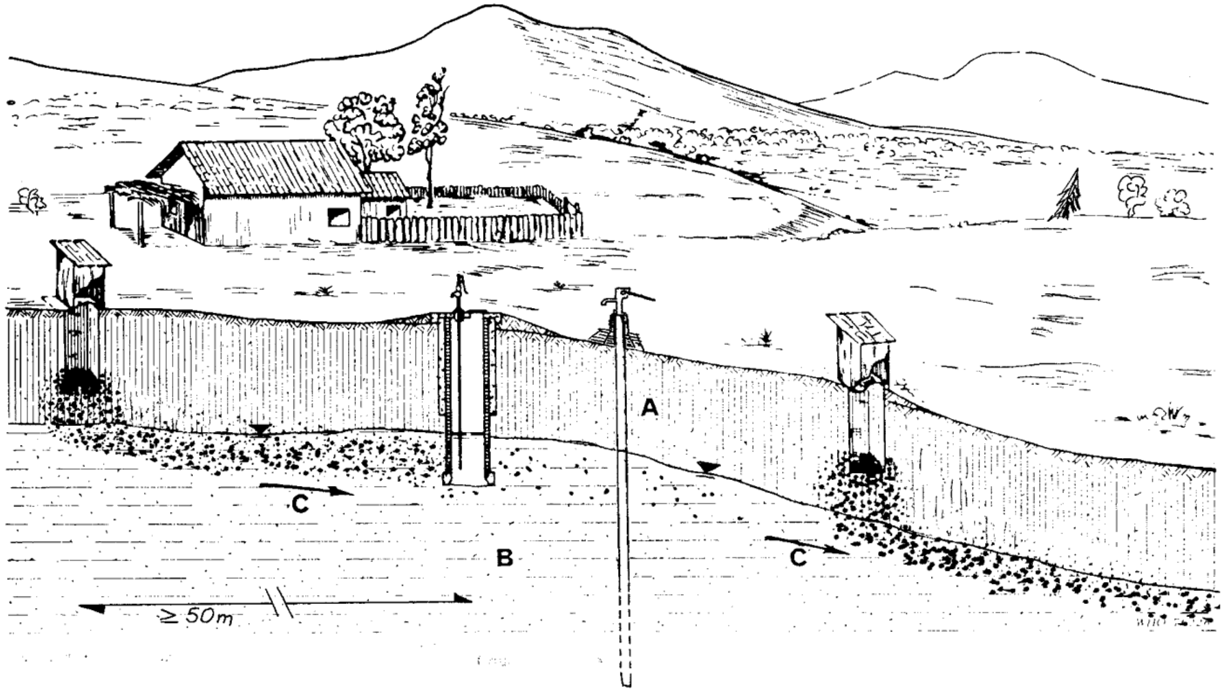
Why do we need groundwater protection?

	Settlement	Sanitation installations (pit latrines, septic systems)	Leaking sewage systems	Waste water discharge	Waste deposits and landfills	Runoff from sealed surfaces	**Agriculture**	Animal Husbandry	Crop cultivation	**Industry**	Waste water discharge	Waste disposal	Storage of organic liquids	**Energy production and storage**	Storage and distribution of fuels	**Mining activity**	**Geological sources**
Microbial																	
Pathogenic microorg.																	
Viruses		X	X	X													
Bacteria		X	X	X				X									
Protozoa		X	X	X				X									
Chemical compounds																	
Inorganic compounds																	
Nitrate, Nitrite		X	X	X				X	X								
Fluoride																	X
Arsenic																X	X
Lead					(X)	X					X	(X)				X	
Metals (Pb, Cr, Cd, Zn)					(X)	X					X	(X)				X	
Organic compounds																	
Petroleum hydrocarbons (e.g. BTEX, PAH)					(X)						X	X	X		X		
Industrial solvents (e.g. chlorinated hydrocarbons)					(X)						X	X	X				
Pesticides									X								

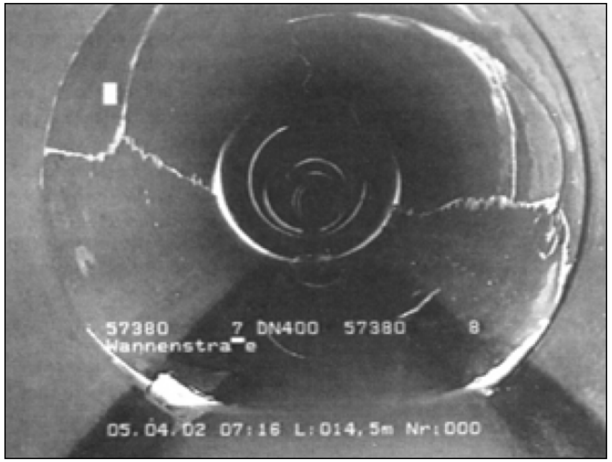
Point source contamination

Potential source of contamination have to be located downstream of a water supply well or spring!

Remediation is possible if the source is identified!



sewage plant in karst area & wastewater release into river

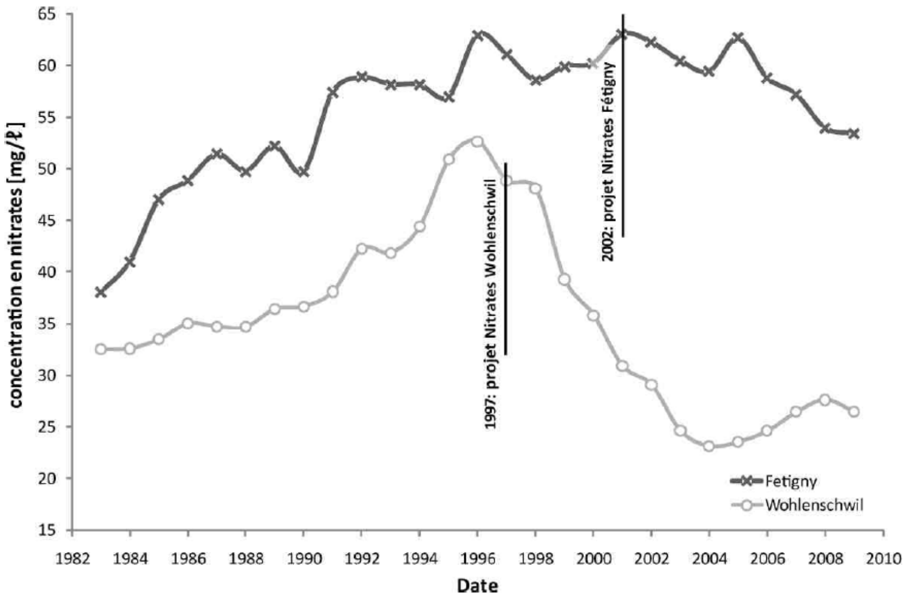


leaking sewage pipe

Diffuse contamination

Mostly related to agricultural activity and irrigation: fertilisers (nitrates), pesticides, increased salinity

Remediation is often difficult – even if activity stops the contamination can still continue for a long time!

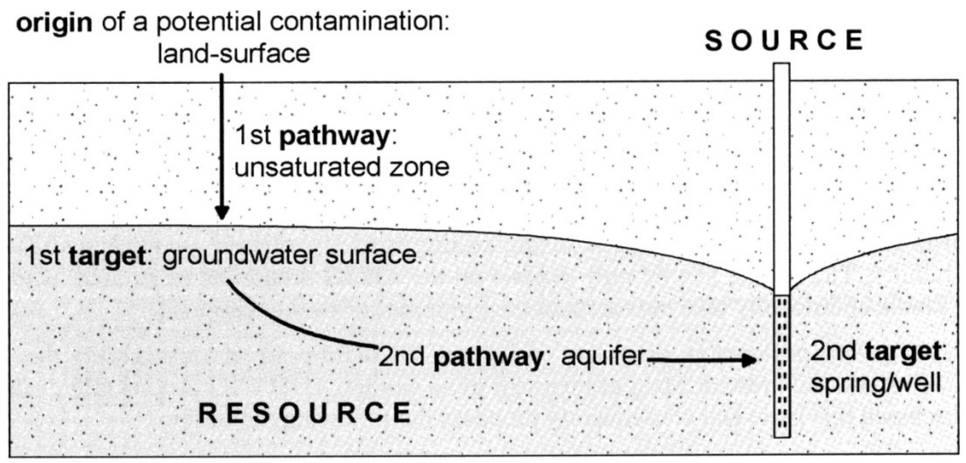


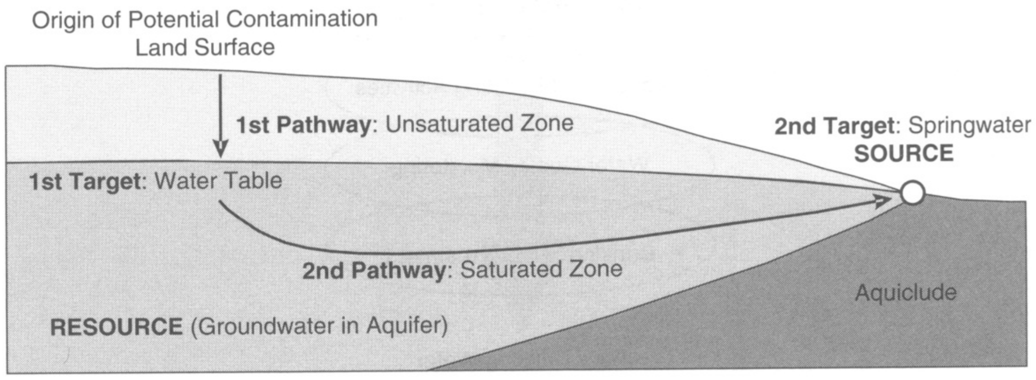
(Baillieux et al. 2010)

Concept of groundwater protection

origin, pathway & target

- the **origin** is the assumed place of release of a contaminant, usually the ground surface
- the **pathway** is the assumed flow path of a contaminant from the origin to the target
- the **target** is water, which has to be protected, either the whole groundwater body (resource) or a drinking water well or spring (source)





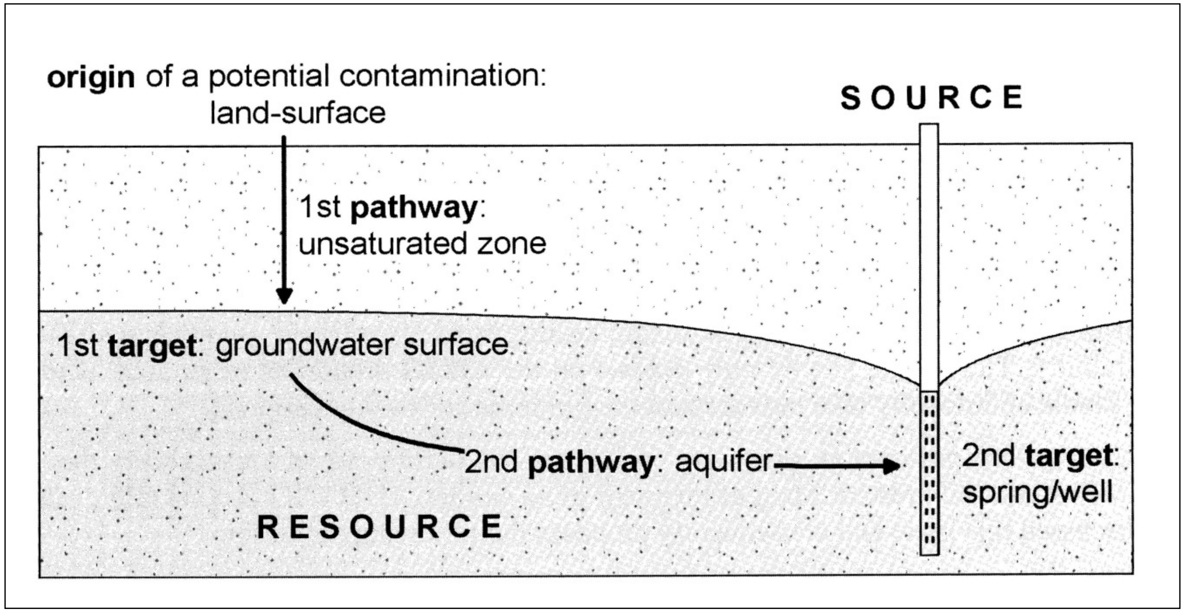
Concept of groundwater protection
origin, pathway & target

Resource protection:

- origin: land surface
- pathway: unsaturated zone (vertical)
- target: groundwater surface

Source protection:

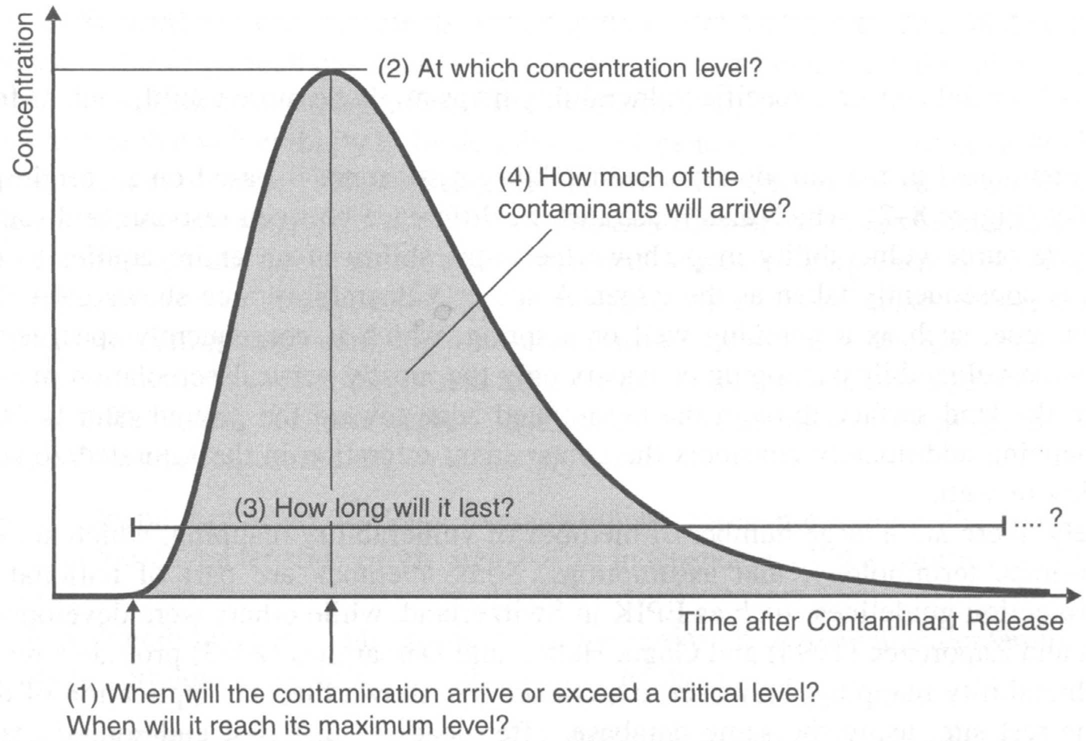
- origin: land surface
- pathway: unsaturated (vertical) and saturated (lateral)
- target: spring or well



Concept of groundwater protection

Four basic questions

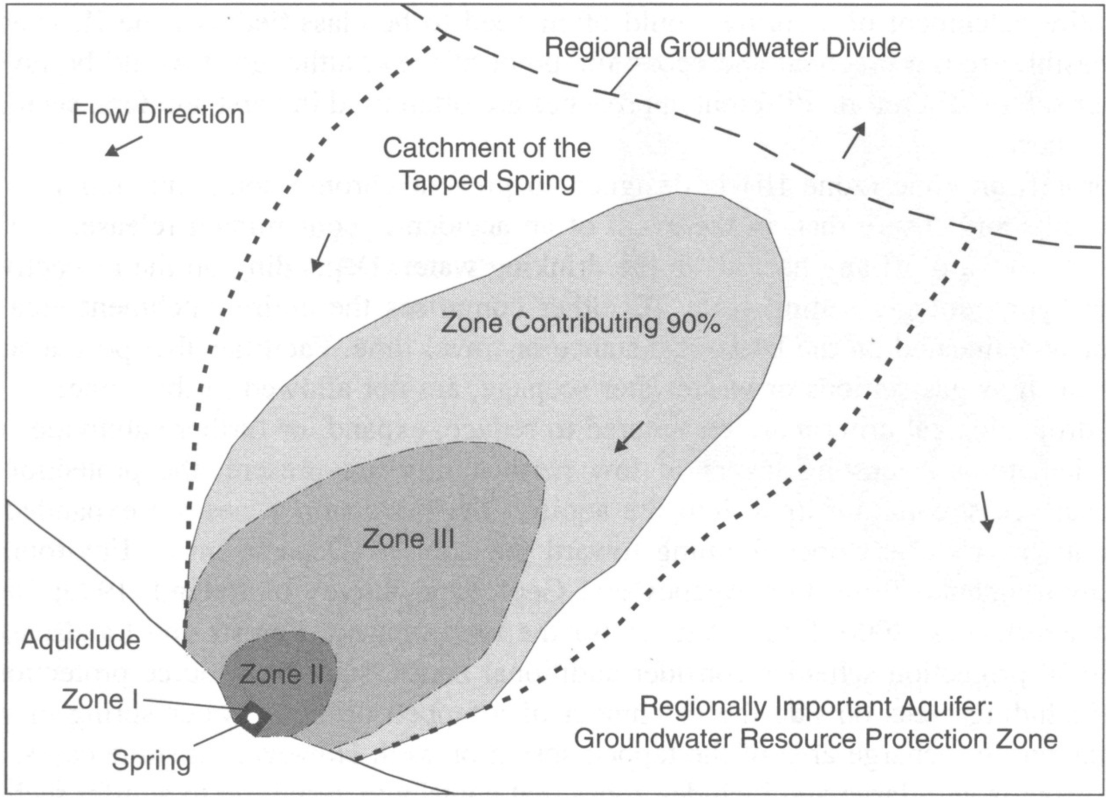
- travel time of the contaminant
- maximum concentration of the contaminant
- duration of the contamination
- amount of the contaminant



Groundwater protection zones

Wellhead protection zone

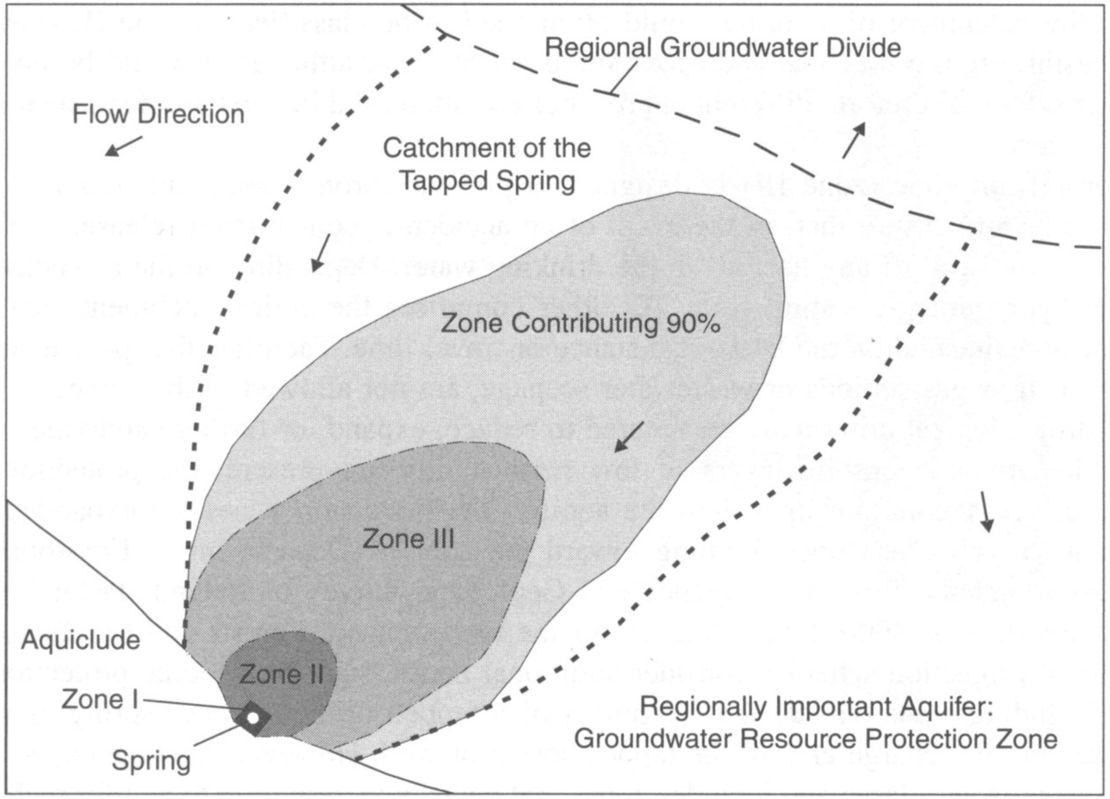
- area immediately surrounding a pumping well or a tapped spring
- protection from any direct impact, mechanical damage, or contamination
- activities not directly related to drinking water supply are forbidden
- zone I extends generally 10 – 20 m around the well or spring



Groundwater protection zones

Inner protection zone

- prevents drinking water contamination with faecal and pathogenic microorganisms
- activities releasing microbial contaminants (e.g. application of liquid manure) are prohibited
- polluting land-use practices and construction works that might obstruct groundwater flow are restricted

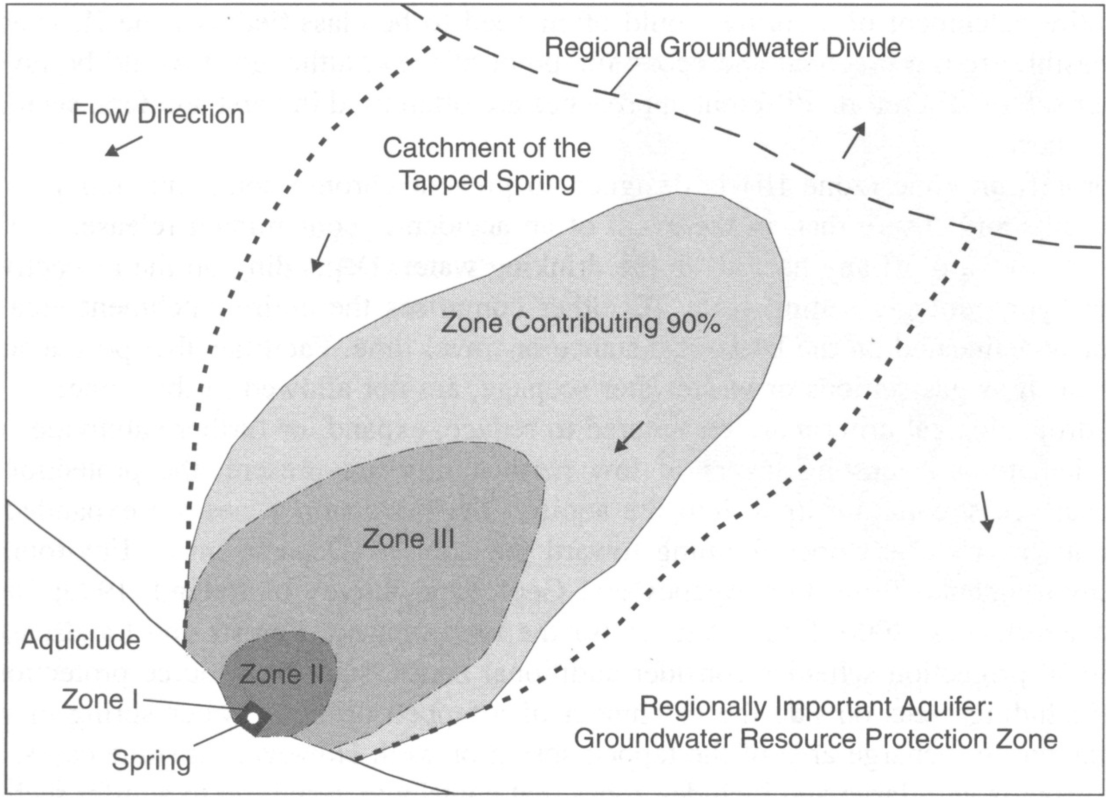


- primary criterion for the delineation of this zone: travel time
- hydraulic methods (from simple calculations to sophisticated numerical groundwater flow models) & artificial tracer tests

Groundwater protection zones

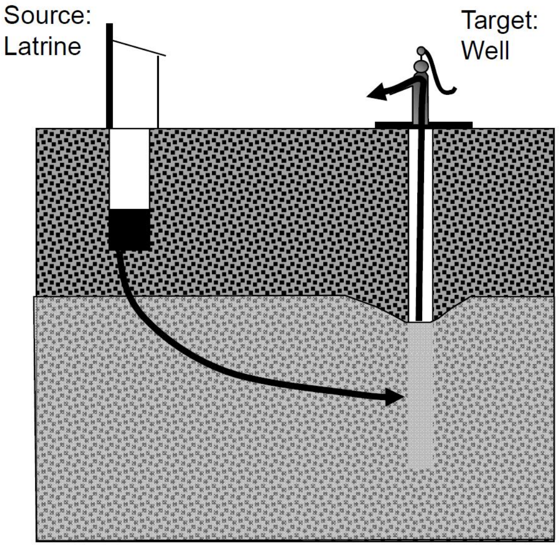
Outer protection zone

- prevents chronic contamination with persistent and mobile contaminants
- ensures sufficient time and space to react to an accidental contaminant release
- facilities that pose a threat to groundwater (e.g. gas stations, wastewater seepage) are not allowed

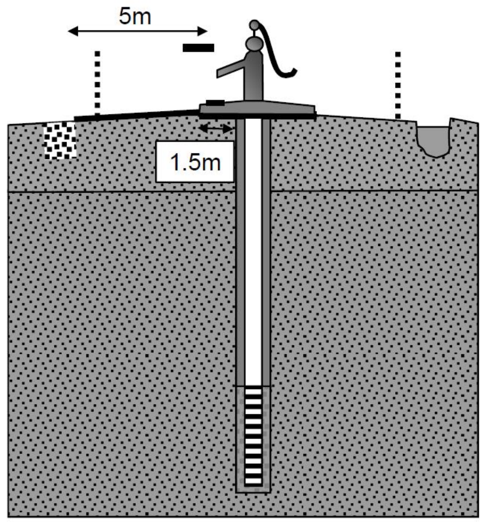


Definition of protection zones requires detailed knowledge of groundwater flow direction!

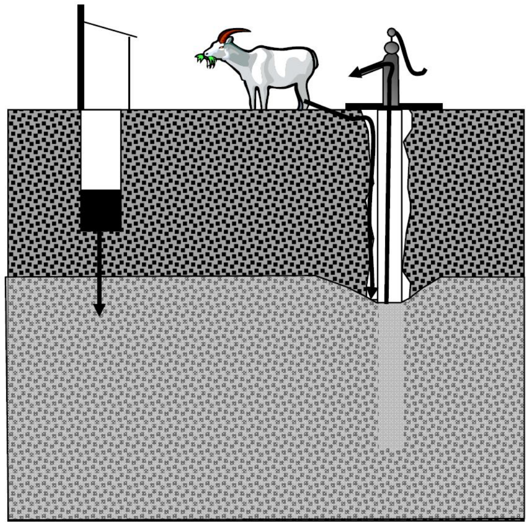
Wellhead protection



- wastewater infiltrates underground & reaches well through aquifer
- filtration / inactivation processes will partly attenuate contaminant



potentially contaminated surface water must not flow towards the well but must be drained away



- poor well construction
- pathogens can travel down into the well and reach drinking water directly
- no attenuation

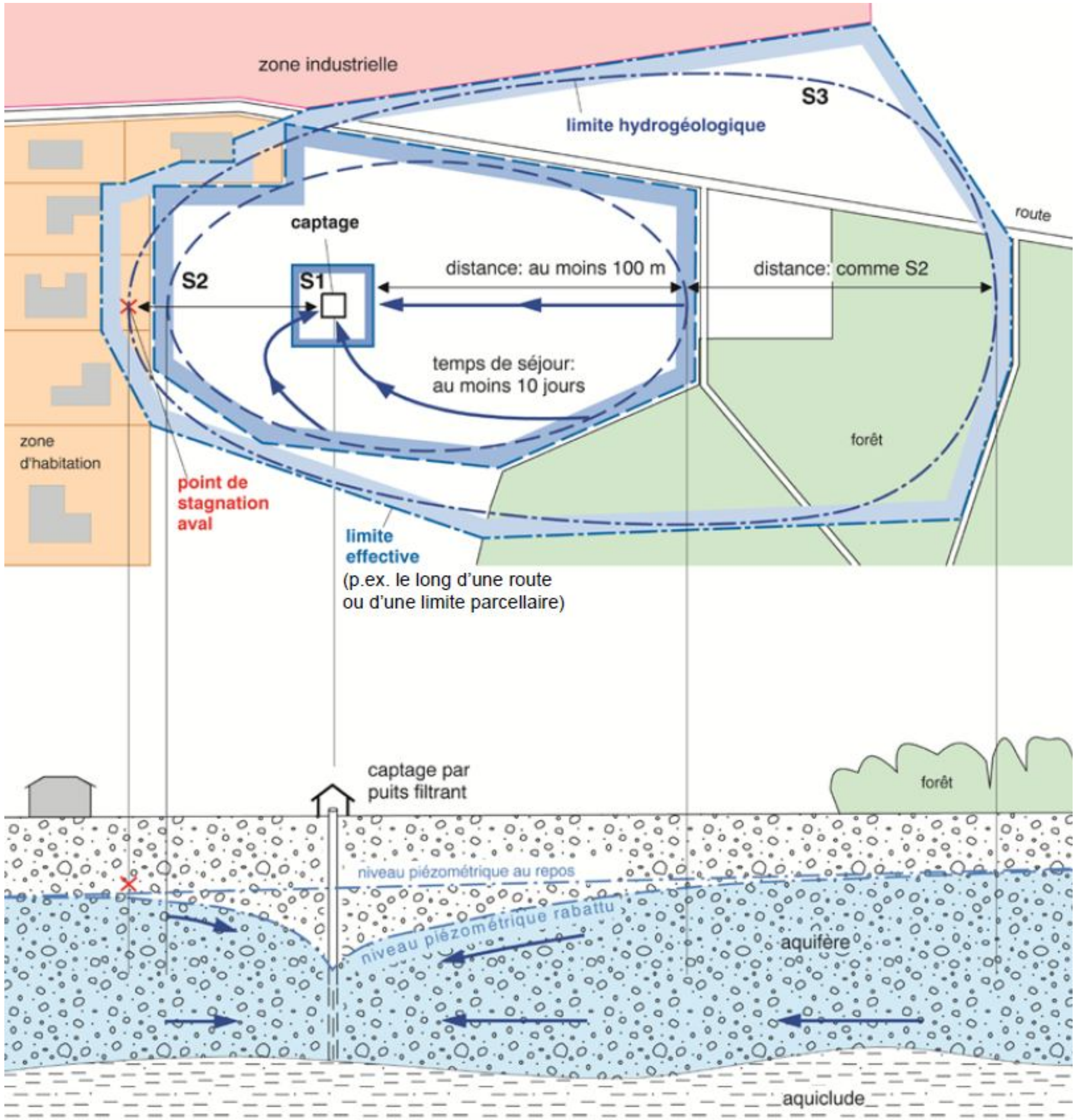
- **vital that well is adequatly protected**

Groundwater protection zones - Switzerland

S1 10 m around the well / spring

S2 at least 100 m upstream from the well / spring and at least 10 days travel time

S3 at least twice S2



How about karst and fissured aquifers?

- in porous aquifers, the 10-day line of groundwater travel time delimits the inner protection zone S2 (Germany 50, Austria 60, Ireland 100 days)
- flow velocities in porous aquifers: < 10 m/day
- inner protection zones in porous aquifers extend therefore only about 100 m (minimum)
- flow velocities in karst & fissured aquifers: 10 – 500 m/h
- inner protection zones would extend up to 120 km and comprise the whole catchment area

→ this would be good for groundwater protection, but the resulting land use restrictions would be inacceptable!

Few words about vulnerability mapping

- the **vulnerability** takes into acount the geological and hydrogeological characteristics of an area (high vulnerability = low natural protection against contamination)

- at least the «vulnerable» zones where contaminants can easily enter the groundwater should be protected
- a vulnerability map aims on a compromise between land use and groundwater protection
- water protection is priority in the highly vulnerable areas; land use can be allowed in less vulnerable zones
- karst and fissured aquifers are highly heterogeneous

➡ groundwater protection zones in karst and fissured areas that are delineated on the basis of a vulnerability map look like a mosaic

General conclusions

Supply of save drinking water from aquifers (or other freshwater resources) requires a fourfold approach:

1. Minimising pollution: wastewater treatment, reduced and sensible use of liquid manure, etc.

2. Groundwater protection zoning: land-use restrictions in the most vulnerable zones

3. Water quality monitoring: e.g. karst springs require event-based, intelligent monitoring strategies (continuous measurements preferred)

hydrogeology

4. Drinking water treatment: filtration, chlorination, ozonation, UV treatment, etc.

UNIVERSITÉ DE NEUCHÂTEL

CHYN
Centre d'hydrogéologie et de géothermie

CHYN TRAINING COURSE FOR

UNHCR WASH STAFF

APPLIED HYDROGEOLOGY

from field investigation towards sustainable water resources management

June 1 to June 6, 2014

Basic concepts of aquifer characterisation: pumping tests

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Agency for Development and Cooperation SDC

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From groundwater exploration to groundwater exploitation

- The aim of this session:

→ Present the basic hydrogeological approaches used in groundwater exploration and in well testing in order to elaborate terms of reference for consultants and to evaluate hydrogeological reports

- Basic concepts of groundwater exploration: how does one look for new water sources?
  - Presentation of the most frequently used geophysical method (cf. field excercise): geoelectrics
- Basic concepts of pumping tests:
  - Step-draw-down tests (definition of well-yield)
  - Constant rate pumping tests and the most frequent interpretation method

From groundwater exploration to well testing: Pumping tests

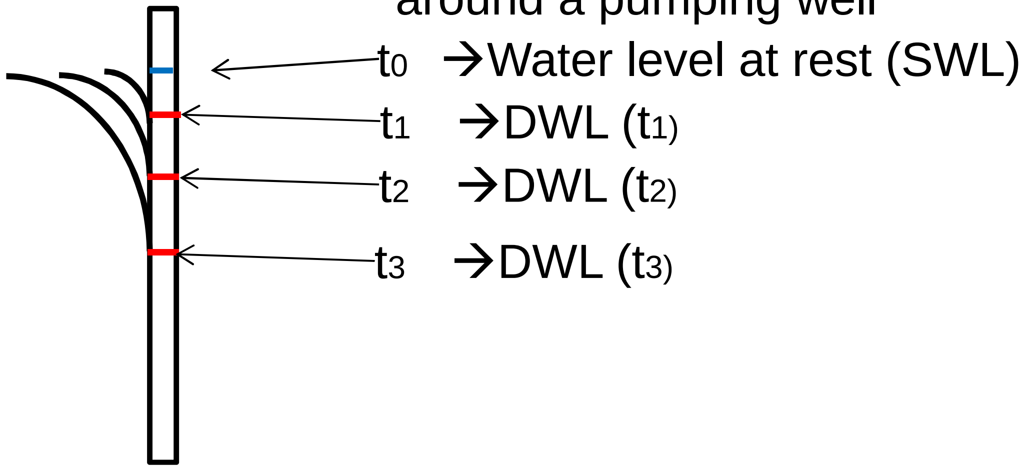
- Are part of the implementation of a new well
- Yield the ‘ID’card of the well
- The tool to define the exploitation scheme of a well
- The tool to obtain information about aquifer characteristics (permeability, storativy-porosity)

The aim of this session:

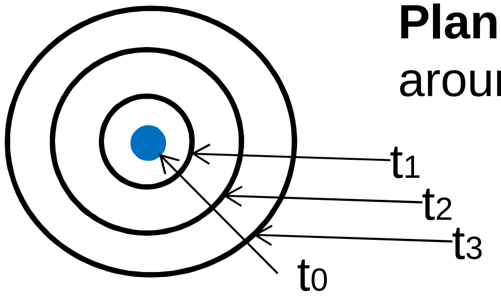
→ Different test types are used for different purposes: which one is used for which purpose and how is it carried out and interpreted (what should you find in a report)?

What happens around a well when pumping takes place?

Cross-sectional view of the expanding depression cone with time around a pumping well



Plan view of the expanding depression cone with time around a pumping well



→The reaction of a well to a given discharge rate yields a relationship between the time, discharge rate and dynamic water level which are 'typical' of the well and its surrounding aquifer

The two major types of pumping tests

Step draw-down test (usually 1 day):

- Specific draw-down
- Qualitative assessment of borehole performance (yield-draw-down)
- 'Safe yield' of the well and pumping rate for constant rate pumping tests

→ Limitations:

  → Pump which is capable of varying the discharge rate

  → Not good at predicting longterm behaviour of the well

  → May vary considerably when carried out under different hydrological conditions

Constant rate pumping tests (from 1 day to several weeks, usually 72 hours):

- Aquifer transmissivity (permeability)
- Storage coefficient (porosity in non-confined conditions)
- Qualitative assessment of ability to maintain the planned yield

→ Limitations:

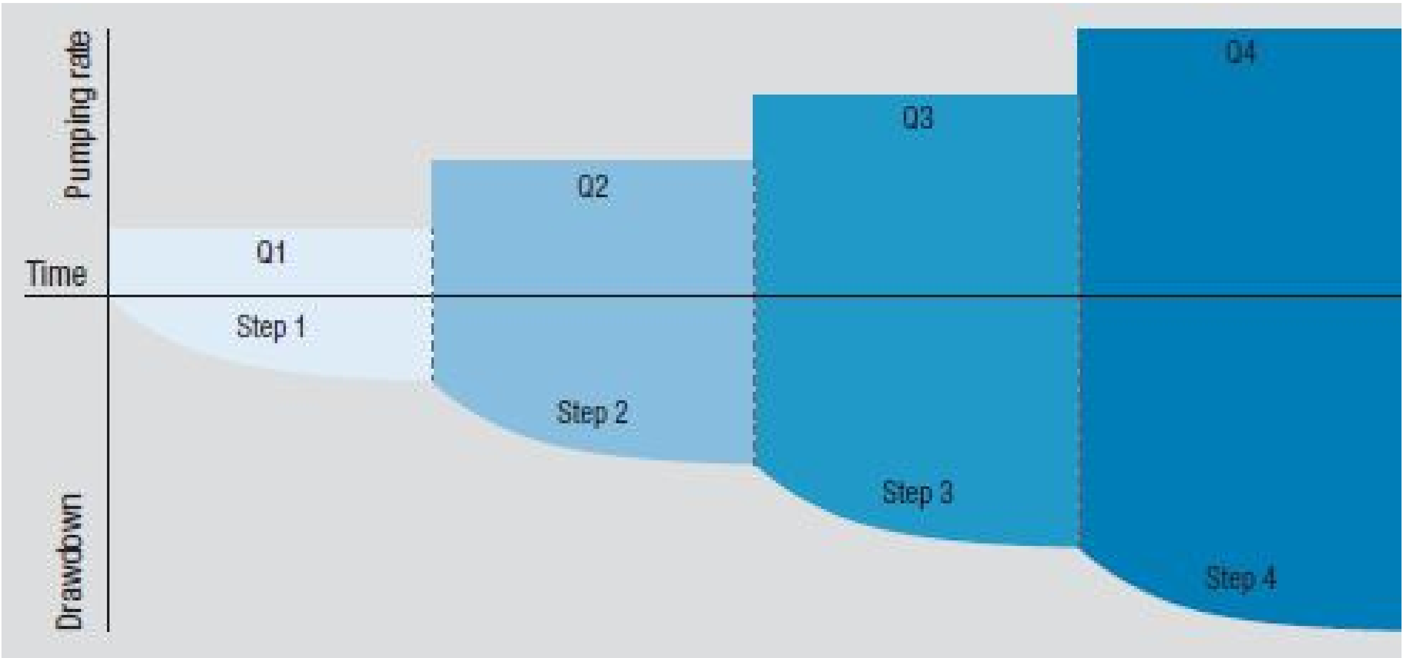
  → Difficult to maintain a constant discharge rate

  → May yield different results under different hydrological conditions

  → Requires a good evacuation system

Step draw-down test

Step-wise increase of the discharge rate and waiting until the water level is stable:
drawdown= (steady water level at rest – steady water level during pumping)

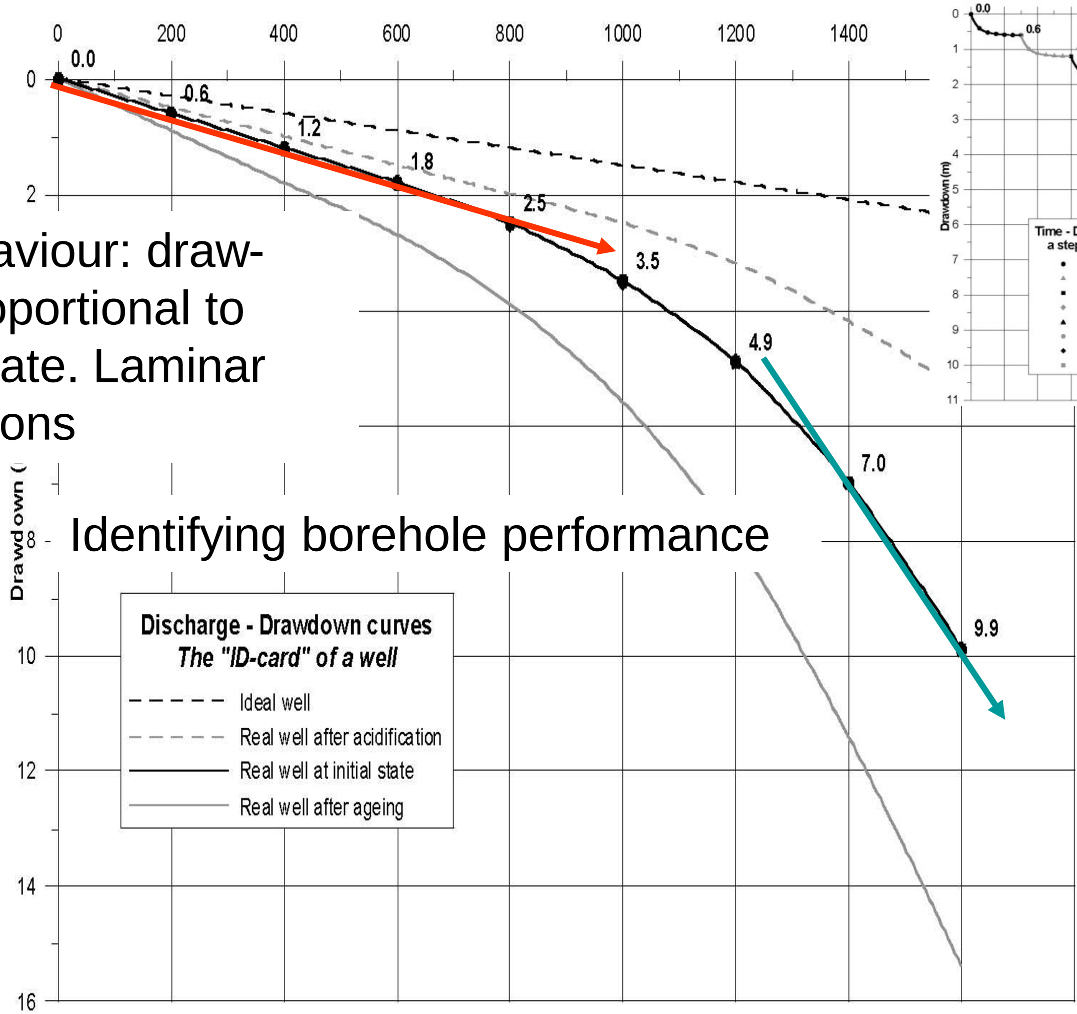


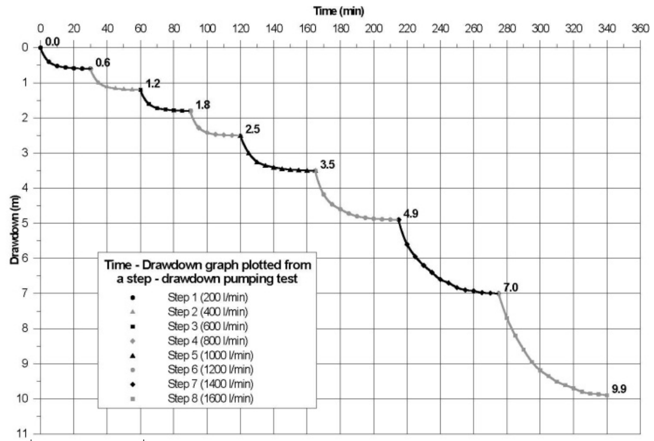
Main difficulty: defining the discharge rate range of the test before having any information!

Step draw-down tests: characteristic curve

A step-draw-down test after well construction yields the ‘ID’card of the well. For instance used to identify aging of a well.

Characteristic curve of the well: Stabilised draw-down of each step versus discharge rate



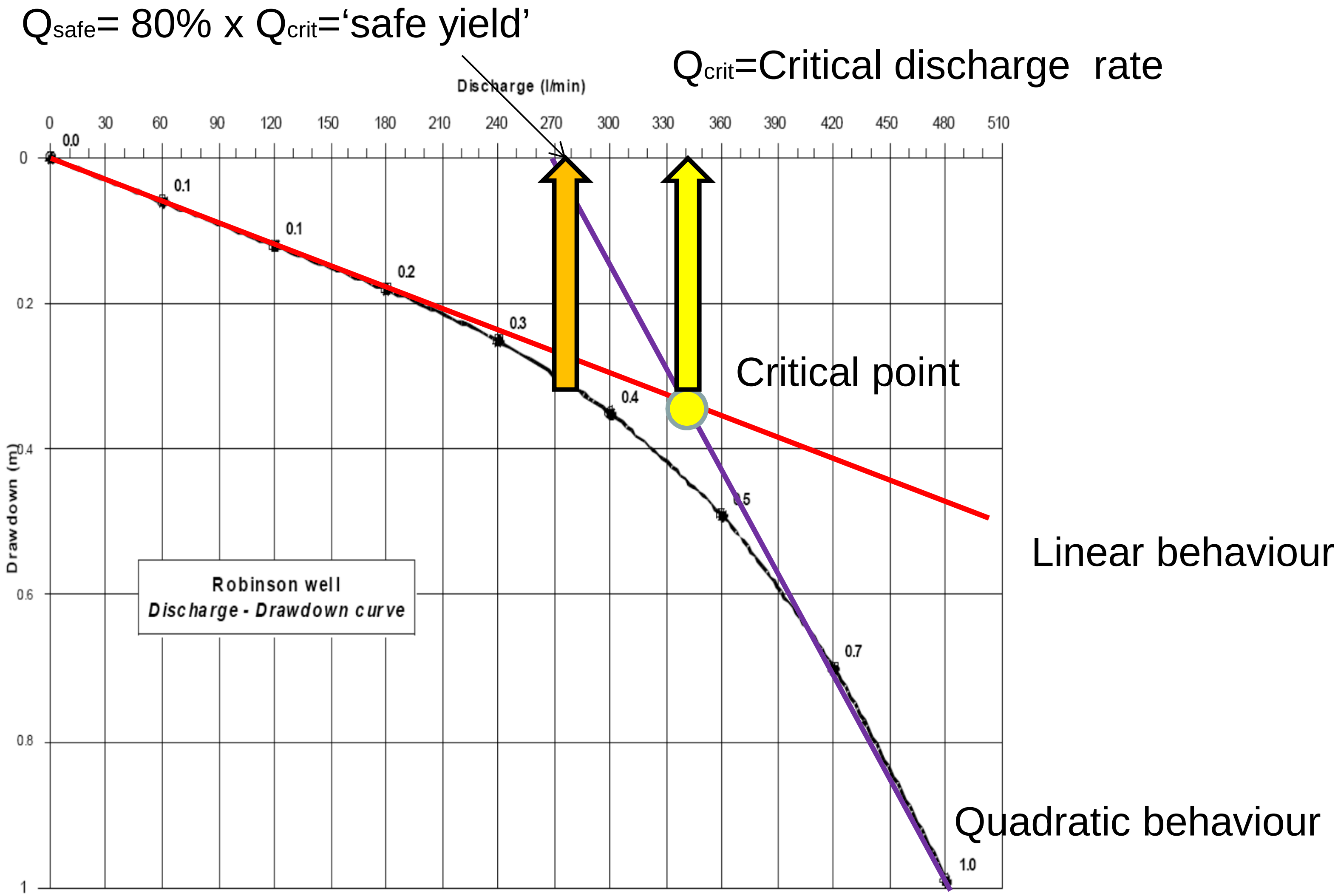


Linear behaviour: draw-down is proportional to discharge rate. Laminar flow conditions

Identifying borehole performance

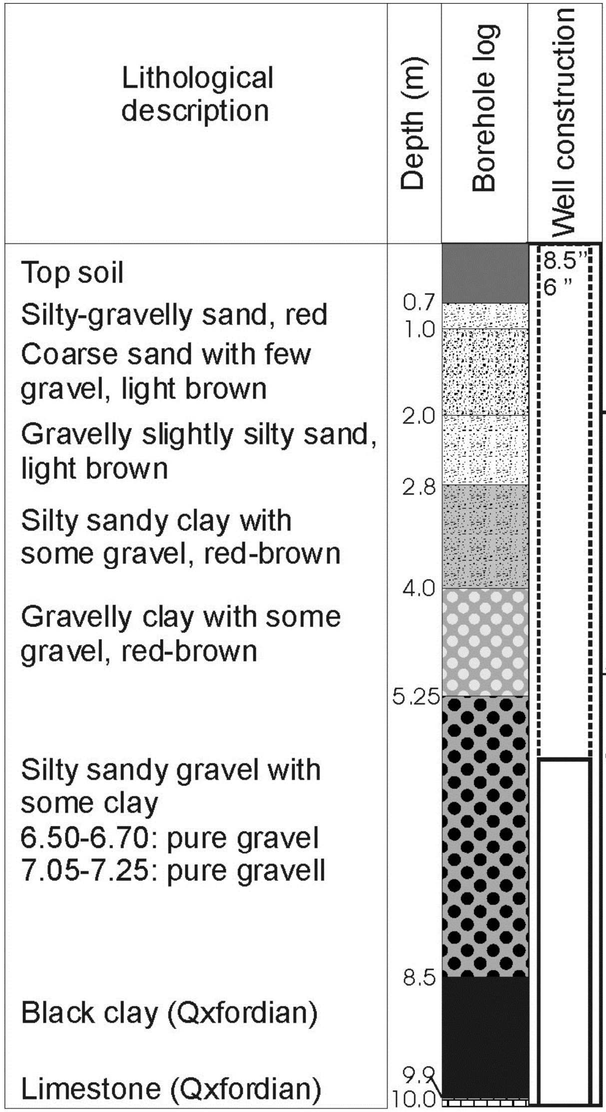
Quadratic head losses: draw-down is no longer linear to draw-down, indicating turbulent flow→ encrustation of screens, inflow of particles etc.

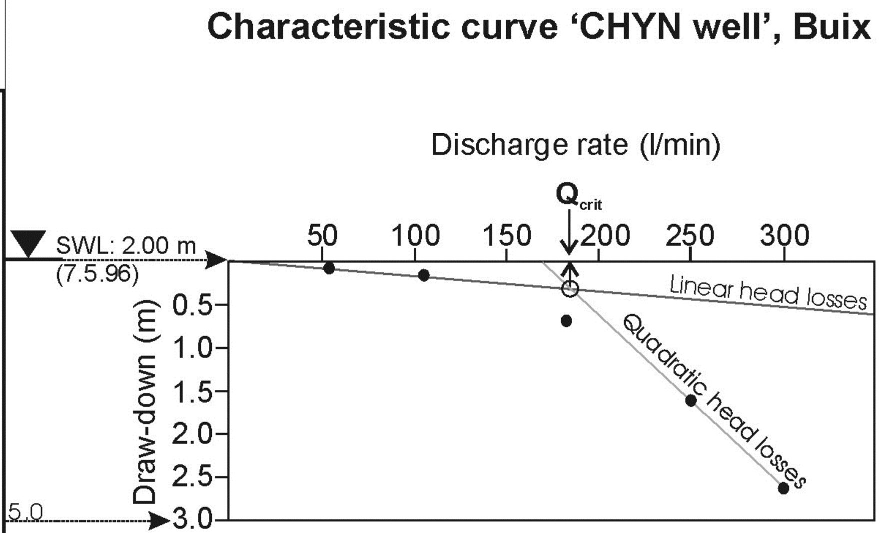
Graphical interpretation method: 'safe yield' of the well



The CHYN well in Buix and its characteristic curve

Field exercice will consists in carrying out the step-draw down test in this well and compare it to the orginal curve





Step draw-down data measured just after construction of the 'CHYN well', Buix

Débit [l/min]	Rabattement [m]	Niveau [m]	t [s]	Remarques
54	0.09	2.25	1200	
105	0.17	2.33	1200	
182	0.68	2.84	2700	
212	0.54	2.7	2610	Panne de la génératrice
250	1.62	3.8	3600	
300	2.64	4.82	1560	

The confusion surrounding the ‘safe yield’

The notion ‘**safe yield**’ is used in two ways:

→To describe the ‘safe yield’ of the well with respect to its aging potential: depends on the well construction in combination with the aquifer

→To describe the ‘safe yield’ of the aquifer, refering to a longterm exploitation: depends on the capture zone of the well and the recharge of the aquifer

The ‘safe yield of the well’ and the ‘safe yield of the well’ are NOT the same!!!

Constant rate pumping tests

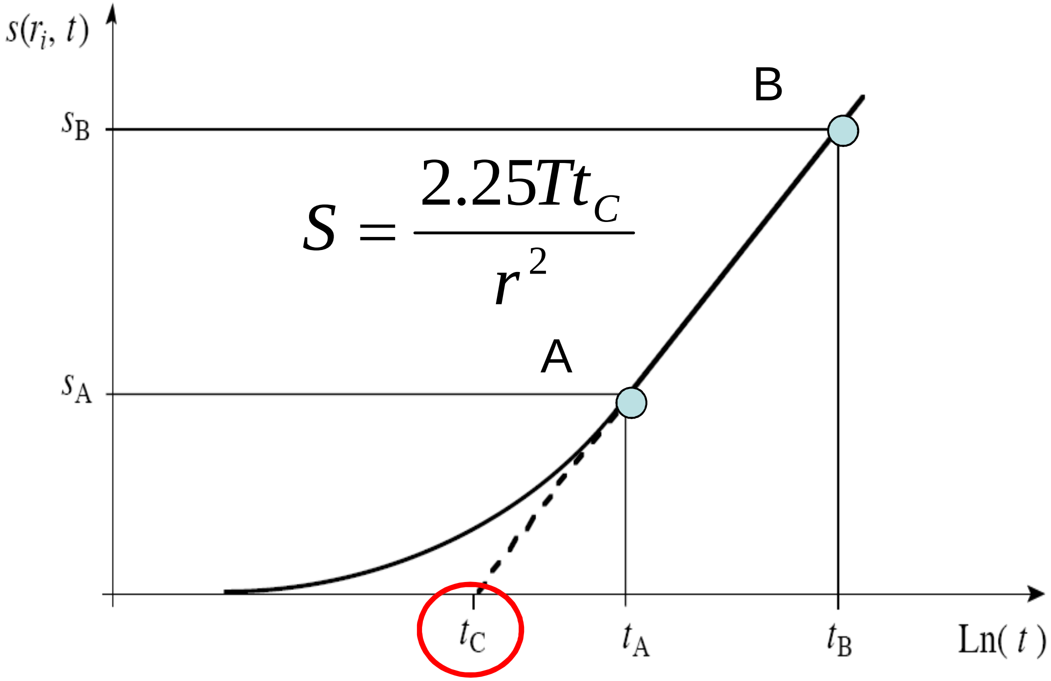
Plotting the draw-down during a pumping test versus the logarithmic time

Method of Jacob:

If there is a well-defined linear correlation, the slope between to points A and B can be used to calculate the transmissivity T, which is the product of the aquifer thickness (e) and the hydraulic conductivity (K):

$$T = \frac{Q}{4\pi(s_B - s_A)} \ln(\frac{t_B}{t_A})$$

If draw-down is measured in a observation well, the Storativity can also be obtained:



$$S = \frac{2.25Tt_C}{r^2}$$

T: transmissivity [m^2/s] =

Q: yield [m^3/s]

$s_{A,B}$: draw-down [m]

at respective times

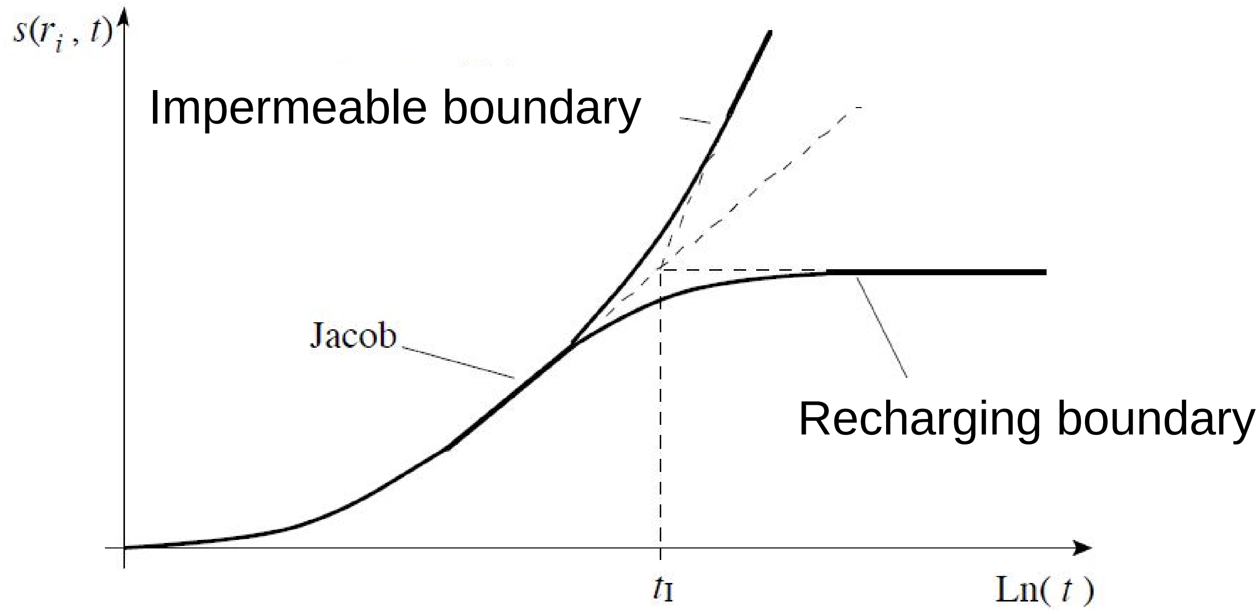
$t_{A,B}$ [s]

T=K*e

K=hydraulic conductivity [m/s]

e=thickness of the aquifer [m]

Deviations from the Jacob line



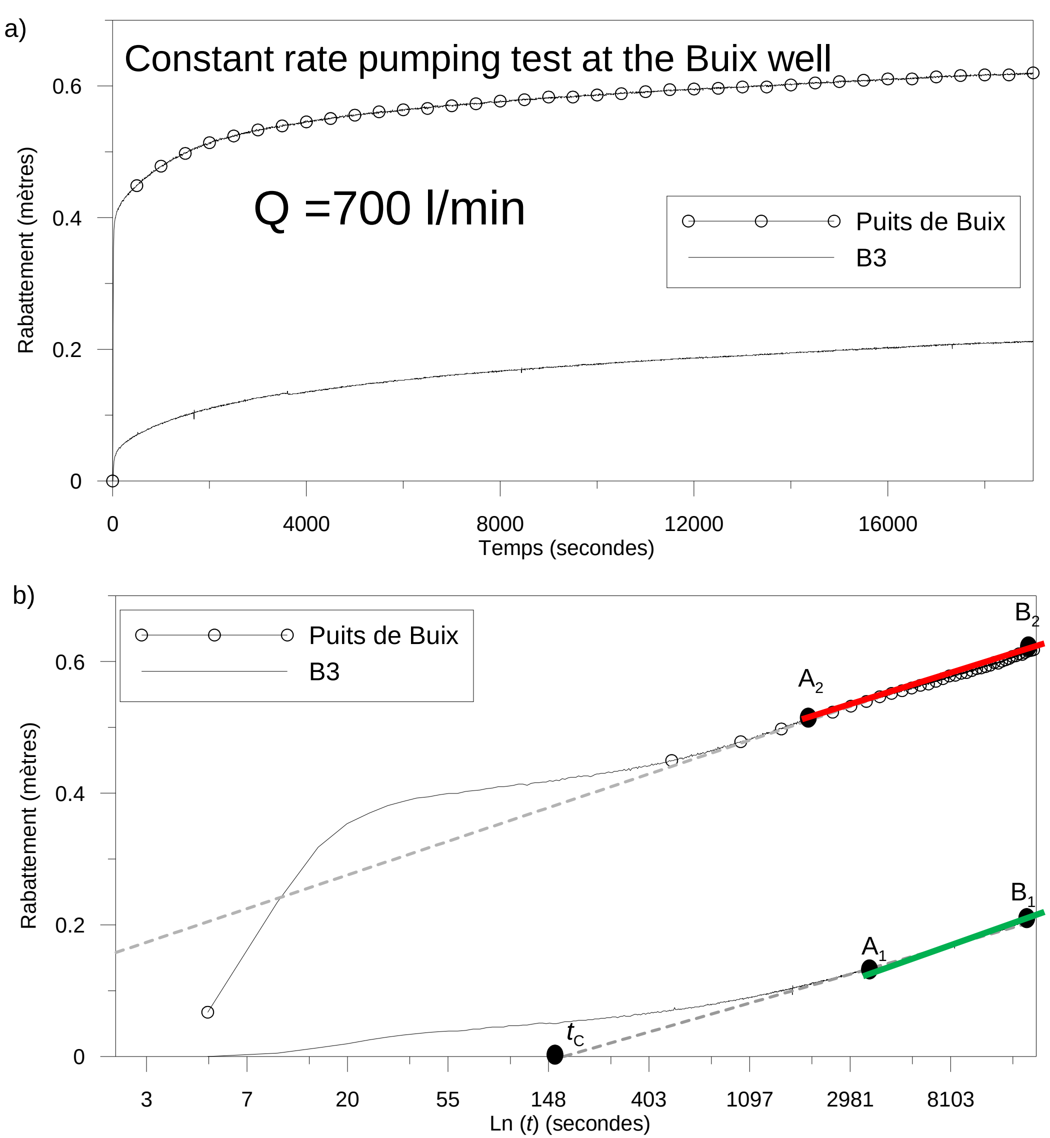
Main assumptions of this interpretation method:

→ Perfectly horizontal flow towards the well

→ Homogeneous and semi infinite aquifer without regional groundwater gradient

→ The well is constructed all the way through the aquifer (if not, the aquifer thickness in the formulation is often replaced by the length of screened section)

Calculate the transmissivity and hydraulic conductivity in the Buix aquifer



$$T = \frac{Q}{4\pi(s_B - s_A)} \ln\left(\frac{t_B}{t_A}\right)$$

Buix well:

t_a= 1255 sec; s_a= 0.49 m

t_b= 19046 sec, s_b= 0.62 m

Observation well B3 :

t_a=1675 sec, s_a= 0.10 m

t_b= 19045 sec, s_b= 0.21 m

T= K x e [m2/s]

e = Aquifer thickness in Buix?

Hydraulic conductivity in Buix? Is it coherent with the literature values?

Let’s try it ourselves in the field now !!!!

Well construction and rehabilitation

Resume Frank Gugger

- Studies of geology, University of Bern, Switzerland
- Work as a geologist in Switzerland
- 2 years as environmental geologist in California, USA
- 2006 - 2011 Stump Foratec AG
- 2012 KIBAG Bohrungen AG

KIBAG BOHRUNGEN AG

- KIBAG: Construction company specialiced road construction, foundation, recycling, concrete production, drilling and more.
- Total KIBAG 1500 employees, drilling/geotherm approx. 60 employees
- Since 1970 well drilling, geotechnical drilling and testing / measurements

Programm

Planning
Drilling
Materials
Design
Development
Rehabilitation

Questions / Discussion

- Planning
  Objectives and investigation
- Drilling
  Various types and drilling methods
- Materials for well construction
  Well casing, screens, seals, centralizers
- Design
  Design, gravel / filter pack, position of screen
- Development
  Objective, methods and tools
- Rehabilitation, troubleshooting
  Problems, reasons of well problems, solutions

Planning of a well

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Planning
Drilling
Materials
Design
Development
Rehabilitation

Questions /
Discussion

OBJECTIVES

- High production rate
- Long lasting (> 20 years)
- Protection of the ground-water (quality and quantity)
- Cost effective solution (construction and maintenance)

- Importance to know the lithology in detail to design the well properly (drilling method, slot opening, diameter and length, gravel pack, sealings …)

PRELIMINARY INVESTIGATION

- Description the lithology
- Literature studies
- Local observation, nearby wells
- Exploration borehole with pumping tests for extended projects

>>> consult a hydrogeologist

Drilling set for shallow wells

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Hand auger equipement
Riverside and gravel drill bit

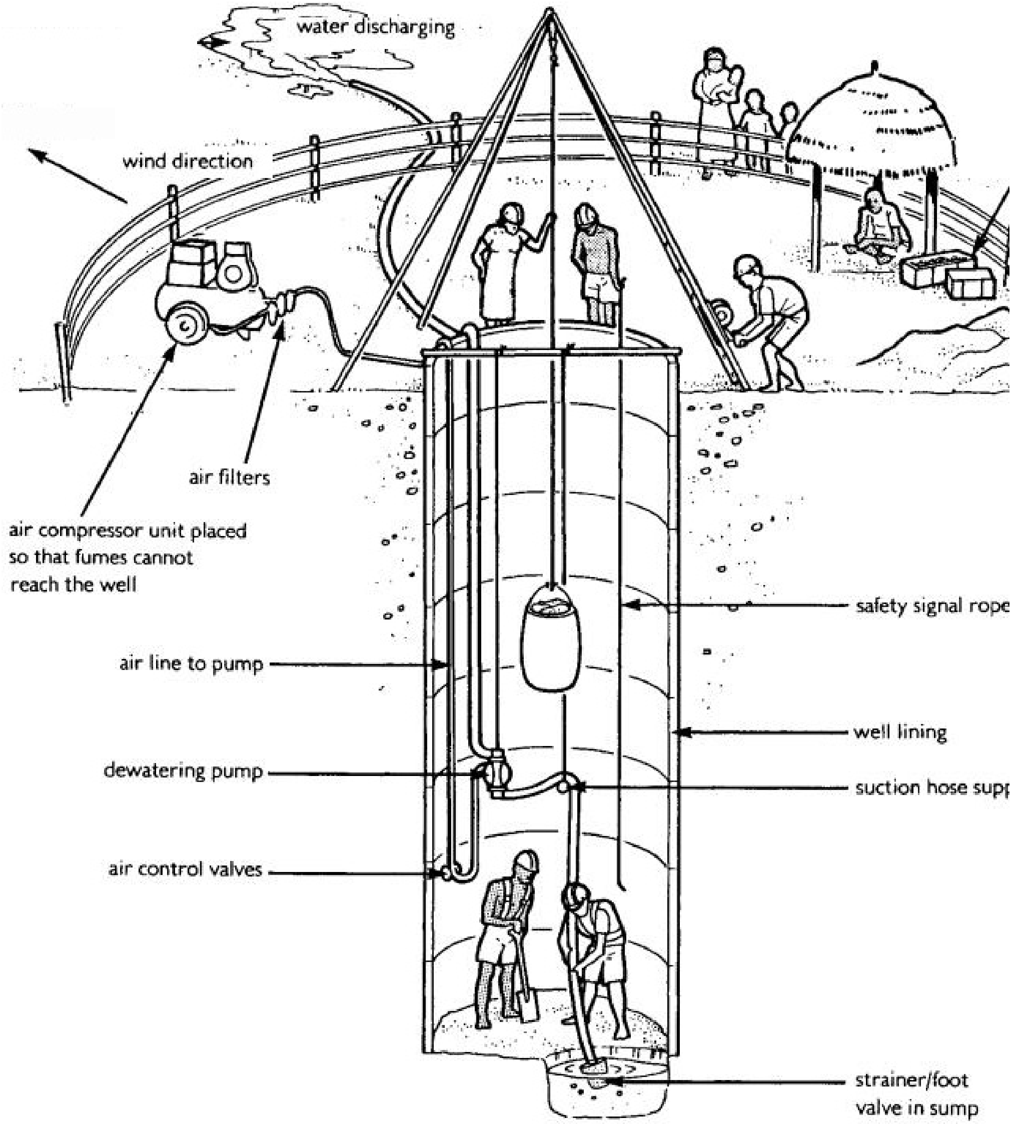
Planning
Drilling
Materials
Design
Development
Rehabilitation

Questions /
Discussion

Hand dug wells, with well liner

Planning
Drilling
Materials
Design
Development
Rehabilitation

Questions / Discussion



handbook

Hand dug wells

Planning
Drilling
Materials
Design
Development
Rehabilitation

Questions / Discussion

Digging deep wells can be dangerous

- collapse of the sides (dig inside precasts concrete liners)
- tools falling from the surface in the well (wear hard hat)
- lack of oxygen in the well (use ventilation)
- poison exhaust gases from a generator used to pump out water (take wind direction into account)
- accidents while climbing in the well (use a safety harness and tripod)

Drilling set for shallow wells

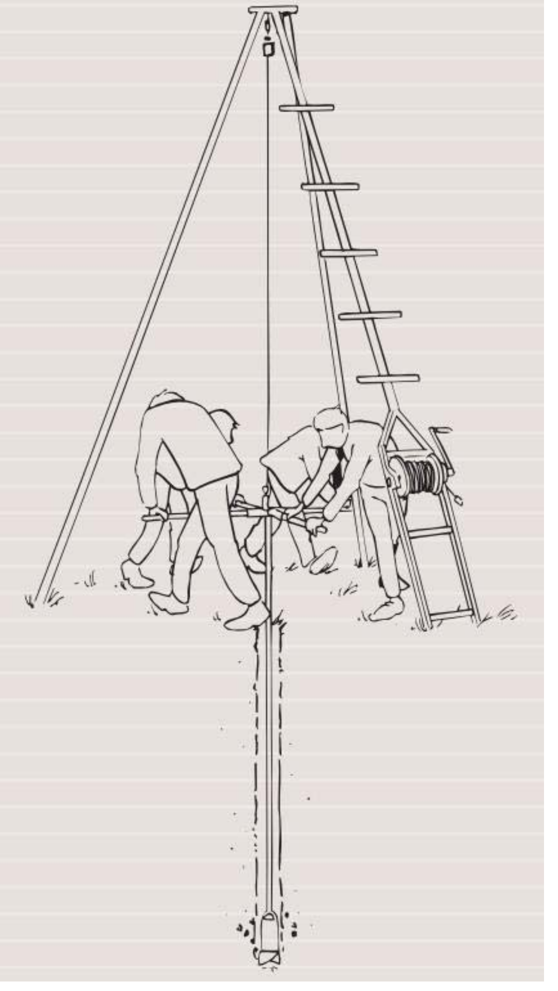
Pros

- Low cost, easily operated equipment
- No highly qualified personal required for operation and maintenance
- Can easily be fixed on-site
- Less dangerous than hand-dug ring wells

Cons

- Not possible in hard rock
- Hard to get through gravel and stone layers

Average 20 – 30 m, diameter approx. 80 mm in sand



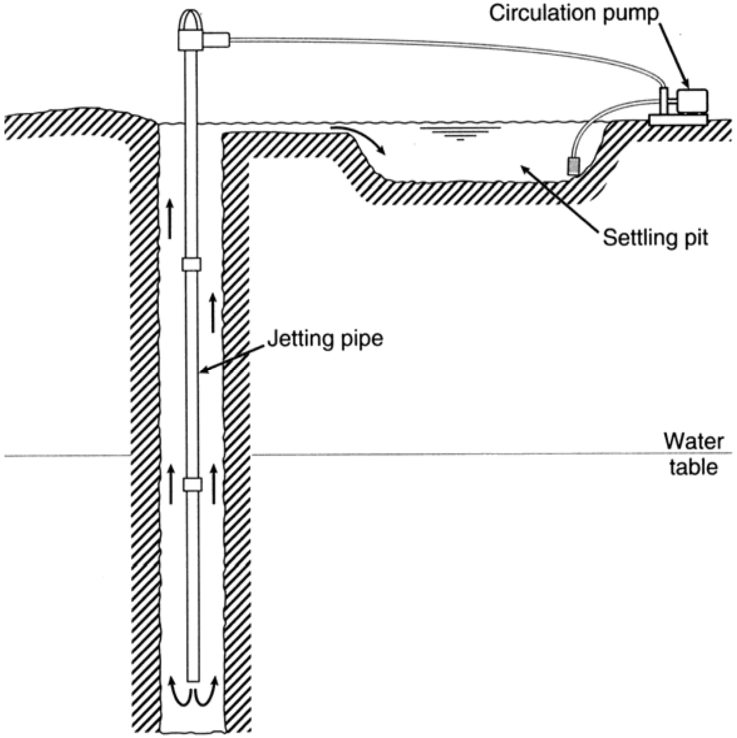
Jetted wells (wash borings)

Planning
Drilling
Materials
Design
Development
Rehabilitation

Questions / Discussion

Needs very little equipment

- Suitable in sands, unconsolidated silts and clays, very fine gravels (alluvial deposits beside rivers)
- Temporary casing might be required to prevent hole from collapsing
- Diameters up to 150 mm

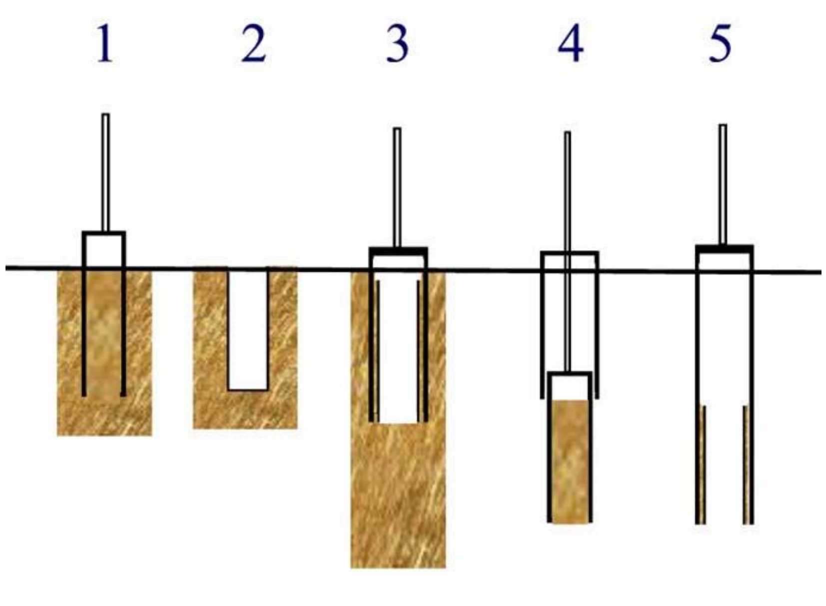


Single core drilling

Planning
Drilling
Materials
Design
Development
Rehabilitation

Questions / Discussion

- Max. diameter approx. 300 mm
- Slow and relatively costly
- Continuous and relatively "undisturbed" samples

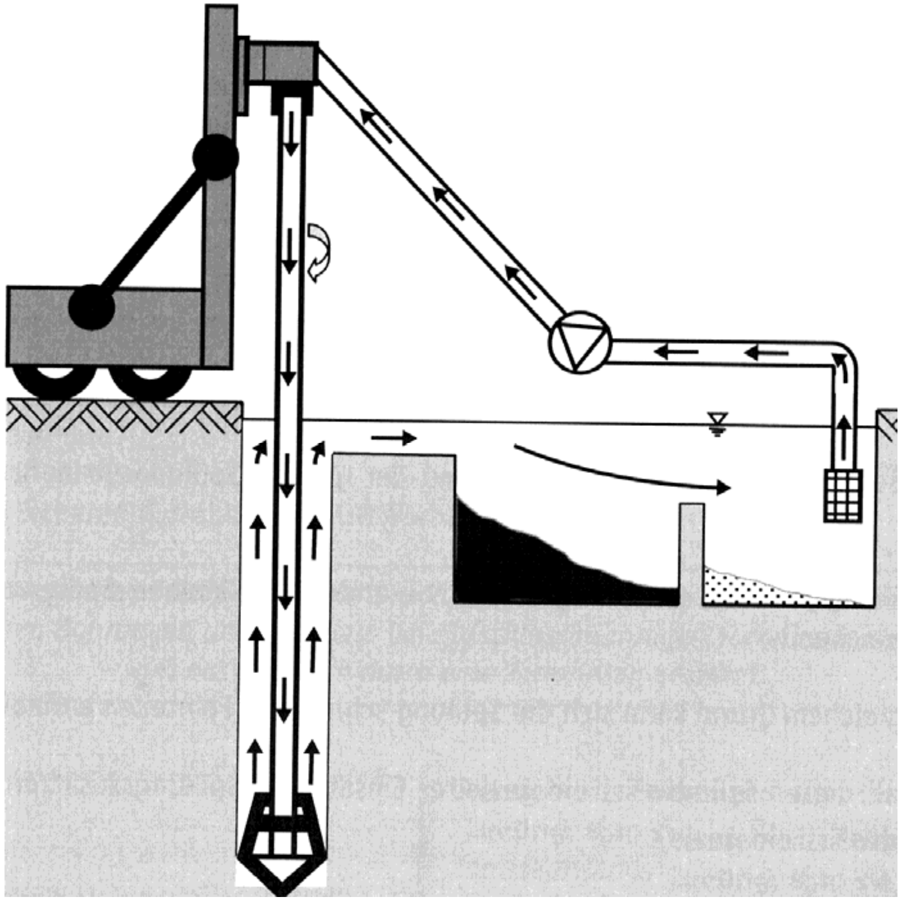


Direct circulation drilling

Planning
Drilling
Materials
Design
Development
Rehabilitation

Questions / Discussion

- Max. diameter approx. 300 mm
- Difficult to take distinctive samples
- Rising speed of water / air is critical, often additives needed (bentonit)
- Good solution for deep wells with small diameter. Using a down-hole hammer.

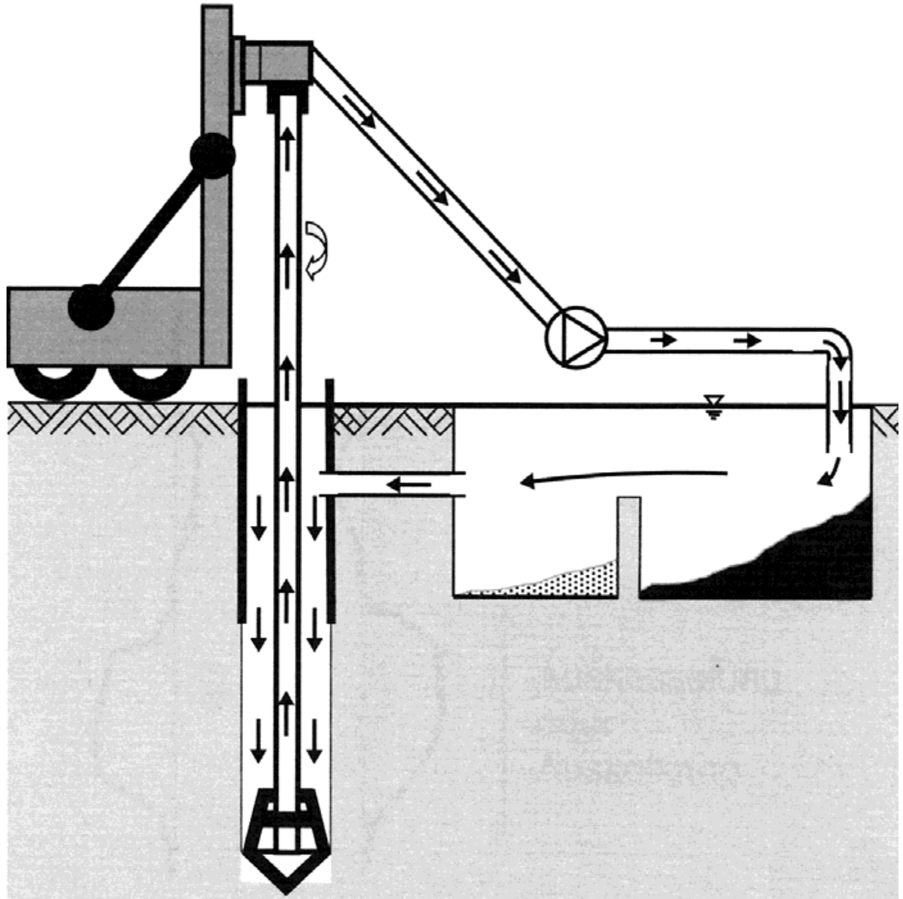


Reverce circulation drilling

Planning
Drilling
Materials
Design
Development
Rehabilitation

Questions / Discussion

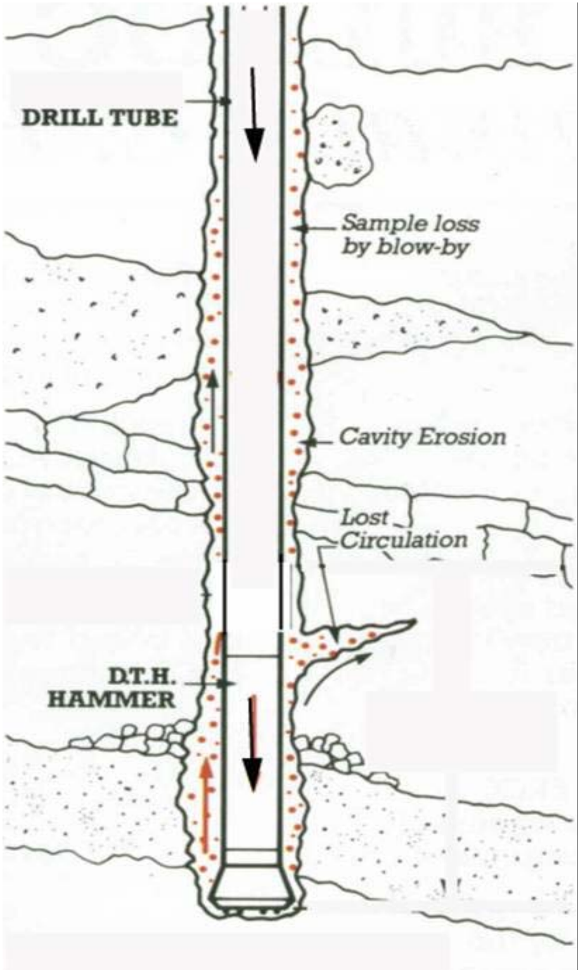
- Small diameter of the double wall drill, rods lead to high velocities and less problems to rise the cuttings
- Needs less drilling fluid and therefore, smaller sedimentation pits
- Needs less additives
- Sampling of the cuttings is easier and more reliable



Down-hole hammer

Planning
Drilling
Materials
Design
Development
Rehabilitation

Questions /
Discussion

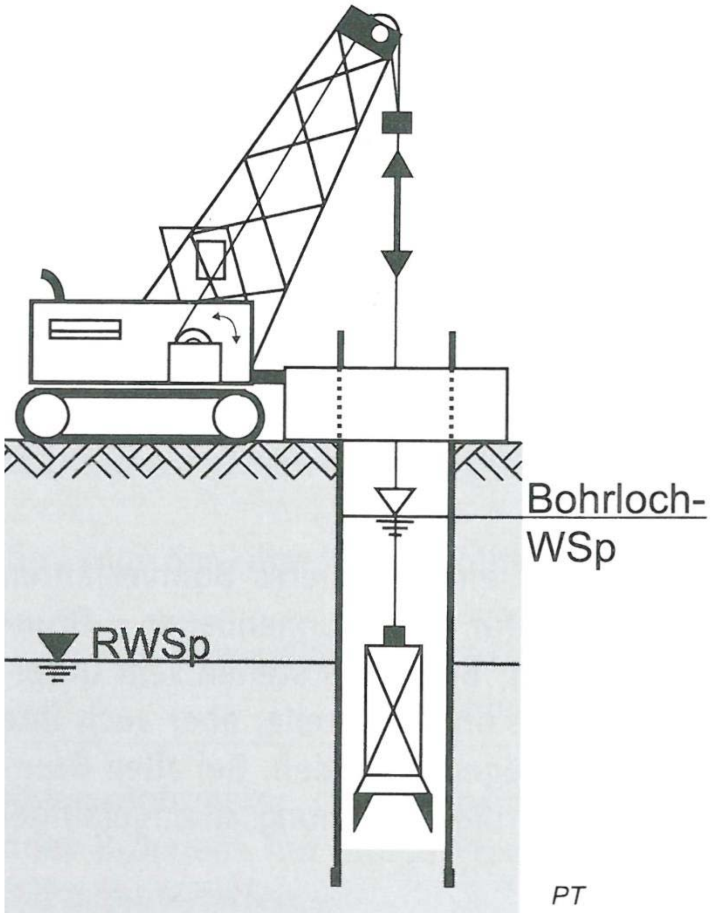


Cable excavator with rotary table

Planning
Drilling
Materials
Design
Development
Rehabilitation

Questions / Discussion

- Large diameters up to 160 cm possible
- Limited to 30 – 40 m
- Can not penetrate bedrock formation.
- Needs very heavy equipment



Common Drilling Tools

Planning
Drilling
Materials
Design
Development
Rehabilitation

Questions /
Discussion

(video youtube)

Drill rigs

Planning
Drilling
Materials
Design
Development
Rehabilitation

Questions /
Discussion

Samples for geological description

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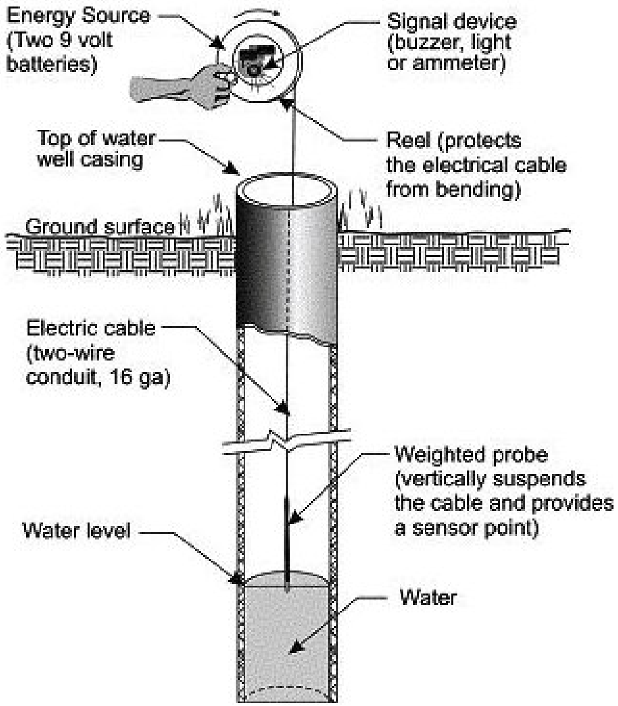
Planning
Drilling
Materials
Design
Development
Rehabilitation

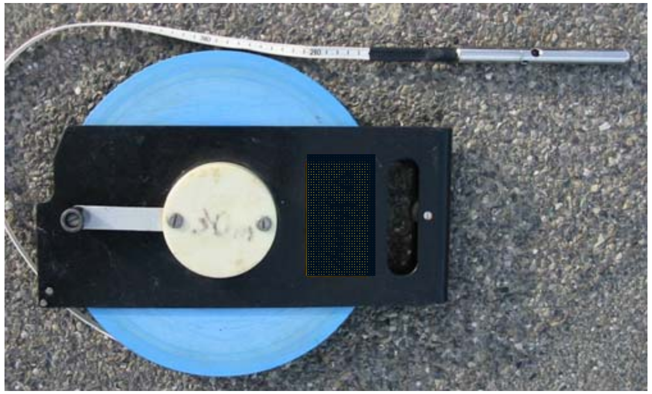
Questions /
Discussion

Measuring of water level

Planning
Drilling
Materials
Design
Development
Rehabilitation

Questions / Discussion

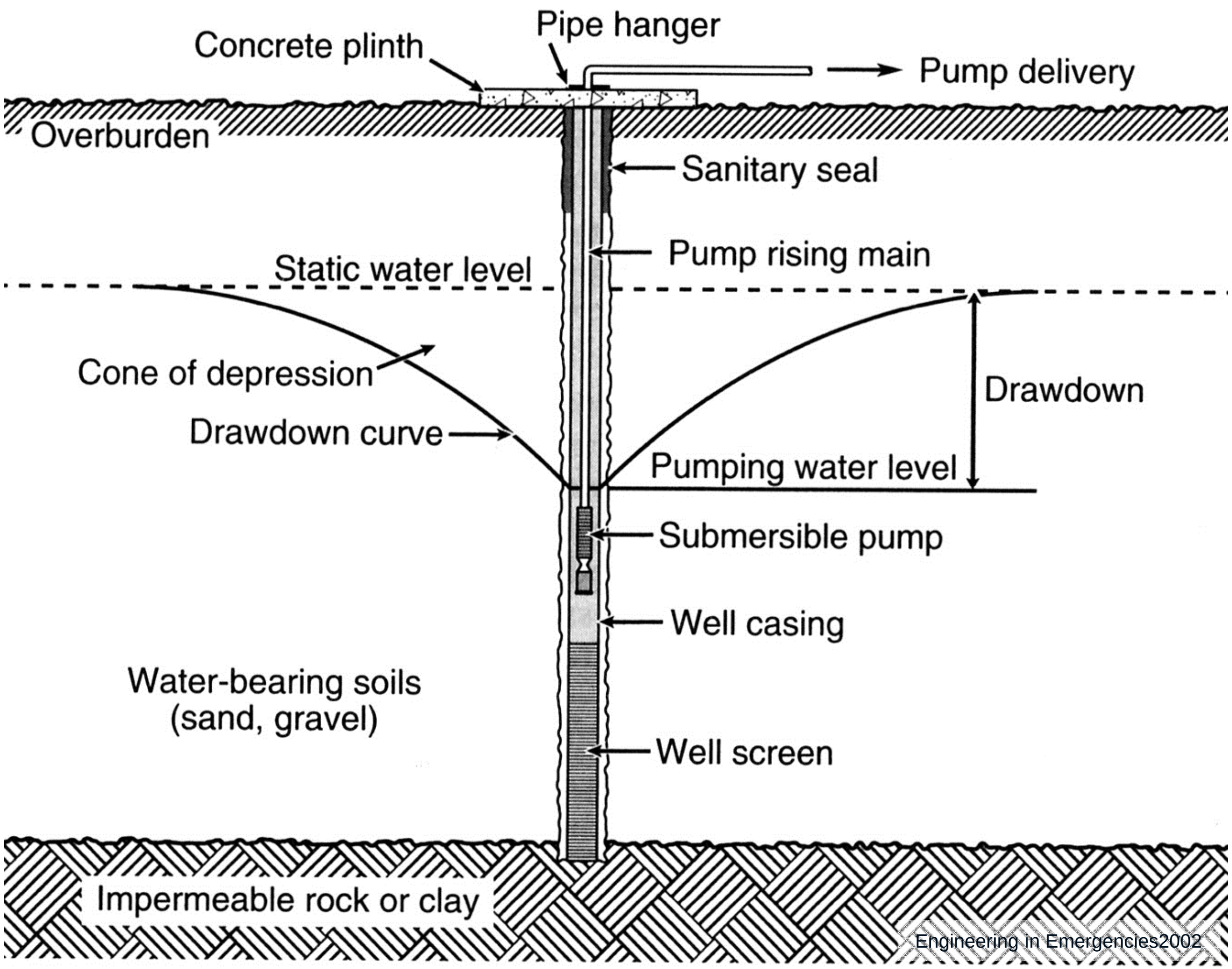




Water well design

Planning
Drilling
Materials
Design
Development
Rehabilitation

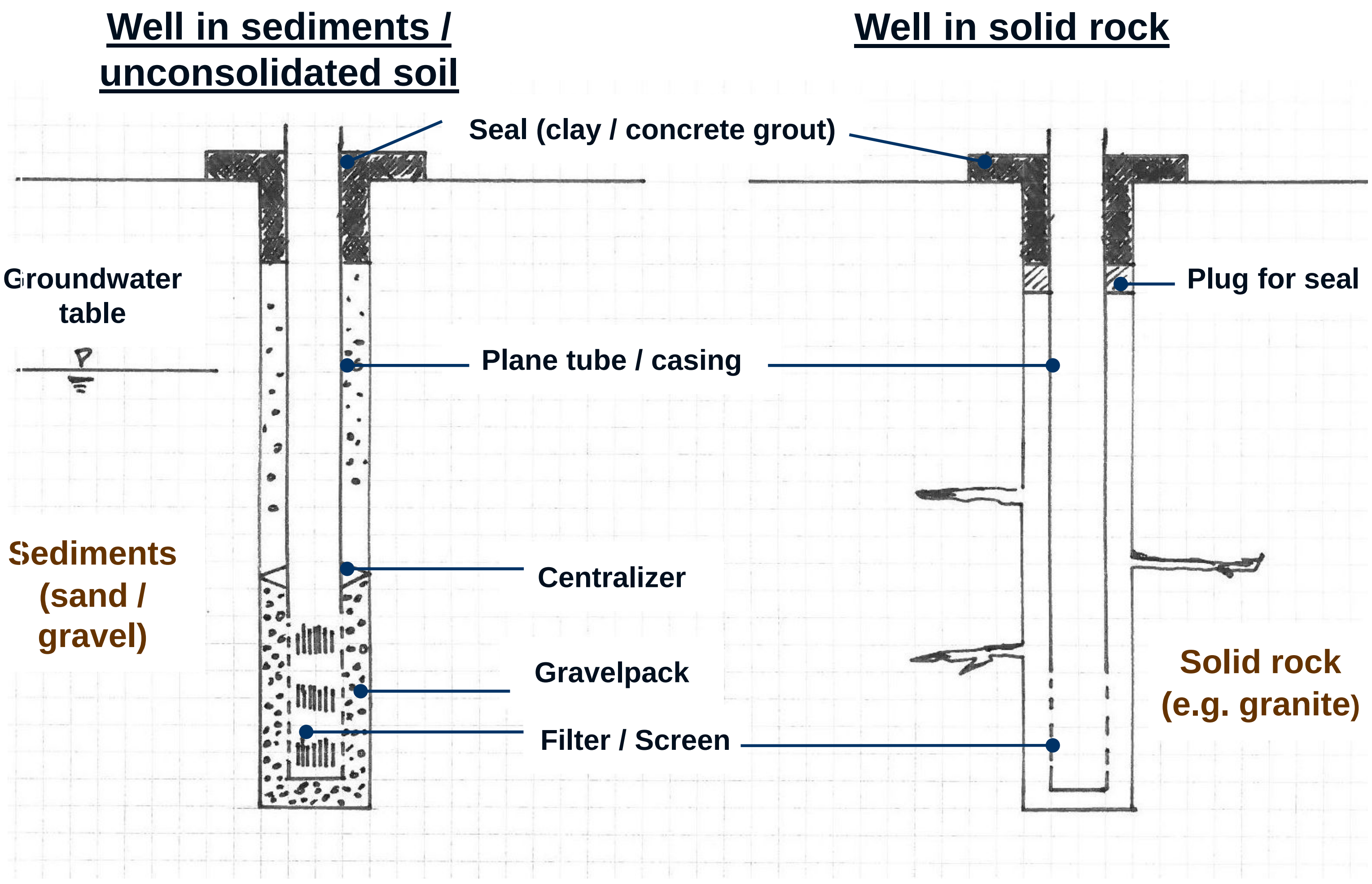
Questions /
Discussion



General well elements (simplified)

Planning
Drilling
Materials
Design
Development
Rehabilitation

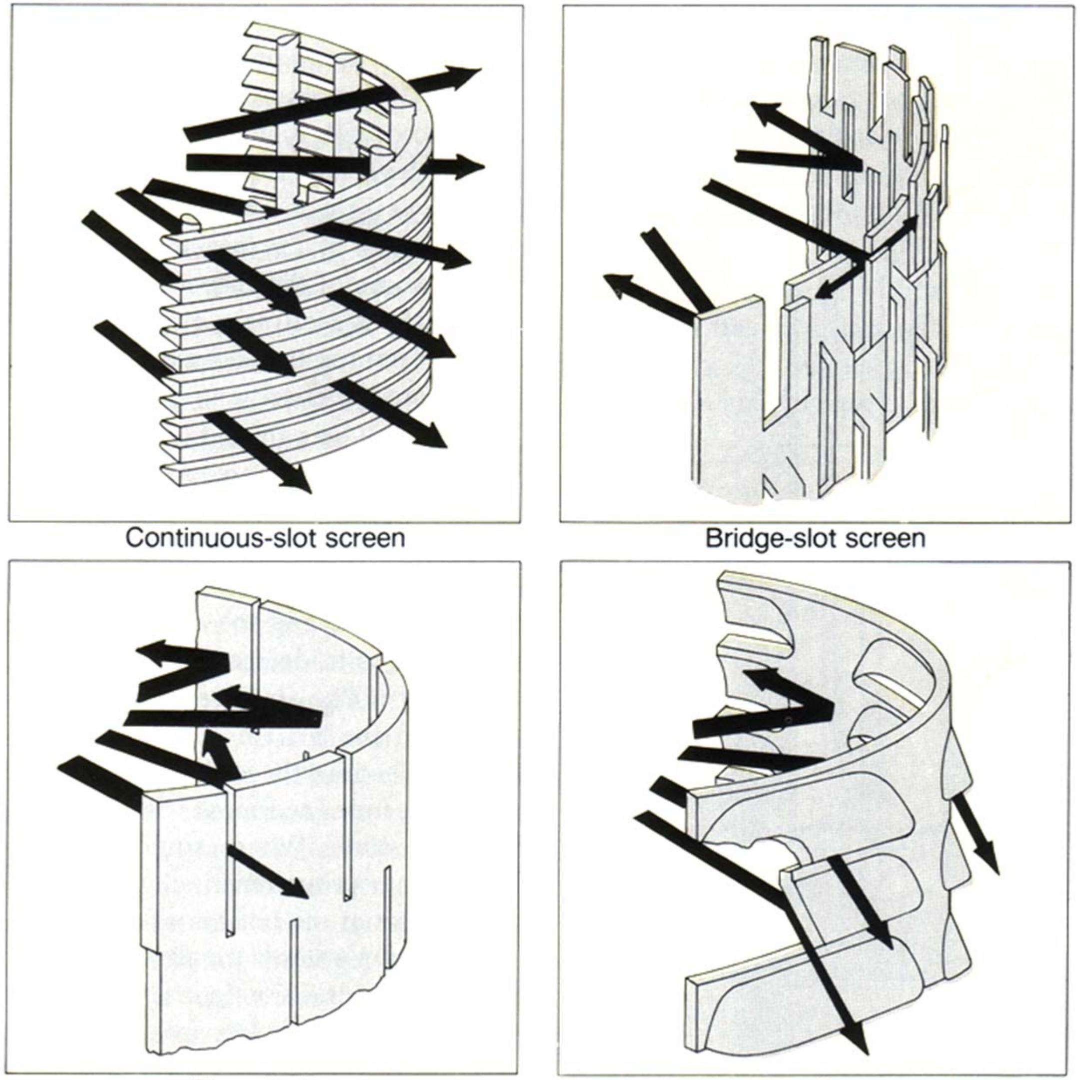
Questions / Discussion



Filter tubes / screens

Planning
Drilling
Materials
Design
Development
Rehabilitation

Questions /
Discussion



Continuous-slot screen

Bridge-slot screen

Slotted pipe

Louvered screen

Wire wrapped vs. simple slotted screens

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Planning
Drilling
Materials
Design
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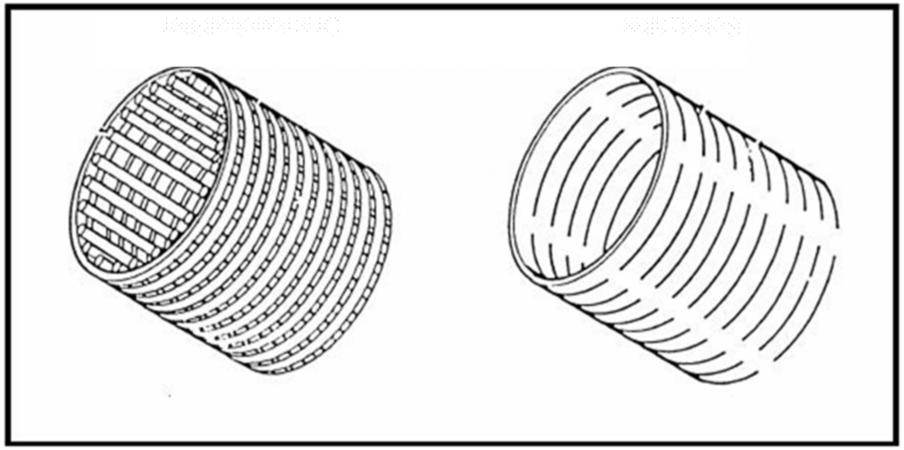
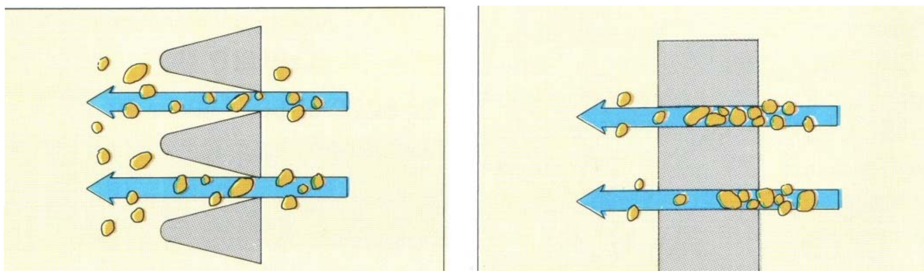
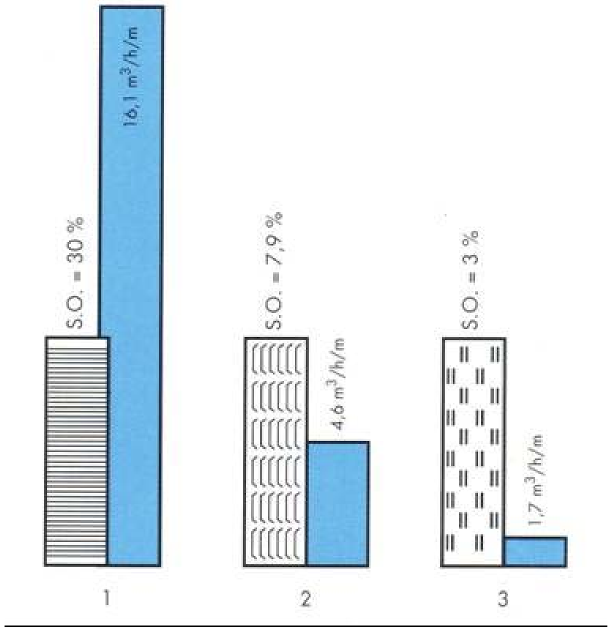
Rehabilitation

Questions /
Discussion





Wire wrapped screens have approx. 2– 5 times higher flowrates than slotted screens



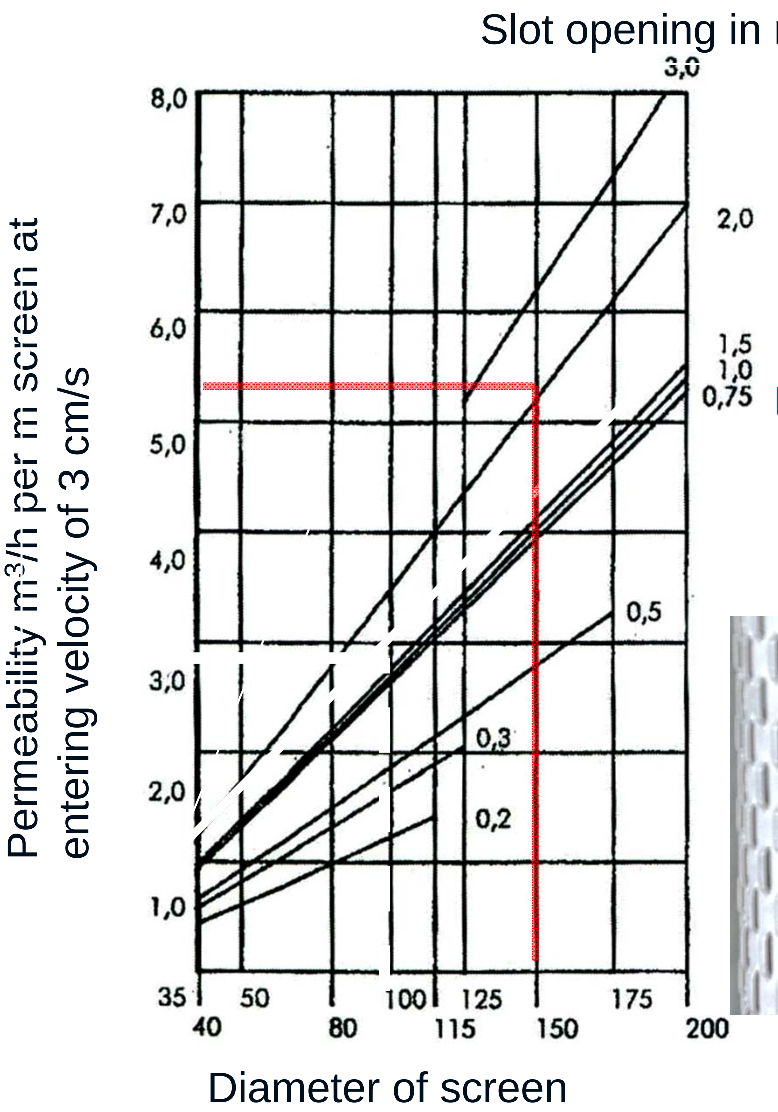
Surface of slots / total surface of tube

1) wire wrapped screens
2) steel bridge-slot screens
3) simple slot screens

Slot opening vs. max. flowrate

Planning
Drilling
Materials
Design
Development
Rehabilitation

Questions /
Discussion



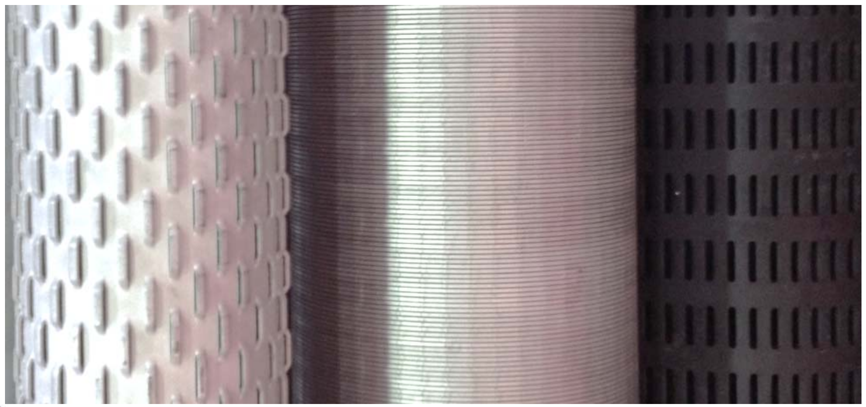
Each product has a specific diagram

Example:

Slot opening: 2.0 mm

Diameter screen: 150 mm (6 inch)

➡ max. yield per meter: 5.3 m^3/h (90 l/min)



Flow rage /slot opening (exercise)

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Drilling
Materials
Design
Development
Rehabilitation

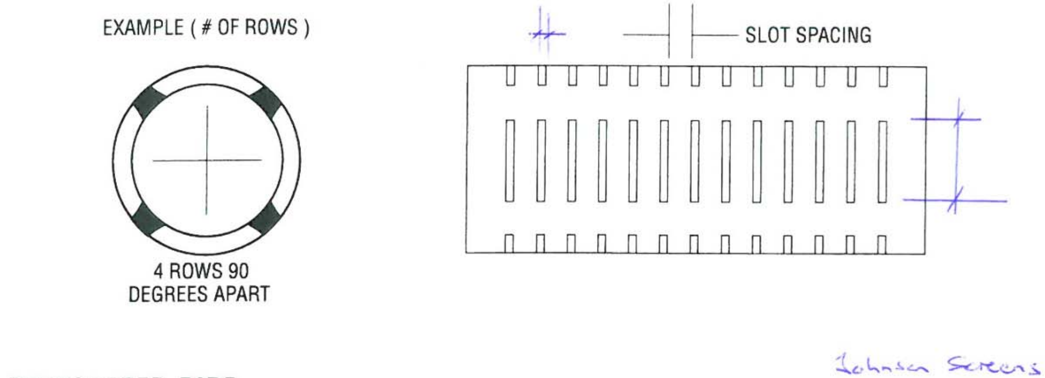
Questions /
Discussion

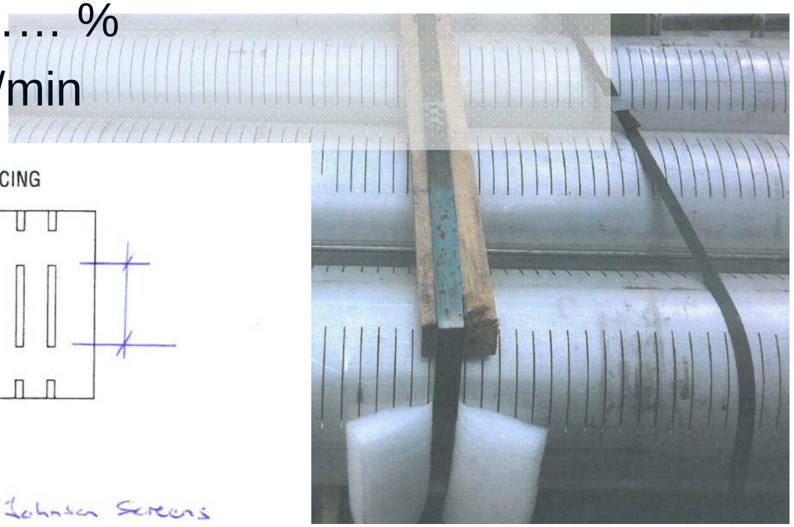
Higher entering velocities than 3 cm/s lead to:

- More sand in the well
- Turbulent current when ground-water enters the well and subsequently leads to incrustation

<u>Excercise</u>

- Filtertube inox, diam. 180 mm,
  4 rows of slots per circumfer-ence, 200 slots per row and filter of 3 m, slots 85 mm x 1 mm.
- Percent opening of tube: …… %
- Max. yield per m: ……….l/min





Factors on yield of a well

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Drilling
Materials
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Questions / Discussion

Basis	**Variable**
Ø filter: 200 mm, s = 3.0 m	***permeability coefficient*** (is a measure of the ability of a porous material) to allow fluids to pass through)
$kf = 1.0 \times 10^{-3}$ [m/sec]	Q = 20.1 [l/sec]
$kf = 1.0 \times 10^{-4}$ [m/sec]	Q = 2.4 [l/sec]
$kf = 1.0 \times 10^{-5}$ [m/sec]	Q = .028 [l/sec]
Kf = 1.0*10 $^{-3}$ [m/sec], s = 3.0 m	***diameter filter***
diameter filter 150 mm	Q = 19.4 [l/sec]
diameter filter 400 mm	Q = 22.1 [l/sec]
diameter filter 600 mm	Q = 23.4 [l/sec]
kf = 1.0*10 $^{-3}$ [m/sec], Ø filter: 200 mm, s = 3.0 m	**total thickness of aquifer**
h = 10.00 m	Q = 20.10 [l/sec]
h = 20.00 m	Q = 43.80 [l/sec]
h = 50.00 m	Q = 117.9 [l/sec]

Material	**Permeability** (m/s)
well-sorted gravel	10^{-2} to 1
well-sorted sands, glacial outwash	10^{-3} to 10^{-1}
silty sands, fine sands	10^{-5} to 10^{-3}
silt, sandy silts, clayey sands, till	10^{-6} to 10^{-4}
clay	10^{-9} to 10^{-6}

Q	Yield [m3/s]
h GW	Thickness aquifer
h	Thinckness aquifer after pumping
R	Radius cone of depression
r	Radius filter
s	Differenz groundwater level pumping / before pumping

Dupuit

$$Q = \pi \cdot k_f \cdot \frac{h_{GW}^2 - h^2}{\ln R/r}$$

$$s = h_{GW} - h$$

Sichardt

$$R = 3000 \cdot s \cdot \sqrt{k_f}$$

Slot size

Filter should retain approx. 40 % of the aquifer material.

Filter should retain approx. 90 % of the gravel pack, if well is built with gravel pack

Planning
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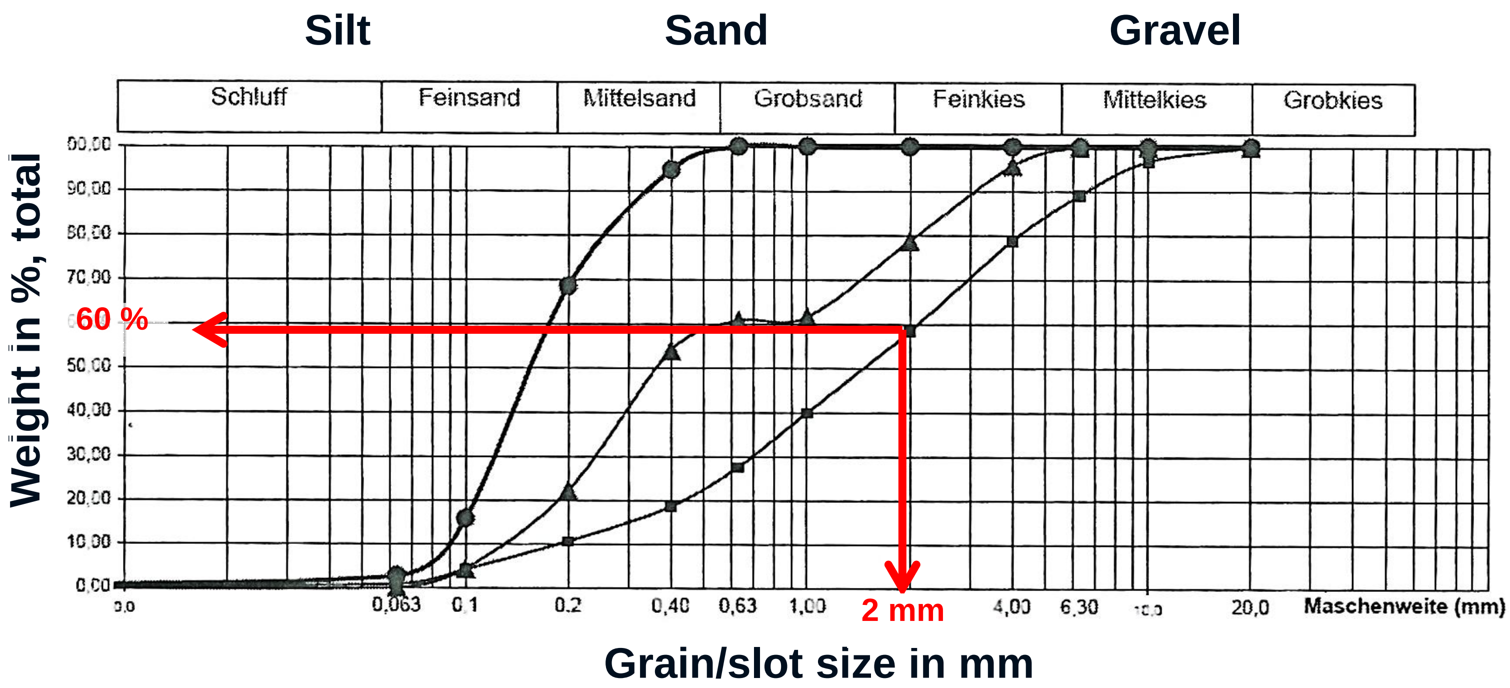
Rehabilitation

Questions /
Discussion



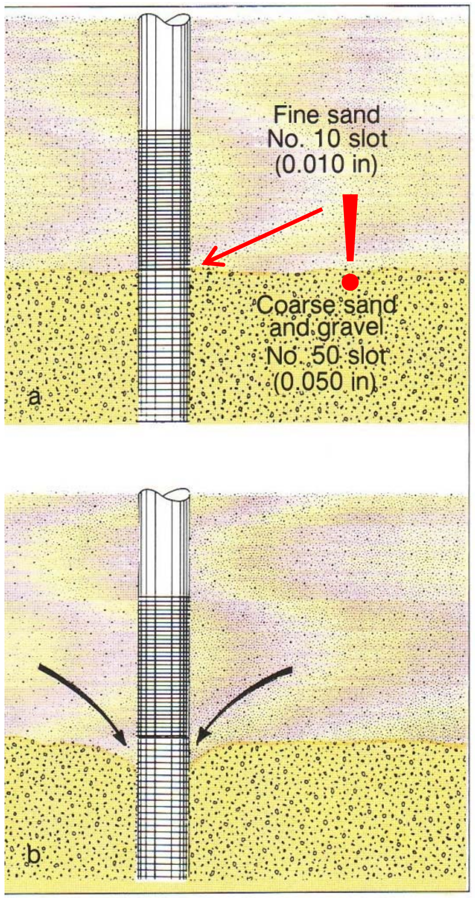
!Various other rules / solutions exit !

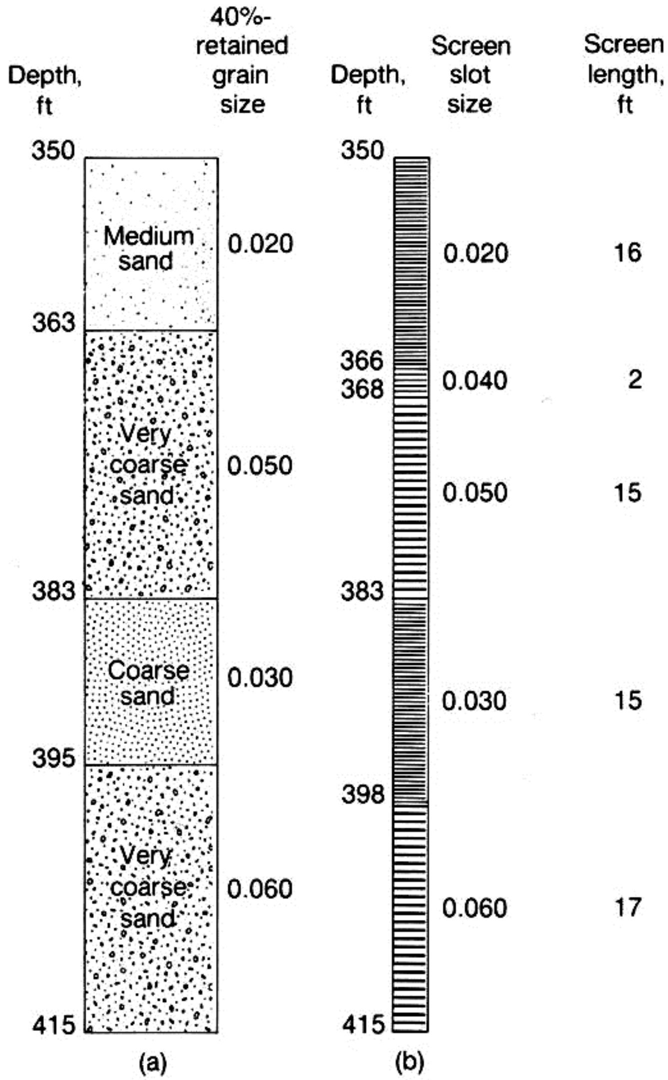
Example of slot size

Design
Materials
Development
Rehabilitation

Questions / Discussion

Filter should retain approx. 40 % of the aquifer material and 90 % of the filter pack



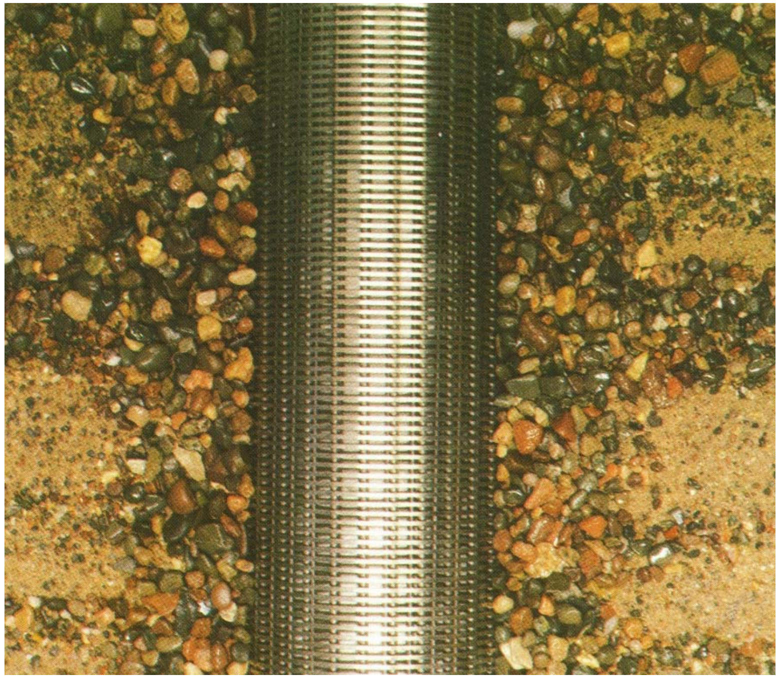


Filter / Gravel pack

Design
Materials
Development
Rehabilitation

Questions /
Discussion

- Gravel pack / filter pack prevents sand or find sand from migrating from the aquifer into the well
- The filter pack should let pass approx. 40 – 60 % of the fines (danger of clogging)
- A filter pack is coarse sand or fine gravel that is placed between the borehole wall and screen
- A filter pack should be installed in all wells except of those completed in rock or gravel
- The grain size depends on the grain size of the aquifer
- Silica-based material since it will not be dissolved, washed, uniformed in size, well rounded (less compact filling).



Filter / Gravel pack

Planning
Drilling
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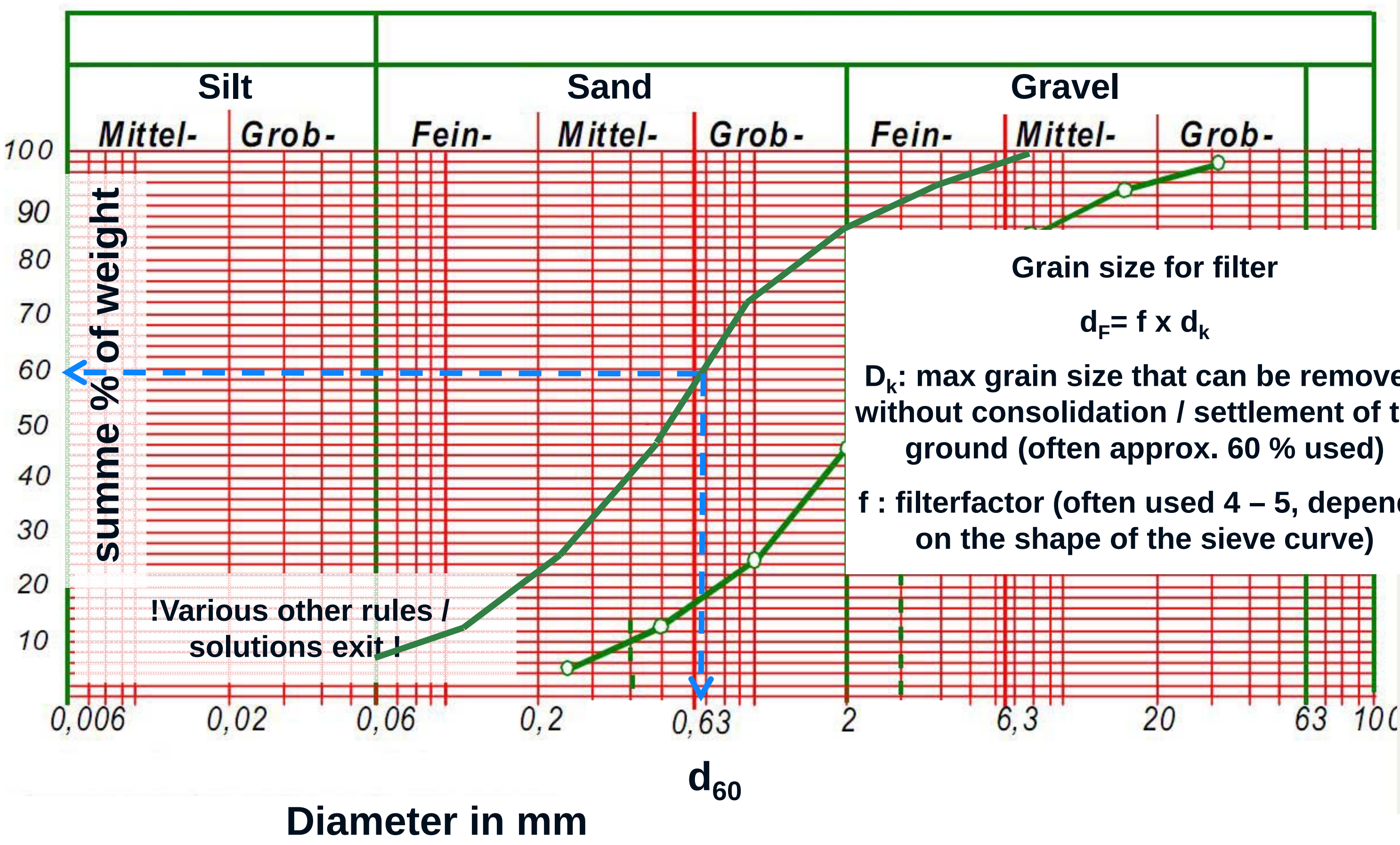
Questions /
Discussion

Rule of thumbs for filter pack



Grain size for filter

$d_F = f \times d_k$

D_k: max grain size that can be removed without consolidation / settlement of the ground (often approx. 60 % used)

f : filterfactor (often used 4 – 5, depends on the shape of the sieve curve)

Filter / Gravel pack

Planning
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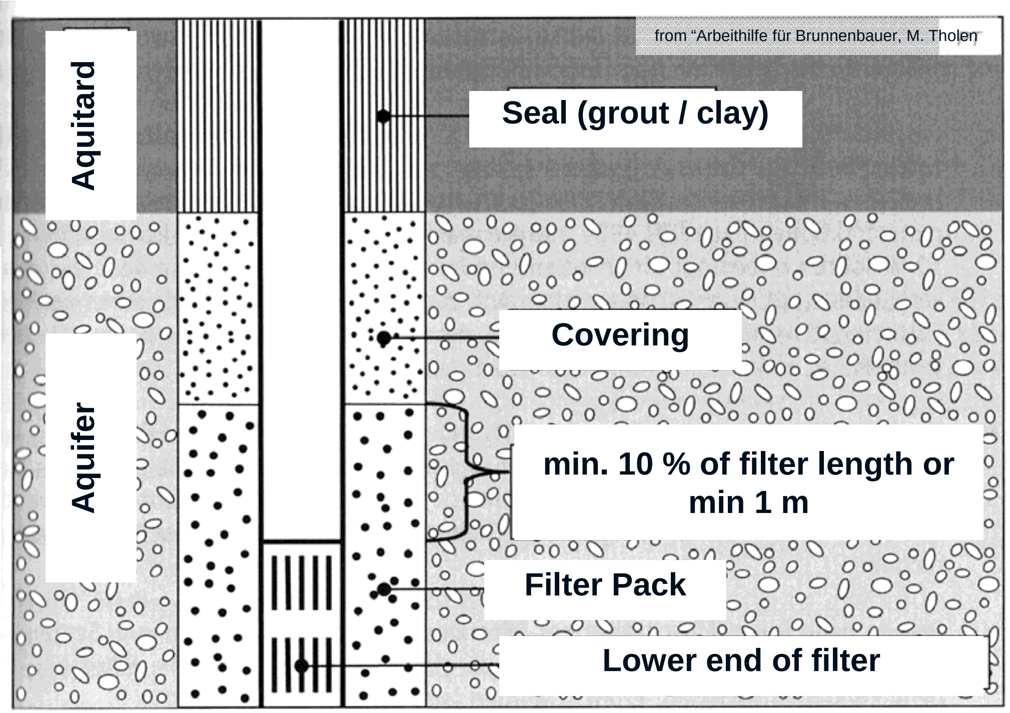
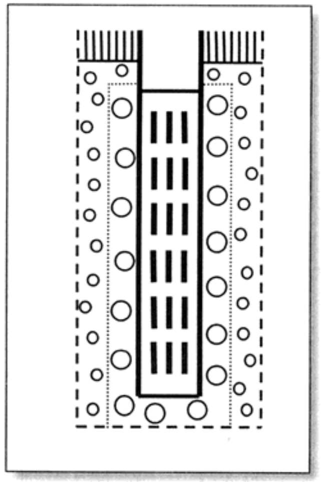
Questions / Discussion

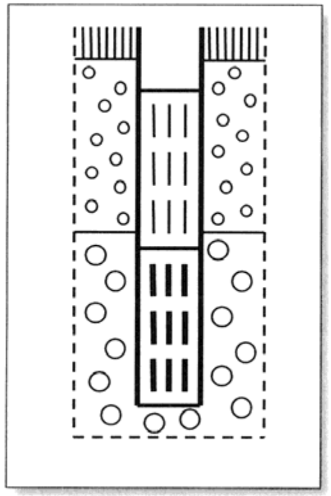


Standard filter pack design

with small diameter grains to prevent fins and annulus seal material (grout / expandable clay) to migrate in the filter pack



Gravel pack various horizontally



Gravel pack various by depth

Centralizers

Planning
Drilling
Materials
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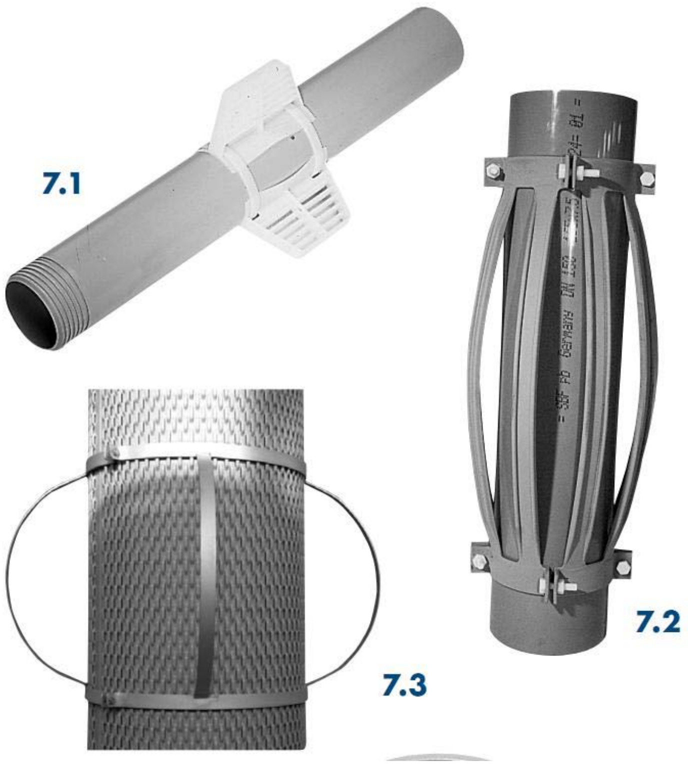
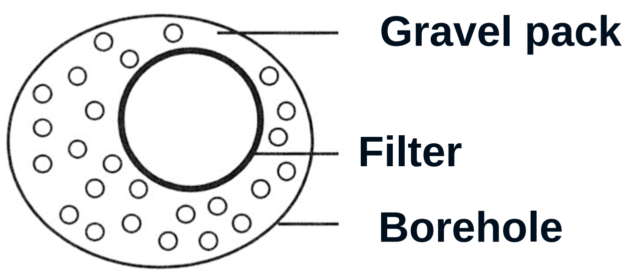
Questions / Discussion





For centering screen and casing columns in a core-hole it is recommended to use centralizers

Important

Centralizer should be positioned:

- above and below filtered section
- below the sleeve (so it can‘t glide)
- never on the filter (may break filter when pulling casing)

Grouting and sealing clays

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Planning
Drilling
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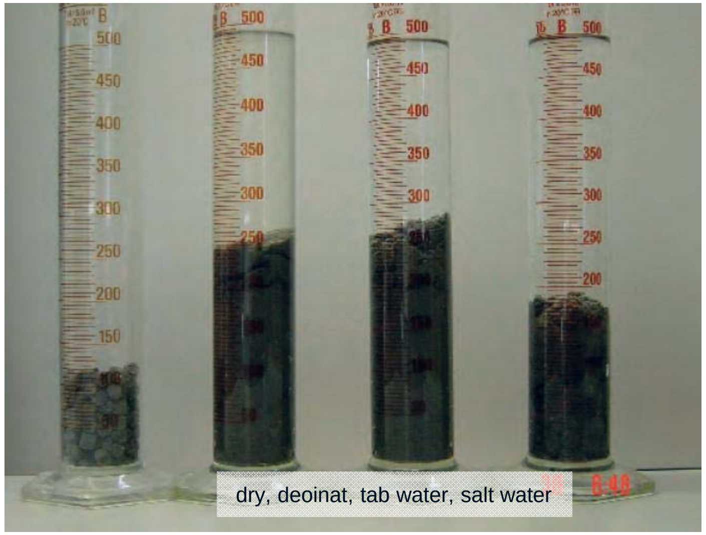
Questions / Discussion

Sealing to prevent surface water or contamination from entering the well or separates two groundwater layers

- Sealing clays
- Cement grout, bentonite

The formation seal must be effectively placed to prevent contaminated surface run-off from infiltrating into the well.



dry, deoinat, tab water, salt water

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Pumps and pumping rates

Planning
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Rehabilitation

Questions / Discussion

Suction pump

Submersibel pumps

Handpumps (suction and subm.)

	Max depth	Max Q (yield)
Suction pump	6 m (7 m)!	max yield pump
Submersible pump	several 100 m	max yield pump
Hand pump (suction)	6 m (7 m)!	Approx. 10 -45 l/min
Hand pump (lift, diaphragm	60 m	4 – 45 l/min

NSP e.U.

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Submersible pumps

Planning
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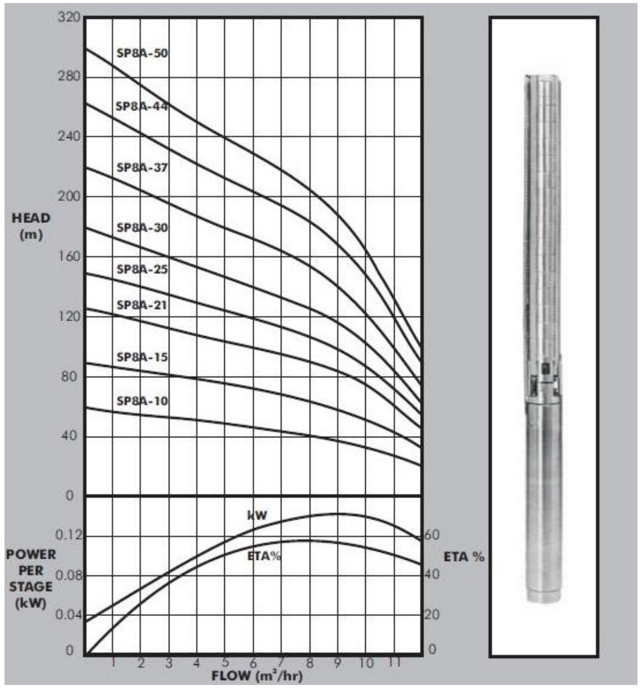
Rehabilitation

Questions / Discussion

Examples with Grundfos pumps

	Volt	Amper	Ø pump	Ø filter	weight	Q		depth
	[V]	[A]	[mm]	[inch]	[kg]	[m3/h]	[l/min]	[m]
SP 14A-10	380	15	101	4.5 “	27	14	230	46
SP 14A-25	380	25	101	4.5 “	68	14	230	130
SP 27-5	380	15	136	6 “	34	27	450	36
SP 46-6	380	25	145	6 “	62	46	770	50
SP 60-11	380	50	147	6 “	96	60	1000	85
SP 160-4	380	110	203	8 “	220	160	2666	80



Reduction of yield

- Material, length and diameter of pump riser tube
- Material, length and diameter of hose
- Valves, curves e.g.

Important:

Proper choice of diameter and length of electric cable

Placing of the filter and pump

Planning
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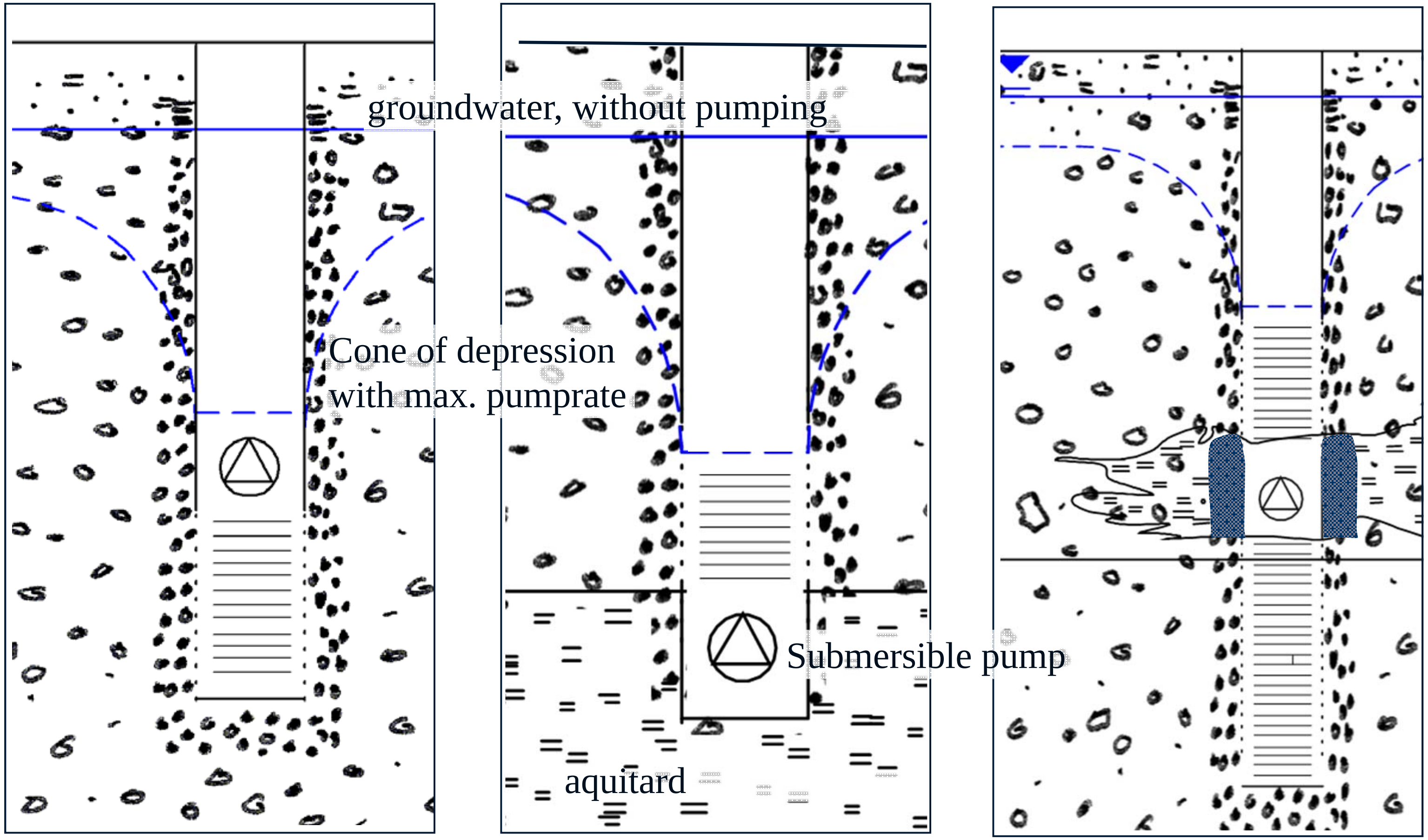
Questions / Discussion



Very thick aquifer

Shallow aquifer

Aquifer with finegrained intermediate layer

General remarks

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Planning
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Questions / Discussion

- A longer filter leads to slower entering velocities in the groundwater well. As a result we have less problems with sand and the well lasts longer (to optimize for economical reasons).
- Avoid groundwater draw-down into the screened section. Connection the groundwater with air leads to incrustation, biofilm e.g.
- Never put a pump in the section of the screen (especially on small diameter wells). It will benefit the suction of sand and other fines due the high lateral velocity of the suck in of the groundwater.
- Avoid to connect different groundwater horizons. You could pollute a clean aquifer.

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Well development

(after completion of borehole and during rehabilitation)

Planning
Drilling
Materials
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Rehabilitation

Questions / Discussion

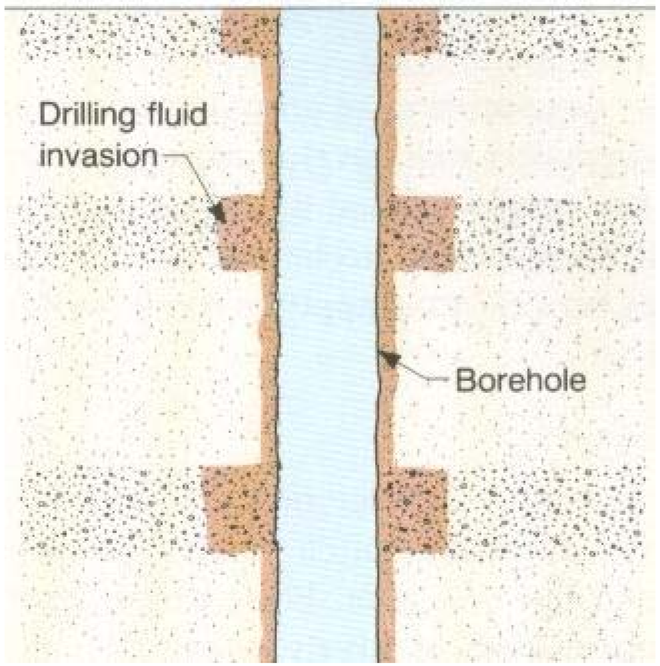
The well development is important to:

- Remove the fine material in the vicinity of the well and so to improve the permeability and the yield of the well
- If the borehole was drilled with drilling fluid (bentonite mud) to remove the coated borehole wall
- Prevent sand pumping and therefore, increases the service life of the pump cylinder and well
- Remove organic and inorganic material which may inhibit effective well disinfection
- Remove biofouling, oxidation products or fines during rehabilitation projects

Methods for well development

- Intermittent pumping, pumping beyond the production rate
- Air lift pumping
- Jetting with rotated tool
- Using surges blocks (piston)

Well development



The key development objectives are

- to remove remnant drilling fluid and cuttings from the bore-hole wall, formation, filter pack and well screen
- create an optimum interface between the filter pack and the water-bearing formation.

(Handbook of GW Development, Roscoe Moss Company

Well development

Planning
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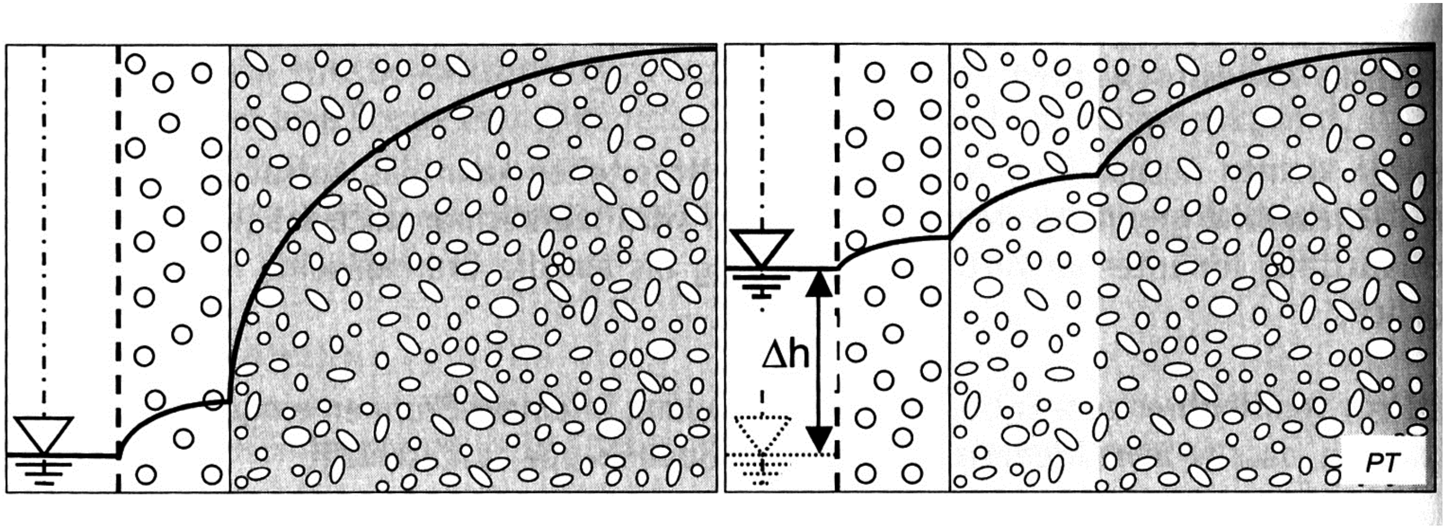
Questions / Discussion



Reduction of the lowering of the water table in the well and the gradient of the cone of depression as a result of intense well development >>> higher yield of the well.

Well development takes very few hours up to one day, depending on the well and the geology and the demands of the client.

Well development

Planning
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Questions / Discussion

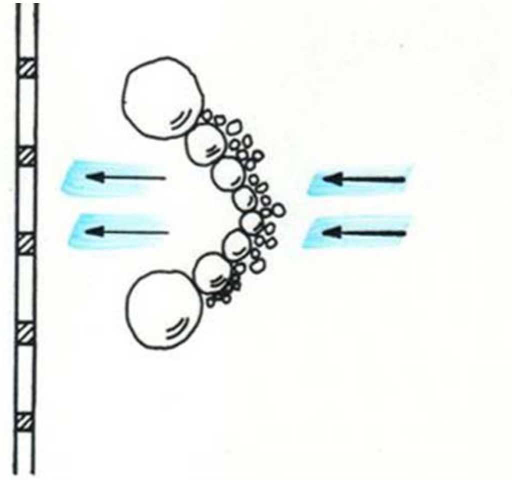


Fig. 102 Formation of grain arches caused by suction desanding in one direction only.

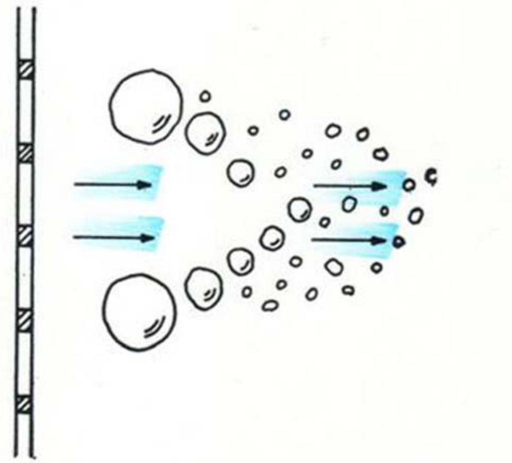


Fig. 103 Dispersal of grain arches through alternating impact desanding.

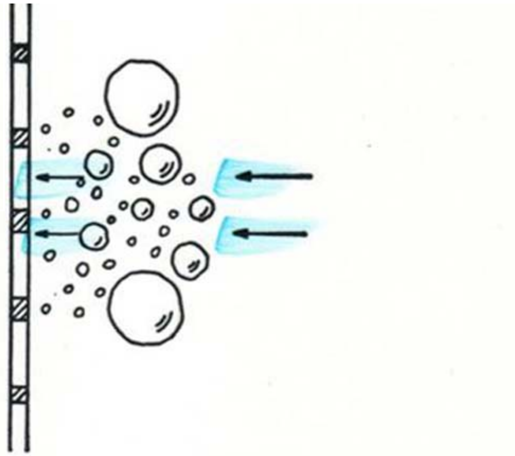
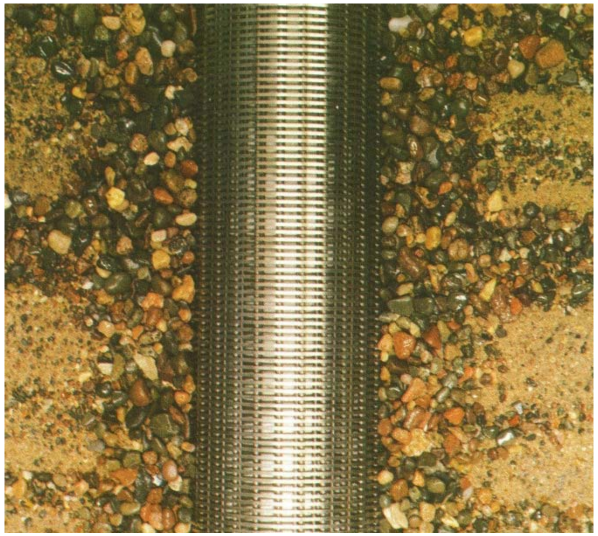


Fig. 104 The finer grains are drawn into the screen by repeated suction, following impacts.



Well development

Design
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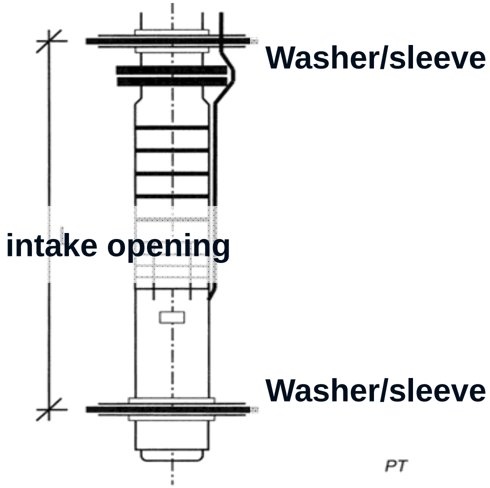
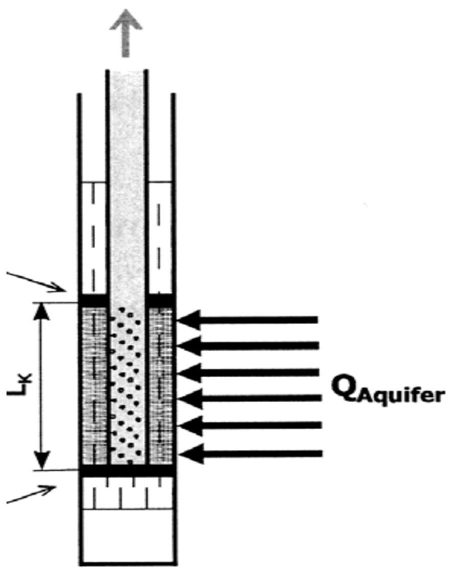
Questions / Discussion





Overpumping well with a higher pumping rate than the production rate

- Simple but not very effective
- High rate of wear on the pump (abrasion by fines)
- Leaves well only sand free but not really developed, the water moves only in one direction
- Has only an effect on the section of the well with the highest permeability (can also be enhanced by attaching a rubber washer around the top and bottom of the submersible pump)

Well development

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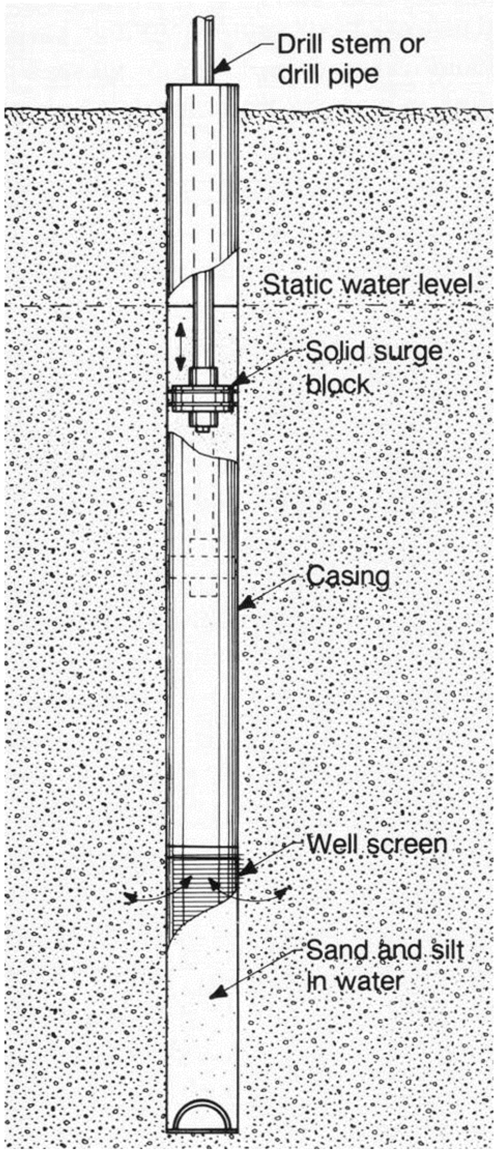
Questions / Discussion



Surge Block

Flat seal that closely fits the casing interior and is operated like a plunger beneath the water level.

- Because it seals closely to the casing, it has a very direct positive action on the movement in the well.
- Moves the water in both directions, into the well and into the formation.
- Danger of blocking the surge block if not beginning from the top.

- Improved method: Valve in the surge block or stem reduces the downstroke. Therefore, loose fines will not driven too far into the formation.

Well development

Planning
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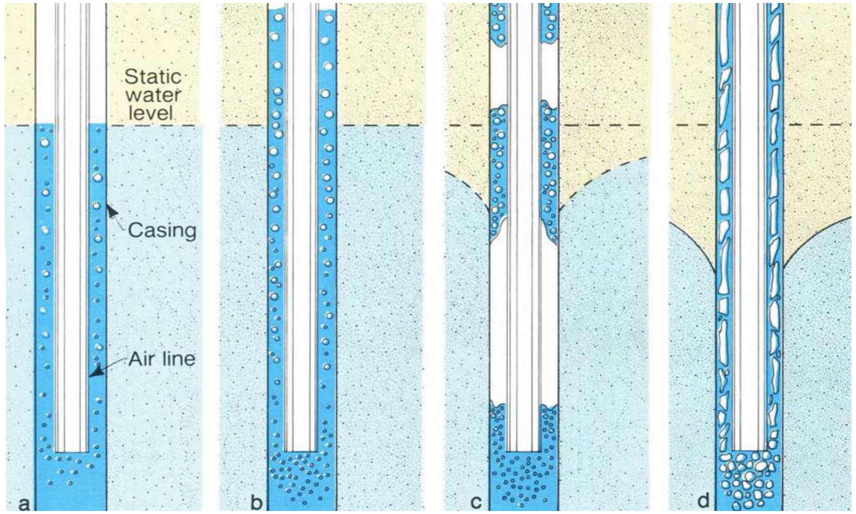
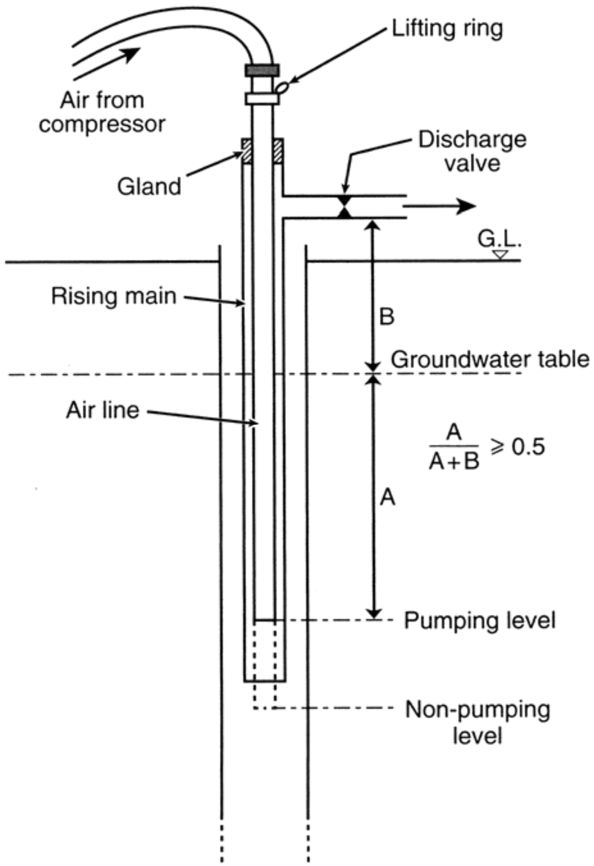
Questions / Discussion





Air lift

Air lift pump (right)

Air lift with back draw after collapse of the water column, forced by closing the discharge valve (left)

Well development

Planning
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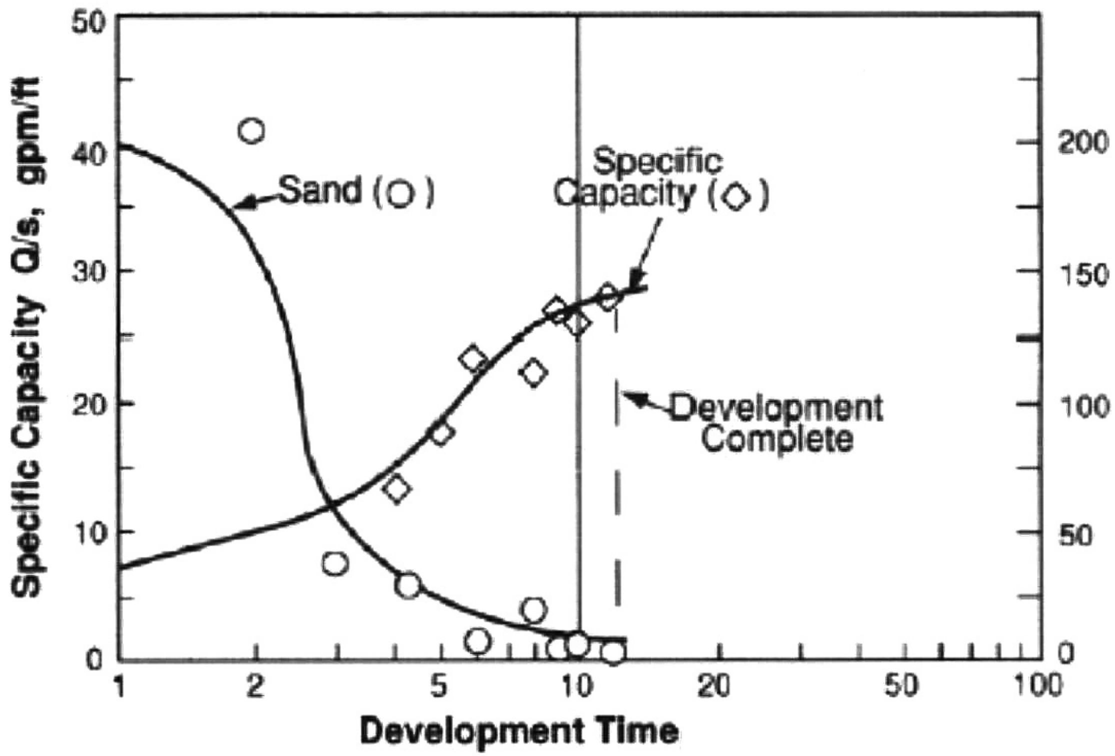
Questions / Discussion



Development of the well until the sand content declines under a pre-defined level.

It is always the sand (> 0.06 mm) that triggers the development, as it is not always possible to avoid turbidity from silt and clay.

Monitoring

Monitoring during well development

Sand Content

Monitoring discharges can be performed with an Imhoff cone or a bucket

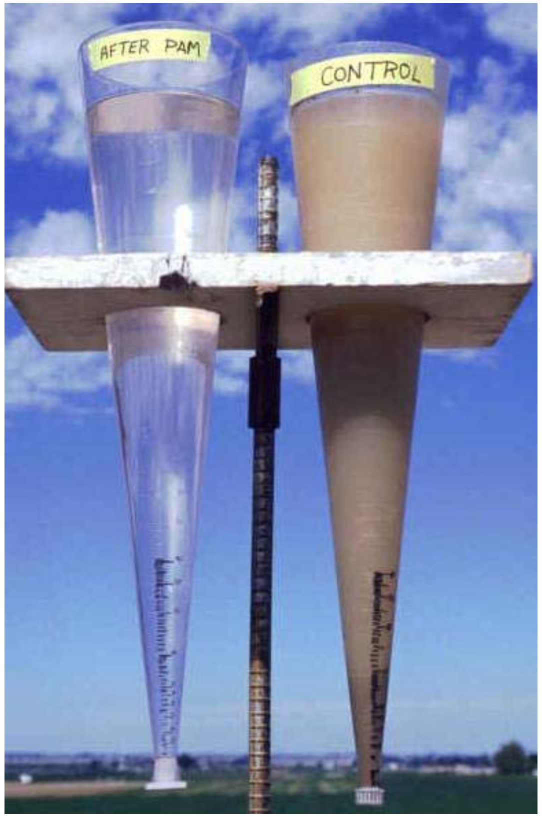
Turbidity

Turbidity refers to the clarity of water and is associated with colloid clay particles. During development, turbidity can be measured in the field with a turbidimeter.

Specific Capacity

The specific capacity of a well is the yield per unit of drawdown (l/s, gpm/ft).

Measured with a circular totalizing of low yields with a bucket and a watch.



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Questions / Discussion

Water well problems

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Questions / Discussion

Caused by drilling contractor / hydrogeologist

- Improper well design (slots size of screen, depths, gravel pack ….)
- Incomplete well development

Caused by characteristics of aquifer

- Depletion of the aquifer
- Borehole stability problems
- Biofouling
- Corrosion
- Incrustation buildup

Caused by the user

- Overpumping

Water well problems

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Reduced Well Yield

Planning
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Questions / Discussion

Possible causes:	What to check for:	How to correct:
Pump and/or water system	Low pump production in spite of normal water level in well. Leak in system; worn pump impeller.	Have a licenced drilling contractor/pump specialist or plumber check the pump and water system.
Aquifer depletion -rate of withdrawal exceeds rate of recharge -periods of drought can temporarily deplete shallow groundwater zones	Compare current non-pumping static water level with the level at the time of well construction. A lower level confirms aquifer depletion. Contact Provincial Government groundwater agency to see if water levels are declining.	Reduce the water use. Install cistern to meet peak water requirements. Drill a deeper well or one that taps into another aquifer.
Biofilm buildup in well casing, well screen or pump intake.	Slime buildup on household plumbing fixtures and livestock waterers. Inspect pump and use down-hole camera to check for slime build-up.	Shock chlorinate the well and water system as required —usually once or twice a year. See Module 6 "Shock Chlorination—Well Maintenance."
Neighboring well interference.	Check for significant drop in water levels in nearby wells. Contact Provincial Government groundwater agency to determine if groundwater use in the area has decreased.	Identify other nearby wells located in the same aquifer. Reduce pumping rates as required.
Mineral scale (incrustation) buildup on perforated well casing, well or pump screen.	Scale formation on plumbing fixtures and livestock waterers. Inspect pump. Use down-hole video camera to check for mineral build-up. Calculate the Ryznar Stability Index to determine the water's incrusting potential.	Once the type of mineral scale has been identified, the well should be cleaned by a licenced water treatment specialist. Treatment could include both physical agitation and chemical/acid treatment..
Sediment plugging on outside of perforated casing or screen.	Sediment in water, followed by sudden decline in yield.	Have a licenced drilling contractor redevelop the well.
Collapse of well casing or borehole due to age of well.	Compare current depth of well with original records. A collapsed well will show a shallower depth than the original well.	Recondition the well. If repair is not economical, plug the well and redrill. See Module 9 "Plugging Abandoned Wells" for more information on plugging a well.

from Alberta Agriculture: "Water Wells that Last for Generations"

Water well problems

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Sediments in water

Planning
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Rehabilitation

Questions / Discussion

Possible causes:	What to check for:	How to correct:
Improper well design or construction.	Sediment appears in water shortly after well completion. Remove pump and use down-hole video camera to inspect well casing and screen.	Have a licensed drilling contractor repair the construction problem.
Insufficient well development after construction.	Sediment appears shortly after well completion. Well production may improve with pumping.	A licensed drilling contractor should redevelop the well.
Continuous overpumping of well.	Sediment appears in water shortly after well completion.	Compare current discharge rate of well with the driller's recommended rate. If the current flow rate is higher, install a flow restrictor on pump. If required, install cistern to meet peak water requirements.
Corrosion of well casing, liner or screen causing holes.	Sudden appearance of sediment in water when there was no previous problem. Often coupled with a change in water quality. Calculate the Ryznar Stability Index to determine the water's corrosion potential.	Consult a licensed drilling contractor. Depending on the well construction, repair or replace well. Alternate construction materials may be required.
Failure of the annulus or casing seal.	Sudden appearance of sediment, coupled with a change in water quality.	Consult a licensed drilling contractor. It may be possible to re-establish the seal. Test water quality regularly and investigate when quality changes occur.

from Alberta Agriculture: "Water Wells that Last for Generations"

Water well problems

Reduced Well Yield

Planning
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Questions / Discussion

Possible causes:	What to check for:	How to correct:
Corrosion of well casing, liner or screen, causing holes. Holes can allow water of undesirable quality to enter the well.	Change in water quality, often coupled with sudden appearance of sediment in water. Calculate the Ryznar Stability Index to determine the water's corrosion potential.	Consult with a licensed drilling contractor about possible repair. Alternate construction materials may be required.
Failure of the annulus or casing seal.	Change in water quality and possible appearance of sediment.	Consult with a licensed drilling contractor about possible repair.
Iron bacteria or sulfate-reducing bacteria (biofouling).	Change in water quality such as color, odor (e.g., rotten egg) or taste. Check inside of toilet tank for slime buildup and inspect pump. (See note 2 below)	Shock chlorinate the we chlorination, see Modul
Contamination from man-made sources.	Changes in water quality as indicated by color, odor or taste. Compare results from regular water analyses for changes. (See note 3 below)	Identify and remove contamination source. Have water analyzed through local health unit to ensure it is safe to drink.
Limited Aquifer Extent/Reduced Aquifier Recharge	Increase in constituents such as hardness, iron, manganese and sulphate. Compare results from original water analyses for changes. Taste and colour changes in the water may also occur.	For surficial aquifers trapping snor or impounding surface water can enhance aquifer recharge and improve water quality.

from Alberta Agriculture: "Water Wells that Last for Generations"

Frequent defects

Planning
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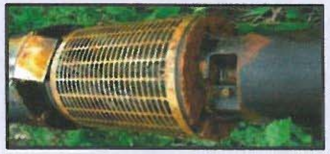
Questions /
Discussion

Problem	Diagnosis	Appearance
Iron Oxide **Iron Bacteria (slime bacteria)**	• Rusty slime inside pipes • Cloudy rusty water at pump start-up • Reduced water flow • Slimy deposits blocking main lines and laterals	    
Manganese Oxide	• Reduced water flow • Blackish-brown deposits blocking pipes • Cloudy water at pump start up • Often found in iron bearing water	   

from Alberta Agriculture: "Water Wells that Last for Generations"

Frequent defects

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Downhole TV, problems

Planning
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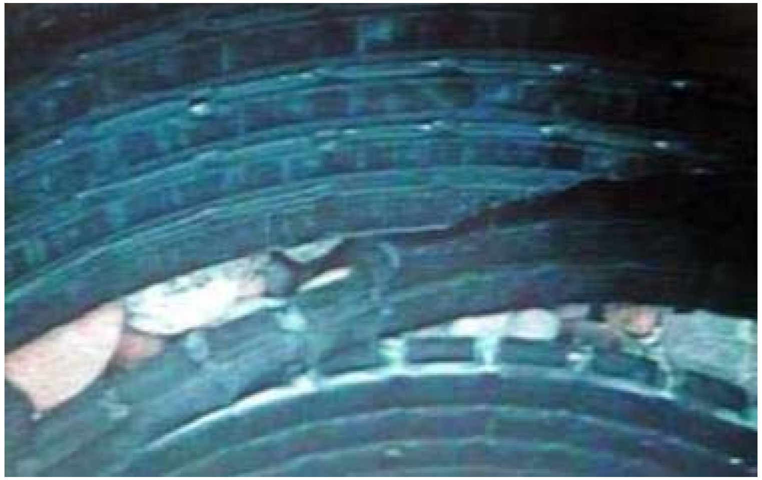
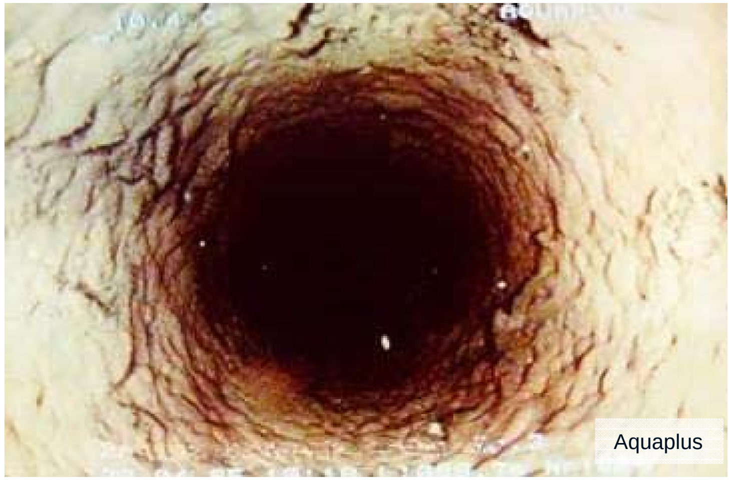
Questions / Discussion





Aquaplus

R. M. Conrad, BBT 2009

Frequent defects

Downhole TV, problems

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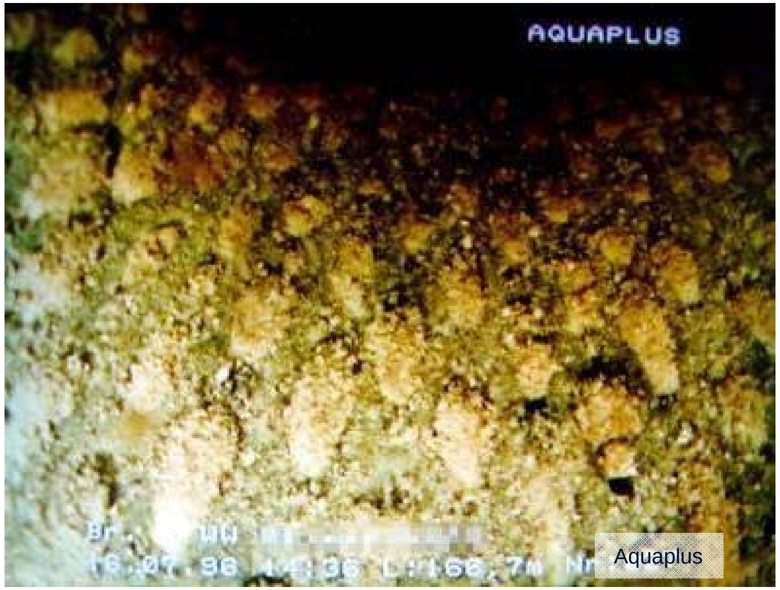

Frequent defects

Planning
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Questions / Discussion

- Grout or clay annulus seal is not properly positioned (>>fine material migrates in well)
- Leaking pipe connections lead to mix of different ground-water layers (>> precipitation of Fe when in contact with surface water)
- Filter pack is not gapless (>> sand in well, settlement)
- Lithology was not described properly, no sieve analyses (>> Inappropriate slot width, depth of filter, gravel pack, wrong positioning)
- Eccentric position of the screen in the boring (>> sand in well)
- ……

Well in good condition

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Downhole TV, example of well in good condition

Planning
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Questions /
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R. M. Conrad, BBT 2009

Well rehabilitation project

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Planning
Drilling
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Questions / Discussion

- Downhole TV
- Pumping test, flowmeter test to measure lateral inflow
- Decision if rehabilitate, repair, or start over new? Cost comparisons of rehabilitation vs. new construction. Better place for a new well
- Planning for rehabilitation
- Choice of methods of well rehabilitation treatment of the well (hydromechanical / chemical)
- Well redevelopment
- Follow-up testing, pumping test

Well rehabilitation

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Brush

physically remove debris prior to a chemical treatment by wire brushing the screen.

Well rehabilitation

High pressure jetting

Tool with a adjustable multihead, water-powered jet. Injects water at a high pressure to dislodge debris from the well.

Planning
Drilling
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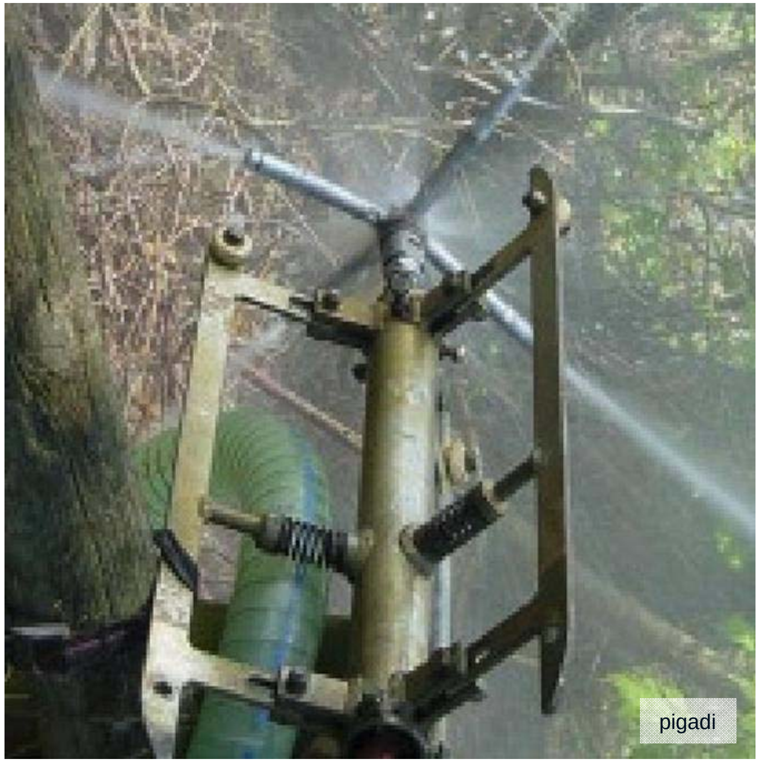
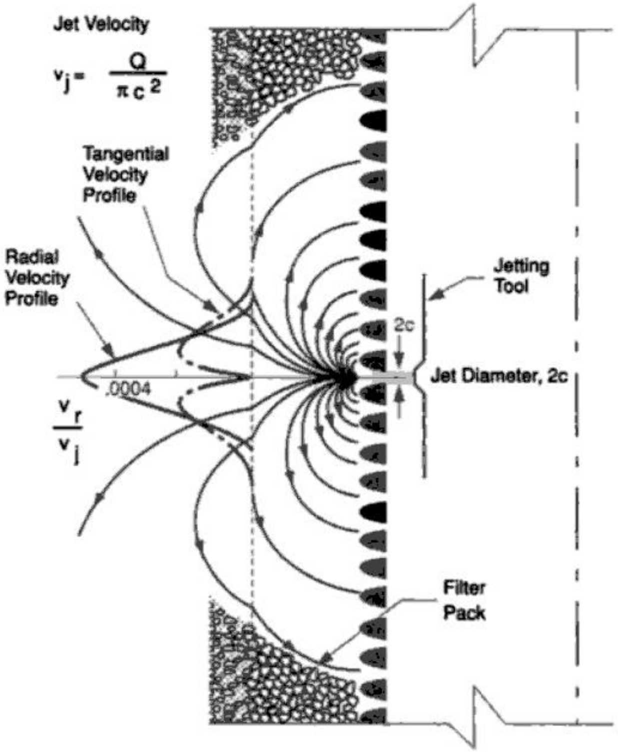
Questions / Discussion

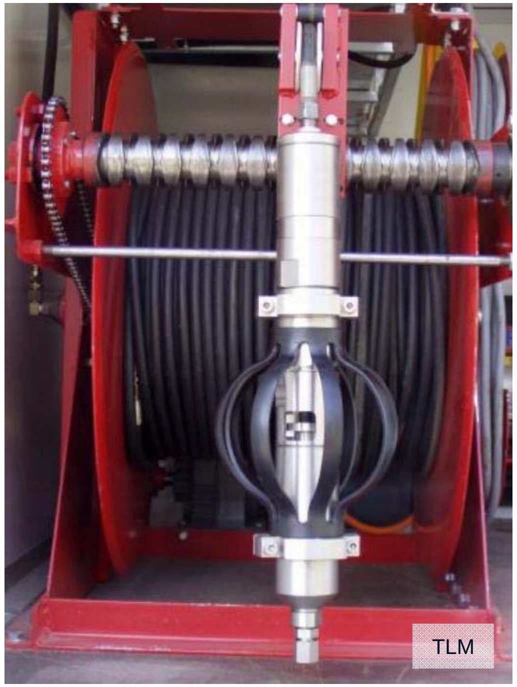


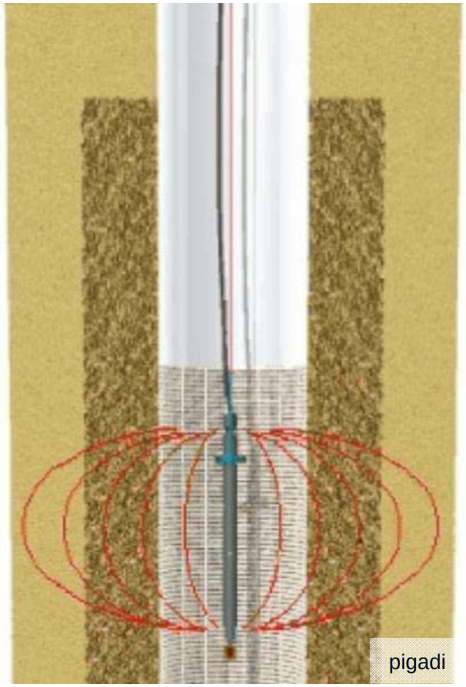


Well rehabilitation

Hydropuls

The hydropuls uses high pressure pulses of gases and liquids to mobilize the gravel in the filter pack and incrustation on the filter screen. The sudden change of volume creates a cravitational effect that looses the material in the filter pack and the pores spaces of the water-saturated aquifer.





Well rehabilitation

KIBAG

Planning
Drilling
Materials
Design
Development
Rehabilitation

Questions /
Discussion

Chemical treatment

Any chemical rehabilitation must take place after hydromechanical cleaning of the well.

To prevent any ground water pollution, chemical treatment of a well should only be used as a last option. In most parts of Europe and North America the use is strongly restricted by regulations.

Common used chemicals are chlorine, hydrogen peroxide, organic acids. The author doesn’t use chemical treatment on a regular basis and therefore refers to literature.

Discussion

Planning
Drilling
Materials
Design
Development
Rehabilitation

Questions /
Discussion

Field impression Niger

Planning
Drilling
Materials
Design
Development
Rehabilitation

Questions /
Discussion

Literature

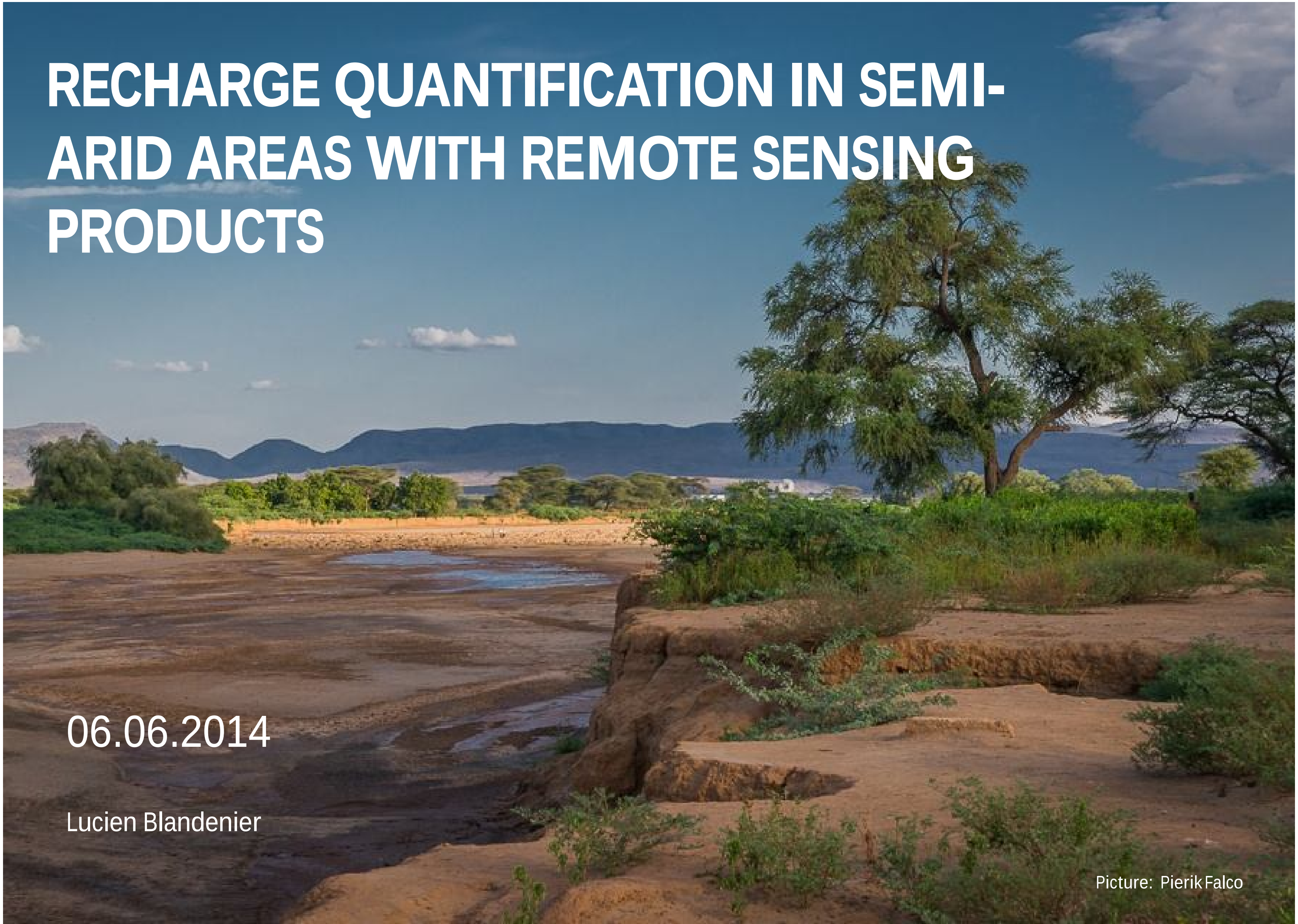
KIBAG

Design
Materials
Development
Rehabilitation

Questions /
Discussion

- Bieske, Rubberts & Treskatis (1998): Bohrbrunnen
- Dresdner Grundwasserforschungszentrum (2003): Untersuchungen zur Bewertung von Gerätetechnik auf die Wirksamkeit in der Kiesschüttung
- Driscoll, F. (1986) Groundwater and Wells, St. Paul: Johnson Division
- Houben & Treskatis (2007): Regeneration und Sanierung von Brunnen (Water Well Rehabilitation and Restauration)
- ICRC (2010): Technical Review. Borehole drilling and rehabilitation under field conditions
- Roscoe Moss Company, John Wiley and Sons, New York, NY (1990): Handbook of Ground Water Development
- Schreurs, R. : Well Development is Critical", Developing World Water, Hong Kong: Grosvenor Press Int'l
- WVGW, M. Tholen (2006): Arbeitshilfe für Brunnenbauer
- Fletcher G. Driscoll (2008, 3. Edition): Groundwater and Wells (Johnson

RECHARGE QUANTIFICATION IN SEMI-ARID AREAS WITH REMOTE SENSING PRODUCTS



06.06.2014

Lucien Blandenier

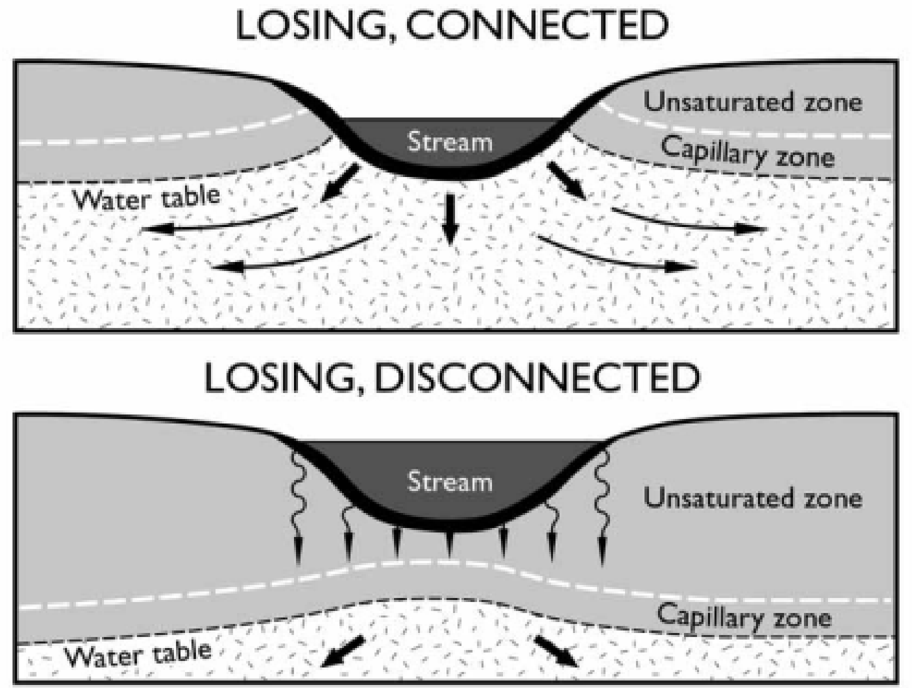
Picture: Pierik Falco

AIM OF THE HYDROGEOLOGICAL STUDY

- Where is the water ?
- In what quantities ?
- In what qualities ?

- Specificity of semi-arid and arid areas:
  - Water availability is not permanent !
  - Quality is often a 'luxury' (there is a lot of brackish or salty water) !
  - Recharge quantification is crucial for a sustainable exploitation

- Low precipitations (200-400 mm/yr)
- $ET_{pot} >> Et_a$
- Rivers are often disconnected and non permanent
- Infiltration is very low (about 0.5 - 5% of rainfall)

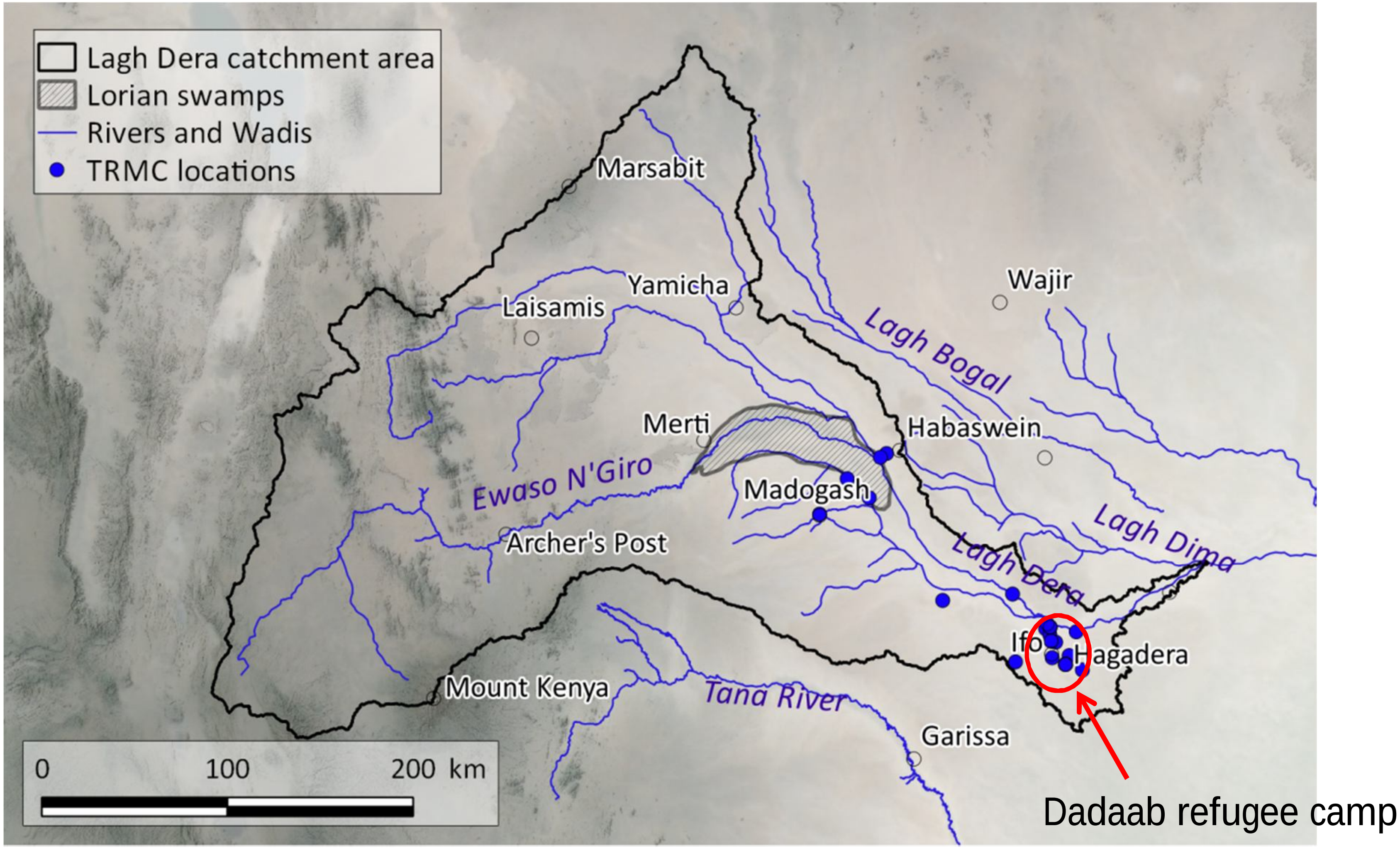


Brunner et al, 2009

MERTI AQUIFER – NORTHEAST KENYA

- The Dadaab camp exists since more than 20 years
- About 400'000 refugees
- About 1'000'000 inhabitants from local communities
- Precipitatiton : between 250 and 400 mm/yr
- Two rainy seasons (November and June)
- « Mega » aquifer , 300 km long and 70 width
- 100 m of unsaturated zone

MERTI AQUIFER – WATER CATCHMENT



MERTI AQUIFER – SCHEMATIC CONCEPTUAL MODEL

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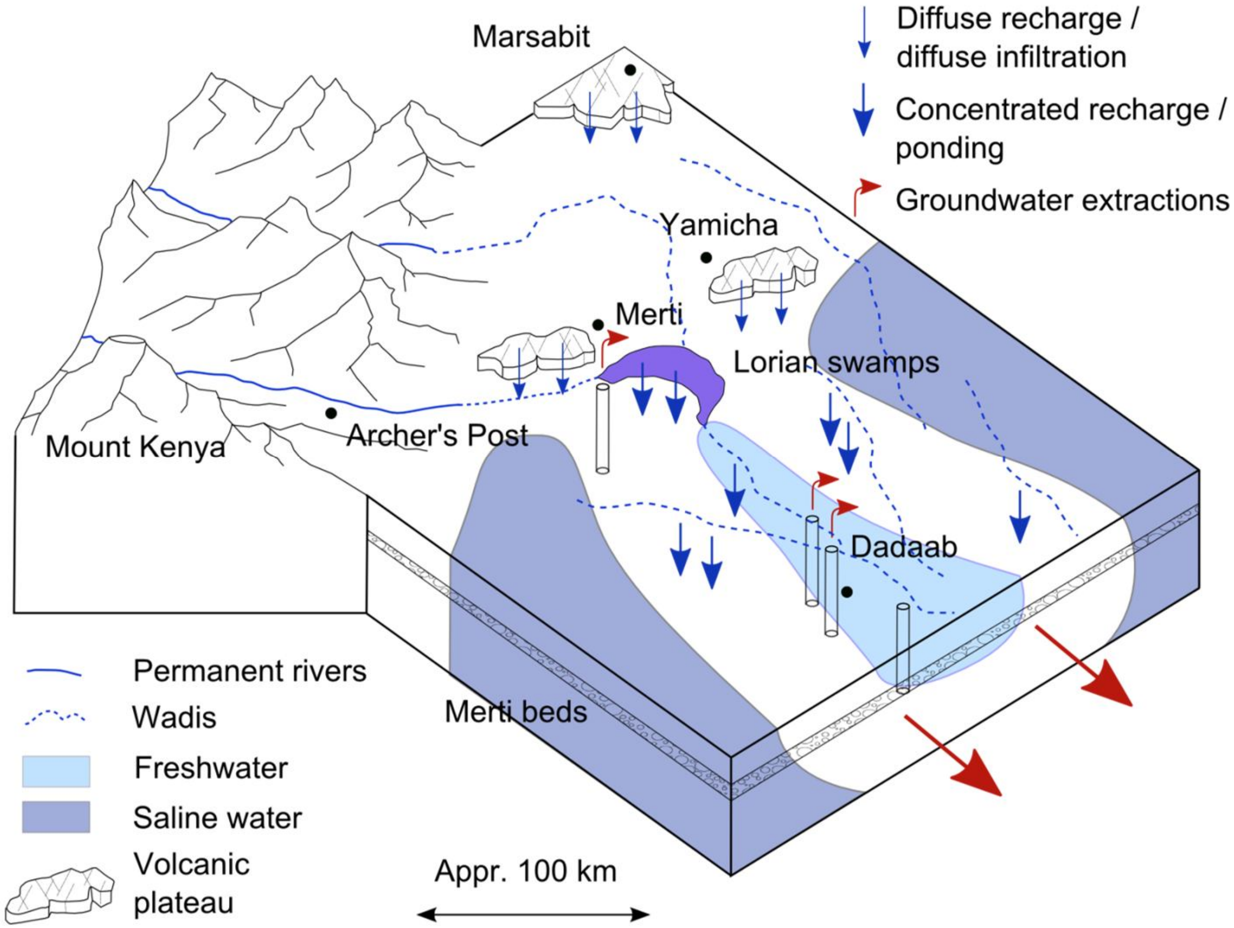
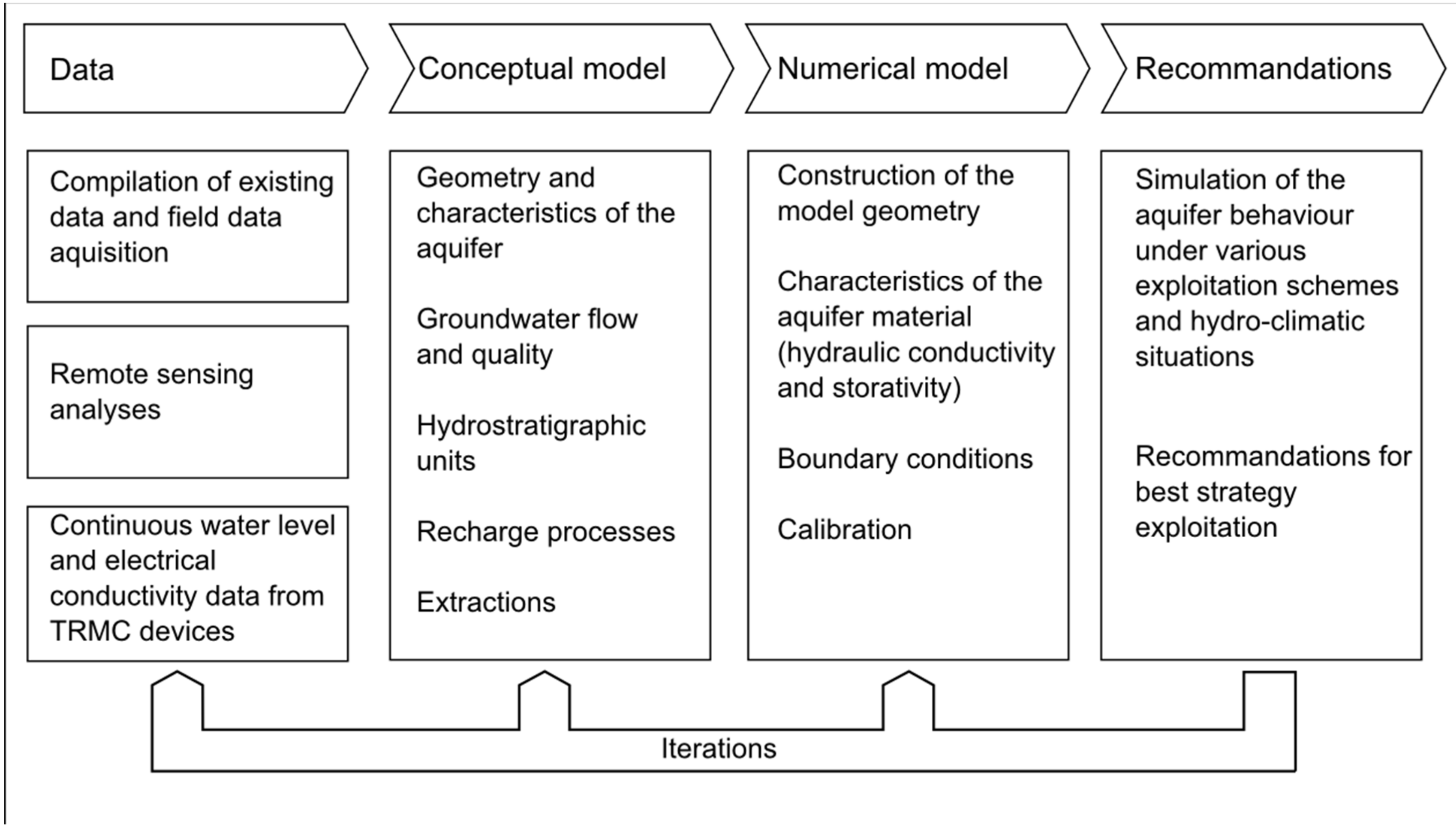


MERTI AQUIFER – METHODOLOGY



MERTI AQUIFER – CONCEPTUAL MODEL ELABORATION

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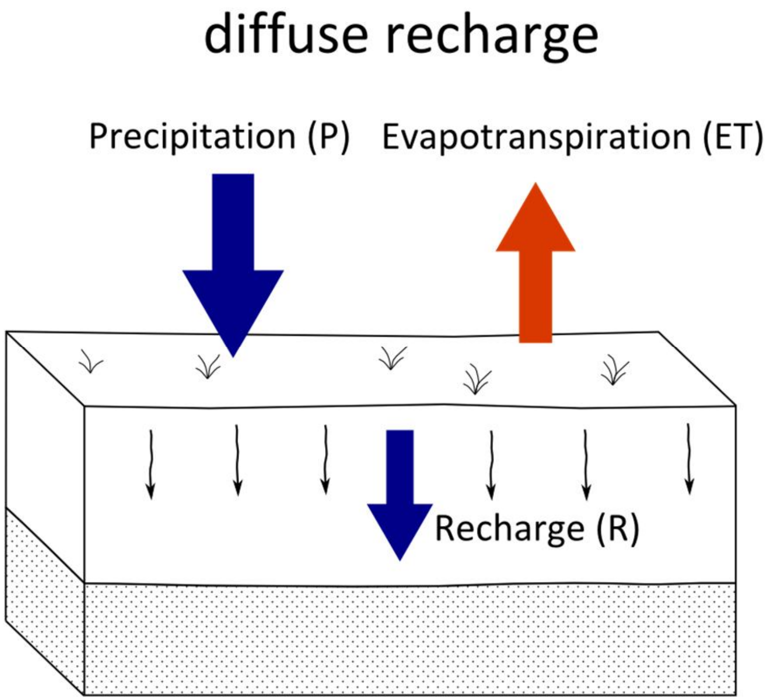
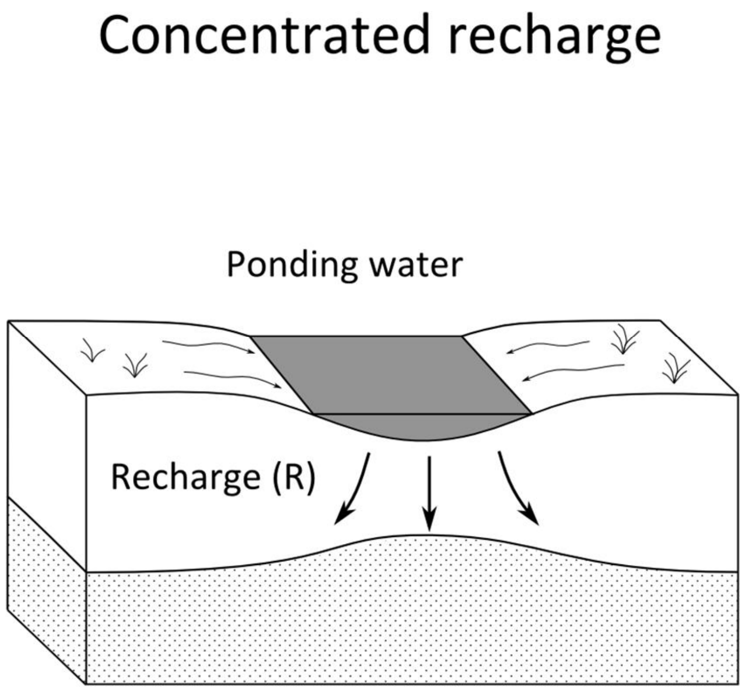
- Recharge
- Extractions
- Geometry and characteristics of the reservoir : permeabilities, storativity (~permeability), …
- Groundwater flow: piezometry
- Groundwater “history” and residence time : water quality (electrical conductivity, major elements, trace elements, isotopes, temperature)

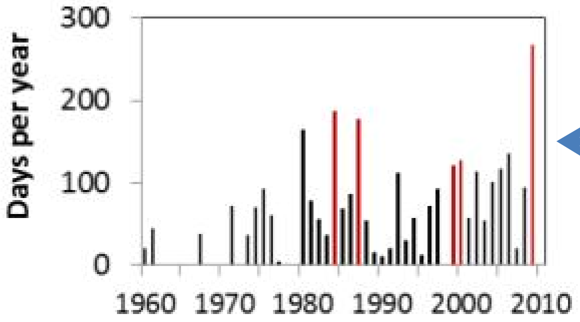
RECHARGE PROCESSES

– Diffuse recharge vs concentrated recharge

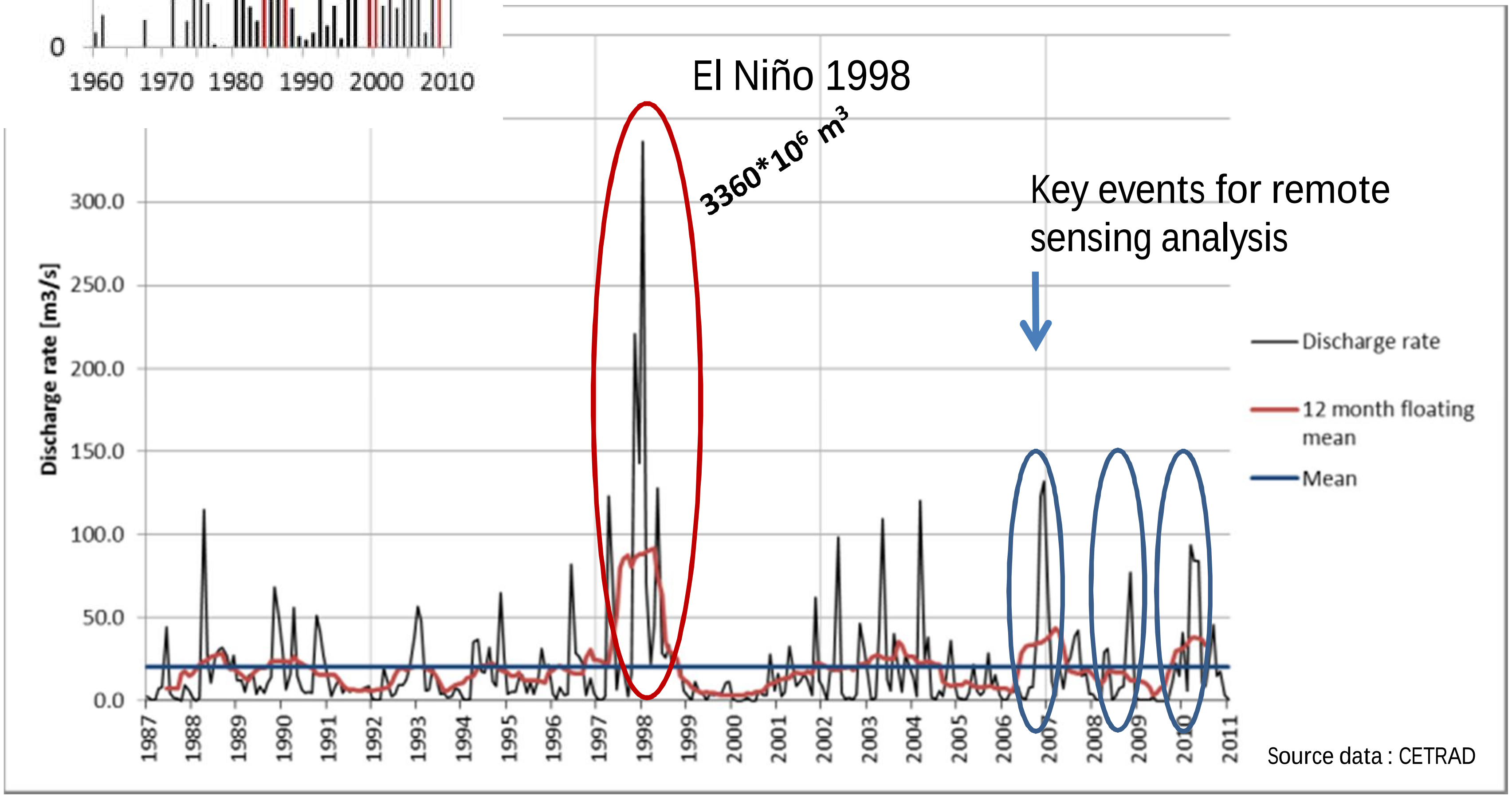




OBSERVED RECHARGE FROM THE SURFACE



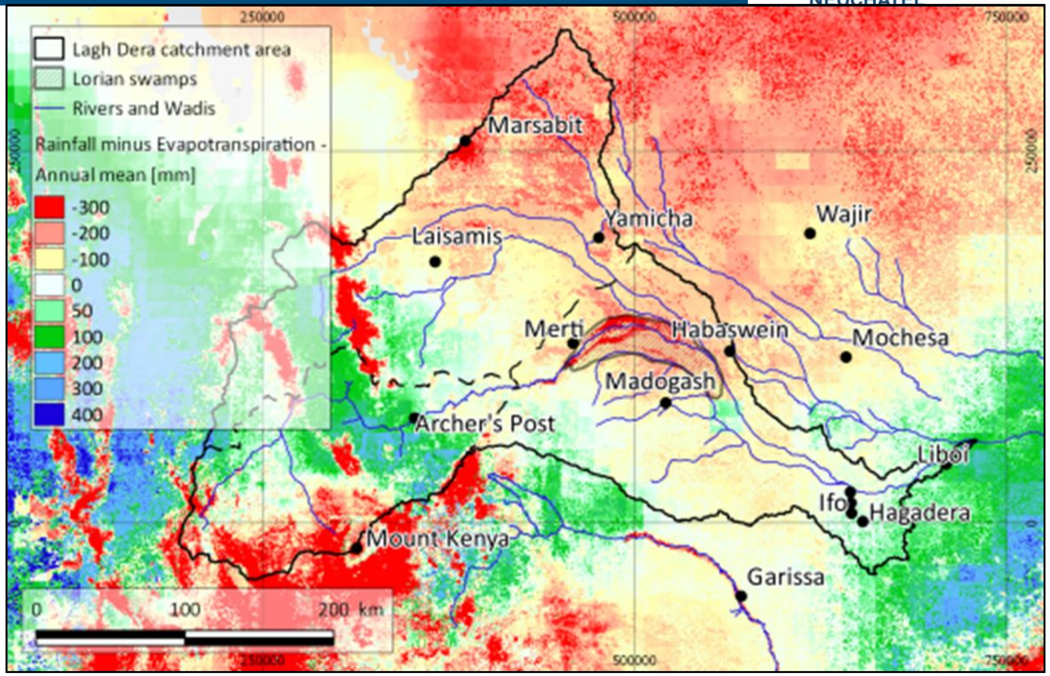
Number of days per year with discharge lower than 2 m³/s



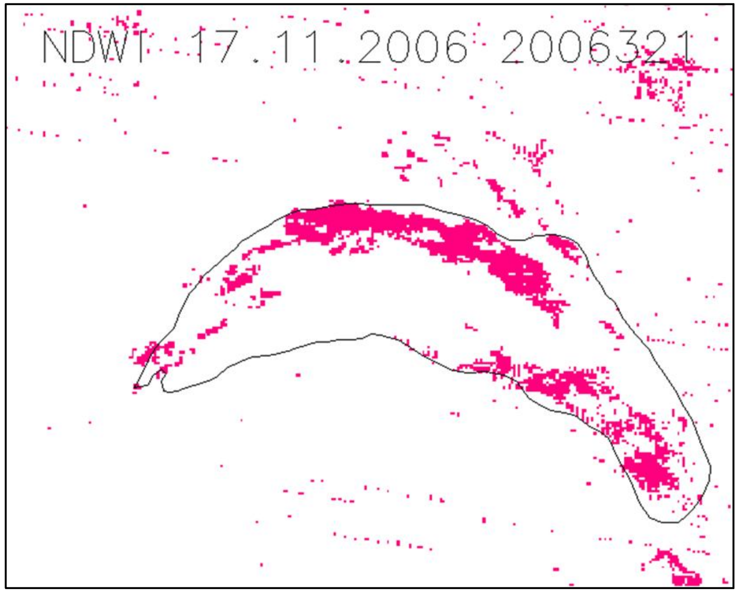
Source data : CETRAD

OBSERVED RECHARGE FROM THE SURFACE

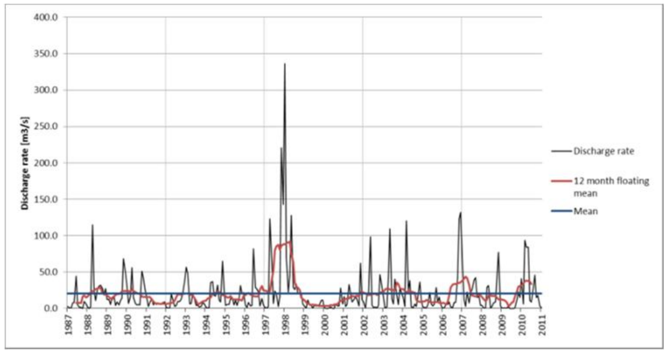
Difference between P and ET



Inundated areas vs time

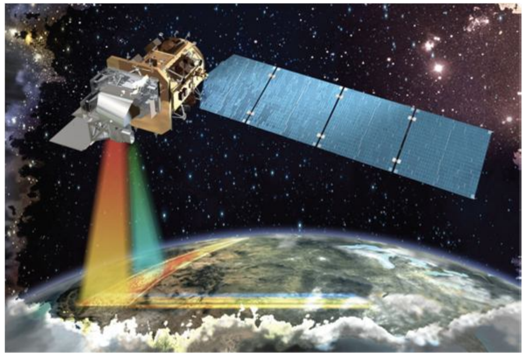


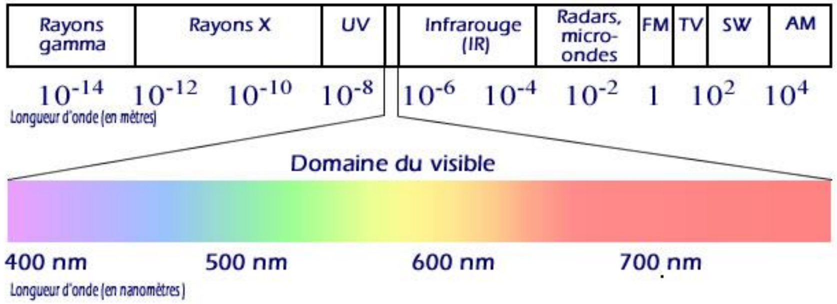
Input : River discharge rate



REMOTE SENSING

– Multispectral satellite images





– Rainfall : Fewsnet (http://earlywarning.usgs.gov/fews/africa/web/readme.php?symbol=dailyrfe)
– Evapotranspiration : MODIS (http://modis.gsfc.nasa.gov/)

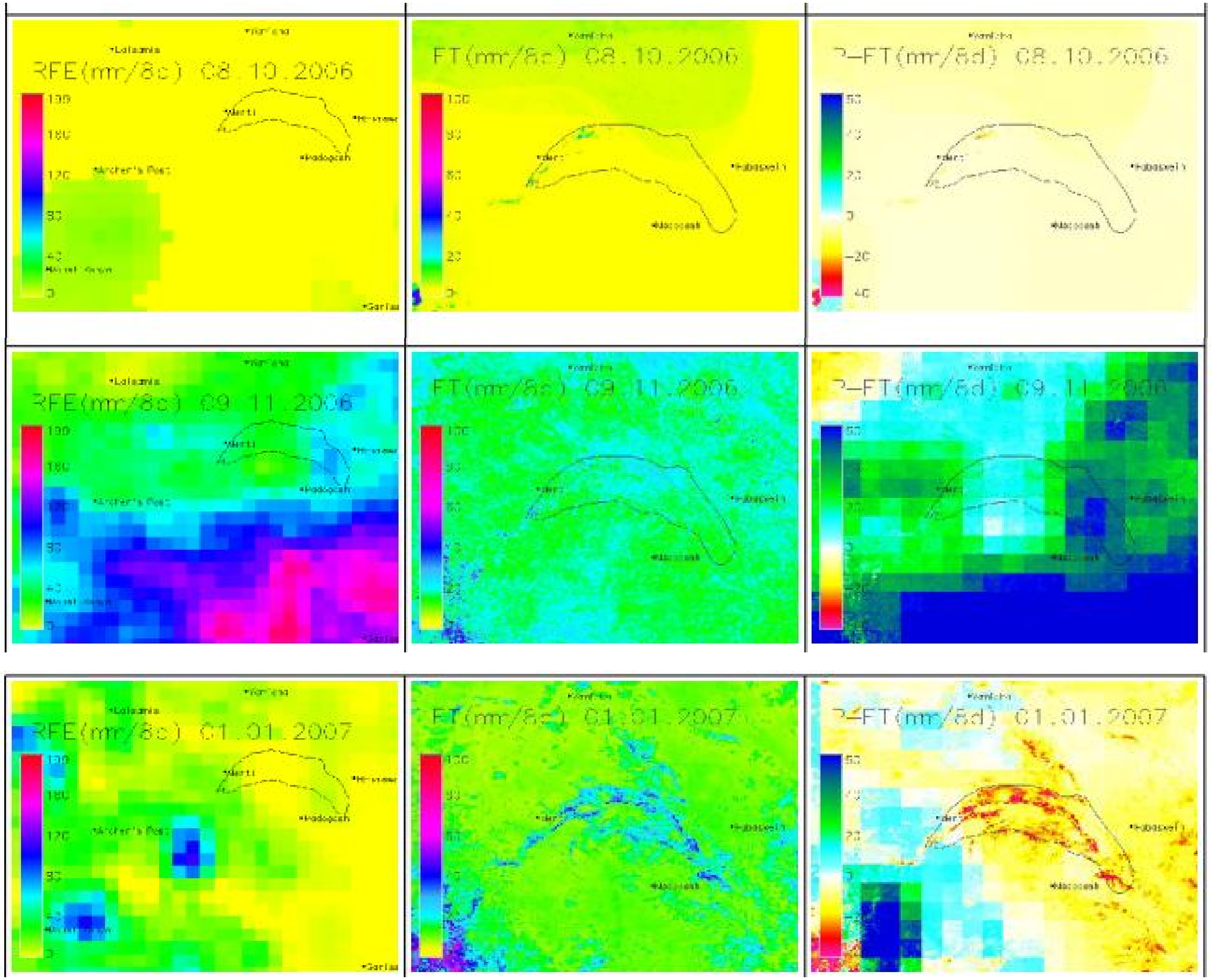
REMOTE SENSING – PRECIPITATION - EVAPOTRANSPIRATION

RFE | ET | P-ET

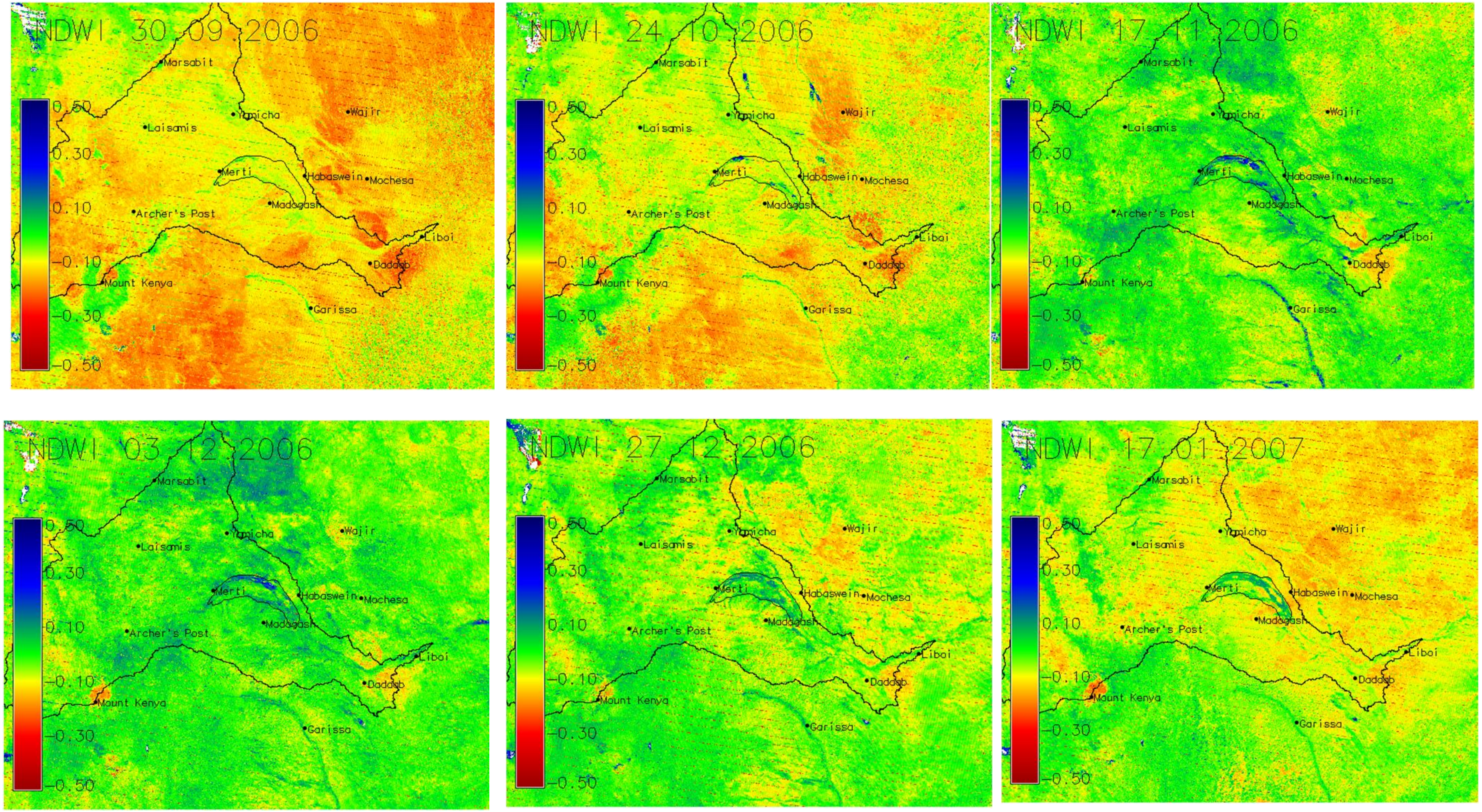
08.10.2006

09.11.2006

01.01.2007



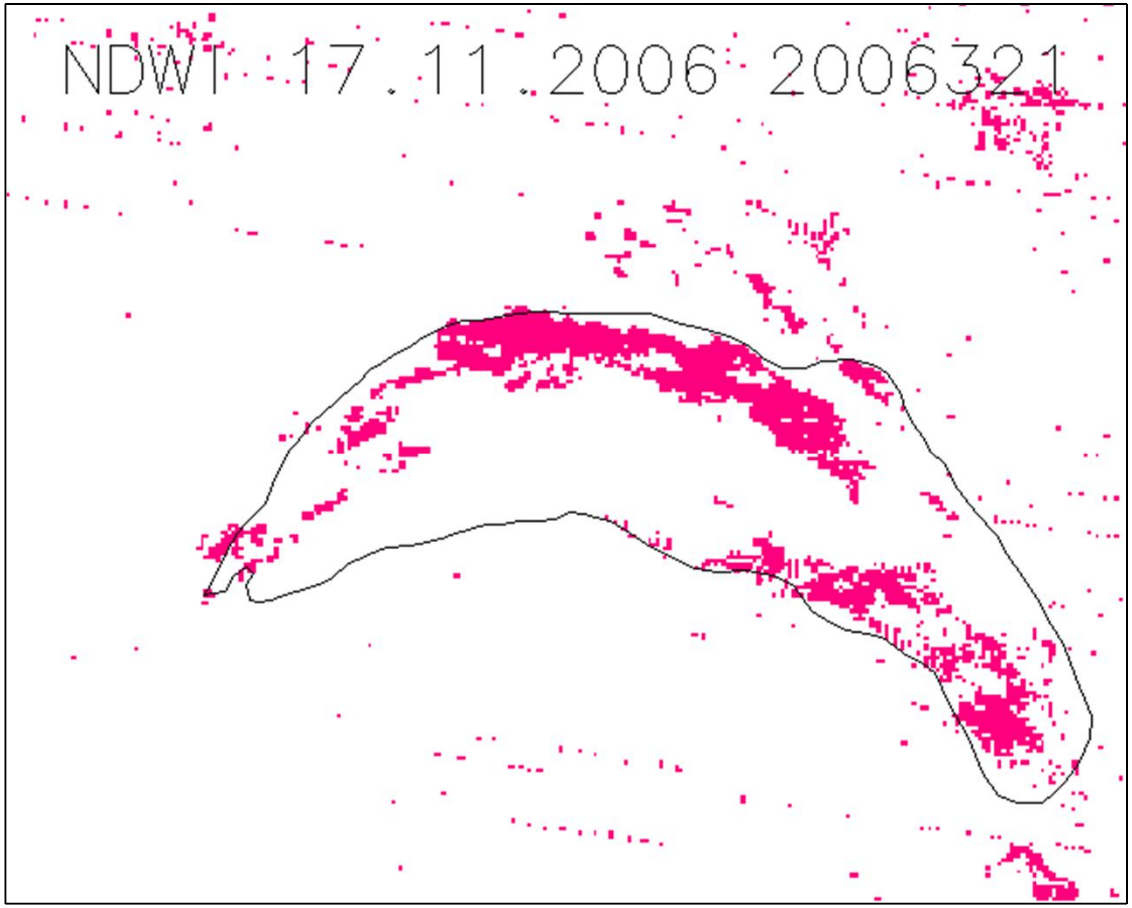
REMOTE SENSING – INUNDATED AREAS



→ Trouver la limite !

OBSERVED RECHARGE FROM SURFACE

Inundated areas vs time

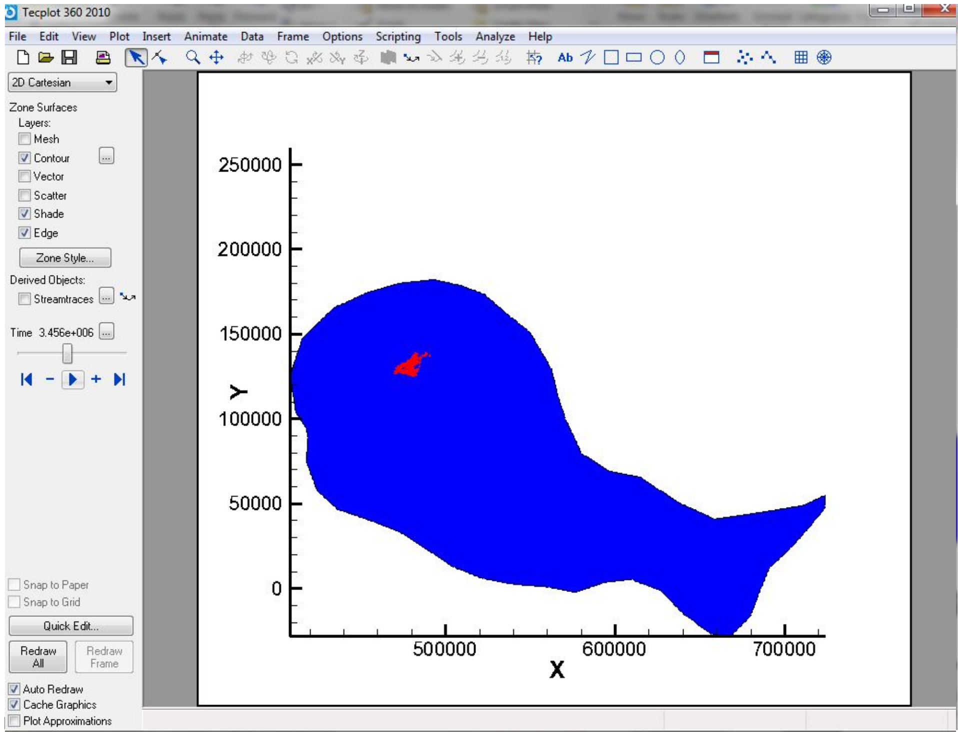


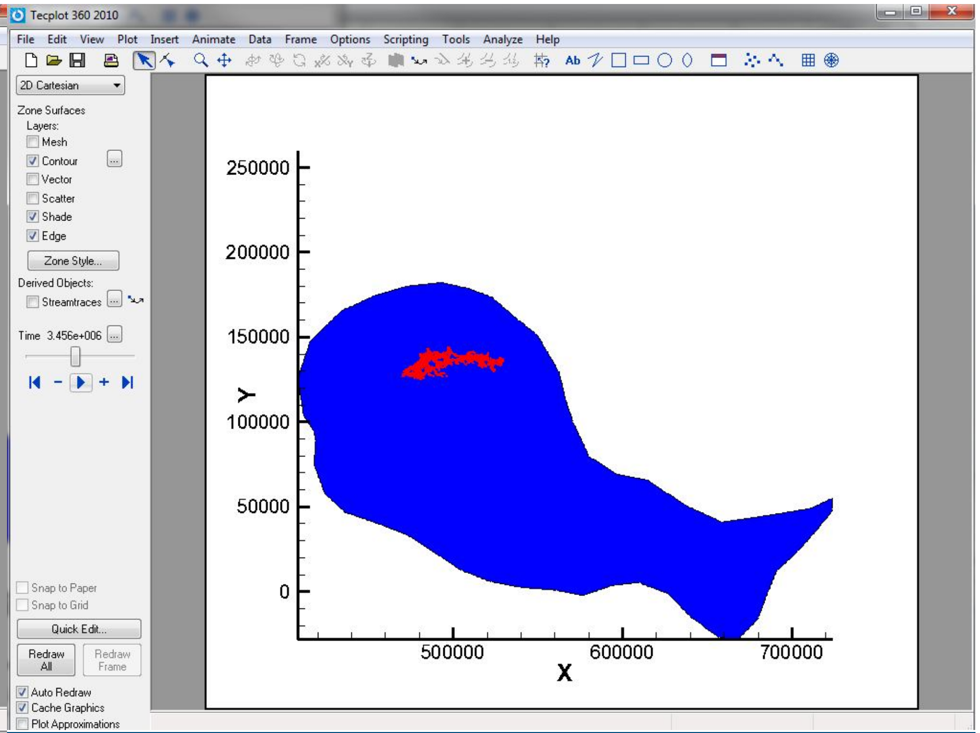
SURFACE RECHARGE MODELLING

Numerical model that includes :

- River discharge rate (Q)
- Precipitation (P)
- Evapotranspiration (ET)
- Soil permeability (K)

→ Q + P – ET = RECHARGE

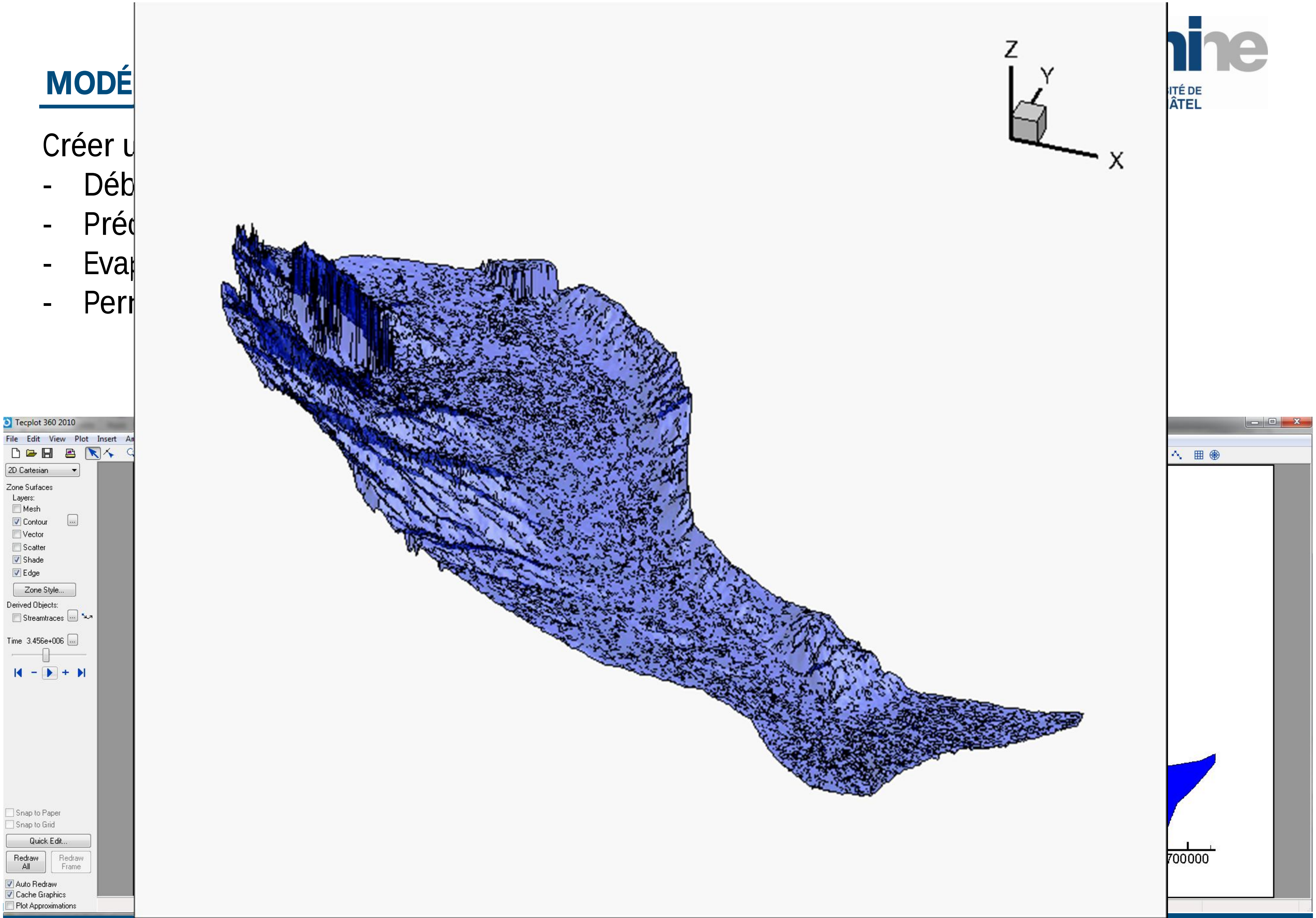




MODÉ

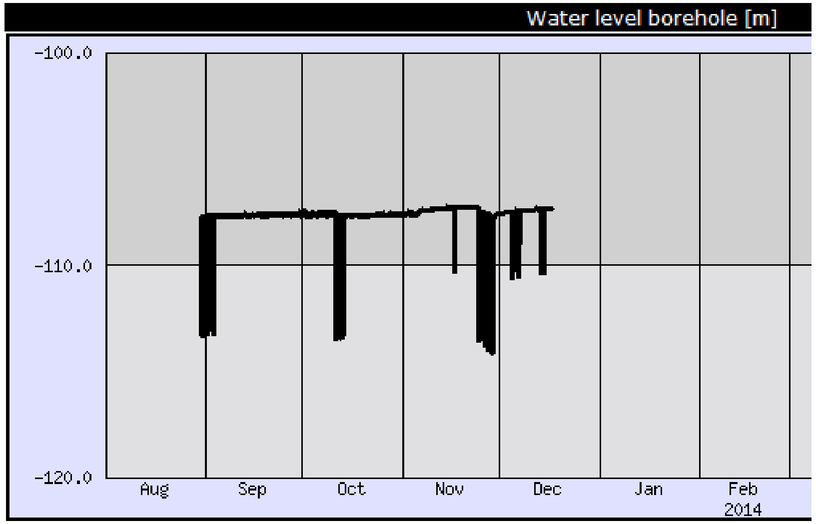
Créer u

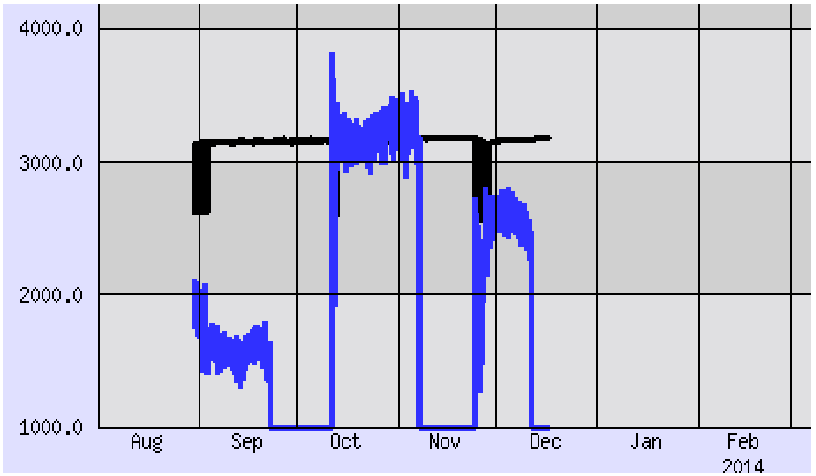
- Déb
- Préc
- Evap
- Perr



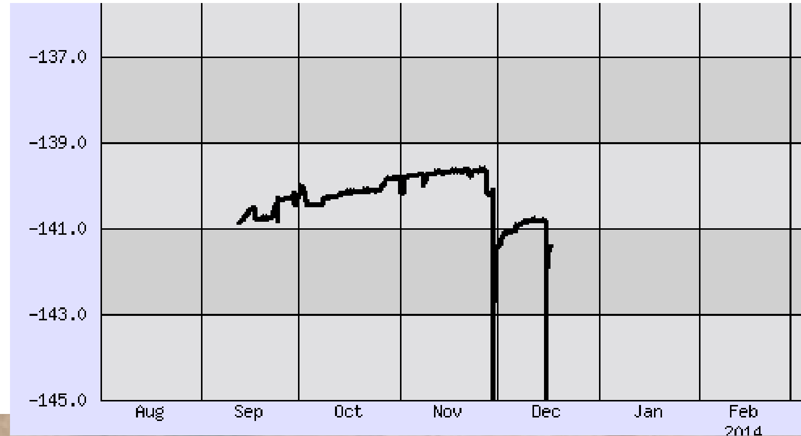
MERTI AQUIFER – RESPONSE OF THE AQUIFER AFTER A FLOOD ?

SKANSKA REDCROSS BH1

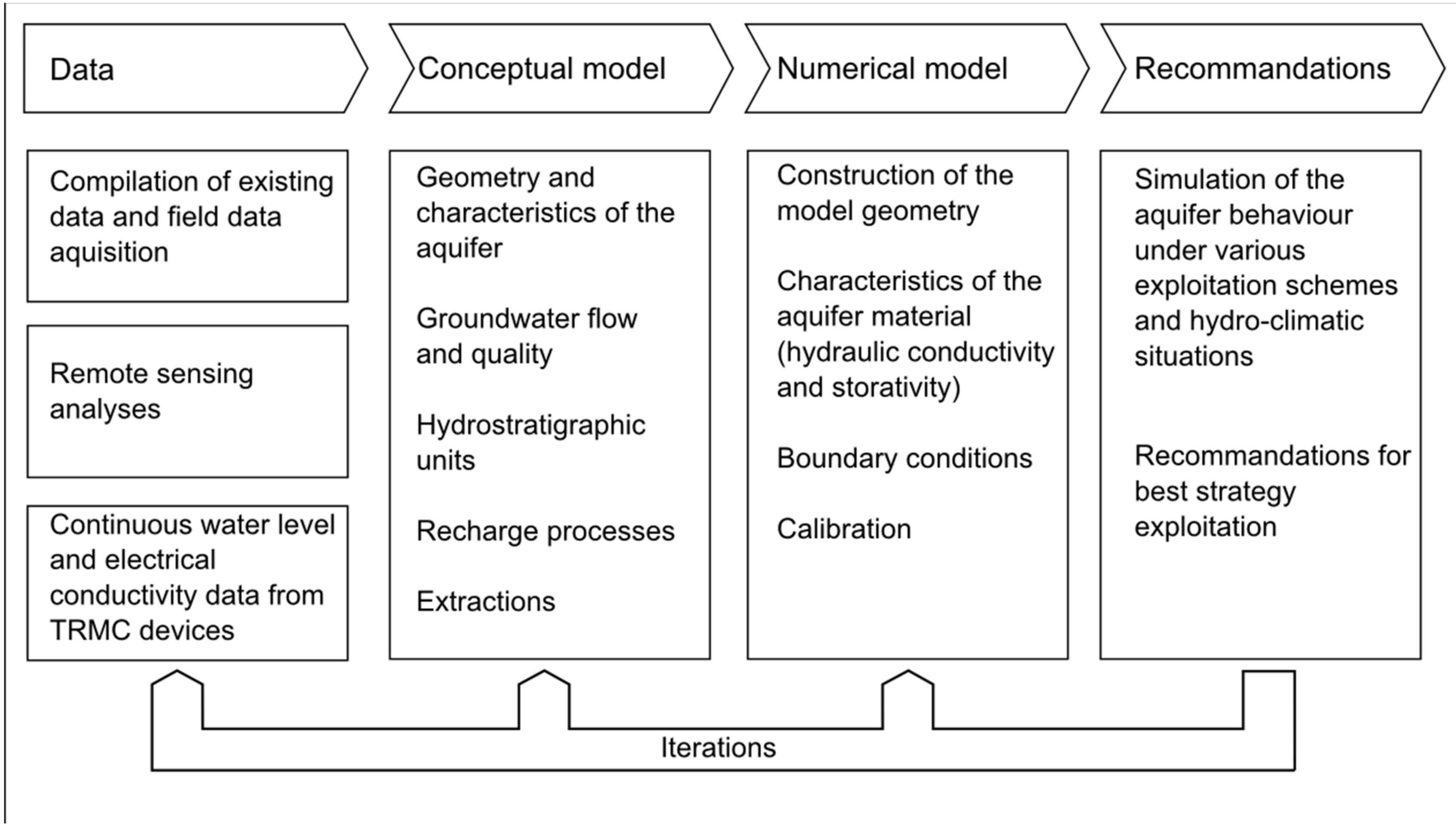




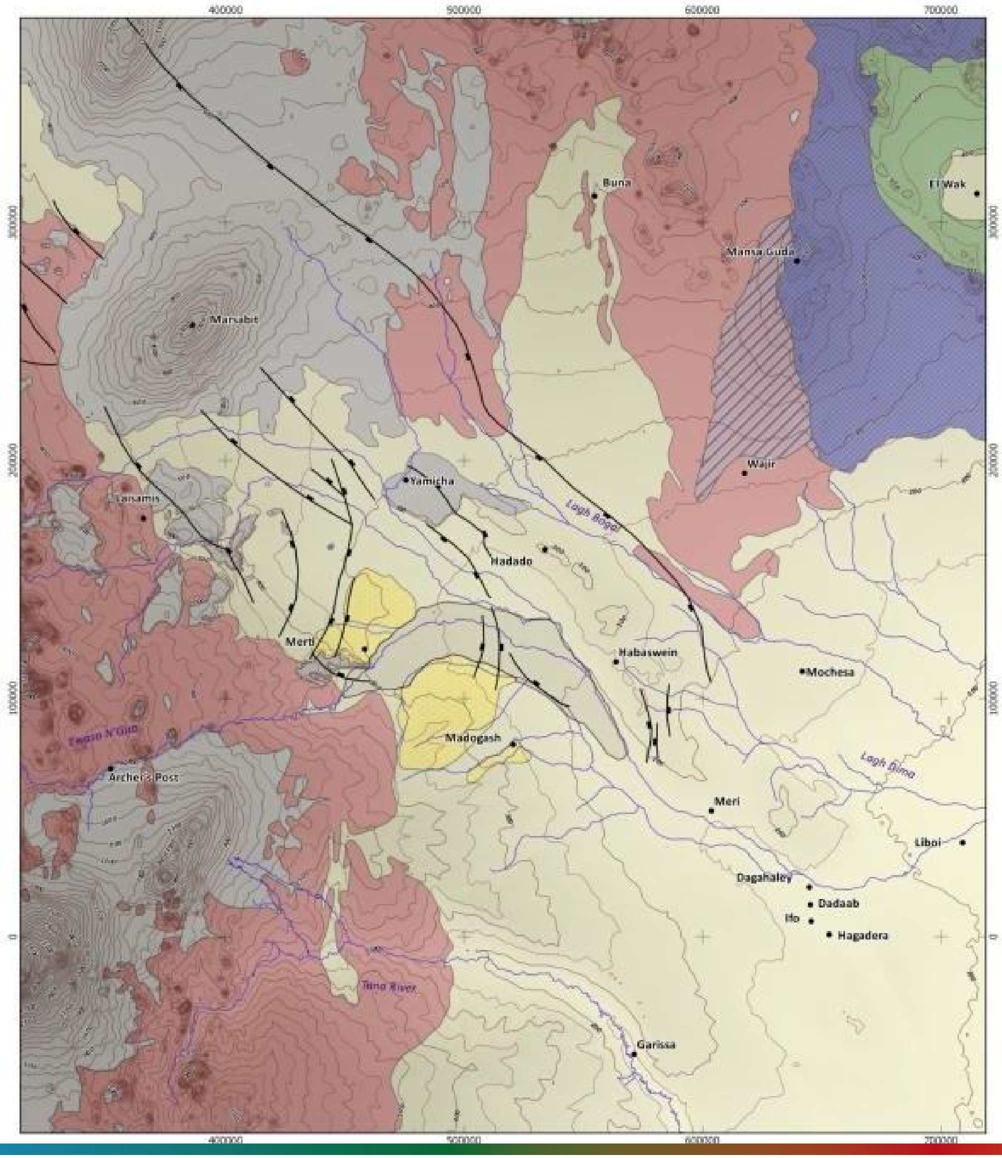
MADOGASHE HOSPITAL BH



MERTI AQUIFER – METHODOLOGY (2)



MERTI AQUIFER – AQUIFER GEOMETRY



Geological units

- Quaternary and tertiary deposits, undifferentiated
- Miocene and pliocene volcanic rocks
- Merti beds (Miocene)
- Mandera series and Daua limestone series (Jurassic)
- Marehan series (Cretaceous)
- Mansa Guda Formation (Triassic)
- Crystalline rocks (Precambrian)

Map elements

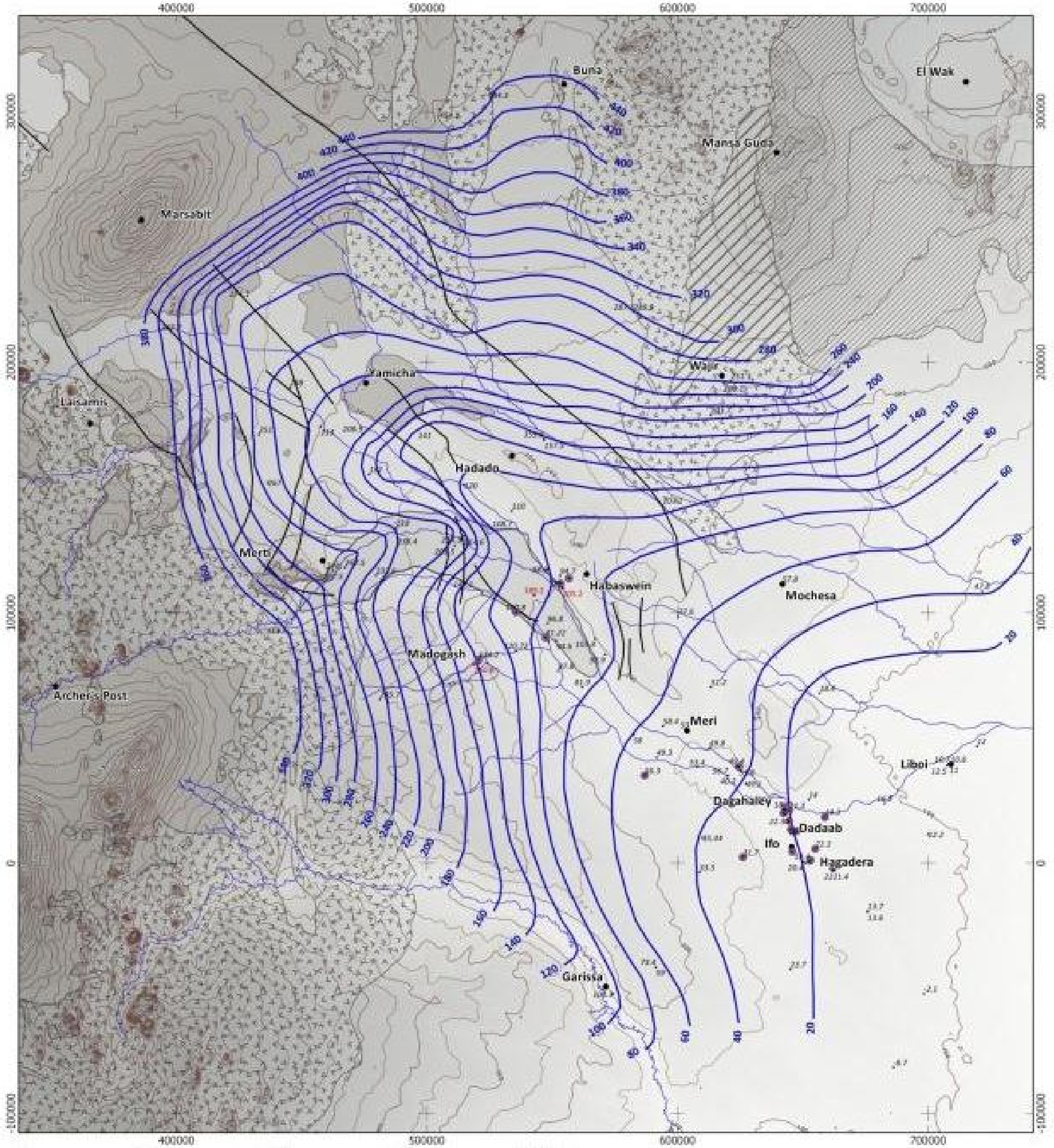
- Locations
- Rivers and wadis
- Lorian Swamps
- Down faults

Scale 1:1.500.000

Contour lines (50m)

Compiled from the Kenyan geological map 1962, Swarzenski 1977, Bosworth 1993, GIBB 2004, Earth Water company 2011, Landsat images

MERTI AQUIFER – REGIONAL PIEZOMETRY



Compiled from Swarzenski 1977, Lane 1995, GIBB 2004, Earth Water company 2011 and 2013

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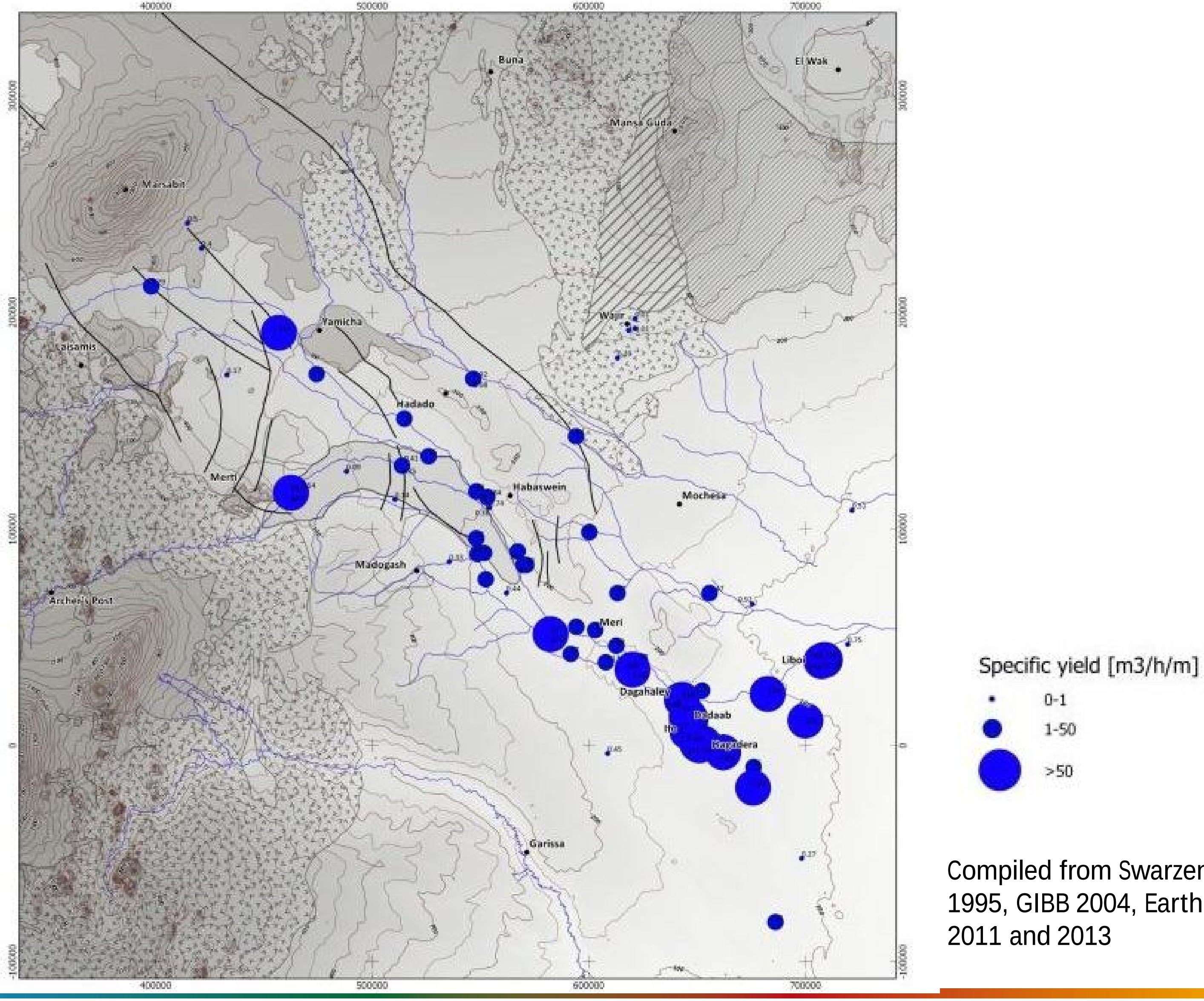
MERTI AQUIFER – SPECIFIC DISCHARGE



Compiled from Swarzenski 1977, Lane 1995, GIBB 2004, Earth Water company 2011 and 2013

MERTI AQUIFER – ELECTRICAL CONDUCTIVITY (SALINITY)

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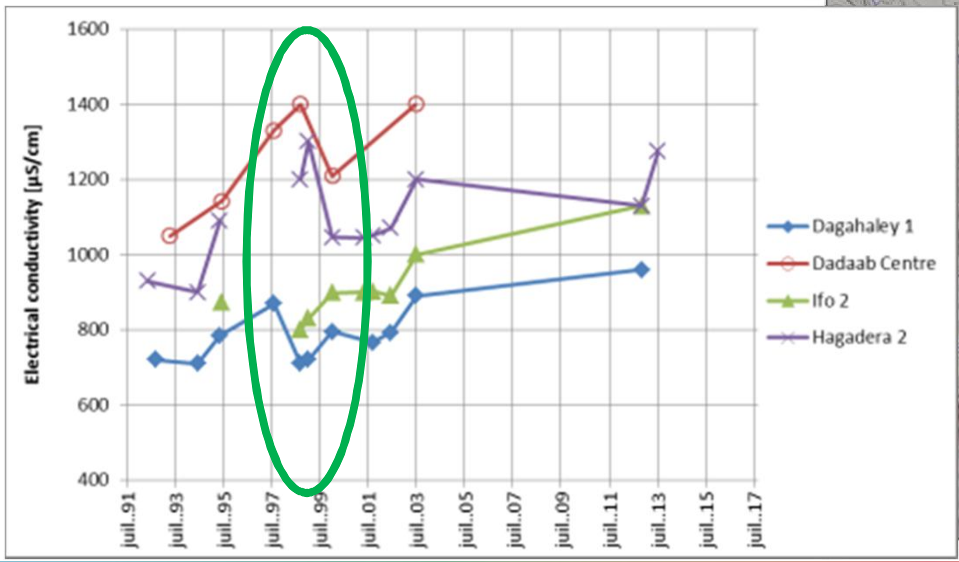
Electrical conductivity [µS/cm]

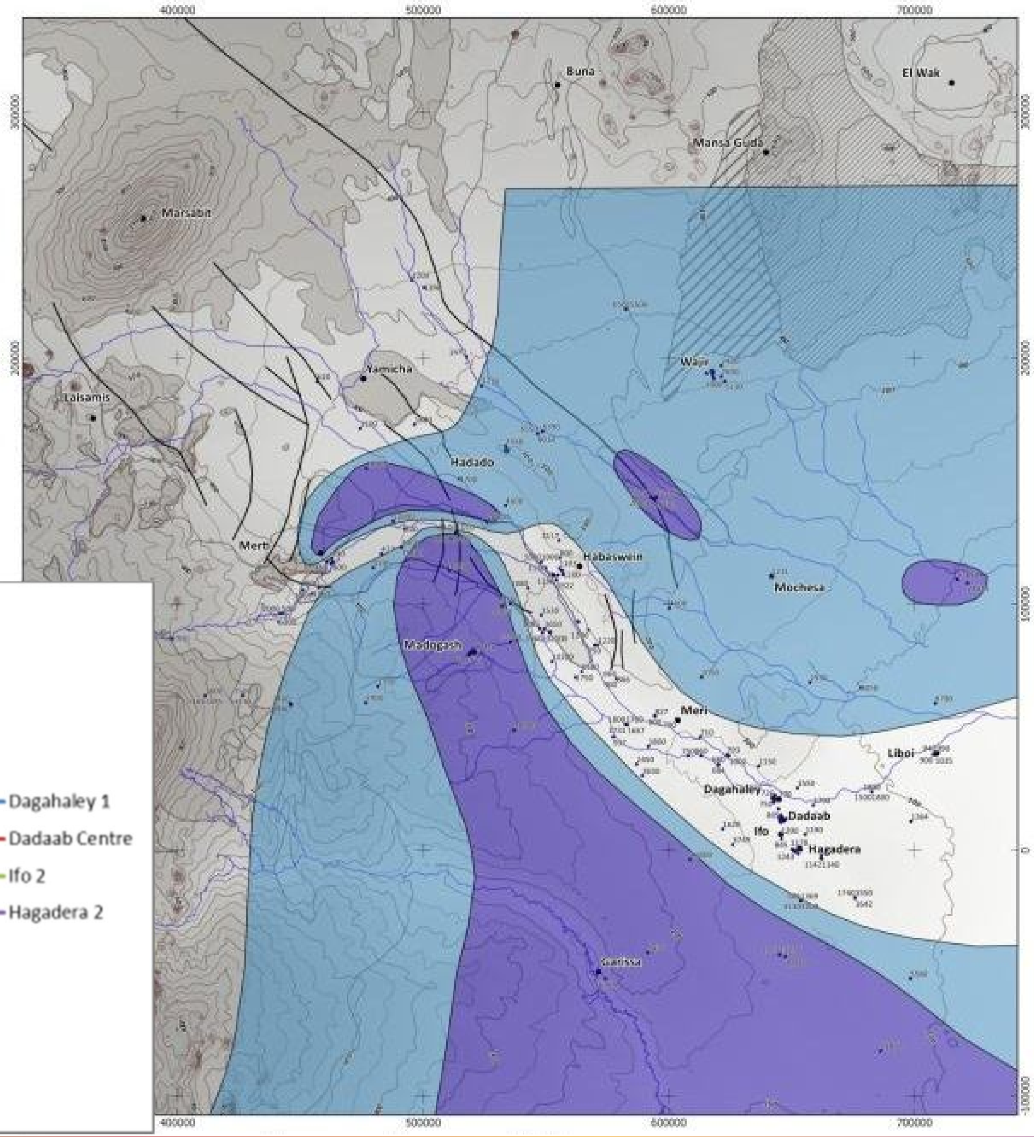
- <5000
- 5000-10000
- >10000
- EC measurements

For comparisation :

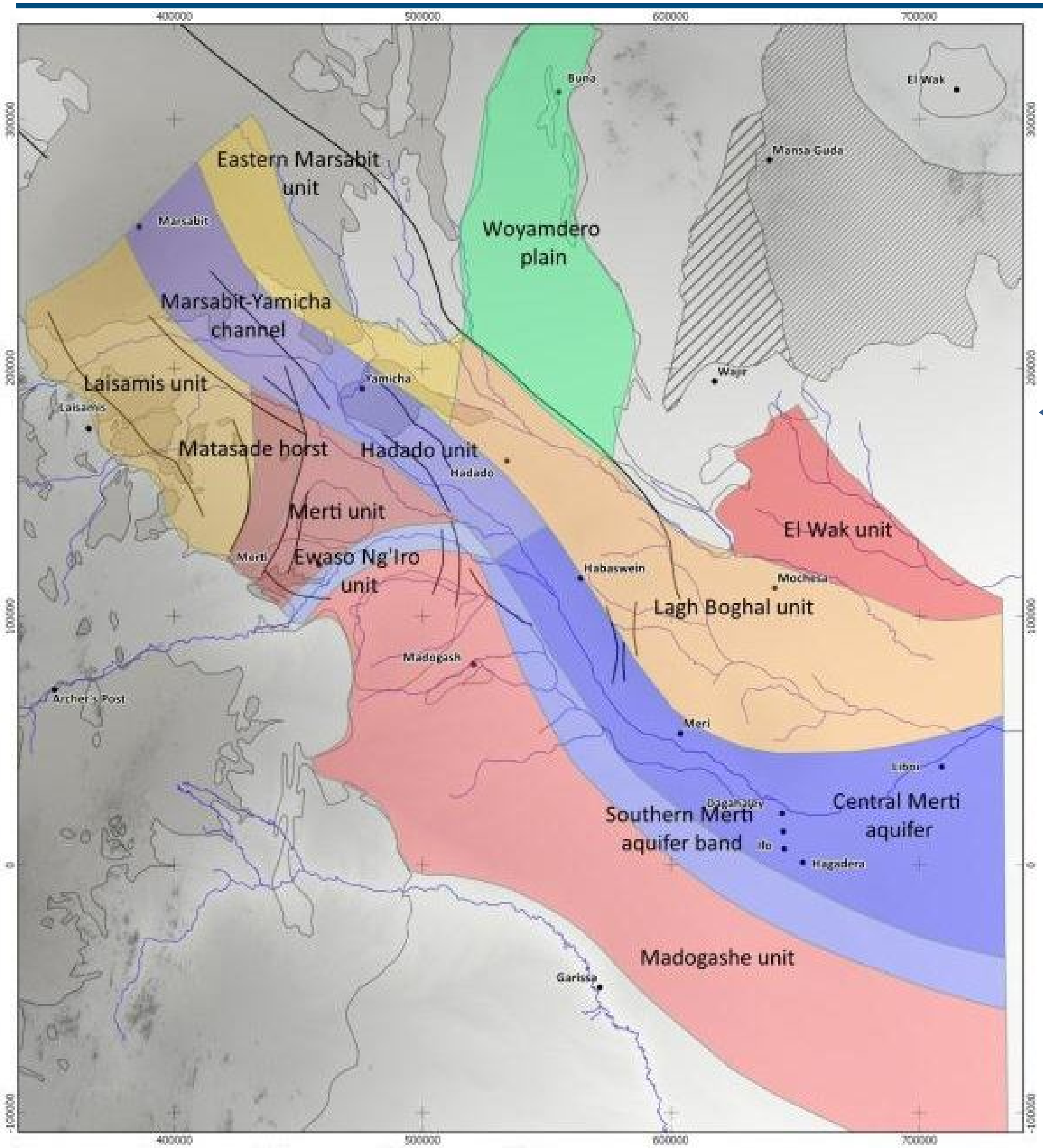
Sea water EC = 50’000 µS/cm

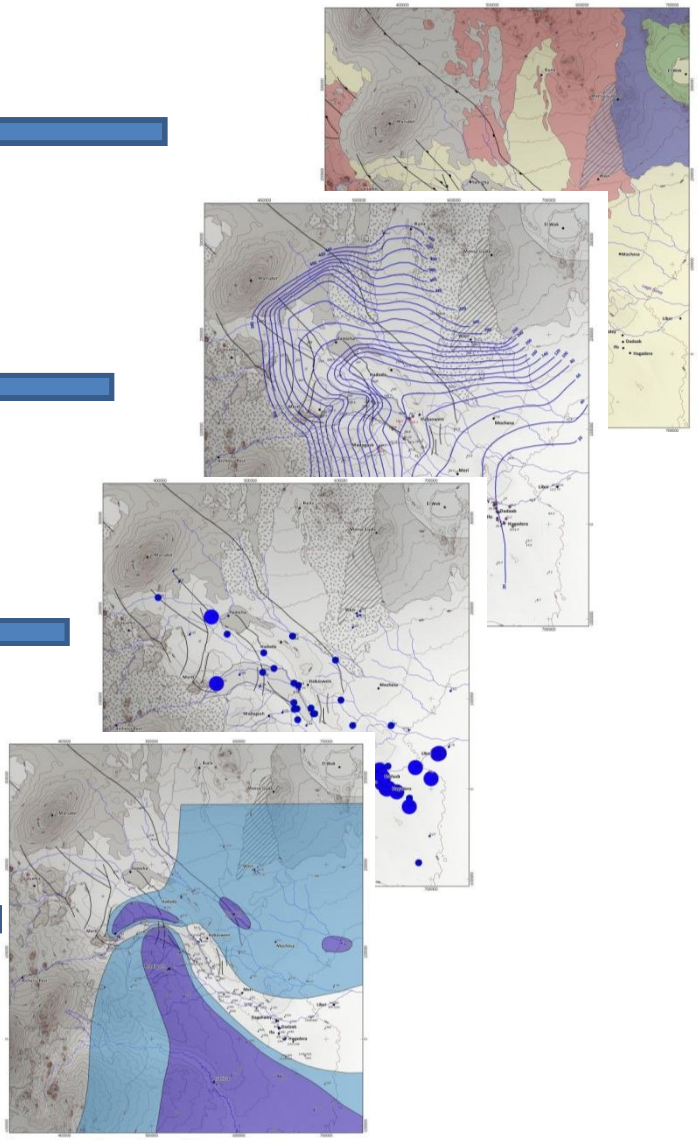
El Niño 1998



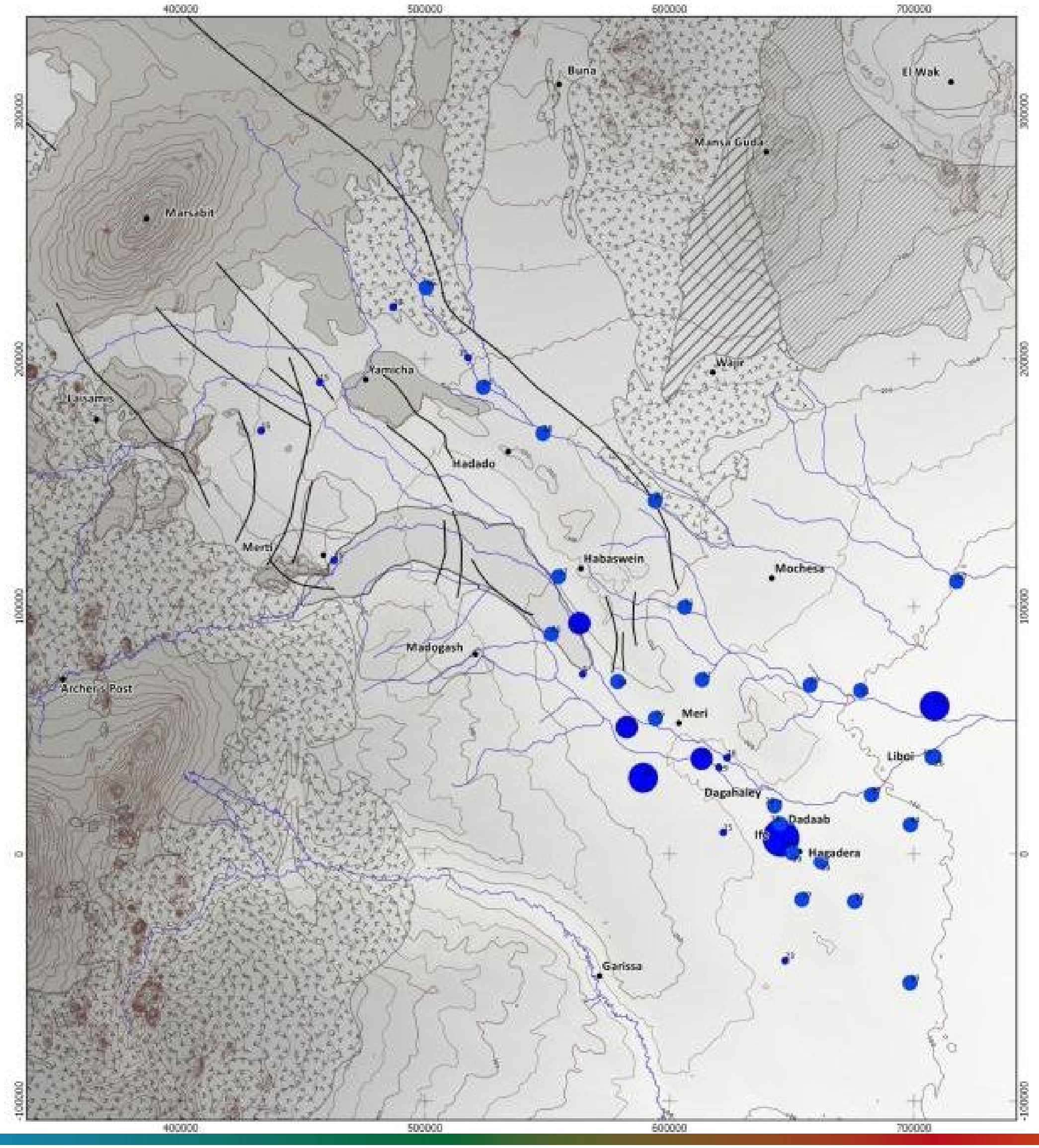


MERTI AQUIFE R– STRATIGRAPHIC UNITS





MERTI AQUIFER – EXTRACTIONS



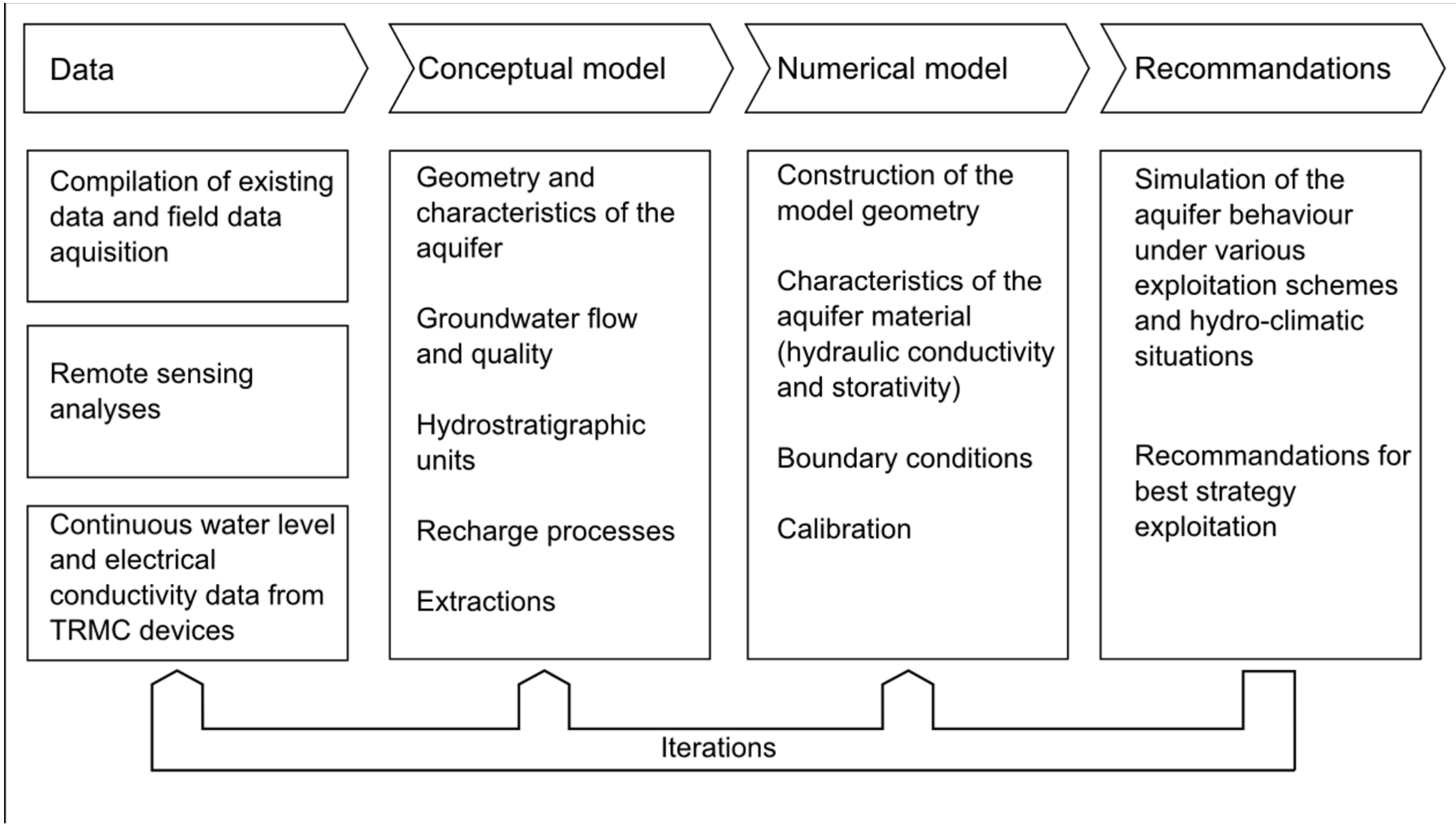
Abstraction rates
(from Earth Water, 2012)

- 0 - 25
- 25 - 50
- 50 - 75
- 75 - 100
- > 100

Total annuel : environ 3 millions de m^3

→ **Water budget?**
Recharge ???

MERTI AQUIFER – METHODOLOGY



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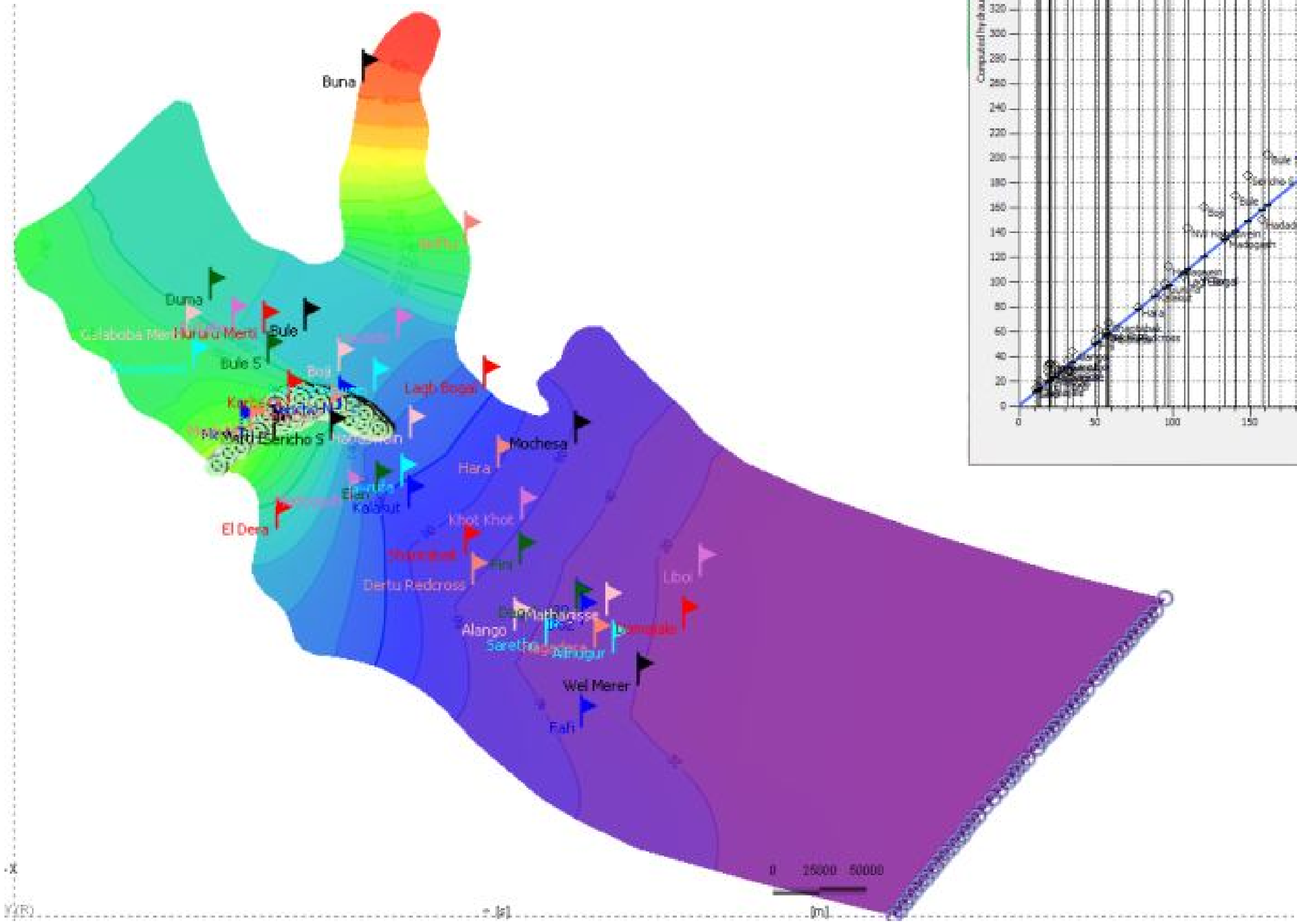

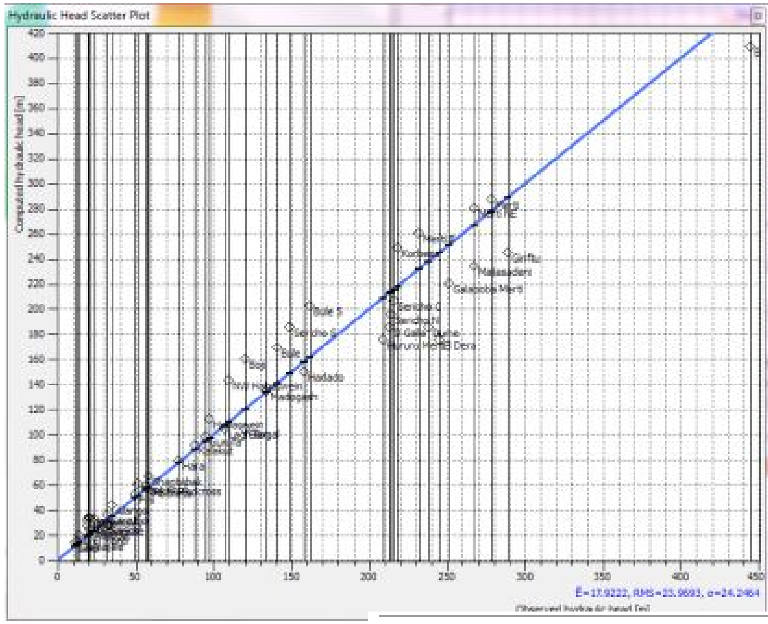

Dirichlet-BCs	-32665.7	
Neumann-BCs		
Cauchy-BCs	-0.796583	+26703.6
Wells		
Distributed Sources/Sinks		+5962.9
Total Balance	-0.000458715	

Thank you !