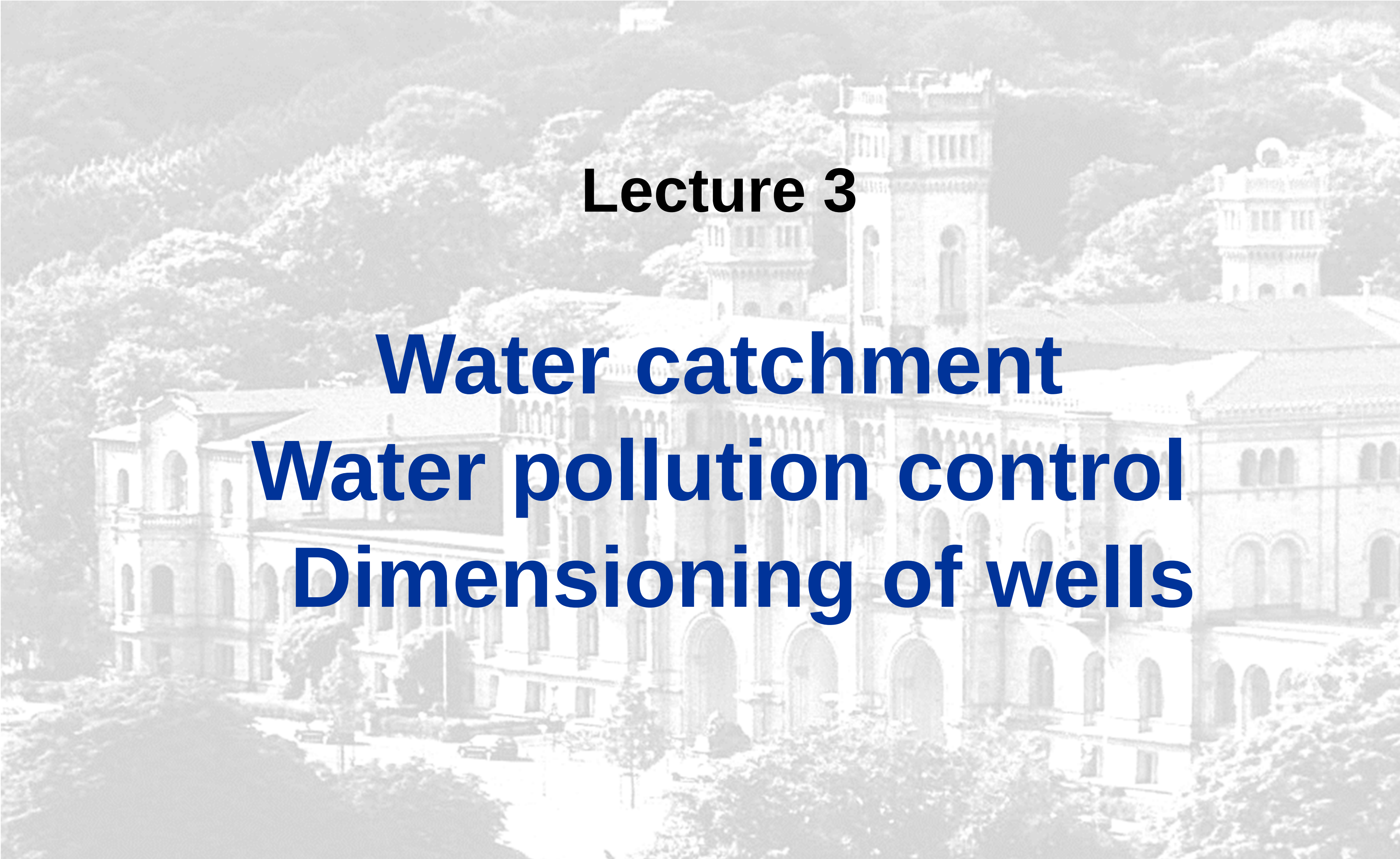


Lecture 3

Water catchment
Water pollution control
Dimensioning of wells

Definition groundwater (DIN 4049, Part 1)

„Groundwater is subterranean water, which coherently fills the cavities of the earth crust.

Its flow is only determined by gravity and by friction force caused by motion.“

Groundwater

Groundwater resources:
(Grundwasservorkommen)

natural groundwater, riverbank-filtrated groundwater, artificial enriched groundwater.

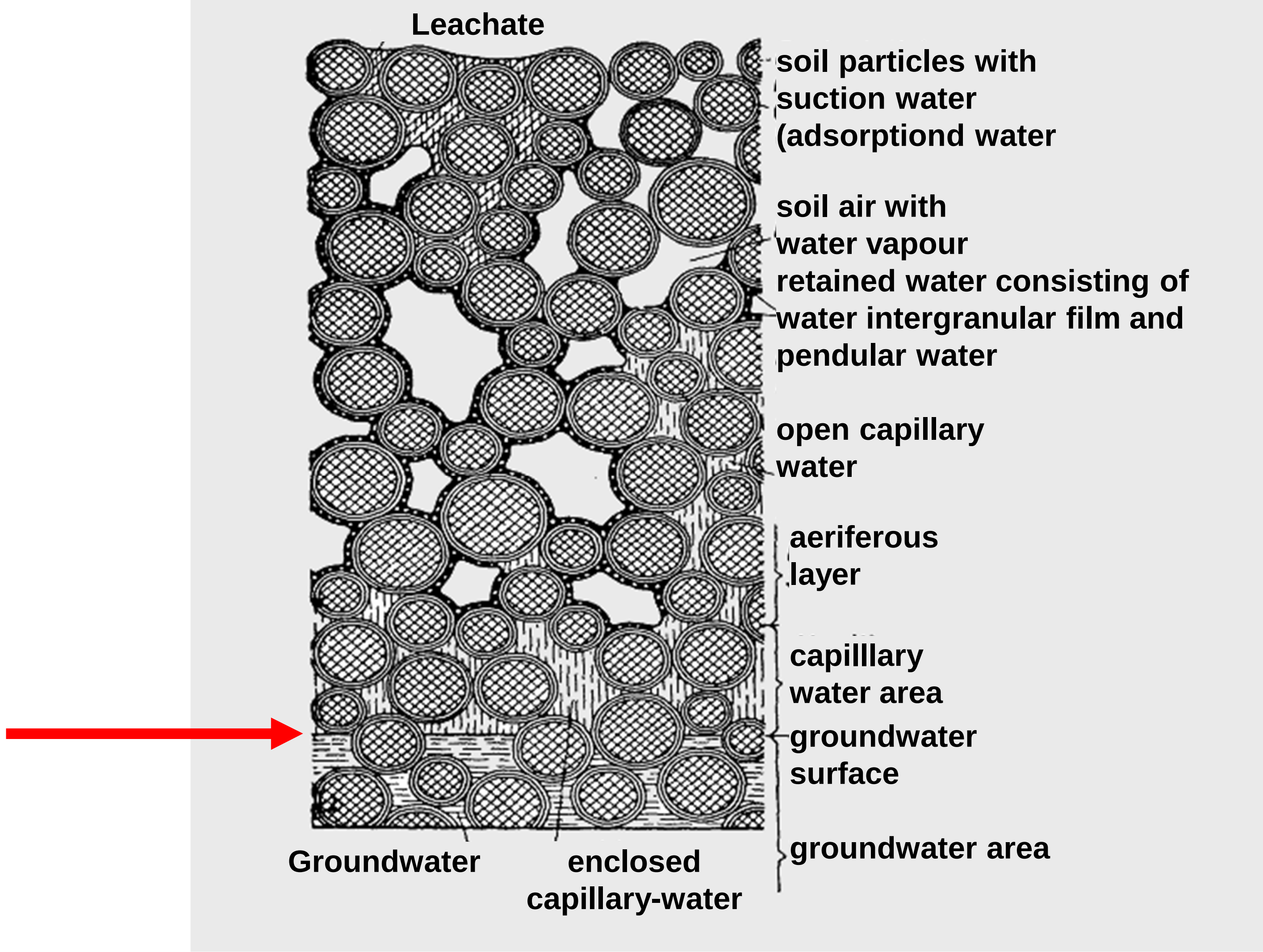
Aquifer:
(Grundwasserleiter)

non-consolidated rocks, soils, sand, gravel, brash (shutter). Consolidated rocks with pores, fissures, gaps or hollows.

Groundwater inhibitor or Aquifuge:
(Grundwasserhemmer oder -nichtleiter)

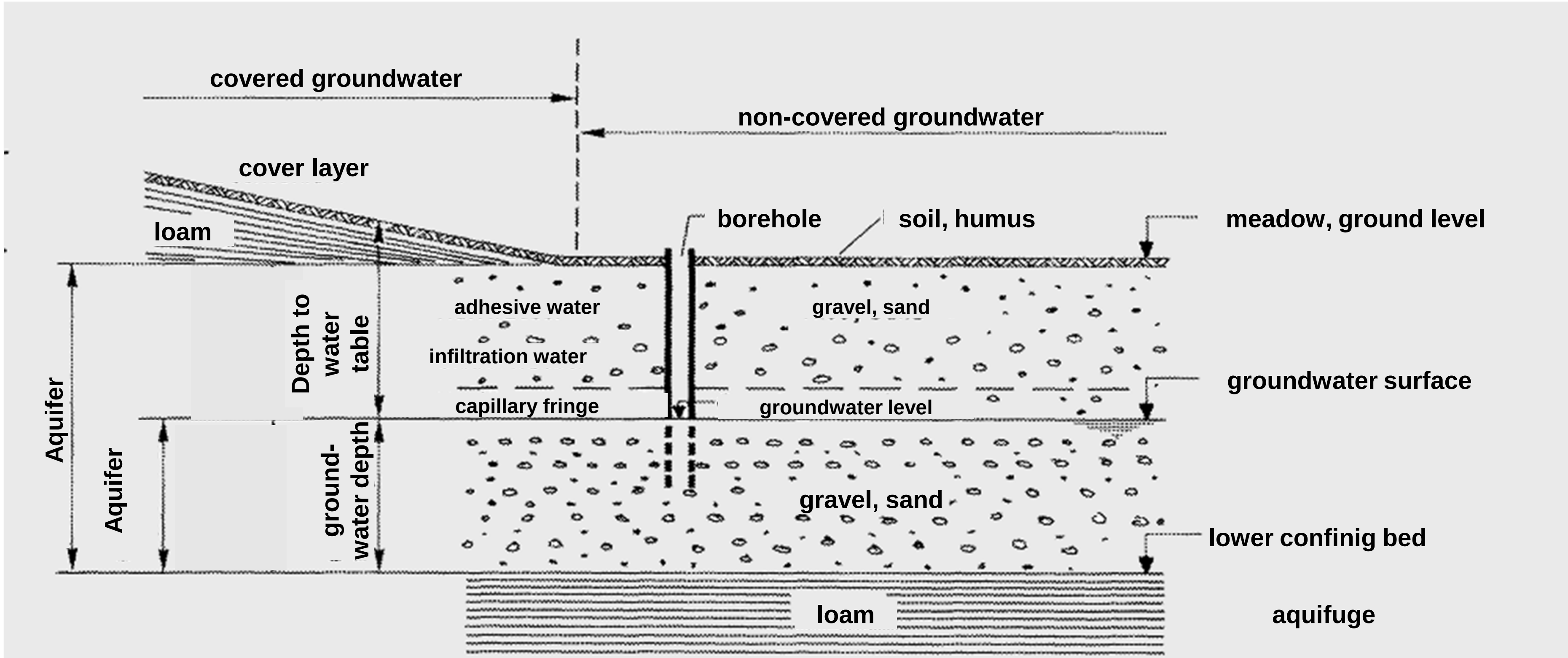
clay, loam, marl, crag
(Ton, Lehm, Mergel, Fels)

Soil water appearance forms



Aquifer

Leibniz Universität Hannover



according to Grombach

Groundwater resources

- Evidences for groundwater resources *(Grundwasservorkommen)* from hydro-geological maps or groundwater frequency maps *(Grundwasserhöffigkeitskarten)*

- Groundwater levels are measured in observation wells *(Peilbrunnen)* (water gauges *(Kabellichtlot)*, well whistle *(Brunnenpfeife)*).

- Water-table curve (isohypses) *(Grundwasserhöhenlinien)* are received by interpolation of the ground water levels → information about groundwater gradient and flow direction*(Grundwassergefälle und –fließrichtung)*

- Groundwater flow velocity *(Grundwassergeschwindigkeit)* (North Germany about 1 m/d) depends on the groundwater gradient and the soil permeability *(Grundwassergefälle und der Bodendurchlässigkeit).*

- Soil permeability is characterized by the k_f-value.

- Groundwater dating *(Grundwasseralter)* (C14-procedure of isotype-analysis)

Impact of groundwater by soil and rock-types

Rock type	Possible properties of groundwater
granite,gneiss, slate	mostly chemically pure, poor in dissolved substances, occasional salt content, organic content
quartz	siliceous
sand stone	barely soluble substances, no humus, very pure (with exceptions)
loess	many soluble substances, much hardness, occasional ferric-content
chalk	many soluble substances, much hardness, occasional ferric-content
gypsum storage	containing sulfate
moor (Moor)	few dissolved substances, in this connection potash, silicic and phosphoric acid, organic substances
fen	Many dissolved substances, potash, iron, few organic substances

Calculation of Field Velocity

Henry Darcy (1803-1858), a French hydraulic engineer, devised a law about water movement of non-consolidated sediment.

$$Q_{gw} = v_f \cdot A \text{ ; with: } v_f = k_f \cdot I$$

$$\rightarrow Q_{gw} = k_f \cdot I \cdot A$$

v_f	= filtration rate *(Filtergeschwindigkeit)*	[m/s]	
I	= gradient *(Spiegelgefälle)*	[-]	
Q_{gw}	= groundwater runoff *(Grundwasserabfluss)*	[m³/s]	
A	= cross sectional area *(Querschnittsfläche)*	[m²]	aquifer *(GW-Leiter)*
k_f	= hydraulic conductivity *(Durchlässigkeitswert)*	[m/s]	

Precondition: Laminar flow and saturated soil.

Laminar flow can be assumed until Reynolds number Re = 2-5

Hydraulic conductivity k_f

Determined by pumping test, mesh analysis, undisturbed soil sample.

Type of Soil	k_f-value [m/s]
gravel (river gravel)	0.015 bis 0.0005
sandy gravel (glacial valleys)	0.001 bis 0.0009
gritty sand (glacial valleys)	0.002 bis 0.00003
medium sand (heath sand)	0.0002 bis 0.0008
fine sand (dune sand)	0.0002 bis 0.00004
silty clay	≈ 0.00000001

Groundwater flow velocity:
- North Germany about 1.0 m/d
- Rhine valley (Mannheim) ca. 1.2 – 1.6 m/d
- Winterthur/Switzerland about 12 – 88 m/d

Recharge rate

Recharge rate depends on:

- Distribution of precipitation
- Soil
- Depth to water table
- Land-use (growth, development and others)
- Precipitation = 663 mm/a

Type of land surface	Area km²	Evaporation % h_N	Evaporation mm	Groundwater recharge mm	Groundwater recharge % h_N	Groundwater recharge Mio. m³/a
Settlement and traffic area	7.95	15	99	*--	*--	*--
Run-off areas with drainage	9.65	15	99	564	85	5,4
Sparse vegeation	17.94	50	331	332	50	5,8
Cropland	18.67	65	431	232	35	4,3
Grass land	10.29	75	497	166	25	1,7
Scrub vegetation	8.41	85	564	99	15	0,8
Forest (forest land)	67.19	90	595	68	10	4,5
Water area	0.88	108	713.2	negativ	negativ	negativ
Total area	**140.98**	**71****	**470****	**162****	**24****	**22.8****

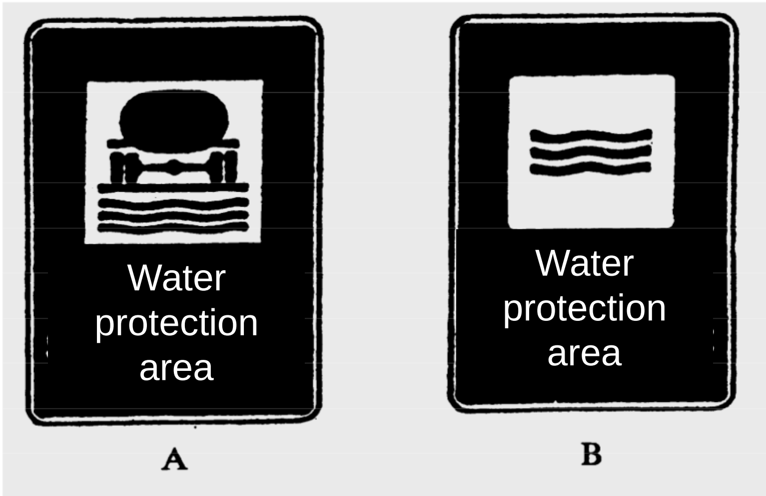
* = only surface runoff ** = weighted average

Groundwater protection areas

Determination water protection area is to be requested in Germany at the lower water authority. Based on § 19 WHG and § 48 NWG.

Involved administrations:

- Health authorities *(Gesundheitsamt)*
- Water management office *(Wasserwirtschaftsamt)*
- Geological state agency *(Geologisches Landesamt)*
- Lower Saxon state agency for Soil research *(Nieders. Landesamt für Bodenforschung)*



Groundwater protection areas

Catchment area (zone I) *(Fassungsbereich)*

The expansion from the axis of vertical filter wells or the other ending of horizontal filter wells amounts to 10 m. The catchment zone should be property of the water supplier. Fencing when necessary. The following restrictions have to be kept besides the ones in zone III:

- no traffic or pedestrian traffic *(Fahr- und Fußgängerverkehr)*
- no appliance of agricultural-chemical agents *(landwirtschaftlich-chemischer Mittel)*
- no agricultural use *(landwirtschaftliche Nutzung)*

In individual cases in which an appropriate surface cover layer exists, zone I can be omitted (not necessary).

Groundwater protection areas

Close protection (zone II) *(Engere Schutzzone (Zone II))*

This Zone has to be so large that the influent ground water reaches the well after 50 days (E. Coli and pathogen‘s life expectancy). The determination of the 50-days-line is done with geohydrological methods. The following restrictions have to be kept besides the ones from zone III :

- No building-up *(Bebauung)*
- No traffic facilities or transit *(Verkehrsanlagen und Verkehrswege)*
- No transport and storage of water hazardous substances *(Transport und Lagerung von wassergefährdenden Stoffen)*
- No wastewater pipes (no small wastewater treatment plant with subsoil infiltration) *(Abwasserdurchleitung)*
- No bath and sport facilities *(Bade- und Sportanlagen)*
- No plants and pest controlling agents *(Pflanzen- und Schädlingsbekämpfungsmittel)*

In individual cases in which an appropriate surface cover layer exists, zone II can be omitted.

Groundwater protection areas

Further protection (zone III) *(Weitere Schutzzone (Zone III))*

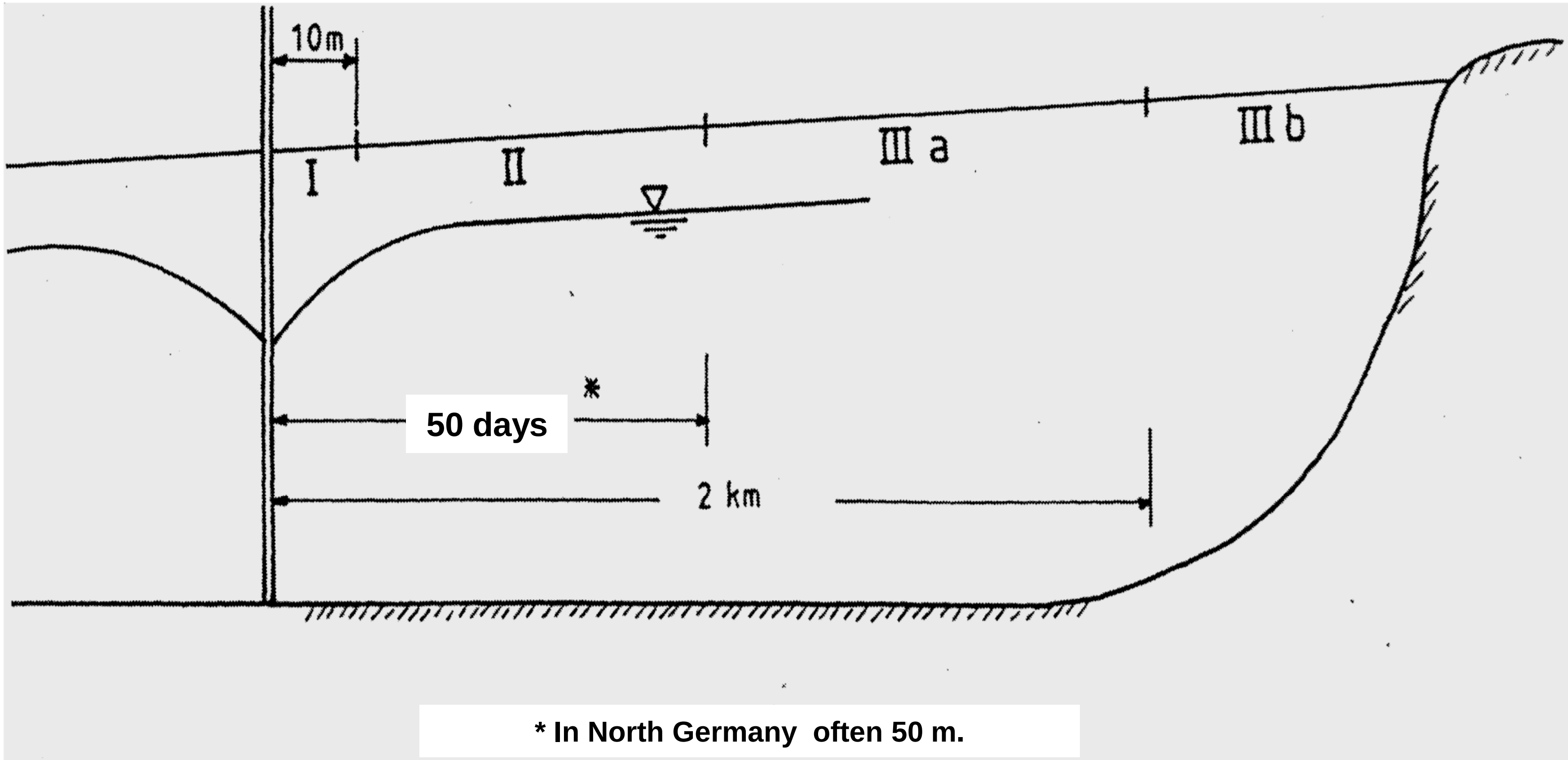
Protection from non or hard degradable substances. Threats are:

- Industrial facilities with water hazardous substances and/or waste materials *(Industriebetriebe mit wassergefährdenden Stoffen und/oder Abfällen)*
- Waste water treatment plants and waste water discharge *(Kläranlagen & Abwassereinleitungen)*
- Waste treatment facilities *(Abfallbehandlungsanlagen)*
- Military facilities *(Militärische Anlagen)*
- Cargo handling centres *(Güterumschlagplätze)*
- Gas stations *(Tankstellen)*

Further details see W 101. (Water Guidelines of DVGW = German Technical and Scientific Association for Gas and Water)

If drainage area is larger than 2 km: Possible division in zone IIIa and IIIb.

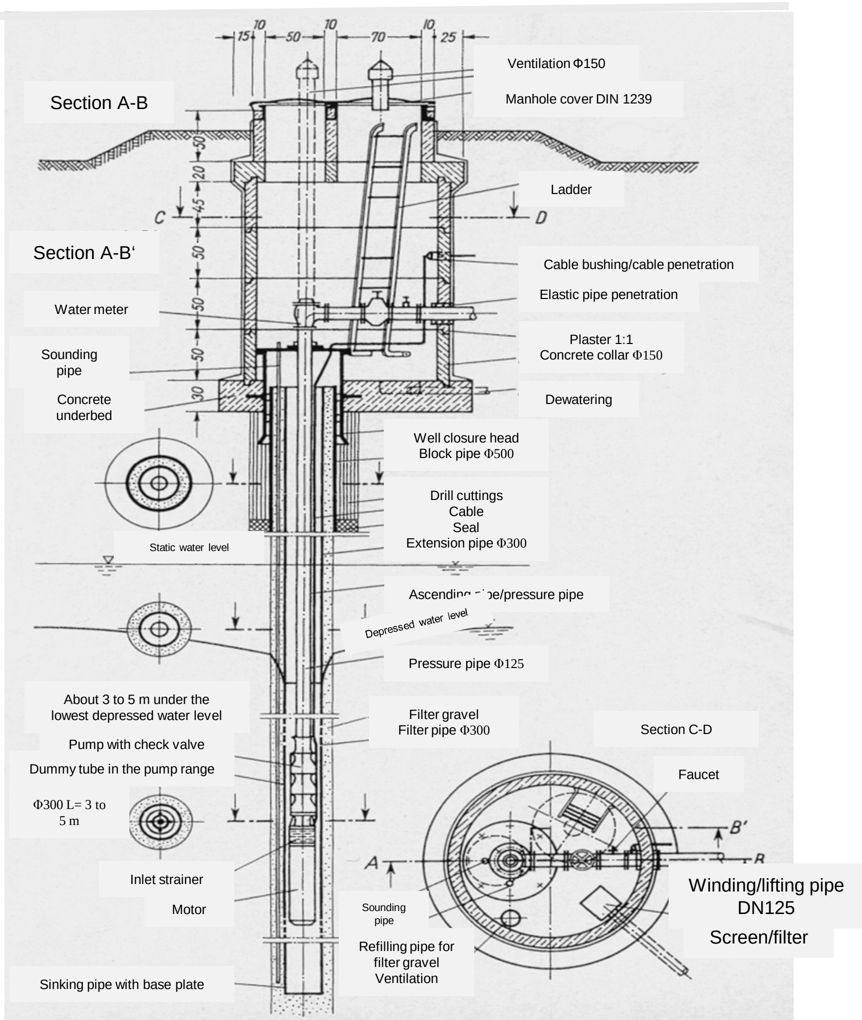
Groundwater protection areas

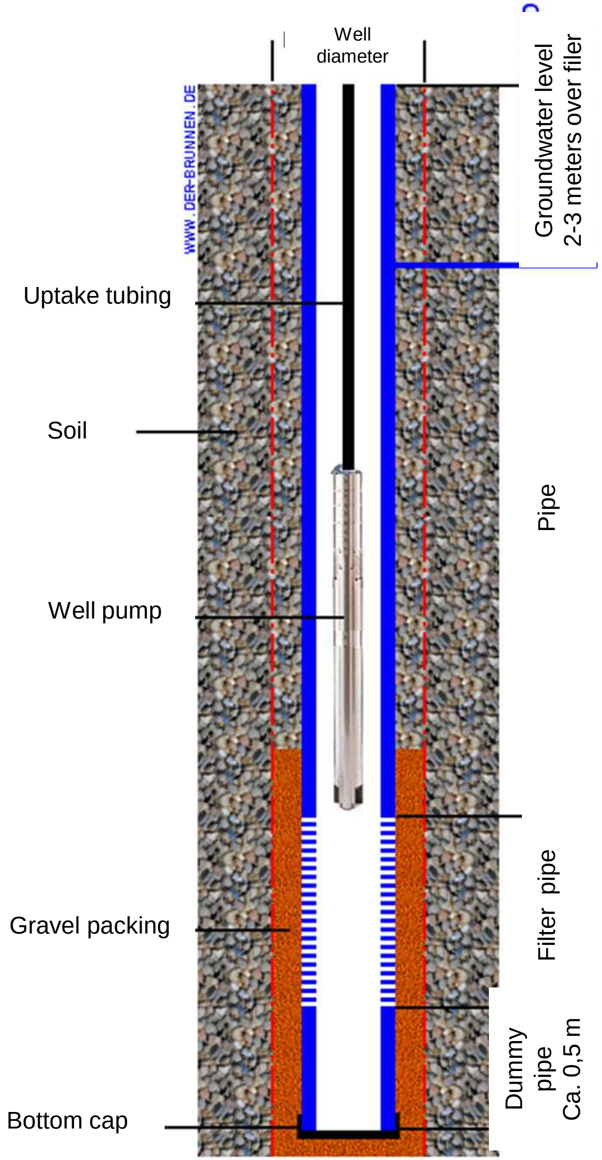


Water catchment

- Vertical filter well *(Vertikalfilterbrunnen)*
- Horizontal drainage catchment (Horizontale Sickerfassung)
- Flushing well (e.g. by garden well too) (Spülbrunnen)
- Shaft well (Schachtbrunnen)
- Horizontal filter well (Horizontalfilterbrunnen)

Vertical filter well

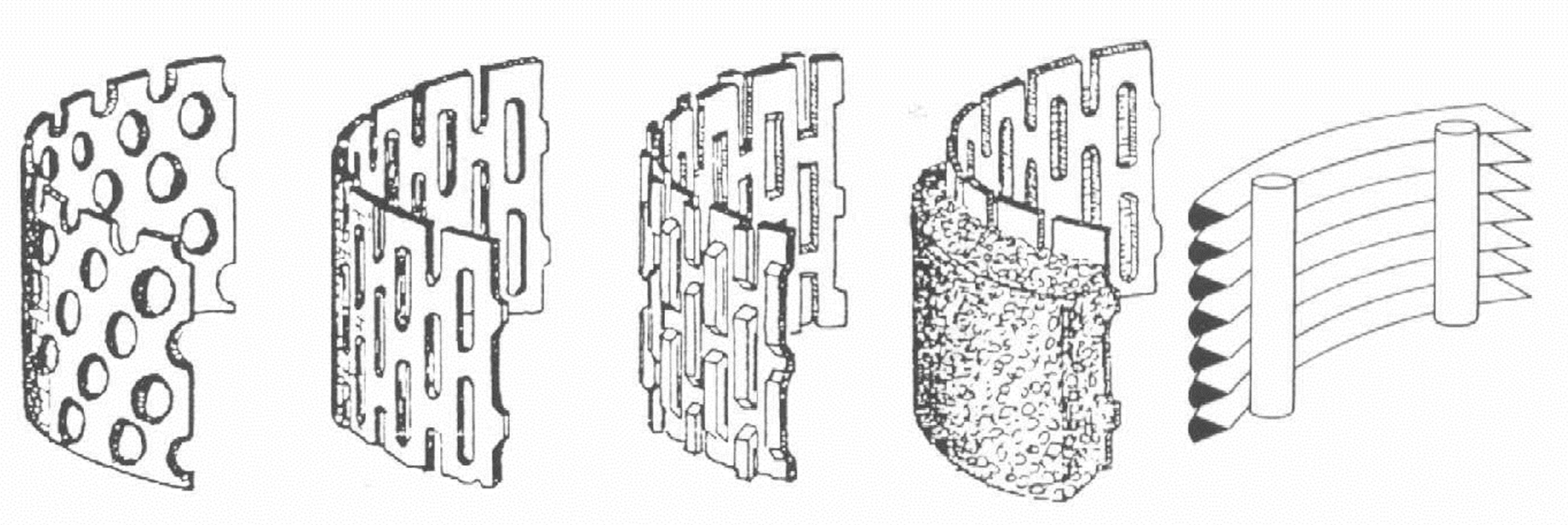




Vertical filter well

Filter

- Steel filter pipes with slits (DIN 4922) and plastic or hard rubber cover.
  Flange, external cover plate and threaded joint (DN 100-1000).



Filter installation

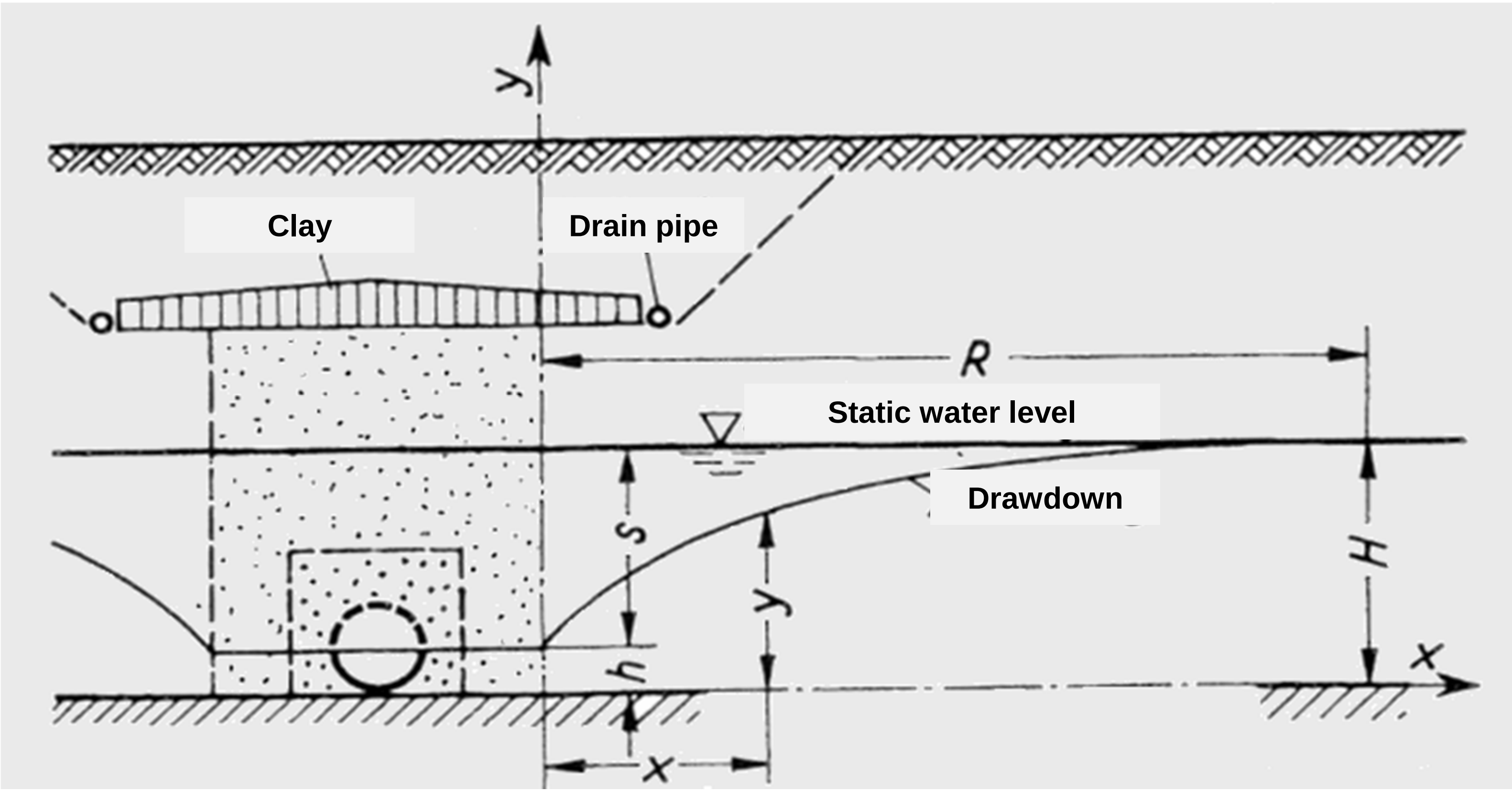
- The filter installation should be constructed based on an accurate well-plan!

Components and materials in well sinking

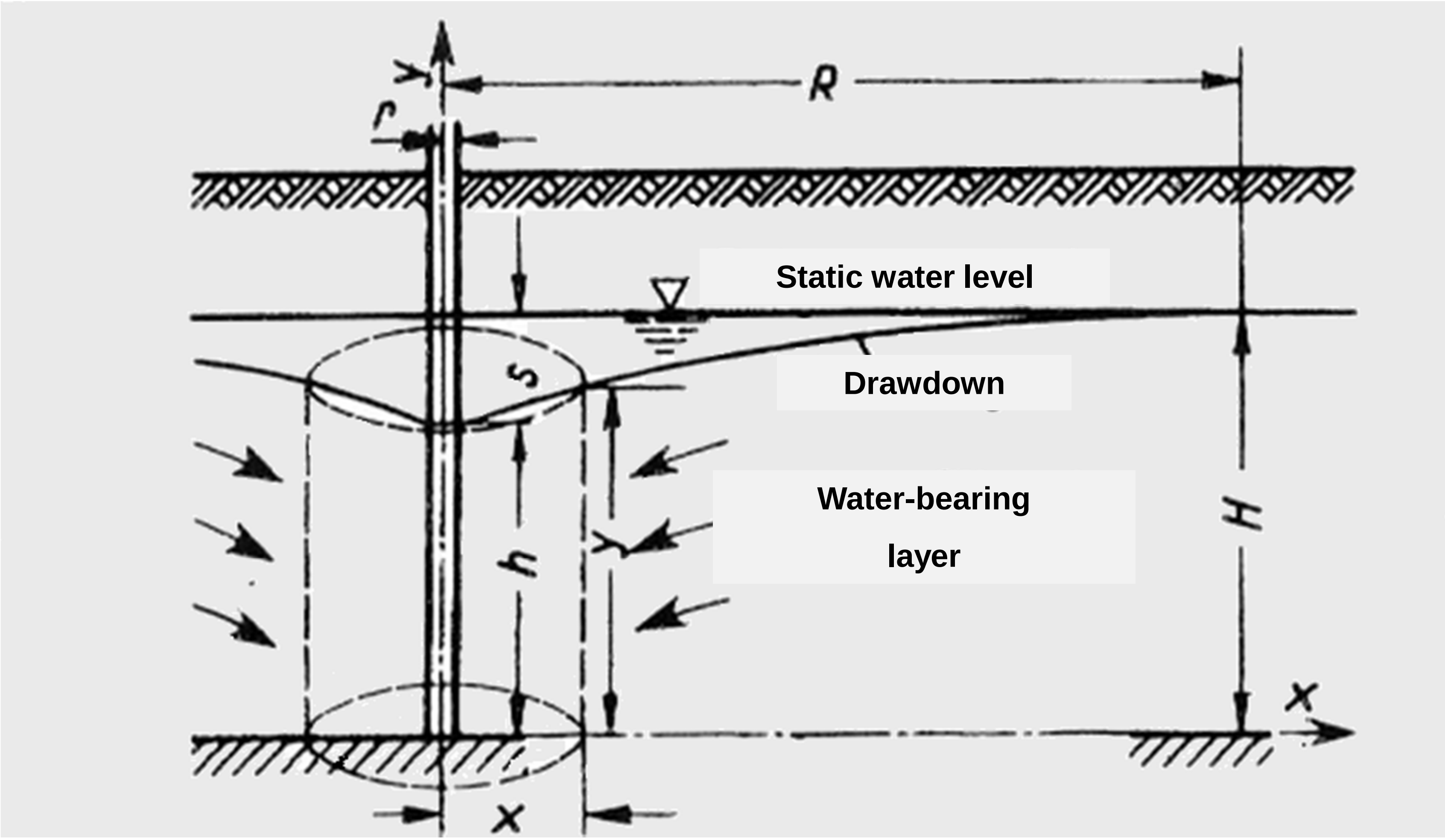
Filter bottom *(Filterboden)*	**Sounding filter pipe and attachment pipe**
Filter pipe *(Sumpfrohr)*	**Fiber frame ring** *(Filter- und Aufsatzrohrführungen)*
Sinking pipe *(Filterrohre)*	**Fiber for filter frame** *(Gewebe für Filterkörbe)*
Dummy tube *(Blindrohre)*	**Filter and Extension pipe-run** *(Gewebekorbringe)*
Attachment pipe *(Aufsatzrohre)*	**Fiber frame pipe-run** *(Gewebekorbführung)*
Pipe head *(Kopfrohr)*	**Braiding or sewing material** *(Flecht- und Nähmaterial)*
Pipe coupling material	**Filter gravel** *(Filterkies)*
Sealing gaskets *(Dichtungen)*	**Puddle clay** *(Dichtungston)*

Horizontal groundwater catchment

Application in case of flat horizontal aquifer layer with relatively small thickness



Section through a vertical filter well in groundwater sink hole



Well inflow calculation

Considering the continuity equation and the Filter Law of Darcy, the following equation results:

$$Q_{gw} = \left(H^2 - h^2\right)\frac{\pi \cdot k_f}{\ln\left(R/r\right)}$$

With:

k_f	Hydraulic conductivity *(Durchlässigkeitswert)*	[m/s]
Q_{gw}	Ground water inflow *(Grundwasserzufluss)*	[m³/s]
H	Static water level over the ground water bottom or groundwater layer thickness	[m]
h	Reduced static water level in well *(abgesenkter Grundwasserspiegel)*	[m]
R	Drawdown range R according to Sichardt *(Reichweite)*	[m]
r	Average well radius *(mittlerer Brunnenradius)*	[m]

Well inflow calculation

Drawdown range R according to SICHARDT:

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

With:

k_f	Hydraulic conductivity *(Durchlässigkeitswert)*	[m/s]
s	Reduction of the groundwater level *(Ruhewasserspiegels)*	[m]
R	Range R of level-reduction according to SICHARDT *(Reichweite)*	[m]

Tangible inflow

The capacity of a well does not only depend on the reduction of the ground water level. It also depends on the requirement, that the well must be able to catch the inflowing water. The tangible (comprehensible) Inflow Q_t *(fassbare Gesamtwasserzufluss)* results from the continuity equation $Q = v \cdot A$ with the cylinders inflow-area

$$\mathbf{A = 2\pi \cdot r \cdot h}$$

and the inflow velocity $v_f = k_f \cdot J$ *(Eintrittsgeschwindigkeit)*

SICHARDT determined the admissible falling gradient (critical hydraulic gradient) *(größtzulässige Gefälle)* through empirical approaches.

$$J_{krit} = \frac{1}{15 \cdot \sqrt{k_f}}$$

Well capacity

The tangible water inflow Q_t will be *(fassbarer Gesamtwasserzufluss)*

$$Q_t = \underbrace{k_f \cdot J_{krit}}_{=v_f} \cdot \underbrace{2\pi r}_{=A} \cdot h$$

$$Q_t = \frac{2}{15} \cdot \pi \cdot r \cdot h \cdot \sqrt{k_f}$$

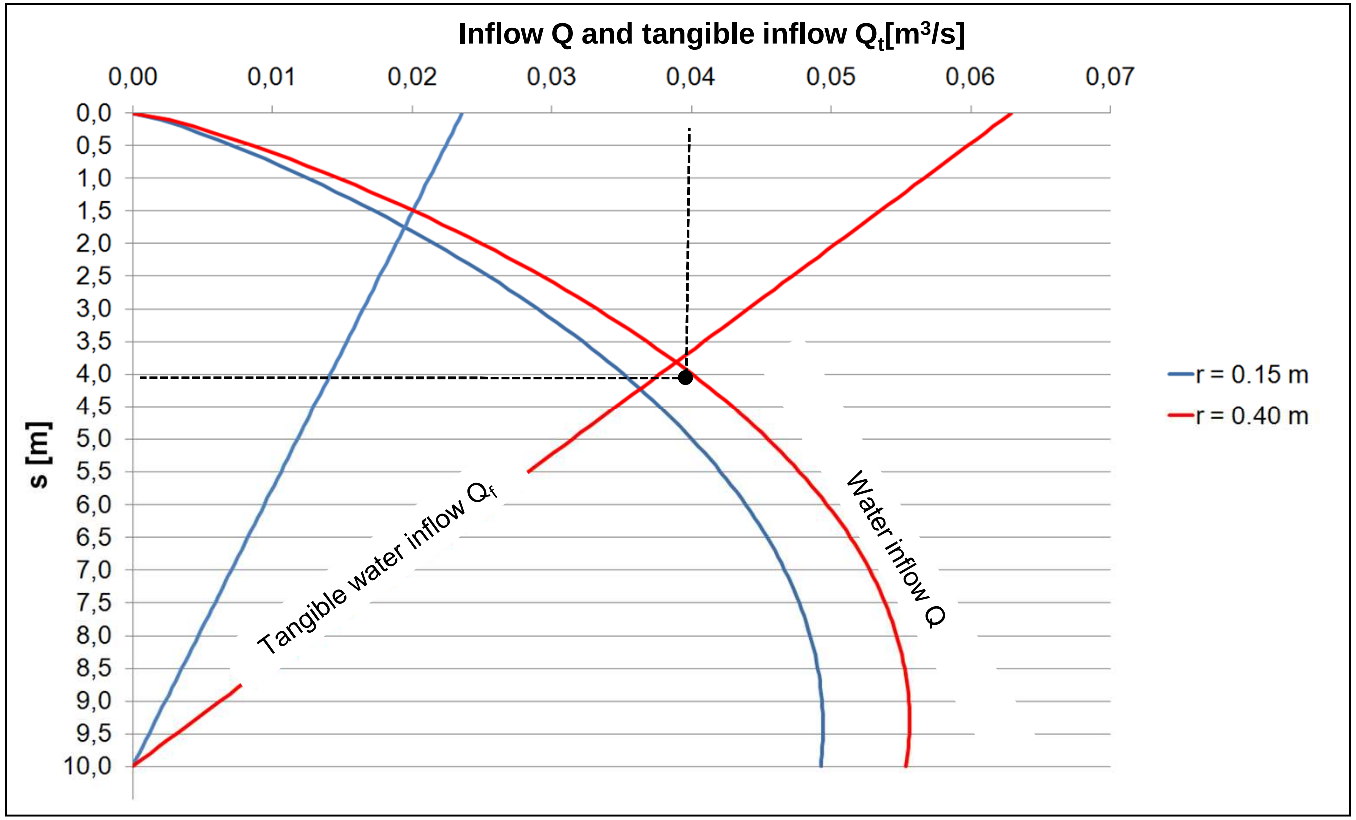
in m³/s; with r and h in m and k_f in m/s

Detailed information about the well inflow or the flow rate and the ground water drawdown level can be determined through a pumping test according to W111.

Well capacity

Plot of the water discharge Q or Q_t as a function of the drawdown s *(Absenkung)*.

▸ The point of intersection gives the greatest possible extraction quantity corresponding to the maximal admissible drawdown (in order to fullfill the condition **$Q_t \geq Q$**)



k_f = 1.4 ·10^{-3} [m/s]
H = 10 [m]

▸ maximum admissible drawdown s = 3.8 m allows an extractable water quantity out of the well of 0.039 m³/s

Superficial water catchment

- **Dam water**

- **Lake water** (oligotrophical lakes, e.g. Lake Constance, extraction 3-5 m over the lake bottom (4° C) and min. 30 m under the water level

Protection zone 1	Storage capacity and river bank,
Protection zone 2	50 m zone,
Protection zone 3	Complete dam catchment area, Baikal lake

- **River water** (in Germany normally only out river bank infiltration abroad and in industries of great importance (London, Paris, Moscow, Bucarest)

- **See water** (Desalination, because of 3,5% NaCl, e.g.: Helgoland, Rügen, Riad)

Utilization of rain water

The following recommendations are to be considered regarding rain water utilisation facilities:

Roof areas: Preferably tiled roofs or flat roofs, with no bitumen material. The roof area and roof drains must be kept clean from leaves, moss, dead animals.

Treatment facilities: Leaf traps, downpipe screens, gravel filters, and back flushing protective filters. A disinfection, e.g. with UV is generally not necessary.

Tank: Protected against light exposure (algae formation) in basements or in the subsoil (cool storage). The storage capacity depends on the function purposes. Possibility of use as drinking water. Sufficient aeration of the stored rain water should be guaranteed.

Utilization of rain water

Booster station: For the distribution of the stored rain water into the distribution network. Safe operating aggregates should be chosen.

Rain water piping: Inside the buildings as well as withdrawal valves should be marked. Connection with the drinking water network is prohibited.

Rain water drainage: On the property with drains has the purpose of ground water regeneration. If groundwater is being extracted with domestic wells on the same property, it can be considered as an indirect utilisation of rain water.

Examples: Cistern e.g. Byzanz (today Istanbul) 80,000 m^3

In northern Germany when daily demand still amounted up to 25 l/E·d a tank of 2.5 - 3 m^3 lasted for 100 days.