GROUNDWATER RECHARGE FROM RUN-OFF, INFILTRATION AND PERCOLATION

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GROUNDWATER RECHARGE FROM RUN-OFF, INFILTRATION AND PERCOLATION

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Cover Graph:
Discharge is generated by precipitation excess and transforms along interfaces into flow components with different turn-over-times and flow directions;. Overland- and inter-flow move both in lateral surface, respectively subsurface directions and have short turn-over-times. In contrast, groundwater recharge percolates vertical down and reappears very delayed in the surface water. The quantitative influence of the above mentioned interfaces on discharge depends from many factors changing with seasons, wet and dry cycles, rain intersities and even during individual rain events.

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PREFACE

Life on continents depends on the availability of fresh-water. Hence, preferred sites for human settlements were situated close to springs, rivers, or shallow groundwater resources, and it was accepted at the dawn of mankind that the local social and economic development was limited by the natural available water resources in a quantity and quality sense; any shortage in the availability of water stimulated people to migrate.

With the growing earth population and during the industrial age, water availability reached a new dimension: By technical means, water became everywhere available by drilling and piping and in more recent times also by low cost desalination methods. This seemingly ubiquitous water availability let in many areas of the world to an overexploitation of water resources often with the consequence of a deterioration of fresh-water quality by salt water intrusions from deep aquifers and in coastal areas from the sea, or by subsidence, which changed hydraulic properties of aquifer systems. These adverse developments have always a transient character; this means the hydraulic system responds with a more or less long delay time till reaching new steady-state conditions and often create new situations that—when ever—can only be managed with high costs.

In humid areas of the world, the limiting factor for groundwater development became mostly water quality, in semi-arid and arid areas, it is both water quantity and quality. To overcome these problems, safe-yield concepts in terms of water quantity and water quality have been developed. Simplistically,

- The quantity safe-yield concept is based on the replenishment of surface/subsurface systems either by natural or artificial (groundwater) recharge; this concept has not only to consider average inputs and outputs, but also the year to year meteorological fluctuations, droughts, floods and socio-economic facts.
- The quality concept is based either on the natural, good water quality or on threshold concentrations to protect health and life of beings and ecosystems.

It is often overlooked that the amount of water extraction, according to the needs of the urban and industrial, agricultural and recreational development of a region, changes not only the local water cycle, but can also introduce new boundary conditions for recharge and discharge pathways. This is often also accompanied by a deterioration of water quality, which cannot be completely governed by respective water treatment measures. Finally, the local water demand has often been satisfied by water imports without considering seriously, if such measures exceed the water drainage and natural attenuation capacity of the respective region and aquifer system.

A new challenge raises with climate changes, in particular a change in the precipitation amount and pattern, which will modify the water cycle, specially the water availability on continents. The groundwater response to such climate changes will not be instantaneous, but transient; therefore, any prediction on respective changes in the fresh-water resources will not persuade at present water users, because negative effects do not appear instantaneously, but it will in a remote time, when deterioration of water resources already proceeded so far that it may have become irreversible.

This book focuses on the present global and local water cycle, especially how precipitation changes water fluxes at the interface atmosphere/lithosphere/biosphere, within the weathering zone of sediments/rocks and in the subsurface. The detailed understanding of these processes allow a better estimate and assessment of the components of the water cycle and a better prediction of the impact of men's activities on the water cycle. These facts are documented by some examples from the main climate zones of the globe. In contrast, this book does not consider the wide field of fresh-water quality.

Klaus-Peter Seiler
Joel R. Gat

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ABBREVIATIONS AND DIMENSIONS

A	Area	m^2 or km^2
BBM	Black-box models	–
b.g.s.	Below ground surface	–
C	Concentration	mg/L or g/m^3
dpm	Decays per minute	–
D'	Dispersion coefficient	m^2/s
D'_L	Longitudinal dispersion coefficient (*x*-direction)	m^2/s
D'_T	Transverse dispersion coefficient (*z*- or *y*-direction)	m^2/s
D	Specific run-off	mm/year or L/(s km^2); 1 L/(s km^2) = 31,536 mm/a
D_G	Specific groundwater run-off	mm/year or L/(s km^2)
D_I	Specific inter-flow run-off	mm/year or L/(s km^2)
D_M	Molecular dispersion	m^2/s
D_O	Specific overland-run-off	mm/year or L/(s km^2)
D_T	Specific discharge transfer	mm/year or L/(s km^2)
D_{SF}	Specific surface run-off	mm/year or L/(s km^2)
DM	Dispersion Model	–
e	Vapor pressure	mbar
eq.	Equation	–
EM	Exponential Model	–
EP	Evaporation	mm/year or L/(s km^2)
ET	Evapo-transpiration	mm/year or L/(s km^2)
g	Gravity acceleration	m/s^2
GMWL	Global Meteoric Water Line	–
h	Height	m
h'	Relative humidity	– or %
H	Hydraulic head at water saturation	
	Volumetric related	*Pa*
	Weight related	*m*

H_c	Capillary head	m
H_g	Gravity head	m
H_o	Osmotic head	m
I	Activity concentration	Bq/L
IN	Infiltration	mm/year or L/(s km^2)
K	Hydraulic conductivity	m/s
LAI	Leave area index	–
LMWL	Local Meteoric Water Line	–
m	Empirical parameter	–
M	Mass	kg
MTT	Mean-turn-over-time, Mean-transit-time Mean residence time	day, year
MTT_W	Mean-turn-over-time of the water	day, year
n	Empirical parameter	–
N		mol/m^3
p	Pressure	mbar
p'	Porosity	– or %
pmc	Percent modern ^{14}C	%
P	Precipitation	mm/year or L/(s km^2)
Pa	Pascal	$kgm^{-1}s^{-2}$
PFM	Piston Flow Model	–
q	Specific flow rate	m^3/(s m^2)
Q	Discharge/flux	m^3/s
r	Capillary equivalent radius	cm
R'	Groundwater recharge	mm/year or L/(s km^2)
R	Isotope ratio, e.g., $^2H/^1H$	–
S	Storage	% or mm/year
S'	Water saturation	– or %
S_c	Storage coefficient	–
S_e	Effective saturation	%
T	Time	second, hour, day, year
T'	Thickness	m
$T_{0.5}$	Half live	year
T	Temperature	°C
TBT	Tracer break through curve	–
TP	Transpiration	mm/year or L/(s km^2)
TU	Tritium unit	–
WMO	World Meteorological Organization	–
v_f	Filter velocity	$m^3/(m^2$ year) or m/year
v_a	Apparent flow velocity	m/year
V_T	Total volume	m^3
V_V	Void volume	m^3

V_W	Water volume	m^3
x, y, z	Distances and Cartesian co-ordinates	m
α	Separation factor	–
α^*	Thermodynamic separation factor	–
α'	Dispersivity	m
β	Water-solid contact angle	degrees
γ	Constant parameter	–
δ	Deviation of stable isotope contents from a standard	‰
ε	$(1-\alpha)$	–
ε^*	$(1-\alpha^*)$	–
λ'	Tortuosity	–
λ	Decay constant	$time^{-1}$
θ	Water content	%
θ_s	Water content at saturation	%
θ_{fc}	Water content at field capacity	%
θ_r	Residual water content	%
θ_w	Water content at wilting point	%
σ	Surface tension	g/s^2
ρ_W	Density of water	g/cm^3
Ψ	Suction	
	volumetric related	*hPa*
	weight related	*mm*
Φ	Hydraulic head as the Sum of $(\Psi+H)$	
	volumetric related	*Pa*
	weight related	*m*

DEFINITIONS

Active groundwater recharge zone: Aquifer zone, which hosts groundwater recharge with mean turnover times of <100years. Groundwater in this zone is also named shallow groundwater (section 2.4, Fig. 2.10).

Base-flow: Surface discharge fed by groundwater (section 2.3, Fig. 4.3). Under dry weather conditions, groundwater is the only discharge component in rivers.

Capillary fringe: The capillary fringe is the transition zone from water unsaturated to water saturated conditions in the subsurface. In it, capillary forces still play a role, but gravity forces increasingly dominate, when approaching the groundwater table/surface (section 2.3).

Connate water: Water entrapped in sediments, which was not in contact with the biosphere since sedimentation time (section 2.4, Fig. 2.11).

Deep groundwater: Groundwater in the passive groundwater recharge zone with mean turnover times exceeding 100 years (section 2.4), but being by far younger than connate water (Fig. 2.11).

Direct run-off: Surface run-off, which immediately responds to rain events. Direct run-off consists of the components overland- and inter-flow (section 2.3).

Discharge: Discharge is made up of the residuals, produced by precipitation in excess to evapo-transpiration and to water retention in the unsaturated zone. It can take the form of base-flow, inter-flow or overland-flow (Fig. 4.3).

DOC: Organic carbon in water with particle sizes <0.45 µm (**D**issolved **O**rganic **C**arbon). In contrast, the sum of all organic matter in water is called **T**otal **O**rganic **C**arbon (TOC).

Epizone of consolidated rocks: Zone of decompression and weathering upon consolidated rocks. The epizone collects infiltration, may create perched groundwater and distributes the infiltration flux between the flow paths of inter-flow and groundwater recharge (section 2.3, Fig. 2.7).

Groundwater recharge: Component of infiltration into the subsurface that joins groundwater through the unsaturated zone, the river bed or lake ground.

Groundwater: Underground water that completely fills the pores of an aquifer, following only gravity forces. Groundwater discharges to rivers, lakes or directly to the ocean.

Indirect run-off: Surface run-off, which responds delayed to rain events. Base-flow or groundwater discharge to rivers is synonymous with indirect discharge (section 2.3, Fig. 4.3).

Infiltration: Infiltration is the process of transition of precipitation or surface water into the lithosphere; strictly spoken, it describes the process of how the dimensions of unsaturated flux and storage are influenced by the entry of water into the lithosphere. Infiltration contributes to inter-flow and groundwater recharge (section 3.3, Fig. 4.2).

Infiltration capacity: Maximum amount of water that can infiltrate into the subsurface. Water in excess of the infiltration capacity produces either overland-flow or excessive ponding at the infiltration surface. Infiltration capacities depend on actual fabrics and water contents of the sediment.

Inter-flow: Run-off component that follows in the subsurface approximately the morphology of the landscape (Fig. 4.2) and was in exchange with stored water of the unsaturated zone, but not necessarily with groundwater (section 3.3). Inter-flow joins on its flow path surface run-off either directly or mixed with overland-flow.

Overland-flow: Run-off component that did not infiltrate (Fig. 4.2) or infiltration excess discharge. It follows flow paths along the land surface and joins surface run-off in rivers (section 3.3).

Passive groundwater recharge zone: Aquifer zone, which hosts groundwater recharge with mean turnover times of >100 years. Groundwater in this zone is also named deep groundwater (section 2.4, Fig. 2.11).

Perched groundwater: Local groundwater accumulation upon low hydraulic conductivity interfaces within the vadose zone; perched groundwater is over- and underlain by unsaturated zones (section 2.3, Fig. 2.7).

Percolation: Flow in the unsaturated zone. In contrast to groundwater flow, percolation can follow all directions, even against gravity, because it is driven by both gravity and capillary gradients (section 2.3).

Regional groundwater: Groundwater of large extent, forming a hydraulic continuum and discharging close to the water table to local and at depth to distant receiving rivers (section 2.3).

Run-off: Components of discharge like direct (overland- + inter-flow) and indirect run-off (base-flow or groundwater discharge), overland-flow, inter-flow, groundwater recharge (Fig. 4.3).

Saturated zone: Groundwater zone.

Shallow groundwater: Groundwater of the active groundwater recharge zone with mean turnover times of <100 years (section 2.4, Fig. 2.11).

Surface discharge: Discharge in a river, representing one or a mix of different run-off components (section 2.3, Fig. 4.3).

Unsaturated zone: The unsaturated zone contains water and air with sharp interfaces, in which flow is governed by both capillary and gravitation forces and in which most of the time capillary forces are dominant (section 2.3).

Vadose zone: The vadose zone stretches from the ground surface to the regional groundwater table/surface and consists of maximum three distinguishable elements: the unsaturated zone, perched groundwater and capillary fringes (section 2.3).