Tracers in Hydrology

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I. Tracers and techniques

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1. Introduction: History, Concept, Approach
2. Tracer substances and their properties
3. Selection of tracer substances
4. Measurement techniques and devices
5. Laboratory and field analysis of tracers

Competence, capacities

- Known references and institutions, background
- Know the properties, advantages and limits of tracers
- Select the right tracer and measurement device
- Know analytical techniques in the laboratory and in the field

Tracers in Hydrology
II. Modeling

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1. Breakthrough curves
2. Transport equation
3. Concept models and analytical solutions: Piston, exponential, dispersion equations
4. Fitting an analytical solution (StanMod)
5. Forward Modeling of experiments (StanMod)

Competence, capacities

- Do a descriptive analysis of experiment
- Chose the right conceptual model for your study
- Fit an analytical solution to your experimental data
- Estimate travel time and expected target concentration
- Forward modeling and scenarios

Tracers in Hydrology
III. Planning and experimental design

III. Planning and design

1. Planning an experiment
2. Tracing surface water – discharge measurement + hydrograph separation (basin outflow)
3. Tracing the unsaturated zones (recharge studies)
4. Tracing ground water
5. Tracing surface-groundwater systems

Competence, capacities

- Chose the right tracers for your specific study
- Define a tracer design
- Calculate the tracer amount
- Estimate the travel time and concentration
- Carry out the injection
- Plan the sampling
- Measure the tracer

I.1 Introduction: History

- Karst hydrology in Austria, 1960ies with artificial tracers (Zötl, Maurin)
- Improvements in fluorescence spectroscopy
- Isotope hydrology
  - 1963 Craig, USA: GMWL
  - Yoel Gatt, Israel
  - Neumaier, Deutschland
- Improvement in analytics: CFCs, trace metals, gases
- Input functions known: CFCs, background values, gases

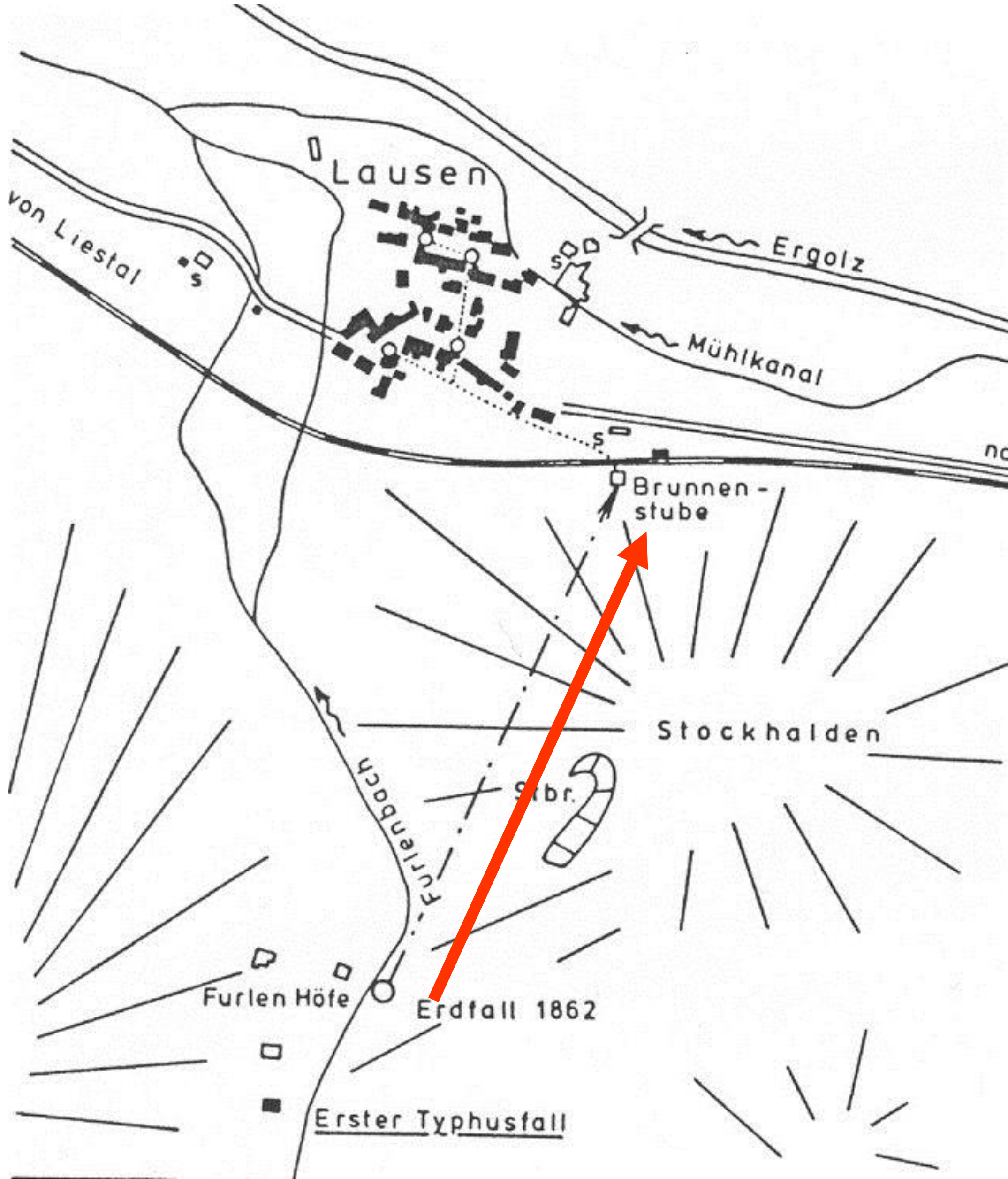
I.1 Introduction: First scientific trace experiment

Hägler, Basel, 1872:

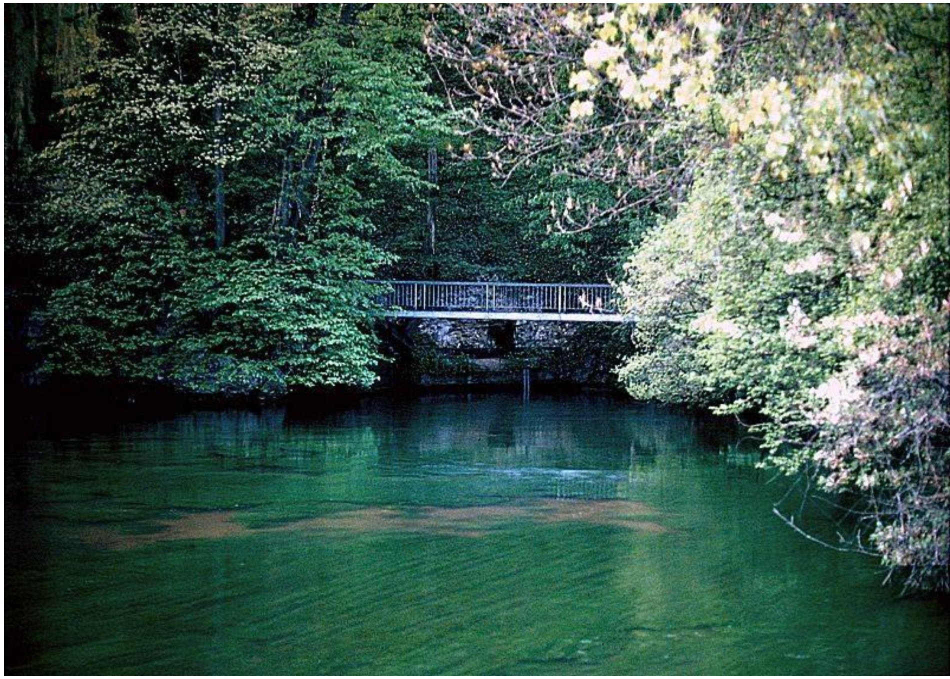
Typhus epidemic, search for causes of water pollution at Lausen (Jura, Karst)

900 kg of salt NaCl (+)

2,500 kg of powder (-)



I.1 Introduction: History – Aach spring



Knoop, 1877: Connection of Danube and of Aach Spring

10 kg of Uranin (+) detection after 2 days

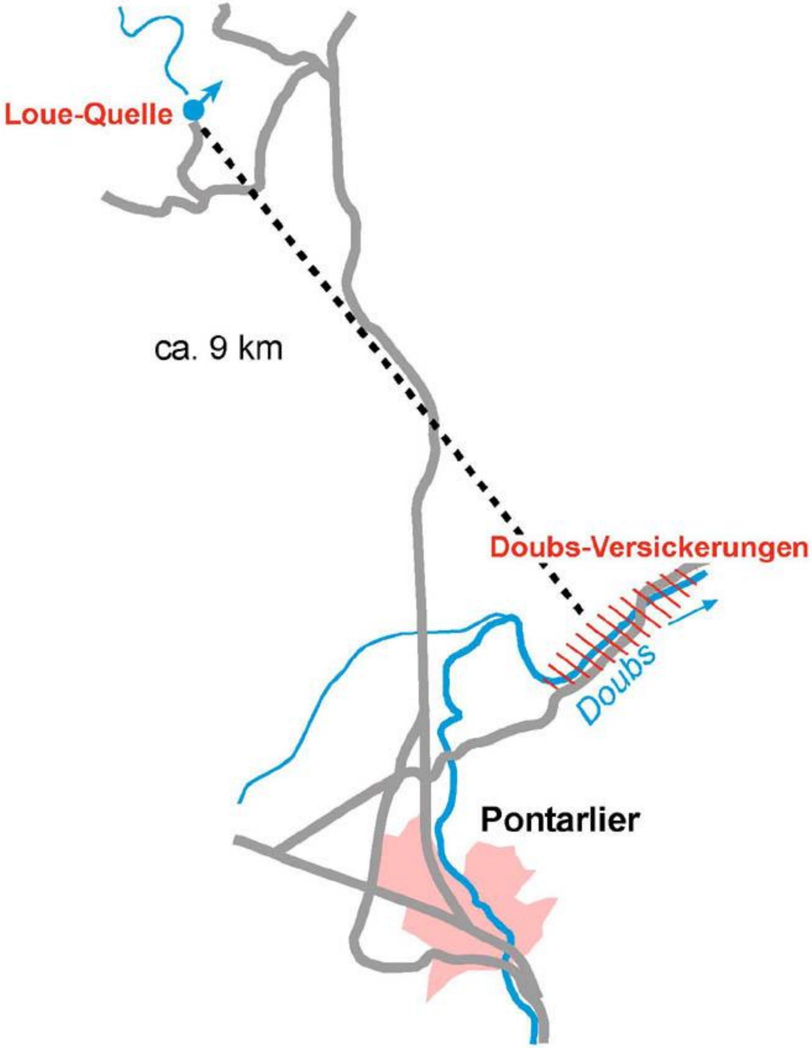
600 kg of oil flow velocity of 4,800 m per day

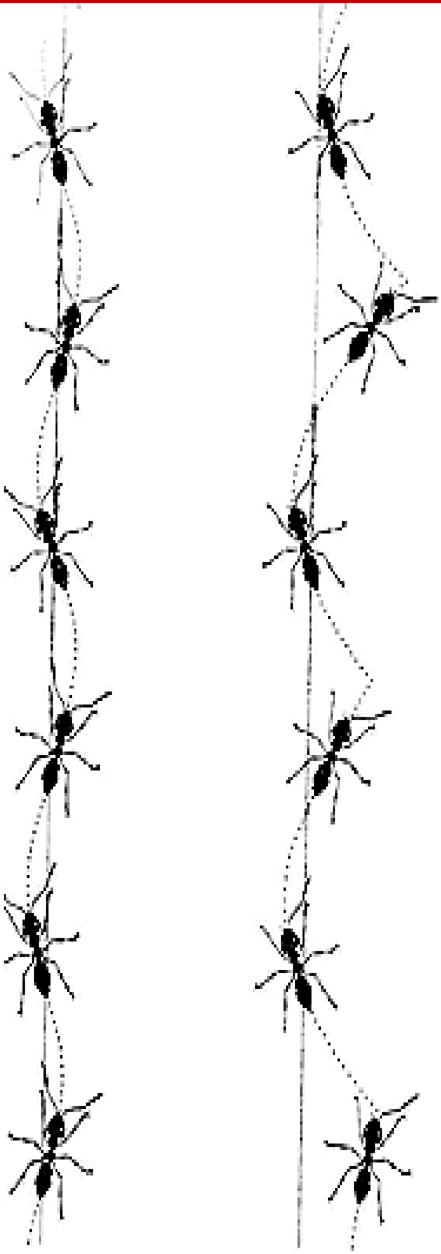
10 t of salt

I.1 Introduction: Concept of Tracing

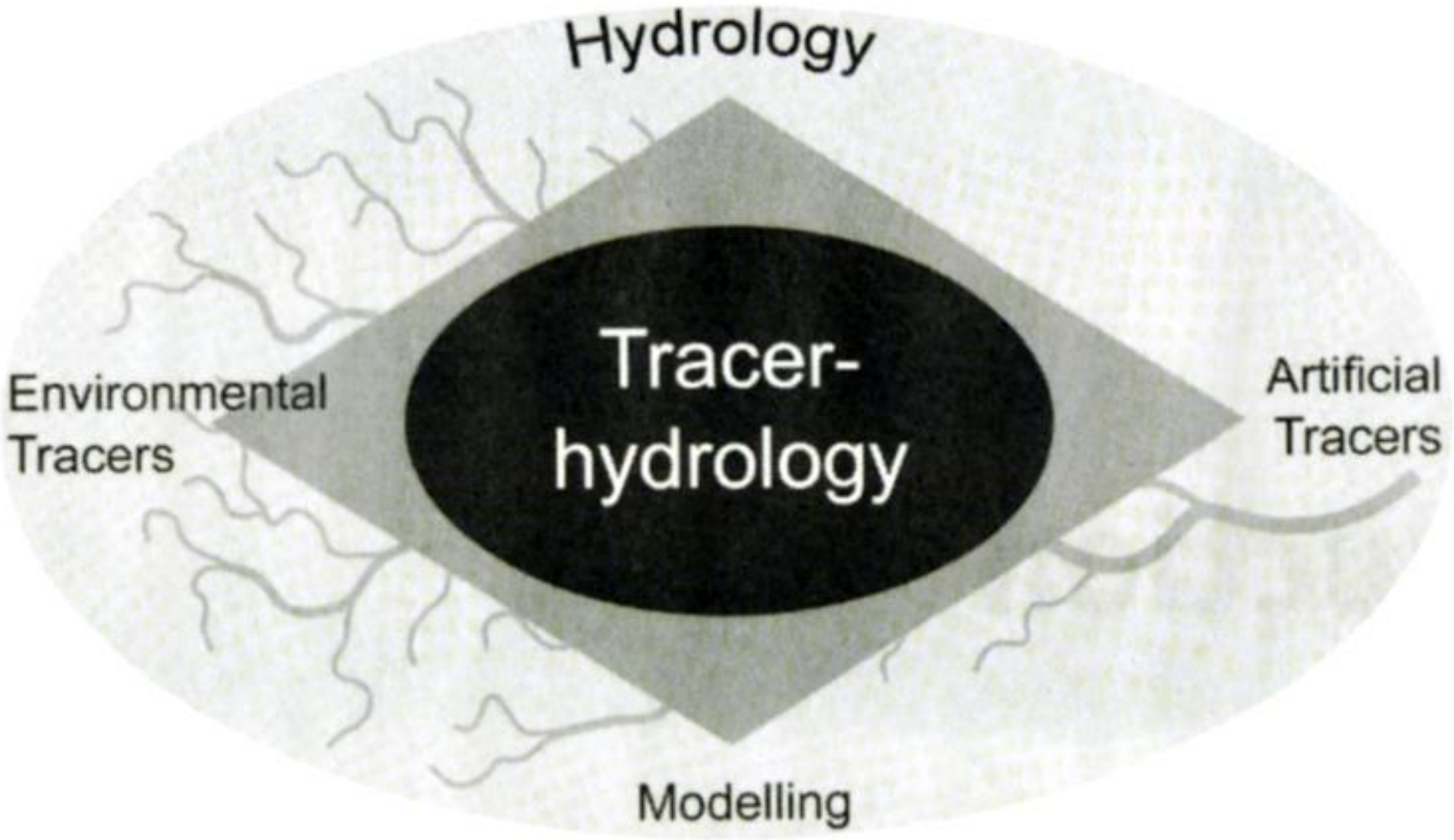
Spring water has a charming smell and taste 1 day later

Accident at ‚La fée verte': Absinth flows to Doubs, 1901



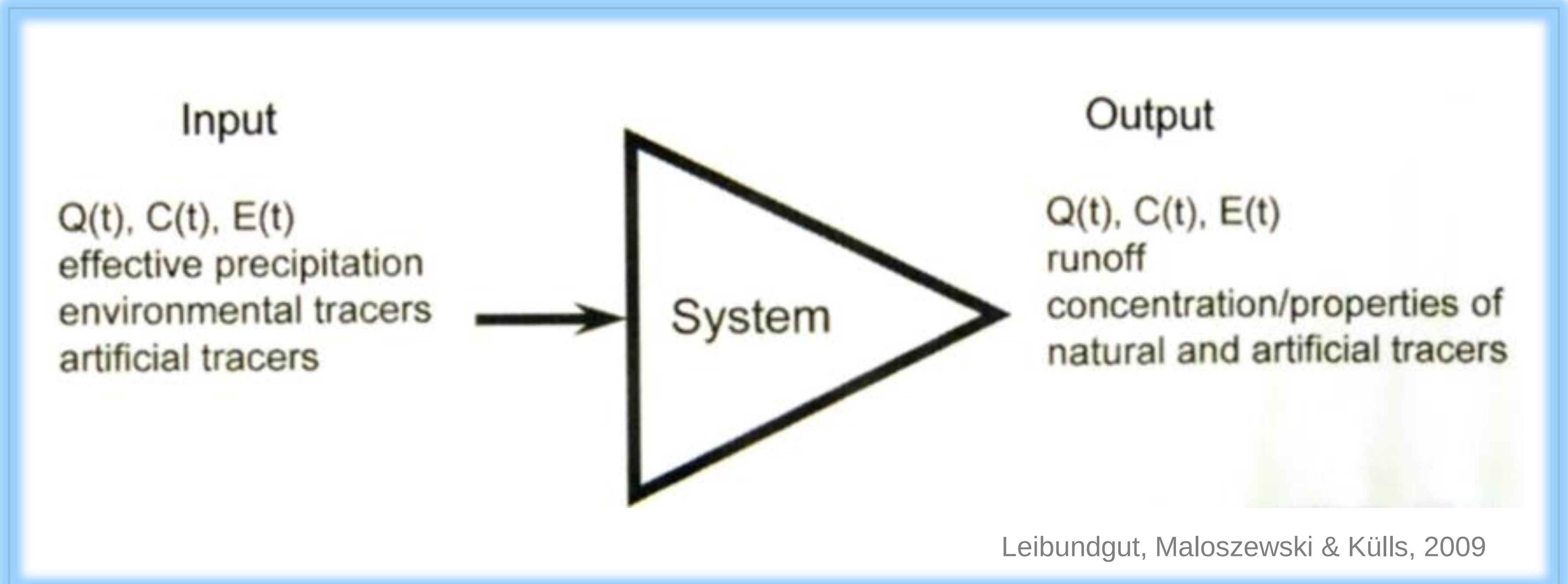


I.1 Introduction: Approach and Compass



Leibundgut, Maloszewski & Külls, 2009

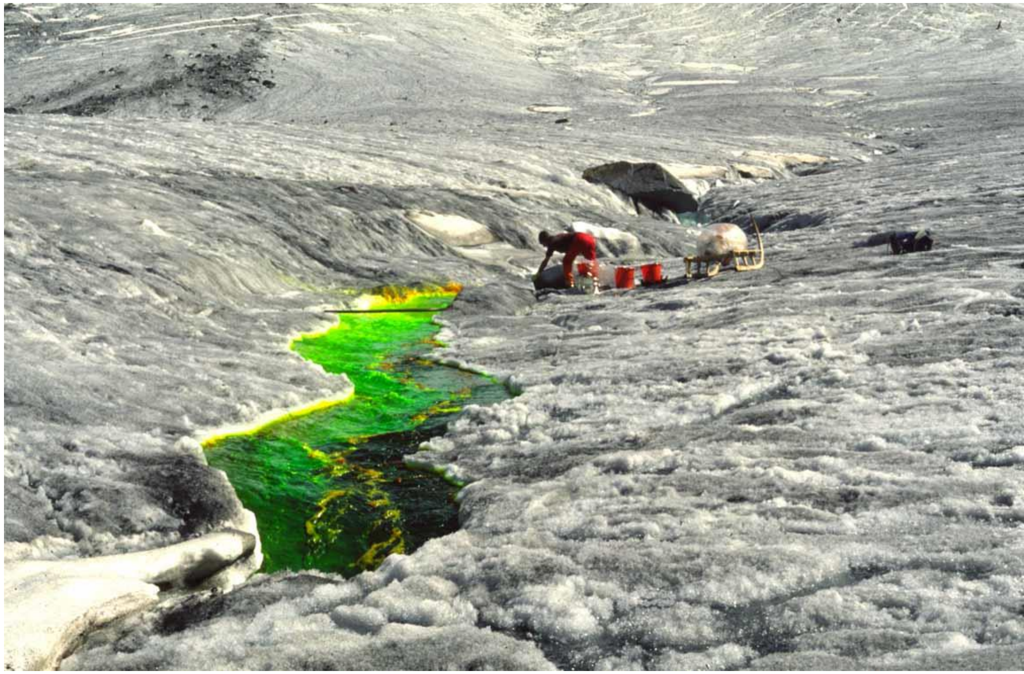
I.1 The Approach of Tracer Hydrology

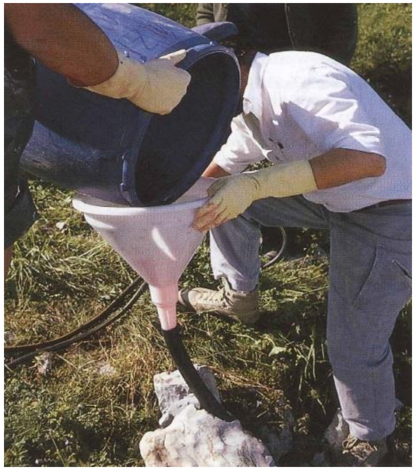


input function	**system transform**	**measured output**
Flow $Q_{in}(t)$,	are transformed	into respective
Mass flows C_{in} (t)	by the hydrological	outputs of $Q_{out}(t)$,
Energy E_{in} (t)	system	$C_{out}(t)$ and $E_{out}(t)$

I.1 Artificial Tracers Applied

- Injection at a specific site and time and into a specific hydrological component
- A specific water and flow component can be traced and followed
- Time and scale are limited
- Only valid for specific hydrological situation (including antecedent conditions)
- Hydrological system state may not be representative or typical (repetitions for drought, wet, flood, low flow conditions)





I.2 Definition of Tracers

Tracers are natural (environmental) or artificial substances that can be detected at low concentration, that can be assigned to a source or input function and hence that can be used to tracer water flow or to identify water sources

Detection limits: < 10^{-9}

Tracers are used in hydrological sciences to investigate sources, flow paths, flow processes and residence times

I.2 Natural and Artificial Tracers

Application of natural tracers	Application of artificial tracers
Environmental Isotopes	**Used as water markers, defined input, measurement of the injected tracer**
stable isotopes of water tritium	radioactive (bromide-82) activated (Indium) salts (NaCl) fluorescent dyes (Uranine) drift particles (Lycopodium)
Natural, historical and spatial input **Hydrochemical Tracer:** geogenic origin	Input by scientist, point and time and substance defined and known, time (seconds to months) and space constraints (pores to few kilometers), depending on velocity: s = v*t with t = 3 months
Pollution tracer (e.g. CFCs)	
Application: Karst-, fracture-, pore ground water, soil water, rivers, lakes, glaciers Specific applications: groundwater recharge, runoff generation, water and solute transport, pollutants sources, waste deposits, protection zones	

I.2 Tracers – Inventory

Available Tracers

Natural Tracers

Environmental isotopes

Stable

Deuterium	**^{2}H**
Oxygen-18	**^{18}O**
Carbon-13	^{13}C
Helium-3	^{3}He
Sulphur-34	^{34}S

Radioactive

Tritium	**^{3}H**
Carbon-14	^{14}C
Silicium-32	^{32}Si
Chlorine	^{36}Cl
Argon-37	^{37}Ar
Krypton-81	^{81}Kr
Krypton-85	^{85}Kr
Freon	

Chemical components

Conductivity	µS /cm
Sodium	Na
Others	eg. Si,...

Artificial Tracers

Radioactive

Tritium	^{3}H
Sodium-24	^{24}Na
Chromium-51	^{51}Cr
Cobalt-58	^{58}Co
Bromine-82	^{82}Br
Iodine-131	^{131}I
Gold-198	^{198}Au

Activatable

- Bromine
- Indium
- Manganese
- Lanthan
- Dysprosium

Inactive

Soluble substances

Salts

- Na^{+} Cl^{-}
- K^{+} Cl^{-}
- Li^{+} Cl^{-}
- HBO_2

Drifting substances

- Lycopodiumspores in different colours
- Fluorescent particles
- Bacteria
- Viruses
- Fungi

Fluorescence tracers

- Uranine
- Eosine
- Amidorhodamines
- Rhodamines
- Naphtionate
- Pyranine
- Tinopale
- Flavines

Special

- Magnetic tracers

Pollution Tracers e.g. Chloride, heavy metals, detergents, radioactive substances, FCKW, ^{222}Rn, etc.

I.2 Ten Ideal Properties of Artifical Tracers

1. Solubility
2. Detection limit and fluorescence intensity (yield)

efficient

3. Sorptivity and sorption behaviour
4. chemical and biological stability
5. Sensitivity to light
6. pH-dependence

conservative

7. Temperature dependency of fluorescence
8. Stability in sample bottles

stable

9. Toxicity and environmental impact

environmental friendly

10. Costs

cheap

International Committee on Tracers (ICT)
IAHS (Int. Association of Hydrological sciencies)

founded in 1991 (General Assembly, Wien)

- Establishment of tracer technology for hydrological research
- Process studies in hydrology with tracers

International Committee on Tracers (ICT)

- **Yokahama 1993**

  TRACERS IN HYDROLOGY
  edited by Peters N.E., E. Hoehn Ch. Leibundgut, N. Tase ² D.E. Walling, (1993): IAHS Publ. N° 215, 350 p., Wallingford.

- **Wien 1994**

  APPLICATION OF TRACERS IN ARID ZONE HYDROLOGY
  edited by Eilon M. Adar & Chris Leibundgut (1995) : IAHS Publ. N° 232, 450 p., Wallingford.

- **Boulder 1995**

  TRACER TECHNOLOGIES FOR HYDROLOGICAL SYSTEMS
  edited by Chris Leibundgut (1995) : IAHS Publ. N° 229, 311 p., Wallingford.

References

- **Rabat 1997**

  KARST HYDROLOGY
  edited by Chris Leibundgut, John Gunn & Alain Dassargues (1998) : IAHS Publ. N° 247, 146 p., Wallingford.

  HYDROCHEMISTRY

  edited by Norman Peters & Anne Coudrain-Ribstein

  (1997): IAHS Publ. No 244, 344 p., Wallingford

- **Birmingham 1999**

  INTEGRATED METHODS IN CATCHMENT HYDROLOGY - TRACERS, REMOTE SENSING AND NEW HYDROMETRIC TECHNIQUES
  edited by Chris Leibundgut, Jeff McDonnell & Gert Schultz (1999) : IAHS Publ. N° 258, 284 p., Wallingford

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- **Liège 2000**

  TRACERS AND Modelling in Hydrogeology

  edited by A. Dassargues (2000)

  IAHS Publ. No 262, 571 p., Wallingford

- **Maastricht 2001**

  Impact of Human Activity on Groundwater Dynamics

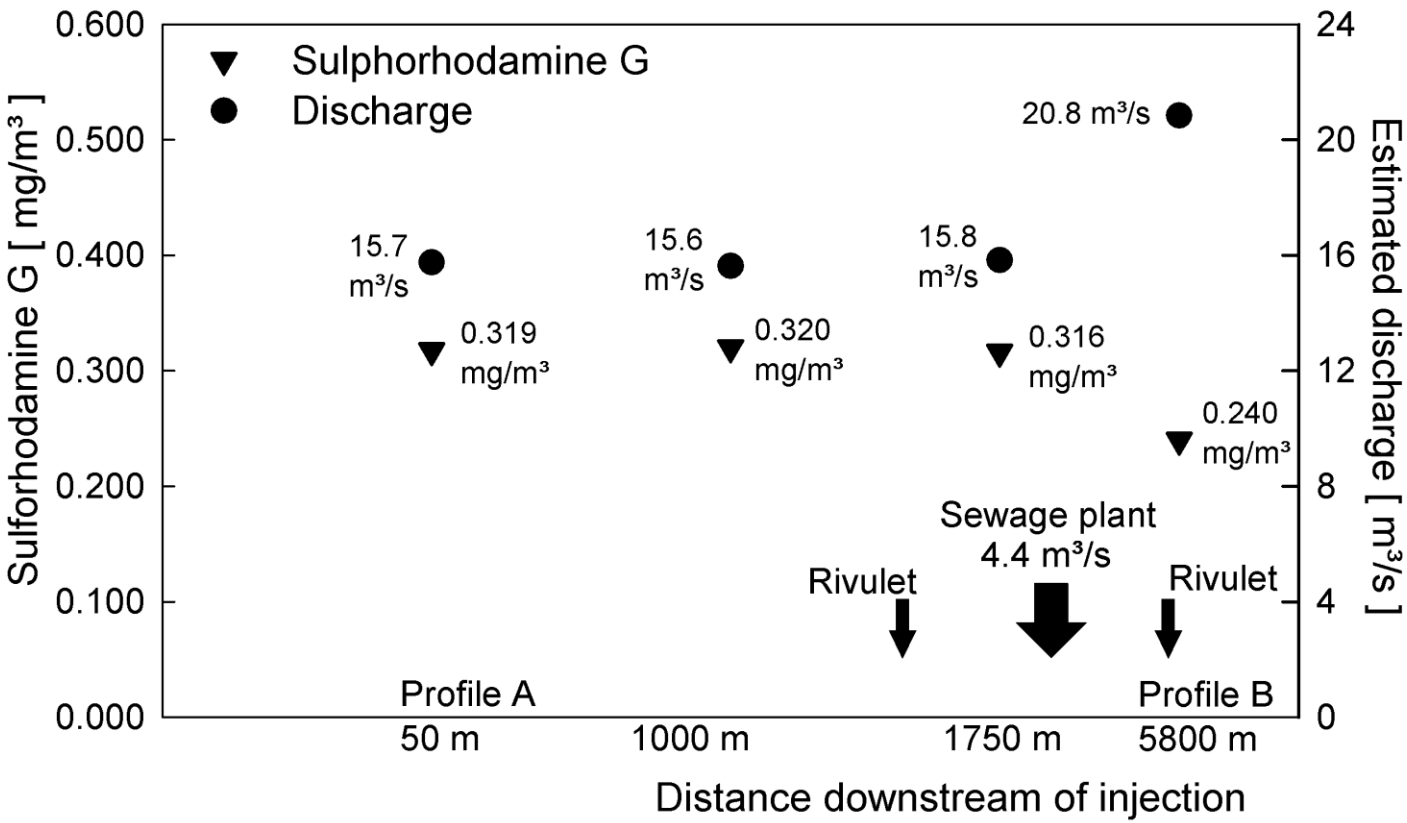
  edited by Gehrels, Peters, Hoehn, Jensen, Leibundgut, Griffioen, Webb & Zaadnoordijk

  IAHS Publ. No 269, 368 p., Wallingford

Case Study Isar

The aim of this artificial tracer study was to investigate the dispersion of water from a sewer channel injecting treated wastewater with 25 l/s into a surface water in southern Germany near Munich. A continuous injection experiment is chosen to study the lateral dispersion in the river. The study reach extends from the injection site to a bridge 5.8 kilometres downstream. The tracer test is done at mean low flow conditions with runoff between 15.4 and 17.9 m^3/s at the upper part of the reach. The inflow of treated wastewater within the study reach ranges from 2.6 to 4.4 m^3/s and increases runoff to a total of 19.8 to 20.5 m^3/s. Small tributaries contribute about 1 m^3/s and approximately 50-100 l/s. During the experiment, there is no rainfall.

Case Study Isar



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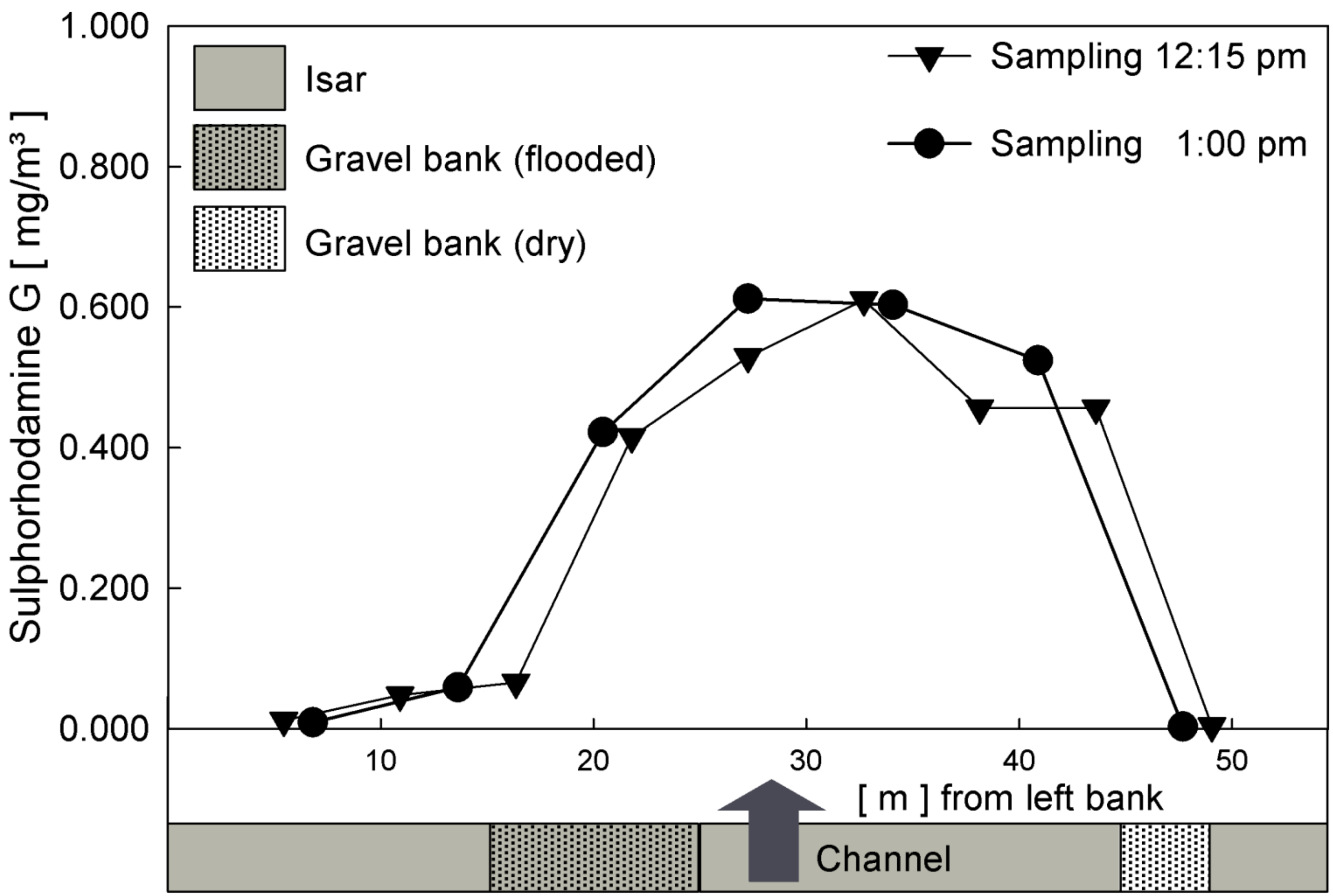

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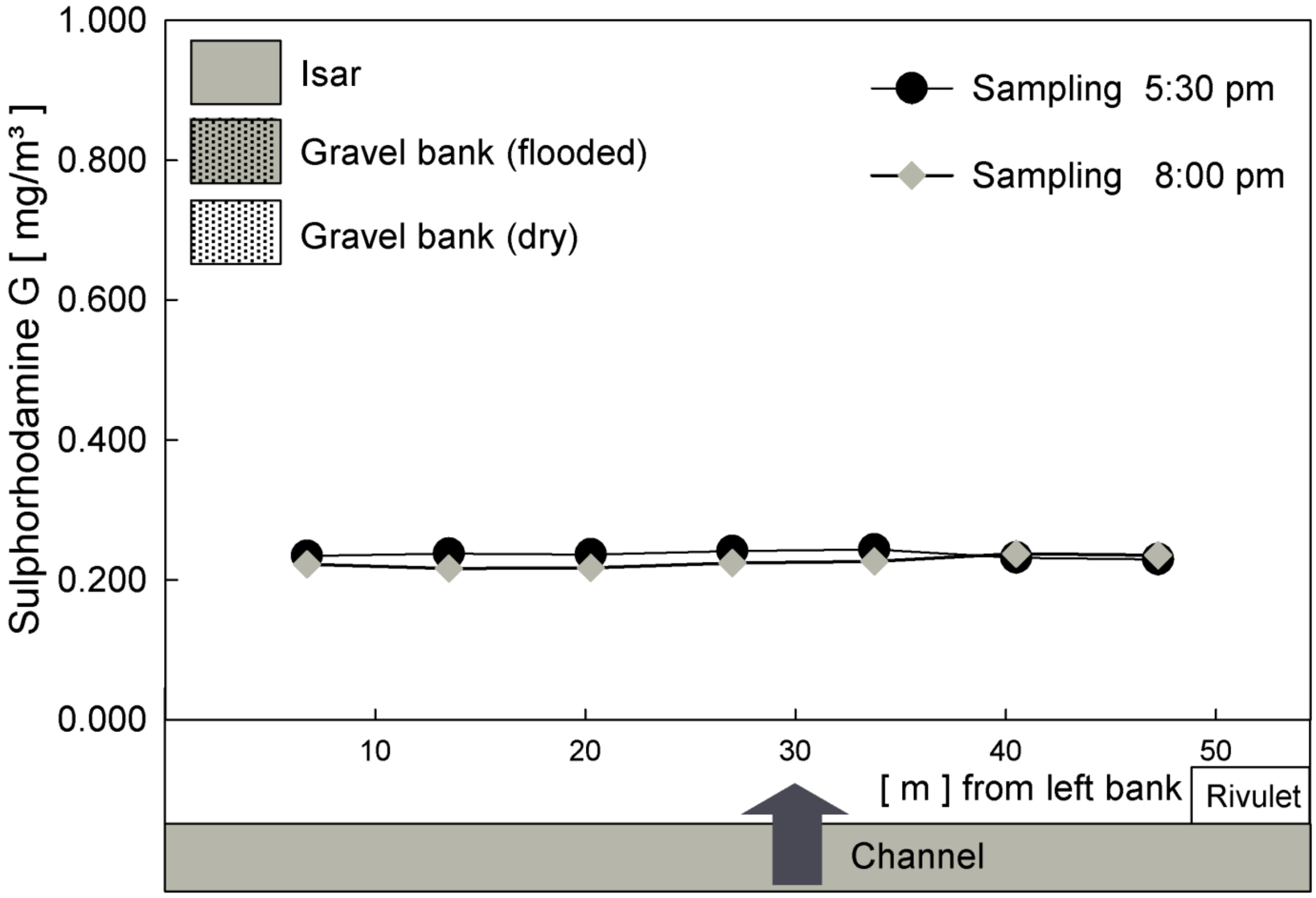

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