Implications of Hydrologic connectivity

水文連通性的意涵

The only thing you need to know about ground water

關於地下水你必須知道的事

Po Yi Chou

周柏儀

Geotechnical Engineering Research Center
Sinotech Engineering Consultants Inc.

中興工程顧問社
大地工程研究中心

poyi.chou@sinotech.org.tw

Outline

The modelling of hyporheic exchange

伏流水交換的模擬

The prediction of fracture transmissivity

山區裂隙導水率的預測

What's Next

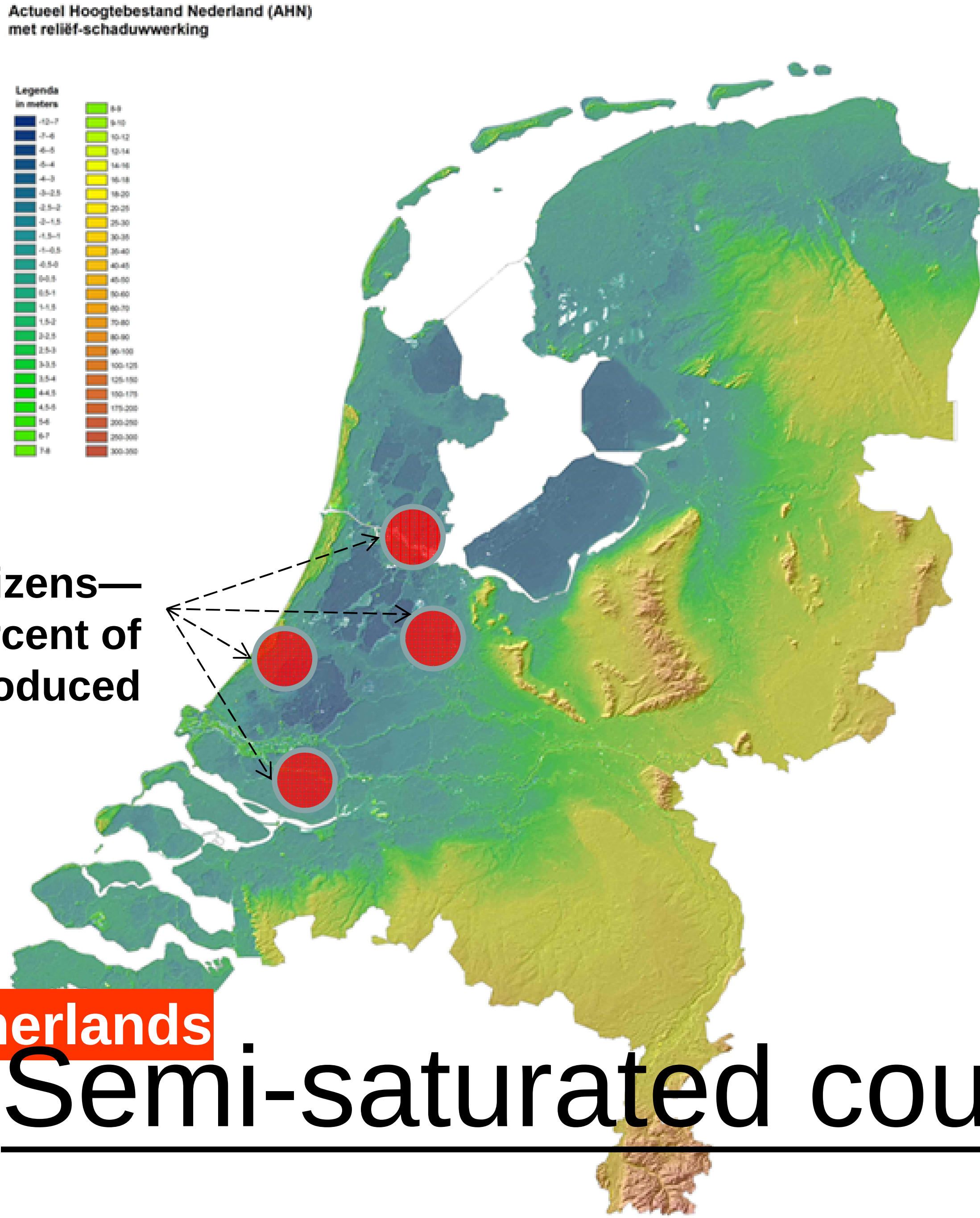
未來研究課題

What is hydrology ?

探討水在地球環境中的流動、分布和品質

the study of the movement, distribution, quality of water on Earth

Is that so ?



2/3 of all Dutch citizens— live in, and 70 percent of Dutch GDP is produced

the Netherlands

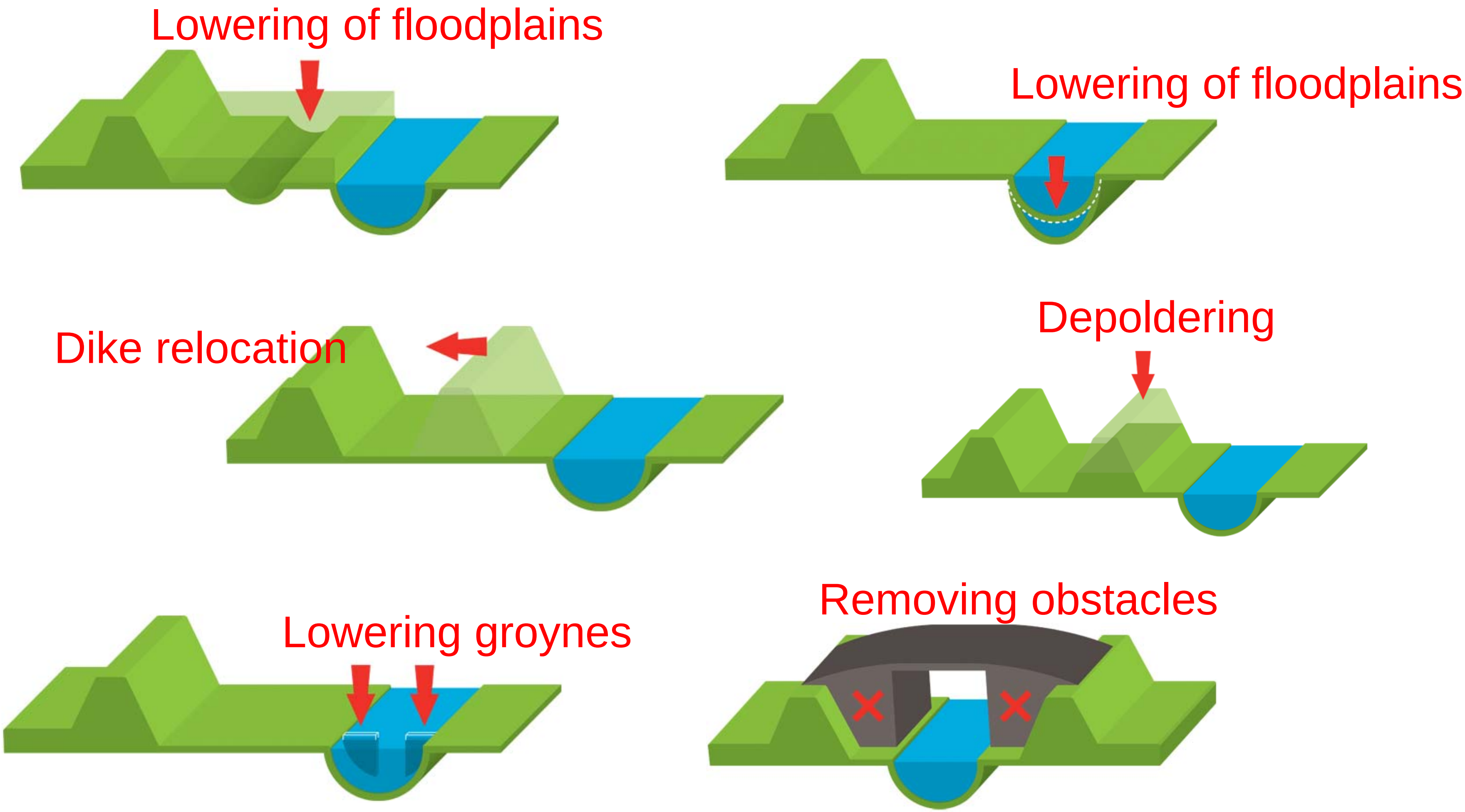
Semi-saturated country !

At a Flood-Prone Land

In Bravery We Face the Water

2006 Ruimte voor de Rivier

Creating Room for the Rivers



Source: www.ruimtevoorderivier.nl/meta-navigatie/english/types-of-measures/

Hydrol. Earth Syst. Sci., 13, 157–161, 2009
www.hydrol-earth-syst-sci.net/13/157/2009/

Hydrology and Earth System Sciences

HESS Opinions
"The art of hydrology"*

H. H. G. Savenije
Department of Water Management, Delft Un
Unesco-IHE, Institute for Water Education, I
*Invited contribution by H. H. G. Savenije, E

Received: 23 September 2008 – Published ir
Revised: 2 February 2009 – Accepted: 2 Feb

Abstract. Hydrological modelling is the sam
and encoding a hydrological theory. A hyd
is not a tool but a hypothesis. The whole d
the inadequacy of hydrological models we
of late, is related to the wrong concept of w
Good models don't exist. Instead of lookin
model, we should aim at developing better n
cess of modelling should be top-down, learni
while at the same time connection should be
underlying physical theory (bottom-up). As
erogeneity occurring at all scales in hydrolo
remains a need for calibration of models. T
we need tailor-made and site-specific model
models are fit for this modelling process, as
of the established software or "one-size-fits-a
process of modelling requires imagination,
ativity, ingenuity, experience and skill. The
that belong to the field of art. Hydrology is a
it is science and engineering.

1 What is hydrology?

What is hydrology? One would think that
question. Hydrology has been long since defined. In my own words, it is the science that describes the occurrence and behaviour of water above, over and through the Earth. It is an earth science. However, depending on someone's background, the interpretation of this definition may vary. People

Correspondence to: H. H. G. Savenije
(h.h.g.savenije@tudelft.nl)

5 The trinity: science, technology and art

We have seen that hydrology is essentially a multi-disciplinary earth science. Only when we realise that water is the connection between geology, ecology, atmosphere and society, and that it involves basic sciences such as physics, chemistry and biology, are we likely to find breakthroughs in understanding how water behaves in the Earth system. In developing new theories and models of how the water behaves, we need to make use of skill, knowledge and experience that belong to the fields of science, technology and art.

One could argue that, defined in this way, art is implicit in both science and engineering and that emphasising the art in hydrology is trivial. That may be true, but in practice I see a lot of papers, both in review and in print, that do not include elements of art. There are many papers that deal with the application of an existing hydrological model, or that describe automated calibration, or that apply standard statistical methods, without much creativity, empiricism or innovation. It is clear that for finding engineering solutions to water related problems science and technology have to go hand in hand, but when it comes to developing new insights and new approaches, art is an essential element of hydrological research.

Acknowledgements. The author would like to thank all people who have contributed to forming the opinions expressed in this paper, either by agreeing or by disagreeing. Particularly the discussants who added so many valuable points to the discussion are thanked for their contributions.

The word "anomaly" is written between quotation marks because previous authors called this phenomenon an anomaly, whereas it was purely physical behaviour that happened to disagree with their perception. Until then, models consistently underestimated the outflows of the main delta branch during a seven-year period (1974–1981) while performing well during the remaining part of the time (1968–2003). The "anomaly" disappeared when he considered the appropriate surface water-groundwater interaction and the interplay

Published by Copernicus Publications on behalf of the European Geosciences Union.

Prof. Hubert Savenije
UNESCO-IHE

What is hydrology ?

跨學門與專業的科學

only when we realise that water is the connection between geology, ecology, atmosphere and society, […]

are we likely to find breakthroughs in understanding how water behaves in the Earth system.

Savenije, H. H. G. "HESS Opinions" The art of hydrology" Hydrology & Earth System Sciences 13.2 (2009).

Belgium

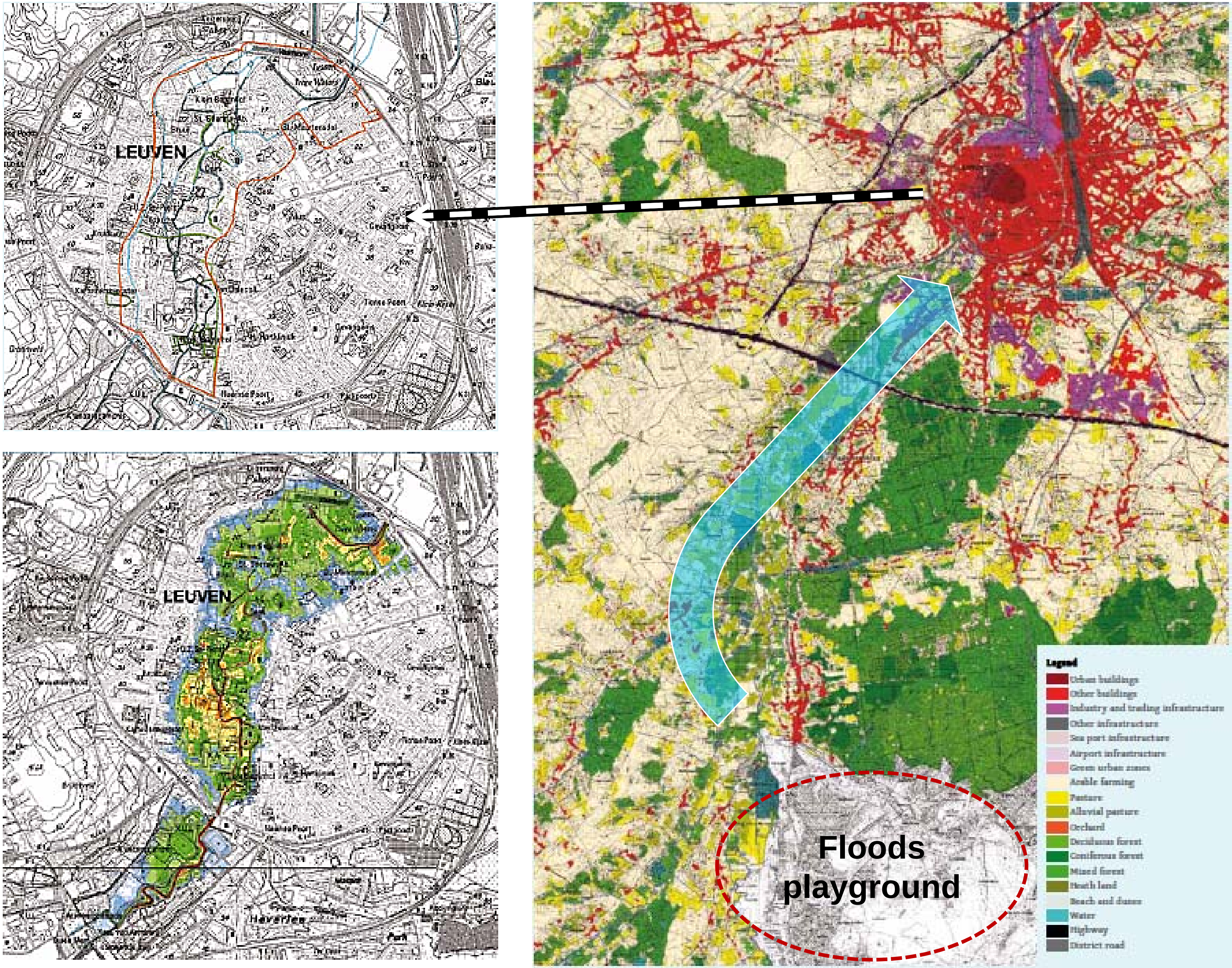
Un-consolidated country !

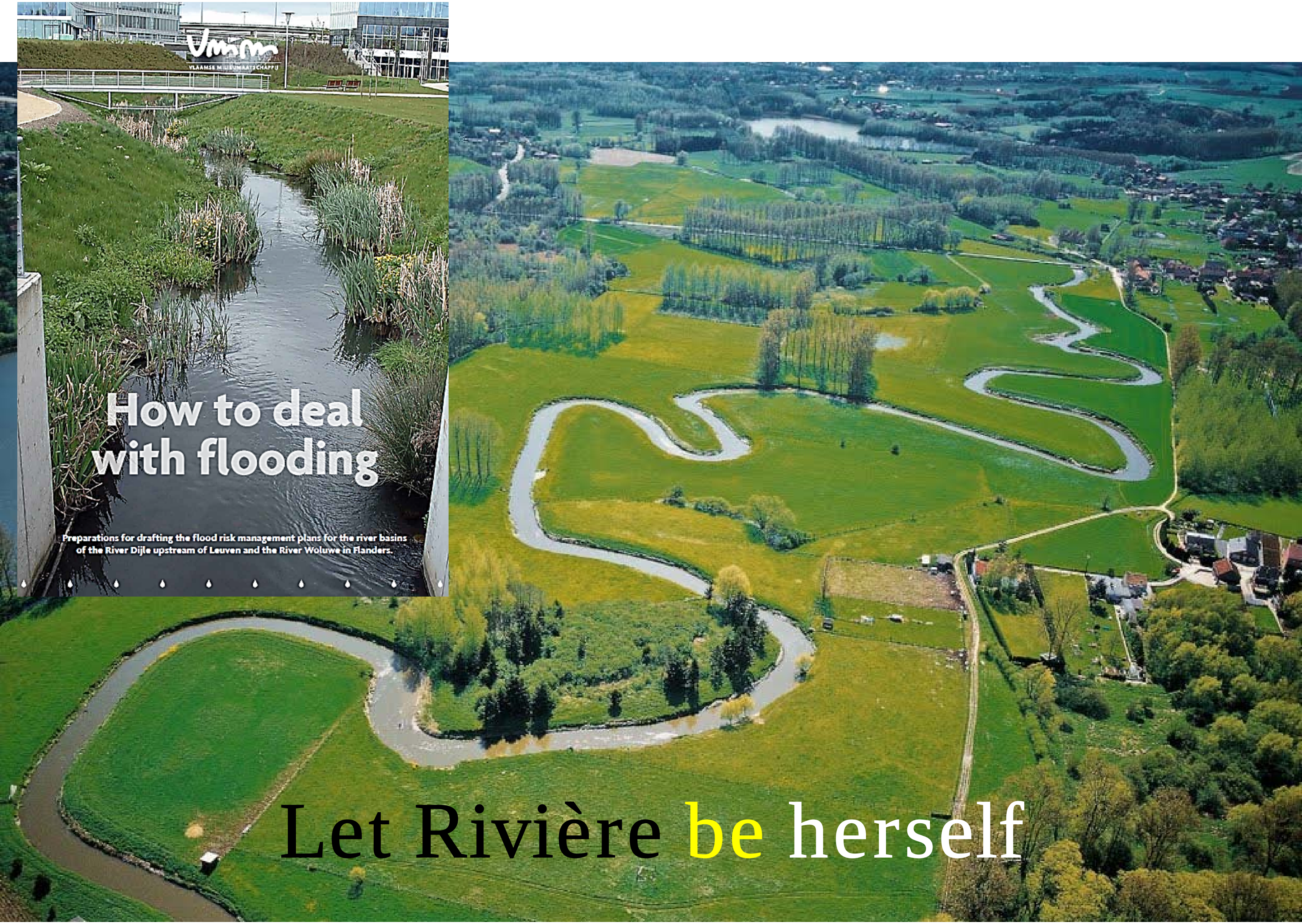
A flood causes physical damage with financial consequences

Houses and apartments: 162,000 ~ 346,000 euros price down
Furniture: 30% of the sales value
Industry: maximum damage of €1,367/m²
Roads and railroads: €710/m to €27,000/m²

The overall economic damage is at least 400 million euros

VLAAMSE MILIEUMAATSCHAPPIJ


LEUVEN
LEUVEN
Floods
playground
Legend
Urban buildings
Other buildings
Industry and trading infrastructure
Other infrastructure
Sea port infrastructure
Airport infrastructure
Green urban zones
Arable farming
Pasture
Alluvial pasture
Orchard
Deciduous forest
Coniferous forest
Mixed forest
Heath land
Beach and dunes
Water
Highway
District road



Let Rivière be herself

G. Wyseure

Hydrologic processes in and around soils

We study the physical processes governing the cycling of water where the soil acts as a major control. Therefore special attention is given to the water pathways and budgets in and around soils. This not only at the micro-scale but also at the scale of landscape elements such as hill-slopes, wetlands, shallow subsurface drainage and interaction between river and groundwater ecosystems. Special attention is given to the connectivity and interaction between different compartments as a control to the flow of water within the catchments. The water carries also dissolved elements like nitrates and dissolved organic matter.

One of the major objectives of a better insight into hydrological processes in and around soils is to create a better holistic understanding of the hydrological cycle. This should lead to a more sustainable management of water resources, land use impact, water quality and water-related natural hazards.

URL projects: ees.kuleuven.be/bwb/projects

Prof. Guido Wyseure
K.U. Leuven

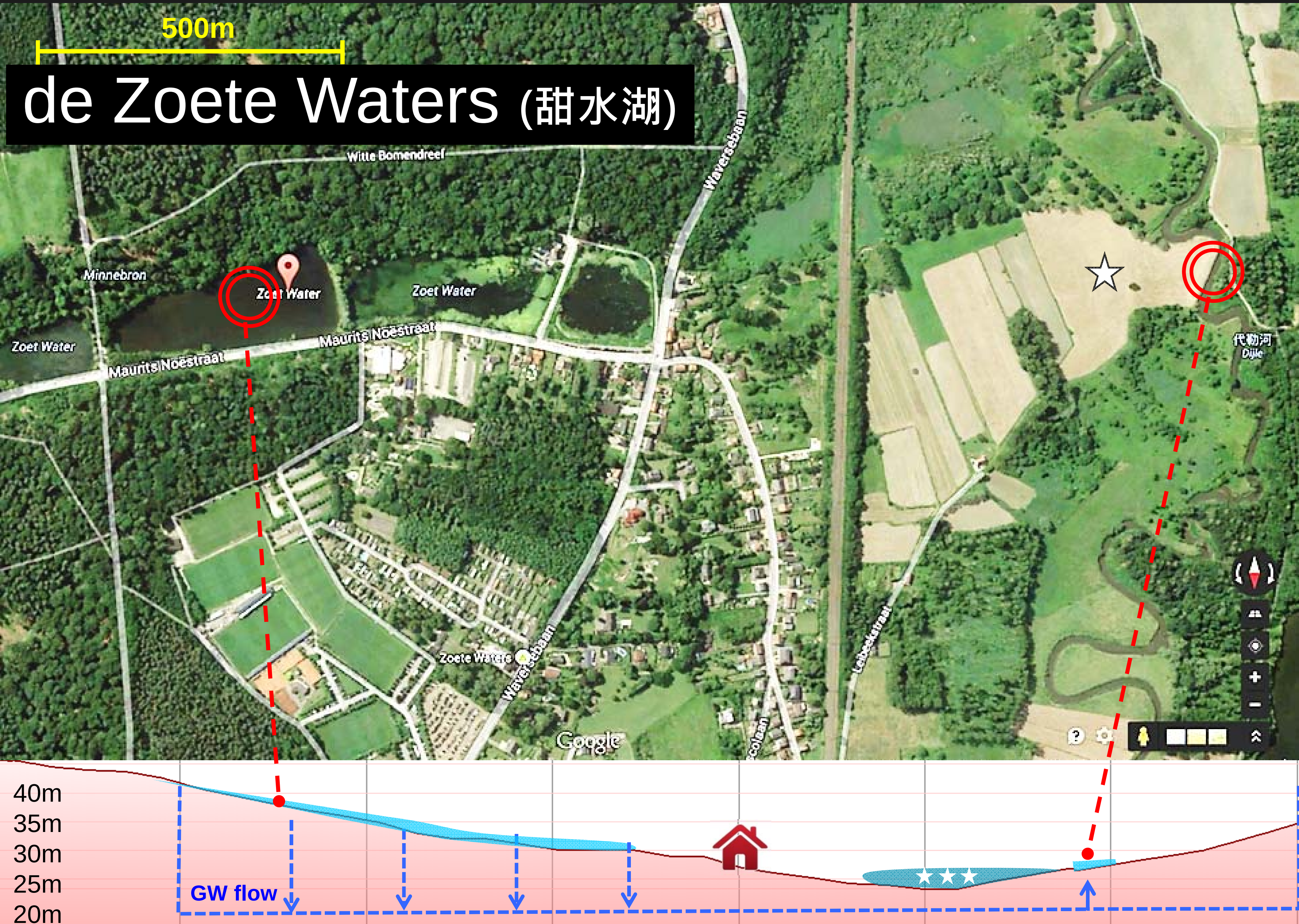
水文連通性是水文學最中心的概念

Hydrological connectivity: a central concept in hydrology

Special attention should be given to the connectivity and interaction between different compartments within the catchments as a control to the flow of water.

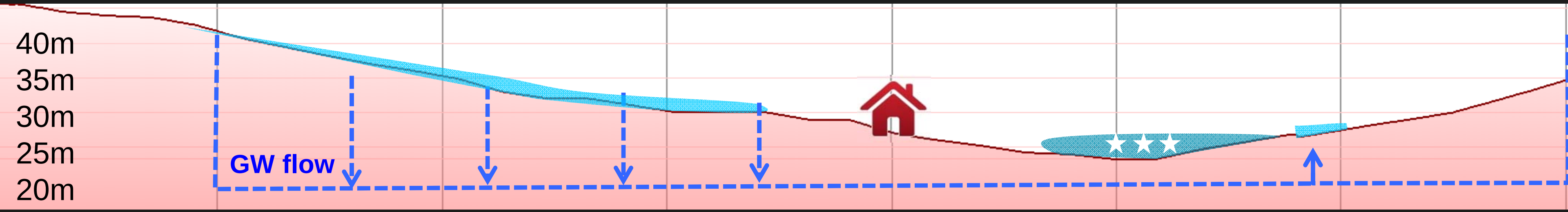
我們必須特別關注流域中不同環境區塊之間的串連和相互影響，才足以了解水體流動的機制

de Zoete Waters (甜水湖)

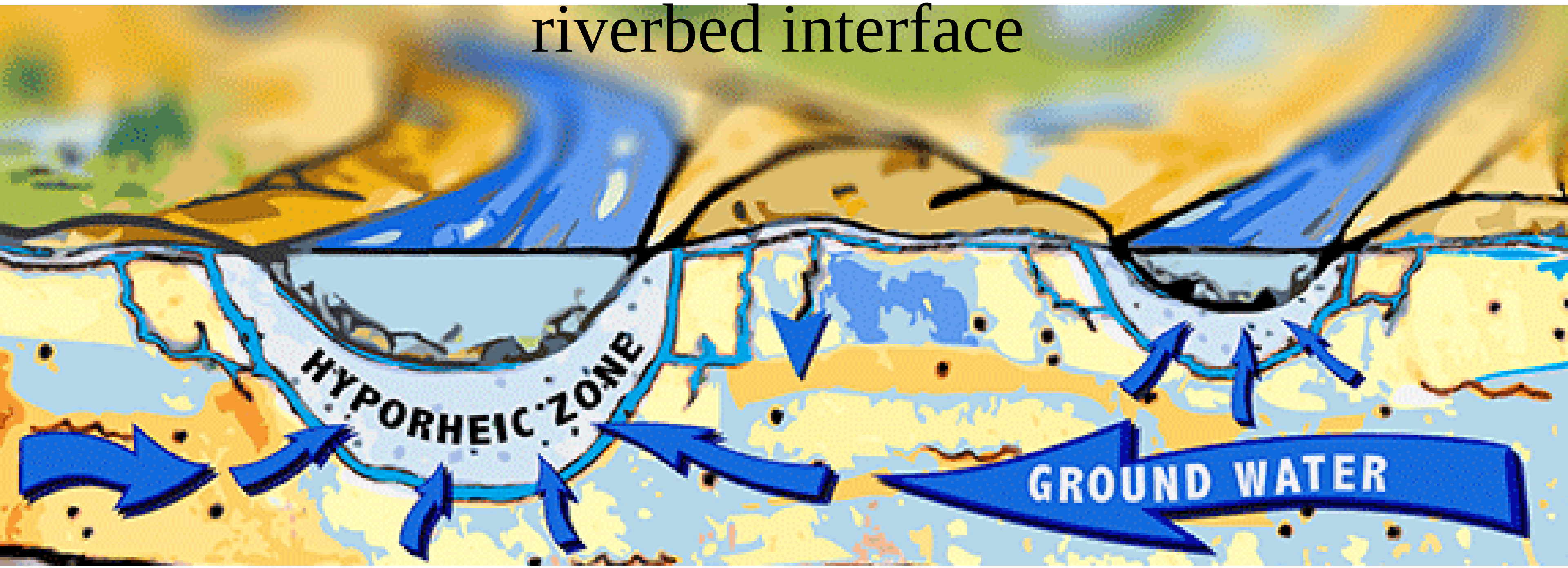


Summer time

Winter time



Hydrologic connectivity: across the aquifer-riverbed interface

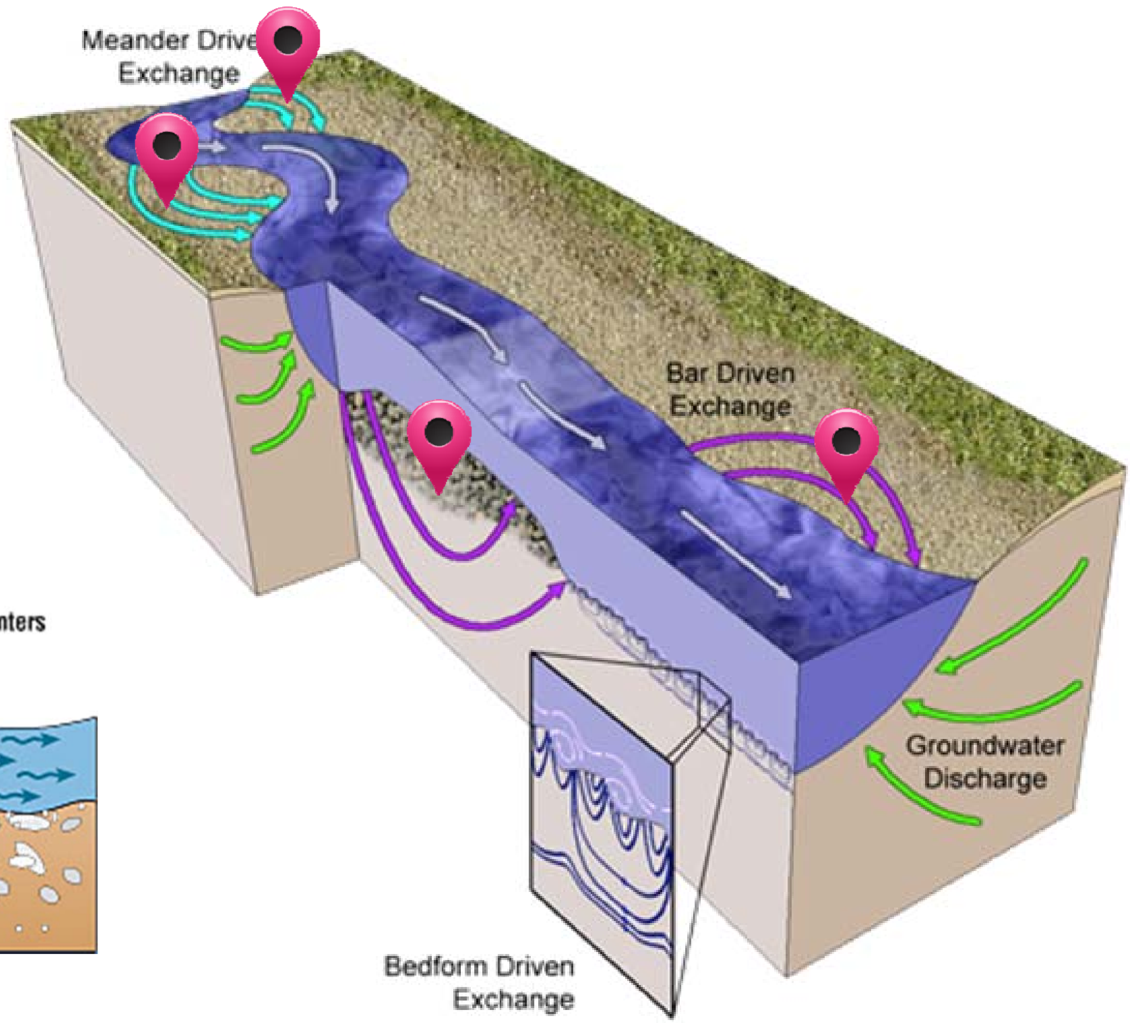


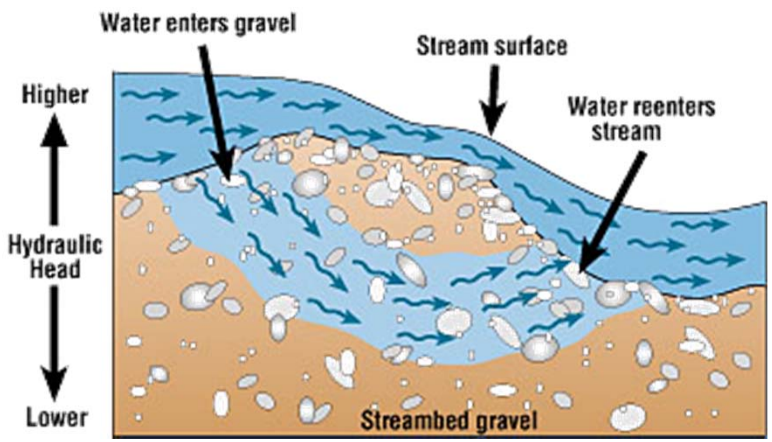
http://chuitna.org/wp-content/uploads/2011/01/hyporheic-flow.png

The hyporheic zone

伏流水帶(或潛流區)，泛指河床底下與側邊，可提供河水與淺層地下水快速混和的區塊

The Concept of Hyporheic Zone (伏流水帶)



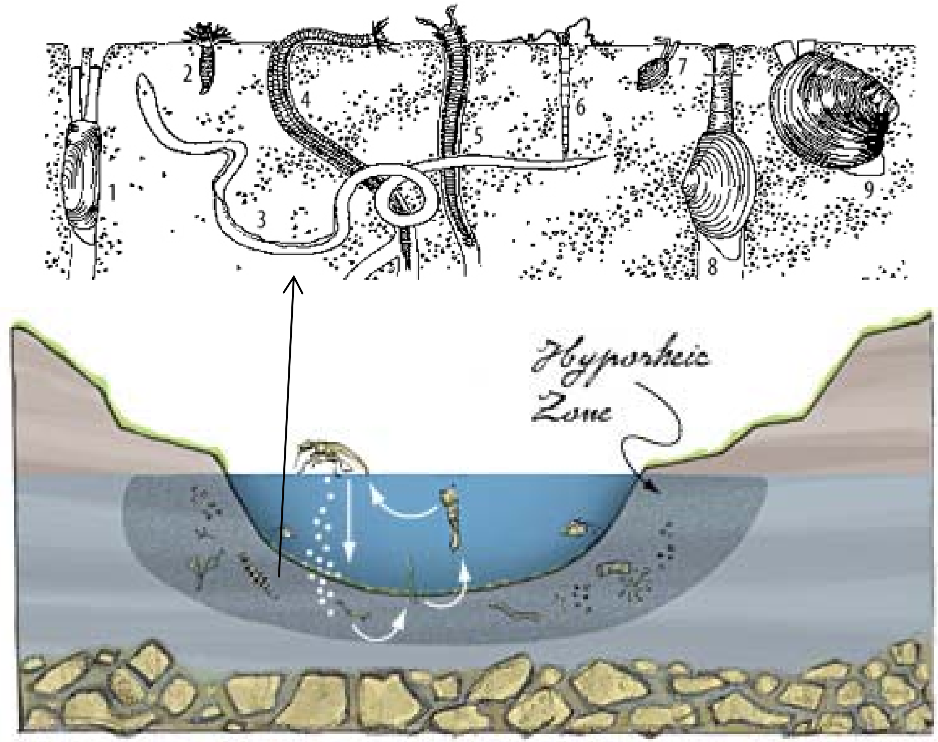


The Concept of Hyporheic Zone (伏流水帯)

THE FUNCTIONAL SIGNIFICANCE
OF THE HYPORHEIC ZONE
IN STREAMS AND RIVERS

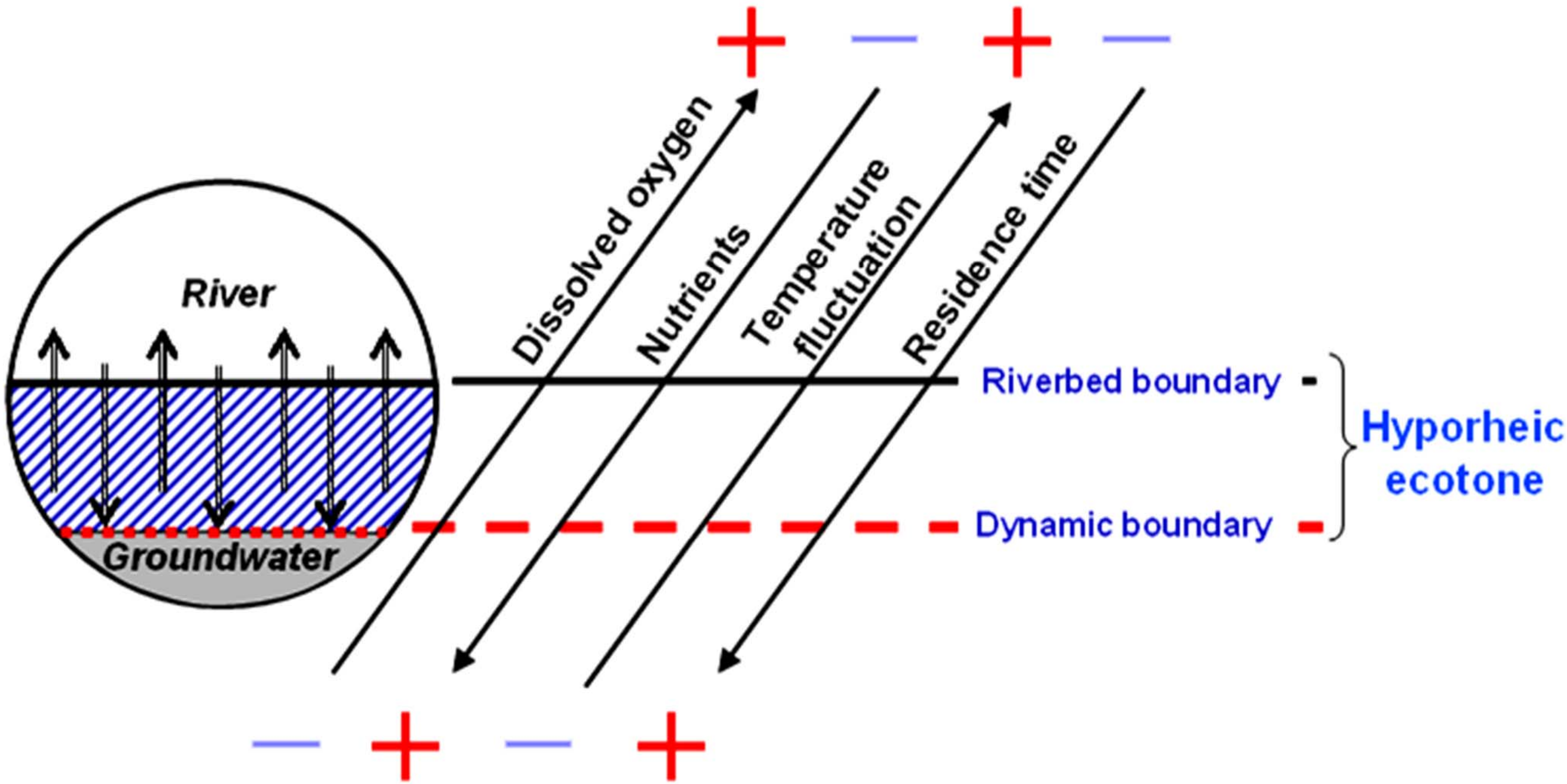
Andrew J. Boulton,[1] *Stuart Findlay,*[2] *Pierre Marmonier,*[3] *Emily H. Stanley,*[4] *and H. Maurice Valett*[5]
[1]Division of Ecosystem Management, University of New England, Armidale, 2351 New South Wales, Australia, e-mail: aboulton@metz.une.edu.au; [2]Institute of Ecosystem Studies, Millbrook, New York 12545; [3]University of Savoie, G.R.E.T.I ESA-CNRS #5023, 73376 Le Bourget du Lac, France; [4]Department of Zoology, Oklahoma State University, Stillwater, Oklahoma 74078-3052; [5]Department of Biology, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061

KEY WORDS: aquatic ecosystems, hydrology, scale, ecotone, model



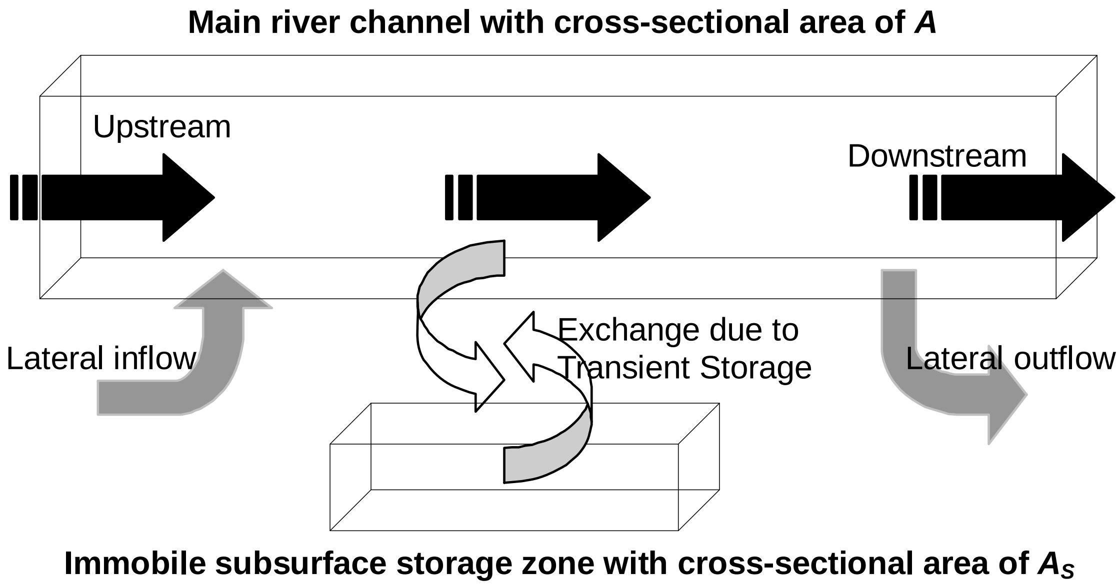
What hydrological, chemical and biological processes occur in HZ ?

Boulton, Andrew J., et al. The functional significance of the hyporheic zone in streams and rivers. *Annual Review of Ecology and Systematics* 29.1 (1998): 59-81.


River
Groundwater
Dissolved oxygen
Nutrients
Temperature fluctuation
Residence time
Riverbed boundary
Dynamic boundary
Hyporheic ecotone
+
–
+
–
–
+
–
+

(Chou, 2009)

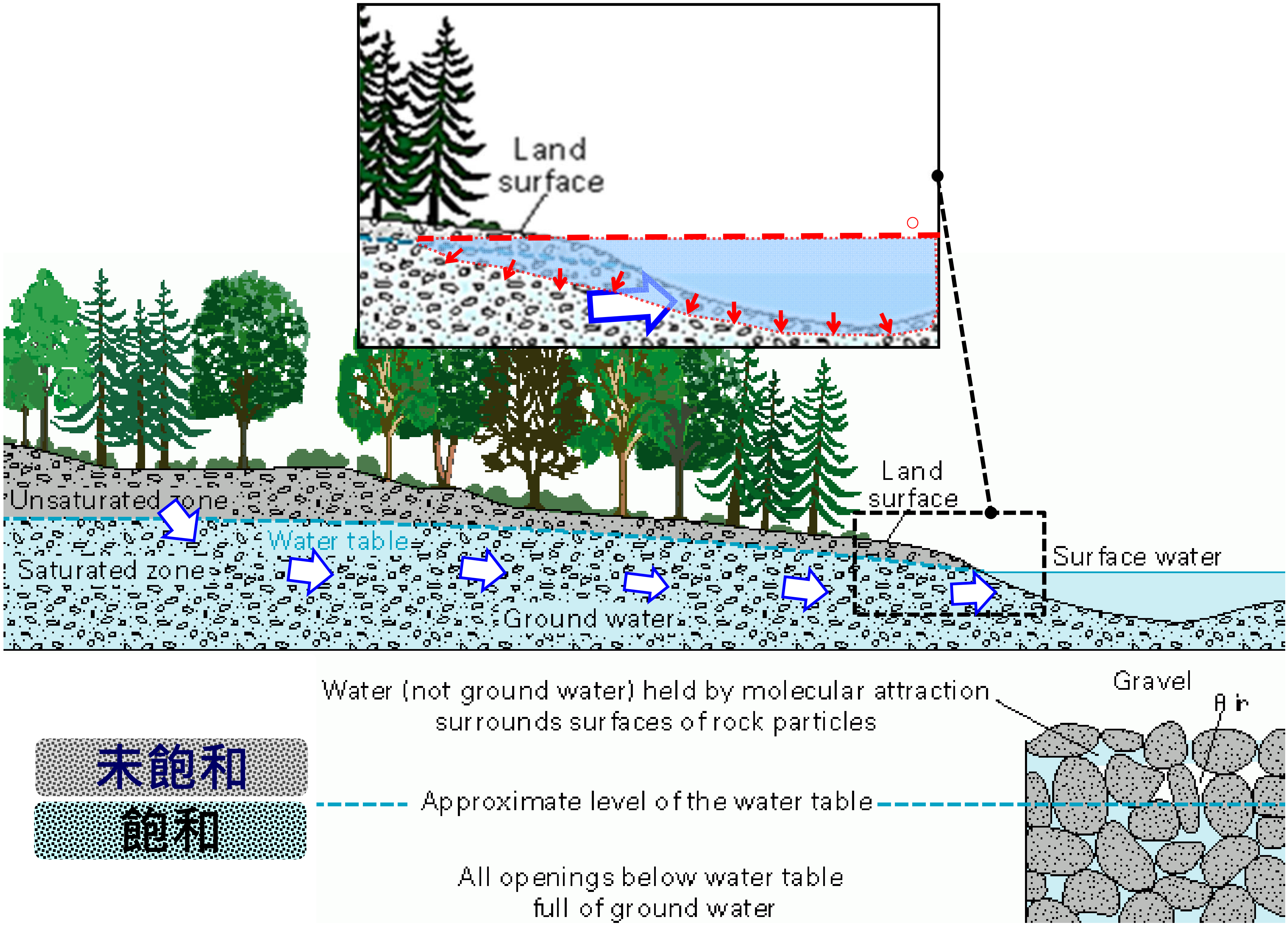
modelling via a river-centric perspective
old method : Transient Storage Model



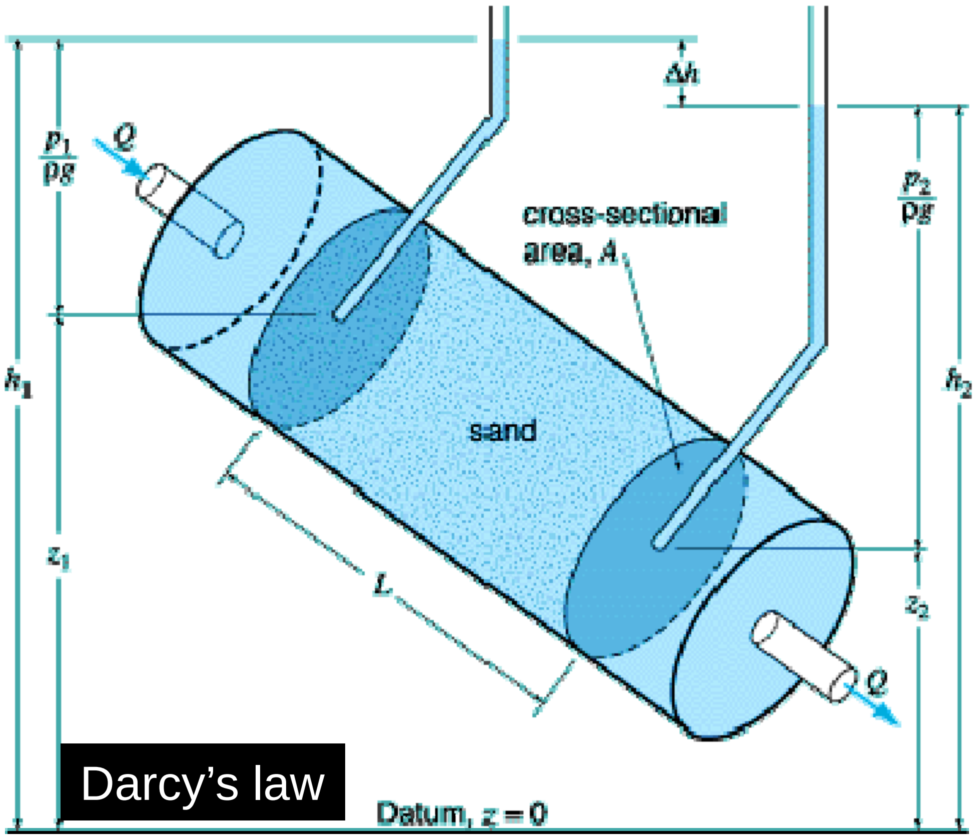
$$\frac{\partial C_R}{\partial t} = -\frac{Q}{A}\frac{\partial C_R}{\partial x} + \frac{1}{A}\frac{\partial}{\partial x}\left(AD\frac{\partial C_R}{\partial x}\right) + \frac{q_{Lin}}{A}(C_L - C_R) + \alpha * (C_S - C_R)$$

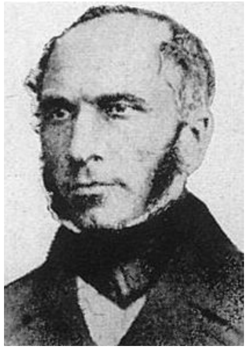
$$\frac{dC_S}{dt} = \alpha * \frac{A}{A_S}(C_R - C_S)$$

TSM did not explicitly represent the process of surface-subsurface water exchange (Zaramella et al., 2006)

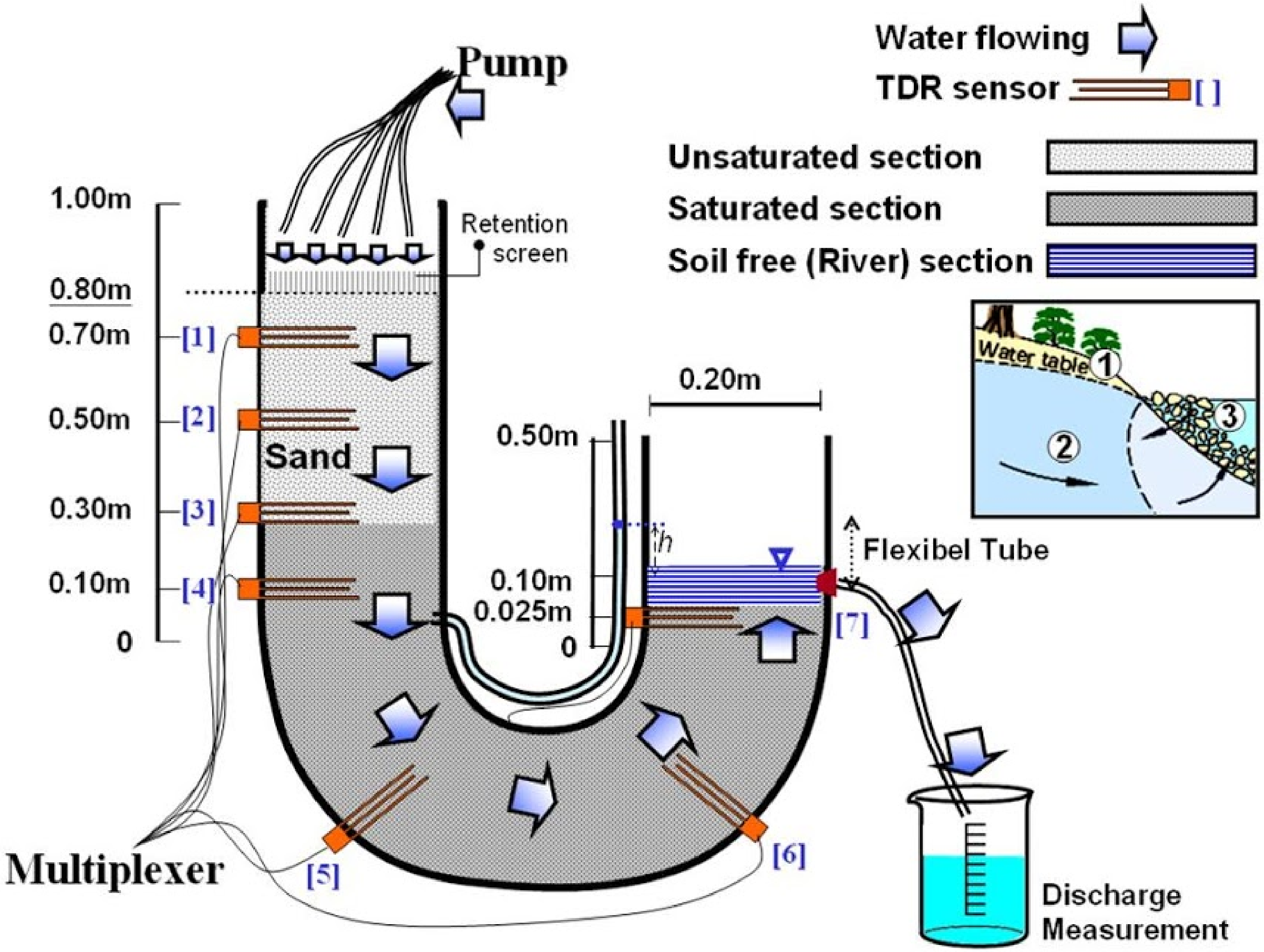

Land surface
Unsaturated zone
Water table
Saturated zone
Ground water
Land surface
Surface water
Water (not ground water) held by molecular attraction surrounds surfaces of rock particles
Gravel
Air
未飽和
飽和
Approximate level of the water table
All openings below water table full of ground water

The J-shaped Hyporheic model





The J-shaped Hyporheic model




11. 09. 2005

Theory: convective-dispersion equation (CDE)

$$R_f \frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial z^2} - V \frac{\partial C}{\partial z}$$

$$D = V^n \lambda + D_e$$

mechanical dispersion molecular diffusion

D is the dispersion coefficient

V is the pore water velocity

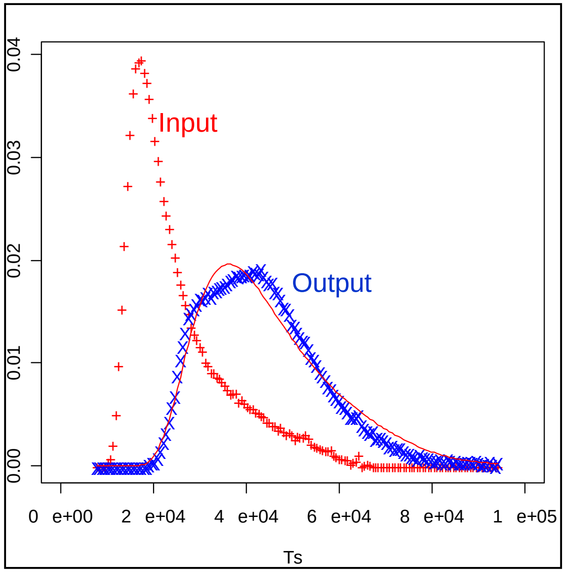
C is the concentration of solute

$\boldsymbol{R_f}$ is the retardation factor

λ represents the dispersivity

n is an empirical coefficient (1~2)

$\boldsymbol{D_e}$ is the molecular diffusion

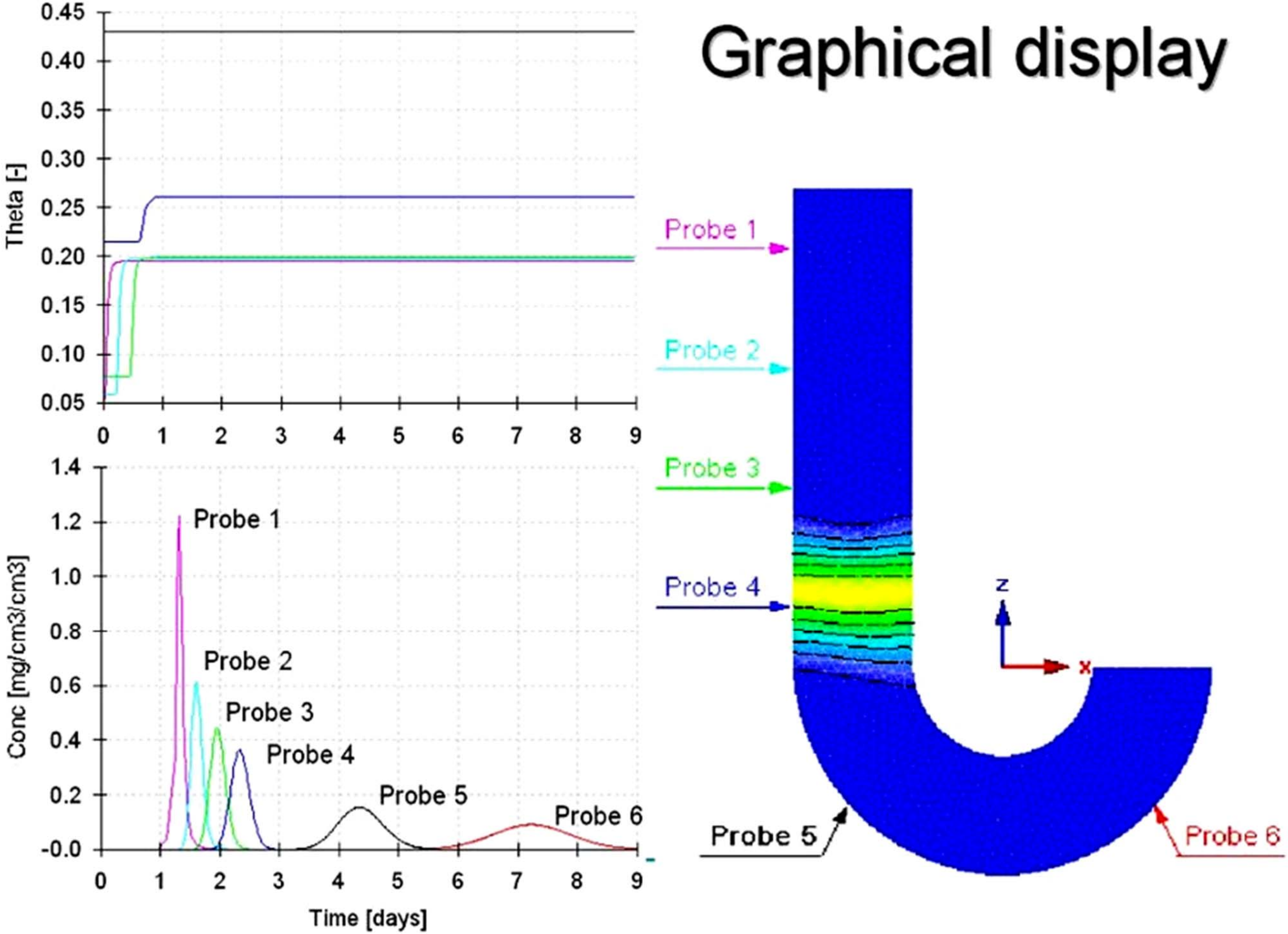


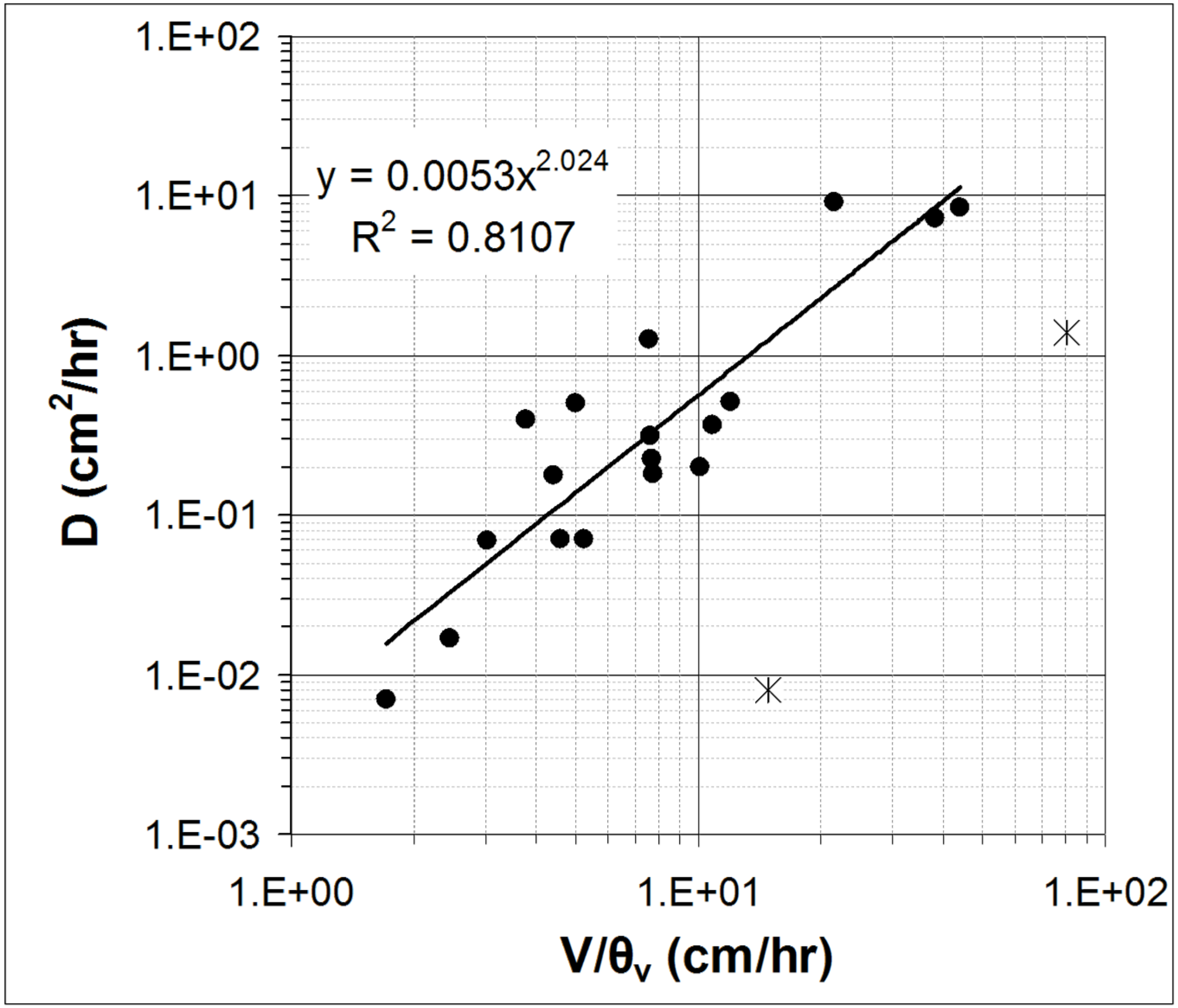
A transfer-function method for analysing breakthrough data in the time domain of the transport process

$$f(t) = \exp\left[-\left(1-\frac{t}{\tau R_f}\right)^2 \Big/ 4N\left(\frac{t}{\tau R_f}\right)\right] \Bigg/ \left[2\tau R_f\left\{\pi N\left(\frac{t}{\tau R_f}\right)^3\right\}^{0.5}\right]$$

Mojid, M. A., D. A. Rose, and G. C. L. Wyseure. "A transfer-function method for analysing breakthrough data in the time domain of the transport process." European journal of soil science 55.4 (2004): 699-711.

Graphical display





Log-log relationships between solute dispersion coefficient (*D*) and ratio of pore water velocity to water content


Hydrol. Earth Syst. Sci., 13, 217–228, 2009
www.hydrol-earth-syst-sci.net/13/217/2009/

Hydrodynamic dispersion characteristics of lateral inflow into a river tested by a laboratory model

P. Y. Chou and G. Wyseure

Dept. of Earth and Environmental Science, Division Soil and Water Management, Katholieke Universiteit Leuven, Celestijnenlaan 200 E, 3001, Heverlee, Belgium

Received: 15 May 2008 – Published in Hydrol. Earth Syst. Sci. Discuss.: 20 June 2008
Revised: 9 January 2009 – Accepted: 10 February 2009 – Published: 23 February 2009

Abstract. Groundwater and river-water have a different composition and interact in and below the riverbed. The riverbed-aquifer flux interactions have received growing interest because of their role in the exchange and transformation of nutrients and pollutants between rivers and the aquifer. In this research our main purpose is to identify the physical processes and characteristics needed for a numerical transport model, which includes the unsaturated recharge zone, the aquifer and the riverbed. In order to investigate such lateral groundwater inflow process, a laboratory J-shaped column experiment was designed. This study determined the transport parameters of the J-shaped column by fitting an analytical solution of the convective-dispersion equation for every flux on individual segments to the observed breakthrough curves of the resident concentration, and by inverse modelling for every flux simultaneously over the entire flow domain. The obtained transport-parameter relation was tested by numerical simulation using HYDRUS 2-D/3-D.

Four steady-state flux conditions (i.e. 0.5 cm hr^{-1}, 1 cm hr^{-1}, 1.5 cm hr^{-1} and 2 cm hr^{-1}) were applied, transport parameters including pore water velocity and dispersivity were determined for both unsaturated and saturated sections along the column. Results showed that under saturated conditions the dispersivity was fairly constant and independent of the flux. In contrast, dispersivity under unsaturated conditions was flux dependent and increased at lower flux. For our porous medium the dispersion coefficient related best to the quotient of the pore water velocity divided by the water content. A simulation model of riverbed-aquifer flux interaction should take this into account.

Correspondence to: G. Wyseure
(Guido.Wyseure@ees.kuleuven.be)

1 Introduction

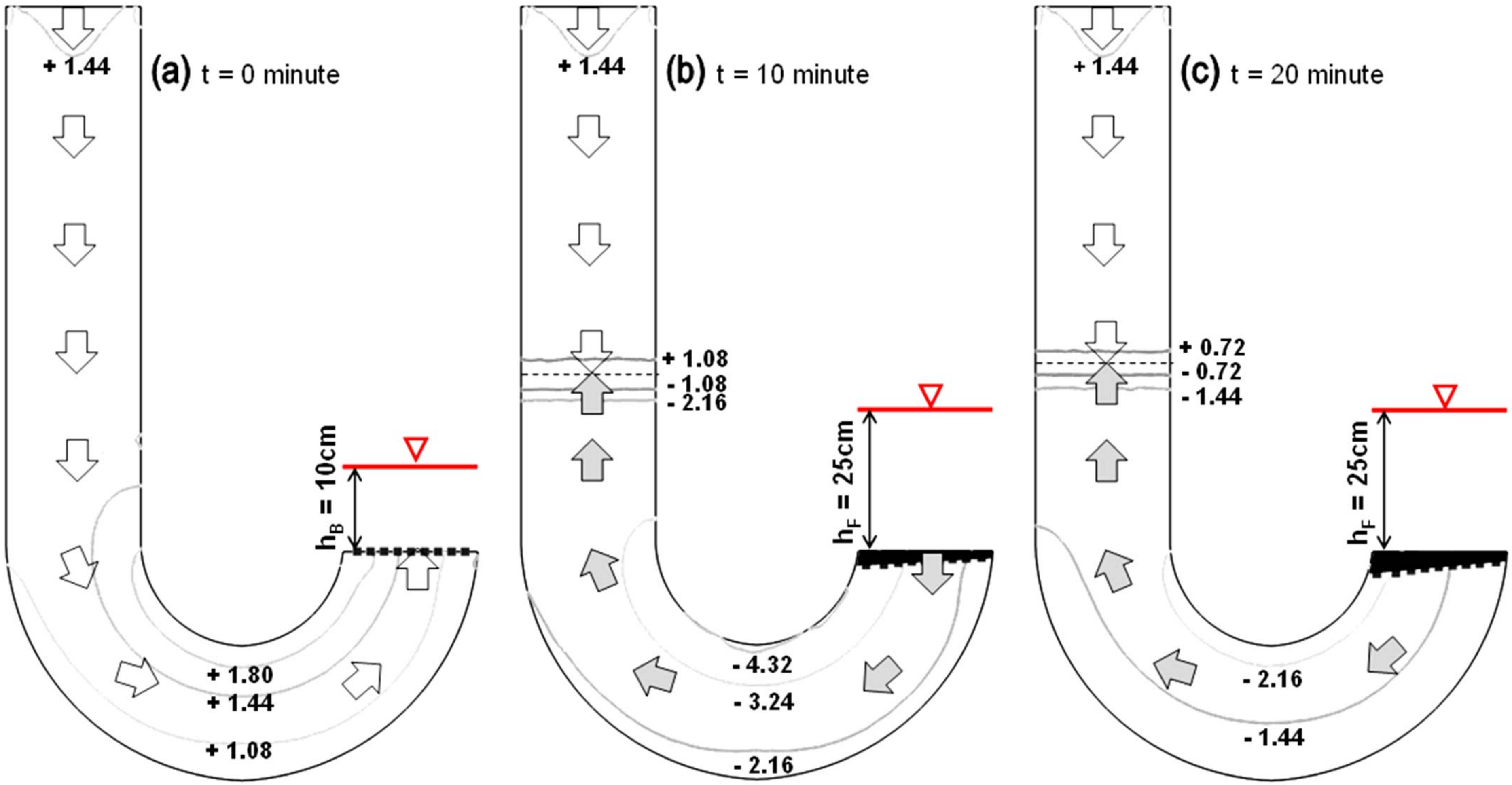
Knowledge of the aquifer and river water interaction is important for understanding the continuum of groundwater and surface water hydrology. The significance of groundwater-surface water interaction is however difficult to quantify (Valett et al., 1994) and is commonly ignored in water-management considerations or policies.

Groundwater has different dissolved minerals, contains less oxygen, and has a more constant temperature as compared to river water. On the one hand riverbed-aquifer flux interactions result in specific dissolved minerals from the aquifer moving into the riverbed, on the other hand down penetrating flow from the river moves substances like oxygen and organic matter into the riverbed and the aquifer below. The part of the riverbed subject to exchange of fluxes is called the hyporheic zone, which also acts as an important heat source and sink that affects river water temperatures (Brown et al., 2005; Moore et al., 2005; Cozzetto et al., 2006) and the solubility of oxygen (Ricci and Balsamo, 2000; Hahn, 2006).

Many studies analyzed the river-subsurface interaction by comparing the difference of tracer concentrations between river water and the subsurface flowpaths as reviewed by Marion et al. (2003) and Zaramella et al. (2006). Conceptual models of the river solute advection dispersion model, such as the Transient Storage Model (TSM) (Bencala and Walters, 1983), are widely adopted to analyze and predict the solute exchange between river water and bed sediment in longitudinal sections of rivers (e.g. Gooseff et al., 2003; Lin and Medina, 2003; Jonsson et al., 2003; Cozzetto et al., 2006; Ge and Boufadel, 2006; Kazezyilmaz-Alhan and Medina, 2006; Zaramella et al., 2006). The transient storage and exchange in the bed sediment is assumed to be governed by

Chou, Po-Yi, and Guido Wyseure. "Hydrodynamic dispersion characteristics of lateral inflow into a river tested by a laboratory model." *Hydrology & Earth System Sciences* 13.2 (2009).

Creating Backflow from the river to the aquifer



ground water

Review Paper/

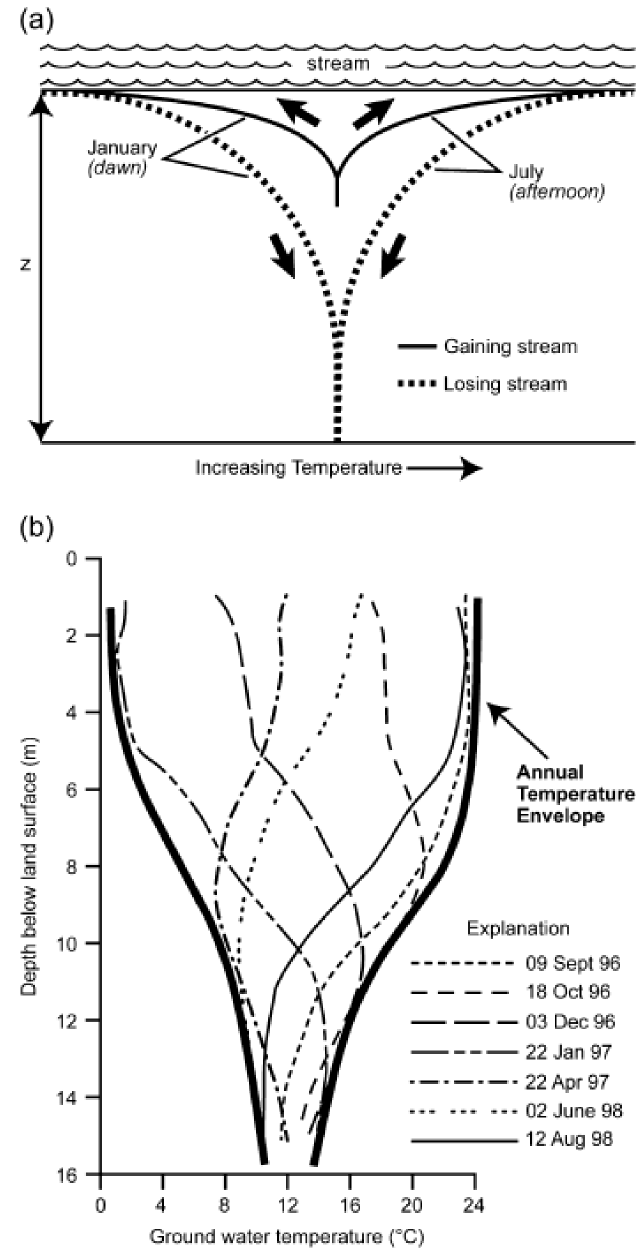
Heat as a Ground Water Tracer

by Mary P. Anderson[1]

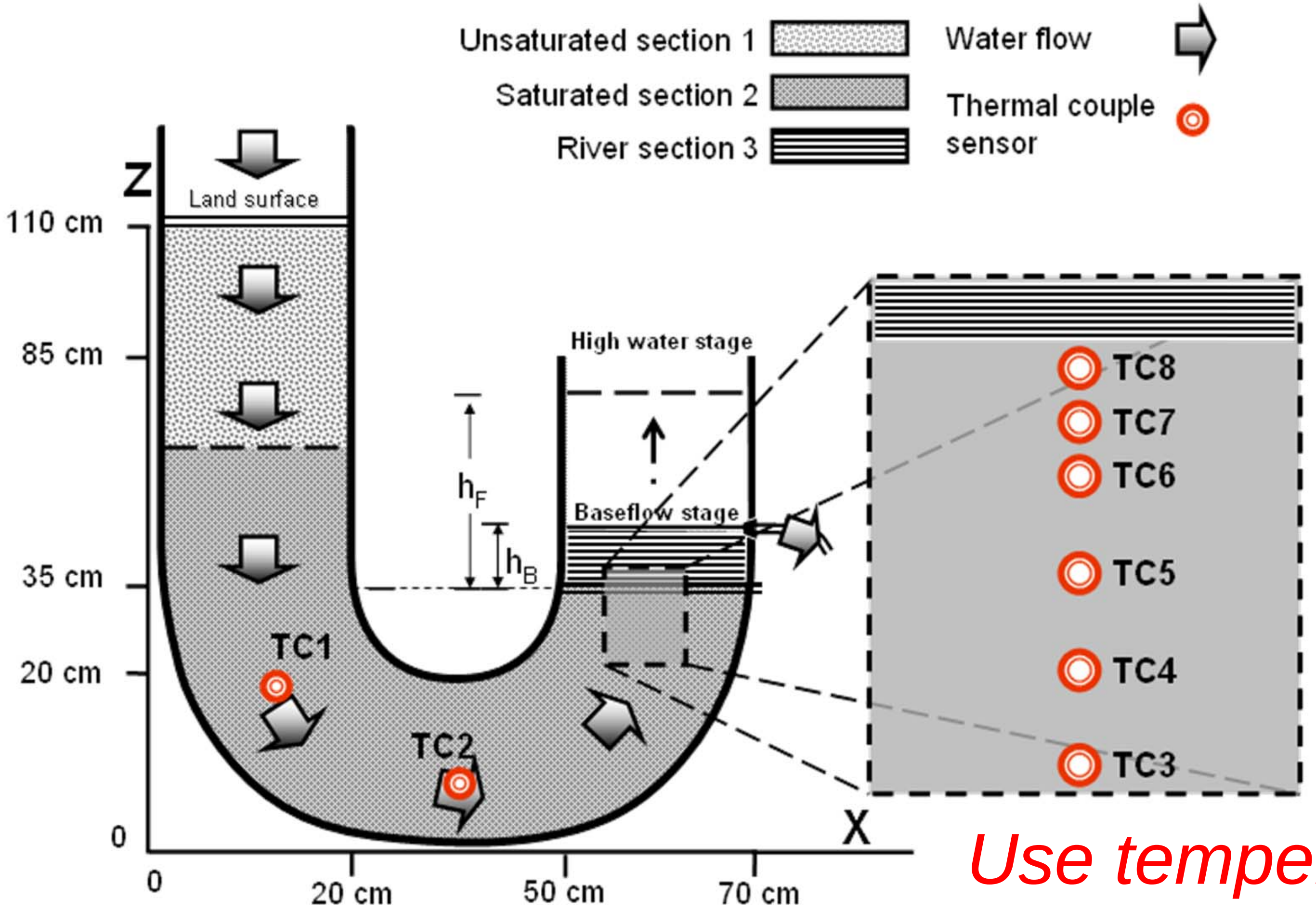
Abstract

Heat carried by ground water serves as a tracer to identify surface water infiltration, flow through fractures, and flow patterns in ground water basins. Temperature measurements can be analyzed for recharge and discharge rates, the effects of surface warming, interchange with surface water, hydraulic conductivity of streambed sediments, and basin-scale permeability. Temperature data are also used in formal solutions of the inverse problem to estimate ground water flow and hydraulic conductivity. The fundamentals of using heat as a ground water tracer were published in the 1960s, but recent work has significantly expanded the application to a variety of hydrogeological settings. In recent work, temperature is used to delineate flows in the hyporheic zone, estimate submarine ground water discharge and depth to the salt-water interface, and in parameter estimation with coupled ground water and heat-flow models. While short reviews of selected work on heat as a ground water tracer can be found in a number of research papers, there is no critical synthesis of the larger body of work found in the hydrogeological literature. The purpose of this review paper is to fill that void and to show that ground water temperature data and associated analytical tools are currently underused and have not yet realized their full potential.

Prof. Mary P. Anderson
University of Wisconsin



The J-shaped Hyporheic model

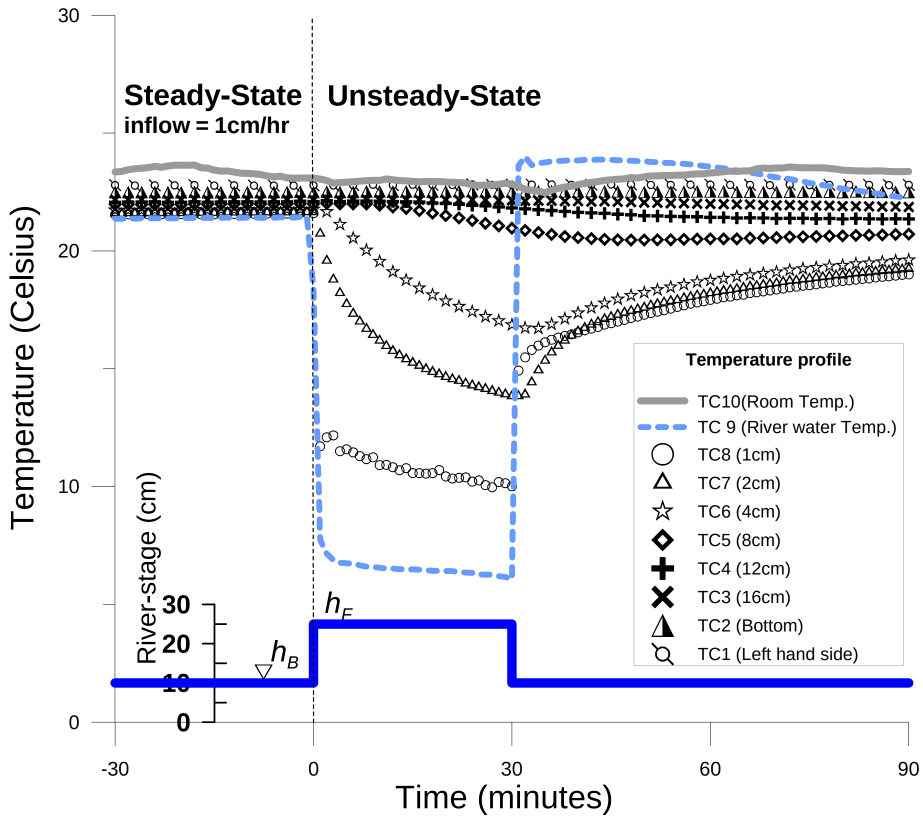


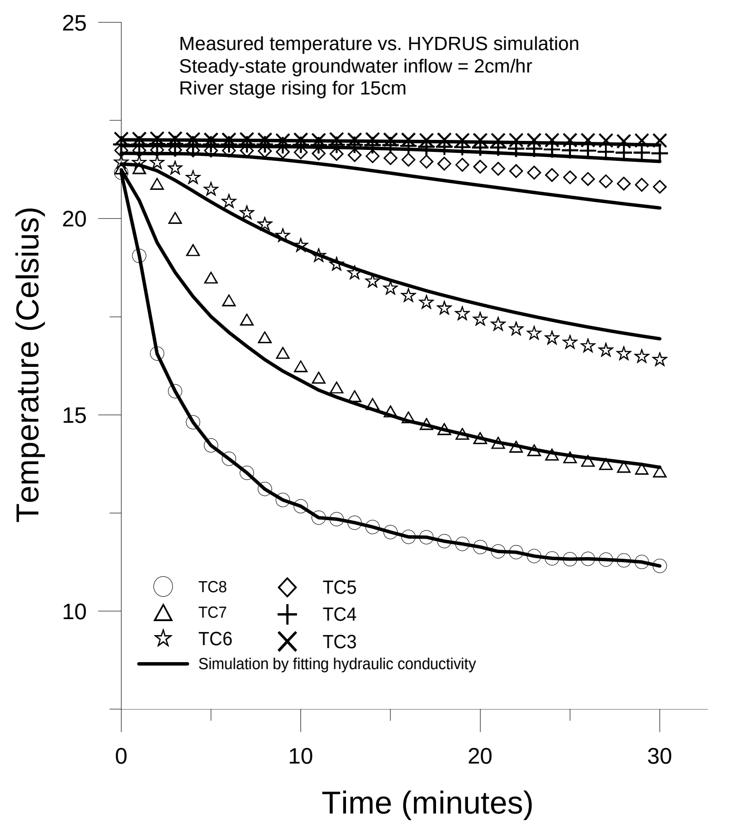
Use temperature as a tool

$$\frac{\partial T}{\partial t} = D_T \frac{\partial^2 T}{\partial z^2} - q \frac{C^*_w}{C^*_B} \frac{\partial T}{\partial z}$$

$$D_T(\theta) = \frac{\kappa(\theta)}{C^*_B} + q\lambda_T \frac{C^*_w}{C^*_B}$$

$$\kappa(\theta) = b_1 + b_2\theta + b_3\theta^{0.5}$$

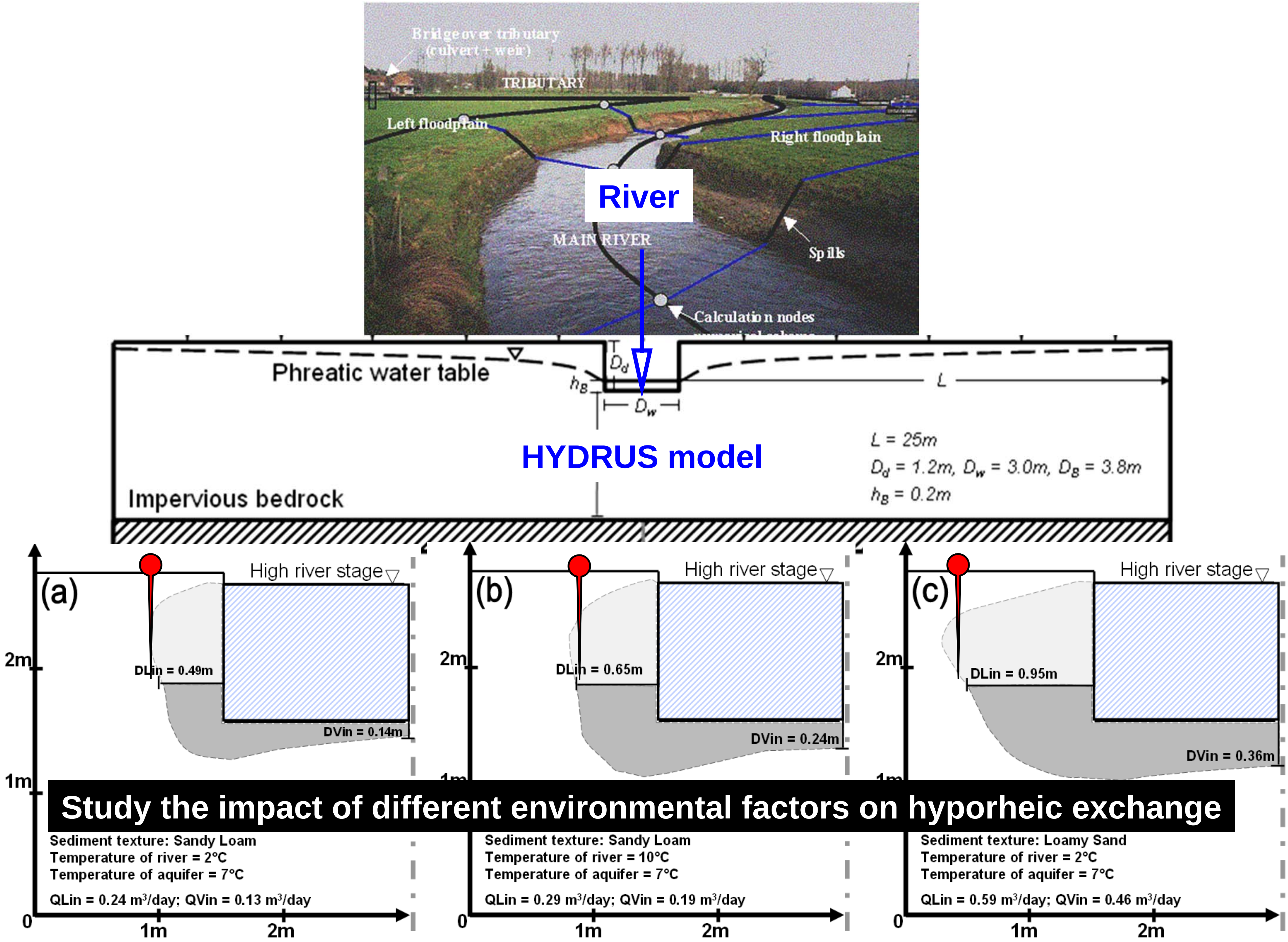


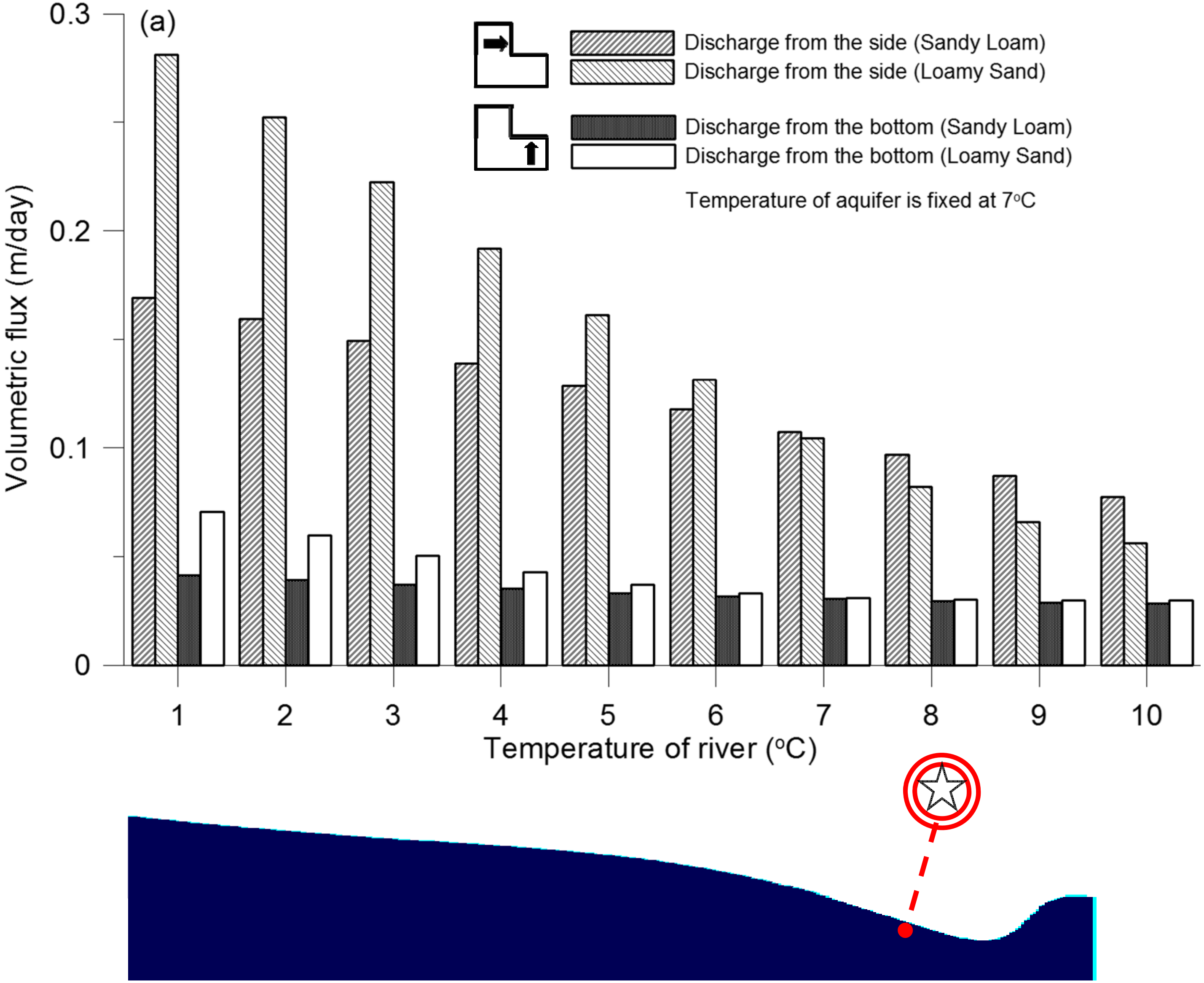


The finding

The rapid change in groundwater temperature has an important effect on K

After determination of the optimal K, the fluctuating water fluxes below the riverbed can be estimated by a numerical model.


Bridge over tributary
(culvert + weir)
TRIBUTARY
Left floodplain
Right floodplain
River
MAIN RIVER
Spills
Calculation nodes
Phreatic water table
D_d
h_B
D_w
L
HYDRUS model
L = 25m
D_d = 1.2m, D_w = 3.0m, D_B = 3.8m
h_B = 0.2m
Impervious bedrock
(a)
High river stage
DLin = 0.49m
DVin = 0.14m
2m
1m
0
1m
2m
(b)
High river stage
DLin = 0.65m
DVin = 0.24m
(c)
High river stage
DLin = 0.95m
DVin = 0.36m
Study the impact of different environmental factors on hyporheic exchange
Sediment texture: Sandy Loam
Temperature of river = 2°C
Temperature of aquifer = 7°C
QLin = 0.24 m³/day; QVin = 0.13 m³/day
Sediment texture: Sandy Loam
Temperature of river = 10°C
Temperature of aquifer = 7°C
QLin = 0.29 m³/day; QVin = 0.19 m³/day
Sediment texture: Loamy Sand
Temperature of river = 2°C
Temperature of aquifer = 7°C
QLin = 0.59 m³/day; QVin = 0.46 m³/day



0.3
0.2
0.1
0
(a)
Volumetric flux (m/day)
Discharge from the side (Sandy Loam)
Discharge from the side (Loamy Sand)
Discharge from the bottom (Sandy Loam)
Discharge from the bottom (Loamy Sand)
Temperature of aquifer is fixed at 7°C
1
2
3
4
5
6
7
8
9
10
Temperature of river (°C)

大地工程研究中心
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岩盤工程組 | 水文地質調查組 | 水文地質模擬組 | 地工技術組 | 地工試驗組

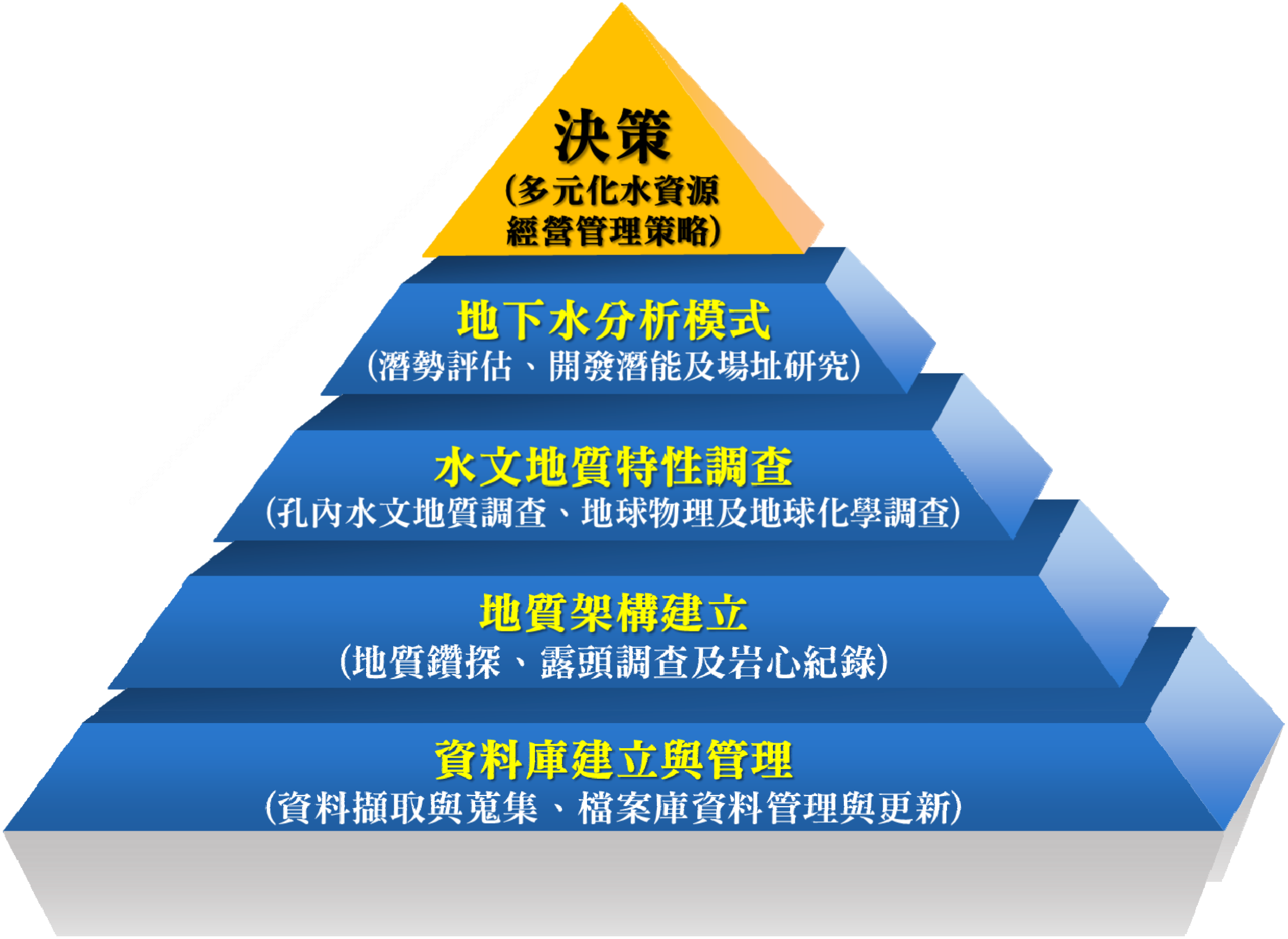
- 山區地下水資源調查與試驗
- 水文地質單元劃定
- 山區地下岩層優勢水流路徑分析
- 現地水文地質試驗
- 坡地水文地質特性調查
- 場址(核廢料及污染物)水文地質特性調查
- 土石流影響範圍模擬
- 集水區土砂產量推估
- 隧道水文地質特性調查

SkyView of TAIWAN

Towards sustainable ground-water management

Rock Aquifer Hydraulic Properties Investigation and Ground-water Monitoring Wells Construction in Mid-Taiwan Mountainous Region

台灣山區地下水資源調查研究整體計畫 2010


決策
(多元化水資源
經營管理策略)
地下水分析模式
(潛勢評估、開發潛能及場址研究)
水文地質特性調查
(孔內水文地質調查、地球物理及地球化學調查)
地質架構建立
(地質鑽探、露頭調查及岩心紀錄)
資料庫建立與管理
(資料擷取與蒐集、檔案庫資料管理與更新)

山區地下岩層水力特性調查

1) 山區涵養水源的黃金區位在哪？

2) 岩層蓄存水源的空間有多少？

3) 水脈的出現位置與分布概況？

4) 山區活水如何補注？

5) 岩層水流路徑的連通性？

6) 地下水位波動的原因?

探討山區的水文連通潛能

To the naked eye
it looks like this...

山區地下岩層水力特性調查與地下水位觀測井建置

Year	Area (km)²	Basin
2010	1577	Mid-Jhuoshuei River
2011	2815	Upper-Jhuoshuei River Dajia River
2012	2026	Wu River
2013	*2410*	*Hulien River* *Liwu River*

調查總面積約9000平方公里流域範圍。

水文地質鑽探井四年共74孔

總深度約7500公尺

Water Supply and Distribution is Difficult

Emergency Water Supplies are Essential

In mountainous areas

Emergency Water Supplies are Essential

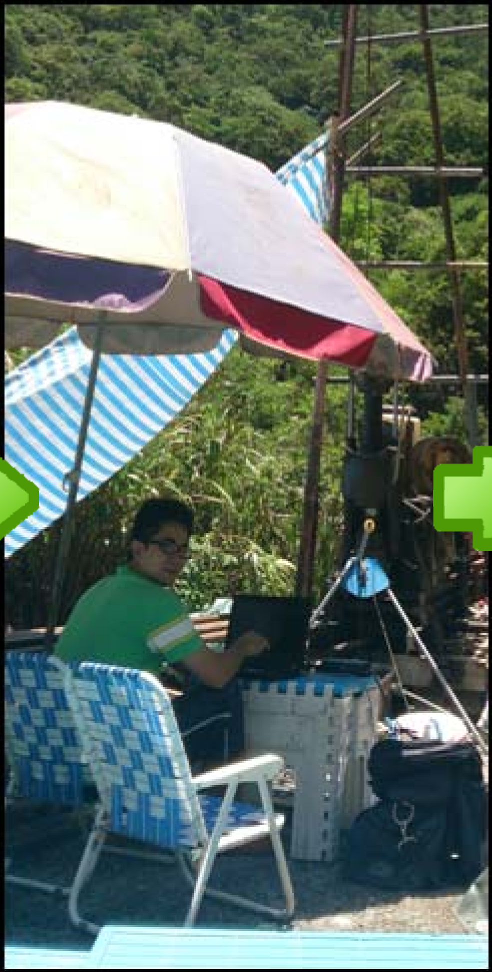
Field investigation and experiments

Geologist mudlogging

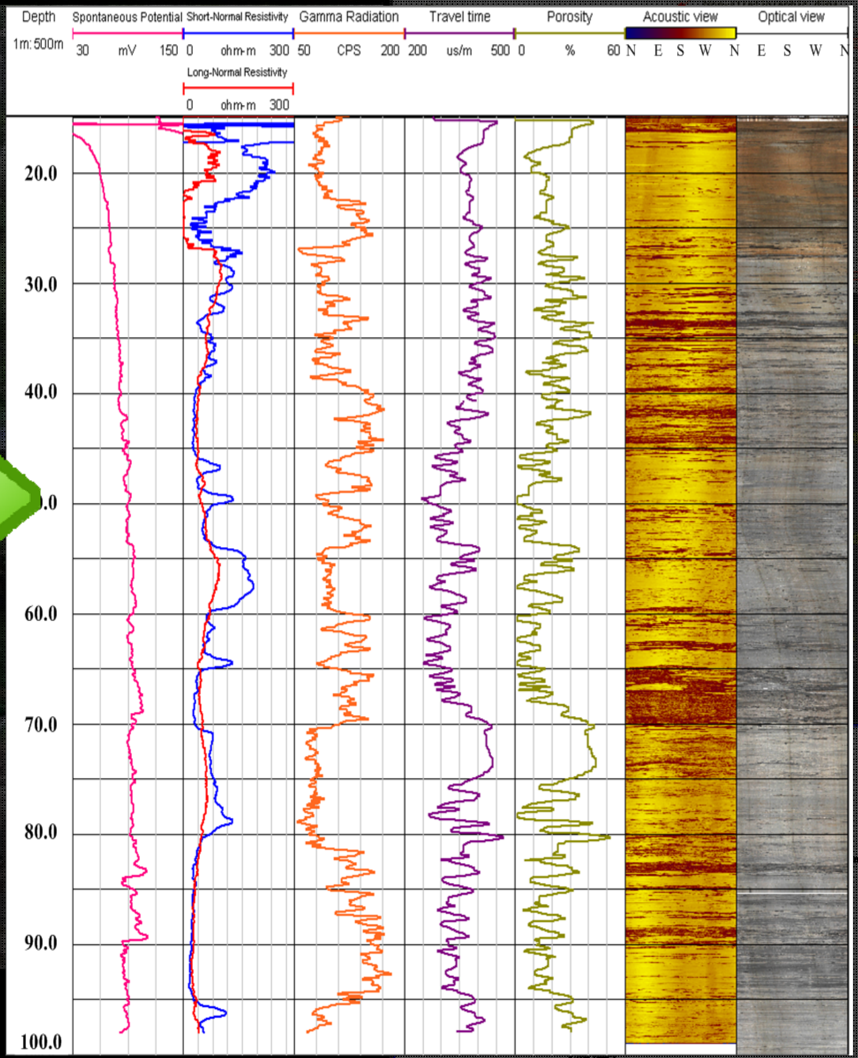
by Dr. J.J. Dong at NCU, Taiwan

Field investigation and experiments

Geologist mudlogging

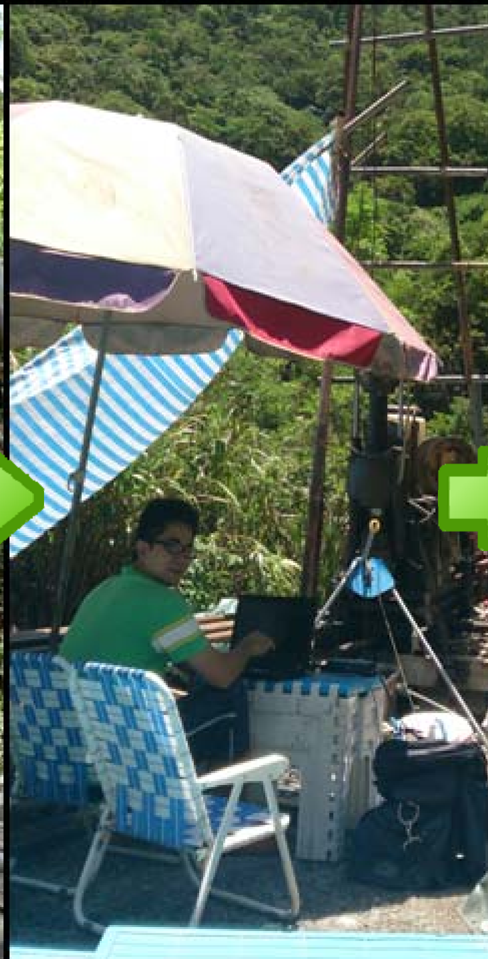


Geophysical logging



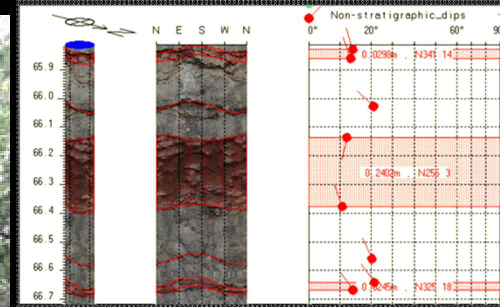
Field investigation and experiments

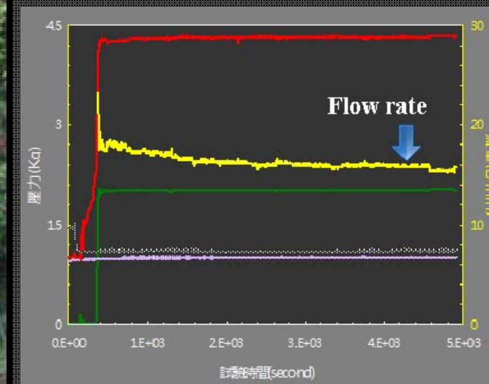
Geologist mudlogging

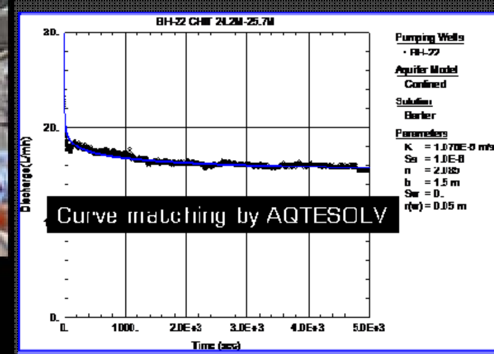


Geophysical logging

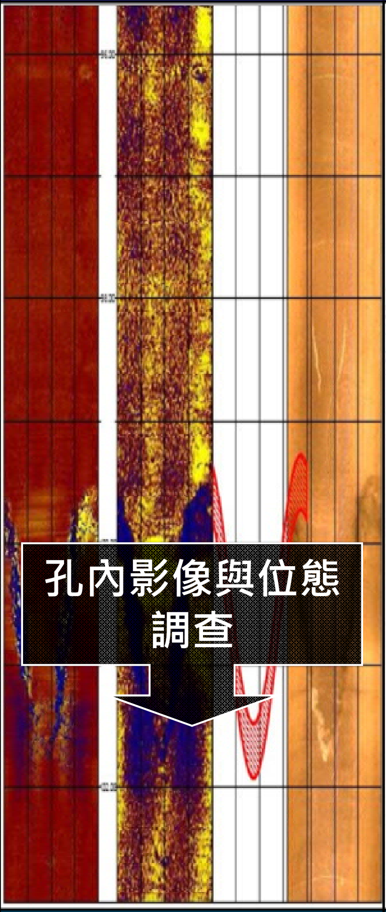
Packer testing



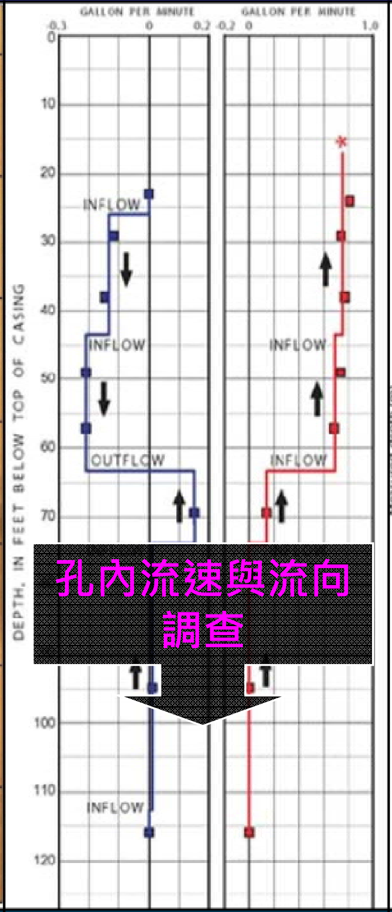




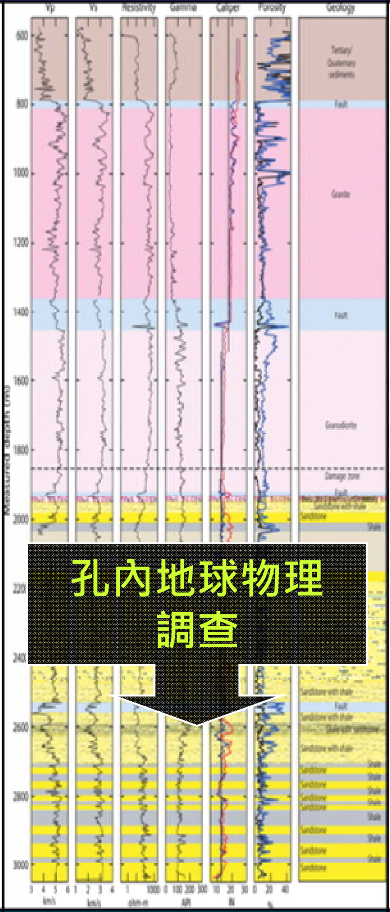
★ 單井水文地質概念模型建立



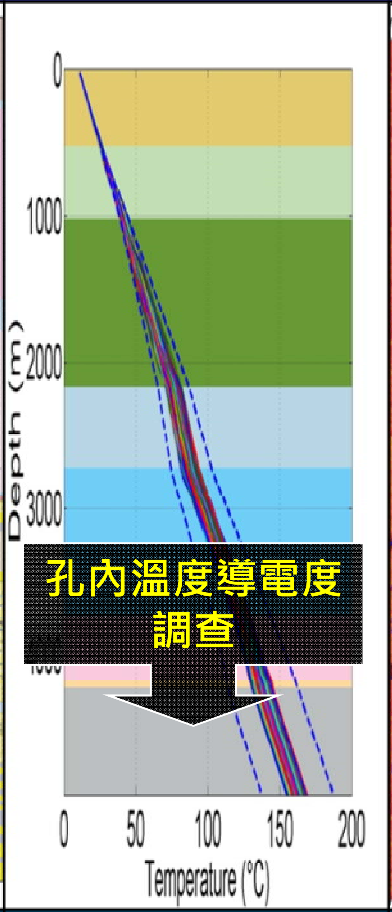
掌握裂隙分布



了解地下水流向



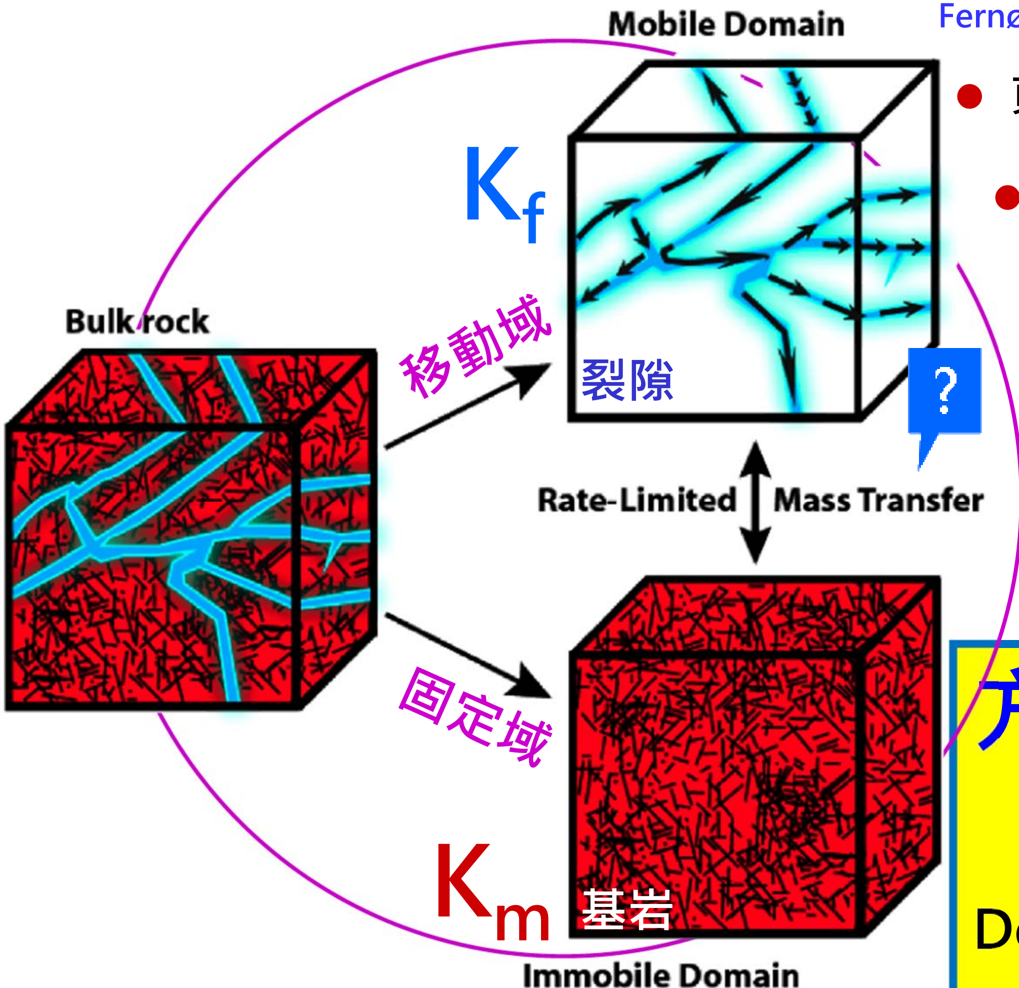
剖析地層構造



觀察流體運動

分析含水層特性

山區裂隙與基岩的透水比例
Study of permeability ratio (K_f / K_m)



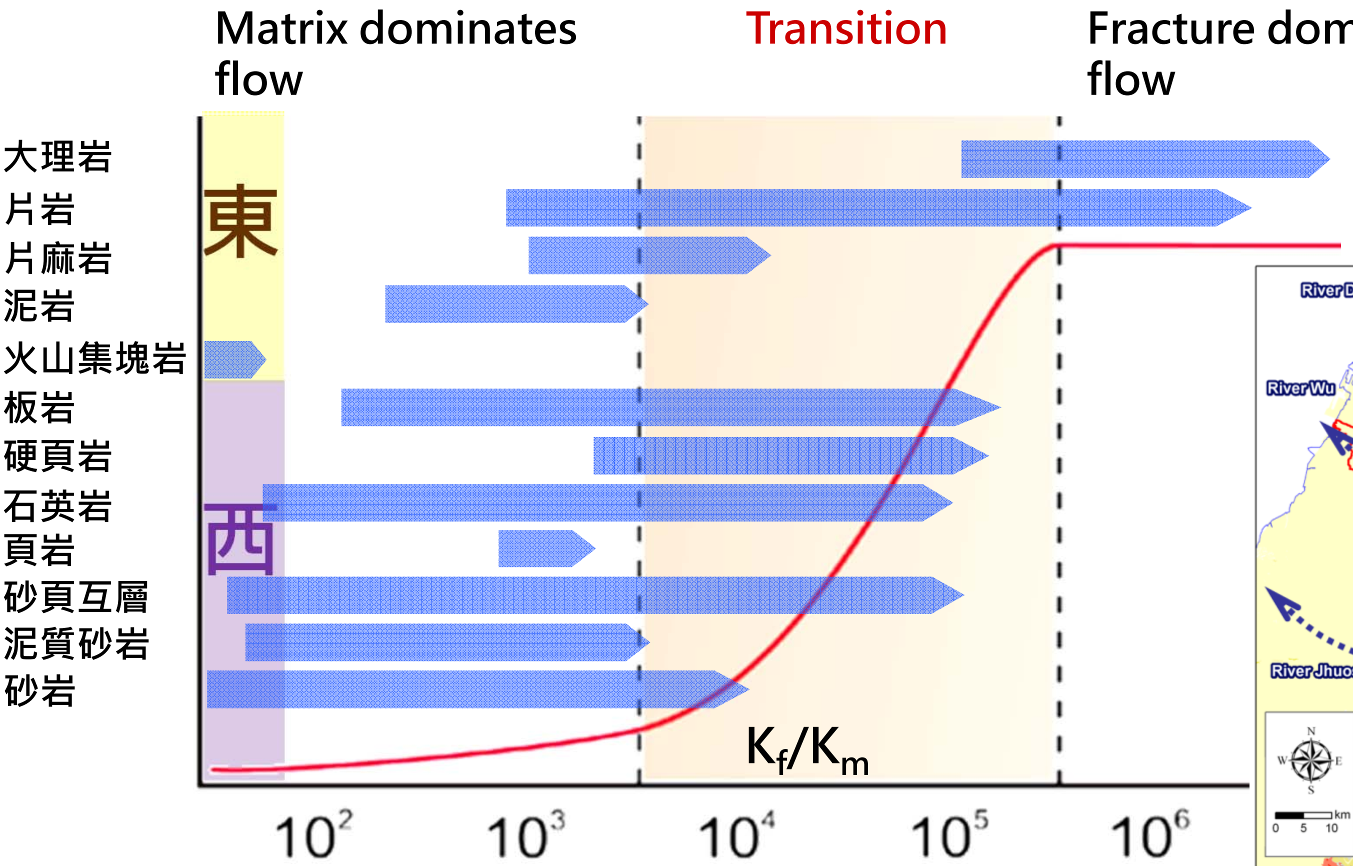
- 石油開採評估 (Hughes et al. 1997, Putra et al. 1999, Fernø et al. 2008, Salimi et al. 2008, Najafabadi 2009)
- 頁岩氣體儲存 (Kalantari-Dahaghi et al. 2011)
- 二氧化碳封存 (Odling and Bonnent 2000, Darvish 2007)
- 異向性的問題(anisotropy)
  anisotropy effect increases only with increasing ratio of (K_m/K_f) (Paul et al. 2011)
- 汙染物傳輸追蹤與控制
  竄流係數 interporosity flow coefficient (λ)
  $=\alpha \times r^2_w \times (K_m/K_f)$ (Chacon 2006)

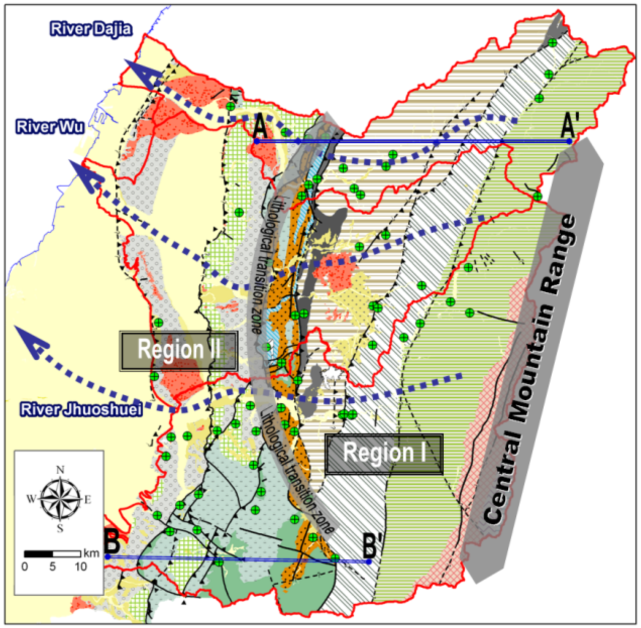
方法→

雙封塞試驗 + 室內試驗

Double packer test + Indoor Gas permeameter testing

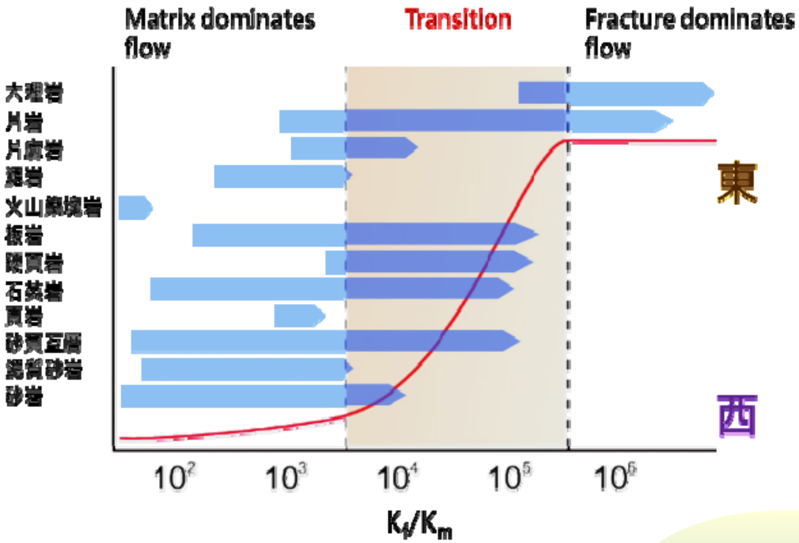
Results





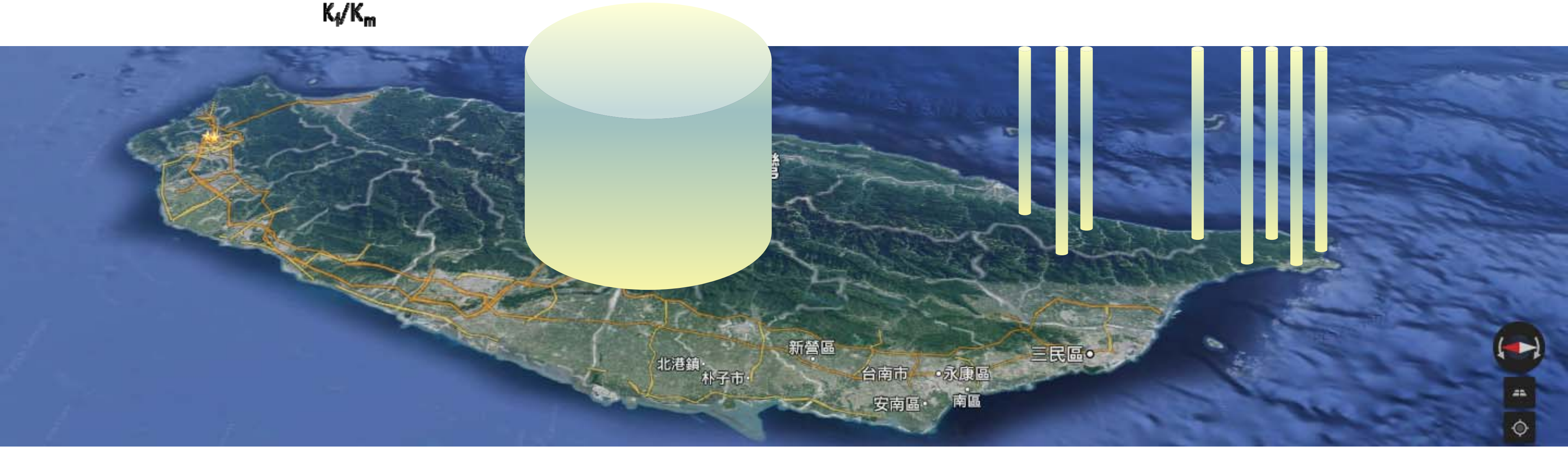
Permeability ratio (K_f / K_m) by rock types

The central vs. the south part of Taiwan



→評估南段山區水文地質參數與中段山區之差異

→補充恆春半島山區水文地質資訊



" Hydrologic connectivity" is the think-link

... of surface flow and groundwater pathway

... of our understanding of rainfall–runoff processes

... structuring the habitats of aquatic communities

... of mountains and floodplains

... of human beings and the environment

Academic

學術研究

Hydraulic industry

水利產業

Geological consultants

地質工程顧問

Waste monitoring

廢棄物監測

Environmental policy

環境政策制定

Soil and land

土地開發評估

Nature conservation

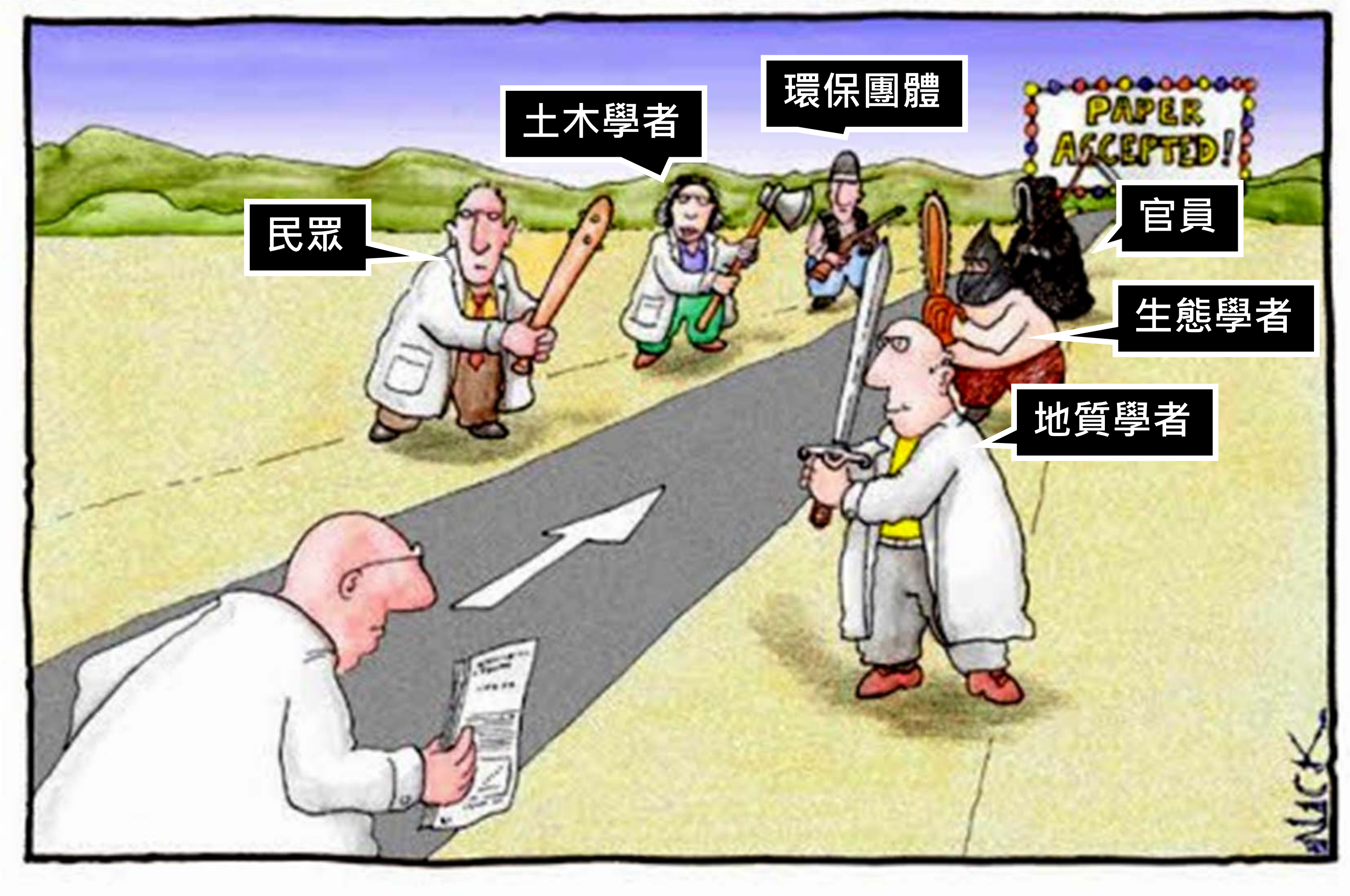
自然資源保育

能源開採與評估

Energy

異中求同的哲學

Seeking Common Ground While Respecting Differences



Thank you