Regional Groundwater Flow Systems: Past, Present and Future

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Human nature of imagination

Springs – hydro-refugia

Where and what is the source of the water?

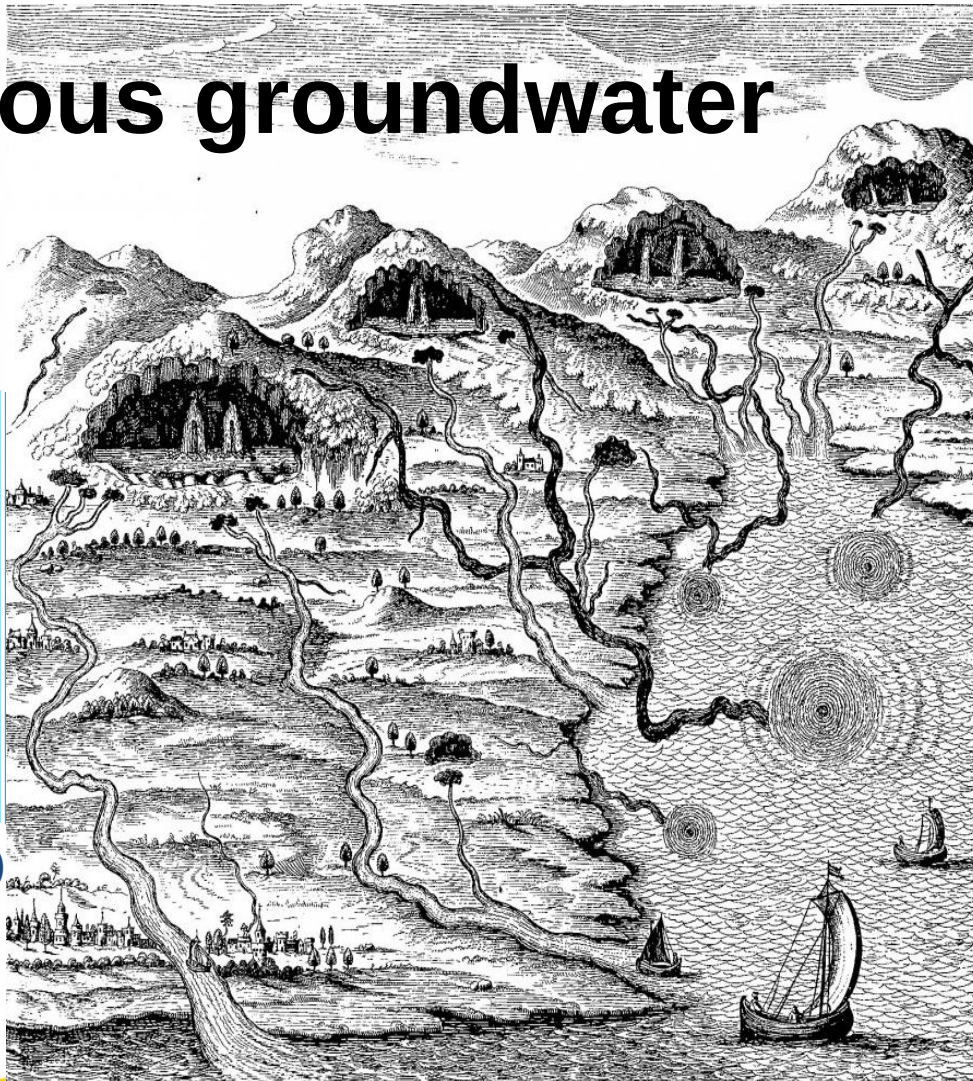
Huybrechts

Groundwater supports life-happiness

Mysterious groundwater

What is the source of the water that feeds our rivers, springs and swamps?

Kircher (1665)
Mundus subterraneus



Chamberlain 1885

But water **flowing "up hill"** is one of the commonest facts of nature, an everyday, an everywhere occurrence, illustrated in every brook, rill, and river, not to say spring.

"It is scarcely too strong to assert that **no rock is absolutely impenetrable** to water.

Artesian fountain in Prairie du Chien, Wisconsin

Pennink (1905)

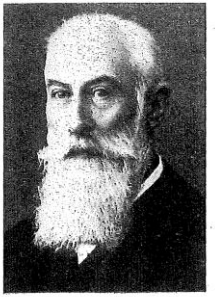


FIGURE 1.4 Johan M.K. Pennink (1853–1936). (Photograph by Amsterdam Water-Supply.)

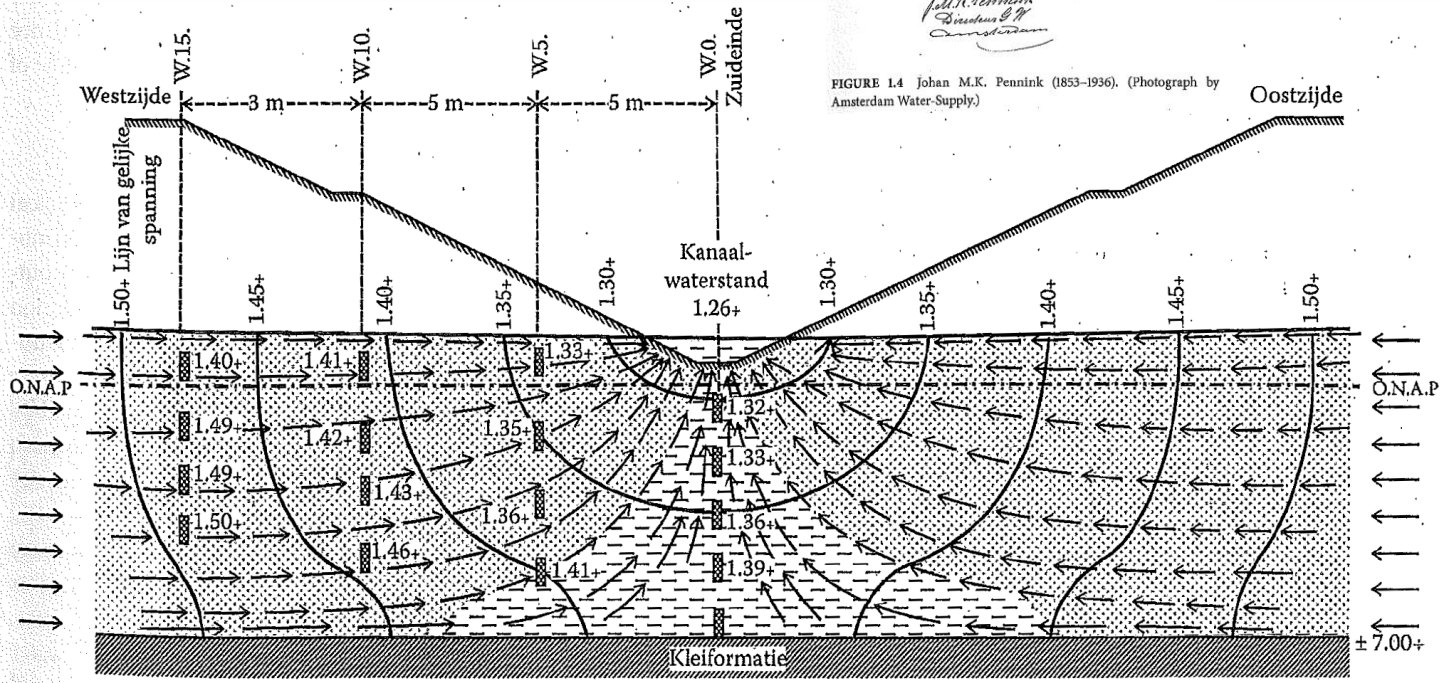
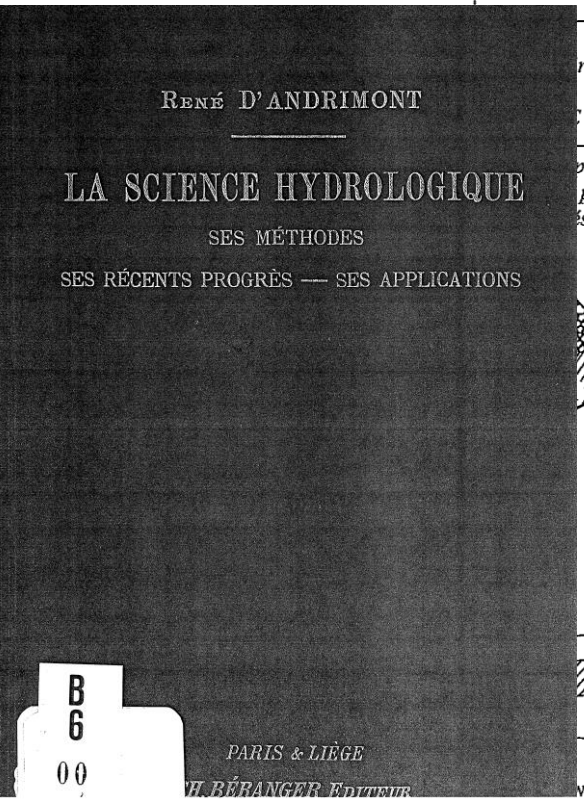
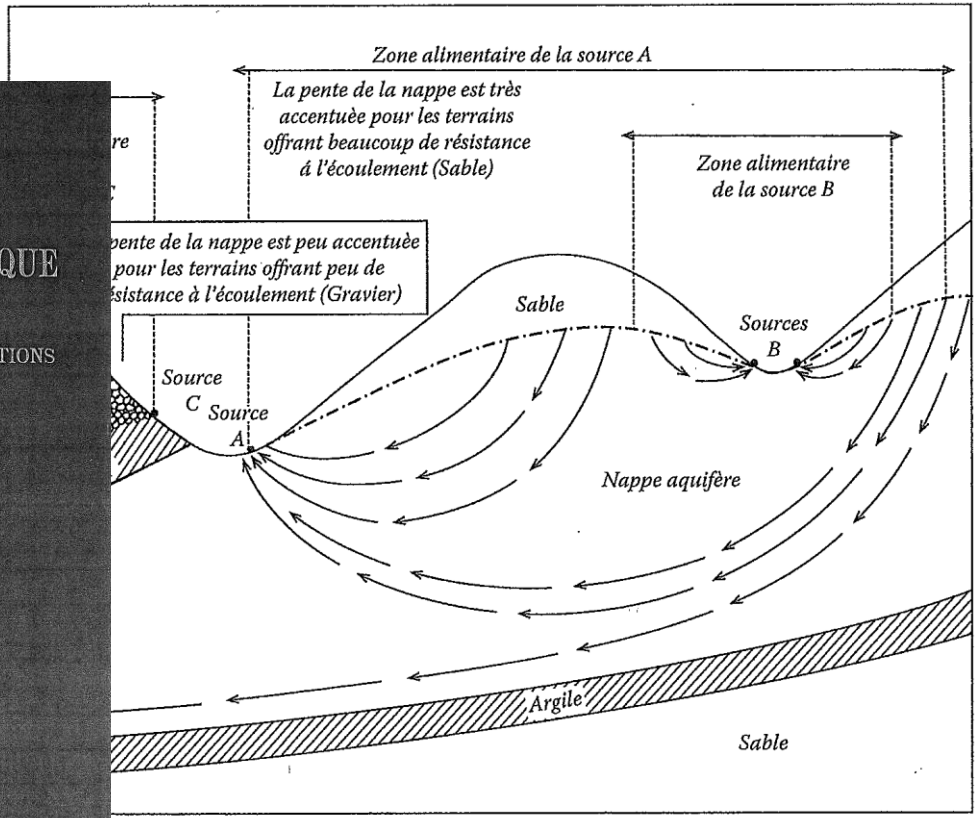


FIGURE 1.5 Flow net around a drainage canal based on hydraulic head observations. (According to Pennink, J.M.K., *De Ingenieur*, 20, 482, 1905.)

Circulation très curieux…





v systems; picture presented at the Brussels World Exhibition in 1910 by René d'Andrimont.

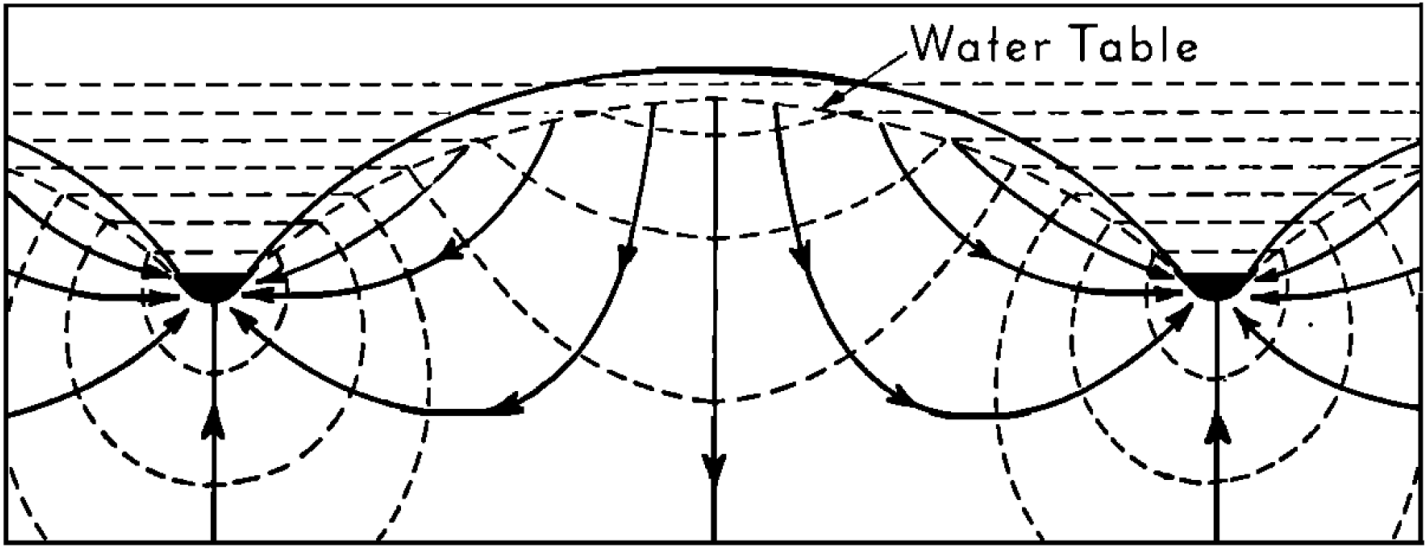
Importance of observations

Peter Meyboom (left) and Joe Tóth (right) during **field trip** on the Prairies, southern Alberta, June 1961.

(Tóth, 2005)

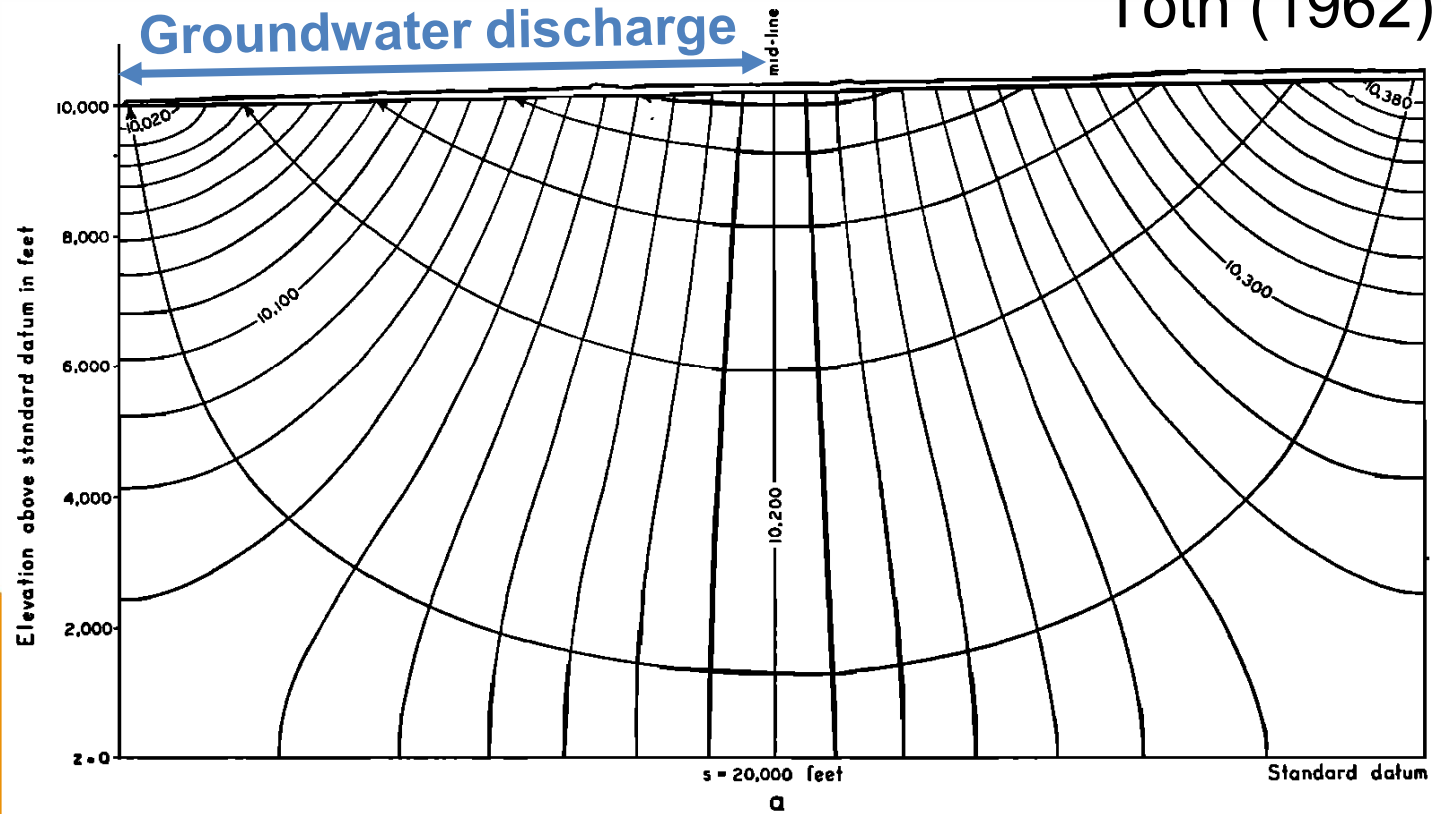
Mental epiphany Tóth

Tóth's conflict: Observable field phenomena vs Hubbert's (1940) theory of ground water motion… result: ***'mental epiphany'***.



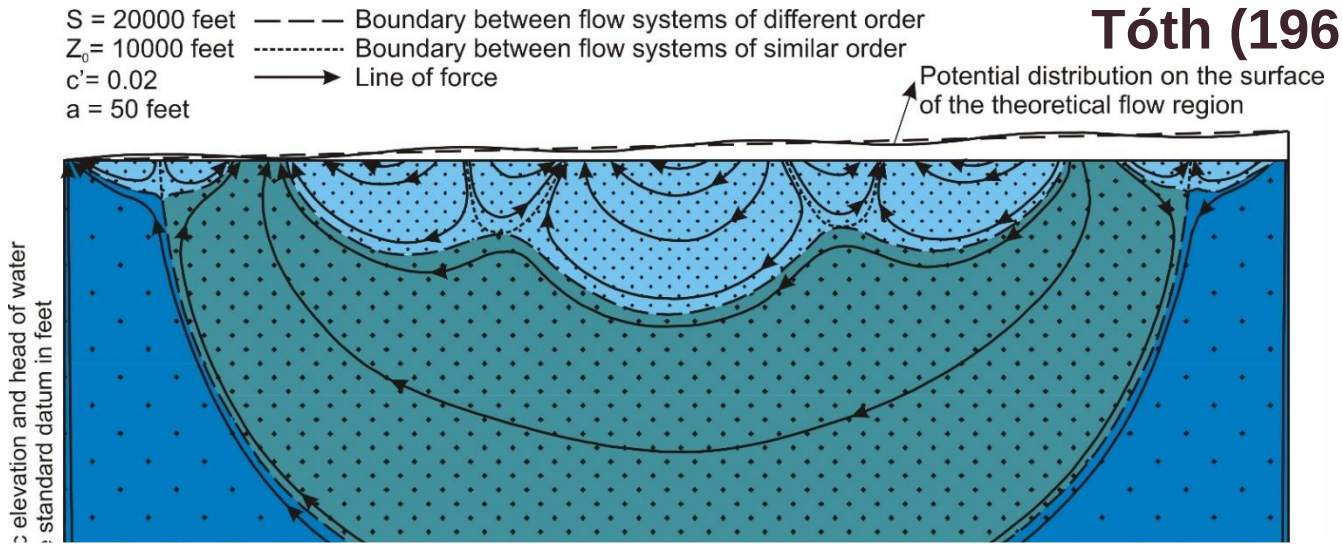
Mental epiphany Tóth

Tóth (1962)



A theoretical analysis of groundwater flow in small drainage basins

Tóth (1963)



[1] Contribution 185 from the Research Council of Alberta, Edmonton, Alberta. Presented at the Third Canadian Hydrology Symposium, Calgary, Alberta, November 8–9, 1962.

Definition GWFS

largest cohesive set

- Tóth's original: *'a set of flow lines in which any two flow lines adjacent at one point of the flow region remain adjacent through the whole region; they can be intercepted anywhere by an uninterrupted surface across which flow takes place in one direction only.'*
- Engelen and Kloosterman (1996): *'a geographical distinct domain of the subsoil, which is filled with a pattern of flow lines from one coherent recharge area to one or more discharge areas'*

Definition GWFS

- Vissers and van der Perk (2008): *'a water volume defined by a set of adjacent flow lines'*

- Many authors: use a loose ambiguous "flow system" for the system as a whole

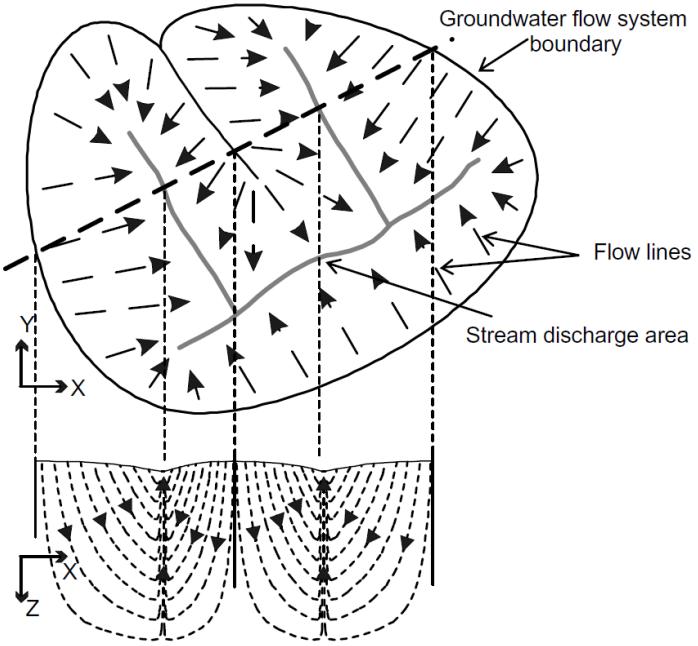
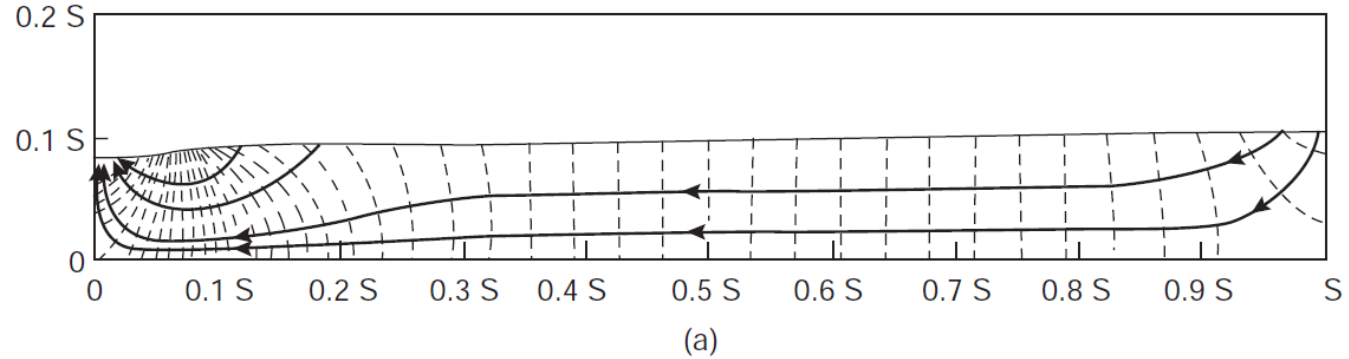


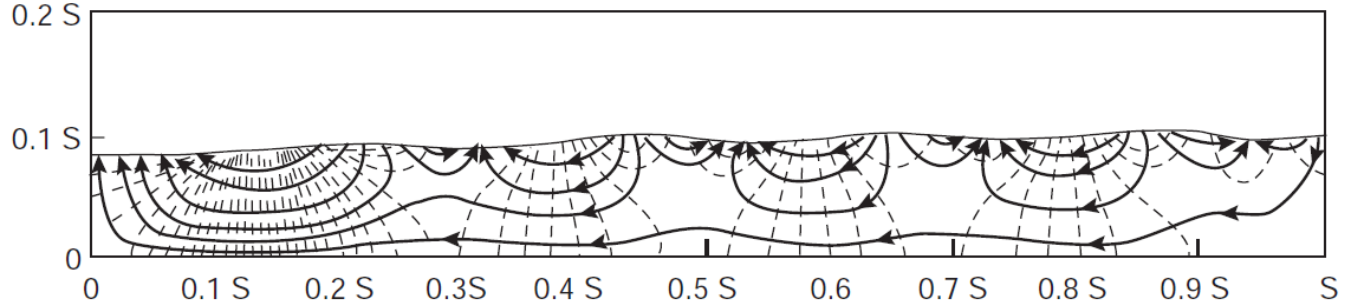
Figure 11 Identification of the groundwater flow systems as the water volume defined by the set of adjacent flow lines.

RGFS: Freeze and Witherspoon

- Numerical investigation effect of heterogeneity, anisotropy and topography:



(a)



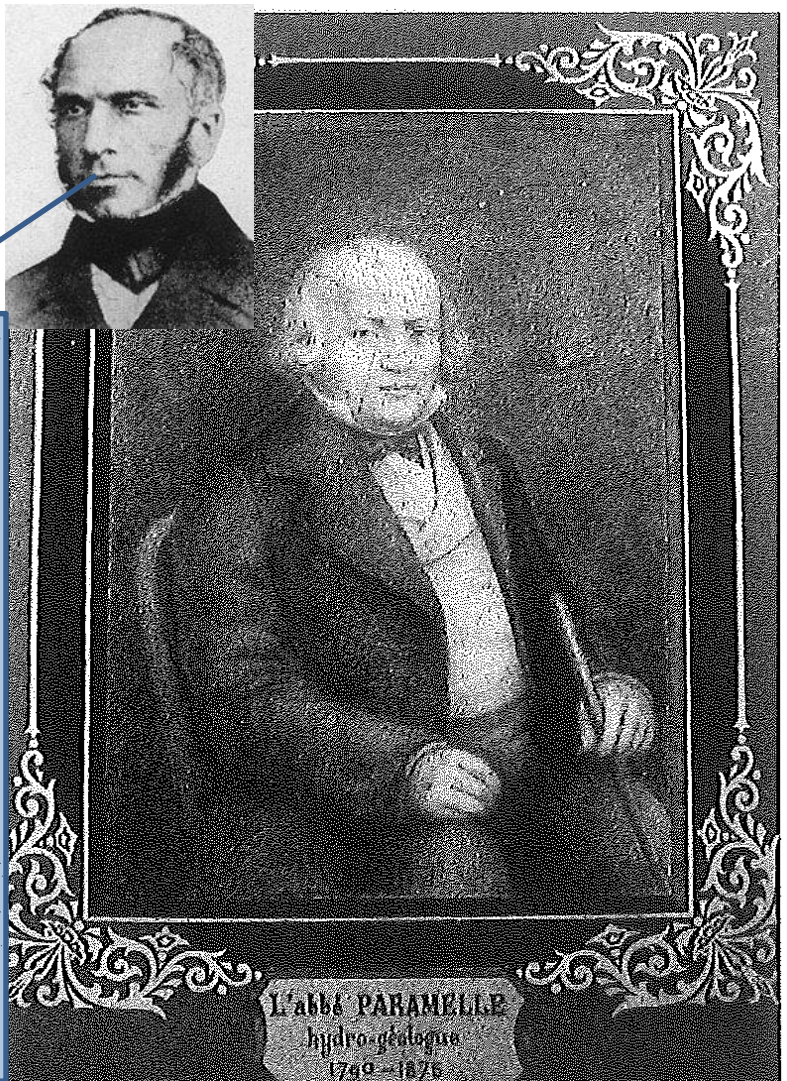
(b) Toth (2009) after Freeze and Witherspoon (1967)

RGFS: Practical usuage

- Hydrogeological mapping (Engelen and Kloosterman, 1996; Zhou and Li, 2011)
- Common field observations of groundwater chemistry (Tóth, 1999); temperature (Lazear, 2006); artesian zone conditions (Wang et al., 2015)
- Groundwater-surface water interactions (Winter, 1976; 1978; Nield et al., 1994; Wörman et al., 2006; Cardenas, 2007)
- Groundwater-dependent ecosystems (Batelaan et al., 2003)
- Petroleum migration (Tóth, 2009)
- Permafrost flow (Bense et al., 2009; McKenzie and Voss, 2013)
- Etc., etc.

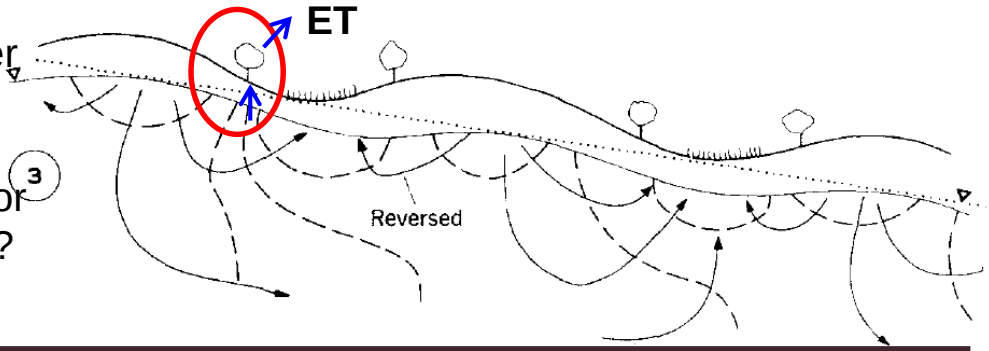
Groundwater dependent ecosystems

‘Spring seeker Father Paramelle seeks to infer from the nature and strength of the plants, the probable presence of water, and even the approximate depth of the water below the ground surface’.



Meyboom (1962, 1966)

Studied groundwater flow in the 'Prairie Profile', sloughs or potholes: recharge or discharge locations?

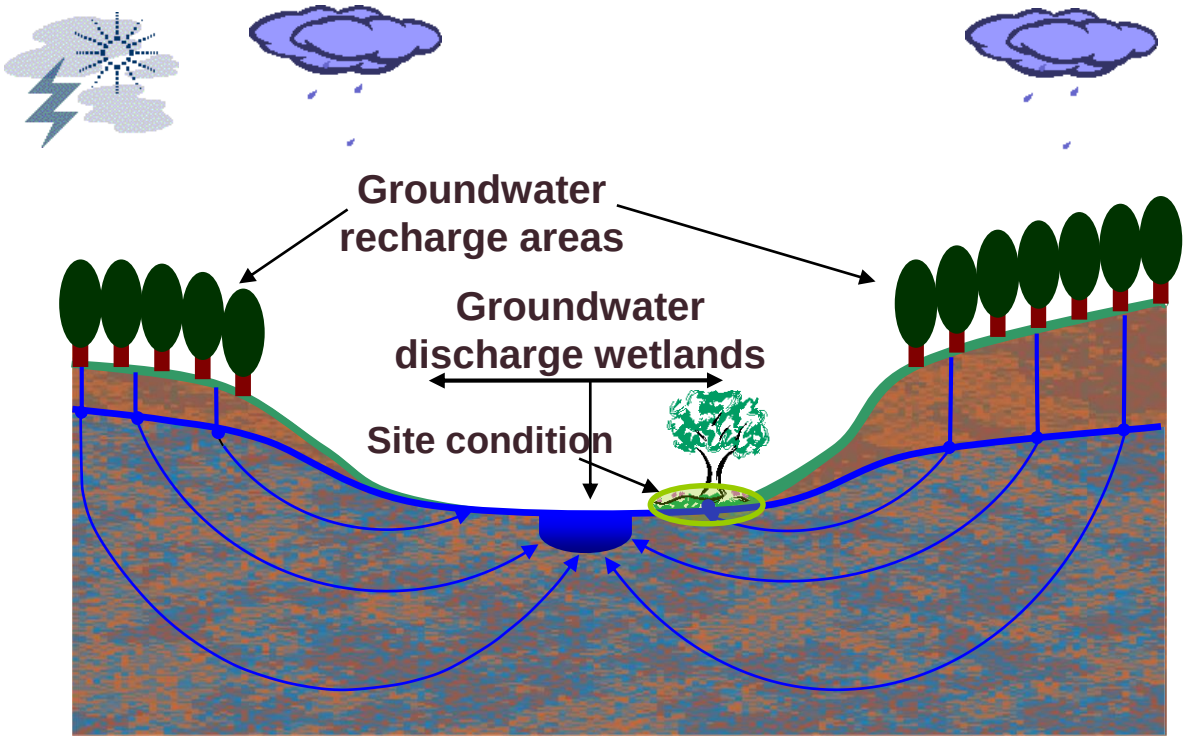


- Still very relevant:

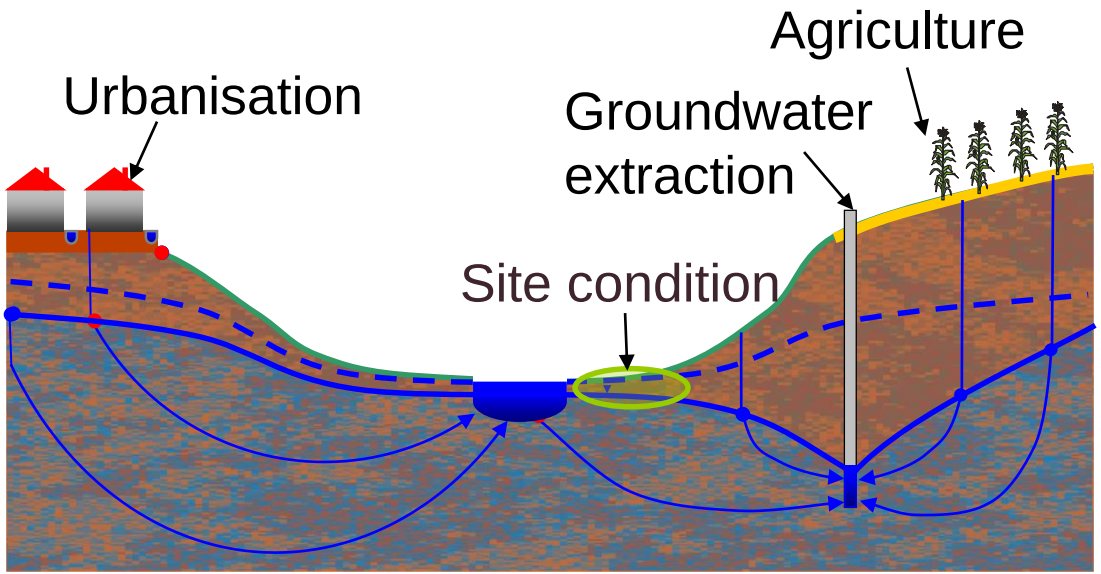
How does vegetation influence GW(FS) and vice versa?

Flow conditions near willow ring: (3) inverted water-table relief due to cone of depression around the phreatophytic willows.

Recharge→Discharge ⟷ linked Vegetation

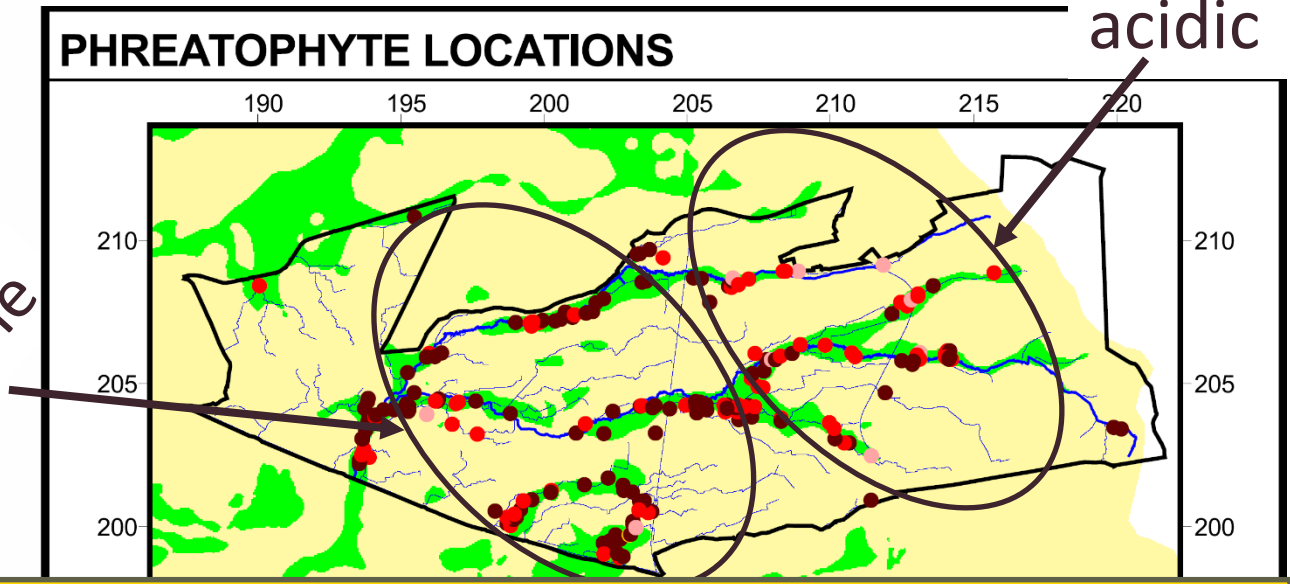


Landuse change ΔRe, Di → impact ecology



Phreatophytes vs RGFS

Batelaan et al. (2003)



- Mapped phreatophytes useful in validating modelled GW discharge areas
- Complementary use of vegetation information in analysis of modelled discharge areas reveals RGFS driven ecohydrological relationships

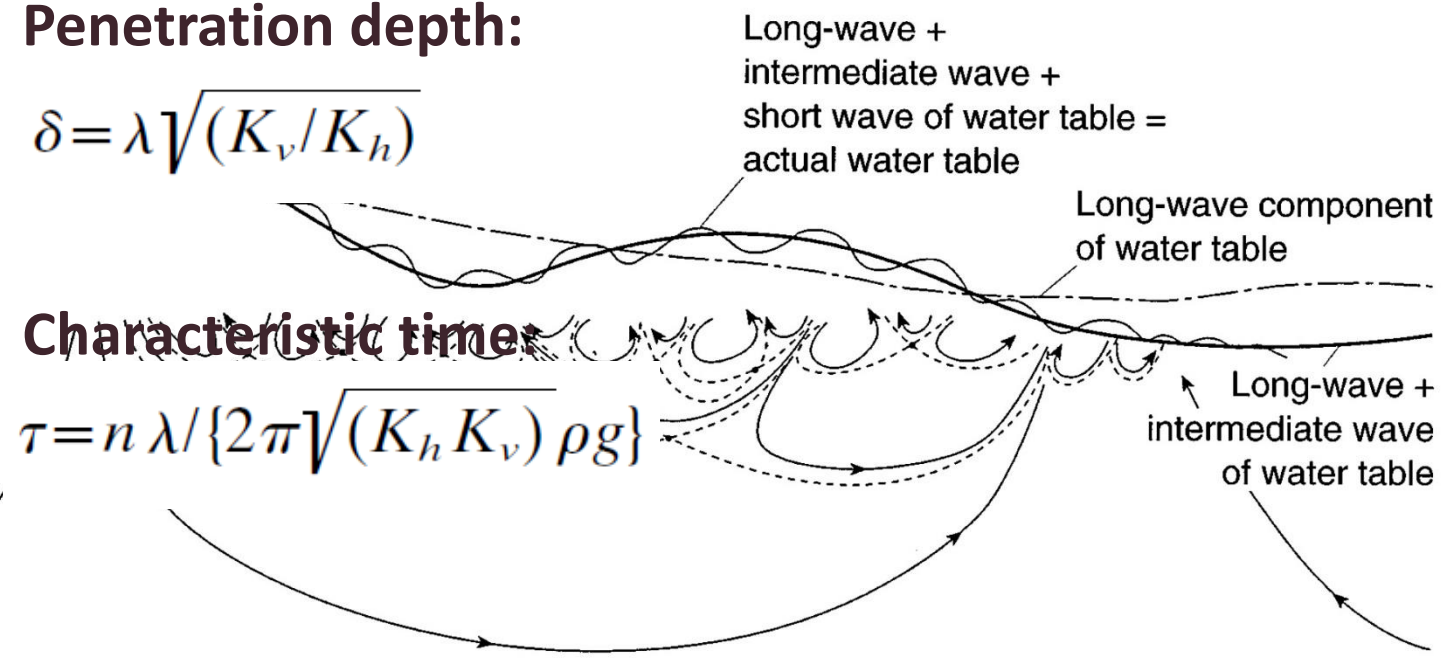
Advances Zijl (1999)

Penetration depth:

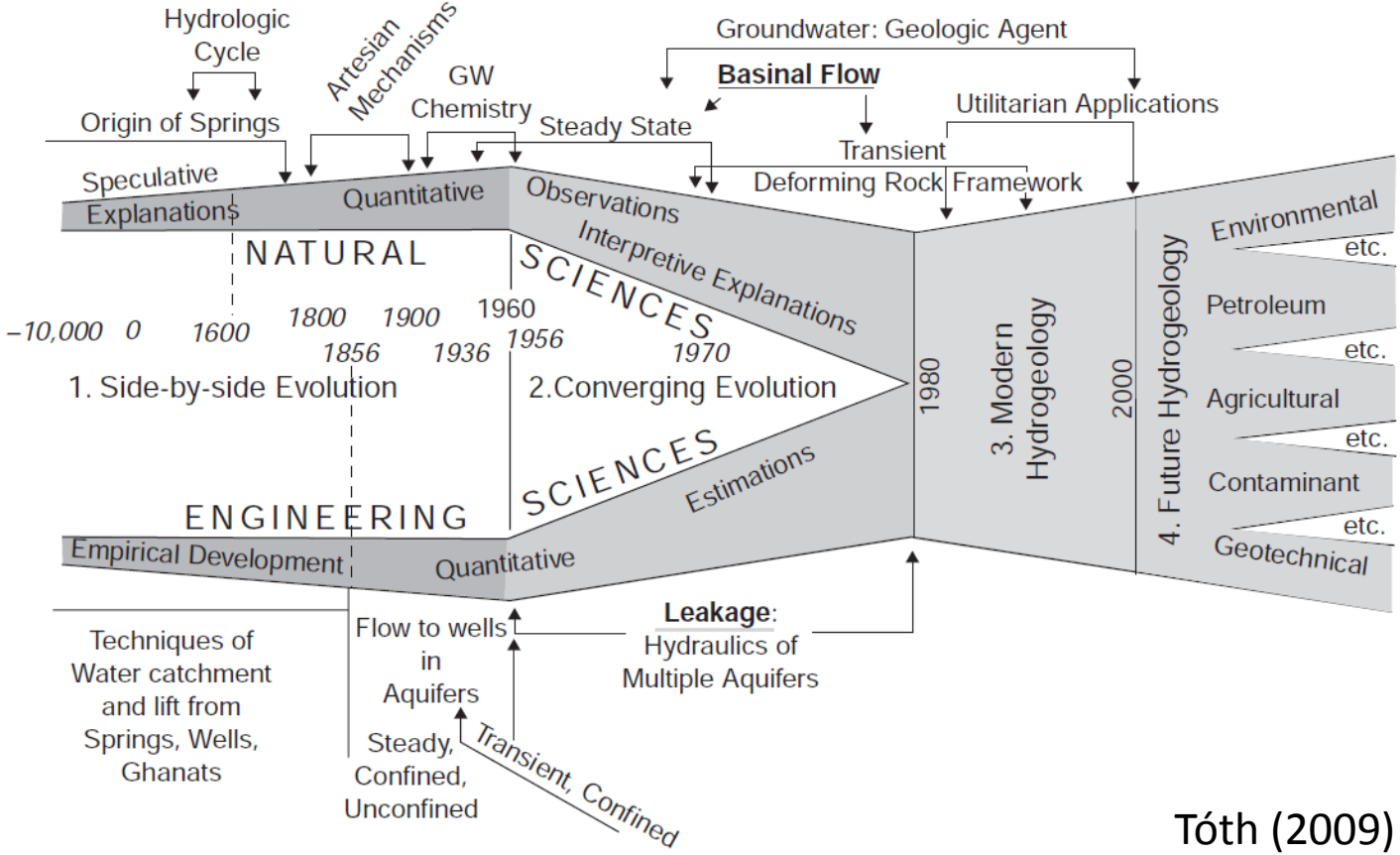
$$\delta = \lambda \sqrt{(K_v / K_h)}$$

Characteristic time:

$$\tau = n\,\lambda / \{2\pi \sqrt{(K_h K_v)}\,\rho g\}$$



Overview 2009



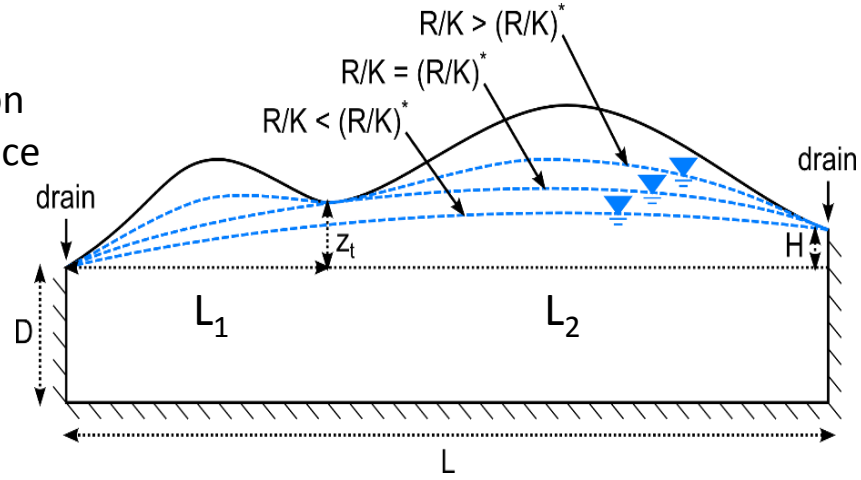
Tóth (2009)

Recent Advances

Groundwater outcrop criterion

$$\left(\frac{R}{K}\right)^{*} = \frac{2Dz_T - 2DH\frac{L_1}{L}}{L_1 L_2}$$

Drain elevation difference

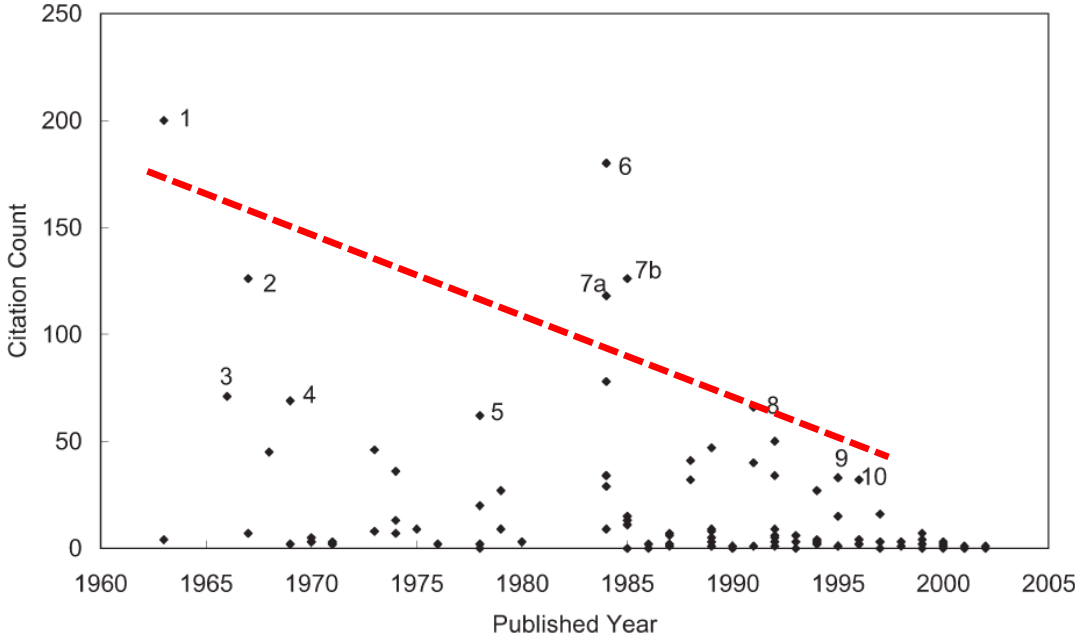


- Effective role of topography on groundwater dynamics (Bresciani et al., 2016)

RGFS: Acceptance in Science

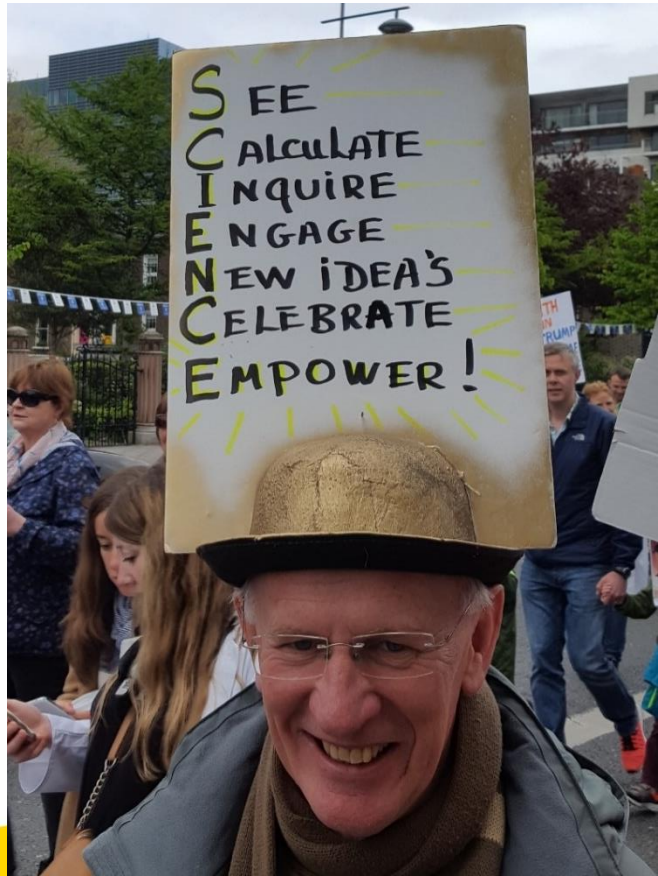
- Tóth's RGFS was a pioneer paper strategically shifting a research strand (Schwartz et al., 2005)

Fig. 6 Total citation count of papers citing Toth's paper [1962, JGR]. "A theory of groundwater motion in small drainage basins in Central Alberta"



RGFS: Review future science

- Beyond the specified-head top boundary condition
- General properties of nested groundwater flow systems under a free-surface water table condition, scaling laws?



RGFS: Review future science

1. Beyond the cross-section: 3D
2. Clarification of stagnation points in 3D

Tough problems

RGFS: Review future science

3. Effects on RGFS by:

a. Spatial distribution of recharge;

b. Interaction with SW-veg;

c. Fractal characteristics of topography;

d. Subsurface heterogeneity

Tough problems

RGFS: Review future science

4. Effects on hierarchy of RGFS by:

a. Pumping;

b. Climate change;

c. Land use change

RGFS: Review future science

Hydrogeol J (2016) 24:1087–1090
DOI 10.1007/s10040-016-1397-8

ESSAY

Groundwater flow systems theory: research challenges beyond the specified-head top boundary condition

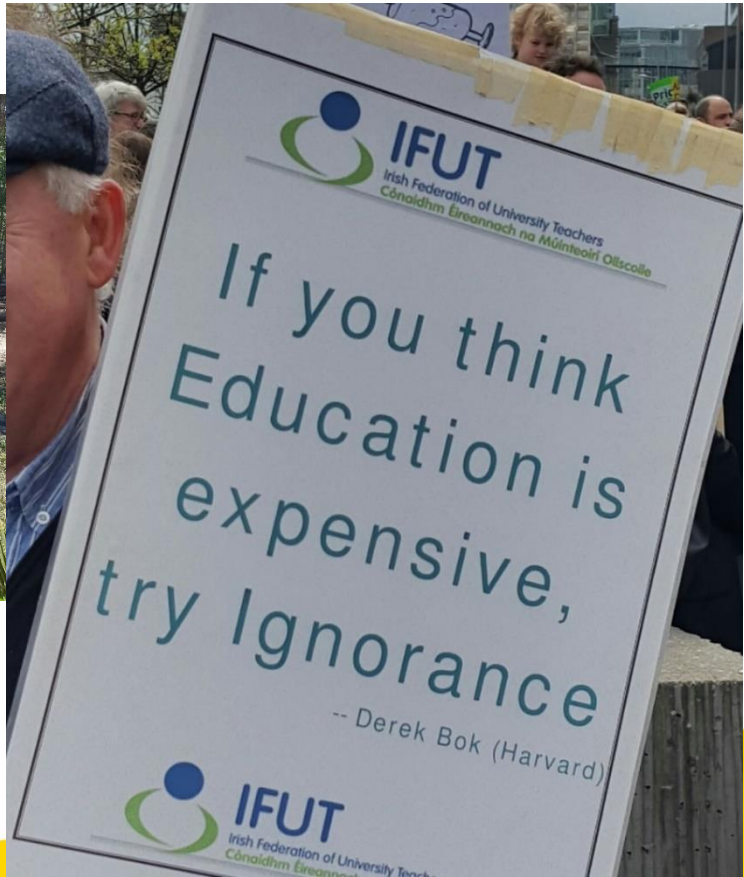
E. Bresciani[1] · T. Gleeson[2] · P. Goderniaux[3] · J. R. de Dreuzy[4] · A. D. Werner[1] · A. Wörman[5] · W. Zijl[6] · O. Batelaan[1]

- “developments of last 50 years already offers tools”
- “issues discussed are not longer relevant”
- “modern integrated models (aquifer-vadose zone-land surface) are the answer... Freeze and Harlan (1969)…; today, computational capabilities and available data outstrip anything that they could only dream.”

RGFS: Review future practice

- In GW modelling concept prevails of ‘aquifer’ – “more shades of meaning than any other term in hydrology” (Freeze and Cherry, 1979)
- Witness of this is that flow systems are in practice never analyzed from model outputs…

Influence: policy, training, education



Groundwater management - Policy

Marry the well-established SW management "catchment" concept with the groundwater catchment concept.

Hydrol. Earth Syst. Sci., 18, 2615–2628, 2014
www.hydrol-earth-syst-sci.net/18/2615/2014/
doi:10.5194/hess-18-2615-2014

SW-GW interdisciplinarity required

Hydrology and Earth System Sciences
Open Access

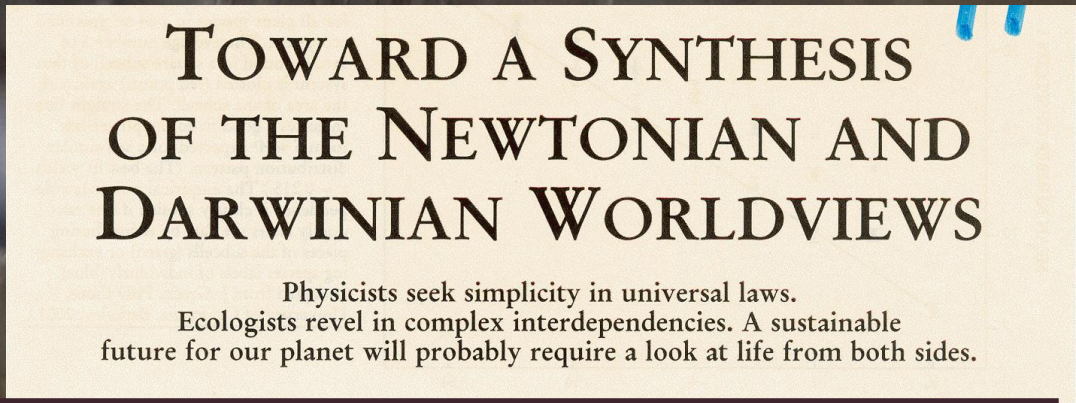
HESS Opinions "Integration of groundwater and surface water research: an interdisciplinary problem?"

R. Barthel

Observation – imagination difficult but essential

RGFS: Old or opportunity?

Harte (2002)



TOWARD A SYNTHESIS OF THE NEWTONIAN AND DARWINIAN WORLDVIEWS

Physicists seek simplicity in universal laws. Ecologists revel in complex interdependencies. A sustainable future for our planet will probably require a look at life from both sides.

- Relevant science
- Combine simplicity with complexity
- Our science with another
- Old stuff with new ideas
- Aim for the difference

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inspiring achievement