Searching for principles to guide sustainable management of karst: lessons from science

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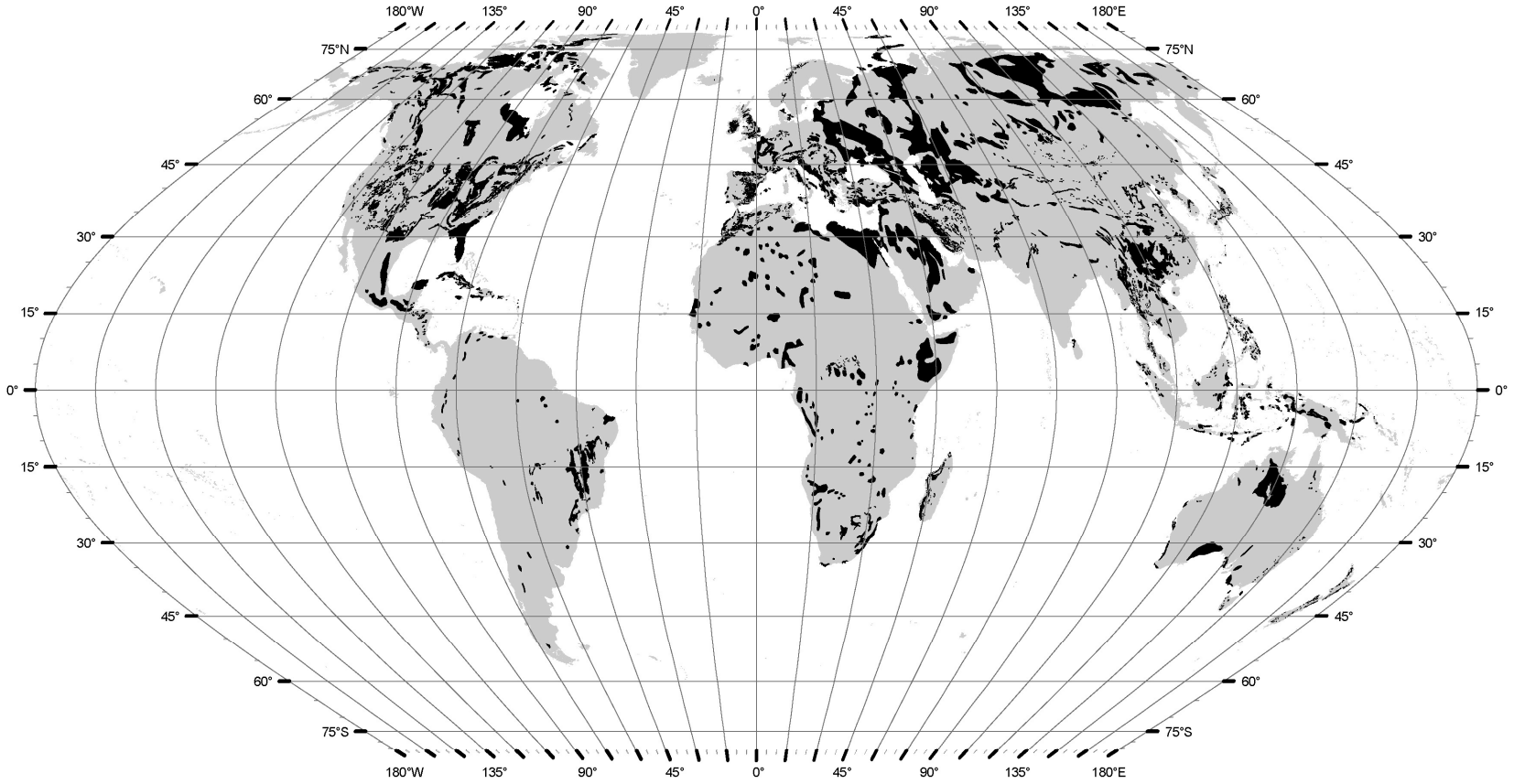
World Carbonate Outcrops



Equal area projection

Swartzkrans Cave,

South Africa

Cultural and

natural heritage

Lascaux Cave, France

Cultural heritage

SUSTAINABLE MANAGEMENT

THIS IMPLIES THE USE OF RESOURCES FOR THE BENEFIT OF THE PRESENT GENERATION WITHOUT LIMITING THE POTENTIAL USE OF THE SAME RESOURCES BY FUTURE GENERATIONS.

EFFECTIVE SUSTAINABLE MANAGEMENT WILL LEAVE THE ENVIRONMENT IN AT LEAST AS GOOD A CONDITION AS WHEN ITS USE FIRST STARTED.

THE CHALLENGE IS TO SHOW HOW THIS CAN BE ACHIEVED AND TO PROVE THAT IT IS BEING ACHIEVED

First lesson from Science

"Nature to be commanded must be obeyed"

Francis Bacon (*'Essays'* 1620)

Lord Chancellor of England.

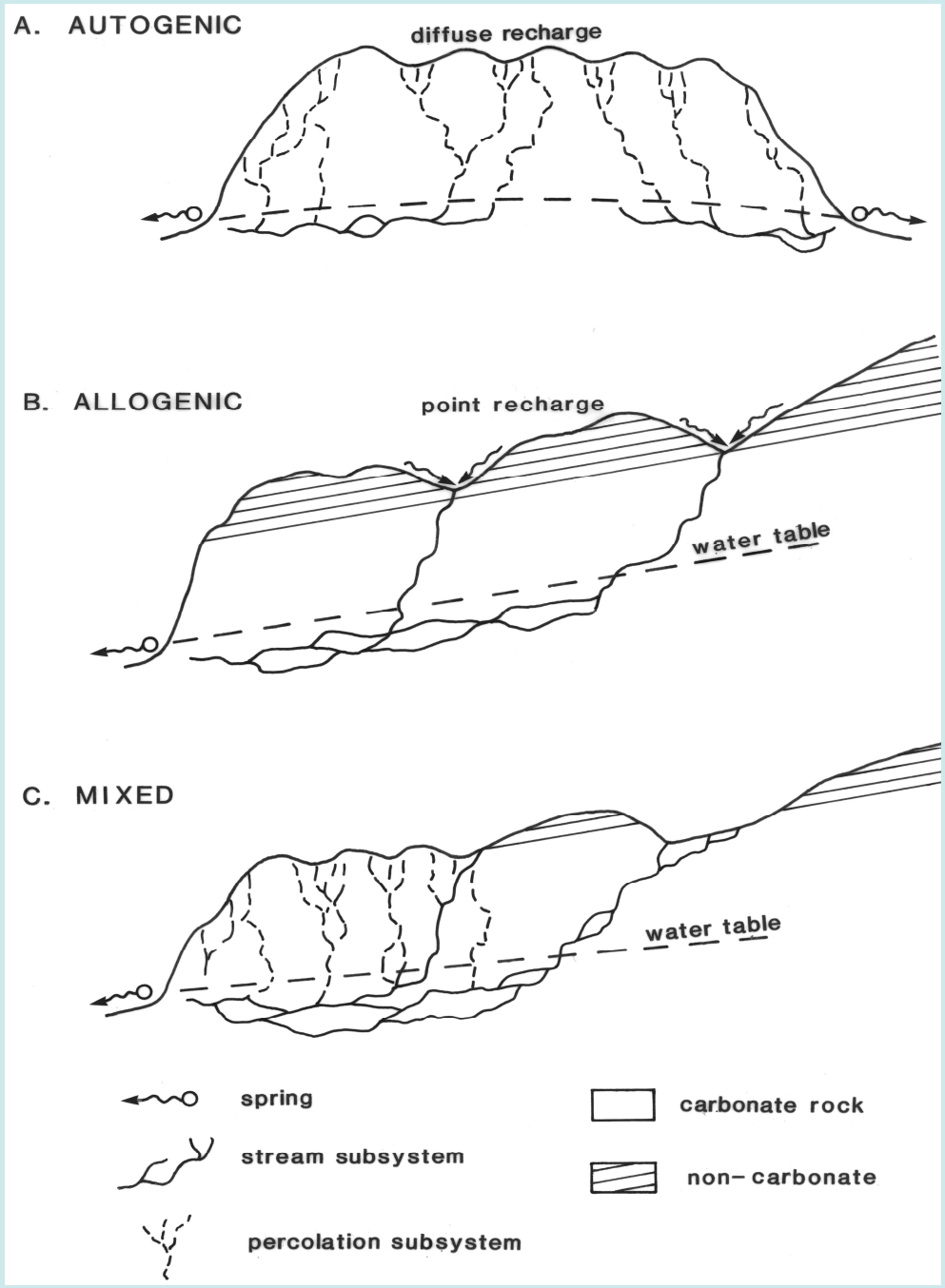
Philosopher who introduced the inductive method into science.

This idea was re-expressed in the 20th century as

'Design with Nature'

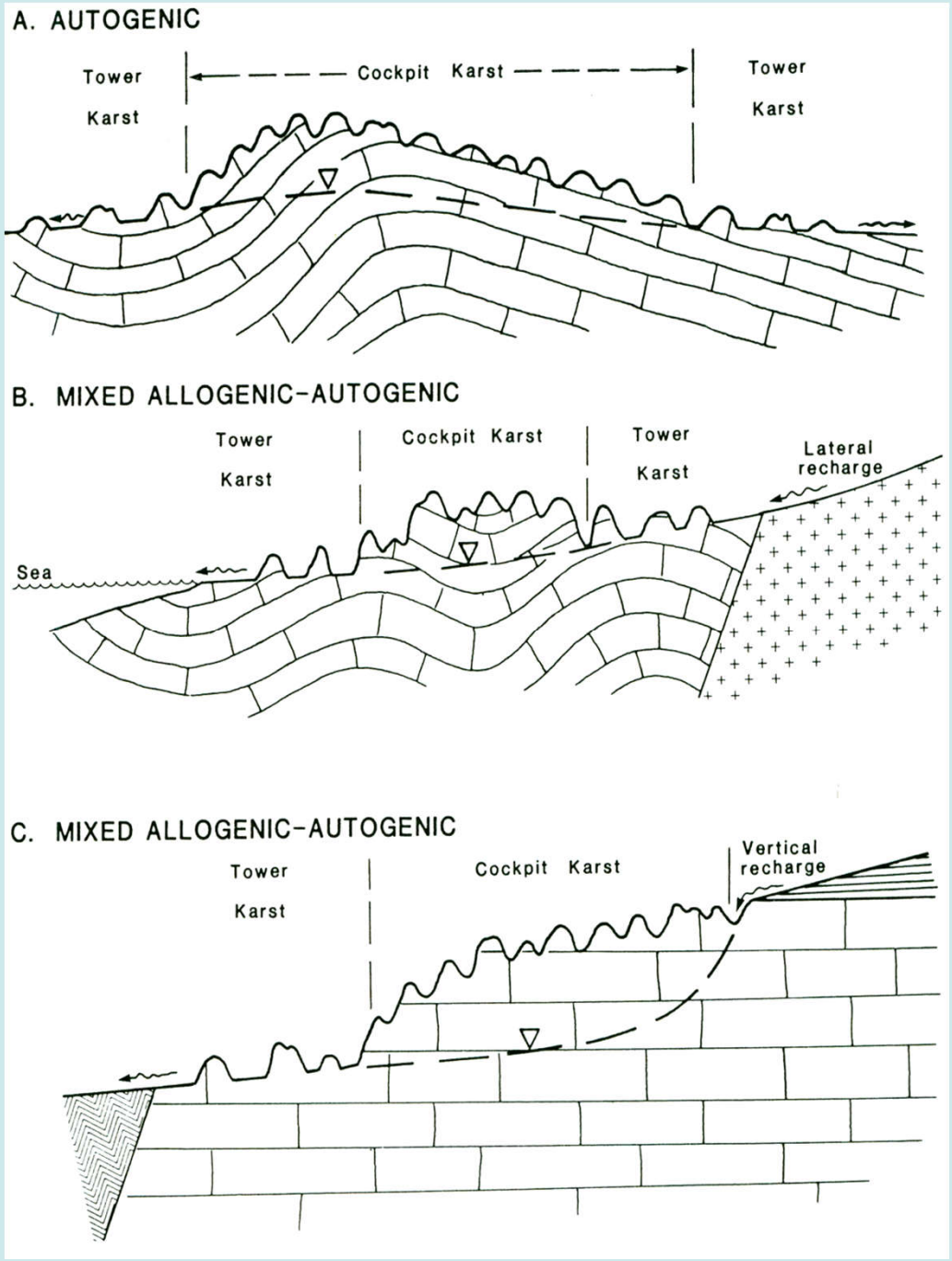
Message:

If we are to work with Nature and use it to our advantage, we must first learn to understand natural processes.



Note that karst is recharged by water from different sources.

Some recharge comes from areas beyond the boundary of the karst.



AUTOGENIC
waters are 100% karst sourced.

ALLOGENIC
waters are of non-karst origin.

Most karsts have mixed recharge from both autogenic and allogenic sources.

Sink of the River Rak, Slovenia

Allogenic
recharge

Guizhou, China

Autogenic waters in karst interior.

Rain that falls directly onto karst provides the greatest source of autogenic recharge.

River Li (Lijiang) and tower karst near Guilin

Some allogenic rivers flow right across karst areas and receive drainage from karst springs.

Manavgat River, Turkey

The world's largest karst resurgence system. 125-130 m^3/s average discharge

Bay of Halong, Vietnam

Runoff affects the quality of coastal waters.

A recent lesson from Science

The epikarst is of fundamental importance in the control of autogenic recharge.

- The epikarst is the uppermost weathered zone of karst beneath the soil.
- It stores and mixes water and redistributes recharge.
- Within the epikarst porosity and permeability decrease exponentially with depth.
- The epikarst is sometimes called the subcutaneous zone. It's about 10 m thick.

Glacially-stripped karren surface, Pyrenees Mts, France

Epikarst (from Mangin 1975)

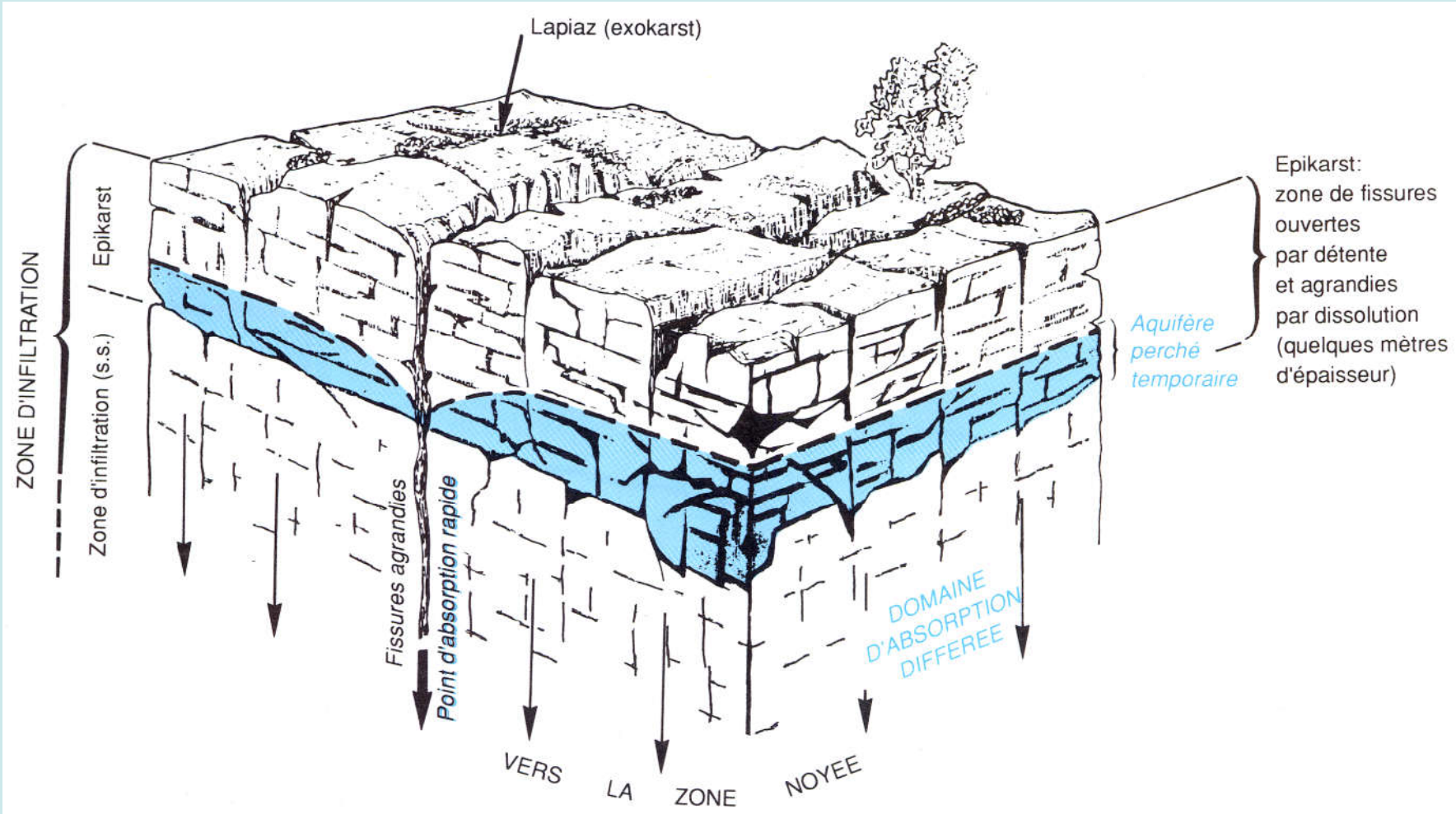


FIGURE 21

Image théorique de l'épikarst (d'après MANGIN, 1975).

Theoretical image of the epikarst (after MANGIN, 1975).

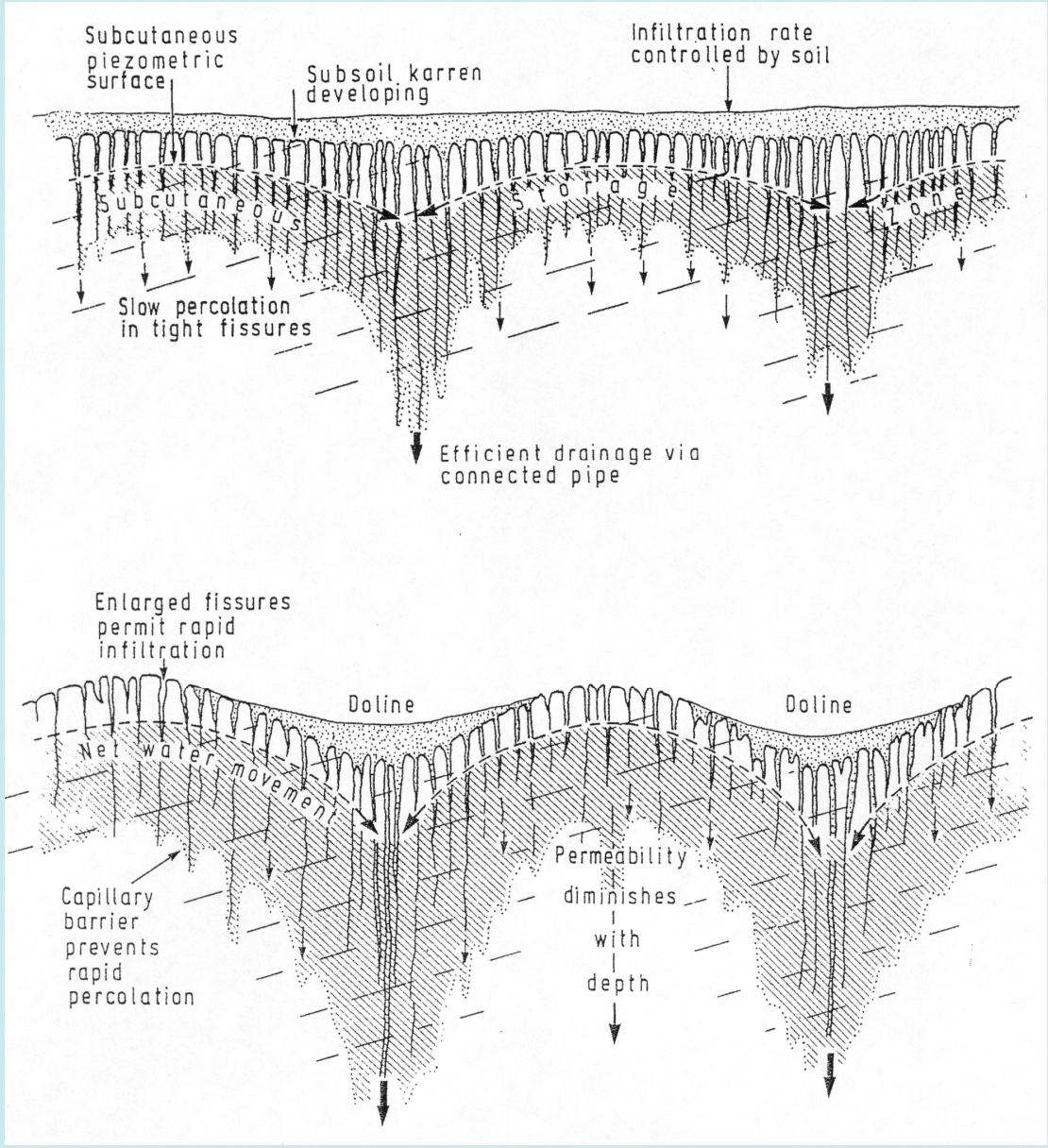
Epikarst, Taurus Mts, Turkey

Epikarst, Bedford Quarry, Indiana

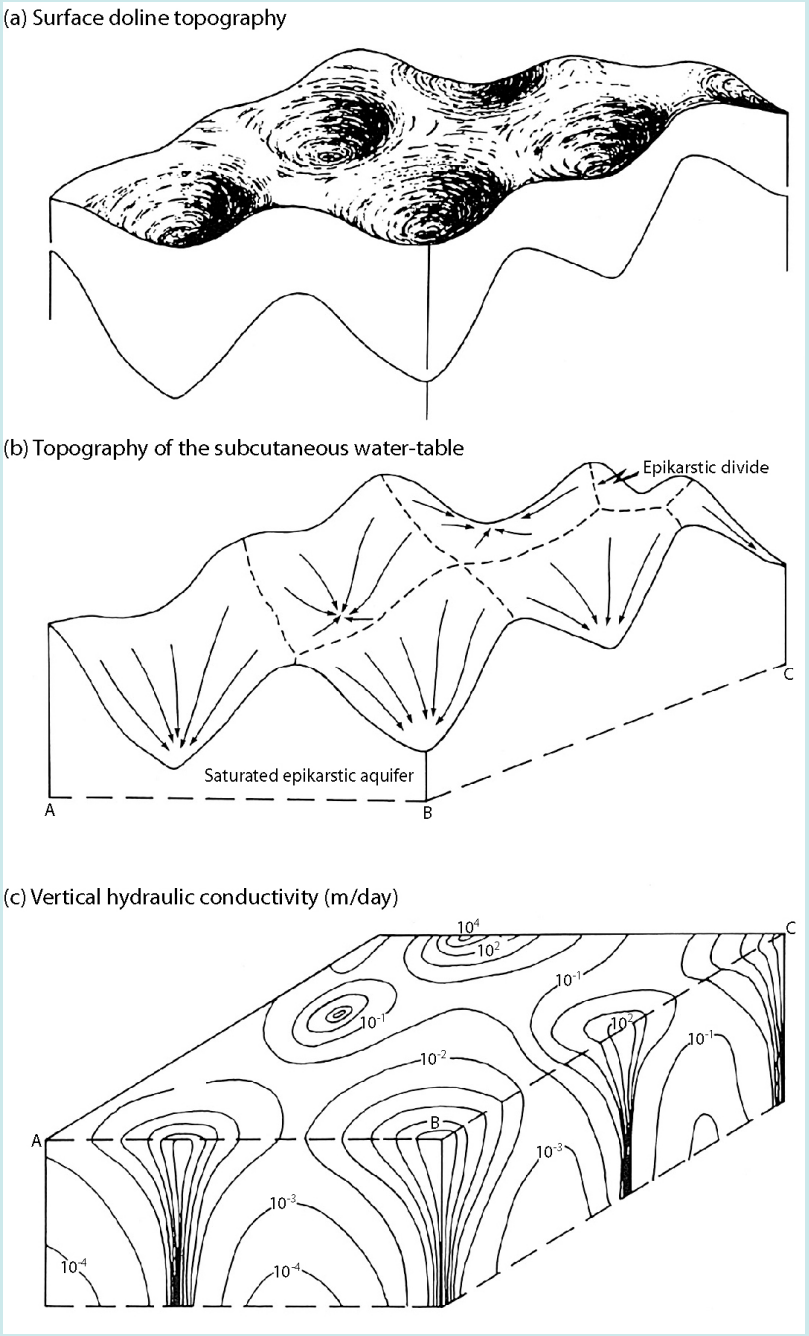
Epikarst, Guizhou, China

Soil covered doline karst, New Zealand

Epikarst (or subcutaneous zone) beneath dolines



from Williams 1983



Karst depressions,

underlying subcutaneous water-table,

spatially variable vertical hydraulic conductivity

from Williams 1985

Ground penetrating radar (GPR) across epikarst, Hortus, France

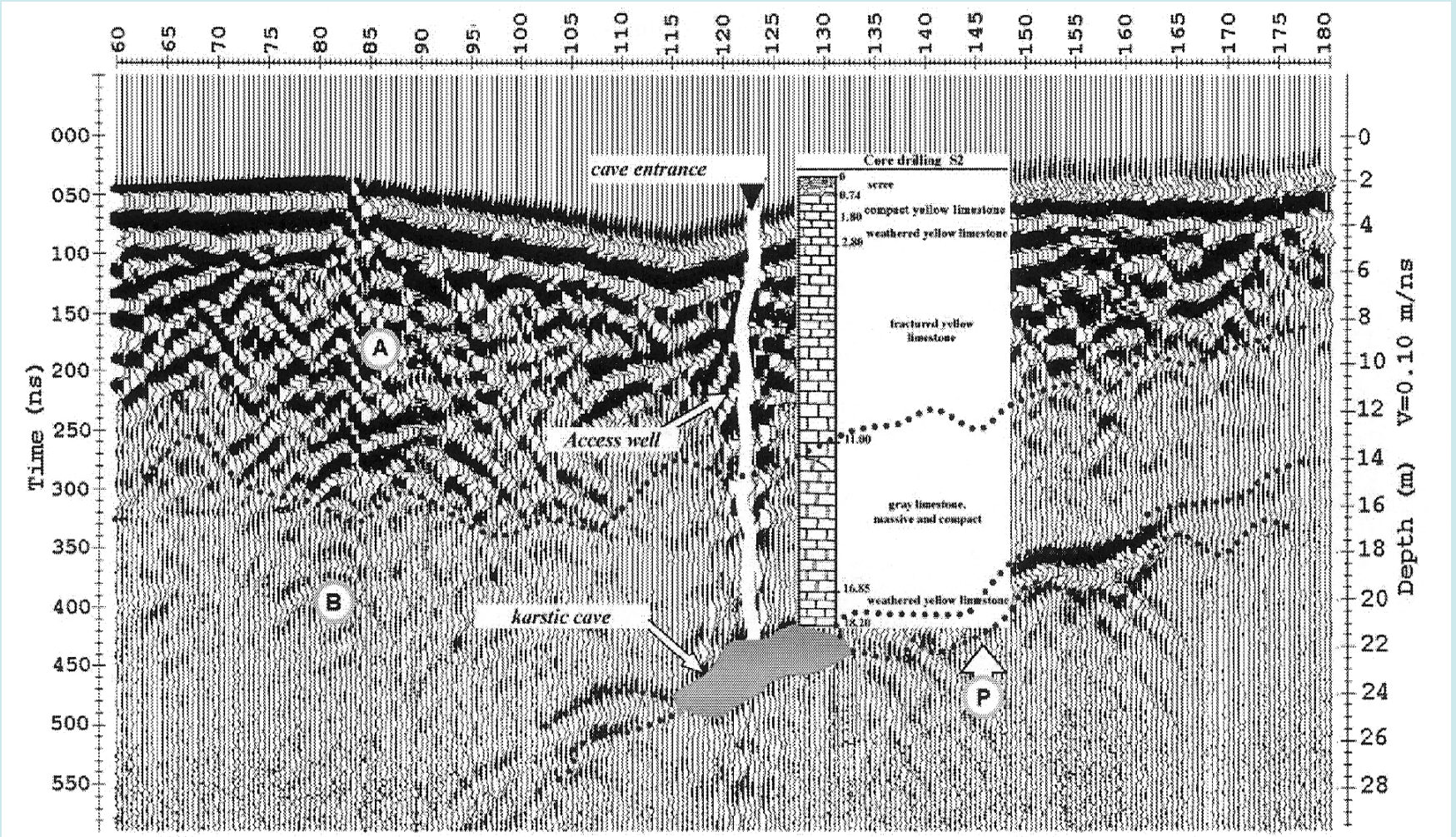
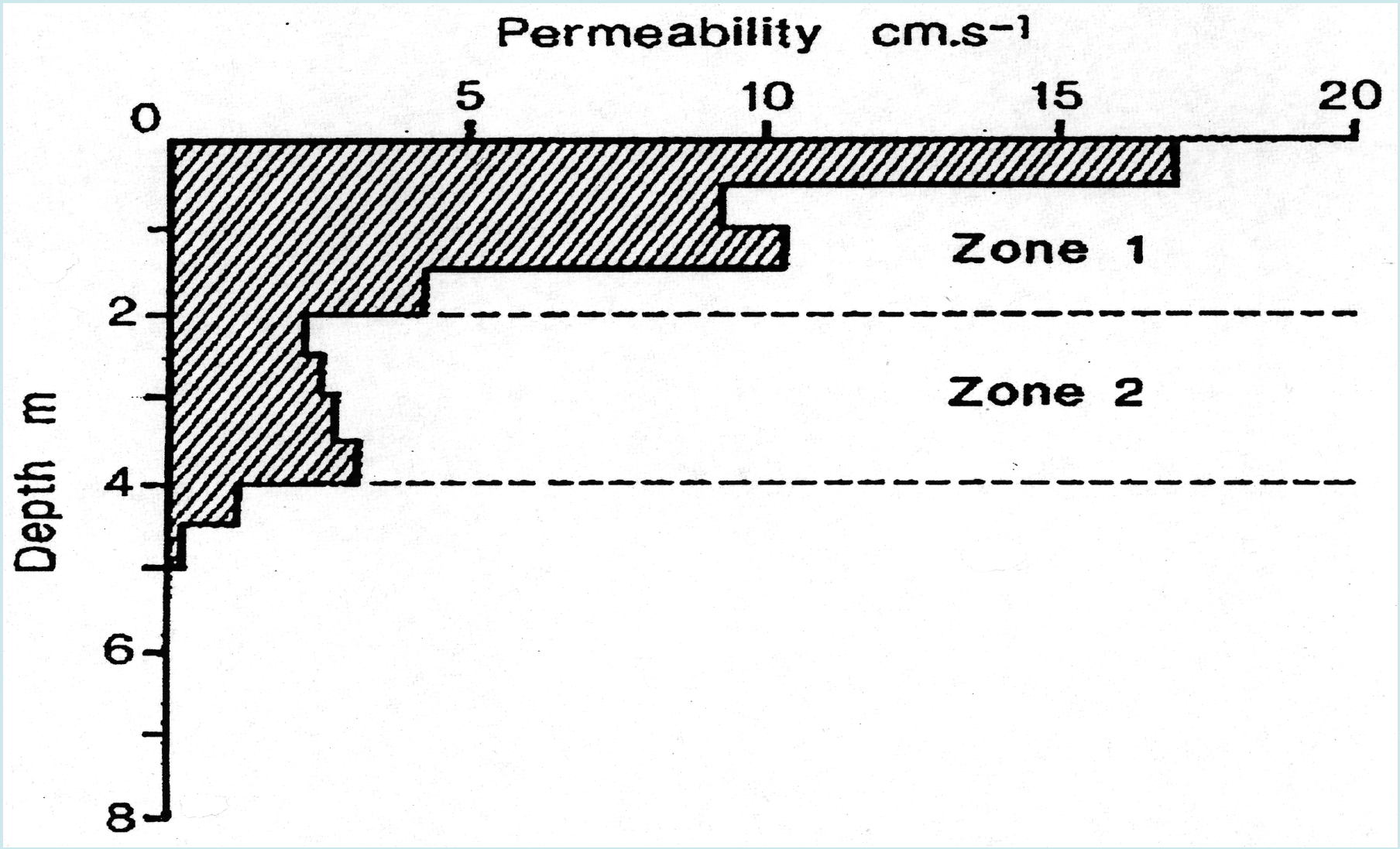


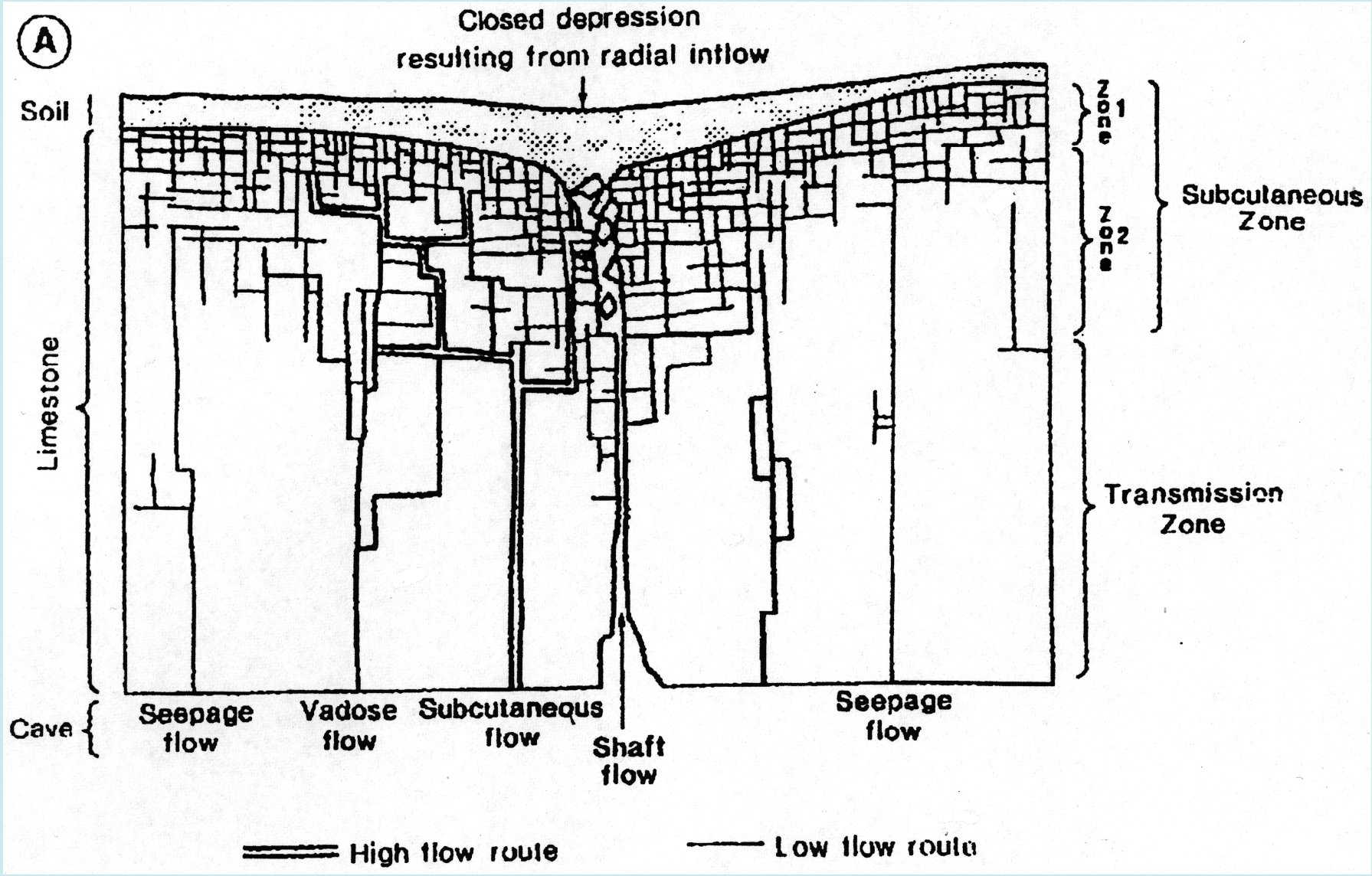
Fig. 6. Location of the karstic cave of the Lamalou experimental site showing the radargramme of profile 5 and the lithological column of boreholes S2 carried out above the cavity. A: fractured and karstified yellow limestone of the epikarst; B: massive and compact gray limestone; P: bedding plane.

from Al-fares *et al.* 2002



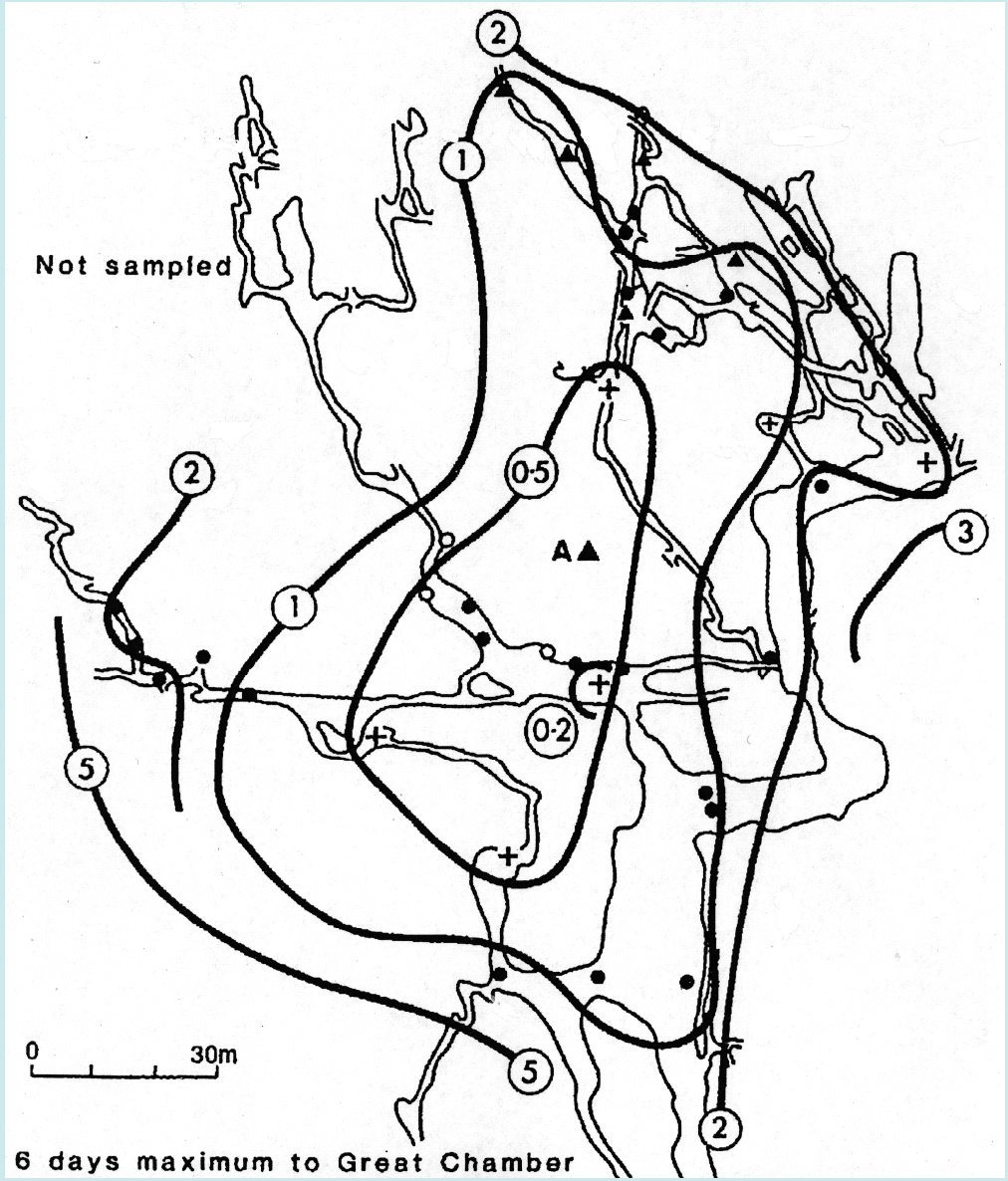
from Gousset 1981

Spectrum of flow paths and flow efficiency in the epikarst



from Smart & Friederich 1987

Flow-through time following dye injection on the surface above GB Cave, UK.

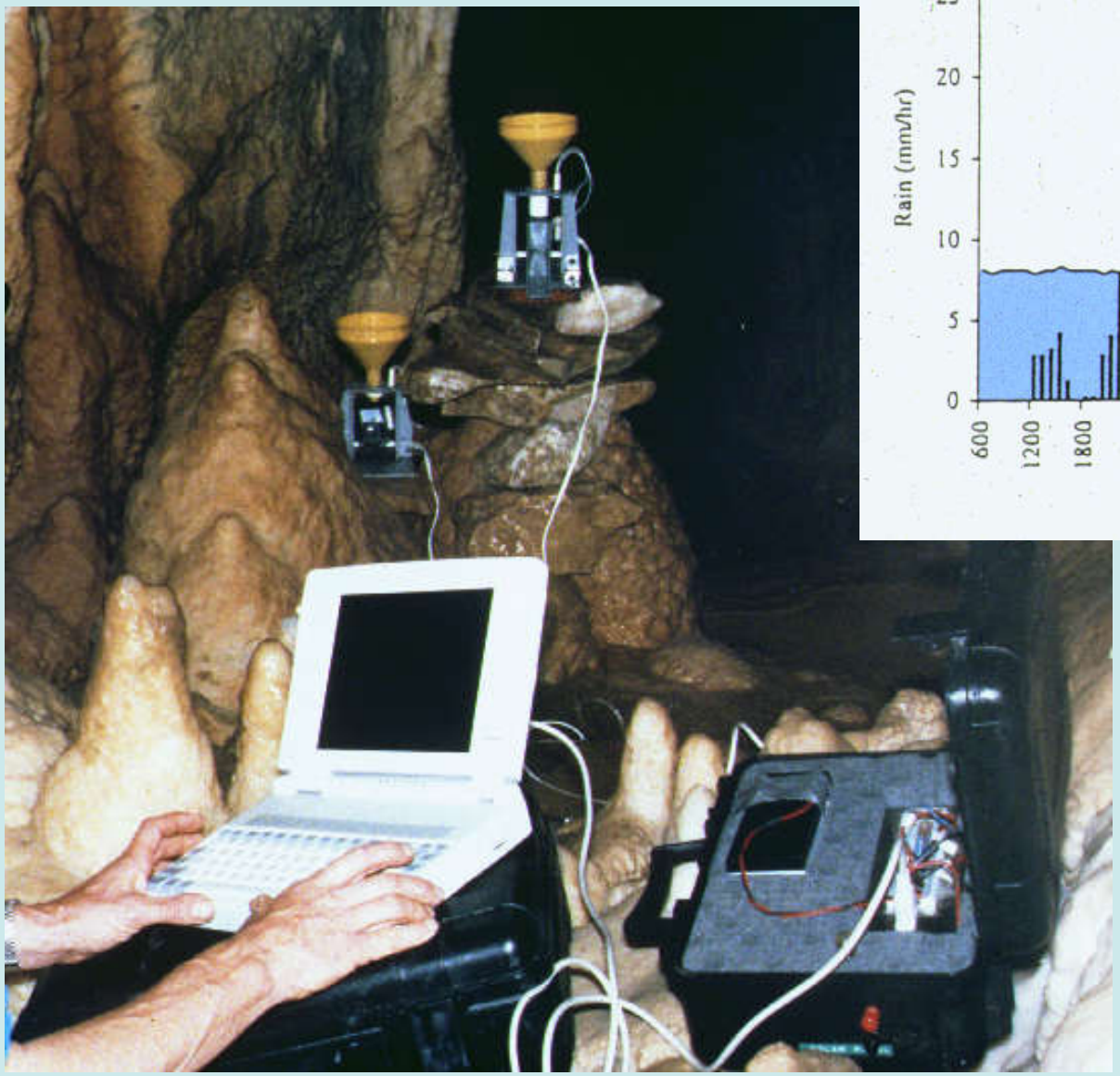


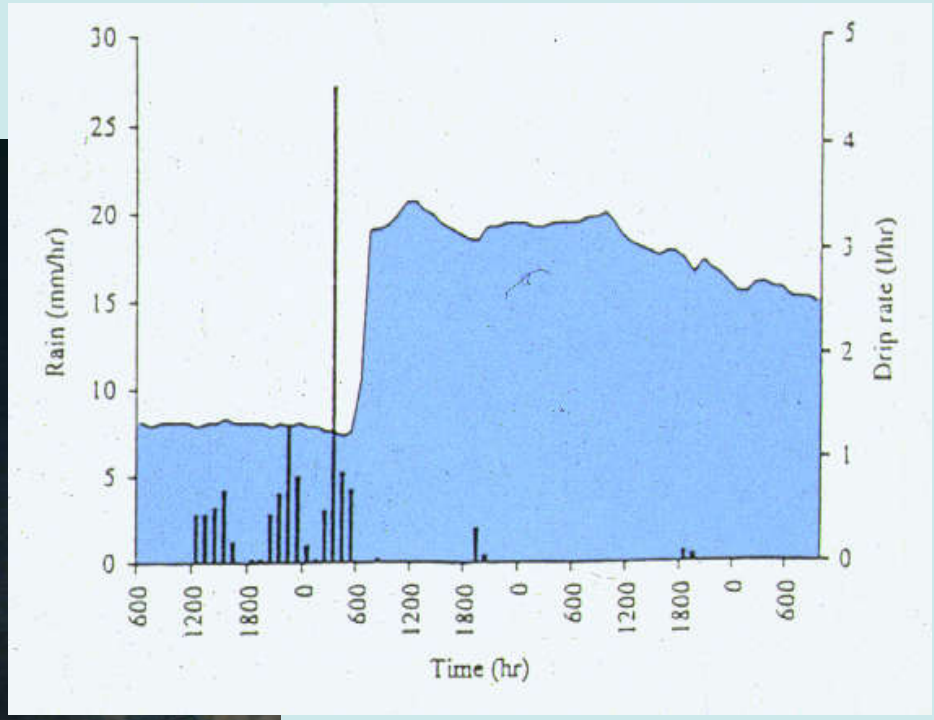
Duffusion of dye occurred in the top 10 m of the epikarst and spread laterally up to 80 m.

Some dye was still detectable in the cave 13 months later.

from Friederich & Smart 1982

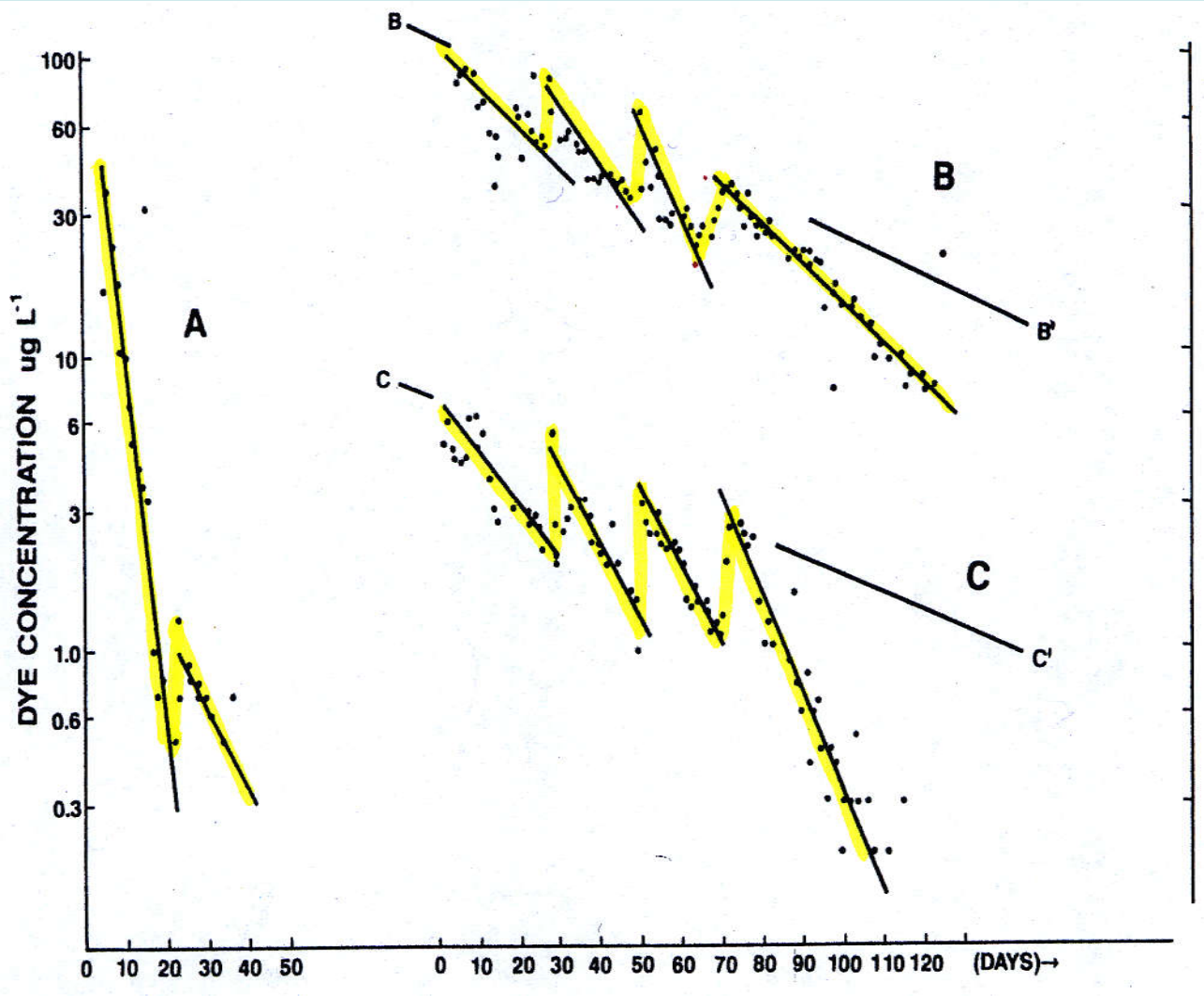
Monitoring percolation water, New Zealand





Note the variable lags between rainfall recharge and percolation response.

Dye appearance in White Scar Cave, England.



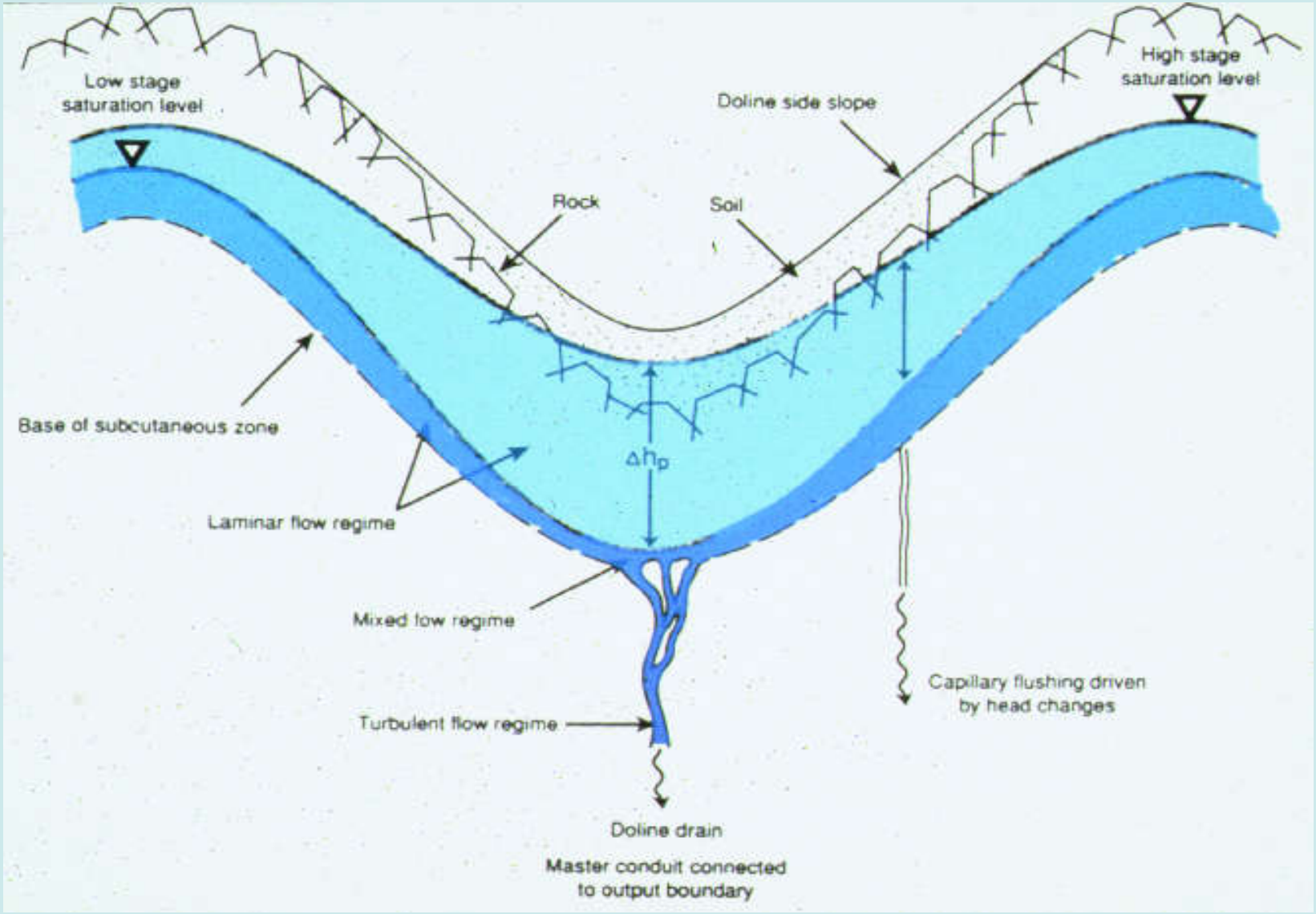
Note sawtooth flushing of dye at observed points in cave following recharge events.

This indicates flushing from epikarst storage.

This lesson applies to pollutants.

from Bottrell & Atkinson 1992

Epikarst flushing is driven by head changes after recharge

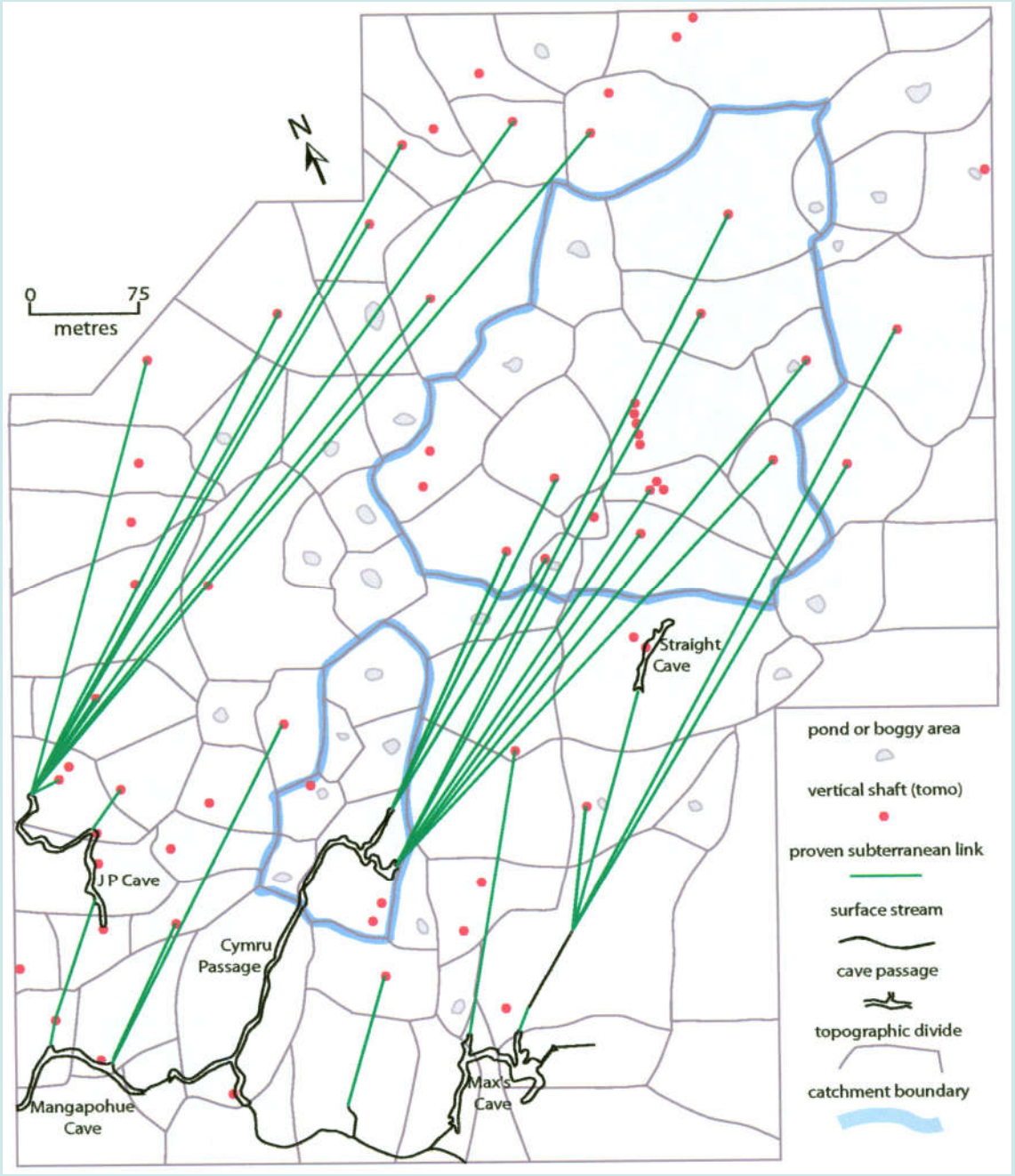


from Williams 1993

Dye tracing from dolines to underlying caves, New Zealand.

Water travels rapidly by shaft flow.

Surface topography provides an imperfect guide to guide to groundwater catchment areas.



from Gunn 1978

Third lesson from Science

Conventional groundwater models do not apply to karst

- **Managers of groundwater resources often use computer models to understand groundwater storage and transmission characteristics.**

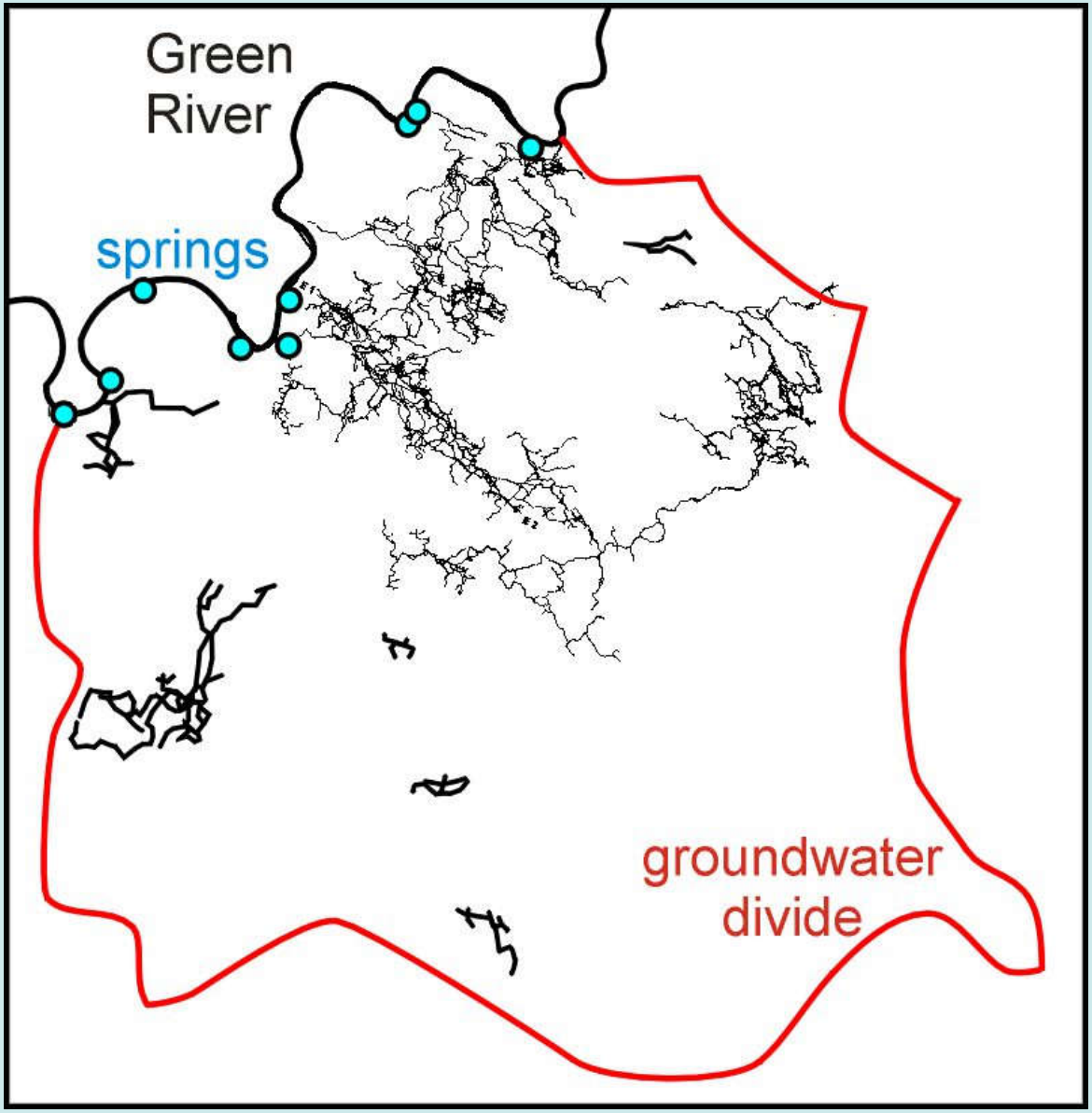
- **Conventional groundwater models are based on a concepts of laminar flow and porous rocks that are not applicable to karst.**

- **Karst aquifers have triple porosity characteristics (porous matrix, fractured rock, with conduits) and have laminar and turbulent mixed flow regimes.**

Mammoth Cave area

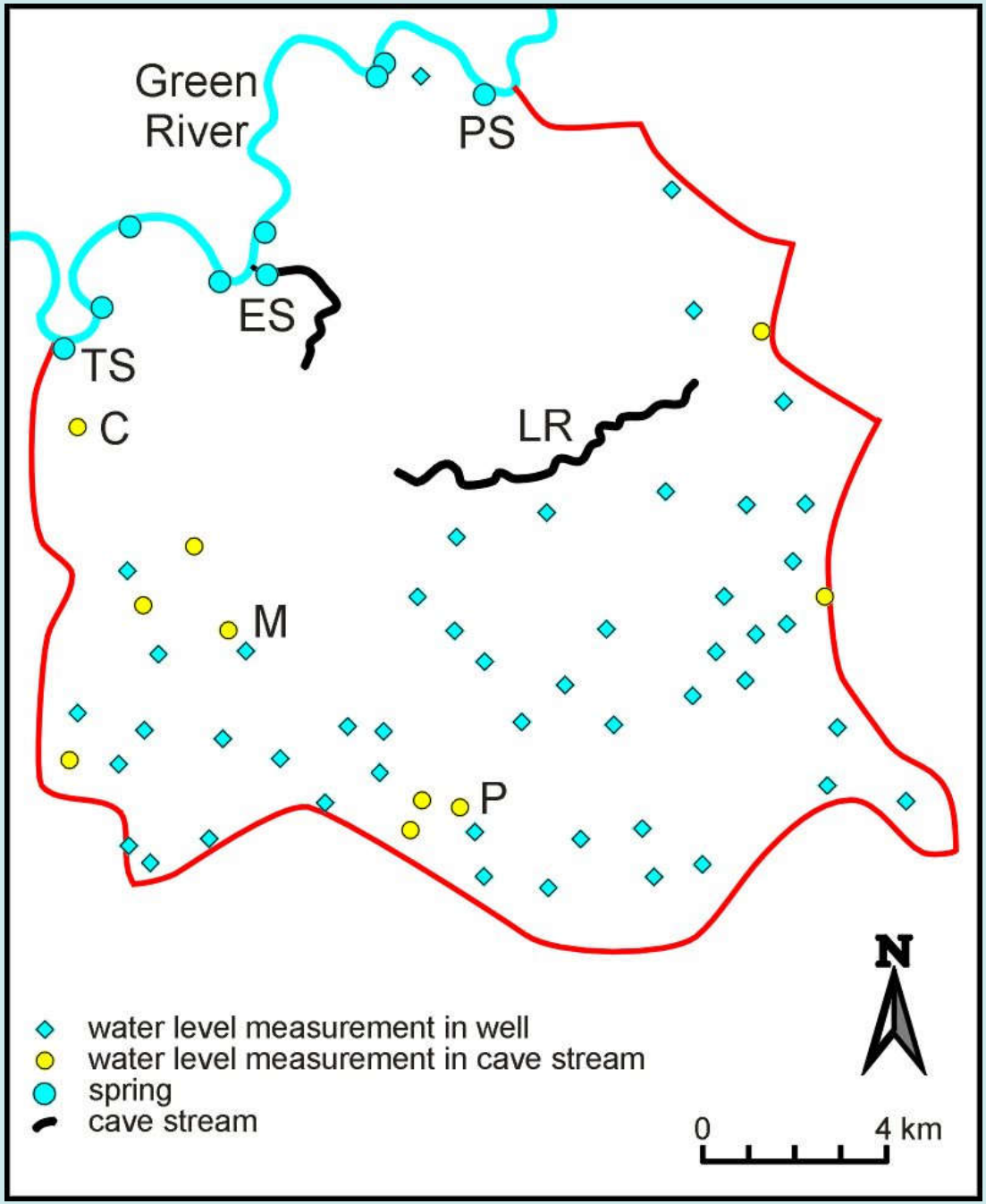
Mammoth Cave
550 km

Martin Ridge Cave
52 km



from Worthington 2004

Water level data from wells and cave streams



from Worthington 2004

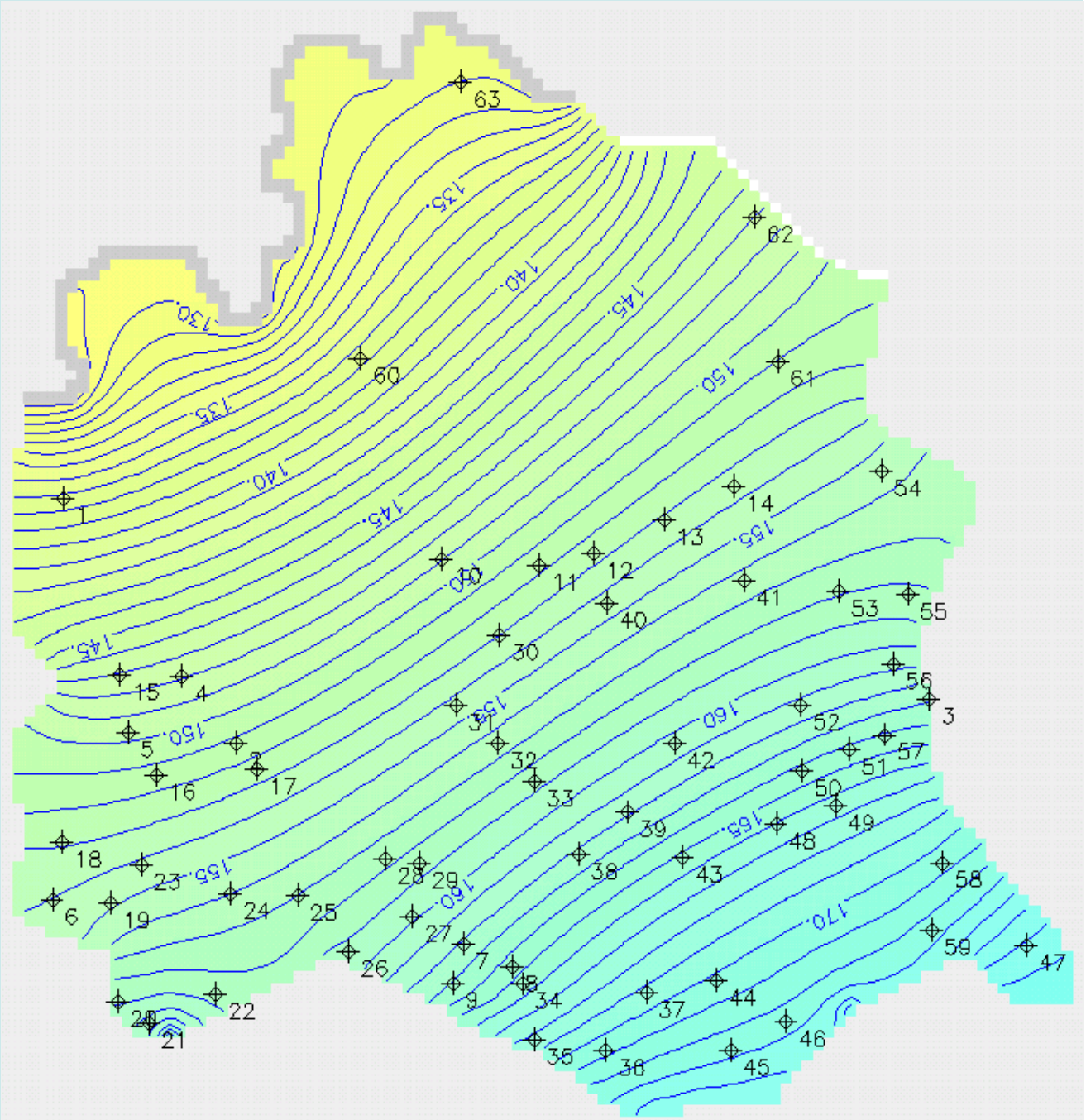
Output of MODFLOW computer model

homogeneous

equivalent porous medium simulation

$K = 1.1 \times 10^{-3}$ m/s

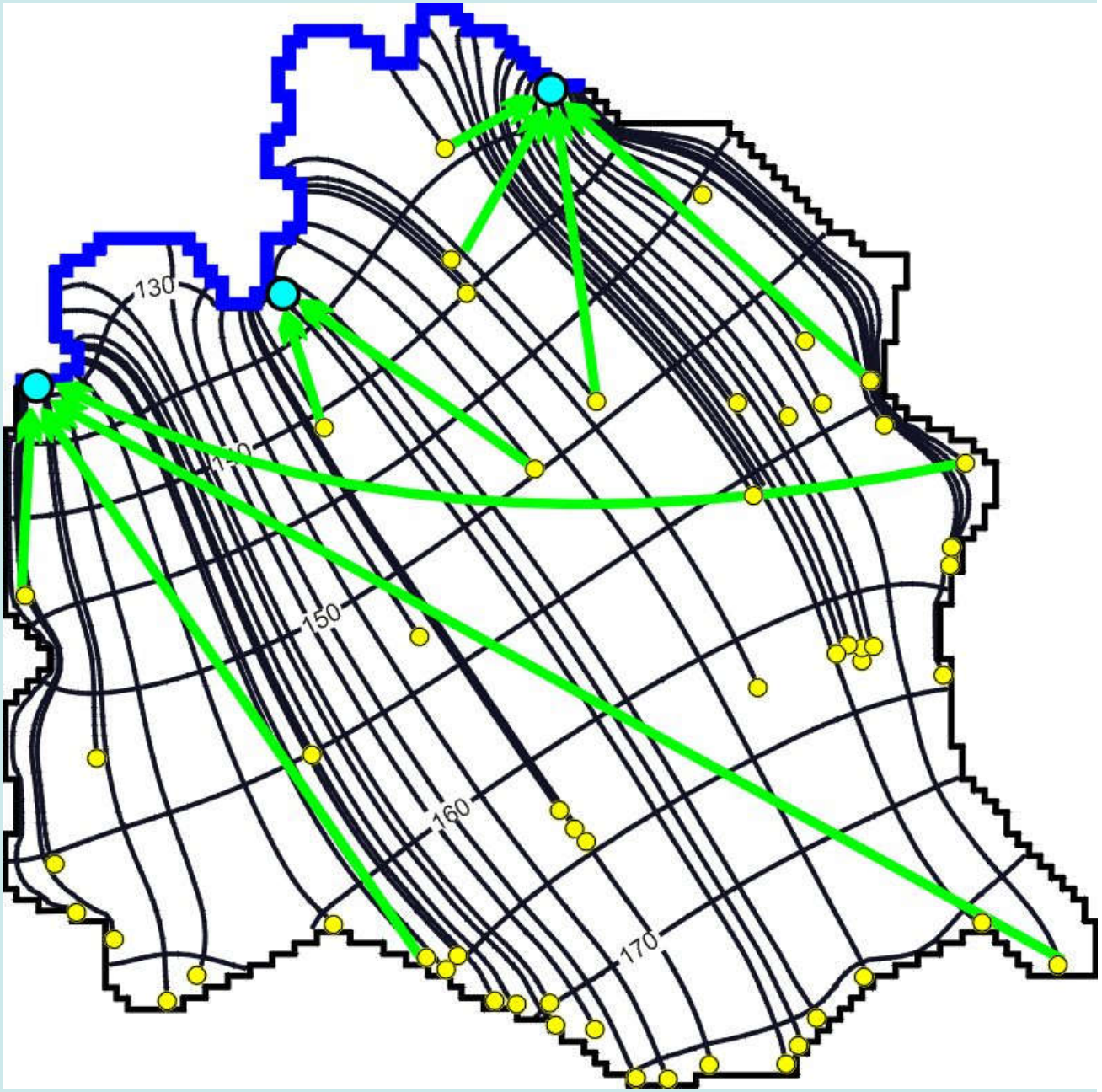
48 wells
mean absolute error = 12 m



from Worthington 2004

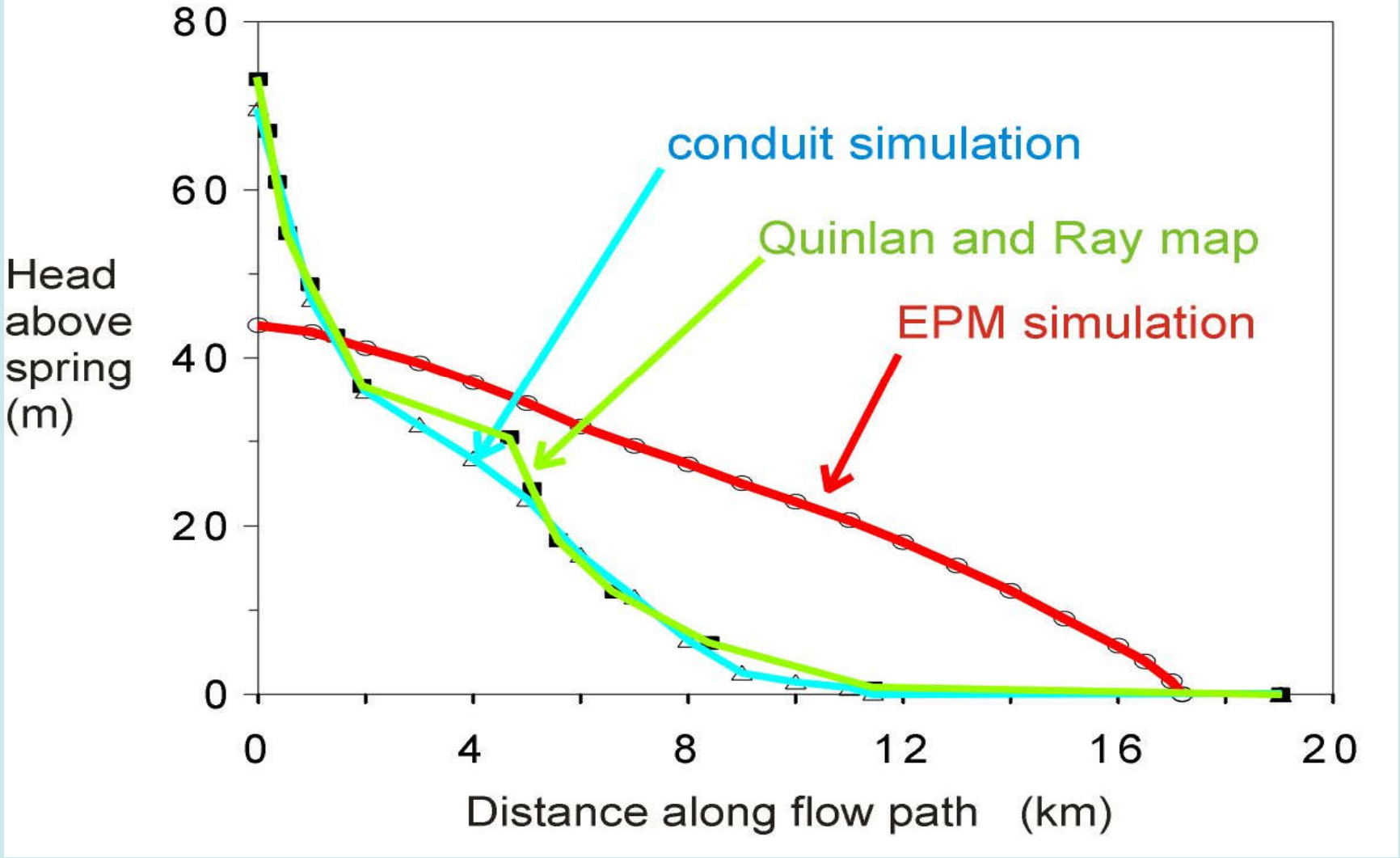
Actual tracer paths cut across model streamlines

54 inputs have been traced to 3 springs



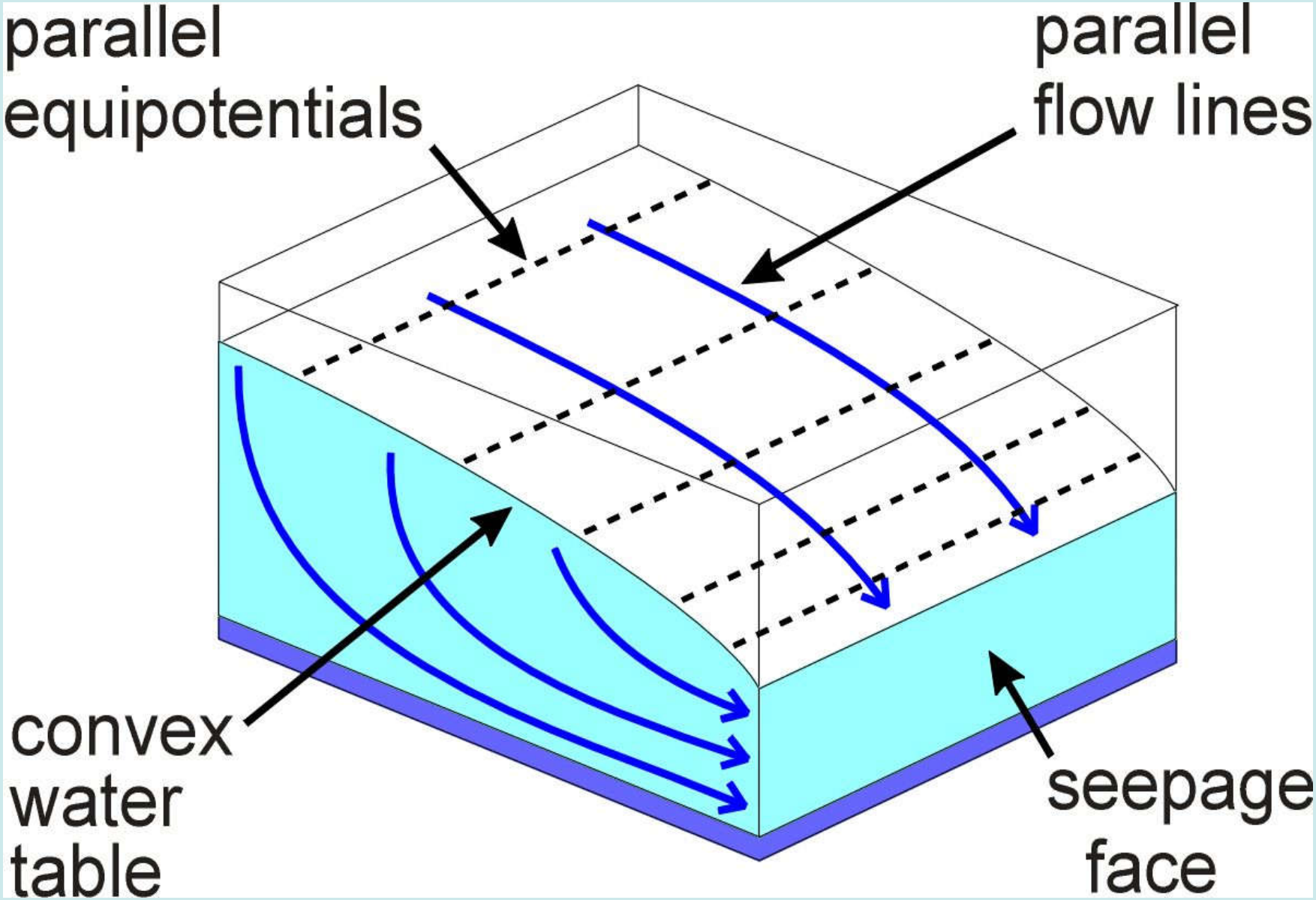
from Worthington 2004

Hydraulic gradients from A to Turnhole Spring

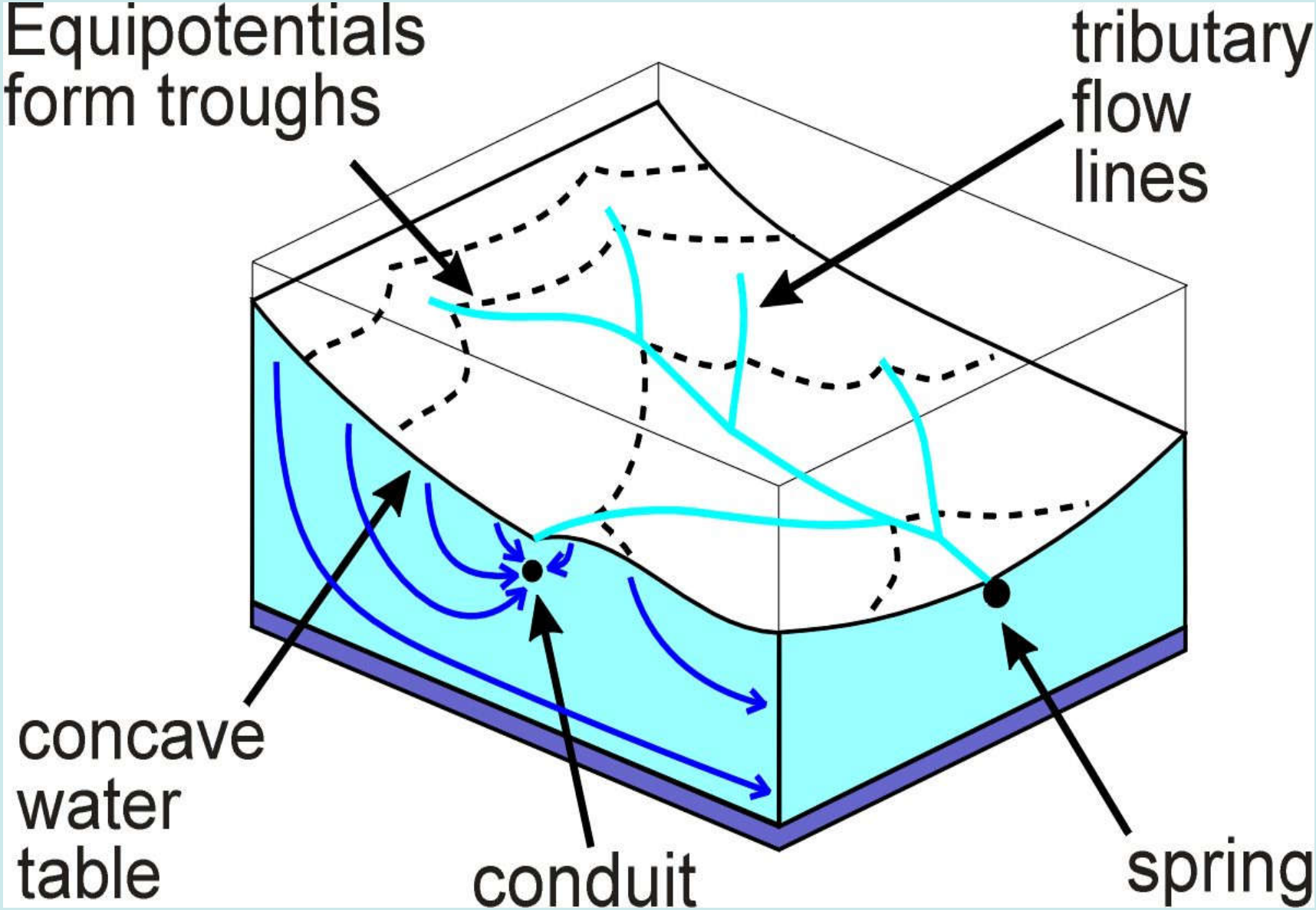


from Worthington 2004

Ideal porous aquifer



Ideal karst aquifer



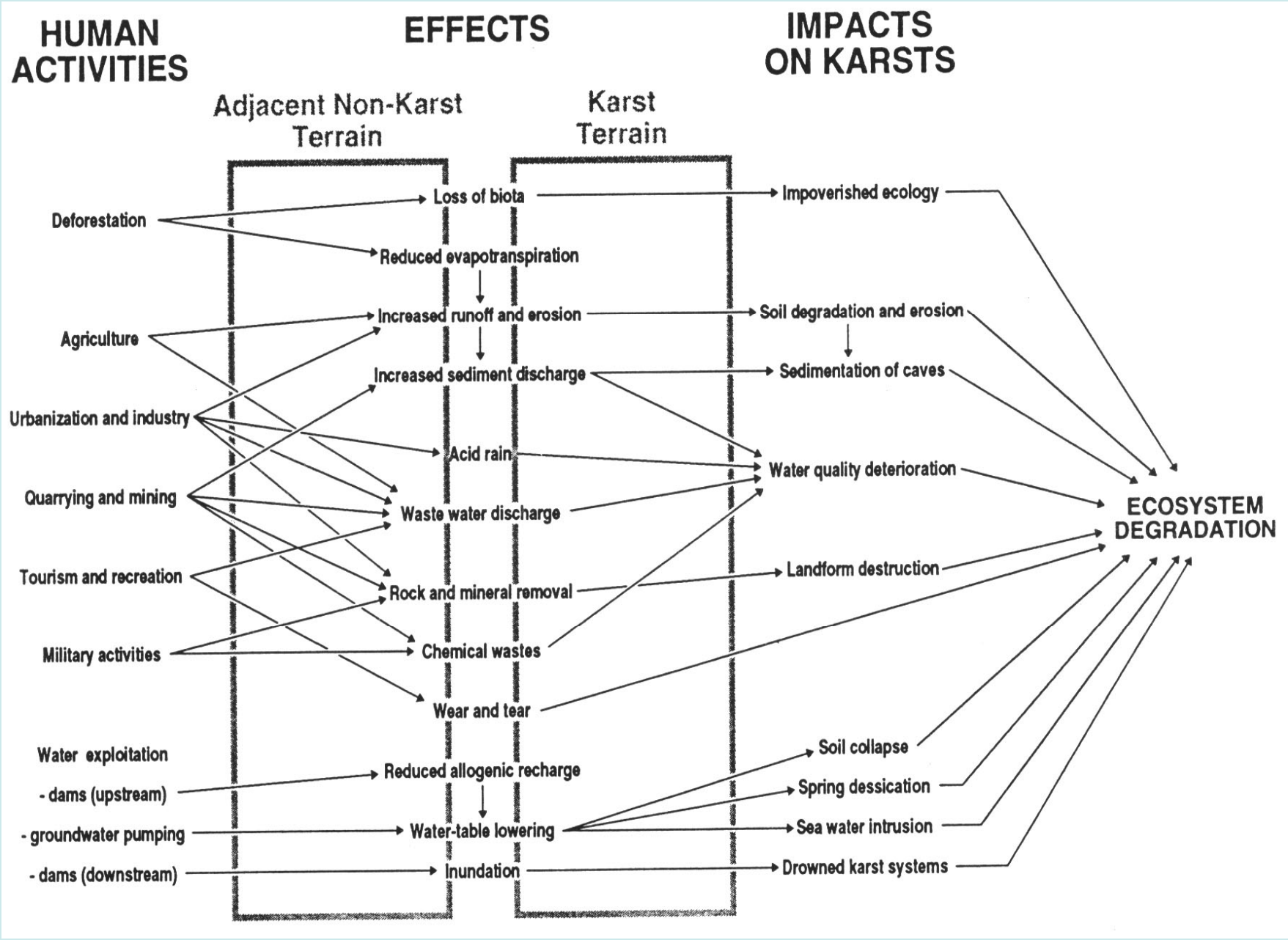
Fourth lesson from Science

The best place to monitor the condition of karst is at the outflow spring

- Water flow at springs integrates the effects of all upstream activities, terrestrial and aquatic, autogenic and allogenic.

- Unsustainable management results in progressive loss of water quantity and deterioration of water quality.

- Water quality is best measured by biological indicators, because aquatic organism live in the water and respond to its long-term quality.



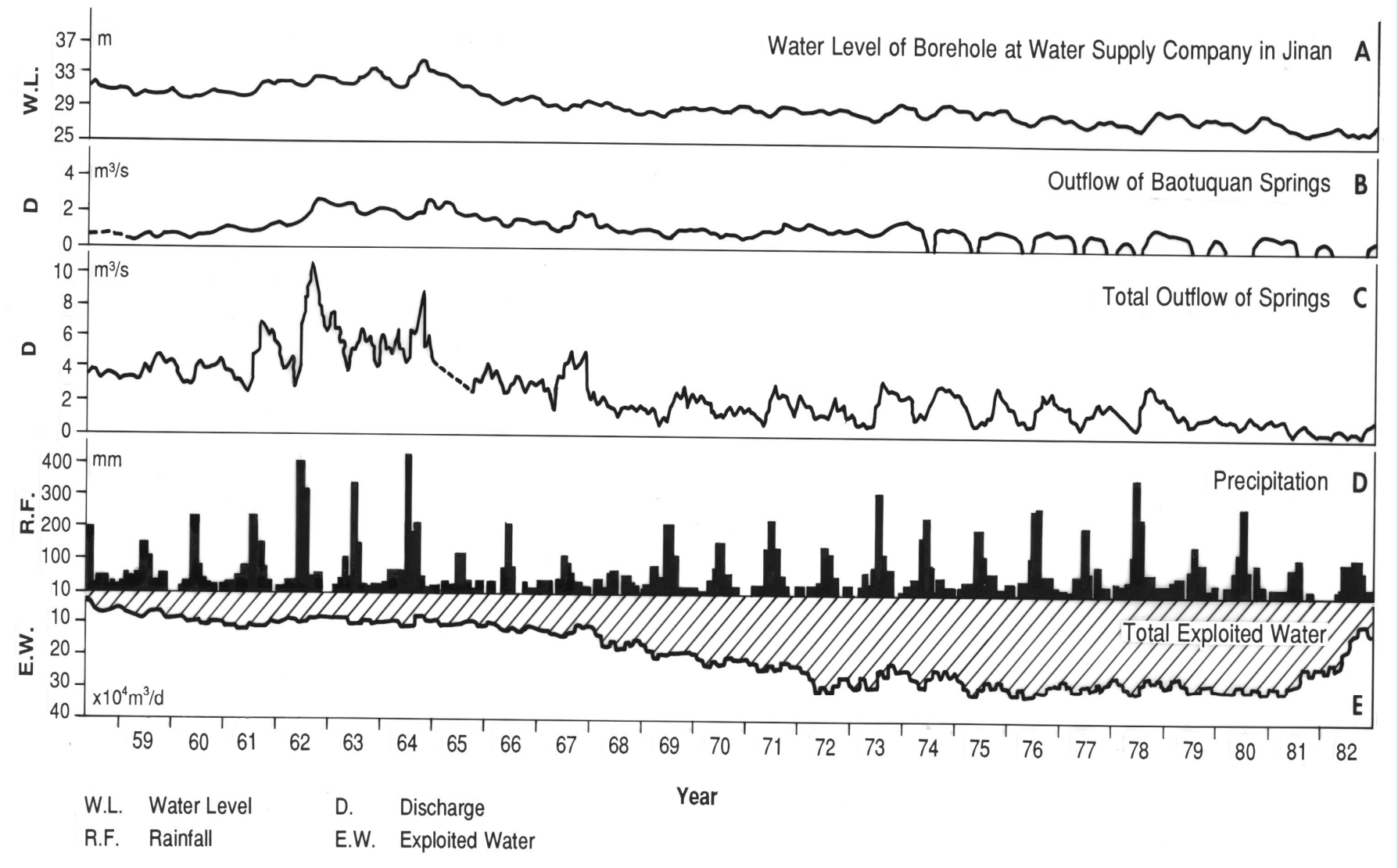
from Williams 1993

Karst springs

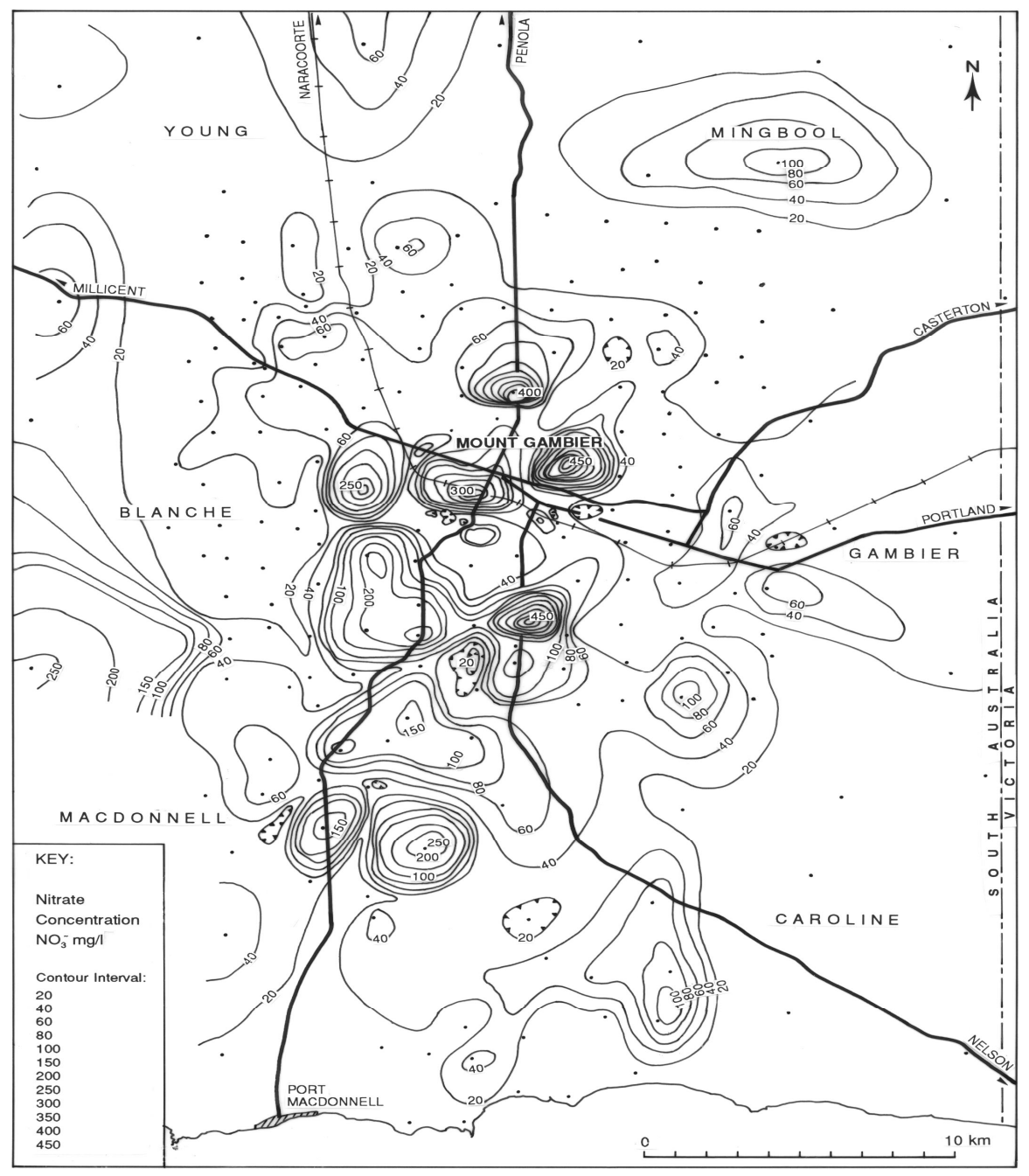
These have provided important sources of water supply for millennia.

Useable supplies are diminishing in quantity and quality.

Progressively reducing spring flow and groundwater level in Baotuquan Spring catchment, China (1958-1982)



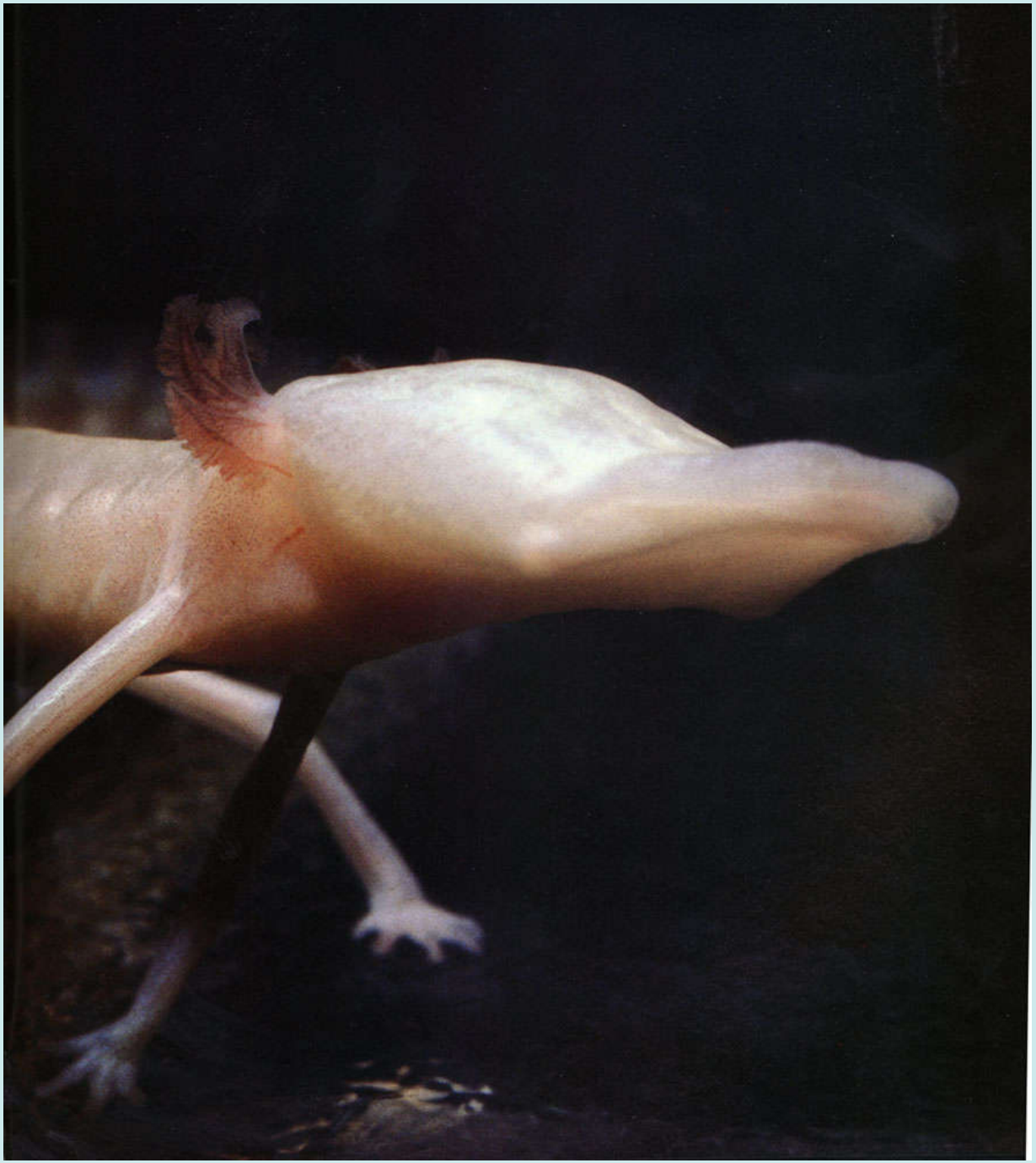
from Chen Zhenpeng 1985



Nitrate pollution of karst groundwater by dairy factory waste, South Australia.

from Waterhouse 1973

Gross pollution of a sinking stream (also used for rice paddy irrigation), Guizhou, China



Groundwater pollution destroys the unique aquatic biota of karst

(Proteus spp)

Blind fish

Fifth lesson from Science

Rocky desertification is the most widespread terrestrial problem affecting karst.

- **Rocky desertifation is a process that produces stony ecological deserts.**

- **The processes is:**

  de-forestation - inappropriate agricultural practices - soil erosion.

- **It is a direct consequence of over-population and selfish or thoughtless over-exploitation of timber resources.**

Process of rock desertification

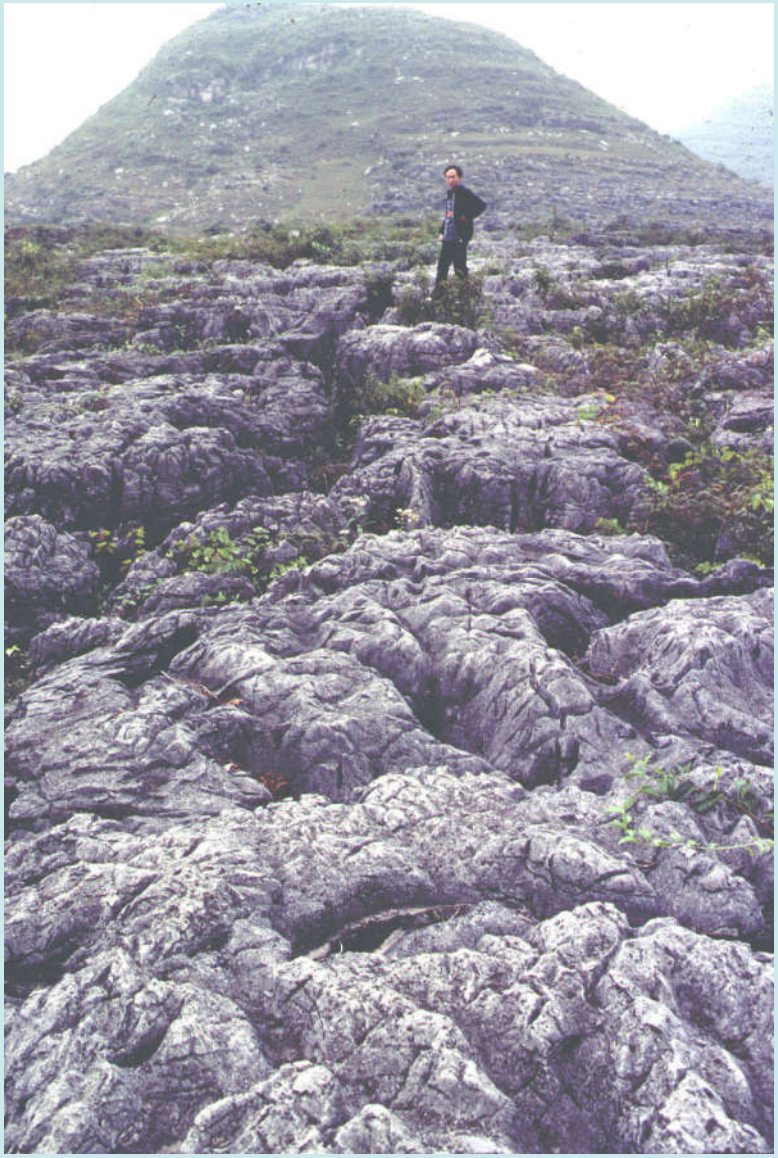
Subtropical monsoon rainforest removed. Rocks exposed on hillsides.

Soil washes from hillsides into karst basins with much soil lost underground where it causes water pollution.

Some secondary re-growth of trees once grazing pressure is reduced.

Rocky desertification

Attempts are sometimes made to capture soil and make fields.



Sometimes desertifiction is too extreme to do this

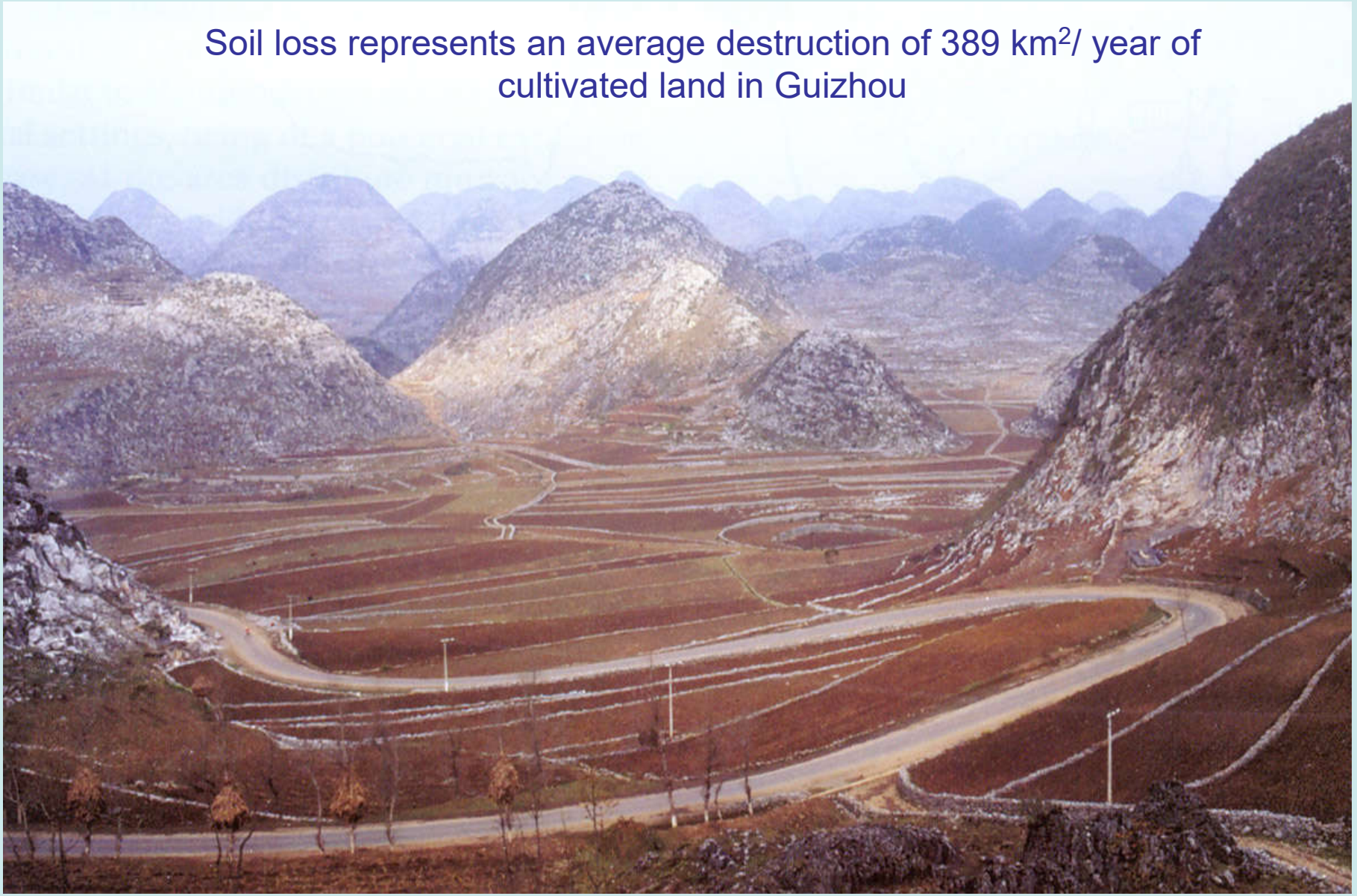
A deforested karst landscape denuded of soil and almost abandoned.

Dinaric karst in the Mediterranean basin

Bakalowicz photo

Advanced rocky desertification in Guizhou

Soil loss represents an average destruction of 389 km^2/ year of cultivated land in Guizhou



Attributes of karst that require special consideration during management

- Karst surface and subsurface systems are integrated and so this renders karst especially susceptible to human impacts.

- Erosion of soil on karst is essentially irreversible at human time scales.

- Karst is a repository of natural and cultural history and has unique subterranean ecosystems. These are part of our heritage.

The first principle of sustainable management is to harness the cooperation of society.

- **Science is impotent without the understanding and support of society.**

- **This implies that sustainable management should proceed by example, because earning support is easier if there is educated self-interest.**

The second principle is to work with Nature.

- **In order to conserve resources for future generations, so far as possible, development and conservation should be compatible.**

- **Nature can be managed in the short to medium term, but in the long-run it cannot be controlled. Even the mightiest dams will infill.**

A lesson from society

Science is impotent without the understanding and cooperation of the people