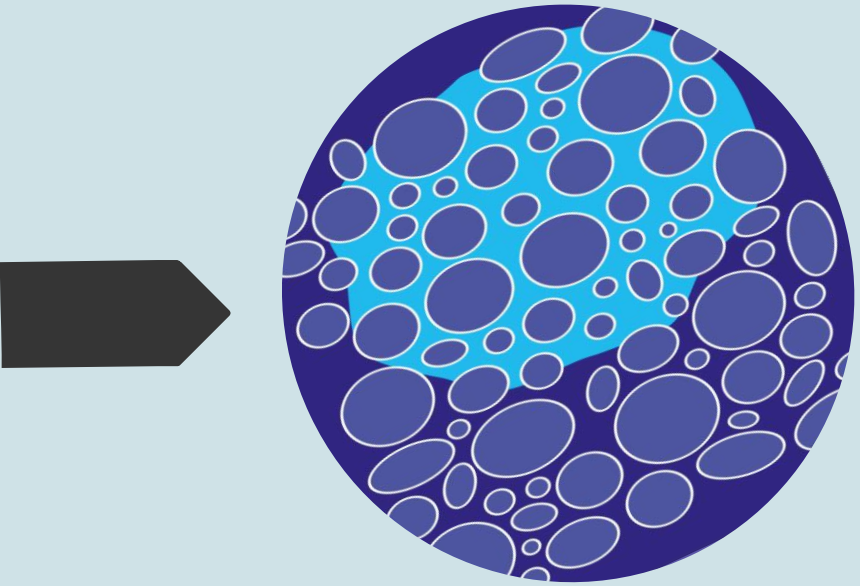

多孔介质污染迁移动力学

Contaminant Transport in Porous Media

郭芷琳

Office hour: 周三 15:00-17:00

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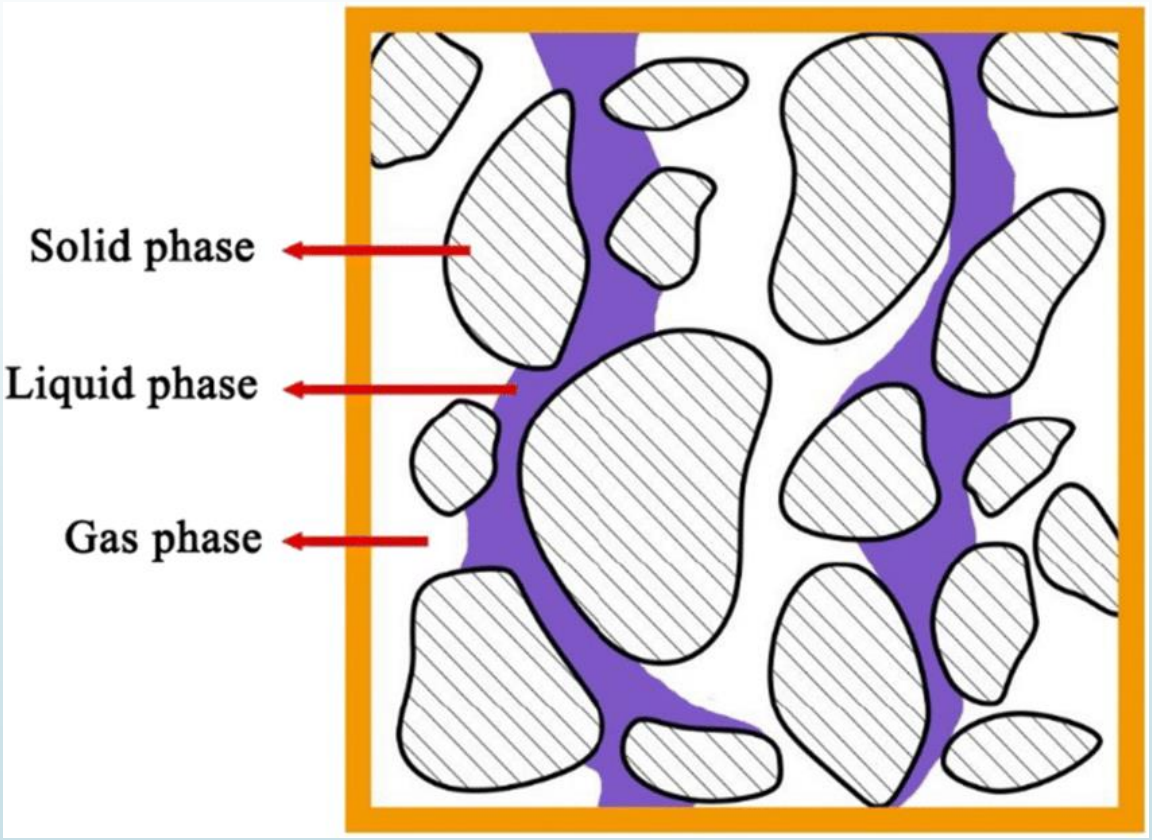
Outline

- 1 What's Groundwater?
- 2 Groundwater Contamination
- 3 Contaminant Transport Processes
- 4 Why do we care?
- 5 Scales of interest
- 6 Conservative and reactive transport
- 7 Remediation of contamination

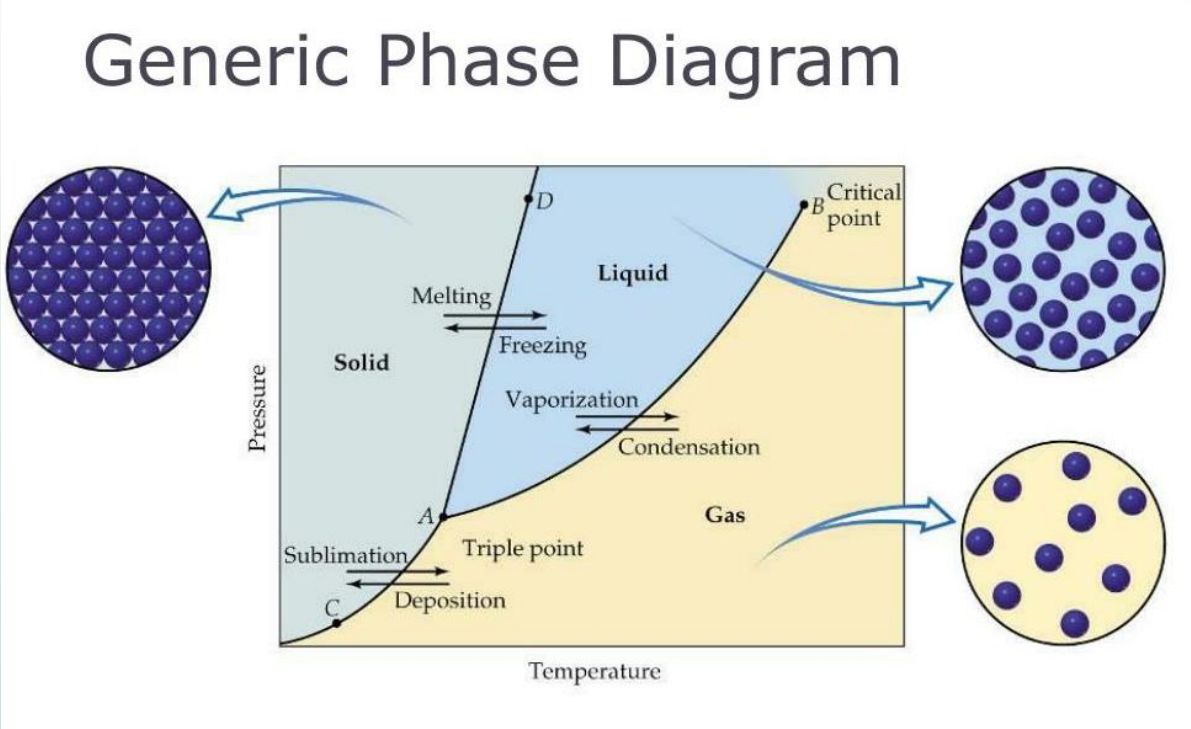
Porous Media

- A spatial domain occupied partly by a solid matrix, with the remaining part, referred to as pore or void space, occupied by one or more fluid phases.



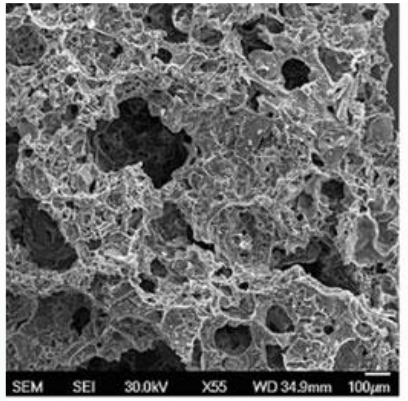
Phases, Chemical Species and Components

- ***A phase*** is a form of matter that is homogeneous in chemical composition and physical state. ⋯
- ***A chemical*** species is an identifiable chemical compound (atom, molecule, or ion) that participates as an entity, whether as a reactant, or as a product, in a chemical reaction that takes place within a phase
- The number of ***components*** (C) is the number of chemically independent constituents of the system, i.e. the minimum number of independent species necessary to define the composition of all phases of the system under equilibrium conditions.



The Porous Medium

- **Naturally occurring porous media:** a geological formations below ground surface. soil is a porous medium, serve as aquifers and as gas and petroleum reservoirs. Highly heterogeneous and often also anisotropic.
- **Manufactured porous media:** e.g., paper, ceramics, foam rubber, bread, and filters. Usually, they are homogeneous.
- **Organic porous media**: e.g., bones, lungs and kidneys.



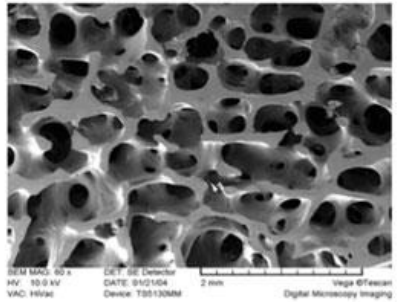
(a) Ceramics

(b) Bioclastic limestone

(c) High porosity sandstone

(d) Franciscan fractured mudstone

(e) Domogene sandstone



(f) Bone

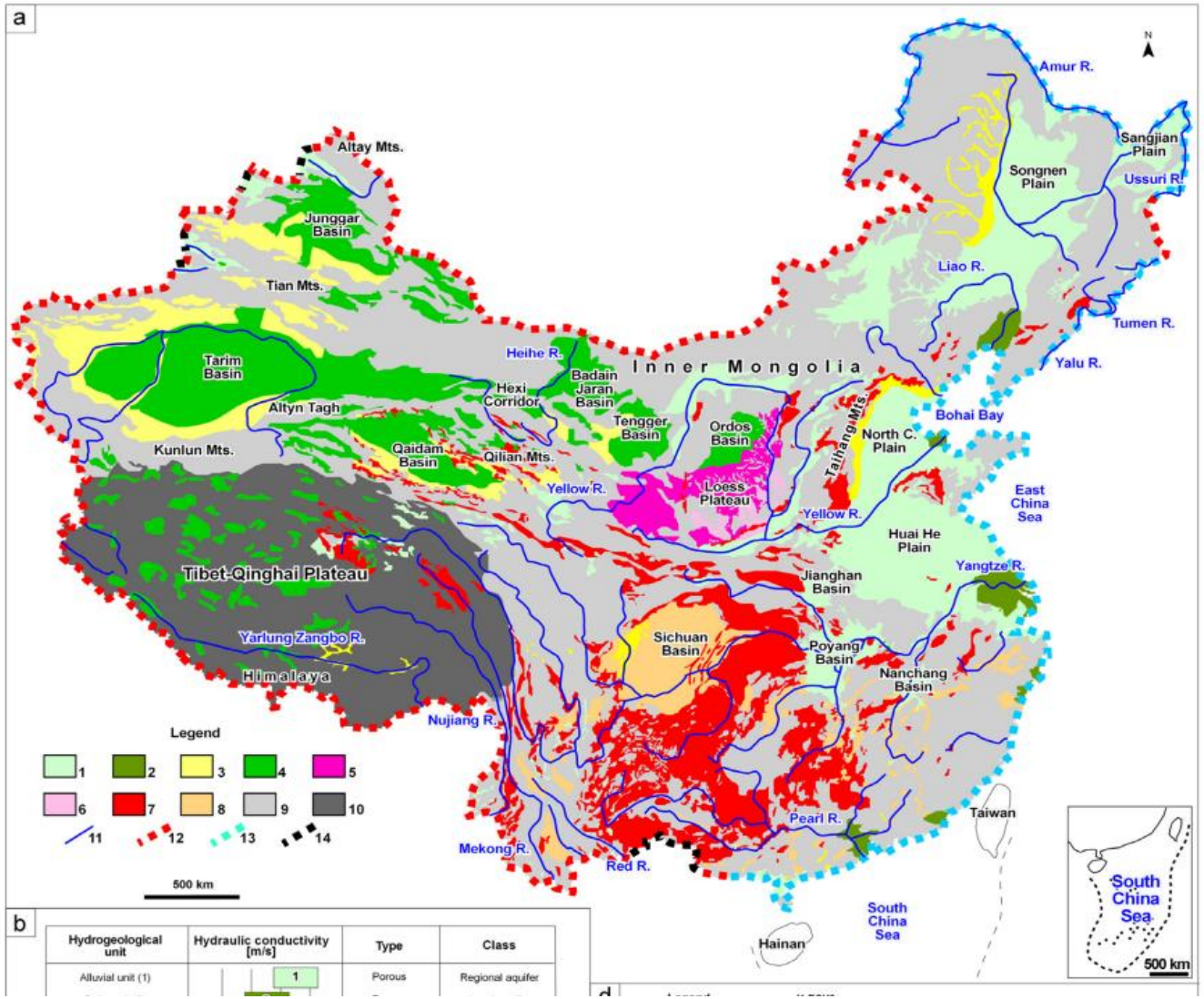
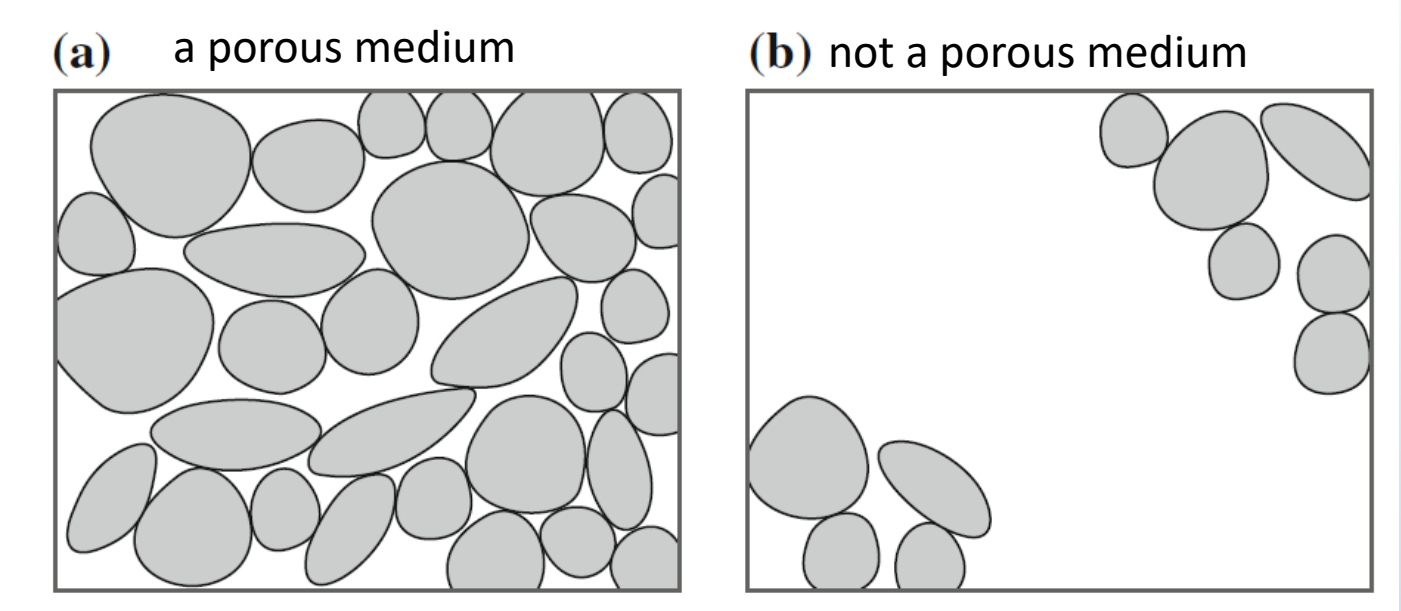


Fig. 1. Aquifer map of China, modified from CGS (2004) (a). Key to the legend: alluvial unit (1); delta unit (2); piedmont unit (3); endorheic clastic unit (4); continuous loess unit (5); discontinuous loess unit (6); karst unit (7); fissured-porous bedrock unit (8); bedrock unit (9); permafrost unit (10); main rivers (11); no flow boundary condition (12); head-dependent boundary condition (13); general head boundary condition (14). Table of the hydrogeological unit (b); groundwater budgets from regional cartography (CGS, 2004) (c); domain discretization via 5 layers (d), green arrows indicate recharge boundary condition (RCH); equivalent water-wells set on Layers 2 and 3 and observation piezometer (CGEMI, 2016) used for calibration (e).

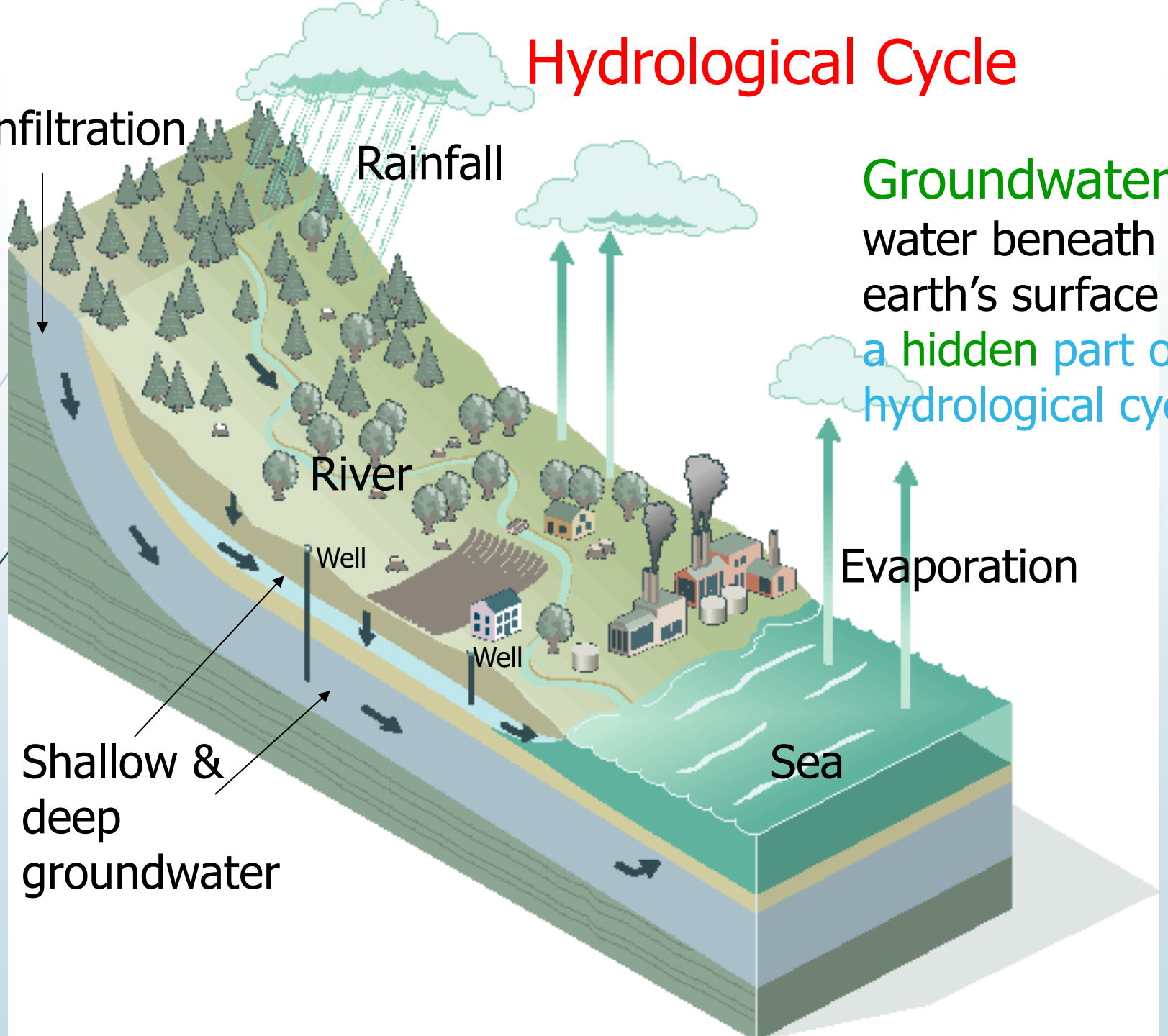
The Porous Medium

An essential feature of a porous medium: both the solid matrix and the void space are distributed all over the domain, albeit, not necessarily uniformly

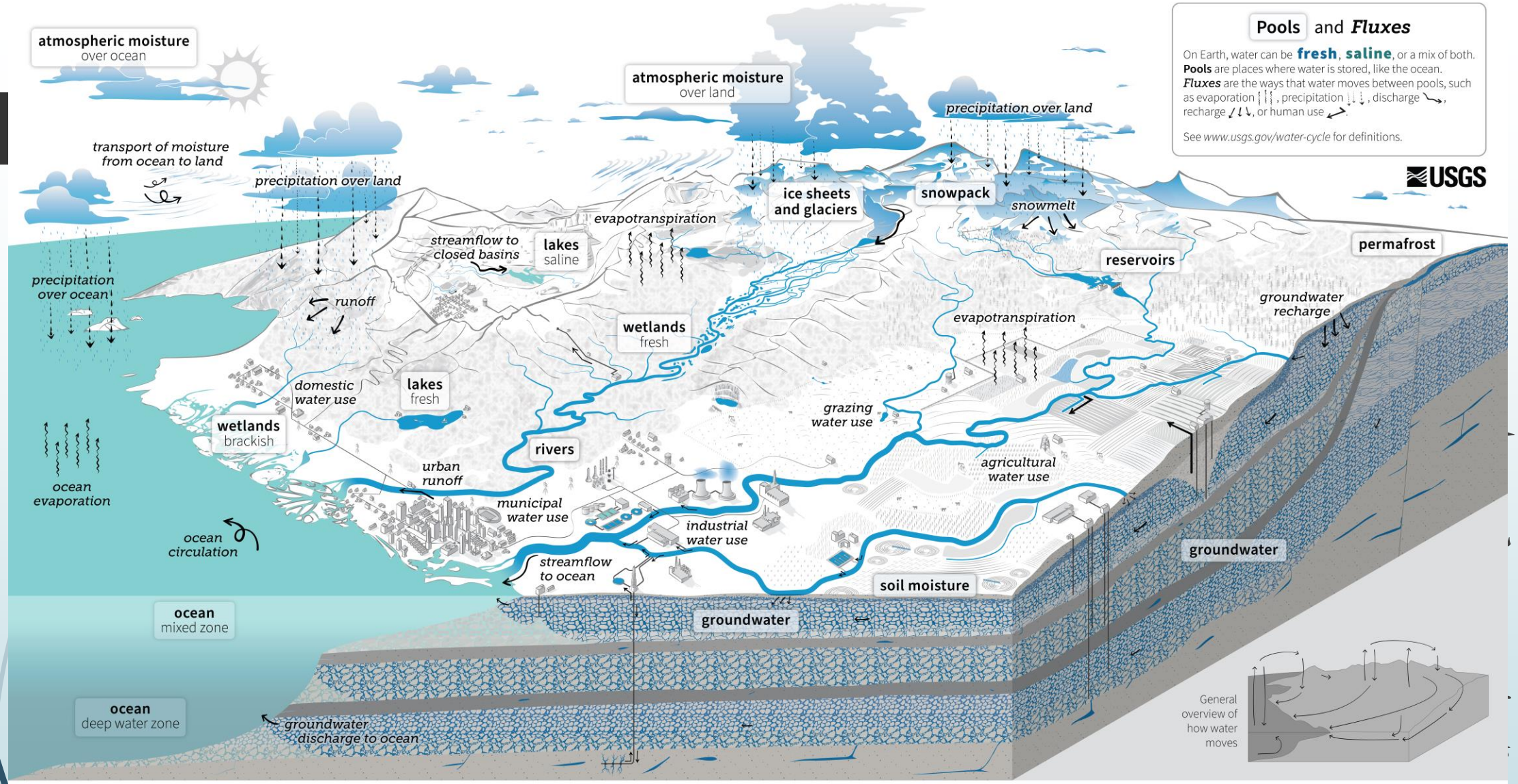


A porous medium is a spatial domain that (1) always contains a persistent solid portion and a void space (meaning 'void of solid'), and (2) that it should be possible to find for that domain a sample, referred to as a ***Representative Elementary Volume*** (REV), of a size such that wherever we place it within the domain, it will always contain both a solid matrix and a void space.

Hydrological Cycle



Groundwater is the water beneath the earth's surface and is a hidden part of the hydrological cycle



The Water Cycle

The water cycle describes where water is on Earth and how it moves. Water is stored in the atmosphere, on the land surface, and below the ground. It can be a liquid, a solid, or a gas. Liquid water can be fresh, saline (salty), or a mix (brackish). Water moves between the places it is stored. Water moves at large scales and at very small scales. Water moves naturally and because of human actions. Human water use affects where water is stored, how it moves, and how clean it is.

Pools store water. 96% of all water is stored in **oceans** and is saline. On land, saline water is stored in **saline lakes**. Fresh water is stored in liquid form in **freshwater lakes**, artificial **reservoirs**, **rivers**, and **wetlands**. Water is stored in solid, frozen form in **ice sheets** and **glaciers**, and in **snowpack** at high elevations or near the Earth's poles. Water vapor is a gas and is stored as **atmospheric moisture** over the ocean and land. In the soil, frozen water is stored as **permafrost** and liquid water is stored as **soil moisture.** Deeper below ground, liquid water is stored as **groundwater** in aquifers, within cracks and pores in the rock.

Fluxes move water between pools. As it moves, water can change form between liquid, solid, and gas. **Circulation** mixes water in the oceans and transports water vapor in the atmosphere. Water moves between the atmosphere and the surface through **evaporation**, **evapotranspiration**, and **precipitation**. Water moves across the surface through **snowmelt**, **runoff**, and **streamflow**. Water moves into the ground through infiltration and **groundwater recharge**. Underground, groundwater flows within aquifers. It can return to the surface through natural **groundwater discharge** into rivers, the ocean, and from **springs**.

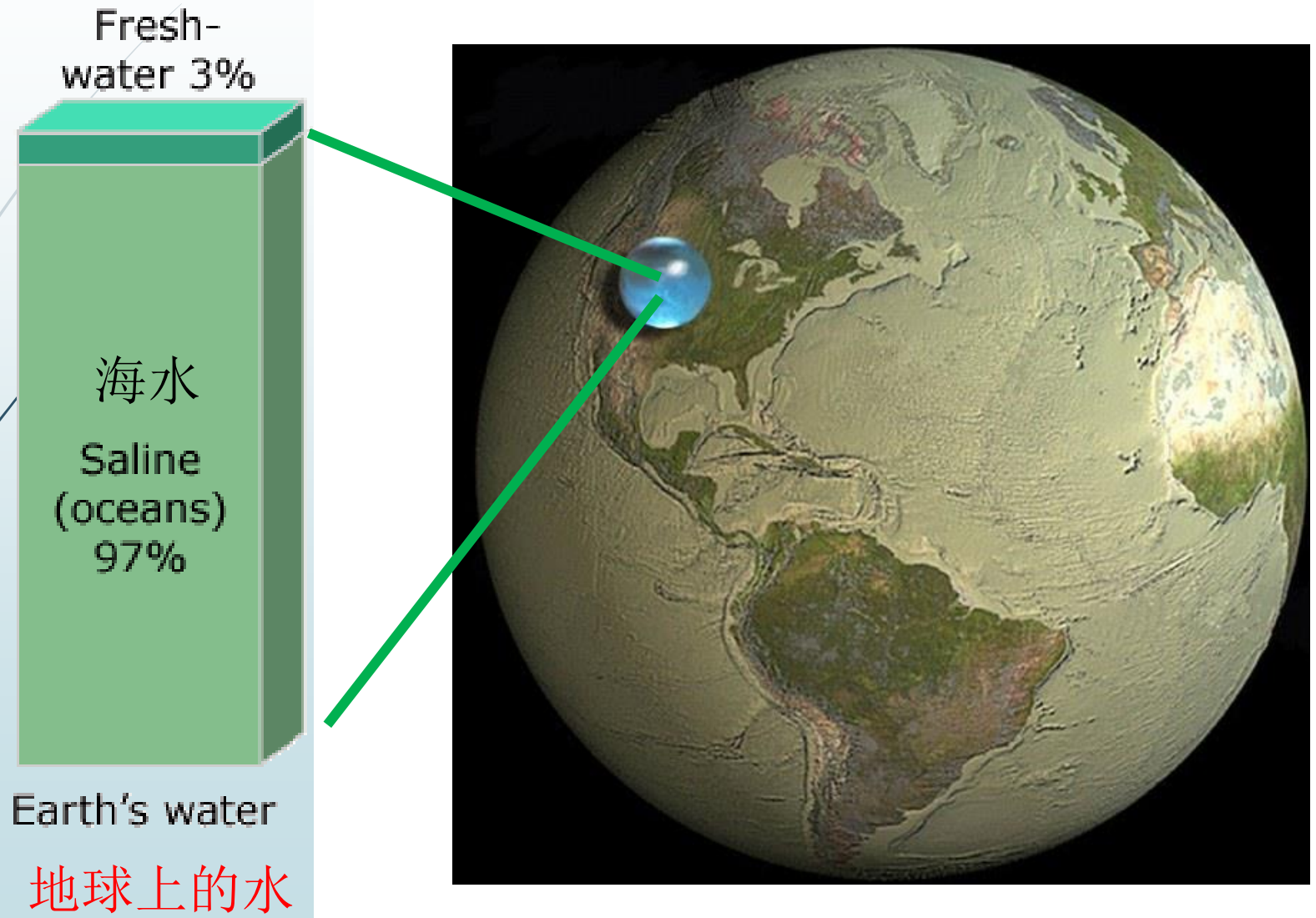
We alter the water cycle. We redirect rivers. We build dams to store water. We drain water from wetlands for development. We use water from rivers, lakes, reservoirs, and groundwater aquifers. We use that water to supply our **homes** and **communities.** We use it for **agricultural** irrigation and **grazing** livestock. We use it in **industrial** activities like thermoelectric power generation, mining, and aquaculture. The amount of water that is available depends on how much water is in each pool (water quantity). It also depends on when and how fast water moves (water timing), how much water we use (water use), and how clean the water is (water quality).

We affect **water quality**. In agricultural and urban areas, irrigation and precipitation wash fertilizers and pesticides into rivers and groundwater. Power plants and factories return heated and contaminated water to rivers. Runoff carries chemicals, sediment, and sewage into rivers and lakes. Downstream from these sources, contaminated water can cause harmful algal blooms, spread diseases, and harm habitats. **Climate change** is affecting the water cycle. It is affecting water quality, quantity, timing, and use. It is causing ocean acidification, sea level rise, and more extreme weather. By understanding these impacts, we can work toward using water sustainably.

地球上水的分布

淡水

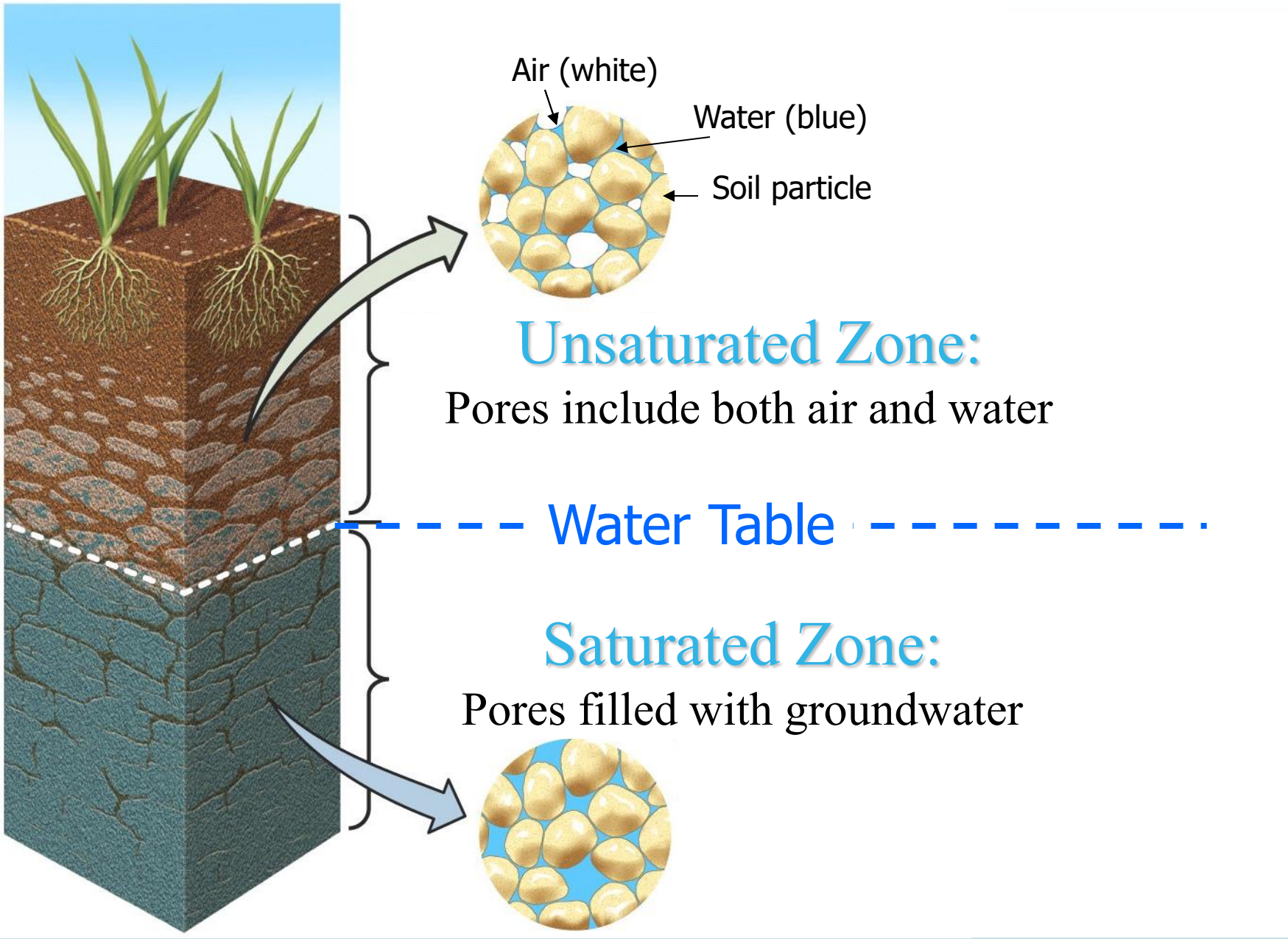
Distribution of Earth's Water



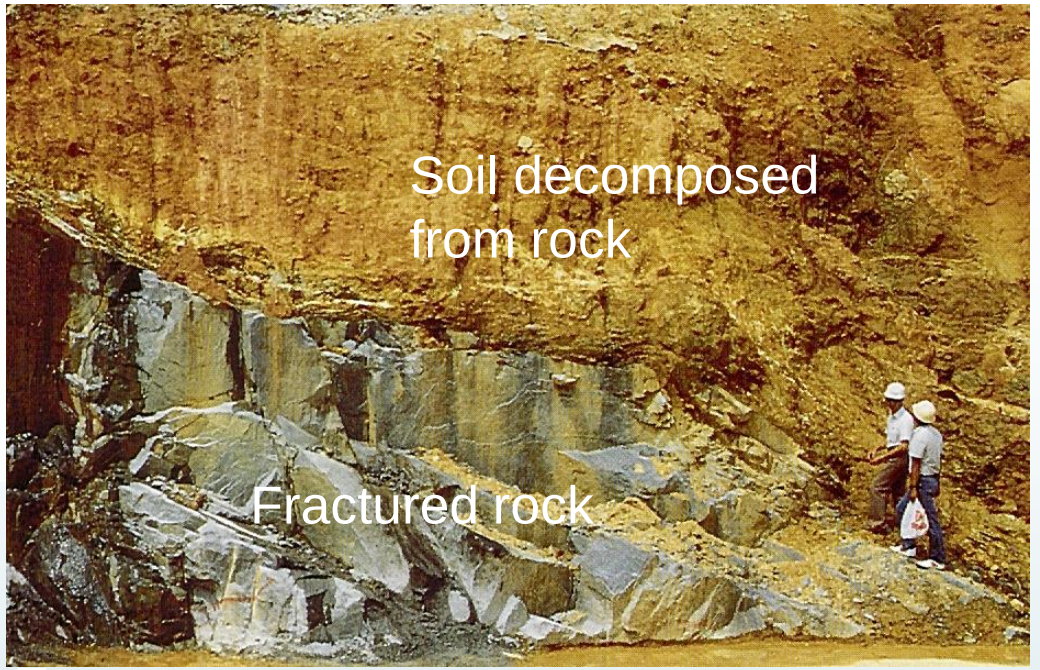
Available Water in the World

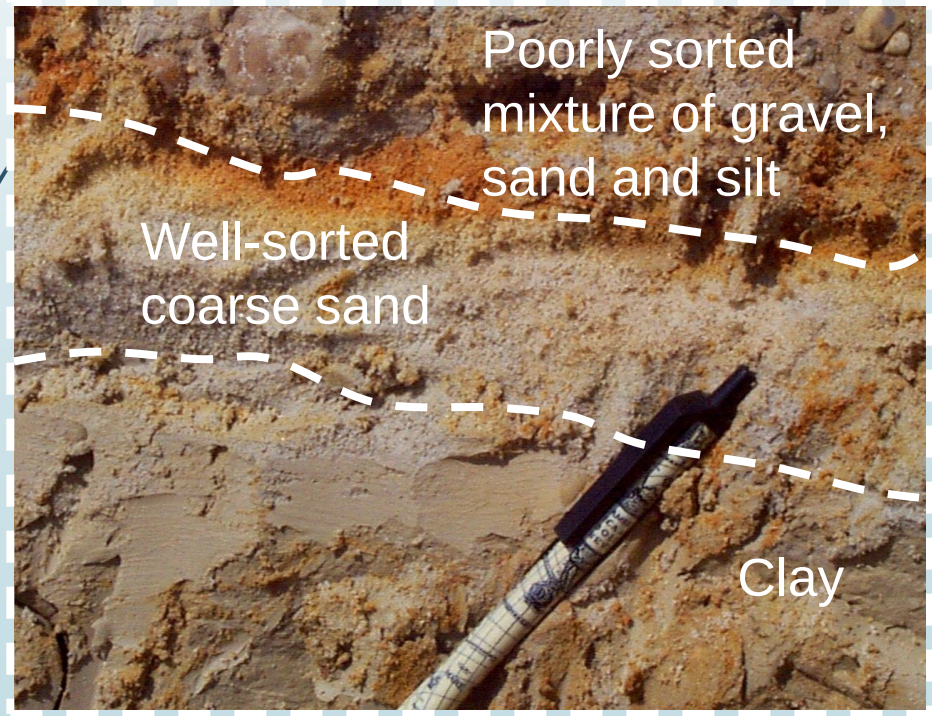
If all of the earth's water could fit into a two-litre bottle, the fresh water we could use would be equal to half of one teaspoon. This is about 1% of the total.

Source: unknown


Air (white)
Water (blue)
Soil particle
Unsaturated Zone:
Pores include both air and water
Water Table
Saturated Zone:
Pores filled with groundwater

Groundwater (GW) is located in soil pore spaces or fractures of geologic formations.



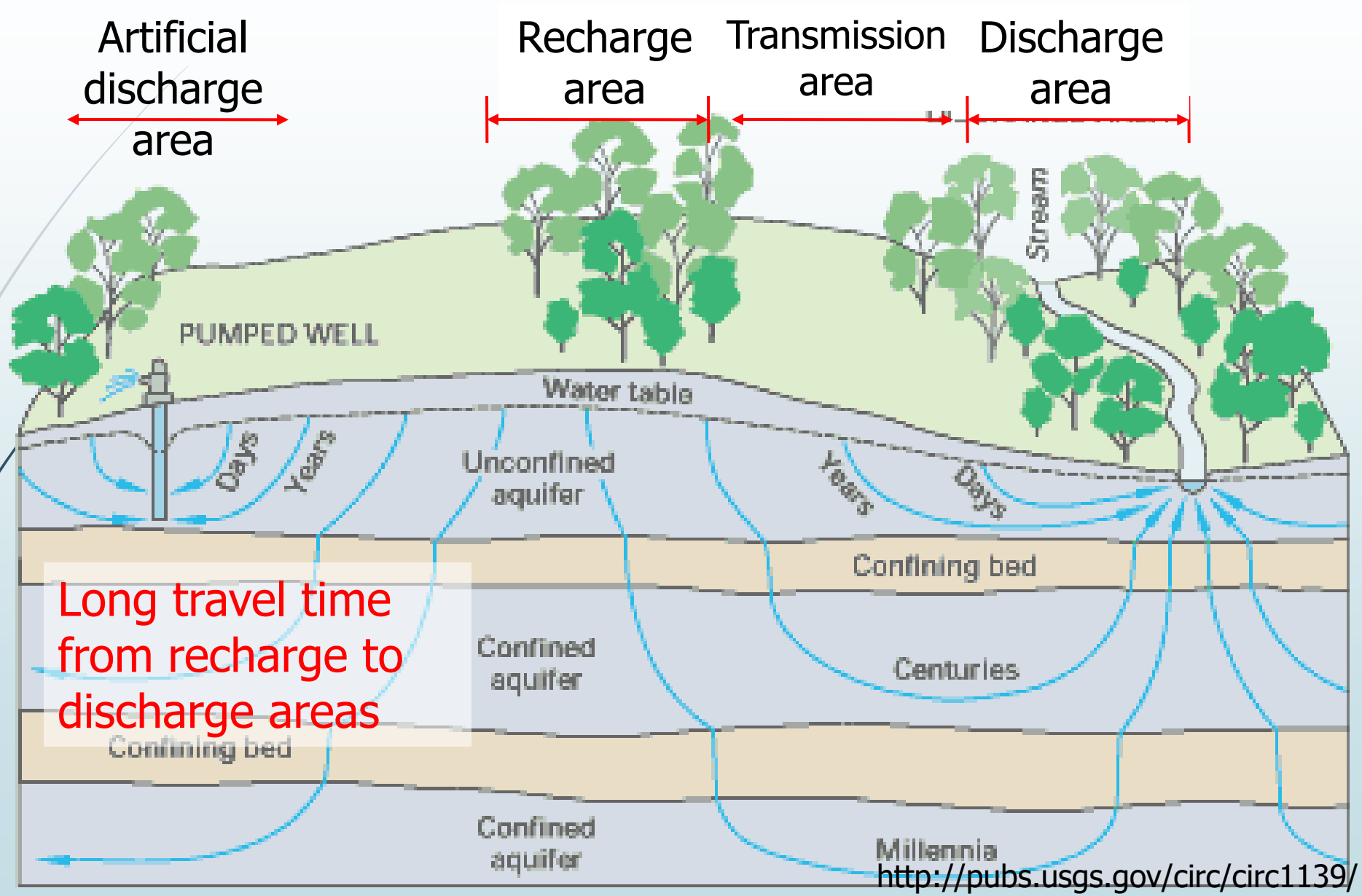


"Swiss Cheese"
Limestone bedrock from the Edwards Aquifer, a karst formation, is extremely porous and provides very fast movement of ground water.

From Groundwater Management District Associations News

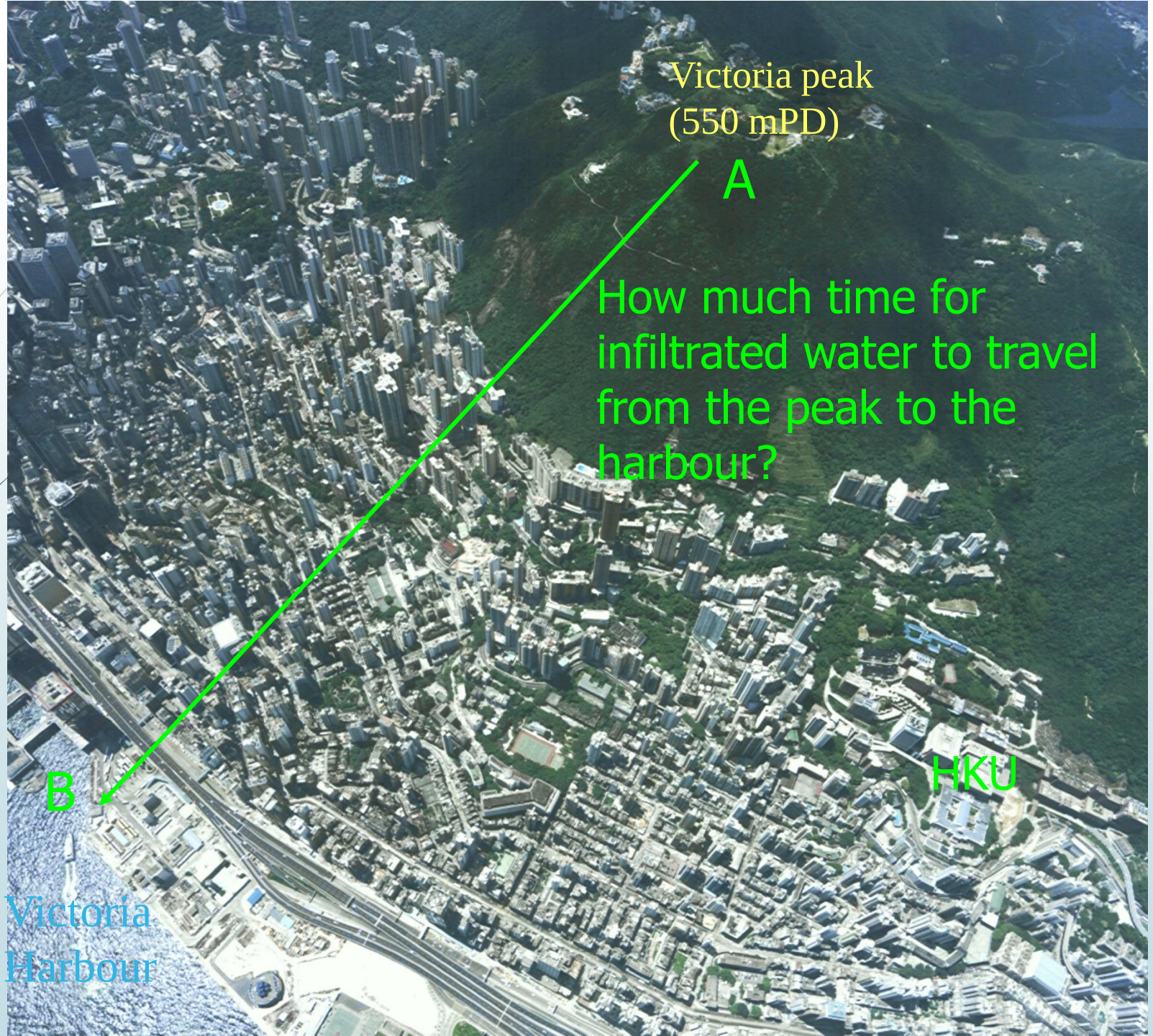
- Aquifers (含水层) are water-bearing permeable geological formations from which GW can be usefully extracted using a well
- Hydrogeology（水文地质）(sometimes called Groundwater hydrology，地下水水文学) is the science dealing with groundwater.

Groundwater movement: How fast?



Long travel time from recharge to discharge areas

http://pubs.usgs.gov/circ/circ1139/


Victoria peak
(550 mPD)
A
How much time for infiltrated water to travel from the peak to the harbour?
B
HKU
Victoria Harbour

Geological section from Peak to Harbour

Darcy's Law (达西定律):

Velocity (V)=Hydraulic Conductivity (K) x hydraulic gradient (I) /porosity (n)

=0.01 m/d x （500/1000） /0.01

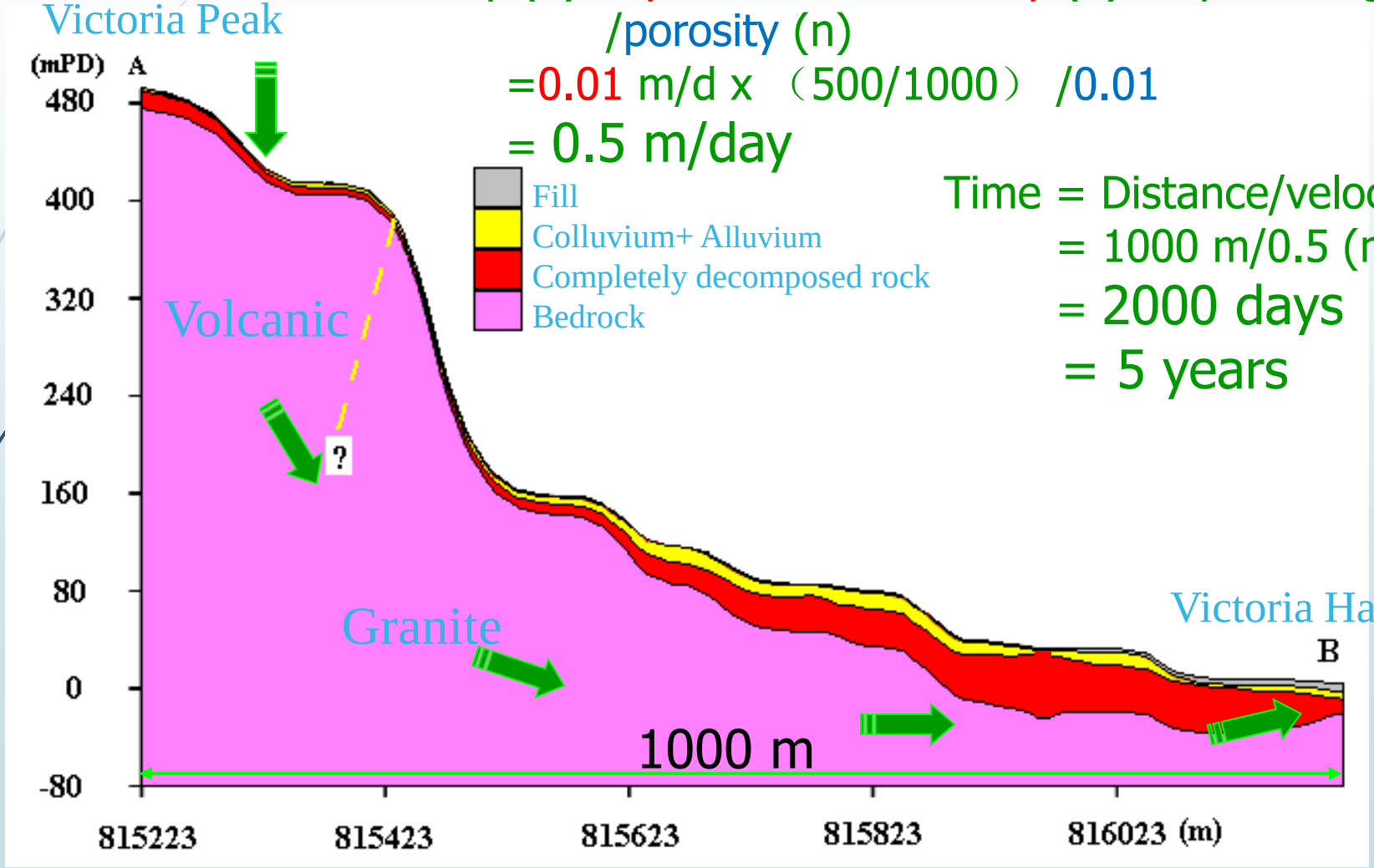
= 0.5 m/day

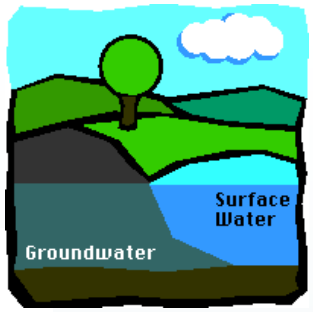
Time = Distance/velocity

= 1000 m/0.5 (m/d)

= 2000 days

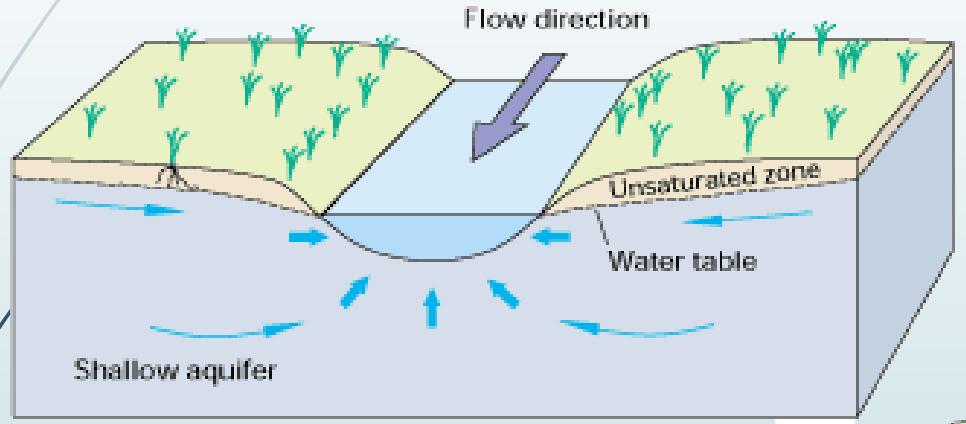
= 5 years



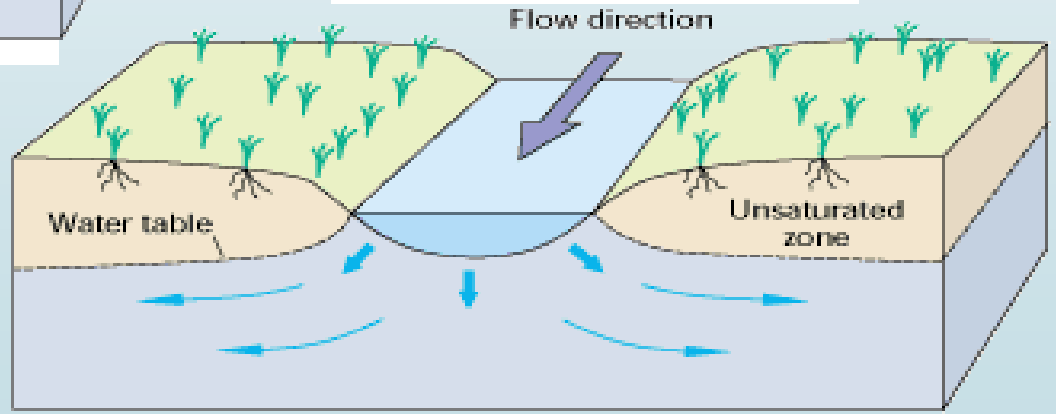


Interaction between groundwater and surface water

Groundwater recharges surface water



Surface water recharges groundwater

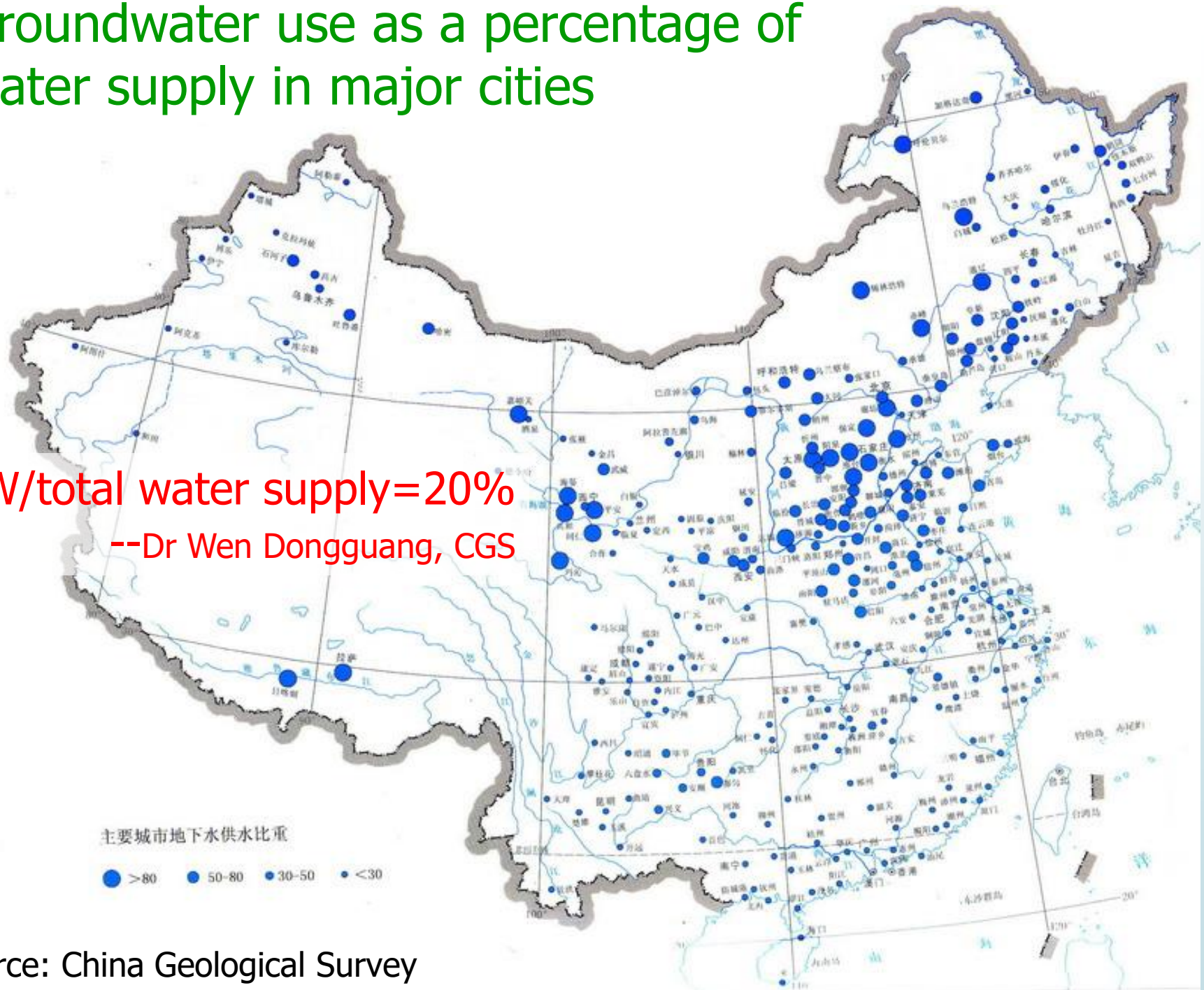


http://pubs.usgs.gov/circ/circ1139/

Groundwater use as a percentage of water supply in major cities

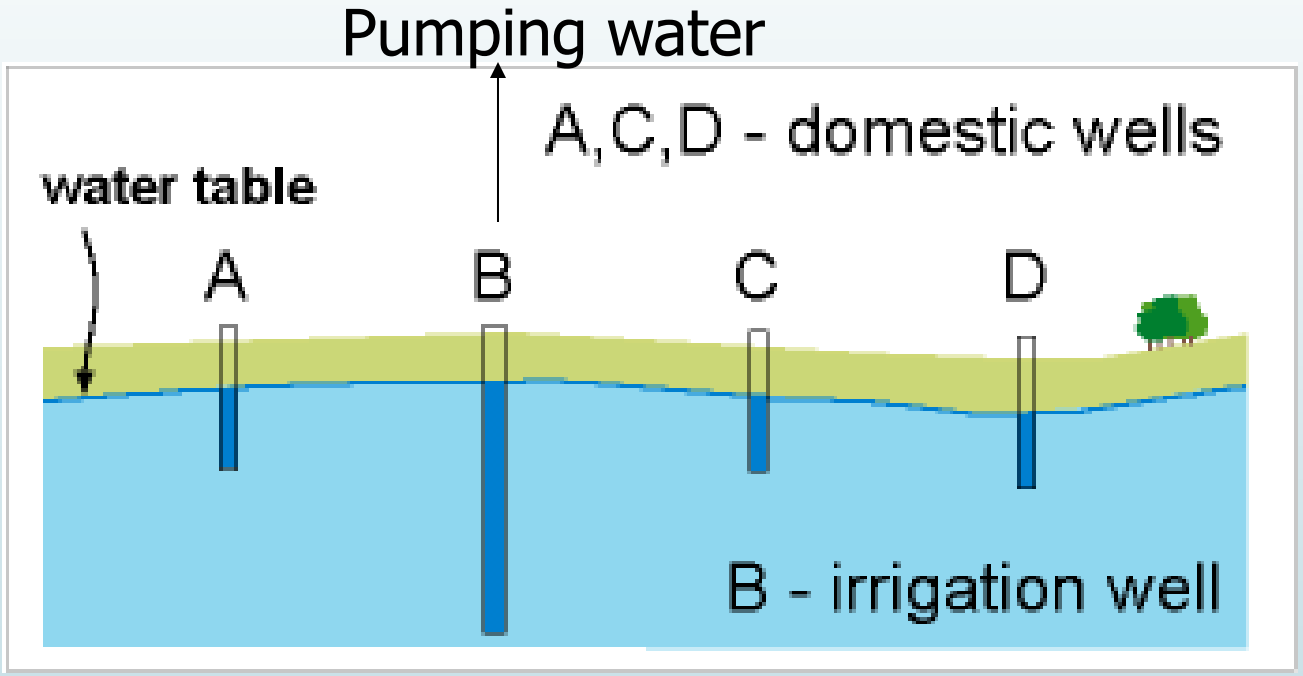
GW/total water supply=20%

--Dr Wen Dongguang, CGS



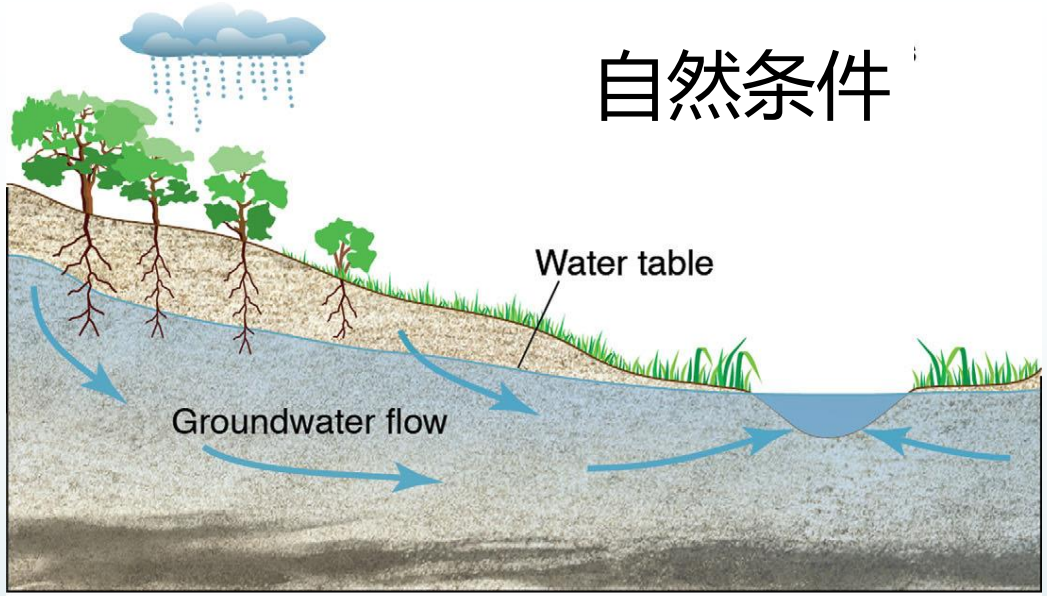
Source: China Geological Survey

Drawdown and cone of depression

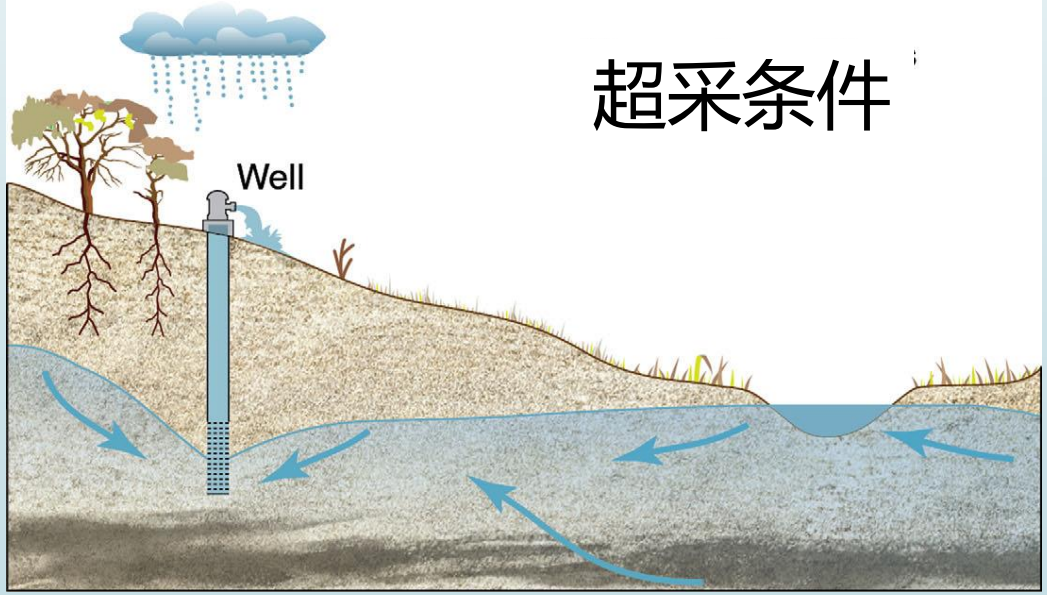


http://www.mhhe.com/earthsci/geology/mcconnell/demo/gwhuman.htm

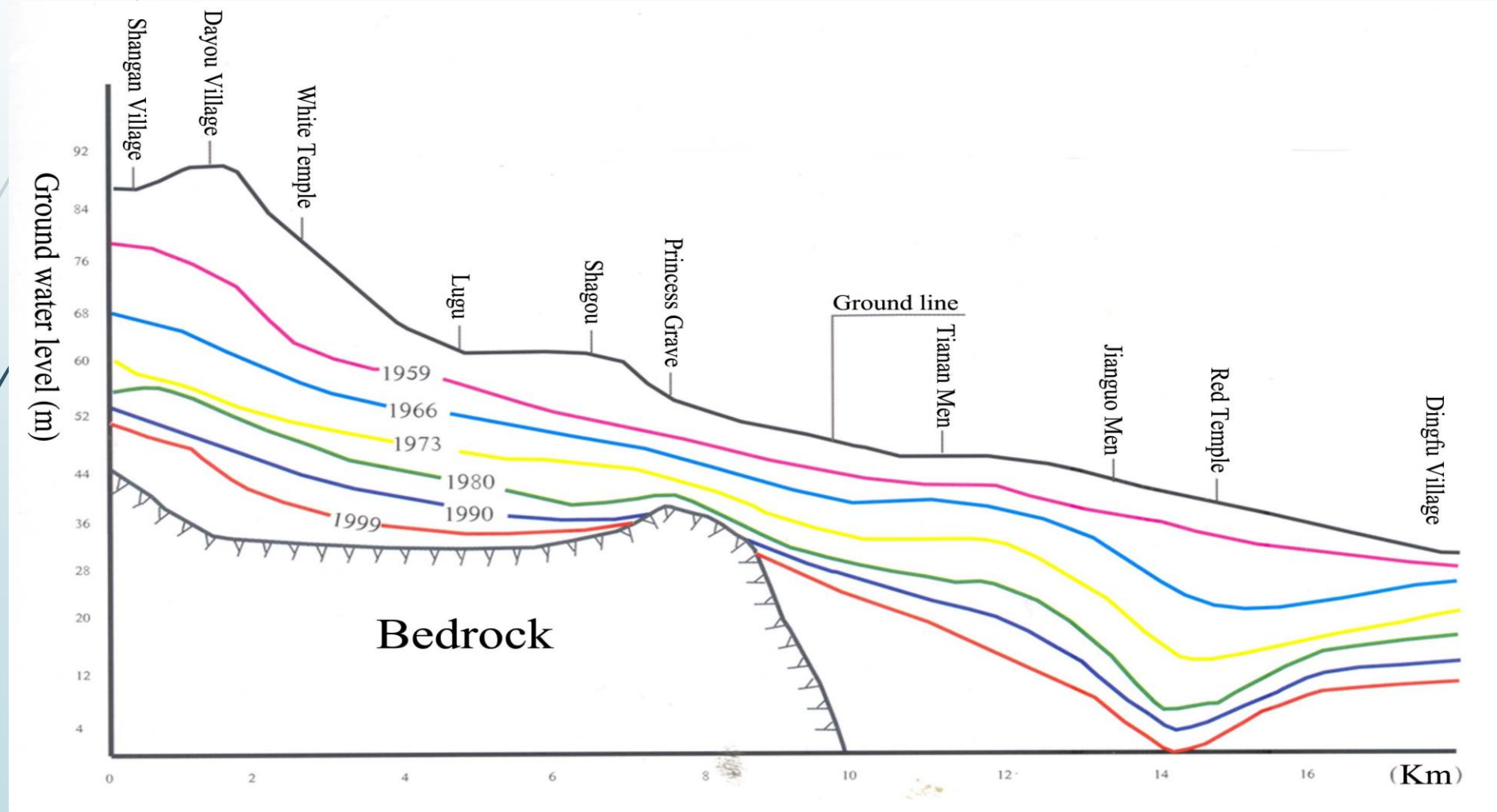
自然条件



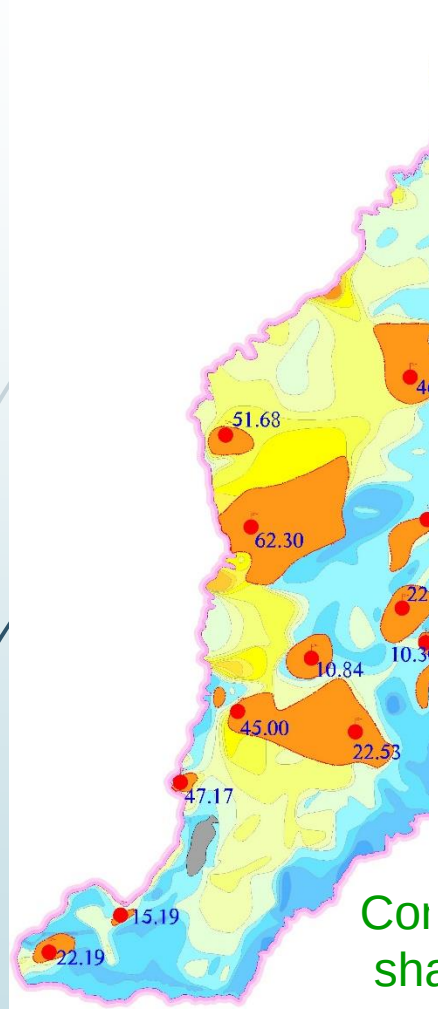
超采条件



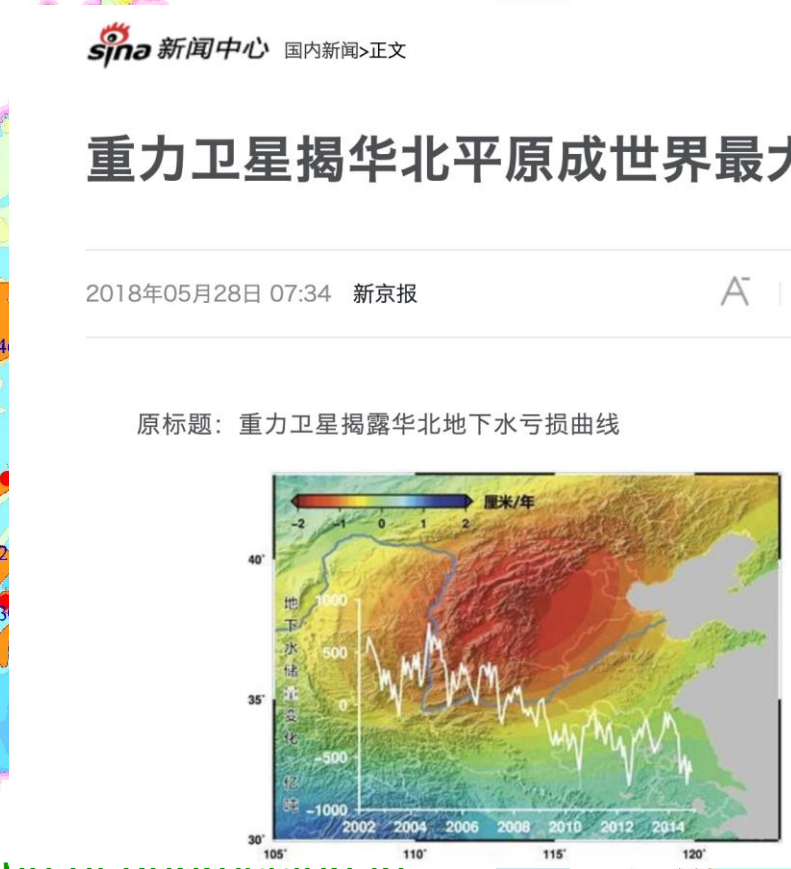
北京近郊多年同期地下水位变化图
Groundwater Variation diagram in Beijing

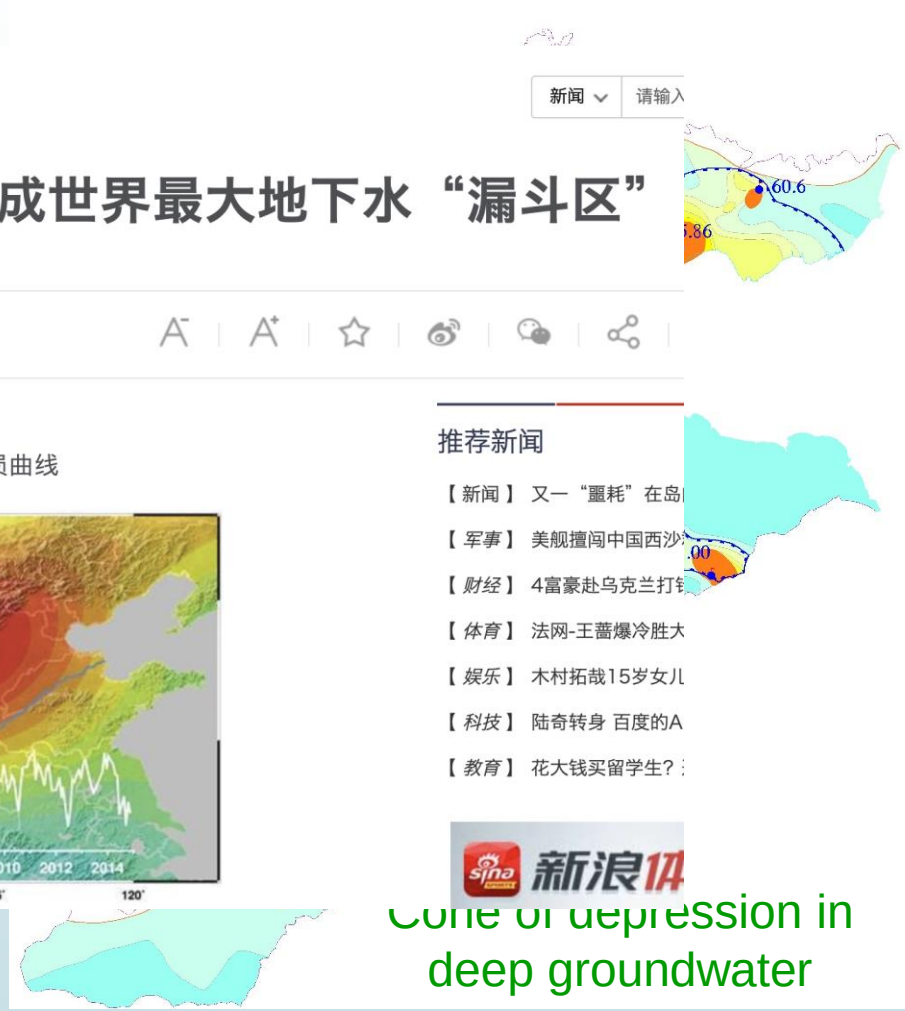


Distribution of the cones of depression in the north China Plain



Cone of depression in shallow groundwater





Cone of depression in deep groundwater

Source: http://www.china.org.cn/chinese/zhuanti/hjgb/1090829.htm

地下水漏斗带来的...

华北平原地面沉降严重 下沉地表难恢复(图)

2011年11月14日10:02　中国广播网　我要评论(0)　字号： T | T

干涸的华北第一大高原内陆湖泊安固里淖。由于连年大旱以及当地人在生产生活中严重超采地下水，使得安固里淖变成一片寸草不生的盐碱地。图/ 新华

Groundwater Contamination

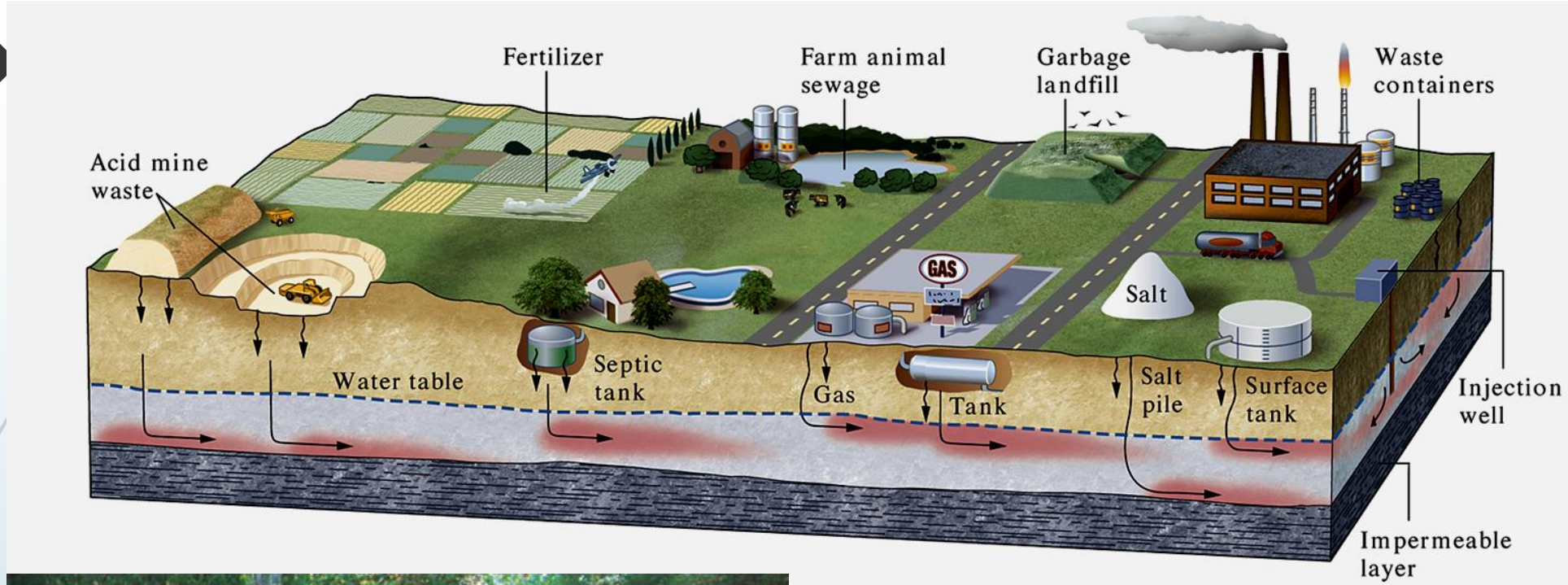
Solute – matter dissolved in fluid

GW contamination (pollution) is defined as undesirable change in GW quality.

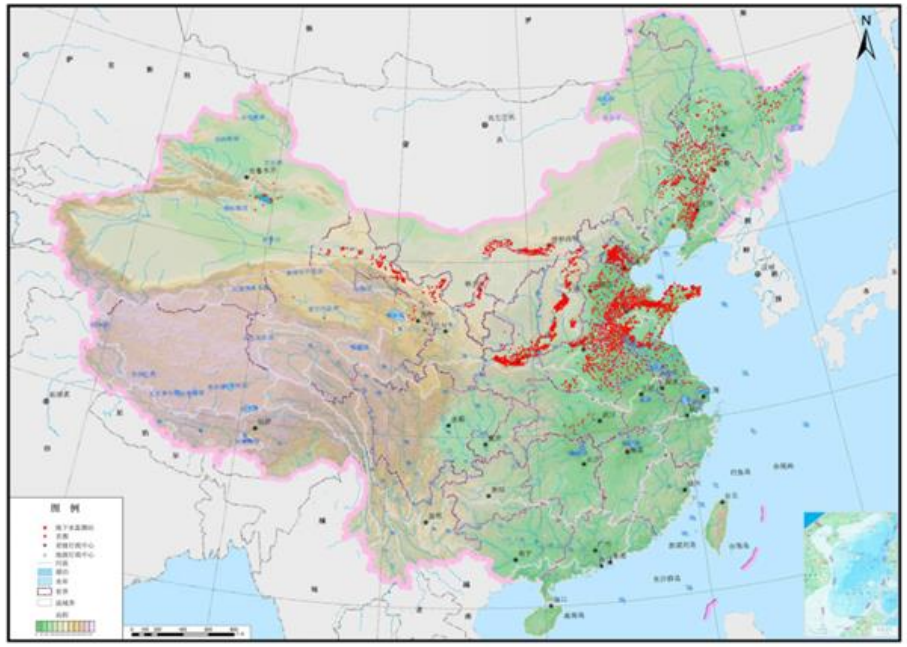
Most concern over GW contamination has centered on pollution associated with human activities. There are natural sources of GW pollution too.

Sites about groundwater pollution:
http://groundwater.ucdavis.edu/Publications/Harter_FWQFS_8084.pdf
http://www.lenntech.com/groundwater/pollution-sources.htm
http://en.wikipedia.org/wiki/Groundwater

GW contamination sources



Groundwater Pollution—MWR Report in April 2016

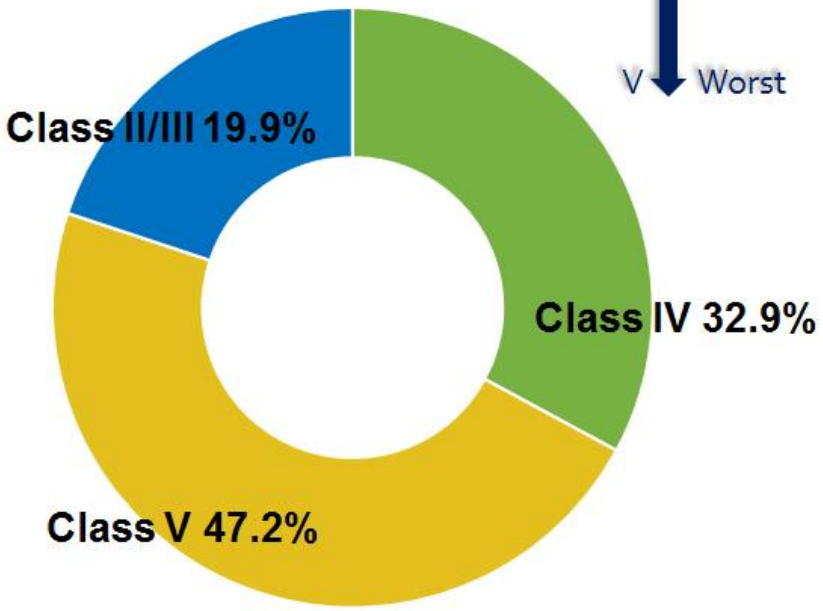


Distribution of groundwater monitoring wells

China's Water Quality Classification Scheme

I Best

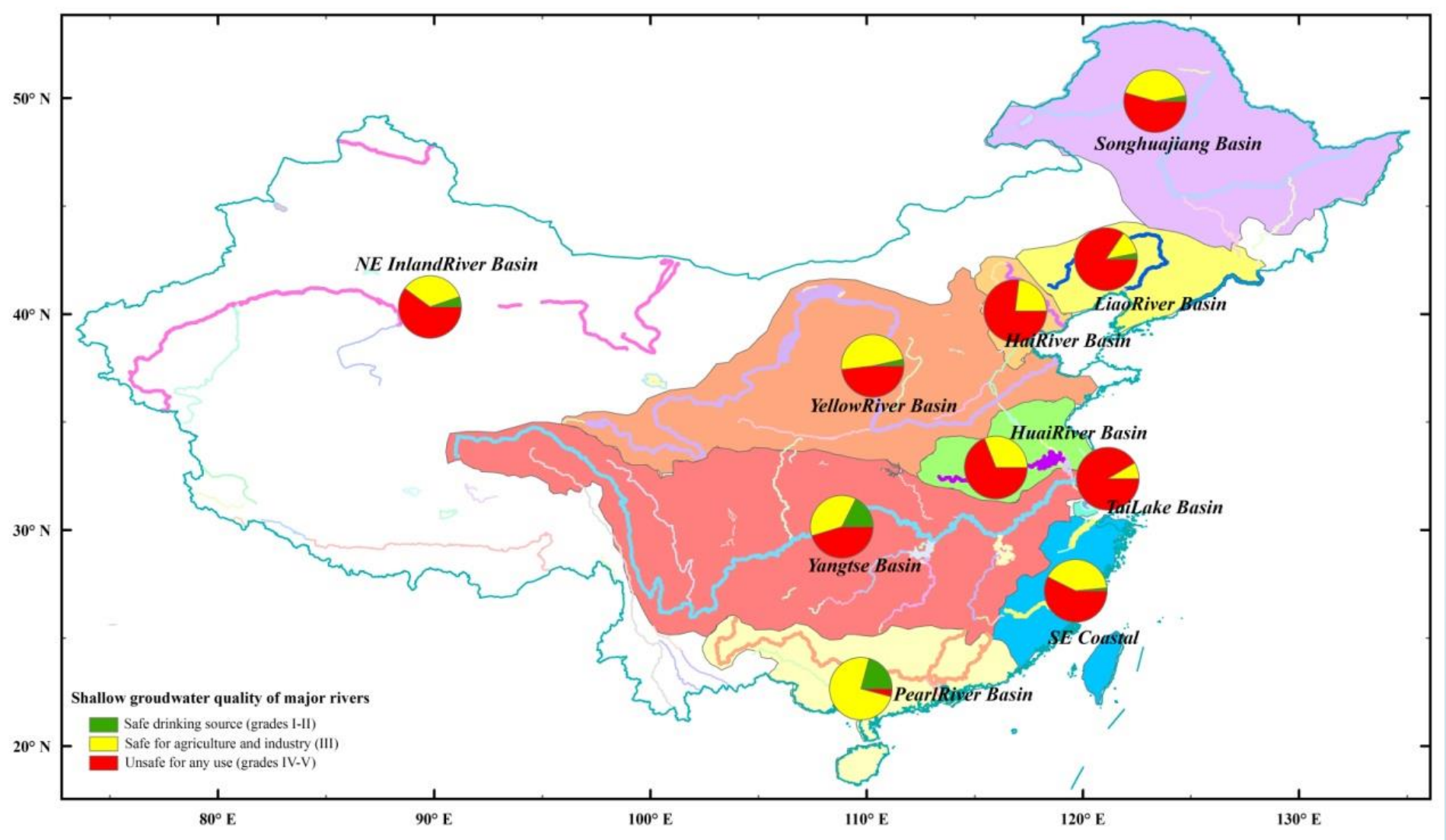
V Worst



Class IV+V: >80%

2022中国环境状况公报：超过61%地下水监测点水质较差-极差。

Groundwater Quality in Major River Basins of China

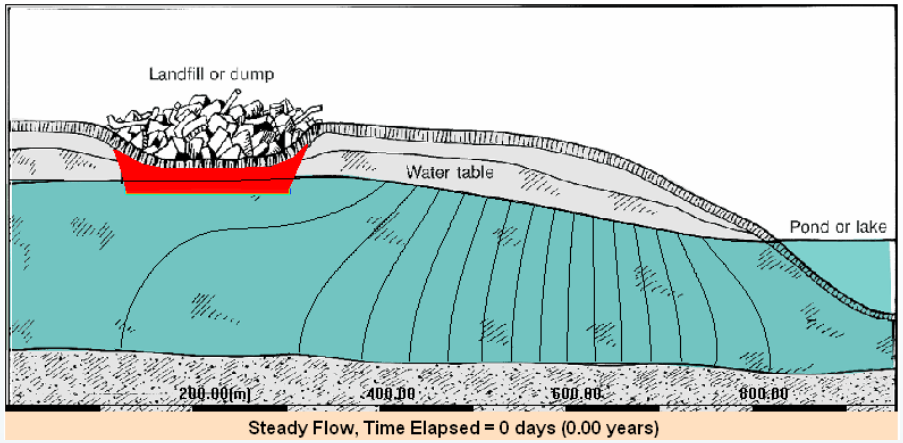


I-II (safe for drinking) , III (for other uses) , IV-V (poor quality, red)

Sources of GW Pollution in China

- Landfills
- Gas stations
- Sewage
- Fertilizer and pesticides
- Septic tanks
- Mining activities
- Naturally occurring factors

Landfills

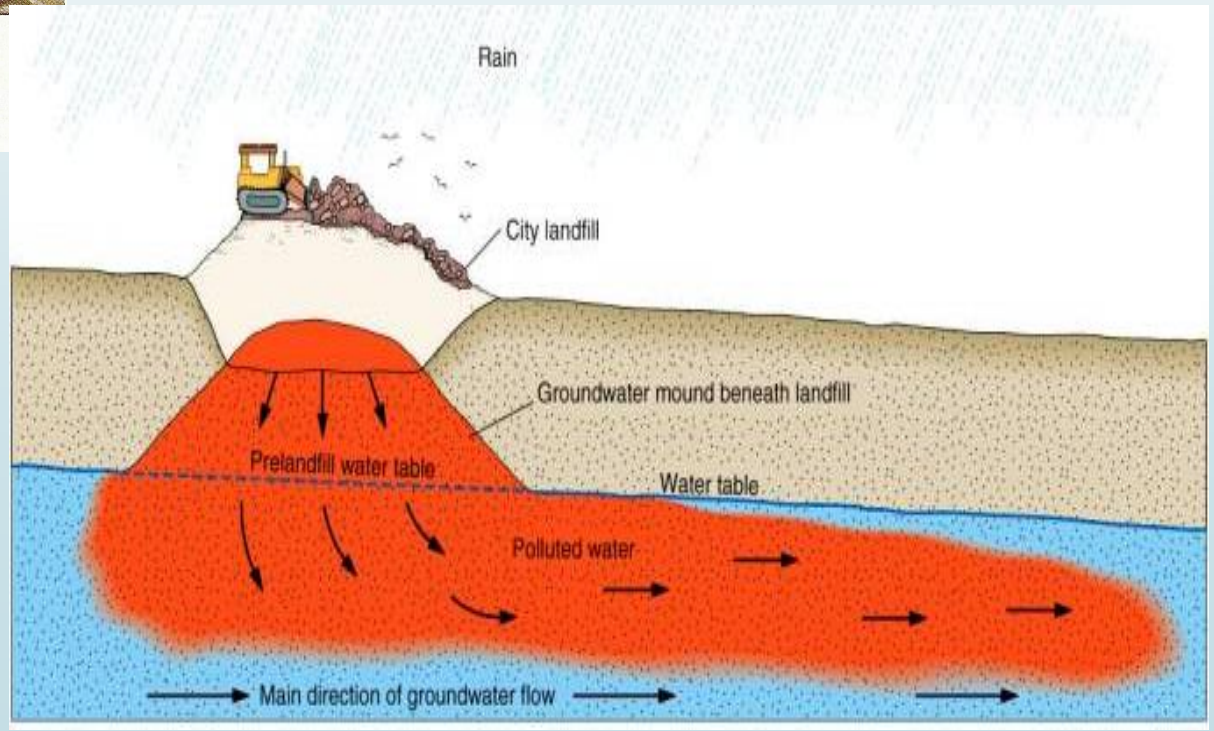


- ~70% landfills are just traditional dumps without proper design.
- Garbage used to be dumped in “suburb” areas, which are now inside city centers as cities expand.
- 2/3 of 668 cities in China are surrounded by rings of landfills

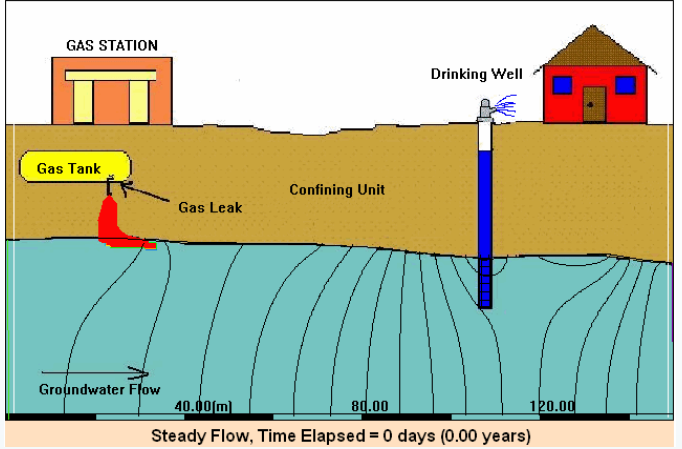
There are 4000 landfills with area > 50 m^2 beyond the 2nd ring of Beijing.

Source: 中国地下水污染到了危急时刻
http://www.chinaeforum.com/ShowPost.aspx?PostID=57315
中国多数城市陷入垃圾围城之窘 处理现状很不乐观
http://news.xinhuanet.com/environment/2006-08/18/content_4977934.htm

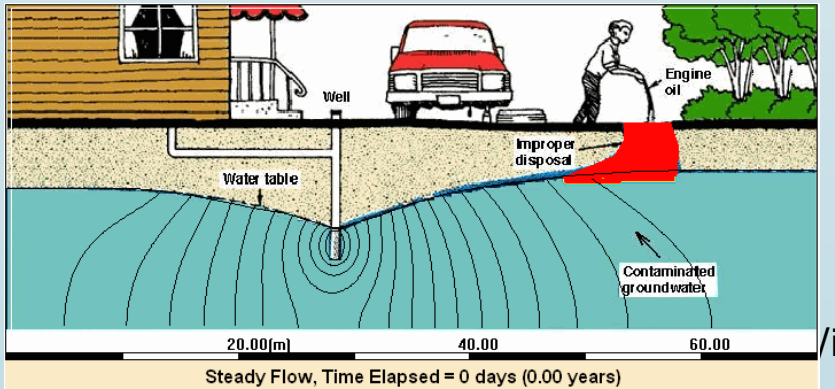
500万吨垃圾包围北京



Gas stations



- China has built 100,000 gas stations. If properly designed/constructed, they should be OK within 20 years.
- However, evidence of leakage has been observed in Beijing, Xian, Chengdu and Tianjin.
- (Overall, 40% of gas stations in USA are leaky. 100% of the stations built before 1970s are leaky)



Source: 我国加油站石油渗漏污染问题亟需引起重视 /info/2005/12/31/a53582da73d41dd4eb55cb5902374ac3.html

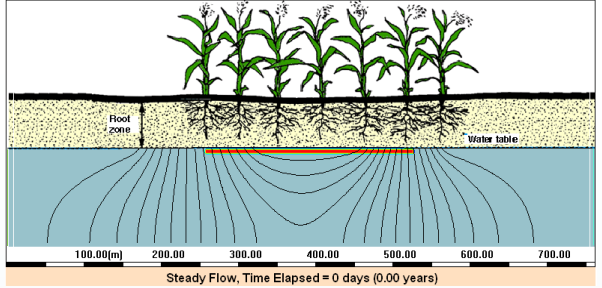
Wastewater

- Every year Beijing produces 900 million tones of waste water. Only 10% is treated. All the 83 rivers in Beijing are polluted. 54 of them are polluted seriously.
- Every year ~33 million tons of waste water is discharged into aquifers.

Source:

http://210.72.100.6/%E5%90%84%E5%9C%B0%E5%B8%82%E8%87%AA%E7%84%B6%E7%81%BE%E5%AE%B3/wr.htm
http://www.stephenvoss.com/stories/ChinaRiverPollution/photo27.html

Fertilizers & pesticides

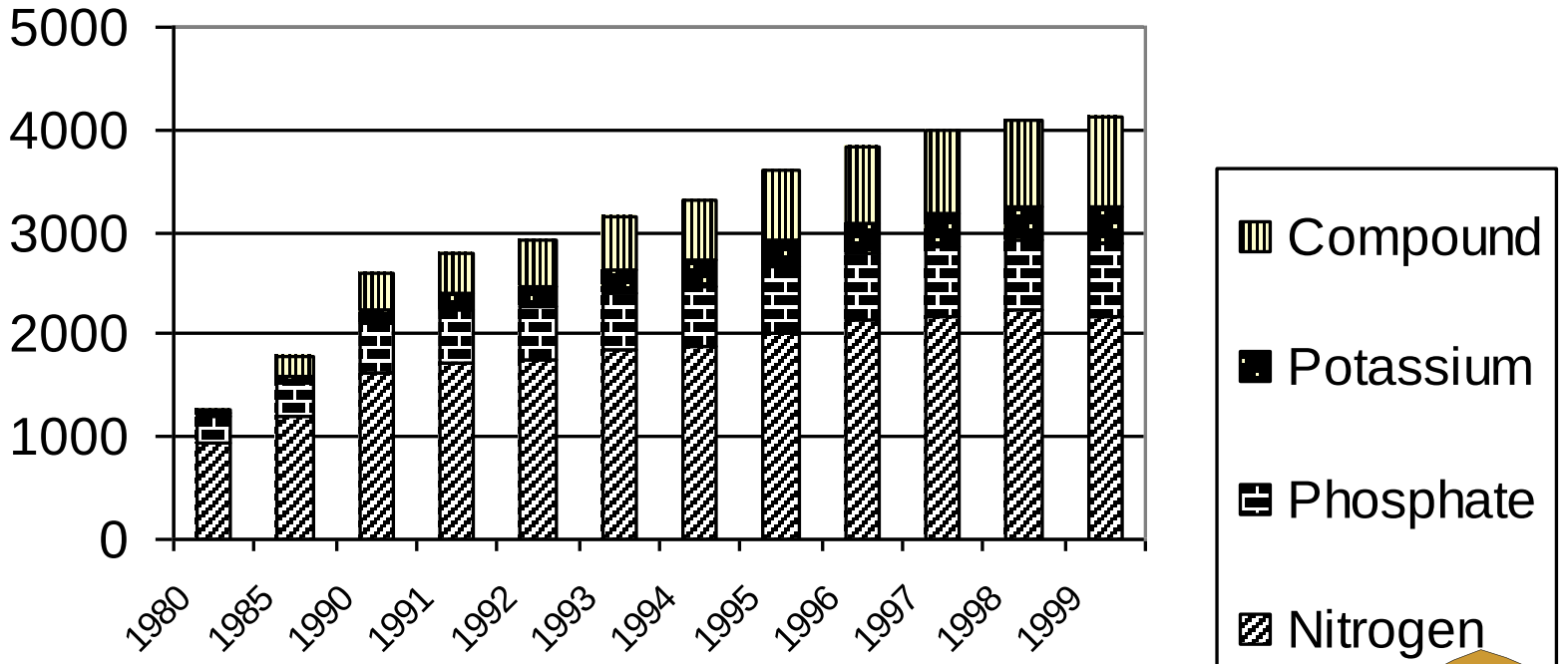


- Farmers use 41.24 m tons of chemical fertilizers/yr, for an average > 400 kg/hectare of farmland, far above the safe limit of 225 kg/per hectare.
- From 1985 to 2000, 9 m tons/yr of nitrogen fertilizers washed away and turned into **pollutants**.
- Overuse of pesticides has destroyed the ecological balance and biodiversity in cropland. Pesticide residue deposited in farm plants may poison humans and livestock.
- China reported a use of more than 1.2 m tons/yr of pesticides, which has contaminated 7% of its arable land.

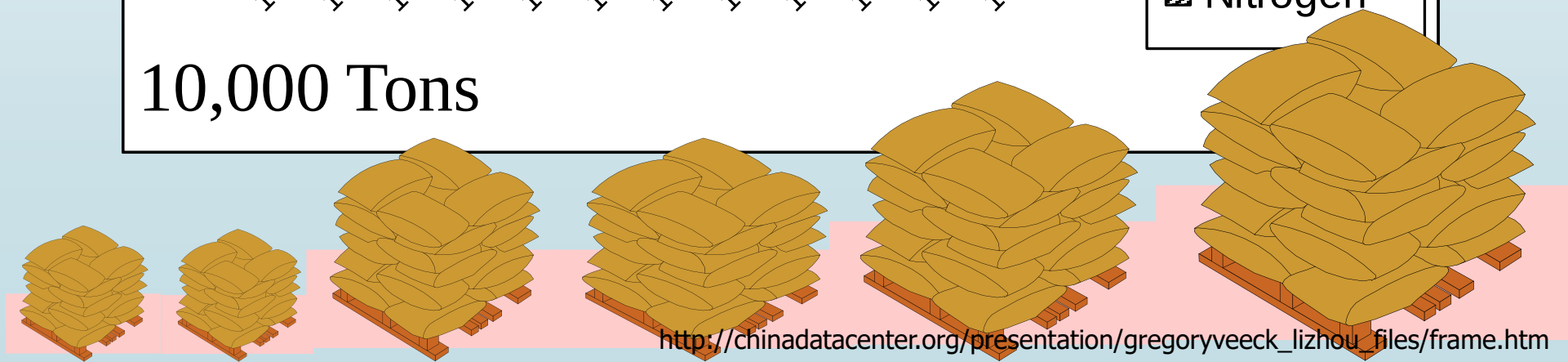
人民网 English
People's Daily Online

Source: China's agriculture causing environmental deterioration
http://english.people.com.cn/200607/05/eng20060705_280053.html

Chemical Fertilizer Consumption: Selected Years 1980 - 1999



10,000 Tons



http://chinadatacenter.org/presentation/gregoryveeck_lizhou_files/frame.htm

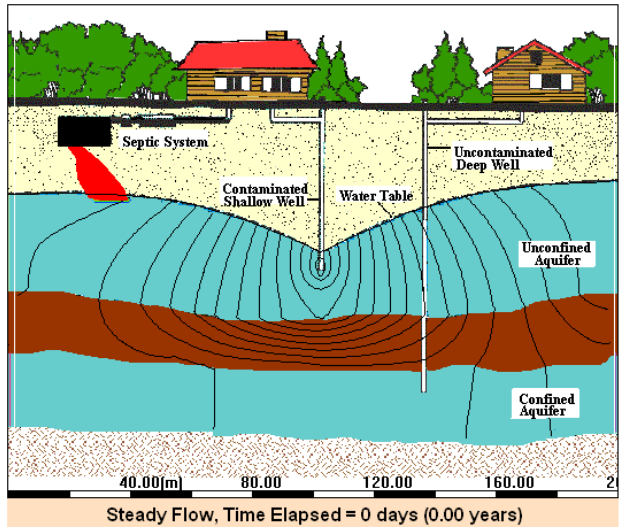
Septic tanks (化糞池)

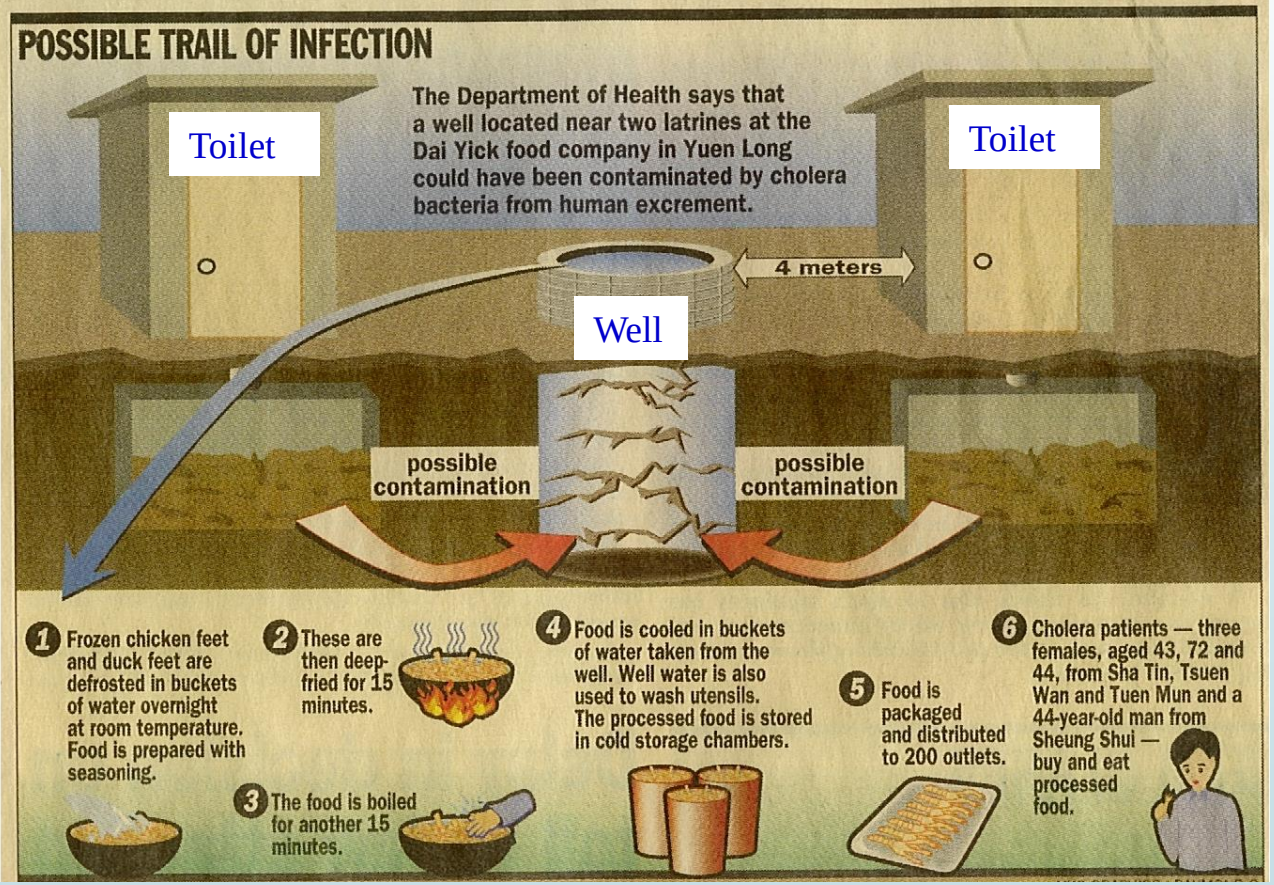
Cholera alert at 200 food outlets

By Ella Lee and Patsy Moy

HEALTH authorities were last night contacting 200 food outlets where she was in stable condition.

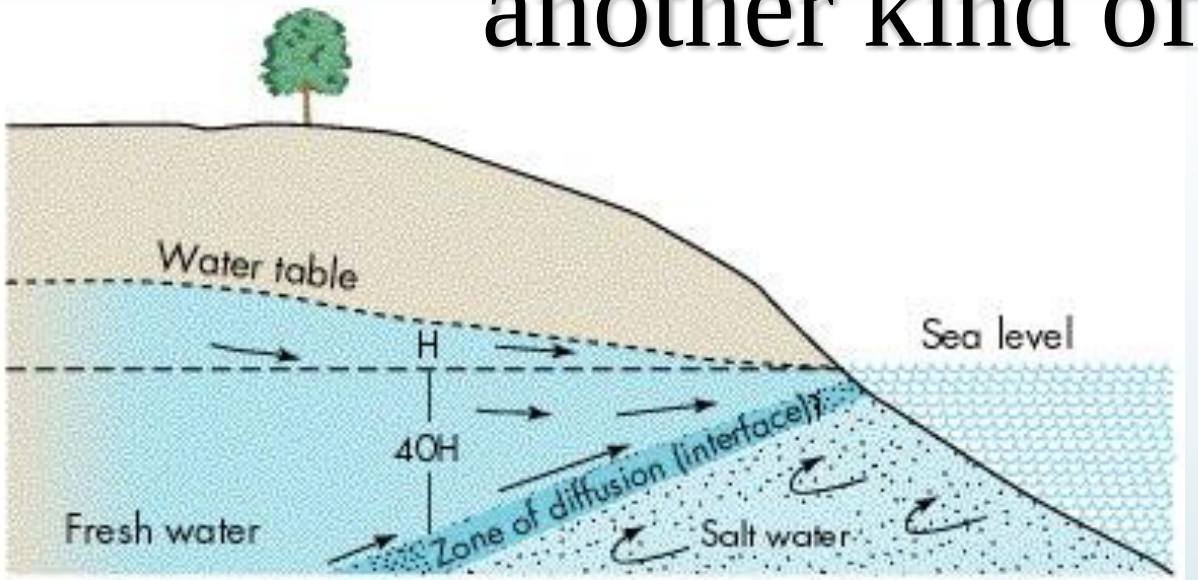
A woman, 81, was discharged yesterday while a 76-year-old was still in critical condition at Tuen Mun

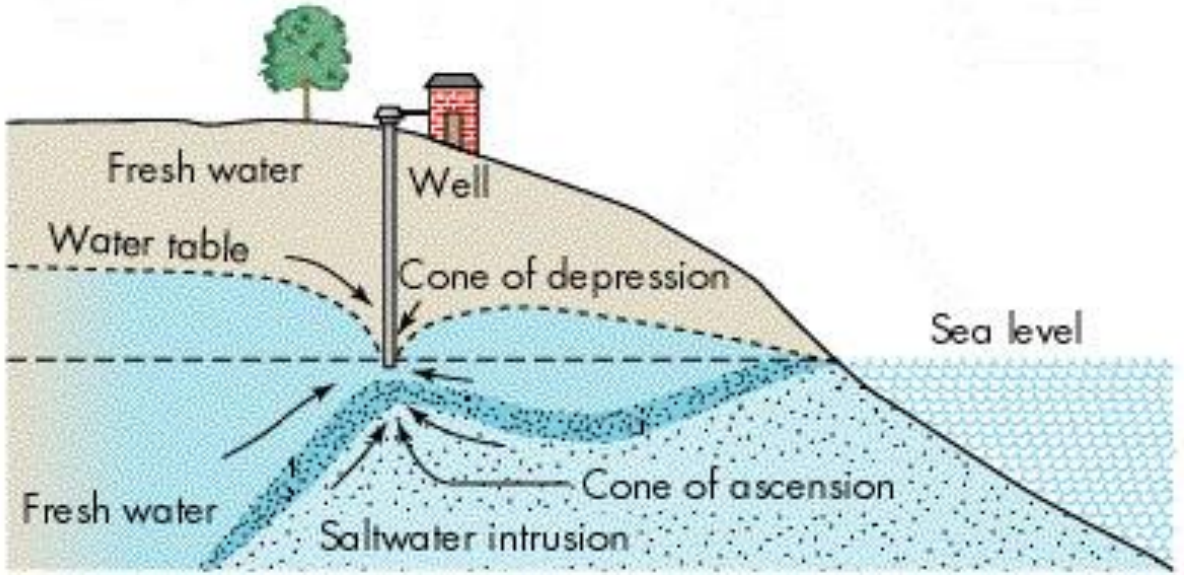




From Standard 15 May, 1997

Seawater intrusion: another kind of GW pollution





Extensive pumping in coastal areas can cause salt water to rise into wells, forming a cone of ascension

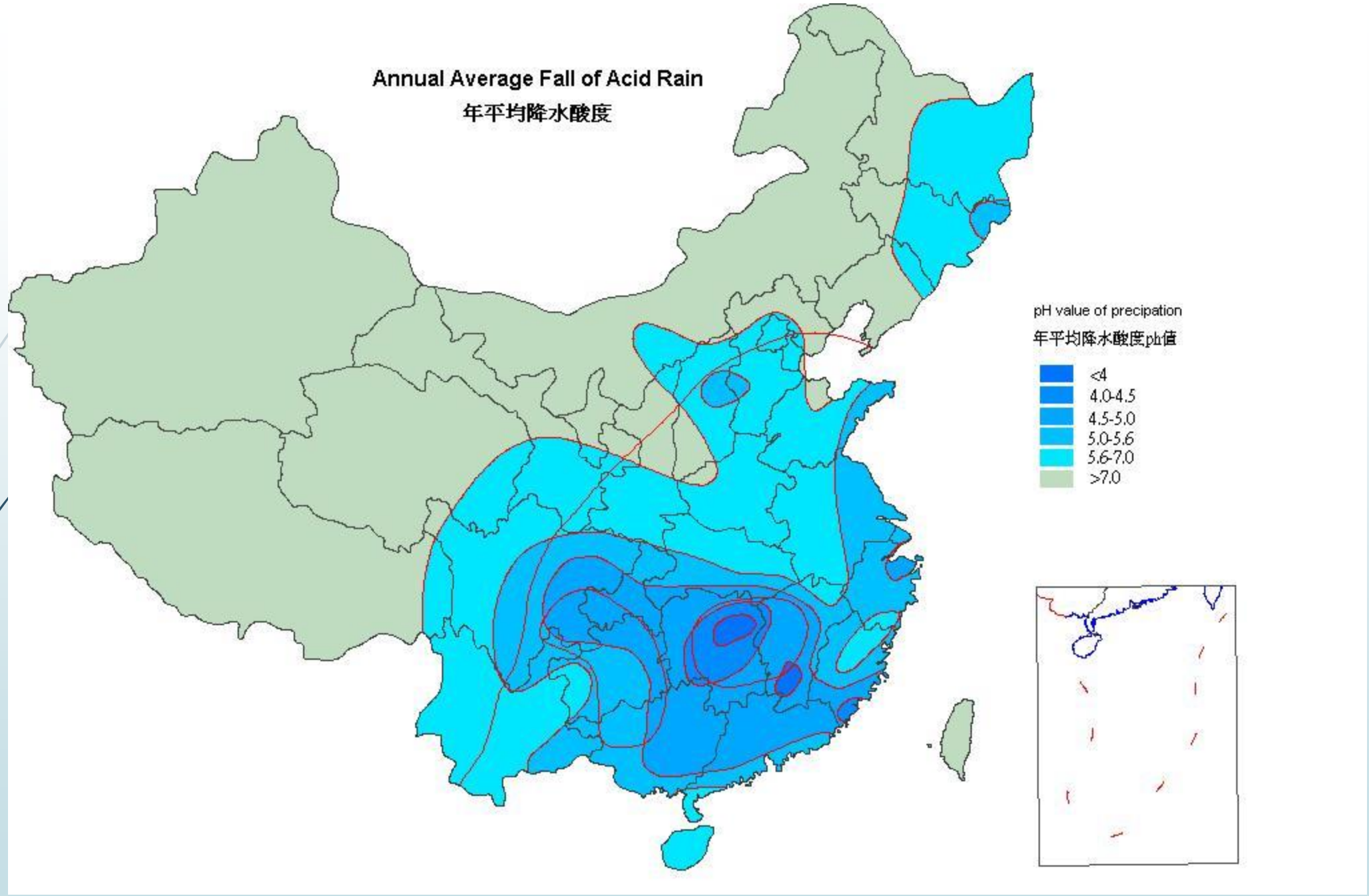
Coastal city Shenzhen worries over seawater intrusion

- SHENZHEN: The coastal city is likely to be threatened by major seawater intrusion unless urgent measures are taken to curb excessive groundwater use, a survey shows.

- The city is suffering lowering levels of groundwater, which means it faces becoming contaminated with seawater coming in to replace it.

THE NATIONAL ENGLISH LANGUAGE NEWSPAPER
CHINA DAILY

http://www.chinadaily.com.cn/english/doc/2005-12/08/content_501417.htm



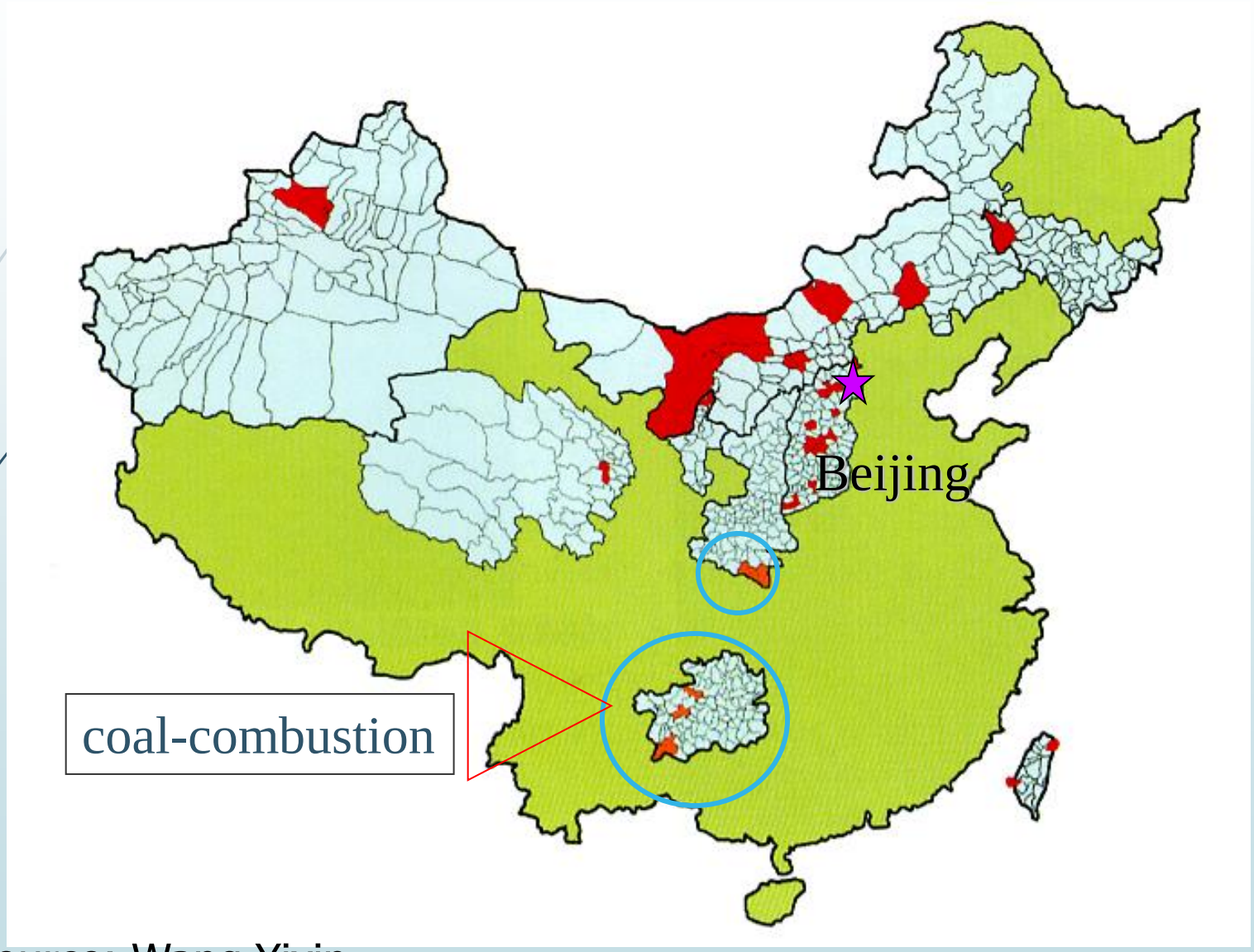
http://chinadatacenter.org/chinageography/MapDisplay.asp?FigureNumber=2.4b

Strip Coal Mining in Ordos

GW Pollution by natural factors

- Arsenic groundwater
- High fluoride groundwater (>1.0 mg L)
- Ammonium-rich groundwater

Regions of arsenic poisoning in China.



Intake of high arsenic water

Regions under threat

Source: Wang Yixin

Health and environmental effect

- Disease and death
- Ecology & Environment

Some "cancer villages" in China

Village	Population	Death	When?
广东翁源韶关市翁源县上坝村	3000	250	Since 1987
河南黄孟营村	2400	114	Since 1992
湖北襄樊市翟湾村	3000	100	Within 2-3 yrs
江苏无锡市广丰村	200	20	Within ~3 yrs
浙江萧山钨里村	2000	3-8/yr	
江西乐安河沿岸 (>10 cancer villages)			Since 1980

Source: 环境污染的后果 - - 哭泣的癌症村

http://www.cymedia.com.cn/society/back/7762.html

Endemic Arseniasis

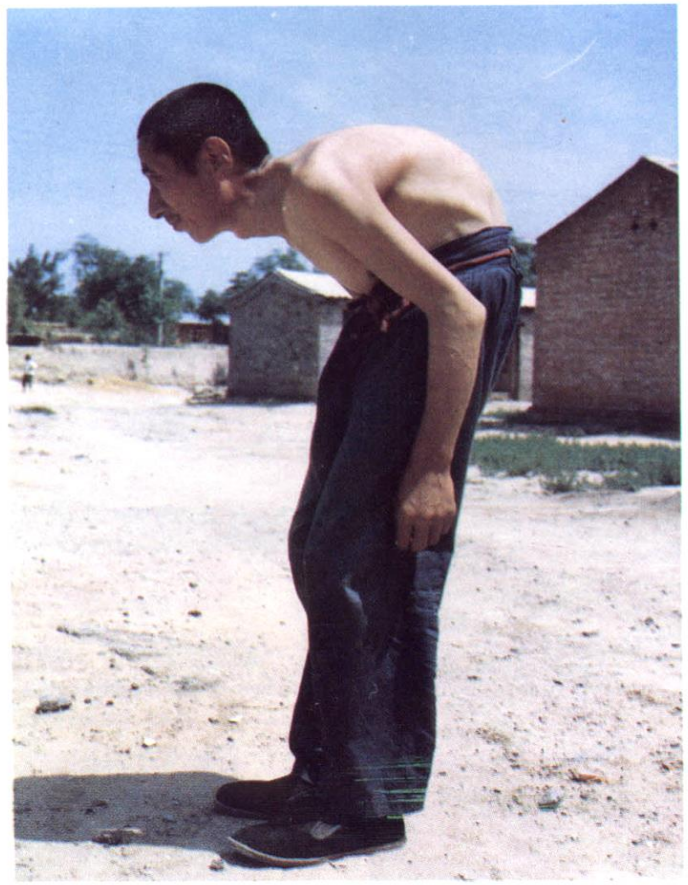
Long term arsenic exposure can lead to skin lesions and keratosis, a hardening of the skin.

Source: http://www.sos-arsenic.net/english/article/index.html

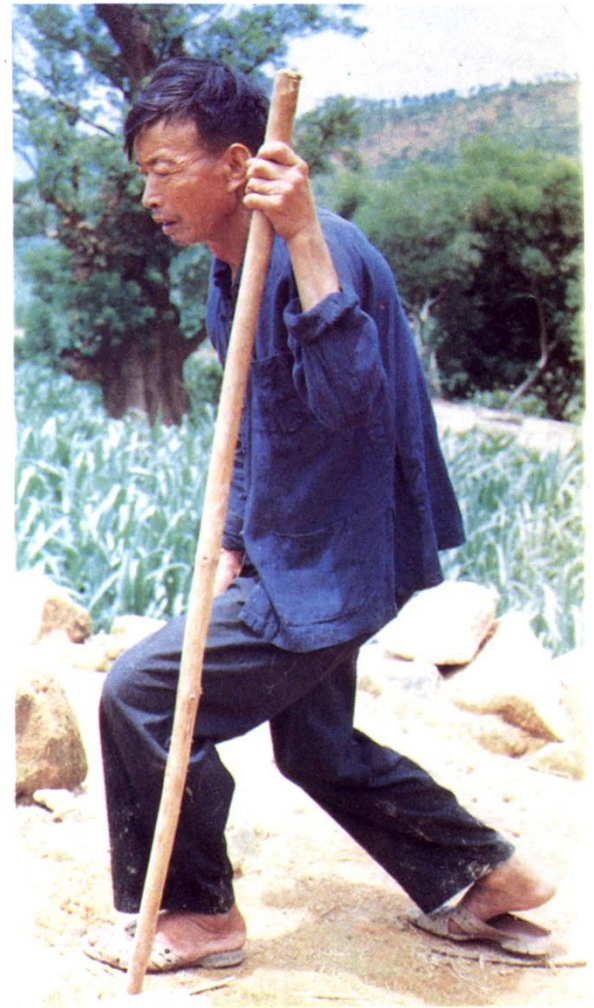
地球化学性疾病(geochemical disease)

氟骨症(Skeletal fluorosis): 变形性骨关节病

严重病例可致矮小畸形、终生残废



氟骨症患者脊柱弯曲畸形 （北京市卫生防疫站供稿）
Kyphosis of vertebral column in skeletal fluorosis patient
(Provided by Health and Antiepidemic Station of Beijing)



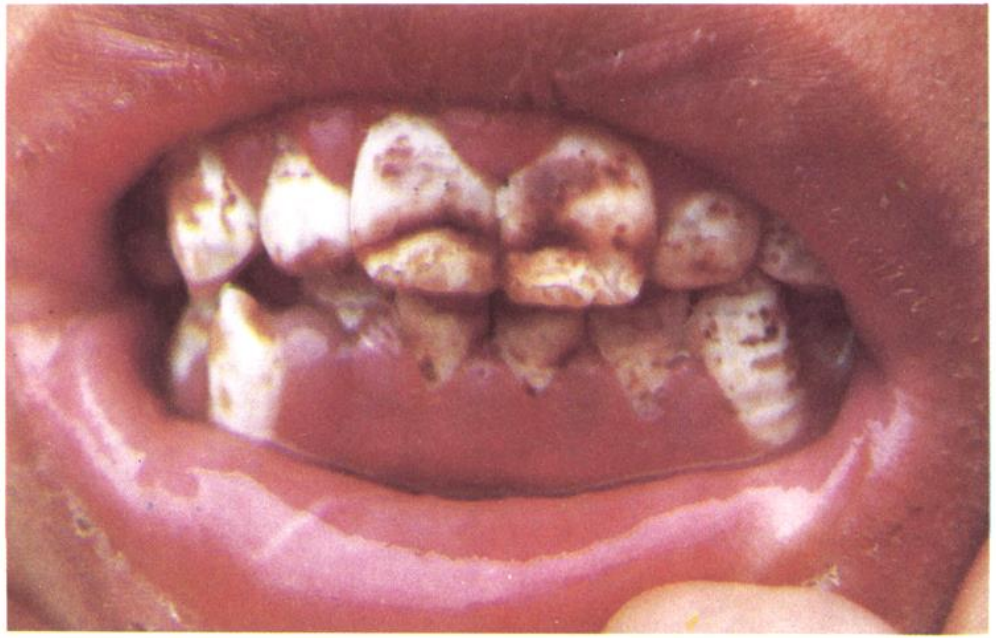
氟骨症患者膝关节功能障碍 （陈兆宇摄）
Dysfunction of knee joint in skeletal fluorosis patient
(Photoed by Chen Zhaoyu).

氟骨症(Skeletal fluorosis)

地球化学性疾病(geochemical disease)

氟斑牙（着色型） （同 上）
Dental fluorosis (Coloured type) (Photoed by Liu Mingda)

氟斑牙 (Dental Fluorosis)



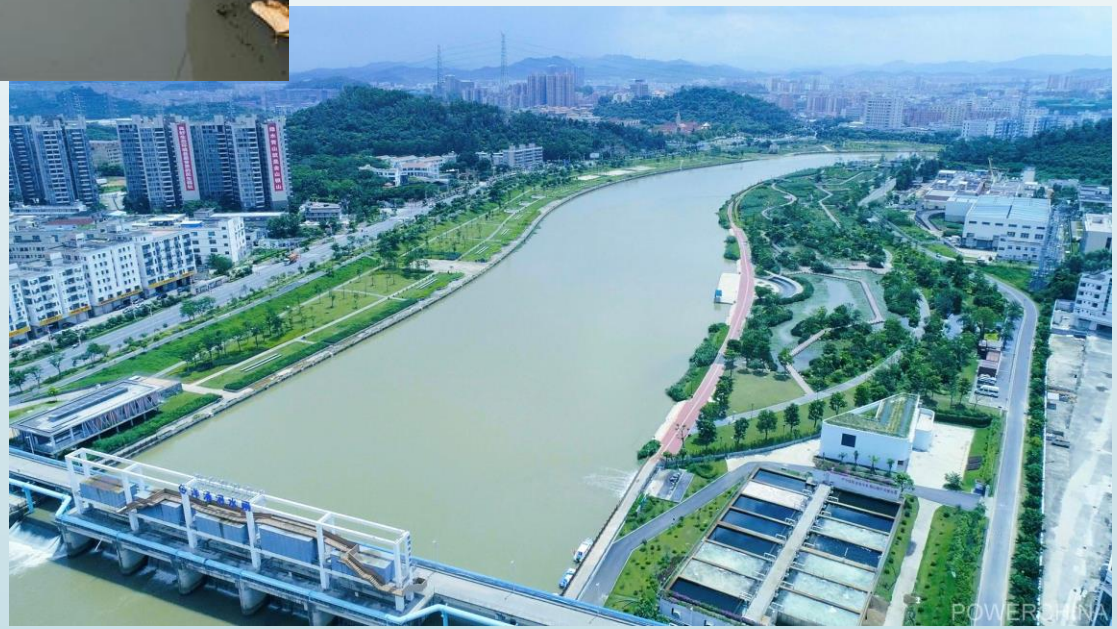
氟斑牙（缺损型）（戴瑞庭摄）
Dental fluorosis (Fragmentary type) (Photoed by Dai Ruiting)

深圳市黑臭水体分布图


N
图例
建成区黑臭水体（36）
黑臭水体（133）
非黑臭水体
深圳河流域
深圳湾流域
茅洲河流域
龙岗河流域
观澜河流域
坪山河流域
珠江口流域
大鹏湾流域
大亚湾流域
东莞市
惠州市
香港特别行政区
0 3 6 12
公里

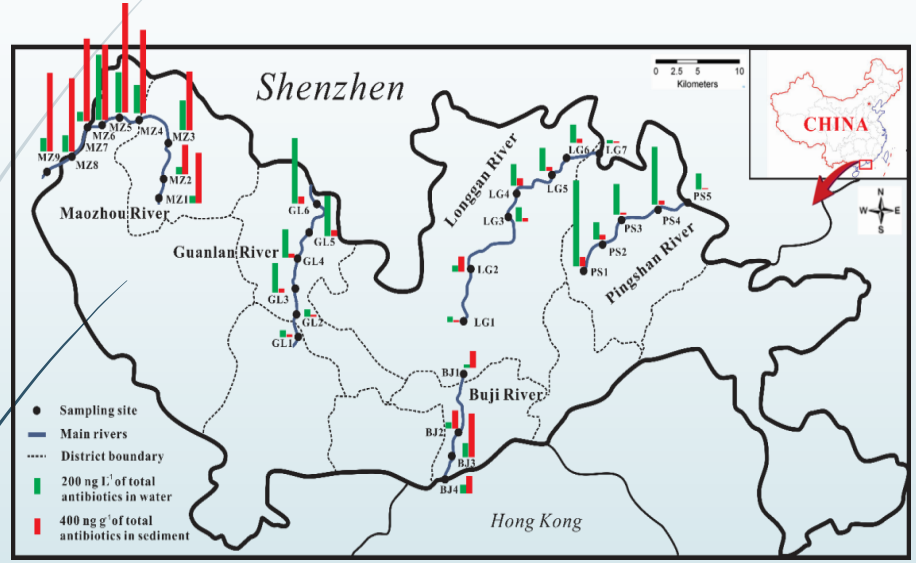
黑臭水体

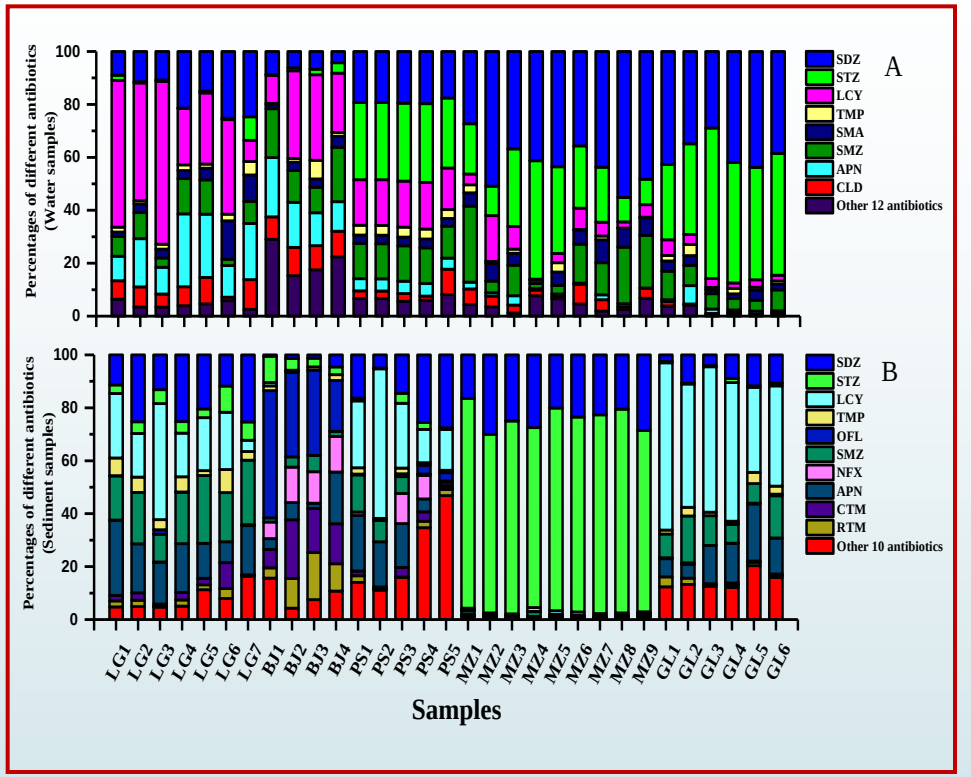
茅洲河新貌

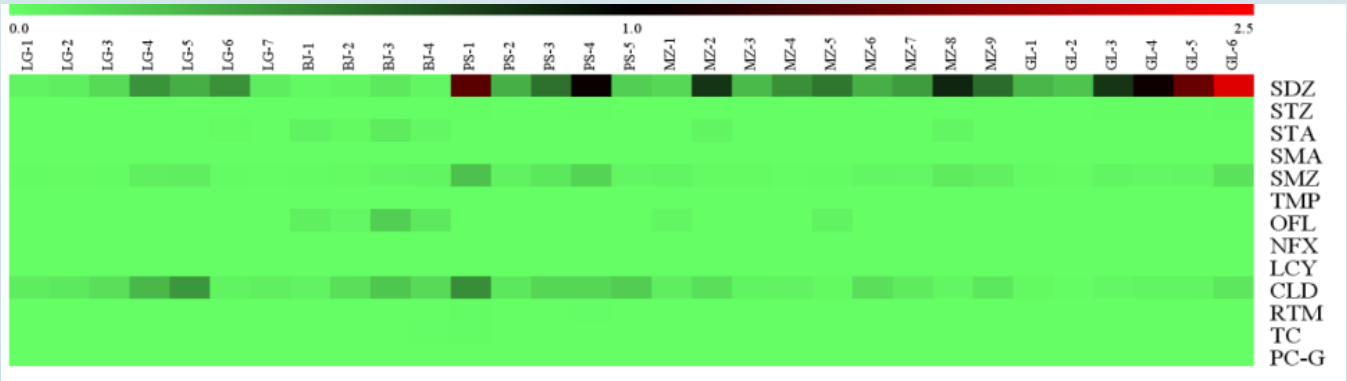


新型污染物-抗生素在深圳市水体中的浓度分布

采集深圳5条河流中32个点的地表水样和底泥样品，进行LC-MS/MS检测分析25中抗生素的含量，其中磺胺嘧啶、磺胺噻唑、林肯霉素在土壤和底泥中的含量最高。

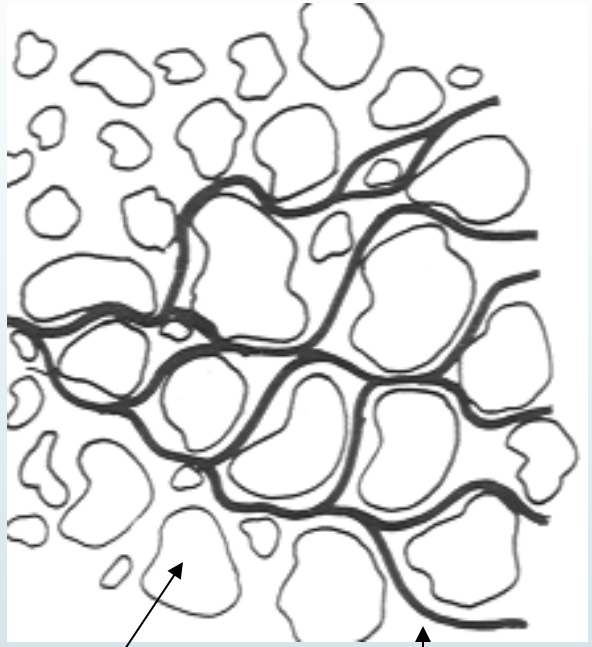






- ✓ 深圳抗生素水体污染水平普遍超过全国其他地域;
- ✓ 茅洲河的污染最为严重
- ✓ 磺胺嘧啶、磺胺噻唑、林肯霉素的污染程度最高
- ✓ 环境风险评价显示，磺胺嘧啶对人体健康风险最大。

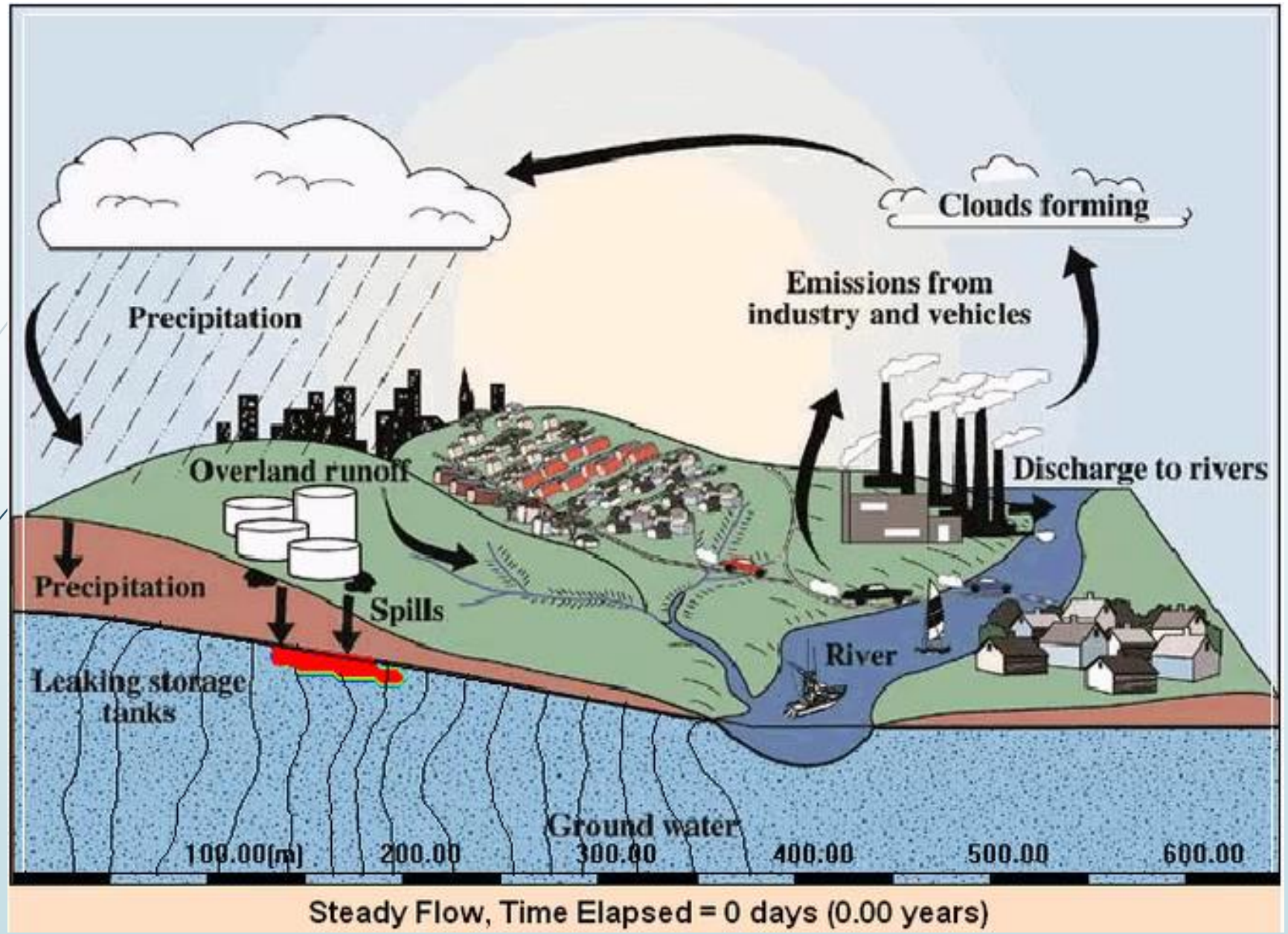
How does a contaminant spread out in aquifers?



The distribution of the contaminant after it spreads out is called plume.

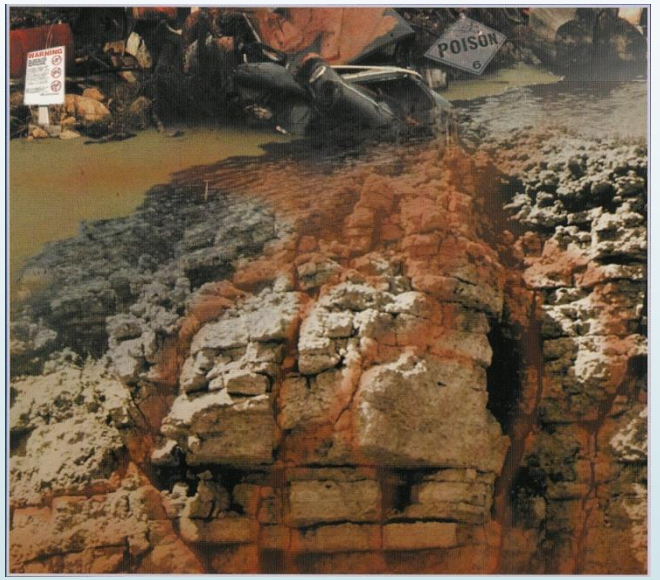
Flow paths in a *porous* medium that cause lateral and longitudinal dispersion.

Fetter, 1994, p456

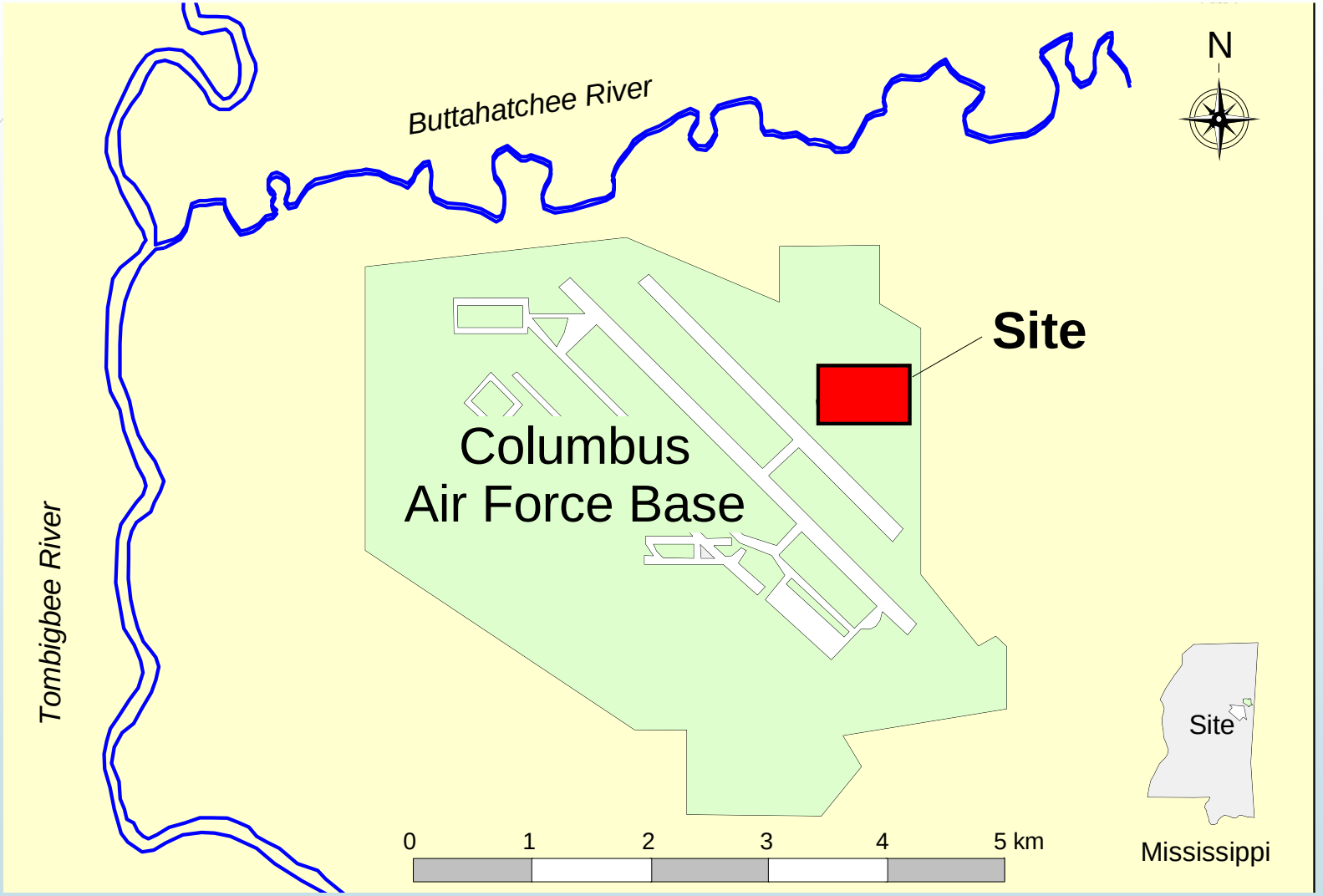

Clouds forming
Precipitation
Emissions from
industry and vehicles
Overland runoff
Discharge to rivers
Precipitation
Spills
River
Leaking storage
tanks
Ground water
100.00(m)
200.00
300.00
400.00
500.00
600.00
Steady Flow, Time Elapsed = 0 days (0.00 years)

Contaminant Transport Processes

- Physical
  - Advection
  - Molecular diffusion
  - Mechanical dispersion
- Geochemical and biological
  - Radioactive decay
  - Sorption
  - Biodegradation
  - mineral precipitation/dissolution
  - …



MAcro-Dispersion Experiment (MADE) Site

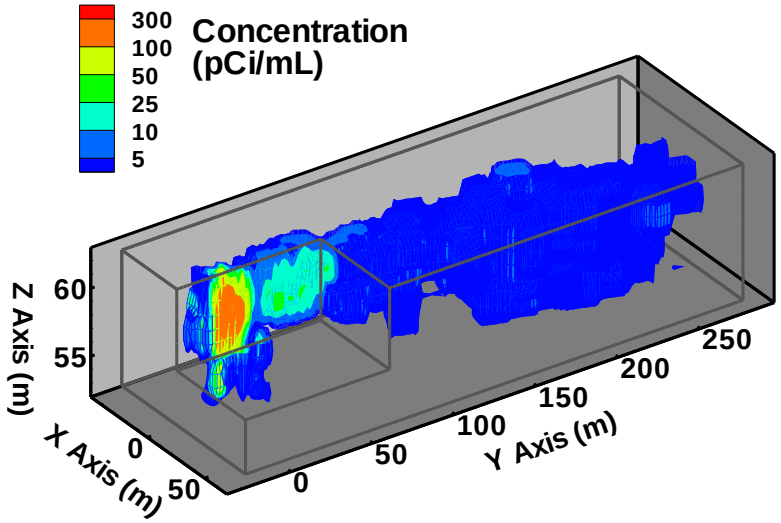


(courtesy of Hank Julian)

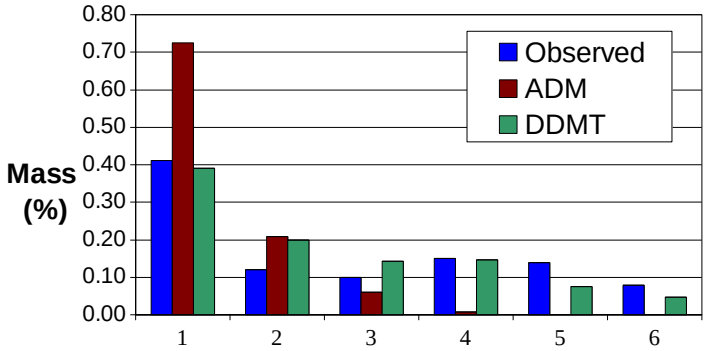
地下水污染物迁移机理示踪试验场研究

MADE Site
1983-now

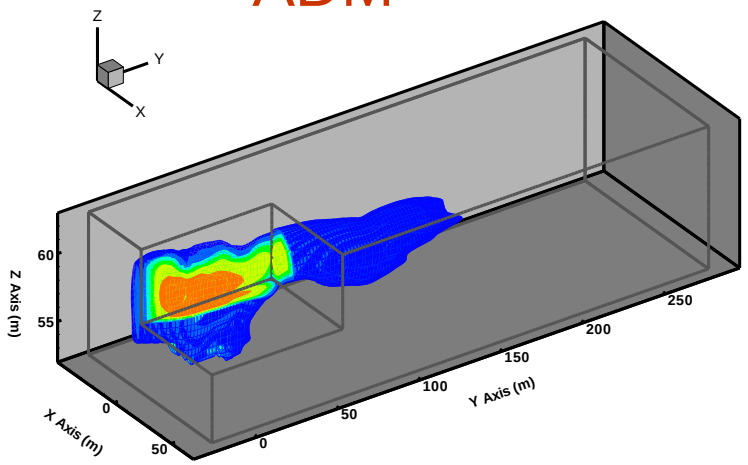
DDMT Model Application to MADE Site



Observed Plume (MADE-2)

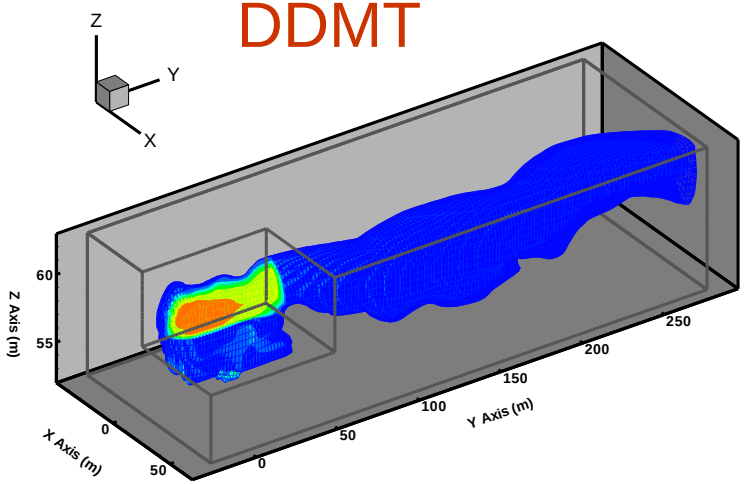


ADM



No preferential flow paths

DDMT



Preferential flow paths ~12%

LETTERS

edited by Jennifer Sills

China's "Love Canal" Moment?
中国的'拉夫运河'时刻？

郑春苗、刘杰 （北京大学水资源研究中心）

IN FEBRUARY 2013, A POSTING IN CHINA'S BURGEONING BLOGOSPHERE ACCUSED BUSINESS owners in Shandong Province of disposing waste water through injection wells and contaminating shallow groundwater (*1*). This seemingly innocuous message, describing a practice that is not uncommon, ignited a firestorm on the Internet (*2*). The outburst of condemnation and concern caught many observers by surprise and reached the uppermost echelon of the Chinese government (*3*). Du Ying, Vice Chair of the powerful National Development and Reform Commission, declared that "China needs a law specifically designed for groundwater protection" (*4*).

Groundwater provides about 20% of total water supplies for China, and 50 to 80% of water in water-scarce north and northwest regions of the country (*5*). However, the outlook for groundwater quality is bleak. According to the latest round of water well sampling in 2011 in more than 200 cities and administrative regions by China's Ministry of Land and Resources, fully 55% of more than 4700 samples indicated groundwater of category IV or V [on a scale of I to V from the best to poorest quality (*6*)]. Still, no one knows the true extent and severity of groundwater

2013年2月，中国蓬勃发展的博客圈上发布一条消息，谴责山东省某企业通过高压水井处理废水，造成浅层地下水污染，此类新闻似乎司空见惯，却在互联网上引发了轩然大波。积聚已久而突然爆发的谴责和高度关注让许多人感到惊讶，也引起了中国政府最高领导层的关注。国家发展和改革委员会杜鹰副主任宣称，"中国需要专门保护地下水的法律"。

中国大约20%的供水来自地下水，而在缺水的华北和西北地区，该比例更是高达50%到80%。但是，中国地下水水质状况十分令人担忧。根据中国国土资源部于2011年在200多个城市和行政区进行的地下水采样结果，在4700多个地下水样中，55%显示为IV或V类水质（I到V分别表示水质从最好到最差）。而全国范围内地下水污染的严重程度，目前仍没有准确的数据。

中国政府的当务之急是要积极、果断地应对地下水污染问题，美国和其他发达国

“拉夫运河”事件始末

- 1978年美国卡特总统宣布“Love Canal”地区由工业垃圾填埋旧址引起的地下水污染为“联邦紧急事故”，标志着地下水污染开始引起政府和公众的广泛注意。
- 美国政府因此成立了地下水污染“超级基金”，开始大规模调查和治理地下水污染。
- “拉夫运河”场地的调查与修复最终共花费2.5亿美元。

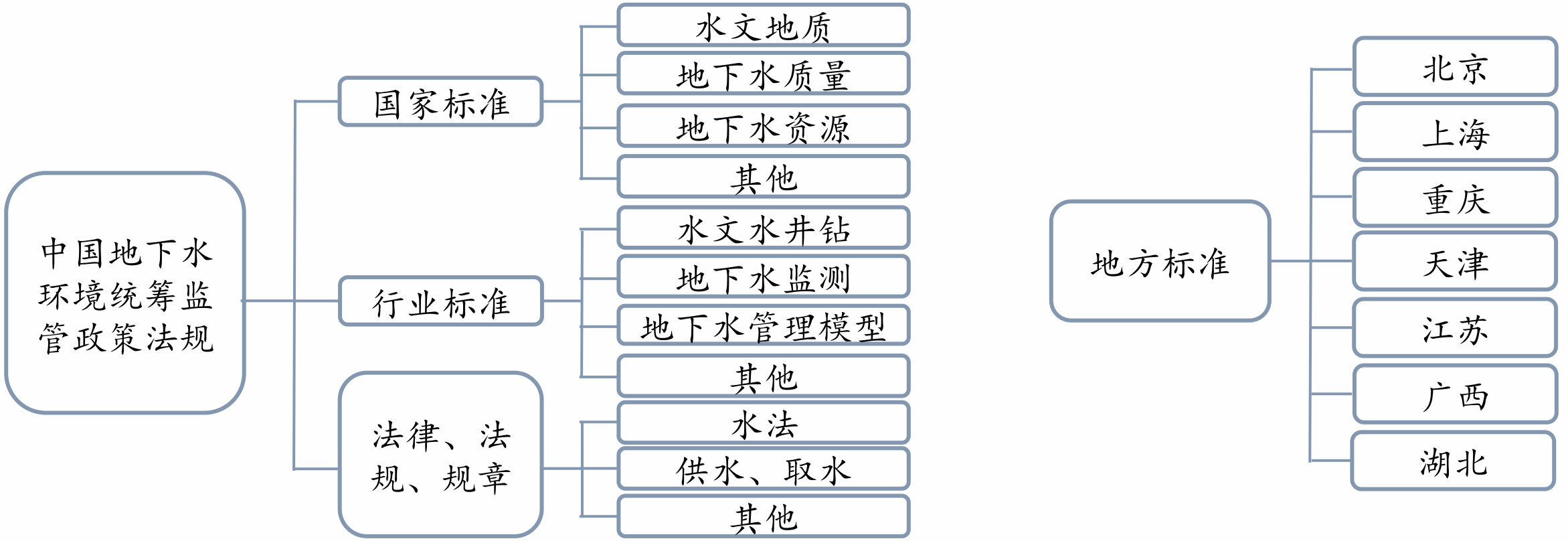

Canada
Washington
Montana
North Dakota
Minnesota
Maine
Oregon
Idaho
Vermont
New Hampshire
South Dakota
Wisconsin
New York
Massachusetts
Wyoming
Michigan
Connecticut
Iowa
Pennsylvania
New Jersey
Nebraska
Nevada
Ohio
Utah
Illinois
Indiana
Maryland
Delaware
California
Colorado
West Virginia
Kansas
Missouri
Virginia
Kentucky
Tennessee
North Carolina
Oklahoma
Arizona
New Mexico
Arkansas
South Carolina
Atlantic Ocean
Mississippi
Alabama
Georgia
Texas
Louisiana
Florida
Pacific Ocean
Mexico
Gulf of Mexico
Reservations near Superfund sites
Indian Reservations
Superfund Sites
50 miles buffer of Superfund sites
Tribal Lands and Superfund Sites
319 out of 542 Indian Reservations are within 50 miles from Superfund Sites
UCSD SBRP Outreach Team
March 2004
Sources: ESRI Data & Maps CD
US Federal Lands database
EPA CERCLIS database

Lessons learned from USA

- Average cost needed for remediation of a Superfund site in the States: $30 million (3000 万美元).
- Estimated cost of cleaning up the existing U.S. hazardous waste in the environment over the next 30 yrs: $1 trillion (1万亿美元)

Source: Wang Mingyu

中国地下水环境统筹监管政策法规



- 当前涉及地下水环境监管政策法规主要集中在国家层面，对地下水质量、水质、水文水井、地下水监测及管理模型、供水取水等方面均有相关国家标准、行业标准、法律法规规章，但政策法规相对较零散，没有统筹的地下水政策法规，且相关的地方标准不多。

国外地下水环境统筹监管政策法规—美国

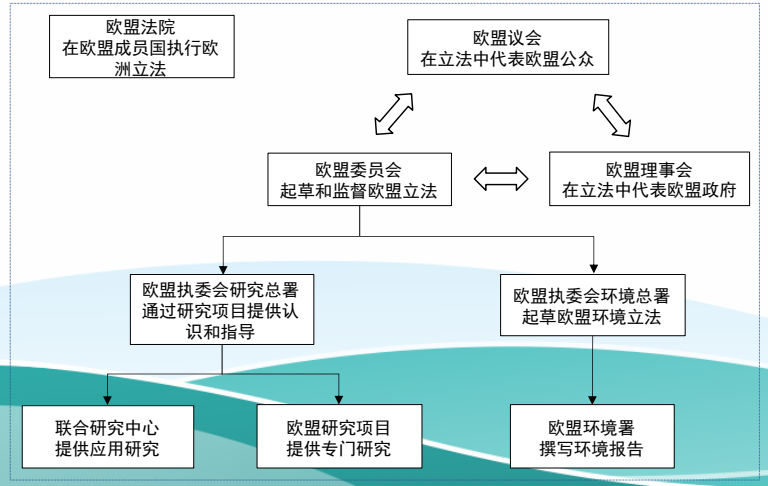
- 美国地下水环境统筹监管政策法规
  - 清洁水法（Clean Water Act）（1977年）：集中保护地表水水质的法律，其中强调协同地下水保护
  - 国家监测系统（1991年）：要求积极建立地表水和地下水资源联合利用制度
  - 地下水条例（Ground Water Rule）（2006年）：保护用于作为饮用水的地下水免受致病微生物影响
  - 地下水可持续管理法案（2018年）：明确地下水管理中要协同监管地表水与地下水
- 美国地下水相关技术标准
  - 地下水系统概念化和特性化的标准指南
  - 地下水场地及监测井、监测相关标准指南
  - 地下水模型相关标准指南

国外地下水环境统筹监管政策法规—欧盟

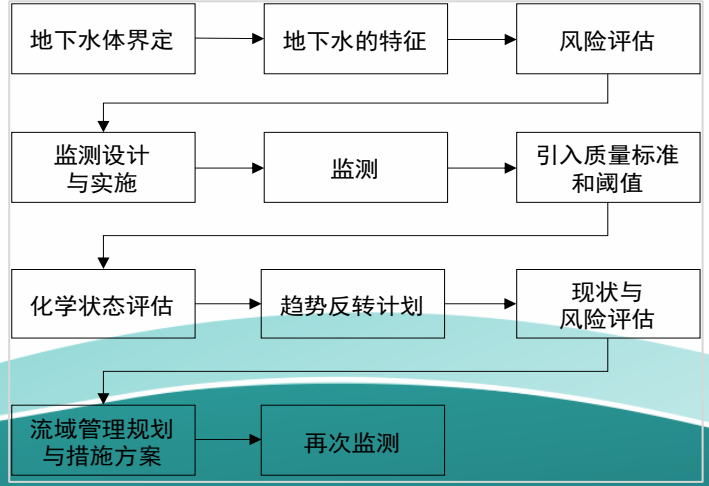
欧盟地下水环境统筹监管政策法规

- 保护地下水免受特定危险物质污染指令(20世纪70年代)
  - 地下水保护框架，禁止具有毒性、持久性和生物蓄积性污染特向地下水体排放，以避免这些物质对地下水造成污染
- 水框架指令（2000年）
  - 水管理综合指令，“逐步减轻地下水污染”和“地下水资源超采现象将被扼制”是该指令的重要目标
- 地下水指令（2006年）
  - 对地下水管理保护作了专门规定，明确提出了地下水管理的目标，即：防止地下水污染，取得良好的水质状态，且不对人类和环境造成显著的风险影响

欧盟地下水主要管理机构



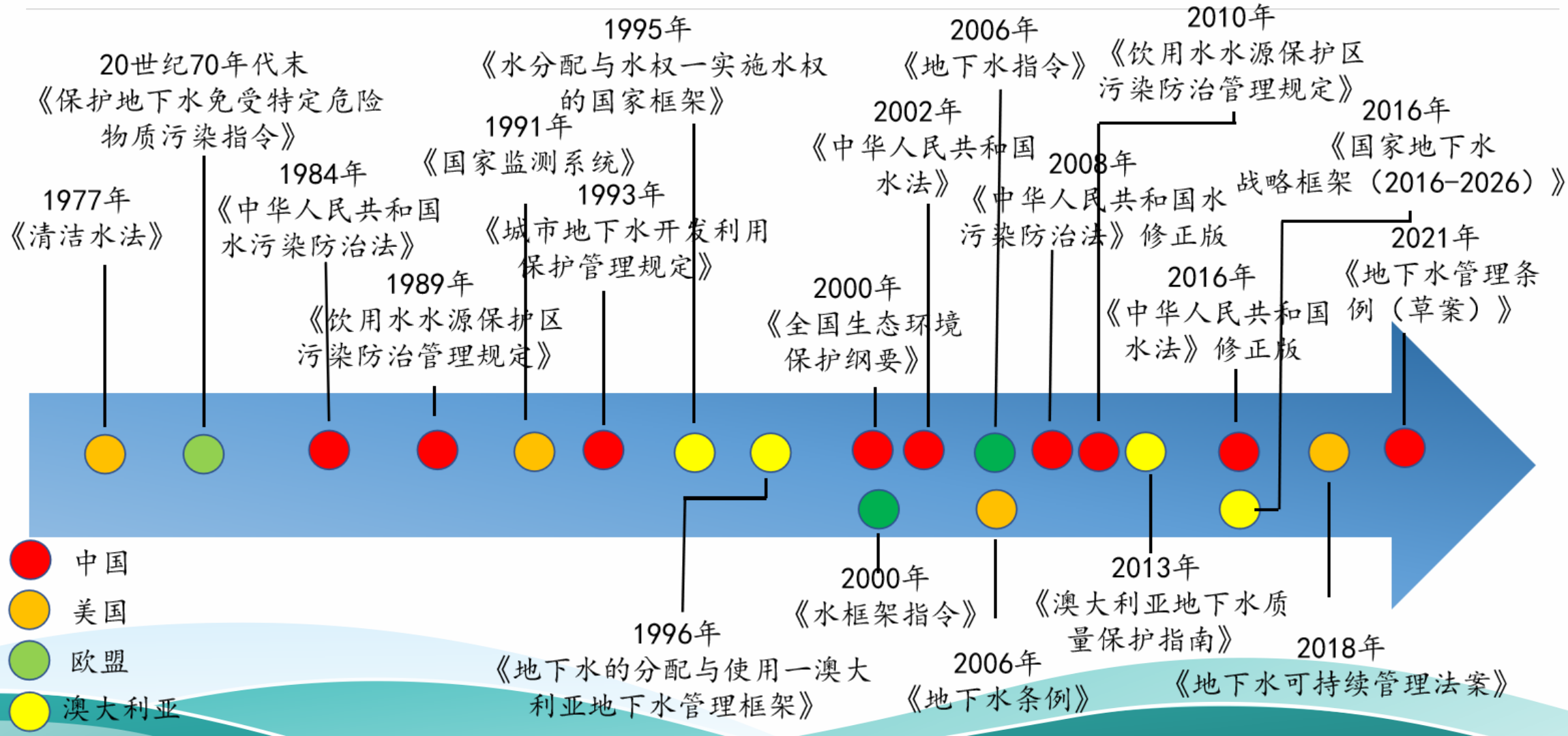
欧盟地下水监测方案设计概念模型



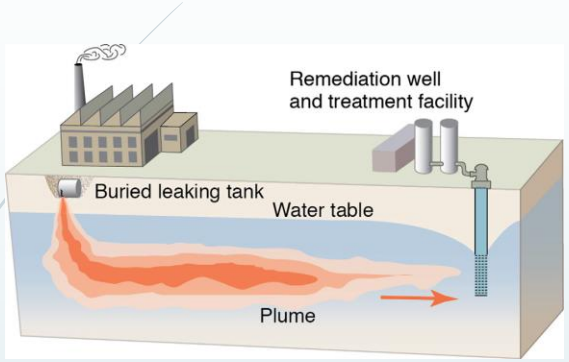
国外地下水环境统筹监管政策法规—澳大利亚&日本

- 澳大利亚地下水环境统筹监管政策法规
  - 水分配与水权一实施水权的国家框架（1995年）
    - 明确了国家管理水资源的客体包括地下水，并且与地表水地位同等，强调地表水与地下水资源的统一管理，地下水与地表水的相互作用和地下水的环境价值
  - 地下水的分配与使用一澳大利亚地下水管理框架（1996年）
  - 澳大利亚地下水质量保护指南（2013年）
    - 旨在支持《国家水质管理战略》的总体目标，重点是保护并提高地下水的质量，以提高环境质量和预防地下水污染
  - 国家地下水战略框架（2016-2026）
    - 旨在保护地下水可持续发展，并制定可持续开采及最佳利用、提高使用地下水信心、及规划未来地下水管理
- 日本地下水环境统筹监管政策法规
  - 没有一套完整的关于地下水的法律法条，但有许多不同的、独立的法条有提及关于地下水的运营、管理及保护。这些提及地下水运营的法律法条包含强大的关联网，是一个复杂的组成部分

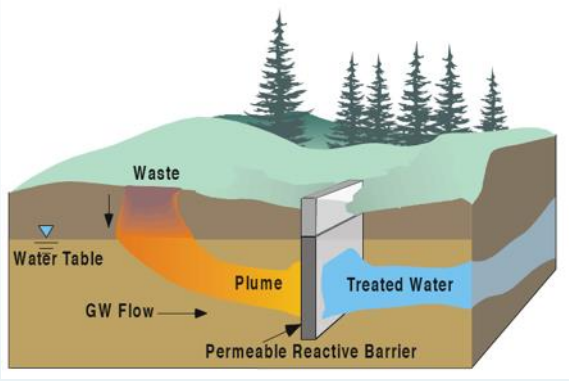
国内外地下水环境统筹监管政策法规



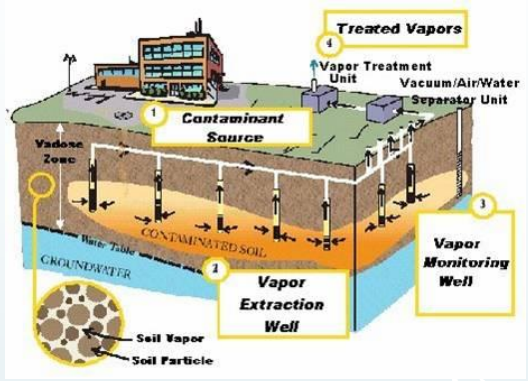
Remediation Technologies



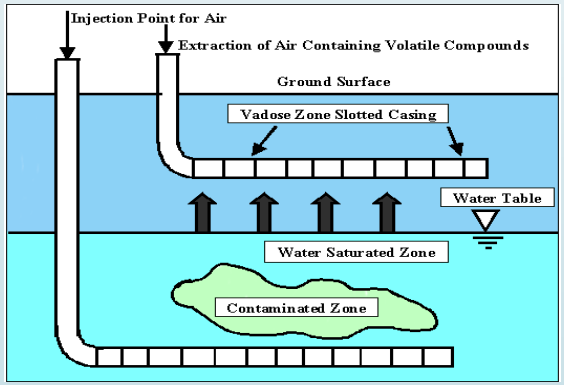
Pump and treat



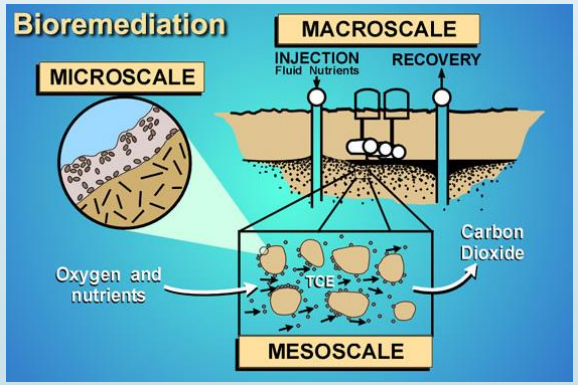
Permeable Reactive Barrier



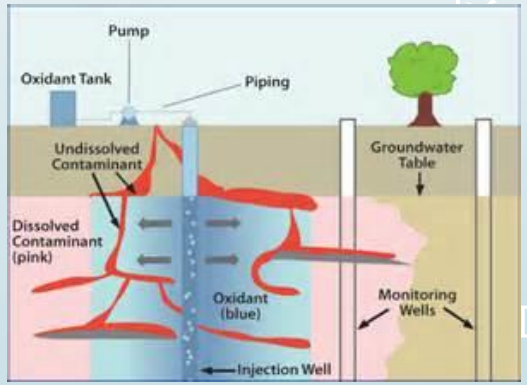
Vapor Extraction



Air Striping



Bioremediation



In-situ Chemical Remediation

课程的目的与要求

1. .理解环境介质的多介质特性、多过程特性、多组分特性、多相流特性、多界面特性、多尺度特性以及多场耦合特性；

2. 理解多孔介质污染物迁移模型，污染物在多孔介质中迁移的物理过程，包括对流、弥散及吸附过程，化学过程和生物降解过程等；

3.掌握多孔介质污染物迁移基本微分方程、固-液相互作用发生链式衰减时的多孔介质污染物迁移方程、多孔介质多相多组分污染物迁移的一般方程、多孔介质中流体密度变化时的污染物迁移方程以及多孔介质污染物迁移定解条件和数学模型等

4.注重培养学生的思维能力，采用理论与实践相结合，理论讲述与案例分析相结合的方法进行教学，培养和提高学生分析问题和解决问题的能力，使学生完成本门课程的学习任务之后，能够自觉地对实践中存在的问题进行反思并提出解决办法。

本课程成绩

- 本课程48学时，3学分
- 总成绩=平时成绩（占30%）+作业成绩（占30%）+实例报告（占40%）

平时成绩占总成绩的30%，由出勤率（50%）和课堂情况（50%）的成绩组成，每项必须达到2/3以上，否则没有成绩；

作业占总成绩30%；课程实例报告成绩占总成绩的40%。

计算机数值模拟技术

国际通用的商业化专业软件，主要有：

地表水软件：SMS, WMS，SWAT, MIKE, HEC, WEATP

地下水软件：GMS，MODFLOW，FEFLOW ， GFLOW，AquiferTEST，AquaChem，NetPath，MT3D

水环境软件：WASP，DELFT, BASINS，AGNPS, EFDC

其它软件： ArcGIS ， MapGIS ，CAD， Surfer，SPSS ，MatLAB，GeoStudio

可视化、仿真性、虚拟技术正被开发利用。

教材与参考文献

教材及主要参考书

《Modeling Phenomena of Flow and Transport in Porous Media》，Jacob Bear, 2018

《Contaminant Hydrogeology》2nd or 3rd edition，W Fetter, DK Kreamer, T Boving，2017

主要参考书

《Applied Contaminant Transport Modeling》, 2nd edition, Chunmiao Zheng, Gordon D. Bennett， 2002

《地下水污染物迁移模拟》, 孙晋玉、卢国平，2009.