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Overview of Water Resources in Lebanon

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American University of Beirut

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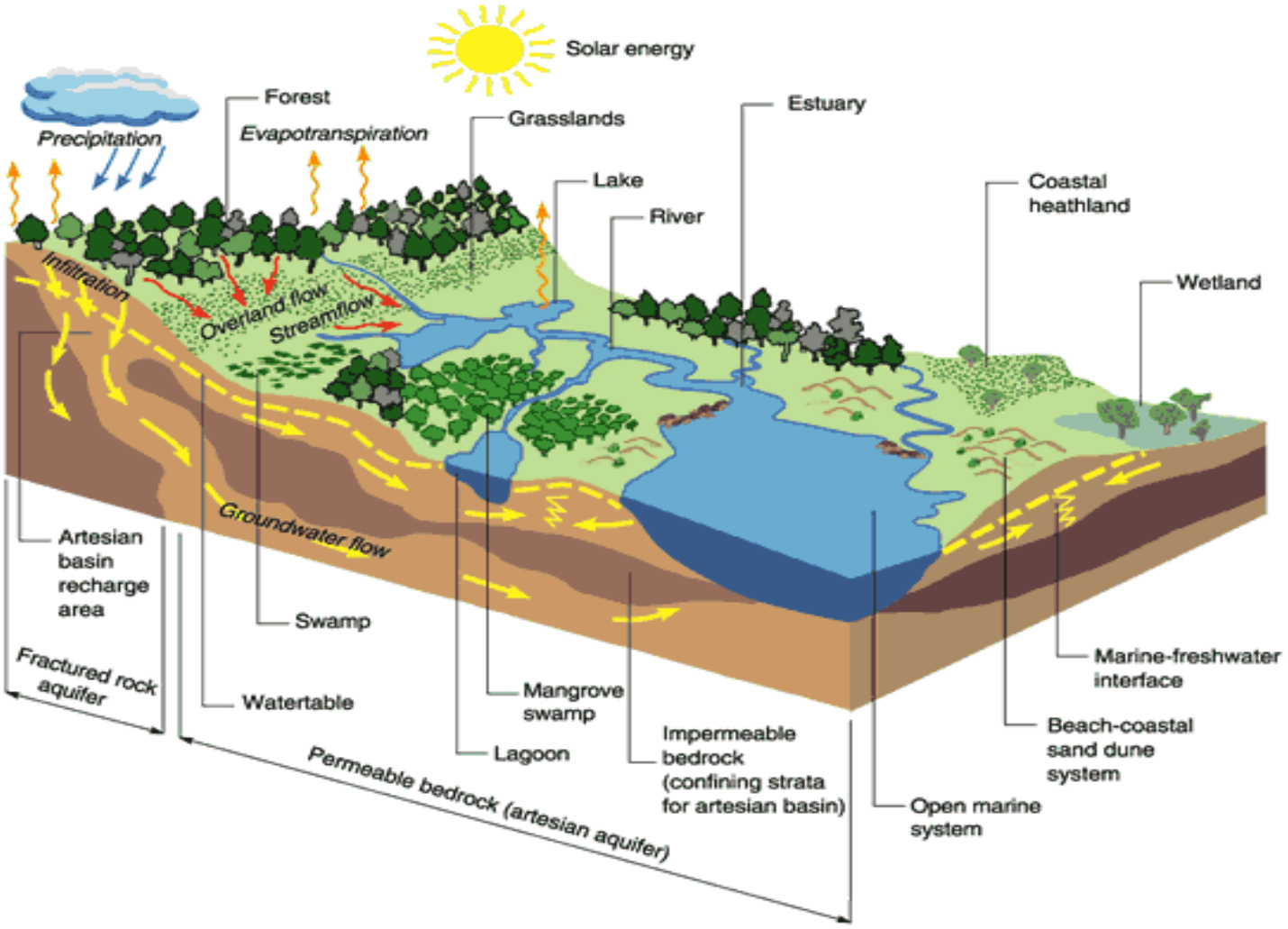
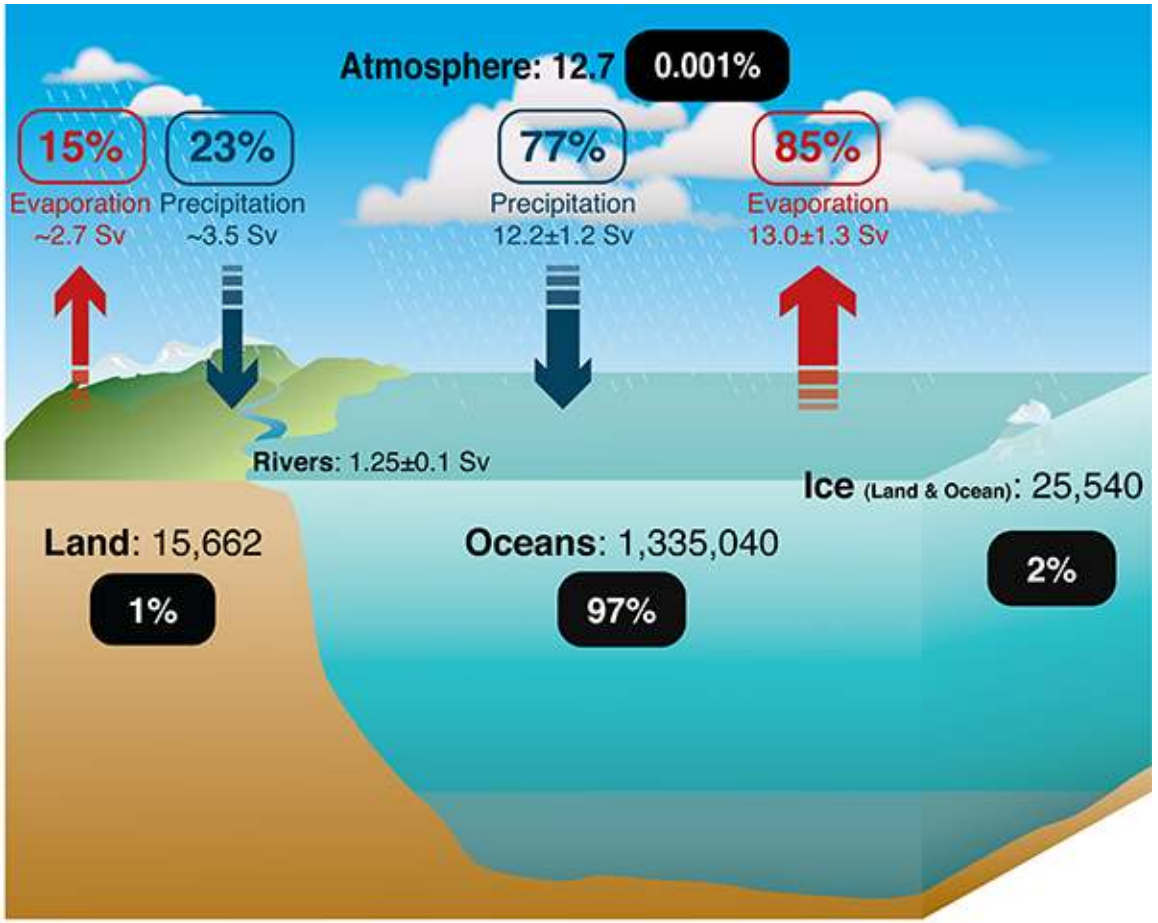
Where it all starts – the Hydrologic Cycle

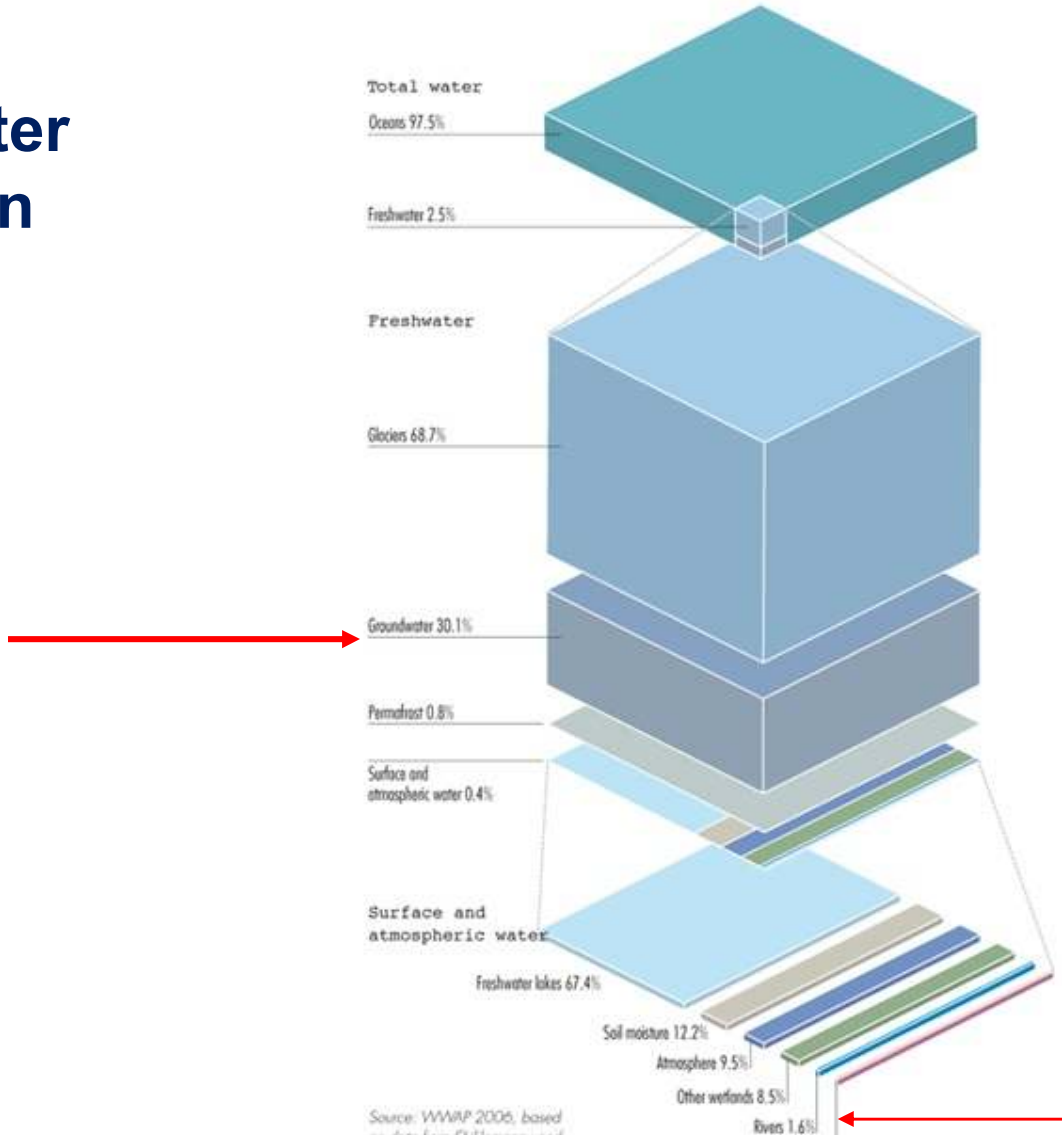


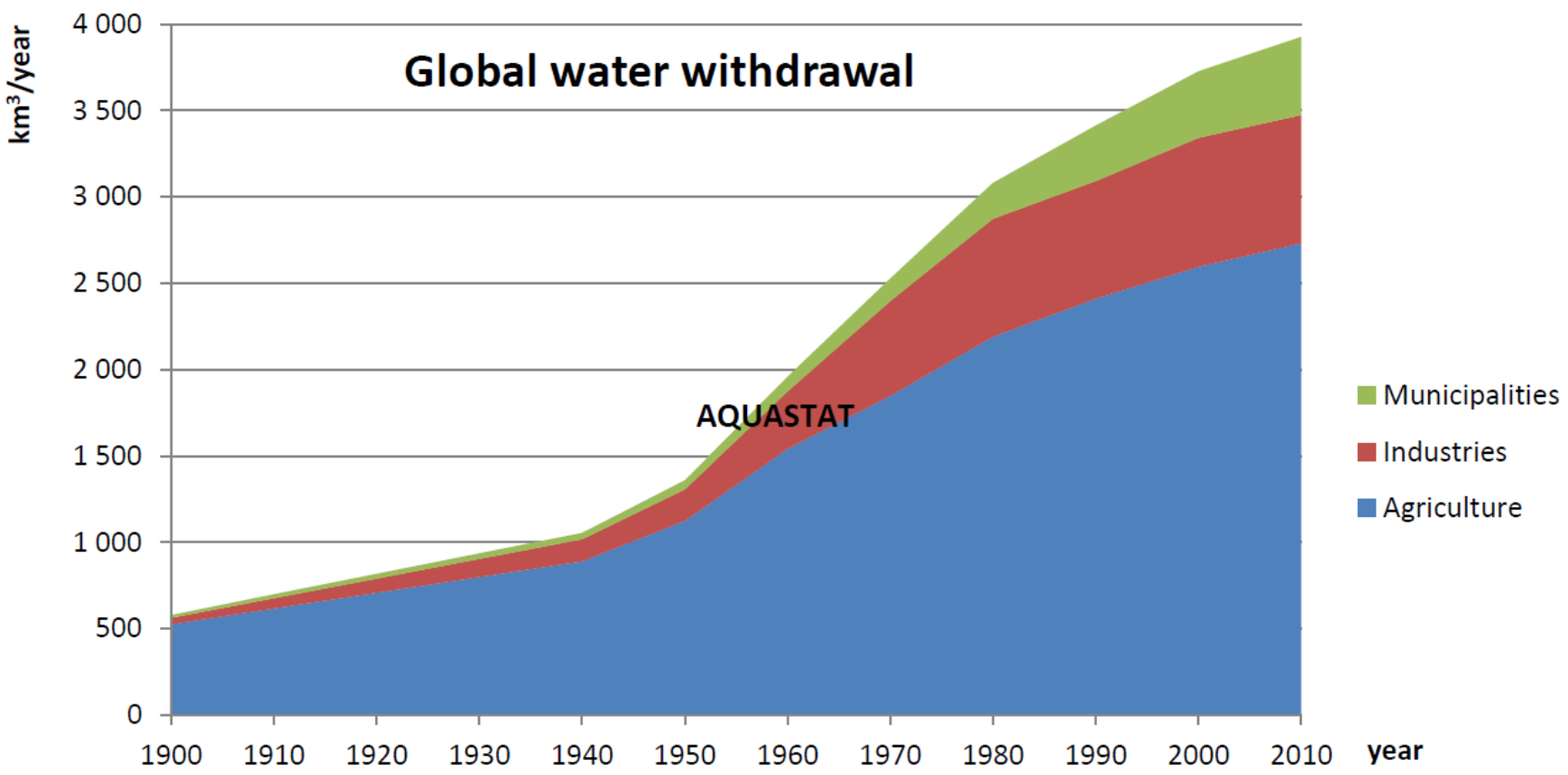
Water Distribution



Reservoirs represented by solid boxes: 10^3 km^3, fluxes represented by arrows: Sverdrups (10^6 m^3 s^{-1})
Sources: Baumgartner & Reichel, 1975; Schmitt, 1995; Trenberth et al., 2007; Schanze et al., 2010; Steffen et al., 2010

Global Water Distribution

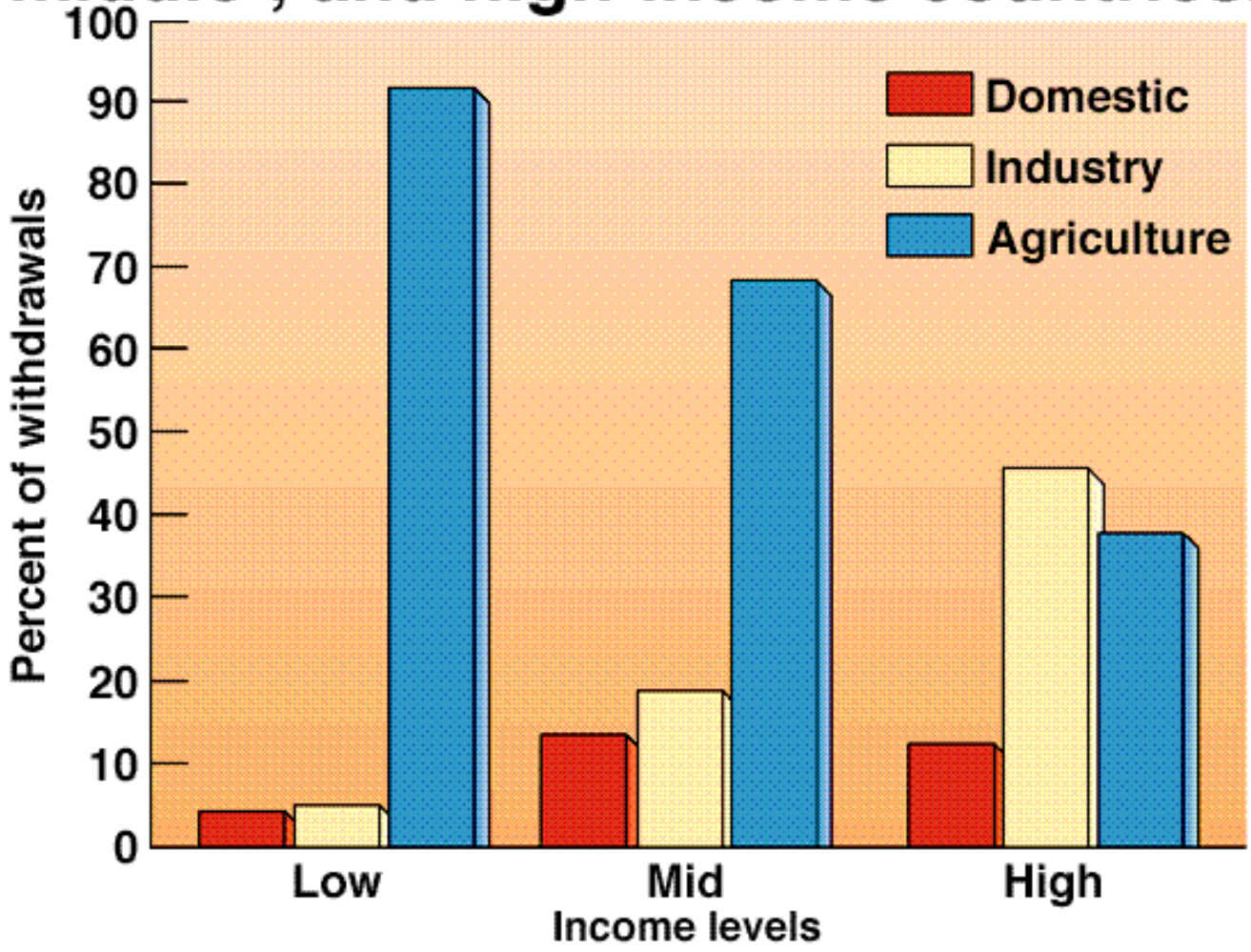




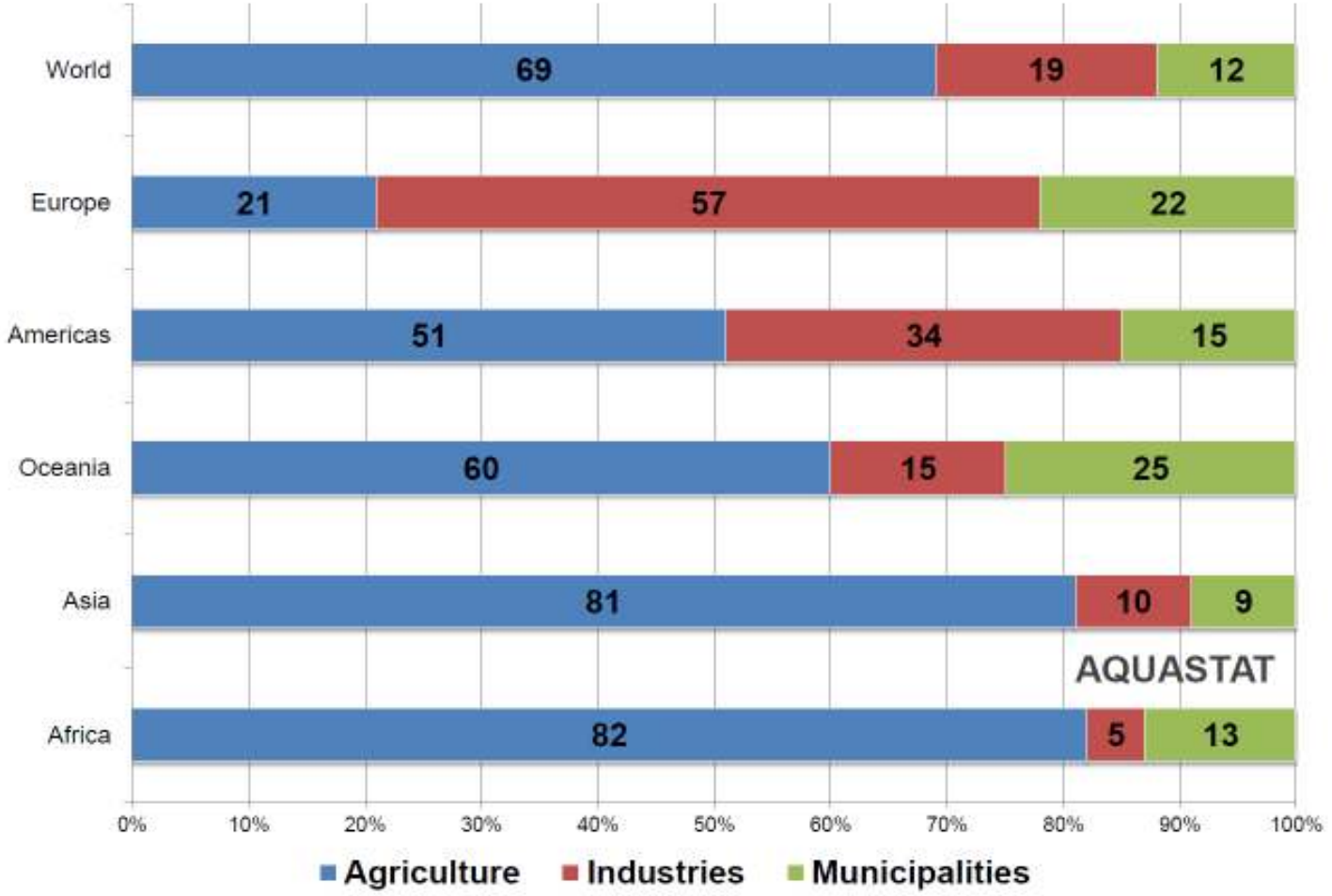
Sources:
FAO-AQUASTAT: 2010; I.A. Shiklomanov: 1900- 2000

http://www.fao.org/nr/water/aquastat/water_use/index.stm

Water withdrawals by sector in low-, middle-, and high-income countries.

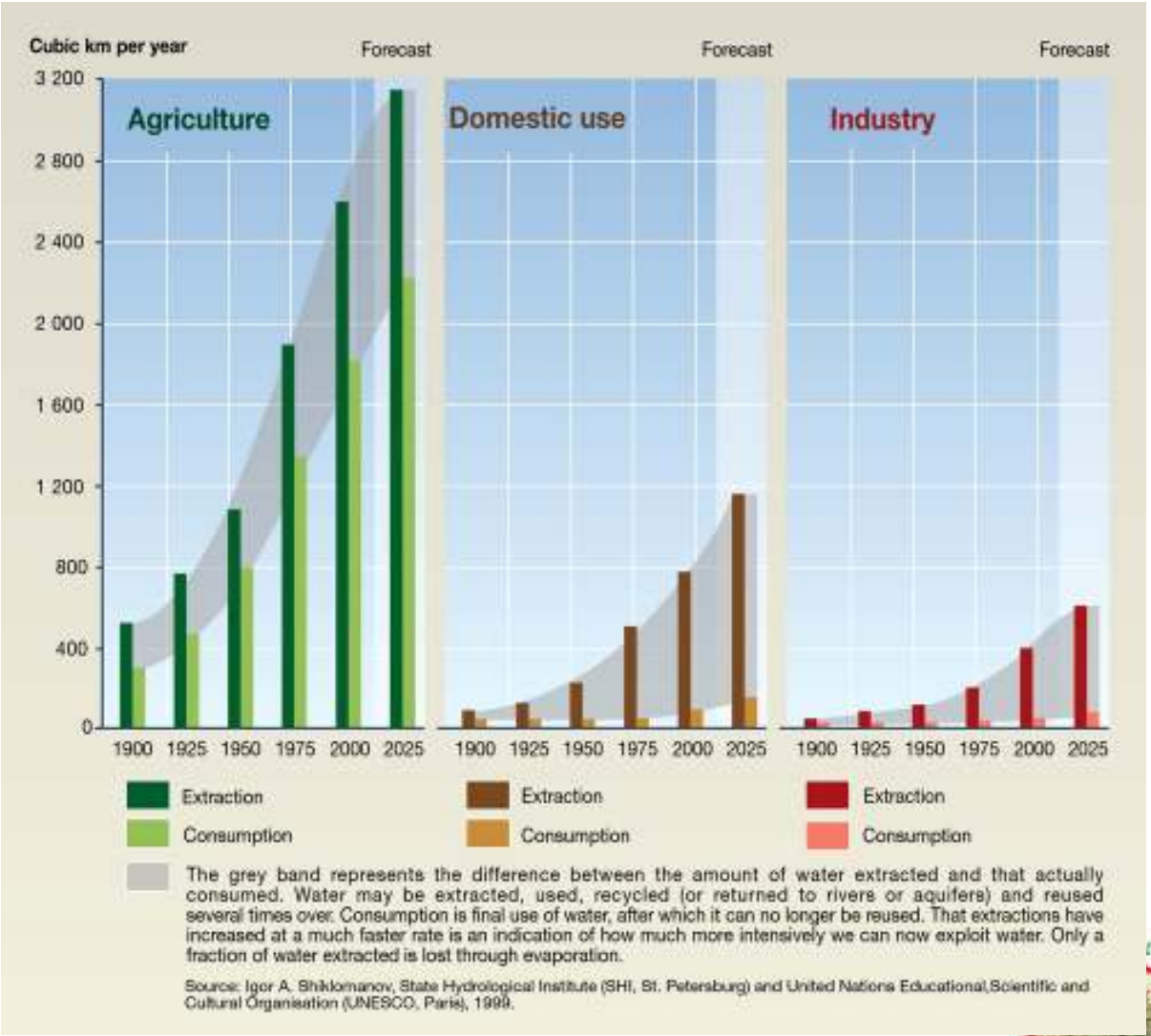


Water withdrawal ratios by continent



Date of preparation: September 2015

How Efficient is each Sector?



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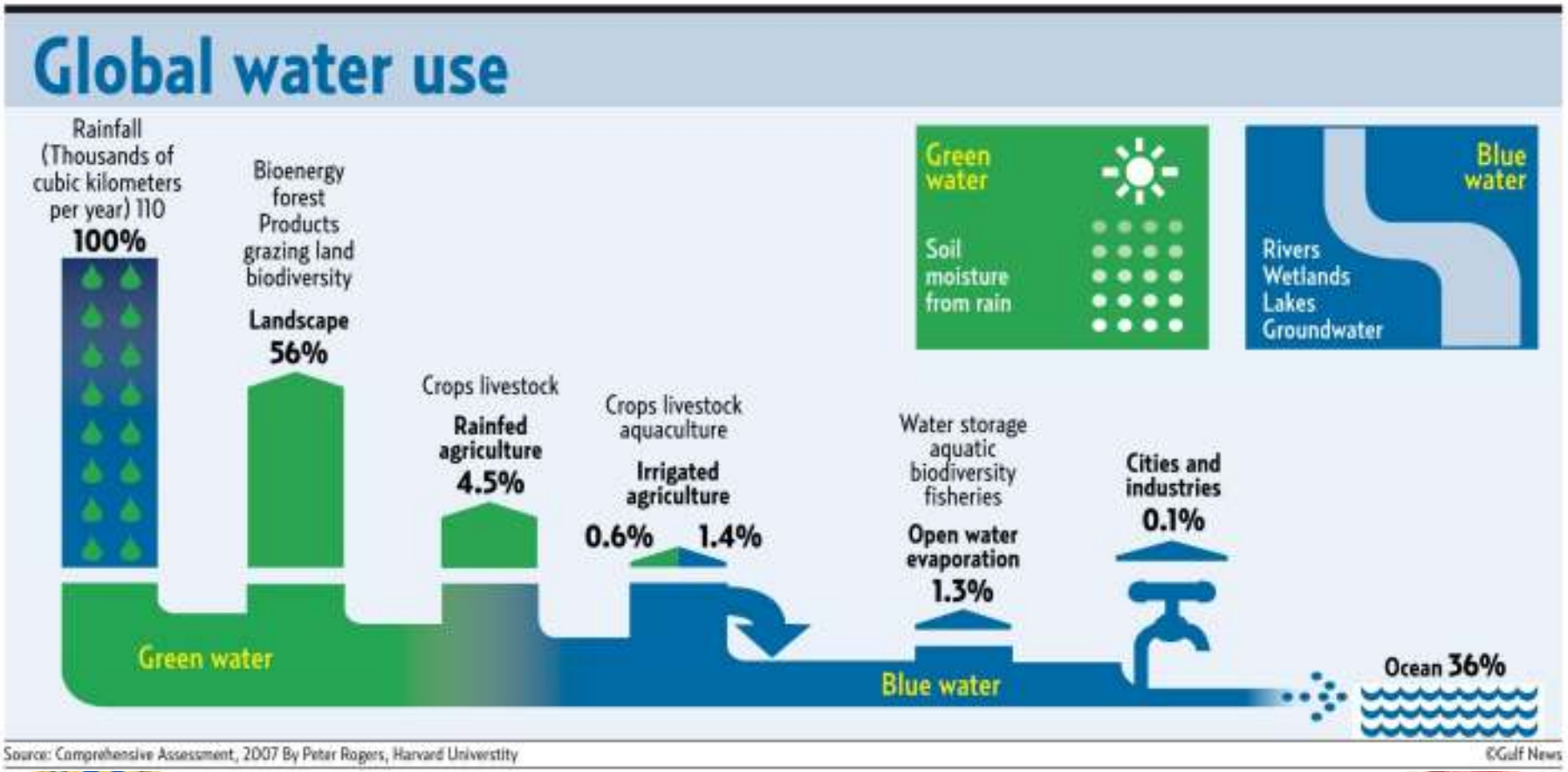
Where Does the Water Go?



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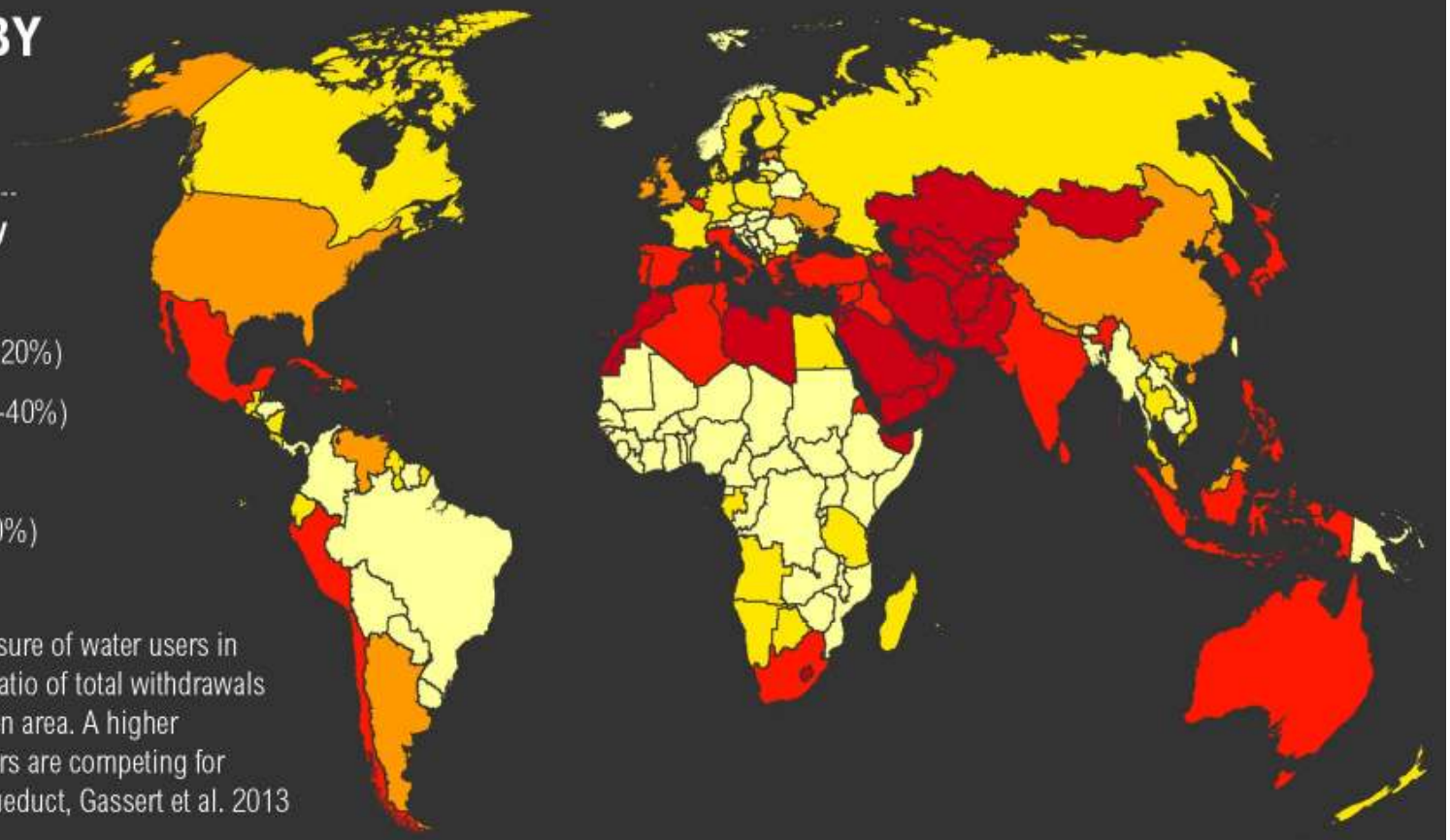
WATER STRESS BY COUNTRY



ratio of withdrawals to supply

- Low stress (< 10%)
- Low to medium stress (10-20%)
- Medium to high stress (20-40%)
- High stress (40-80%)
- Extremely high stress (> 80%)

This map shows the average exposure of water users in each country to water stress, the ratio of total withdrawals to total renewable supply in a given area. A higher percentage means more water users are competing for limited supplies. Source: WRI Aqueduct, Gassert et al. 2013

AQUEDUCT

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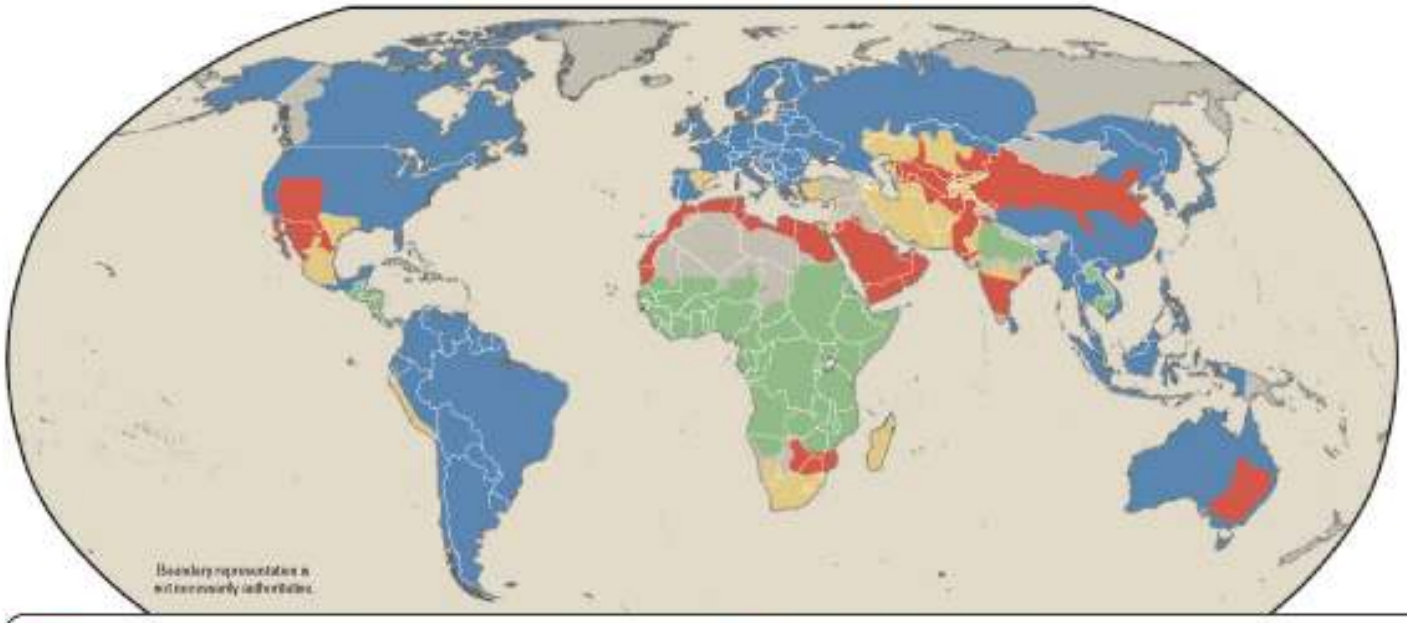
Projected Global Water Scarcity, 2025



Physical water scarcity: More than 75% of river flows are allocated to agriculture, industries, or domestic purposes. This definition of scarcity — relating water availability to water demand — implies that dry areas are not necessarily water-scarce.

Approaching physical water scarcity: More than 60% of river flows are allocated. These basins will experience physical water scarcity in the near future.

Economic water scarcity: Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exists.

Little or no water scarcity: Abundant water resources relative to use. Less than 25% of water from rivers is withdrawn for human purposes.

Not estimated

Source: International Water Management Institute.

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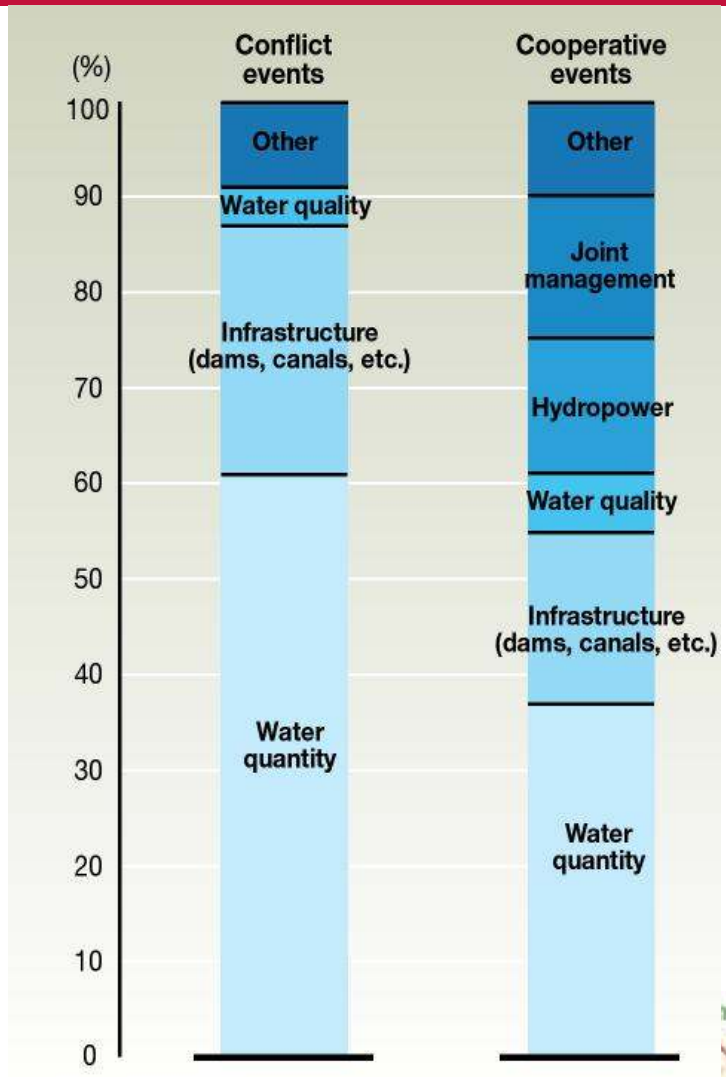
- Oregon State University compiled data covering every reported interaction over water going back 50 years
- Only 37 cases of reported violence between states over water (30 of them in the Middle East)
- Over the same period more than 200 water treaties were negotiated between countries.
- 1,228 cooperative events were recorded, compared with 507 conflict events, more than two-thirds of which involved only low-level verbal hostility



Source: Wolf 2006.

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Hydrologic Analysis

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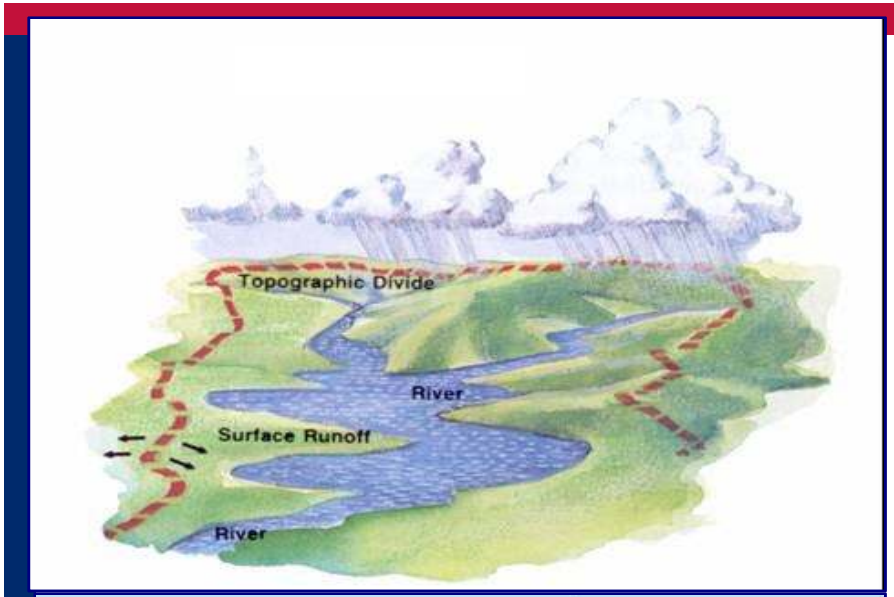
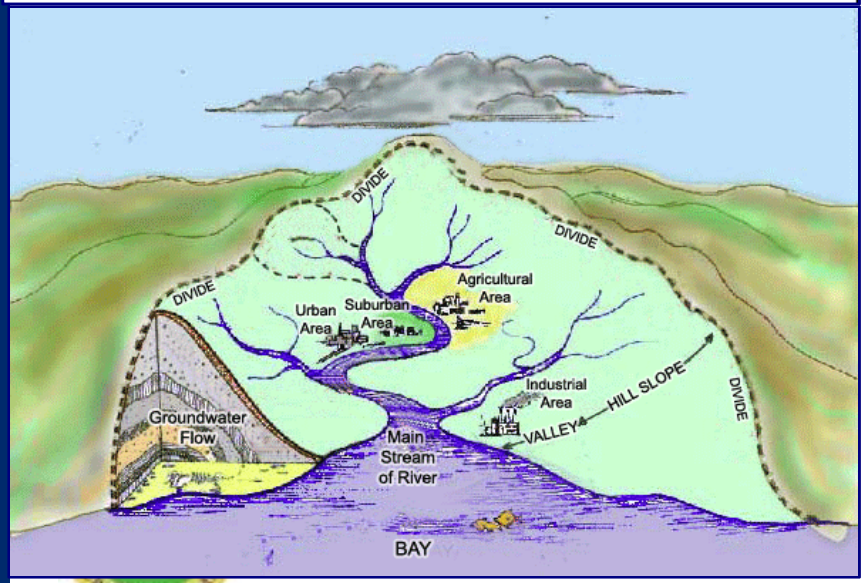
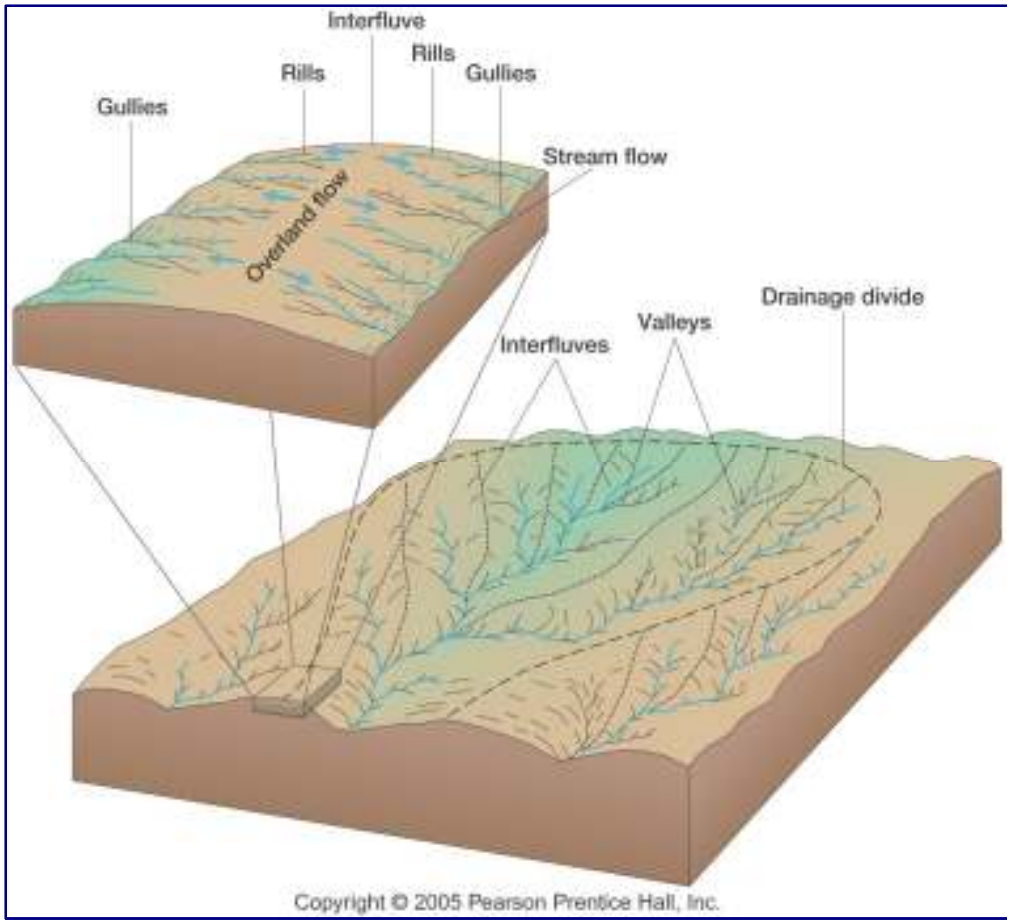
Watershed Concept

- The basic hydrologic unit that is used in most hydrologic calculations
- A contiguous area where rainfall or runoff drain to a single outlet and is from other watersheds by a watershed divide – typically it is the topological high points around the watershed
- Are typically characterized by a single main channel and several tributaries draining into the channel
- Some have many sub-watersheds







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Water Balance for a Watershed:

Input – Output = change in storage

Input = Precipitation + Groundwater input
= $P + G_{in}$

Output = Evapotranspiration + Stream Flow + Groundwater Output
= $ET + Q + G_{out}$

$P + G_{in} – (ET + Q + G_{out}) = \Delta S$

Note: Groundwater influence may considered negligible
Change in storage over a long term may also be negligible

$P – (ET + Q) = 0$ or in case of storage facilities, $P – Q – ET = \Delta S$

Note, that this simplified version applies only where the assumptions are considered reasonable.

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Input

Precipitation

- All forms of water that reach the earth from the atmosphere is called **Precipitation**.

- The usual forms are rainfall, snowfall, frost, hail, dew. Of all these, the first two contribute significant amounts of water.

- In nature water is present in three aggregation states:
  - solid: snow and ice;
  - liquid: pure water and solutions;
  - gaseous: vapors under different grades of pressure and saturation saturation

Precipitation

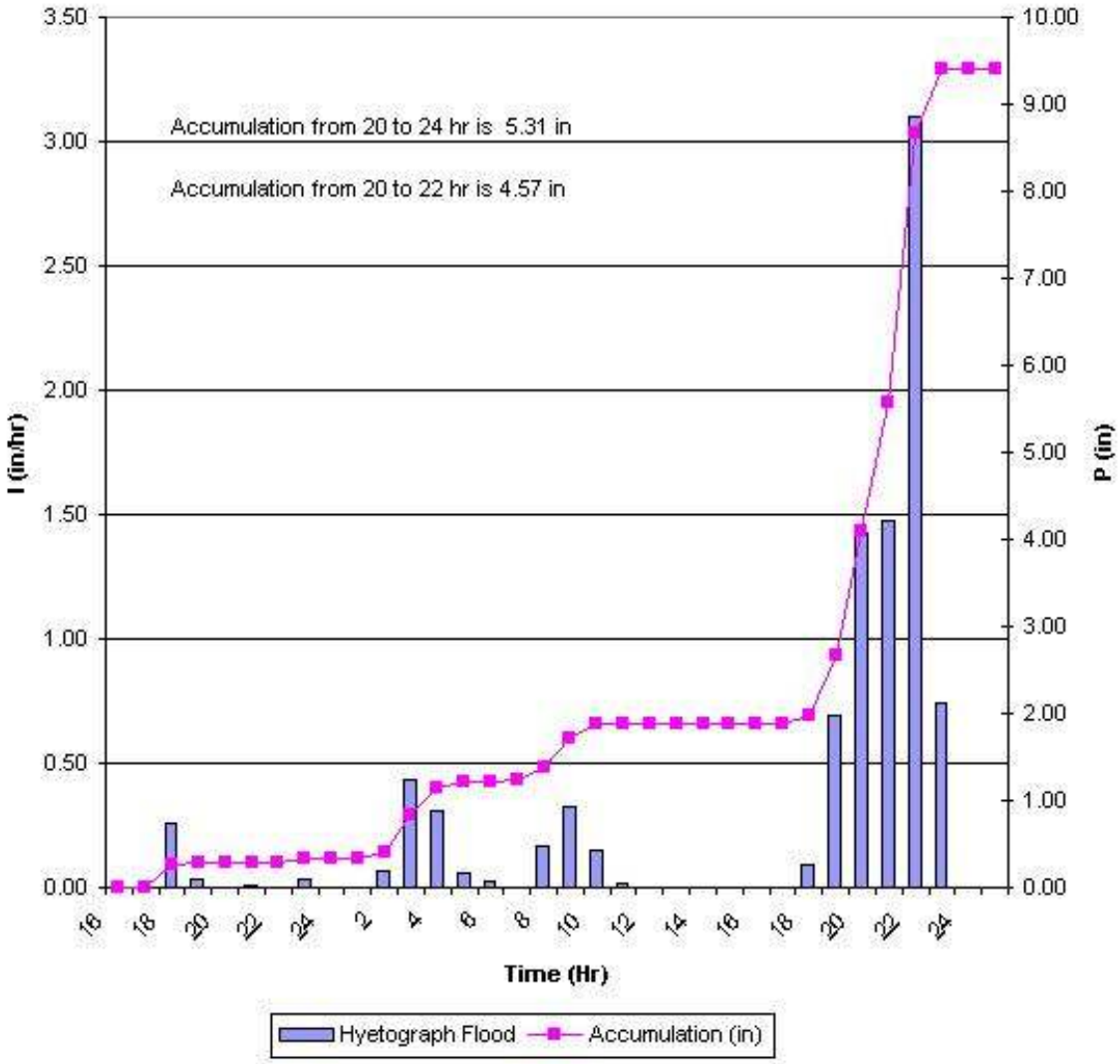
- Precipitation varies spatially:
  - It tends to be heavier on or near coastlines
  - There are distortions in quantities due to orographic effects
  - It tends to be greater on the windward side of mountain barriers

- Precipitation varies temporally :
  - Variations can be seasonal, and
  - Within storms themselves
  - A variety of statistical methods are used to estimate and/or predict this variability

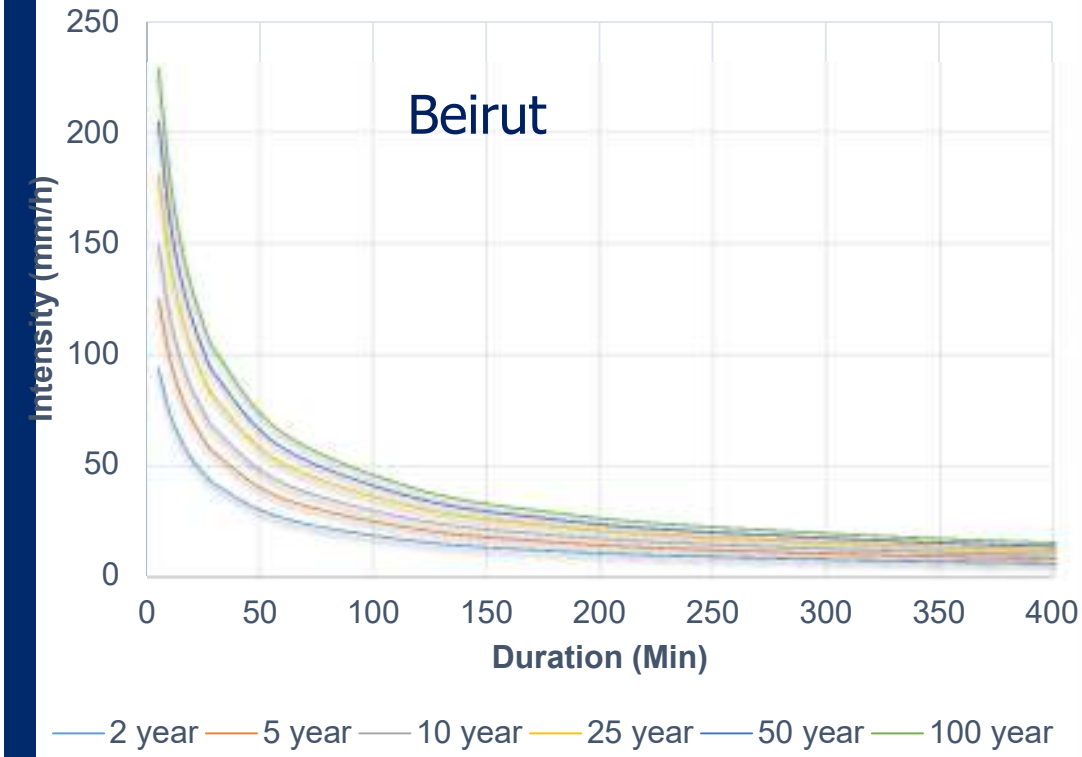
Representing Rainfall

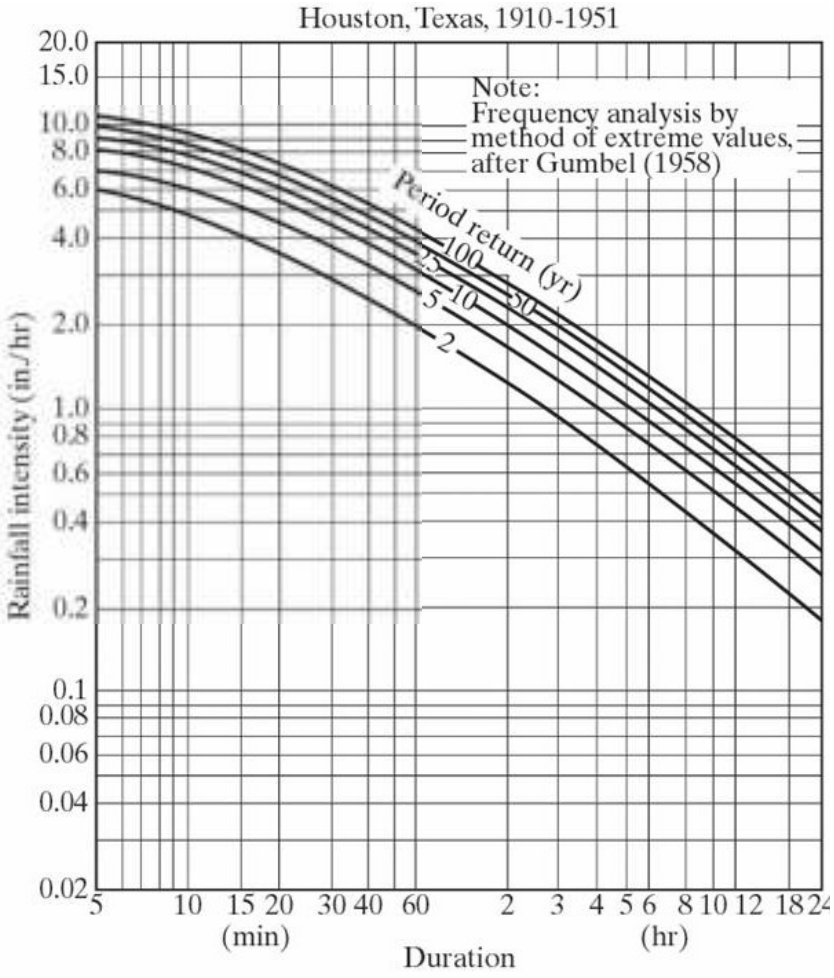
- Point rainfall at a particular gage may be plotted either:
  - as accumulated total rainfall, or
  - as rainfall intensity
- A hyetograph is a plot of rainfall intensity (e.g. mm/hr) versus time (hr)
- A mass curve is a plot of cumulative rainfall (mm or in) versus time (hr)
- An intensity-duration-frequency (IDF) curve is statistical plot that relates the intensity, duration, and frequency of design storms

Graphical Representation



Intensity-Duration-Frequency Curves





Areal Precipitation

Radars

- Radar has become an important tool for estimating spatial distribution of rainfall

- Radars estimate rainfall through a measure of the reflectivity of the radar signal by the raindrop. This relationship is called the Z-R relationship

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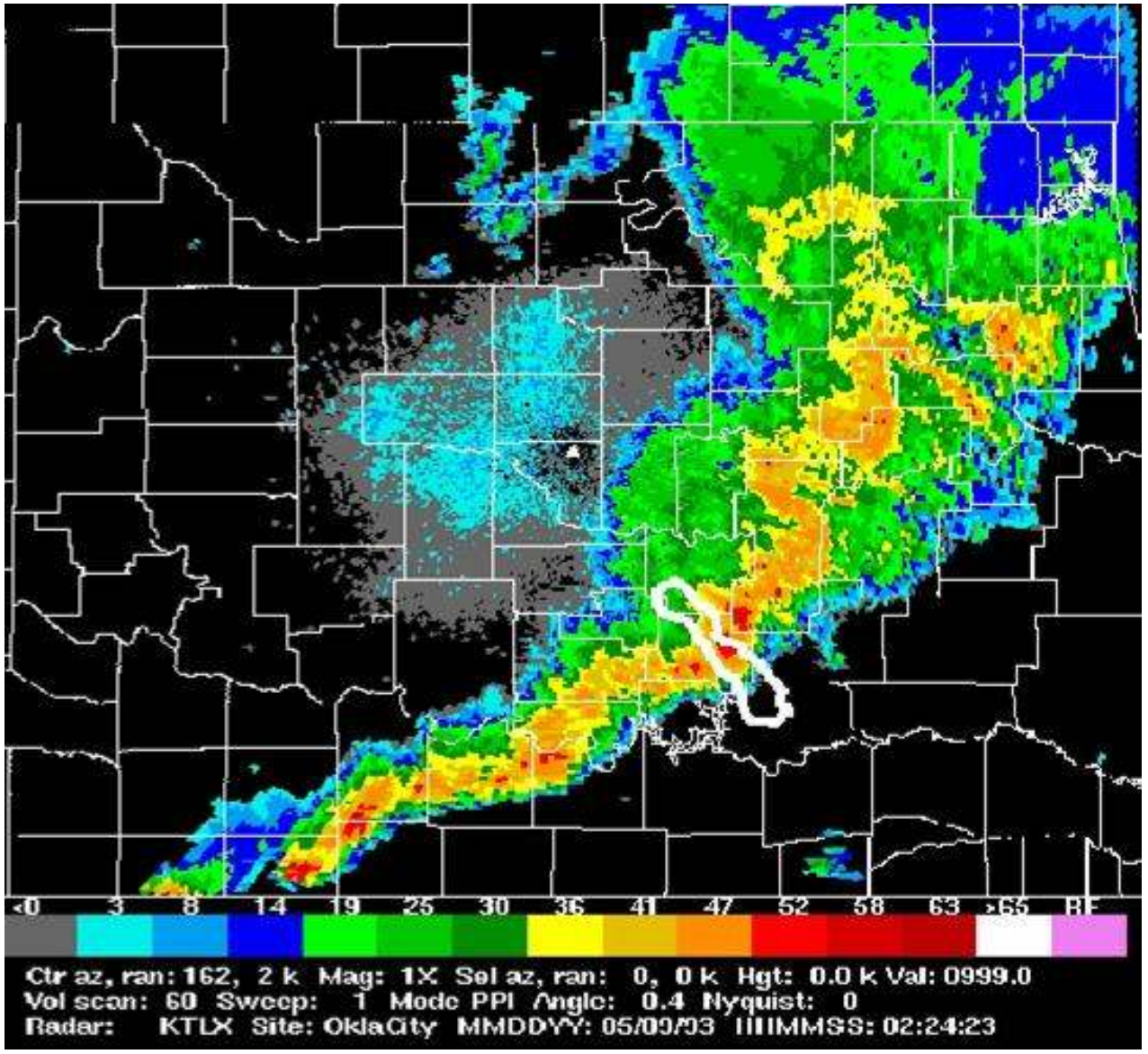
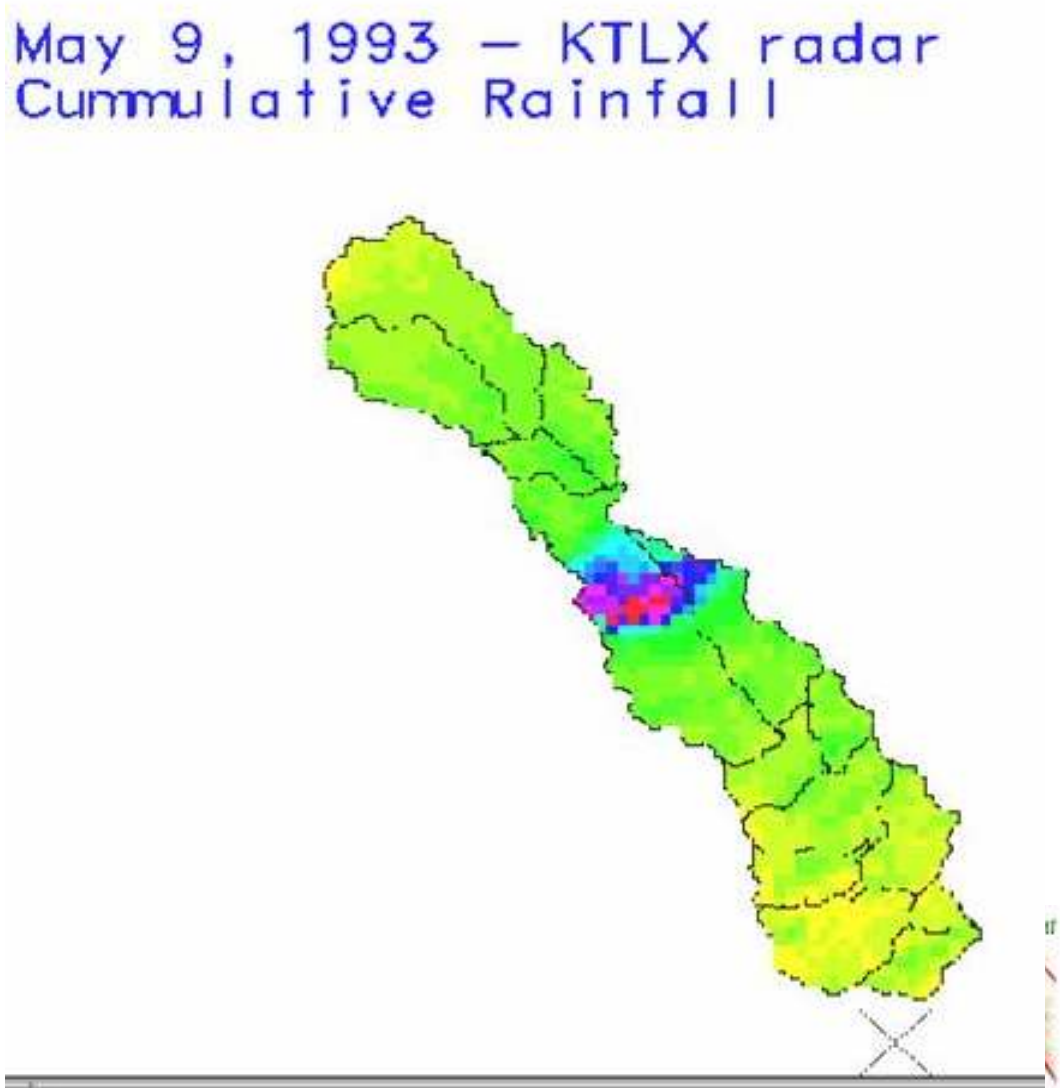
Areal Precipitation NEXRAD



Areal Precipitation NEXRAD



Areal Precipitation Satellites

- There are some usages of satellites for precipitation estimates.
- mostly focused on determining snow accumulation patterns - Advanced Very High Resolution Radiometer (AVHRR).
- Other satellite usage is in tracking storms especially hurricanes and typhoons

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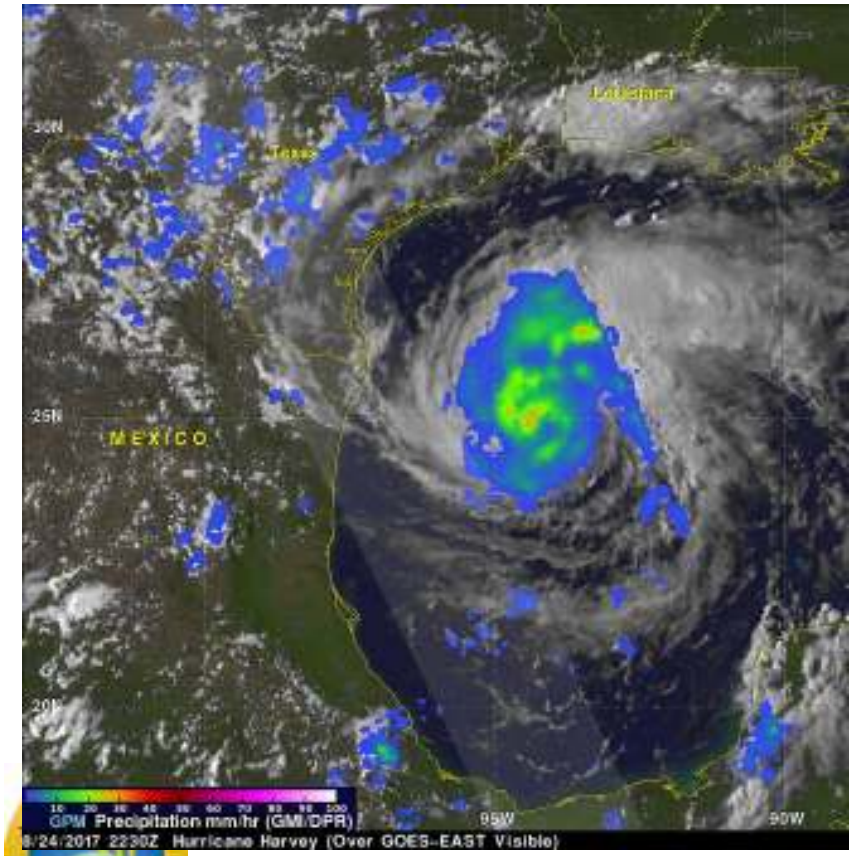
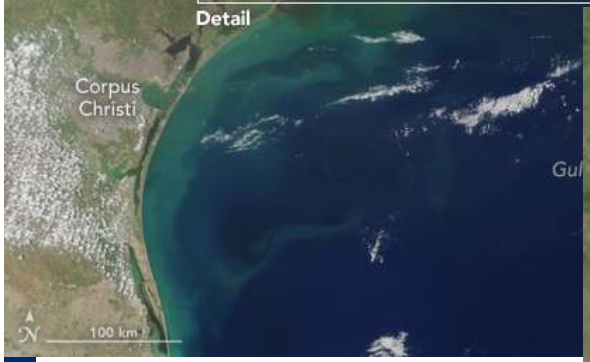
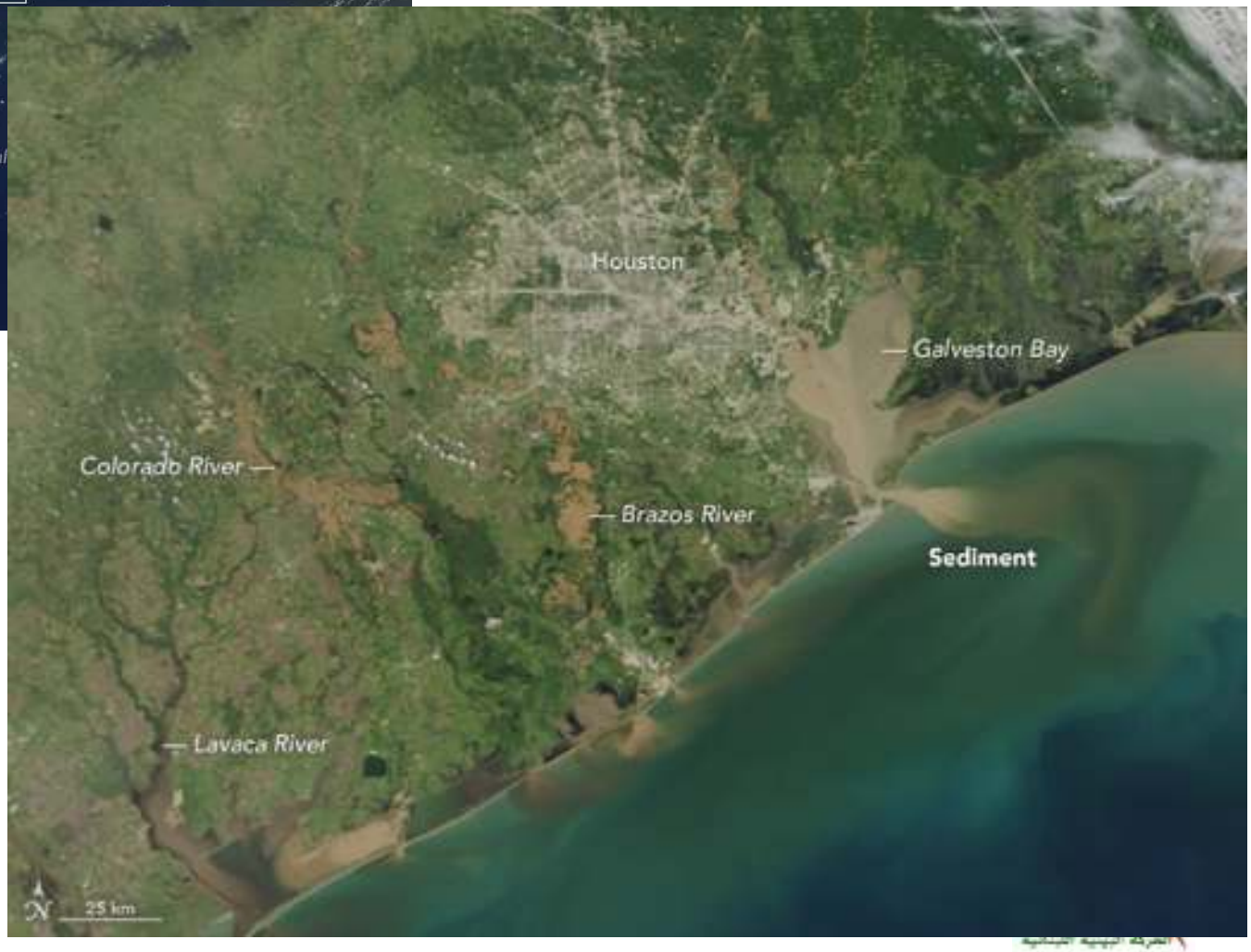
Areal Precipitation Satellites




Houston
Sediment

Detail


Corpus
Christi
100 km


Houston
Galveston Bay
Colorado River
Brazos River
Sediment
Lavaca River
25 km

Output – surface water

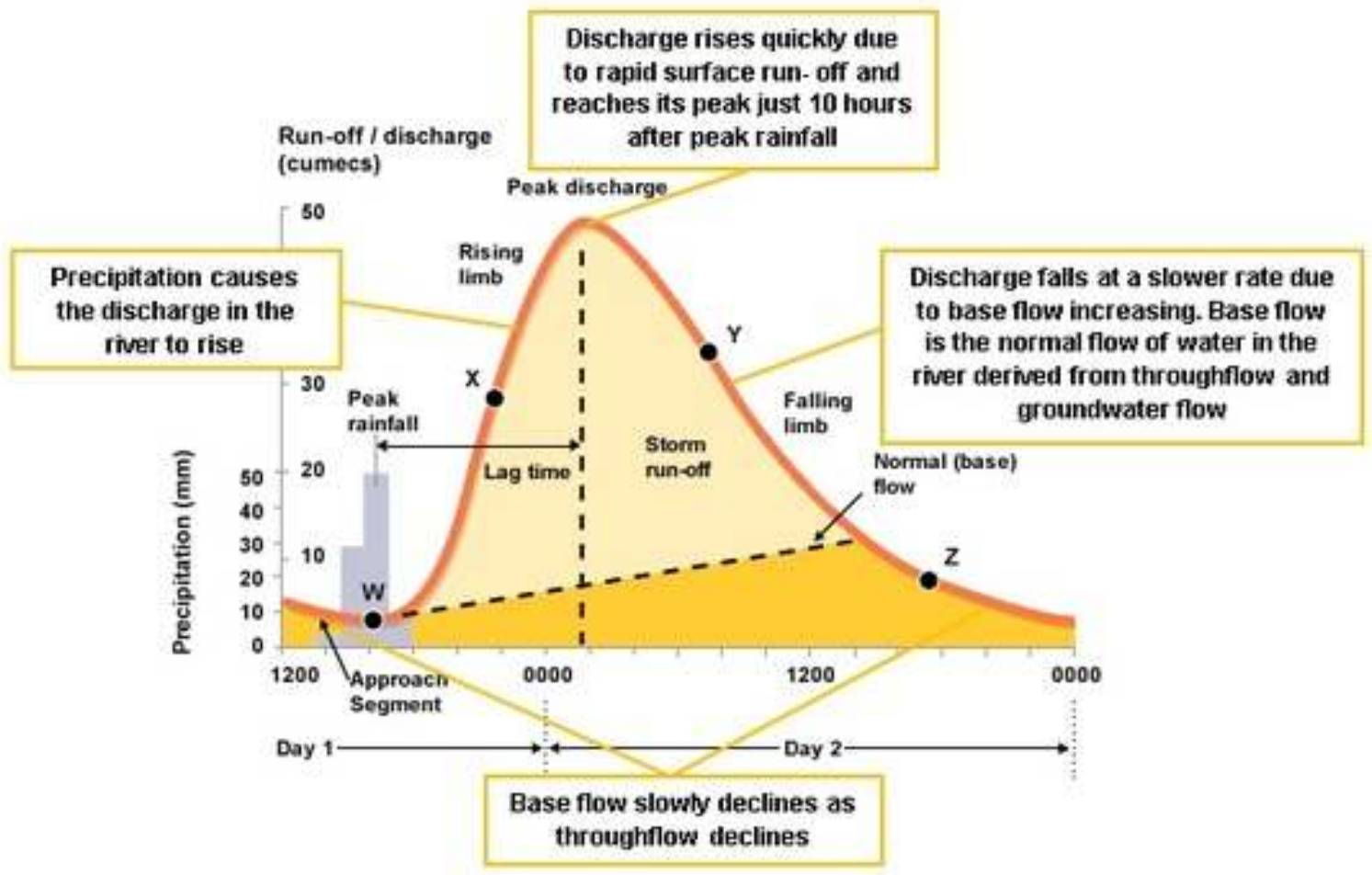
Runoff

- Quantity of water discharged in surface streams
- Includes waters that travel over the land surface and through channels to reach a stream

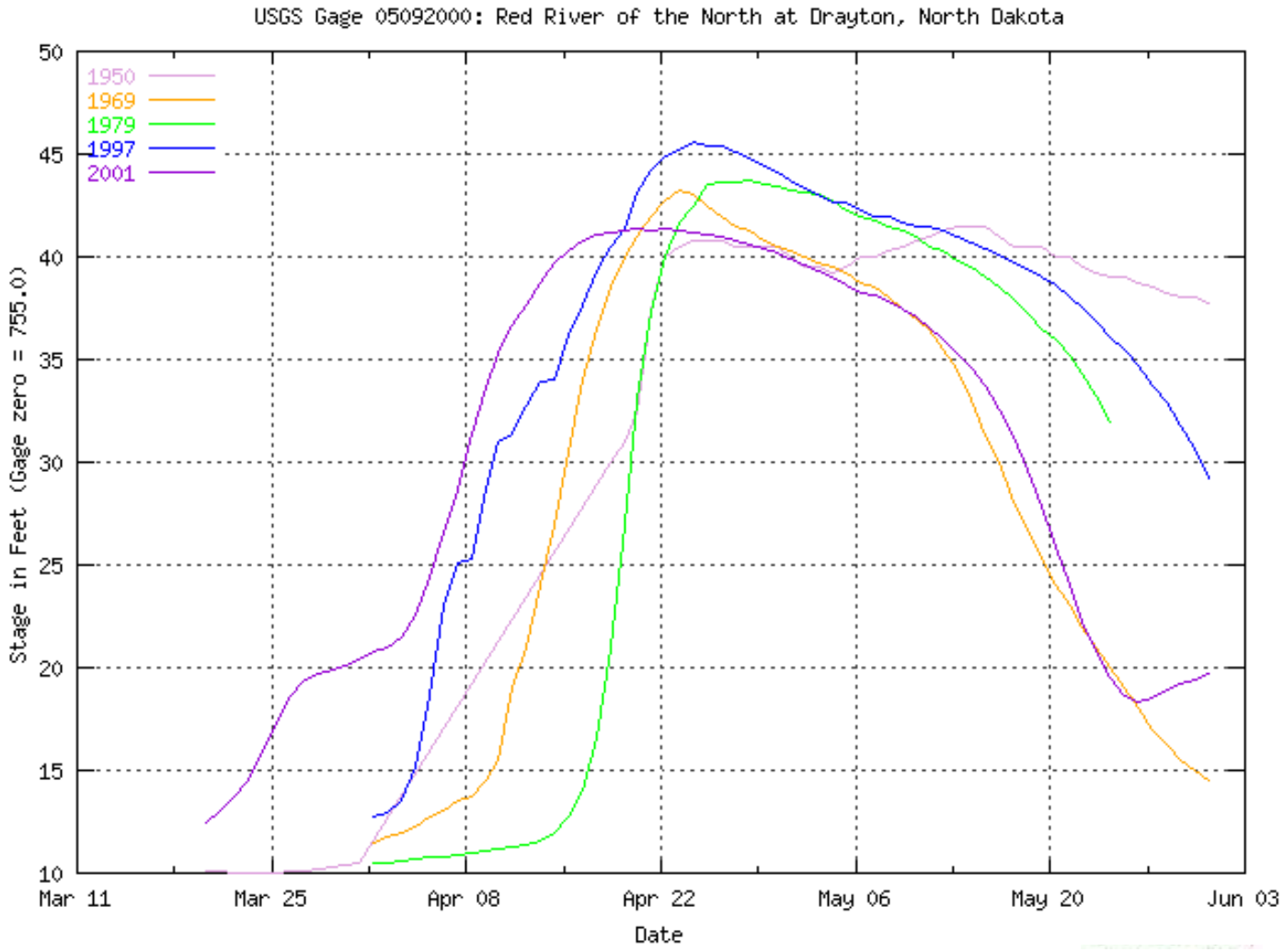
Hydrograph

- is a continuous plot of discharge versus time for a given location within a stream
- it represents the main hydrologic response function of a watershed
- it is the result of a combination of climate, hydrological losses, surface runoff, and base flow
- it is influenced by meteorological and physiographic factors

Components of a Hydrograph



A Real Hydrograph – Red River Discharge



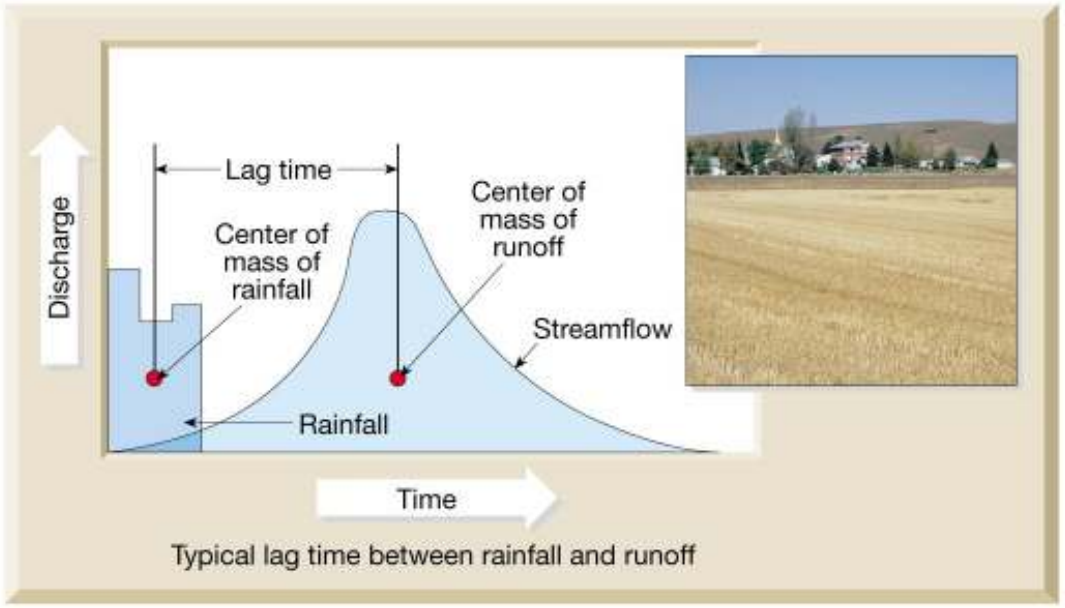
Hydrograph

- Meteorological factors influencing the hydrograph are:
  - Rainfall intensity and pattern
  - Areal distribution of rainfall over the watershed
  - Size and duration of the storm event

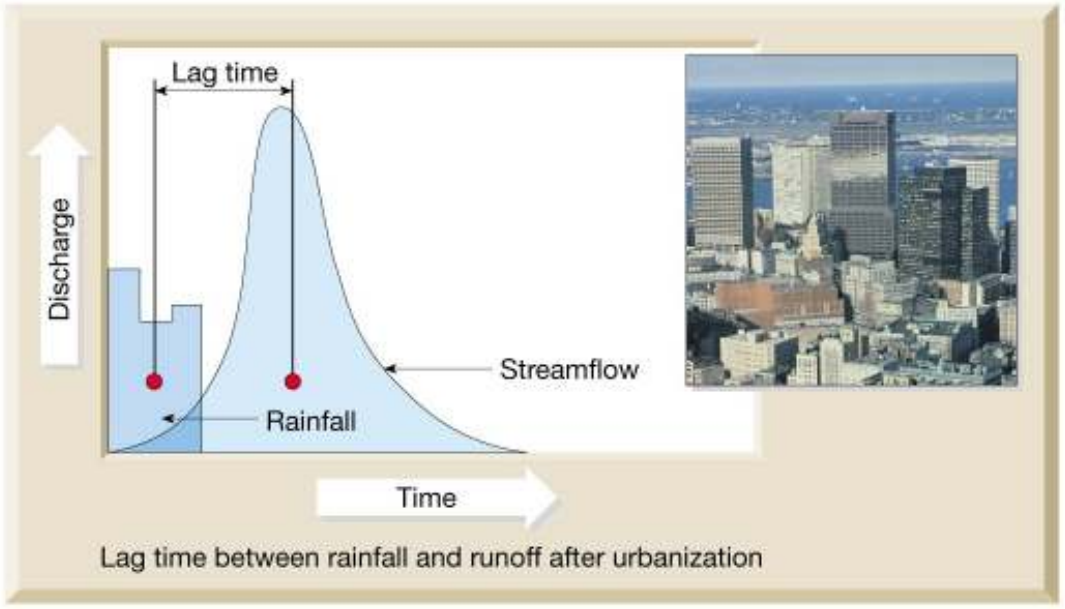
Hydrograph

- Physiographic or watershed factors influencing the hydrograph are:
  - Size and shape of the drainage area
  - Slope of the land surface and of the main channel
  - Soil types and their distribution
  - Storage detention in the watershed

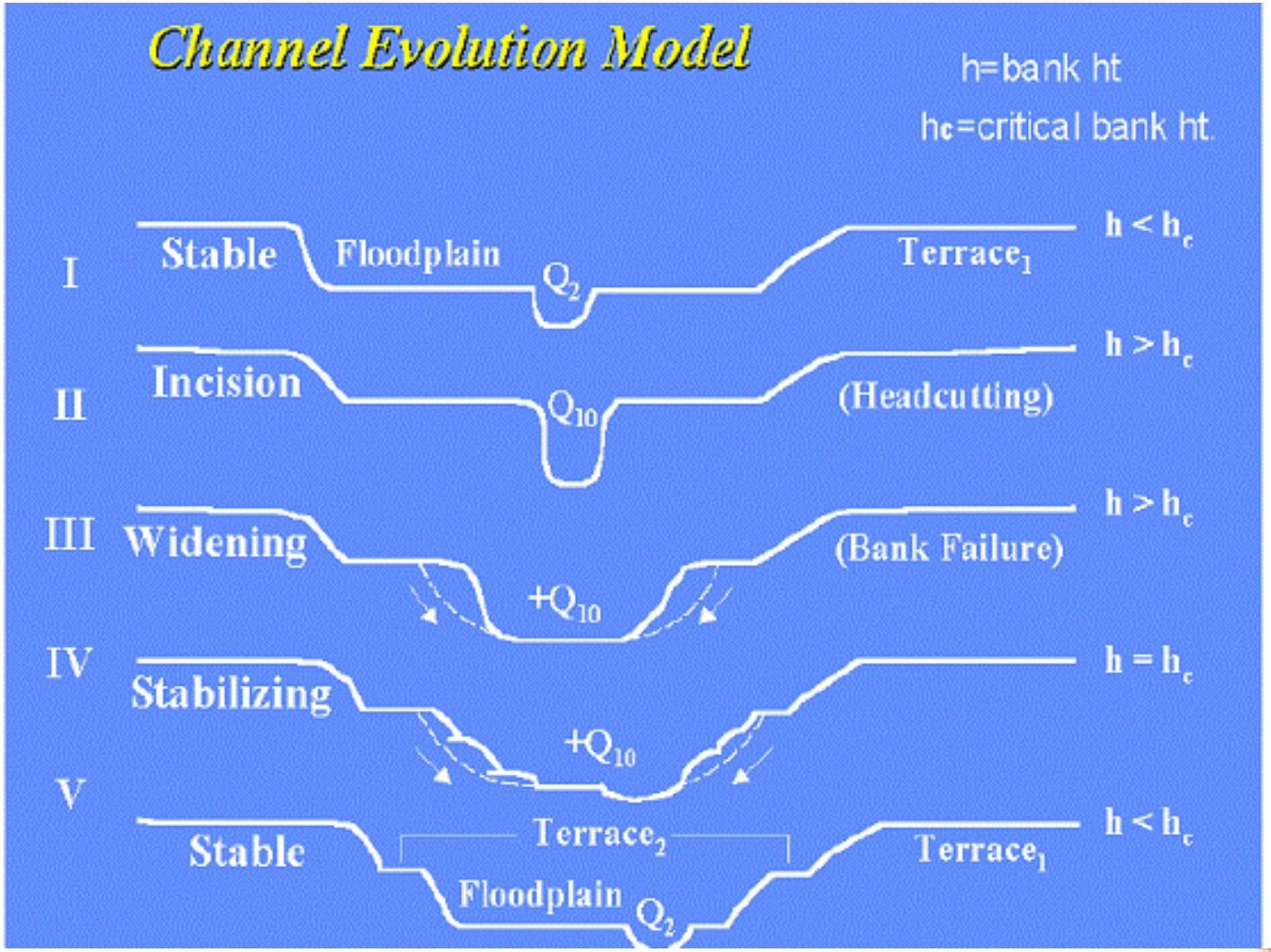
Distribution of Rainfall



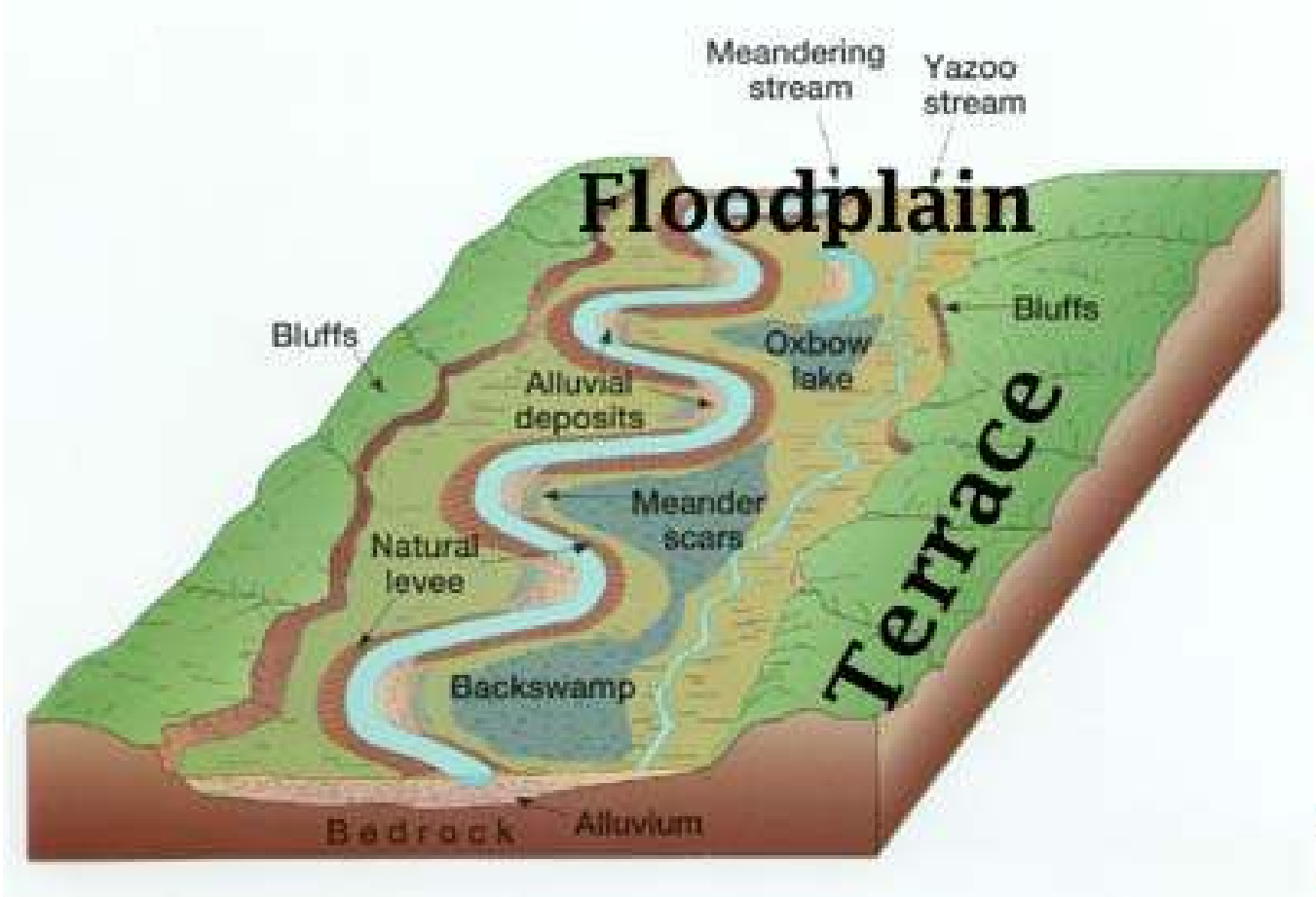
Typical lag time between rainfall and runoff



Lag time between rainfall and runoff after urbanization


Channel Evolution Model
h=bank ht
hc=critical bank ht.
I
Stable
Floodplain
Q2
Terrace1
h < hc
II
Incision
Q10
(Headcutting)
h > hc
III
Widening
+Q10
(Bank Failure)
h > hc
IV
Stabilizing
+Q10
h = hc
V
Stable
Terrace2
Floodplain
Q2
Terrace1
h < hc

Typical Stream Morphology



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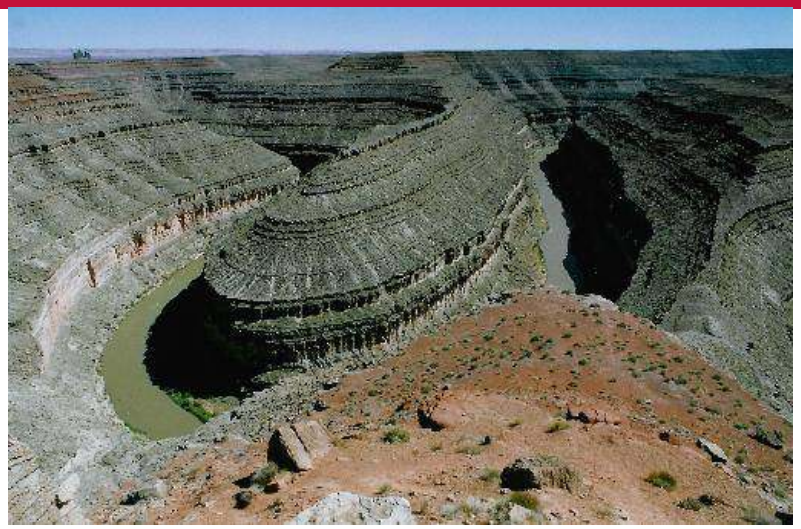
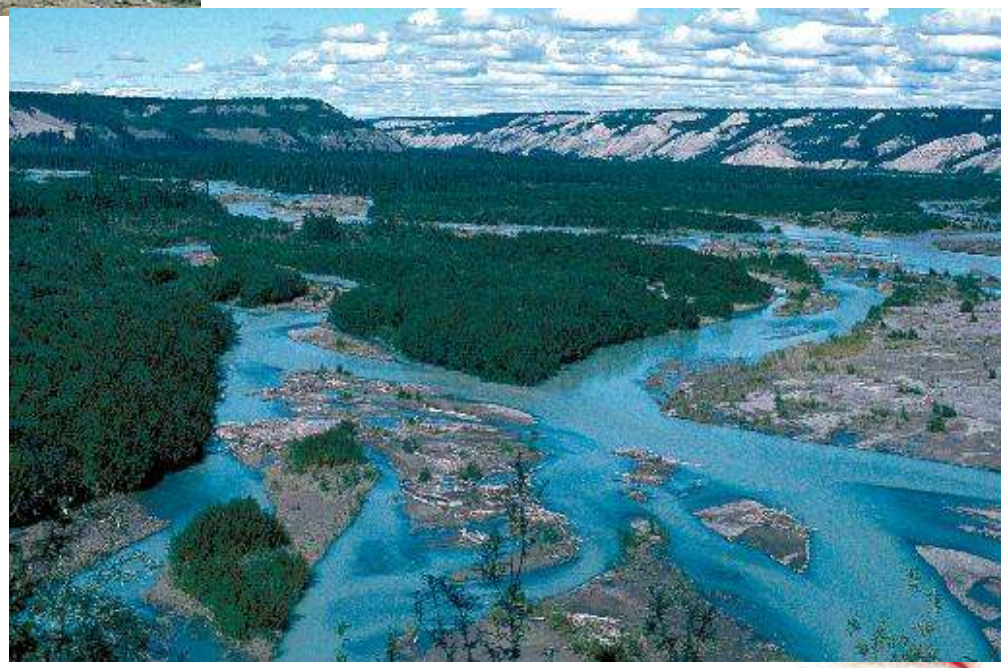




Output – groundwater

Groundwater:

Water occupying *all* voids within a geologic stratum

Vertical Distribution of Groundwater

Two main zones exist:

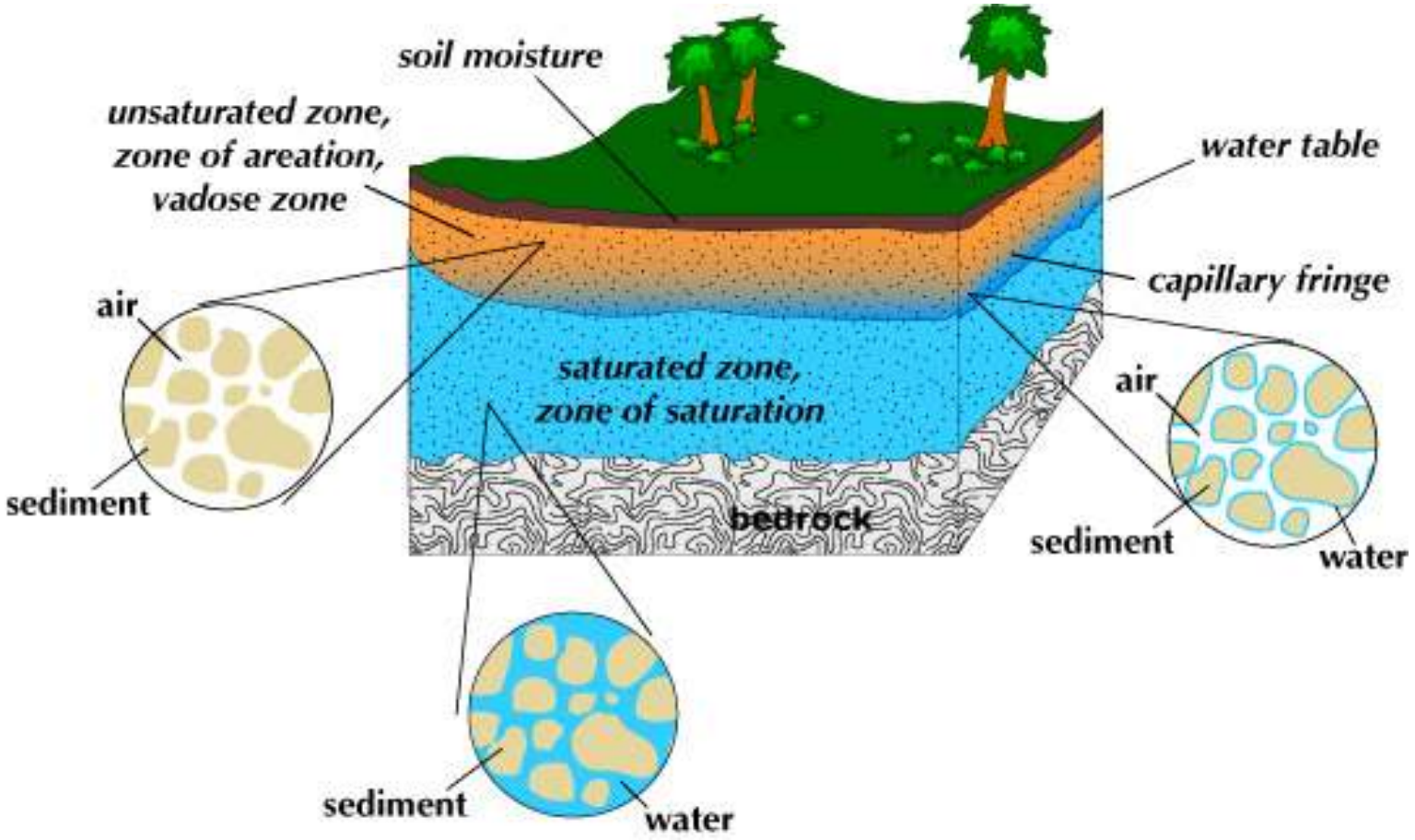
- **Zone of aeration (unsaturated)**: voids occupied by air and water
- **Zone of saturation**: voids totally occupied by water

Vertical Distribution of Groundwater

Zone of aeration or vadose zone is subdivided into:

- Soil-Water Zone
- Intermediate Vadose Zone
- Capillary Zone or Capillary Fringe

Zone of Saturation is typically not subdivided into smaller strata

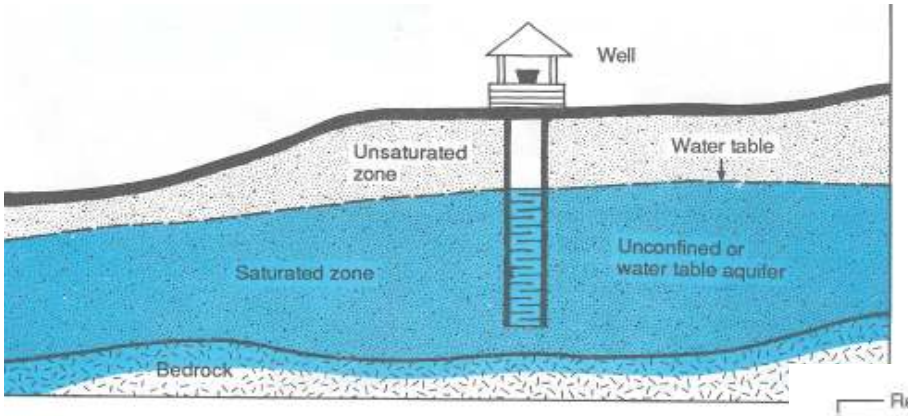

soil moisture
unsaturated zone,
zone of areation,
vadose zone
water table
capillary fringe
air
saturated zone,
zone of saturation
air
sediment
bedrock
sediment
water
sediment
water

Definition of an aquifer:

Formation that contains sufficiently permeable material to store, transmit, and yield water to wells and springs in sufficient quantities

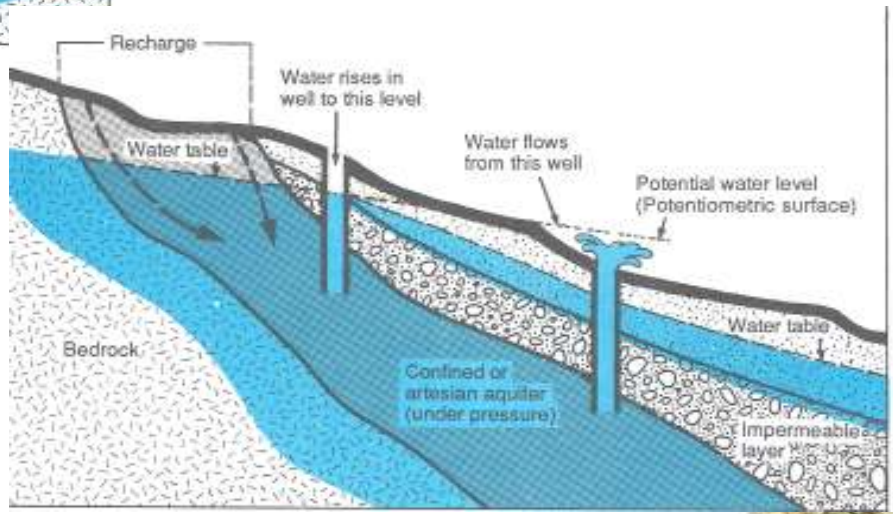
- Confined aquifers
- Unconfined aquifers

Unconfined versus Confined Aquifers

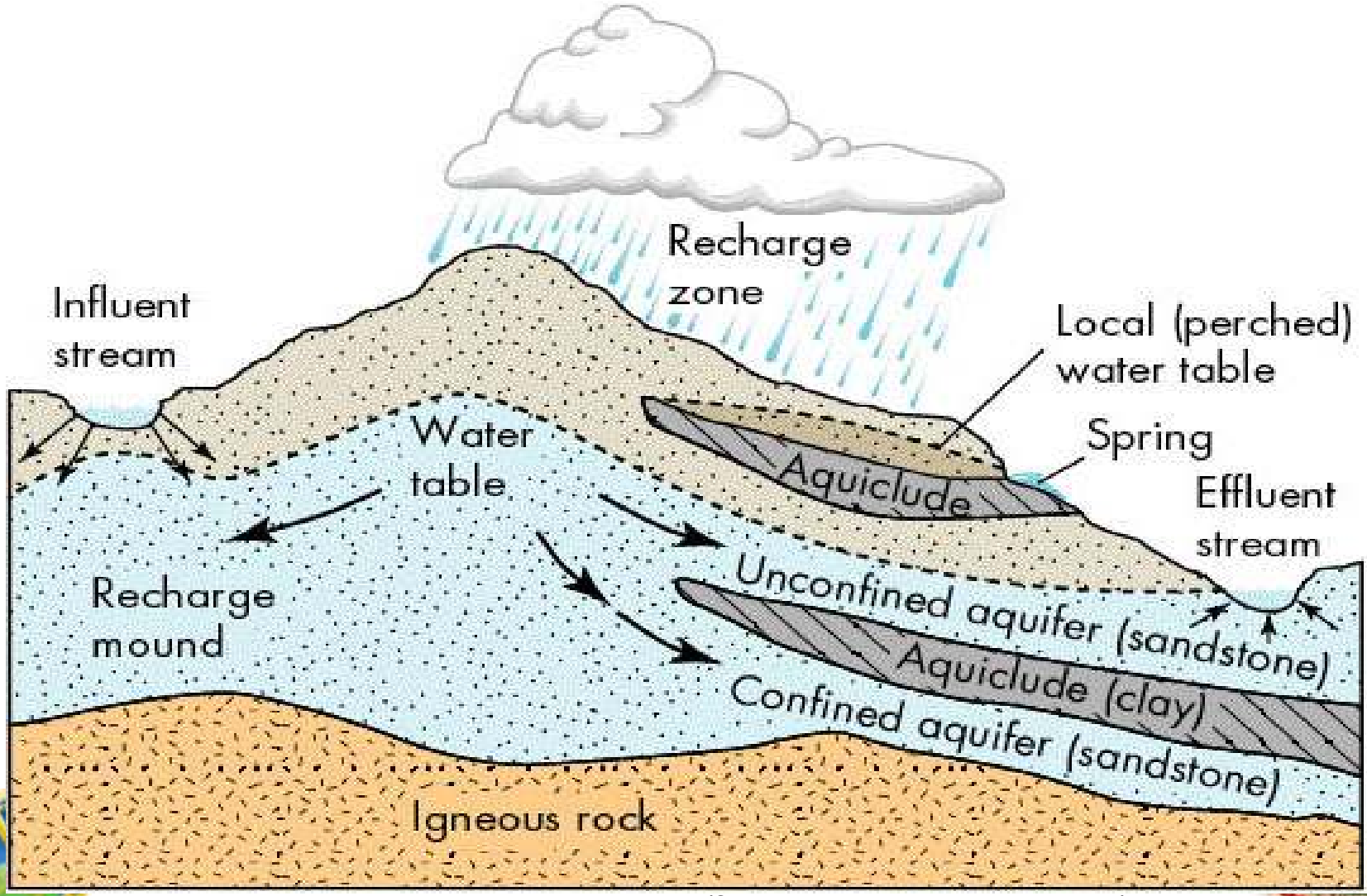


UNCONFINED AQUIFER

CONFINED AQUIFER

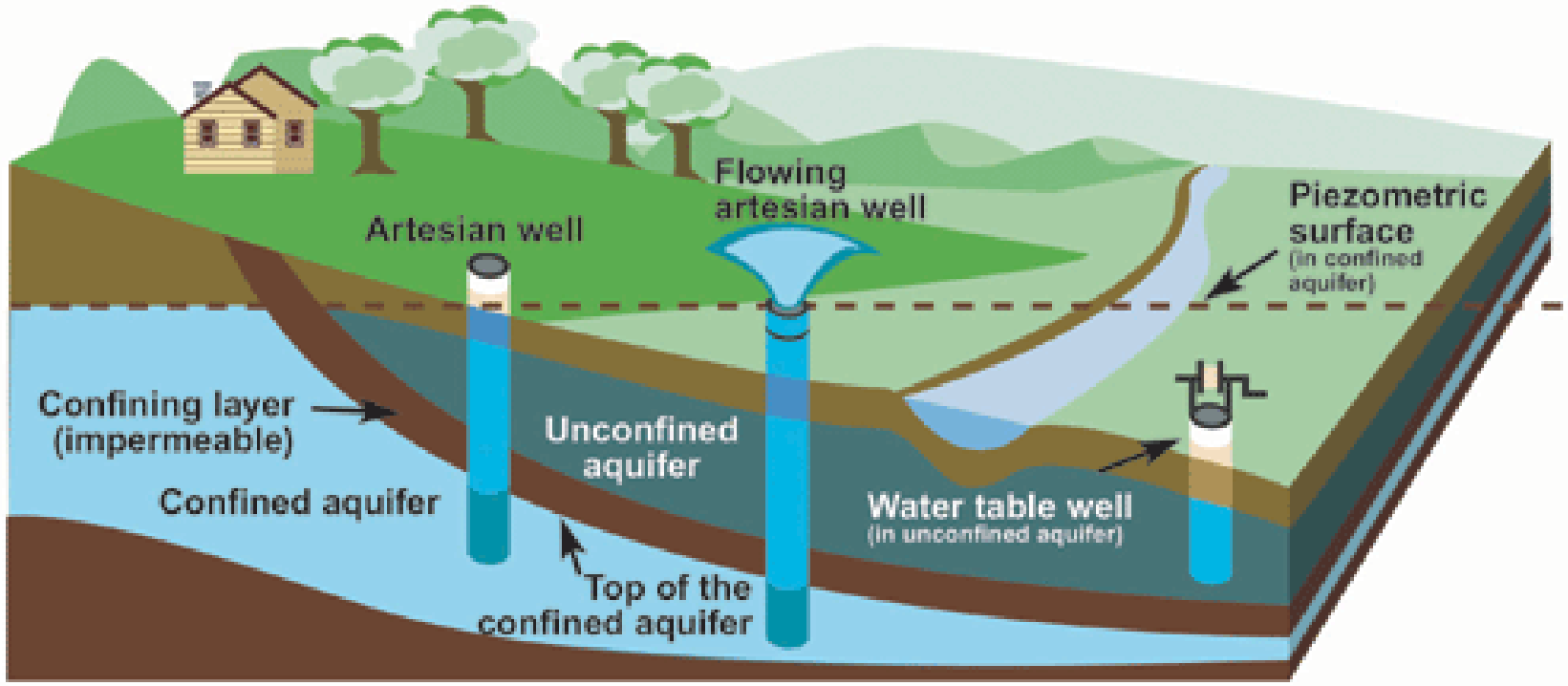


From: Michigan State University Cooperative Extension Service Bulletin WQ 35 What is Groundwater



(from Keller, 2000, Figure 10.9)

Aquifers and wells

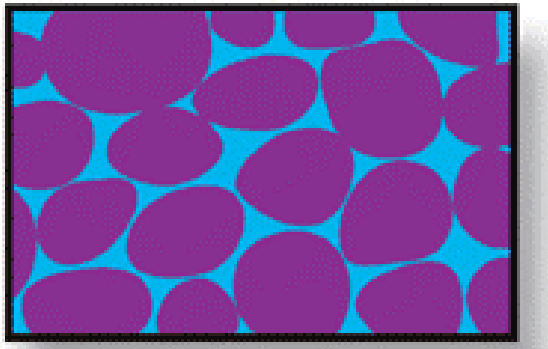


Suitable Material:

- Alluvial Deposits (mostly unconsolidated material e.g. gravel and sand) - 90% of aquifers
- Sandstone -
- Limestone (cavernous limestone)
- Basalt, lava, other volcanic material, if fractured or porous or have interconnected vesicles

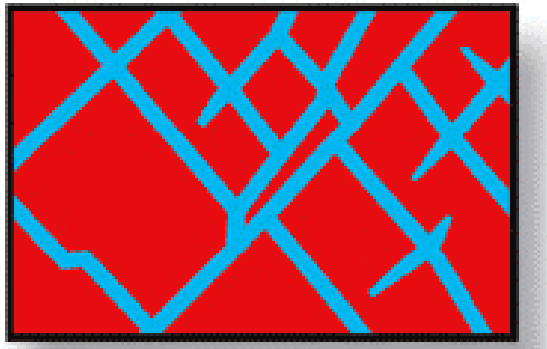
Aquifer Material

Sand and gravel



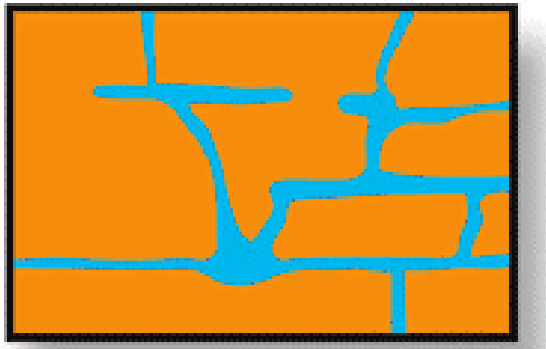
Intergranular

Igneous rocks



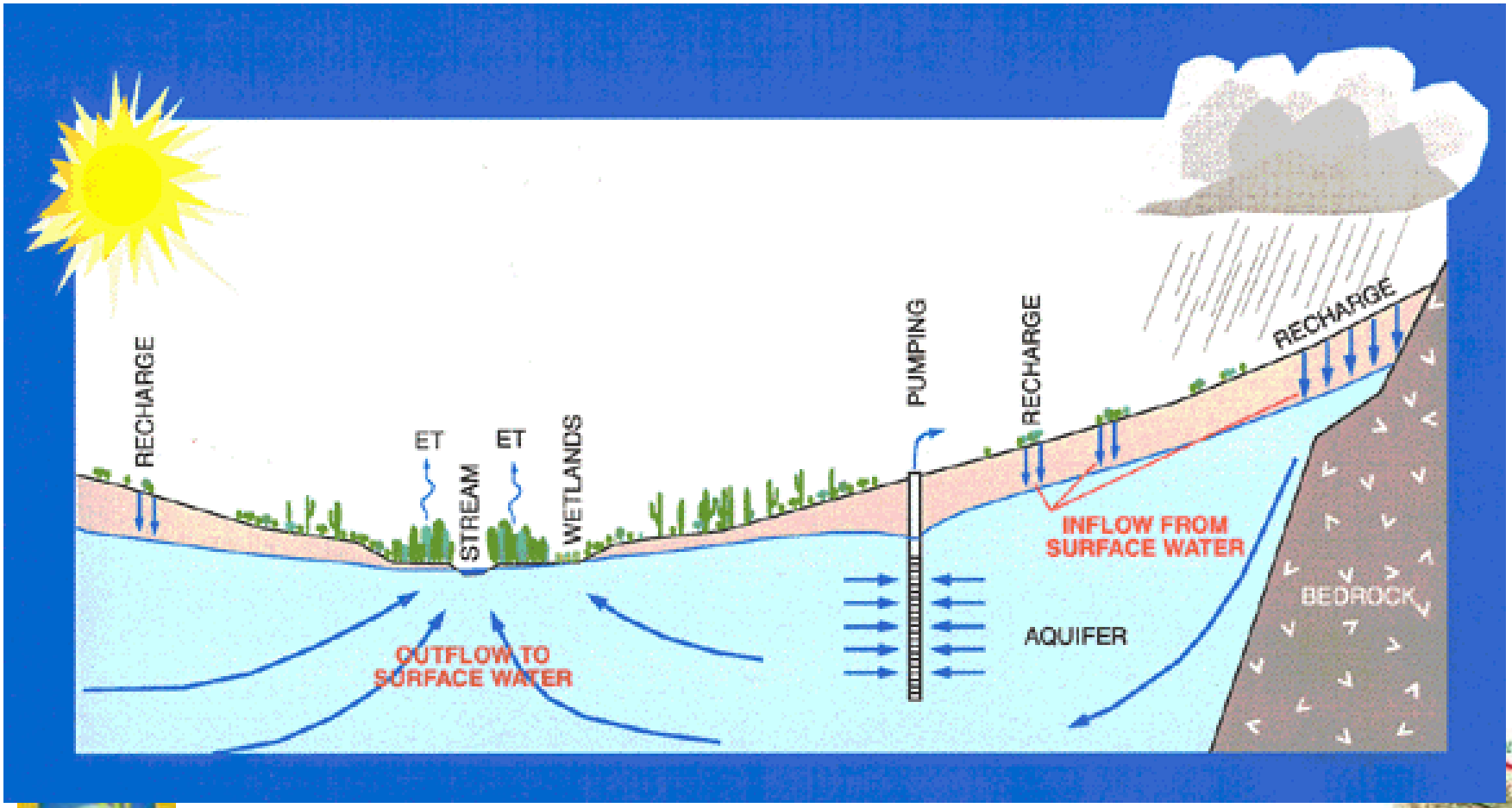
Crevice

Limestone

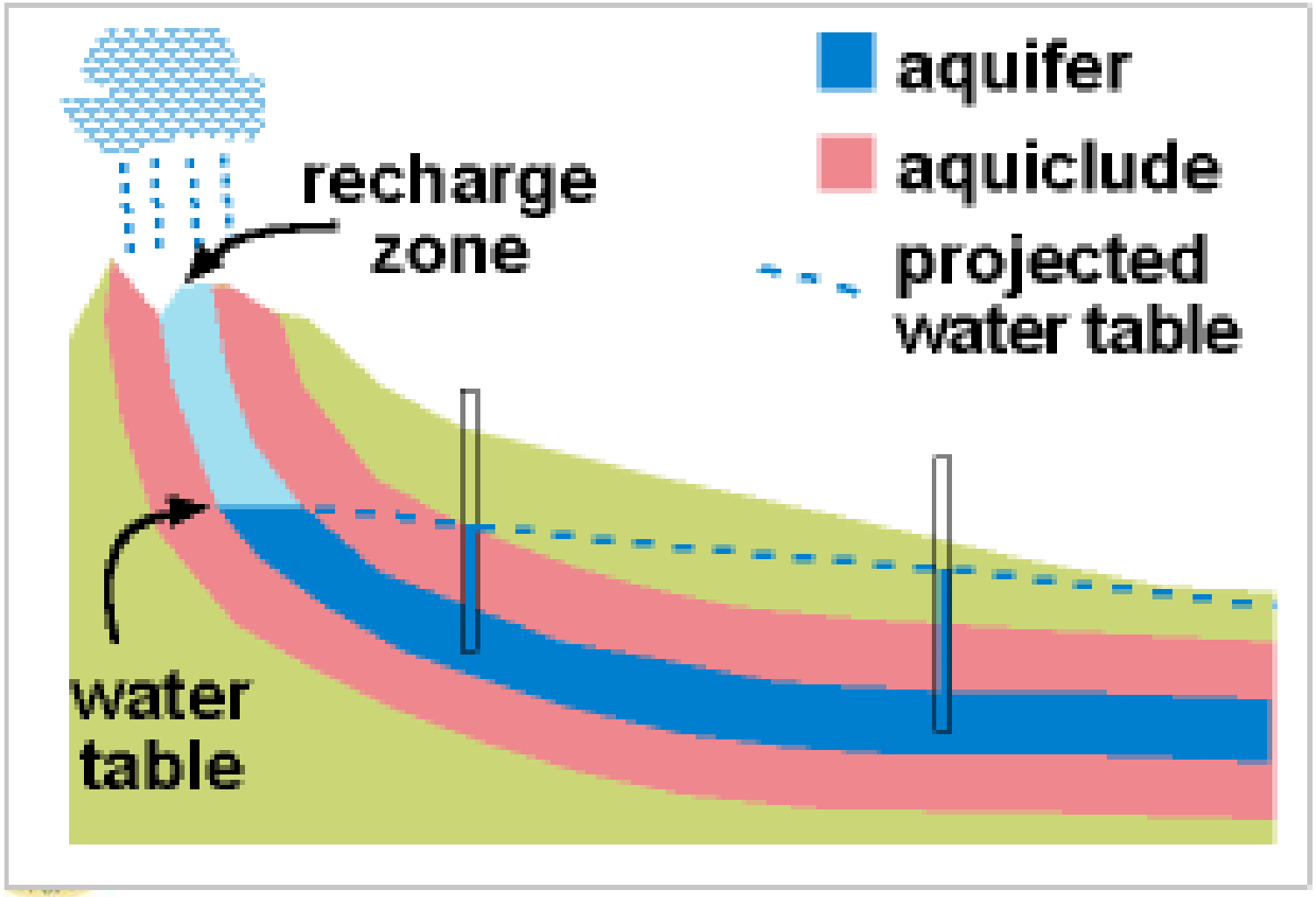


Solution

Groundwater Flow



Groundwater Flow



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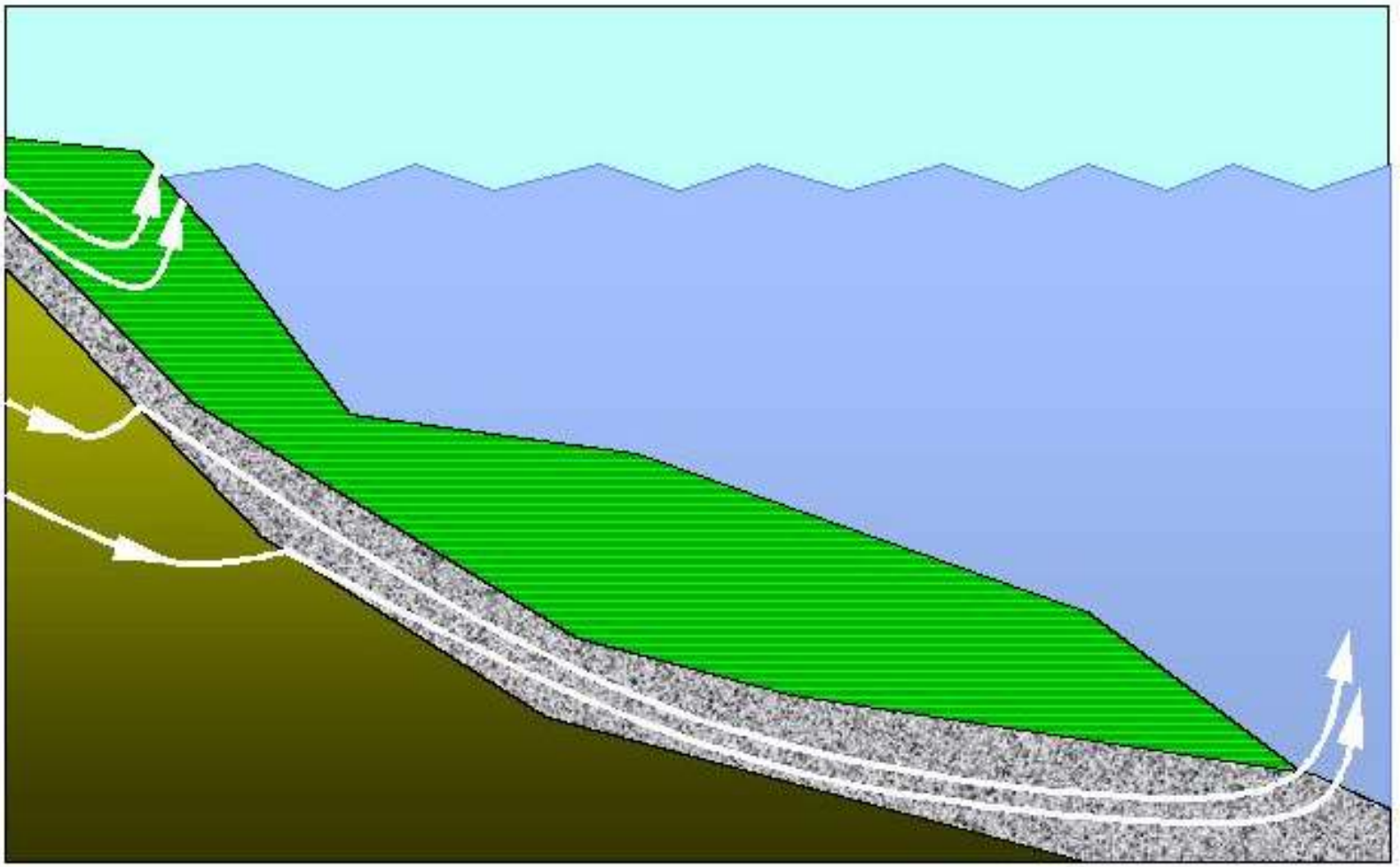
Sea Springs



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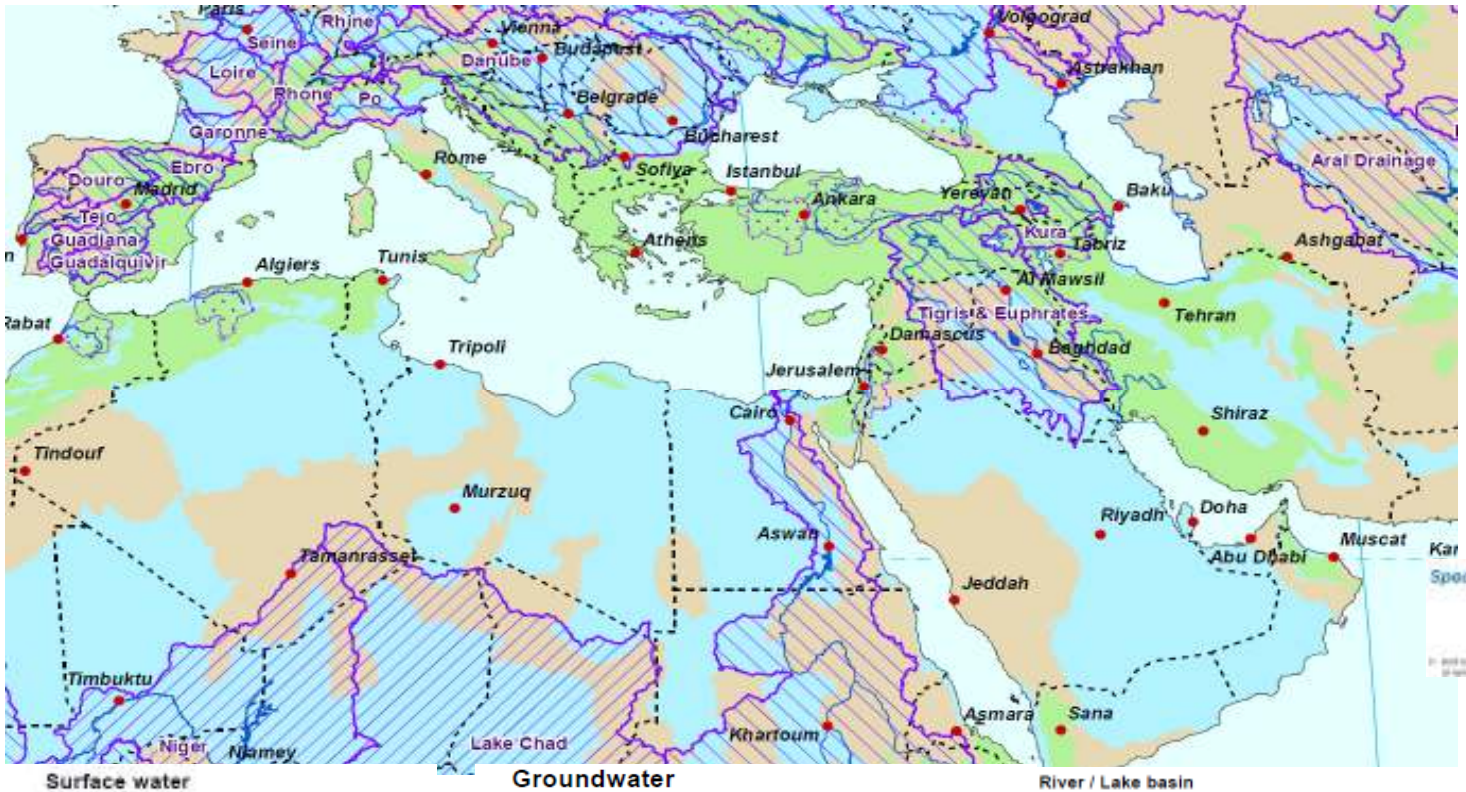
Groundwater Extent



Surface water

- major river
- large freshwater lake
- large saltwater lake
- continuous ice sheet

Groundwater

- in major aquifer basin
- in complex hydrogeological structures
- in local and shallow aquifers

River / Lake basin

- with underlying groundwater basin contained within the boundaries of river / lake basin
- with underlying groundwater basin extending beyond the boundaries of river / lake basin
- less important river / lake basin, partly underlain by groundwater basin
- no active river / lake basin, but partly underlain by important groundwater basin

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Surface Water Pollution

Lebanon Eco Movement

Water Pollution

- What is water pollution:
  - Any chemical, biological, or physical change in water quality that harms living organisms or makes water unsuitable for desired uses

- Sources of pollution:
  - Point source: discharge pollutants at specific locations
    - sewage
    - industrial wastes
  - Non-point source: scattered and diffuse and cannot be traced to a specific site of discharge
    - Agricultural activity [e.g. pesticides, fertilizers, erosion].
    - urban and highway water runoff.

Pollution Sources

- Oil spills – during transportation, either accidentally or intentionally
- Dumping –sewage, chemical disposal, radioactive materials
- Land-based sources –migration of chemical substances.
- Eroded soils:
  - Organic material
  - Soil-borne pathogens
  - Chemicals and nutrients
  - Radioactive material
  - Thermal/heat

Non-accumulating pollutants

Capacity for absorption is higher than rate of injection pollutants may not accumulate.

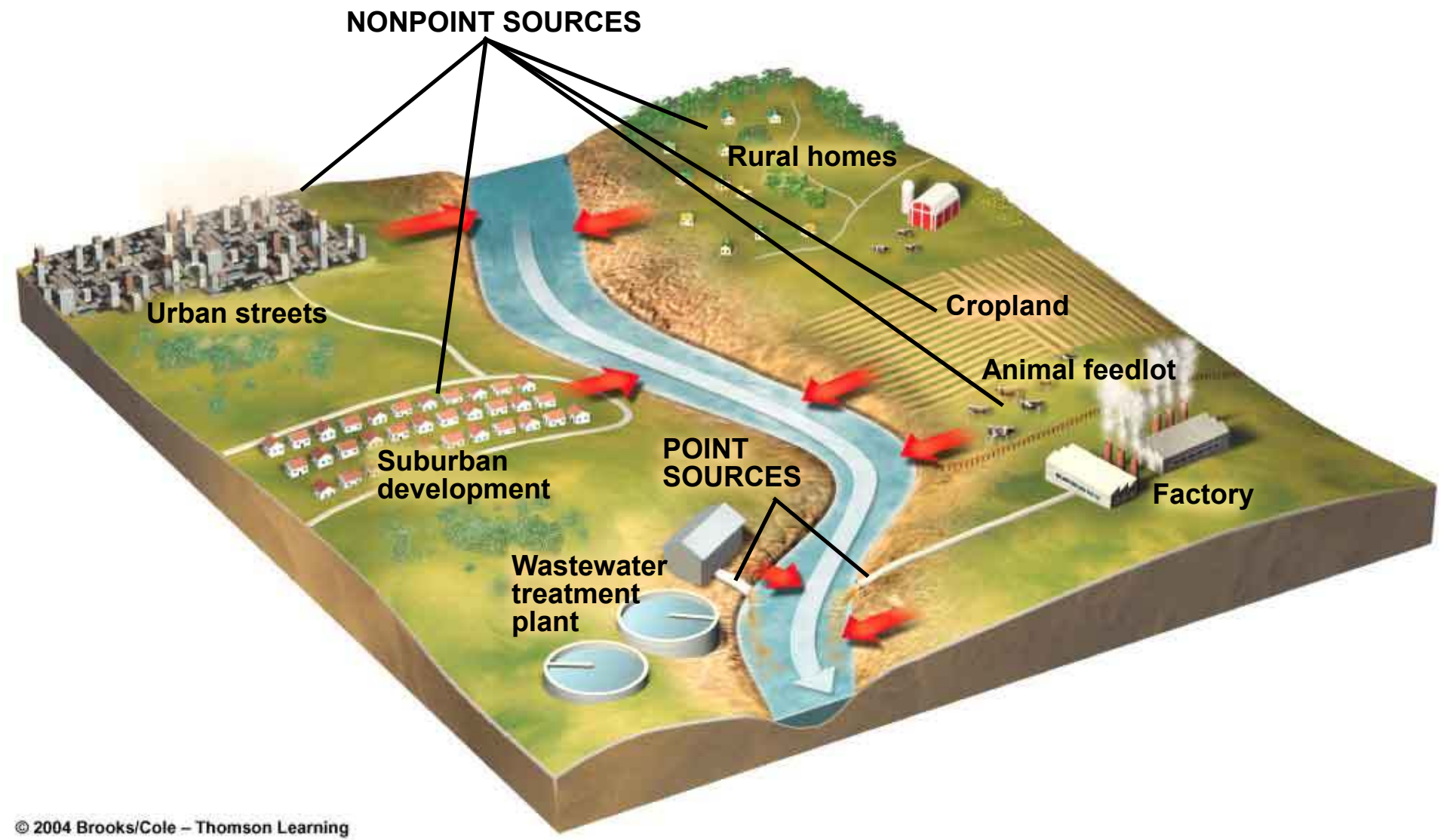
- **Degradable Pollutants**
  - Degrade into component parts within water. Typically are organic residuals attacked and broken down by bacteria and become less harmful.
- **Nutrients**
  - stimulate growth of aquatic plant life, e.g. algae and water weeds.
  - can produce odor if in excess
- **Infectious organisms** [e.g. bacteria and viruses]
  - carried into both ground and surface water by domestic and animal wastes; industrial wastes e.g. tanning and meat packaging
  - Are live organisms that may thrive and multiply in water or decline.
- **Thermal**
  - caused by injection of heat into watercourses by an industrial plant or electric utility using surface water as a coolant, and returning the heated water to the watercourse.

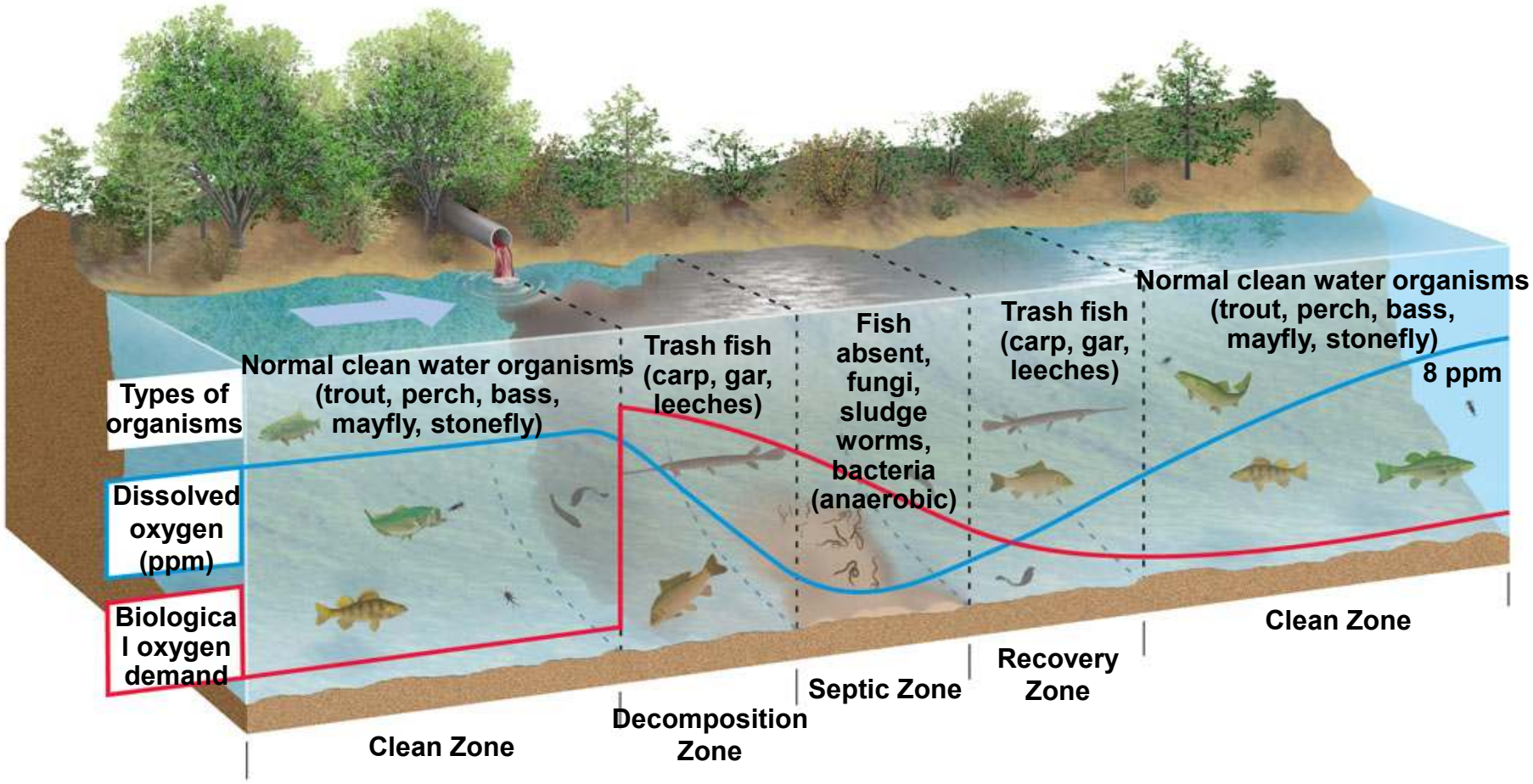
Accumulating Pollutants

- Environment has little or no absorptive capacity [i.e. no natural process removes/transforms them].
  - accumulate over time.

- Examples: non-biodegradable bottles, heavy metals [e.g. lead, mercury]; persistent synthetic chemicals [e.g. dioxin, and PCBs –polychlorinated biphenyls]
  - not easily broken down; so can remain in water for long.
  - also accumulate in the food chain.

Pollution pathways





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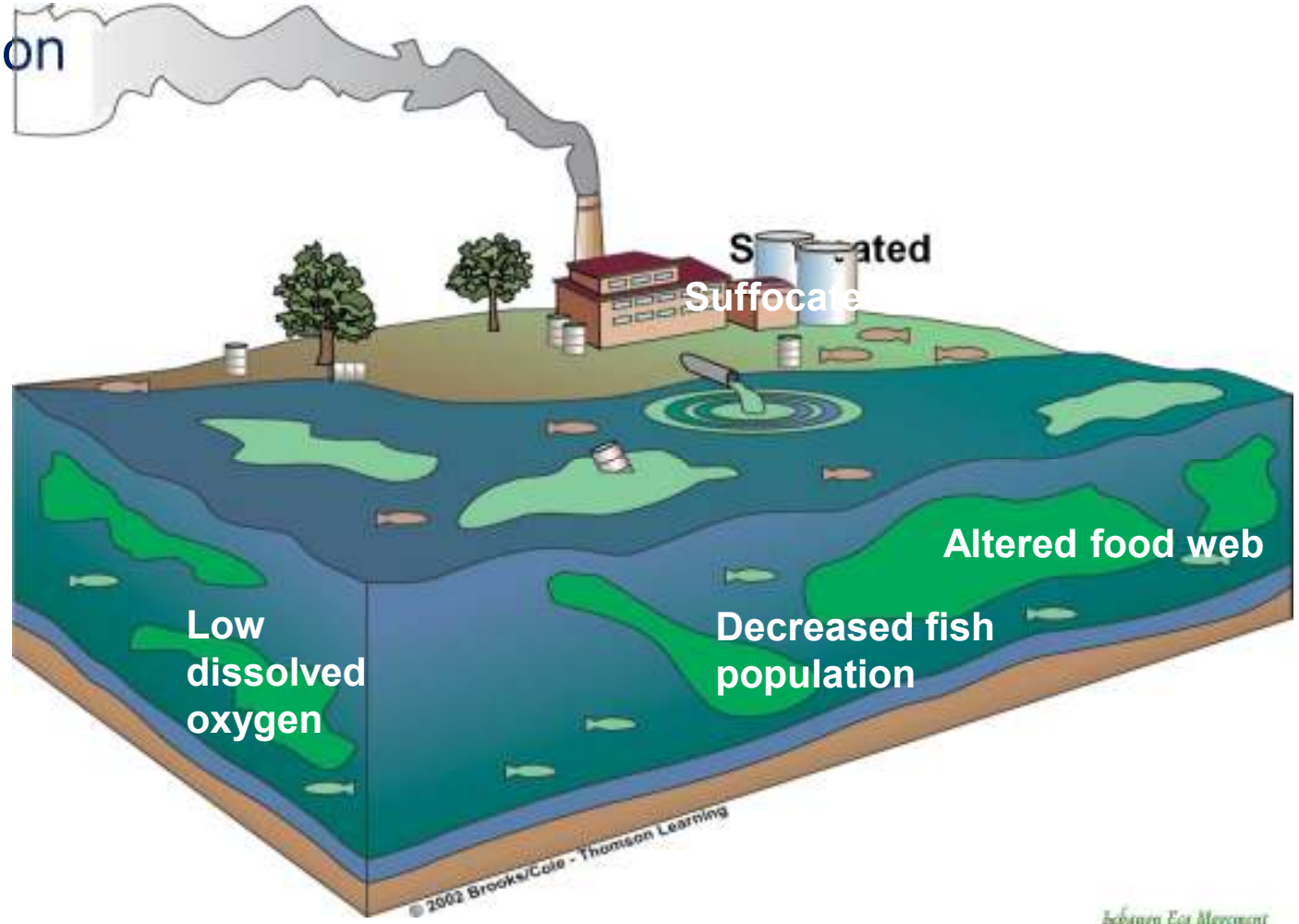
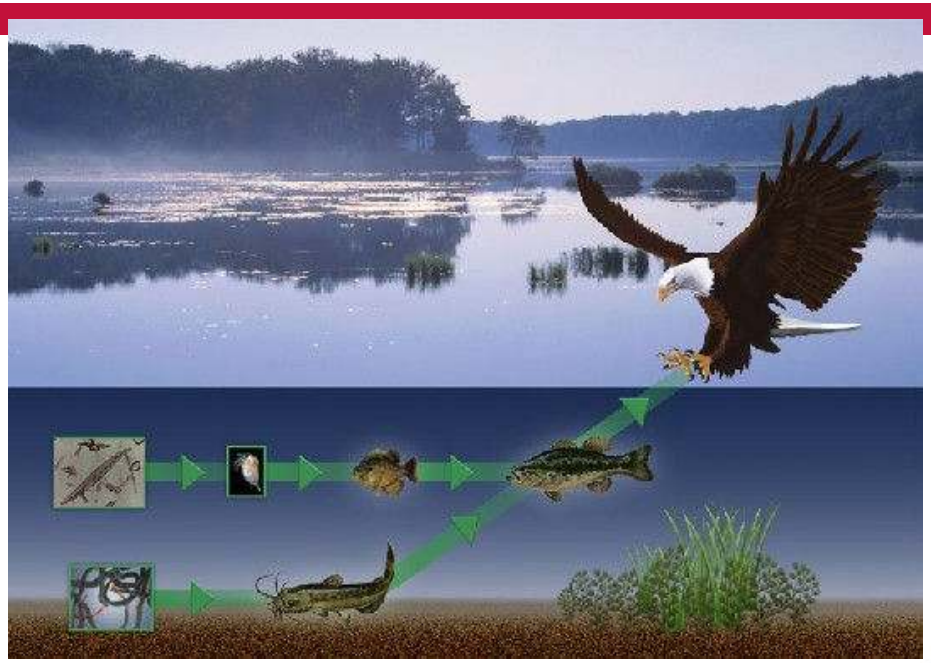
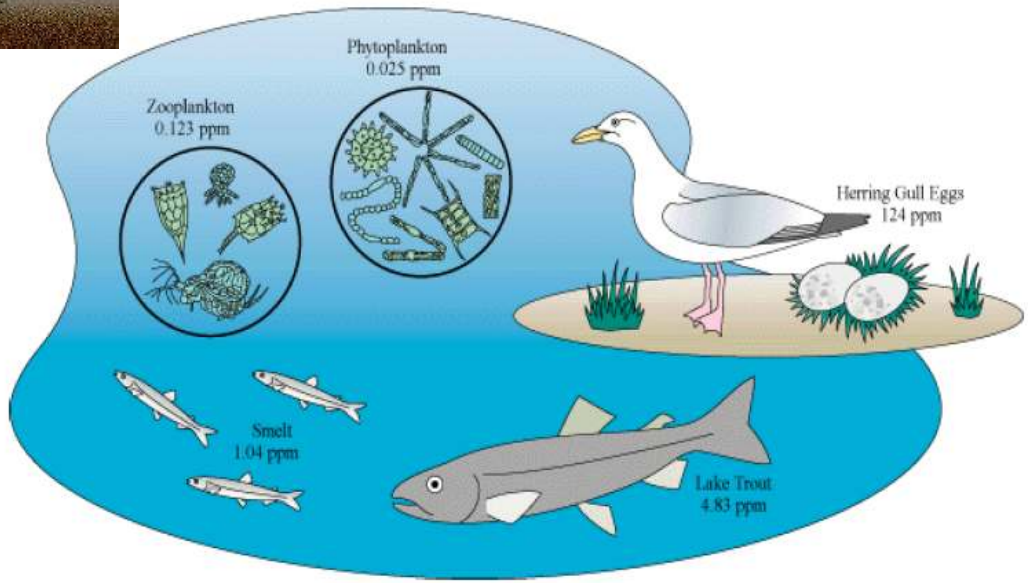
Thermal Pollution






Phytoplankton
0.025 ppm
Zooplankton
0.123 ppm
Herring Gull Eggs
124 ppm
Smelt
1.04 ppm
Lake Trout
4.83 ppm

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Groundwater Pollution

Groundwater Quality

- Dissolved minerals and chemicals
- No turbidity, few microorganisms: filtered out by soil
- Metals - Iron and manganese
- Other specific contaminants
  - Some of the groundwater is contaminated with hazardous substances from landfills and septic systems, as well as illegal and uncontrolled hazardous waste dumps.
  - Once contaminated, groundwater is difficult to restore.

Groundwater Pollution

- Landfills - leachates
- Septic systems, as well as
- Illegal and uncontrolled hazardous waste dumps.

Once contaminated, groundwater is difficult to restore.

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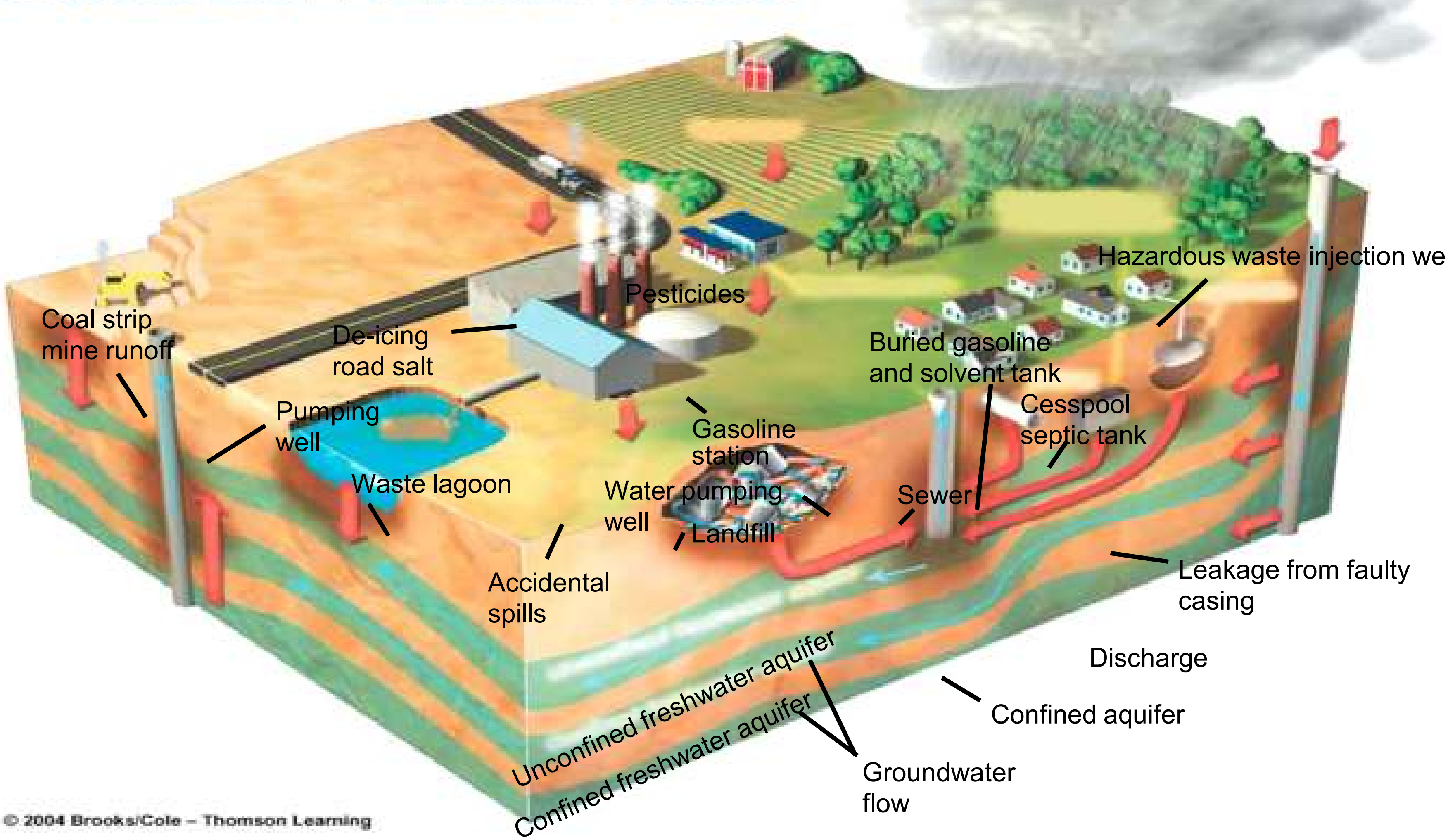
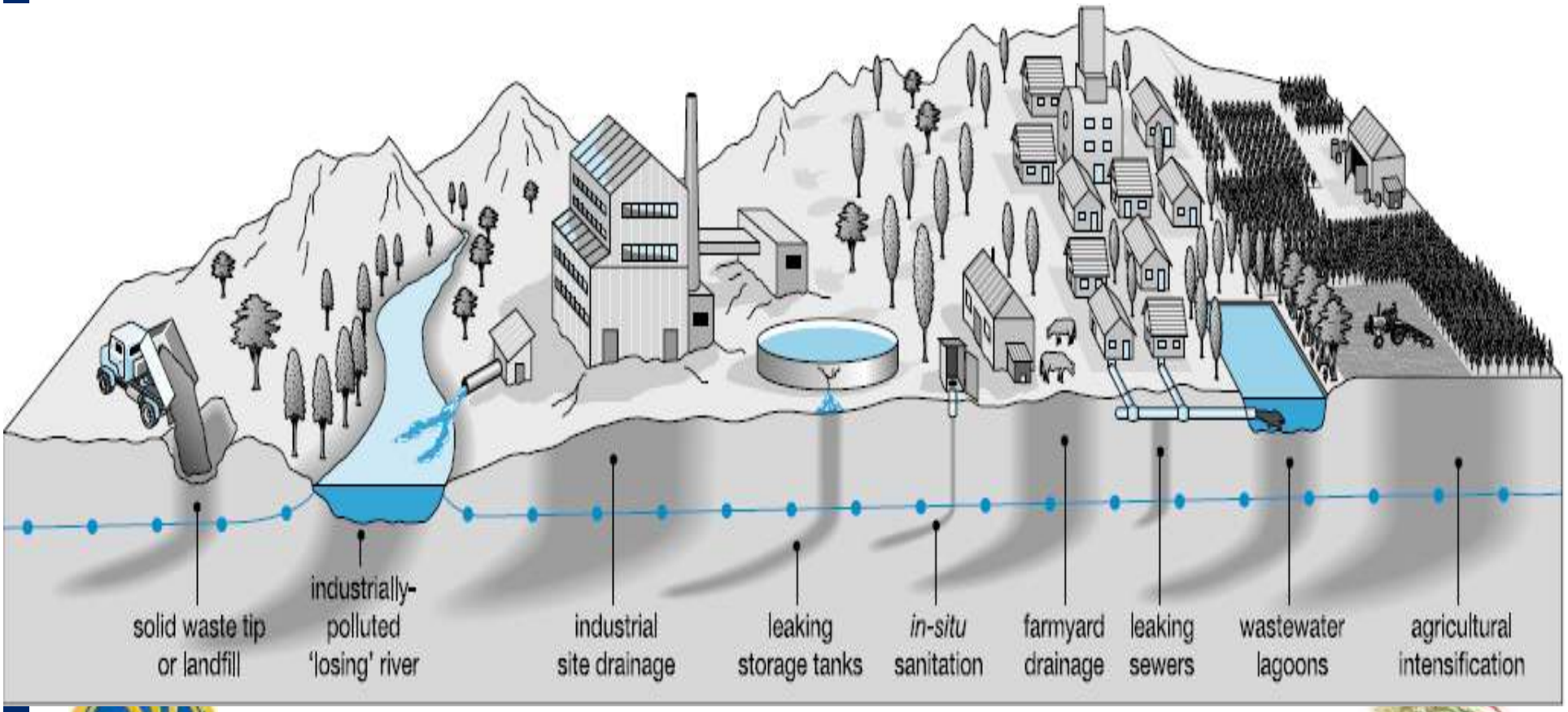
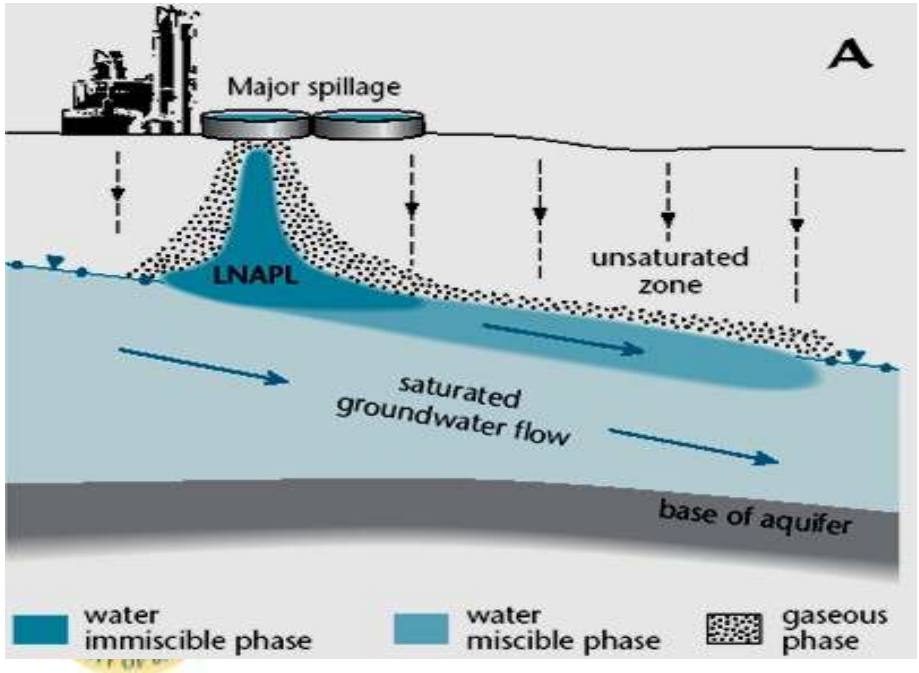
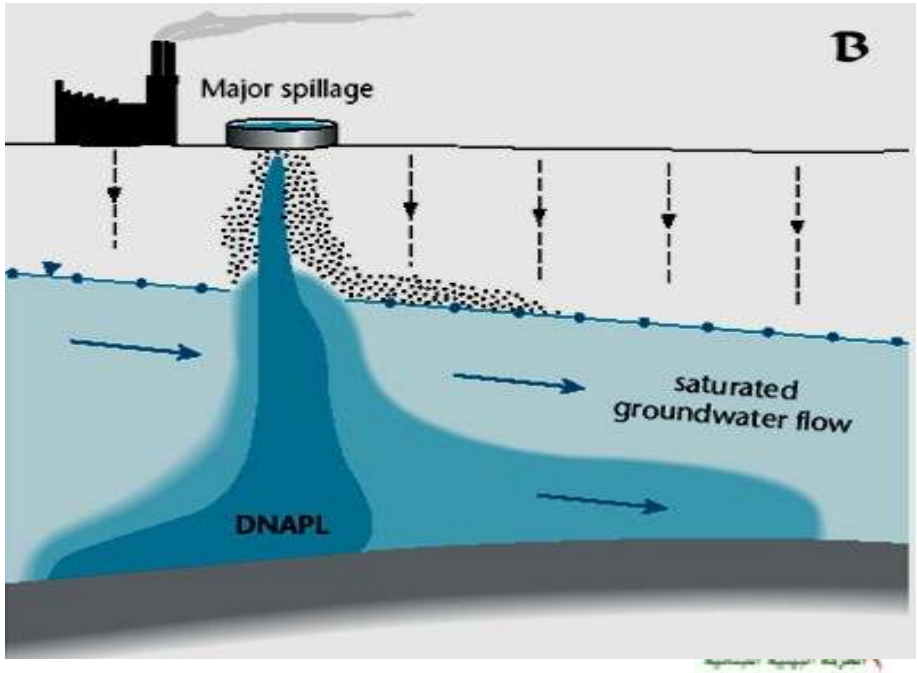
Groundwater Pollution: Causes



Groundwater Pollution: Causes

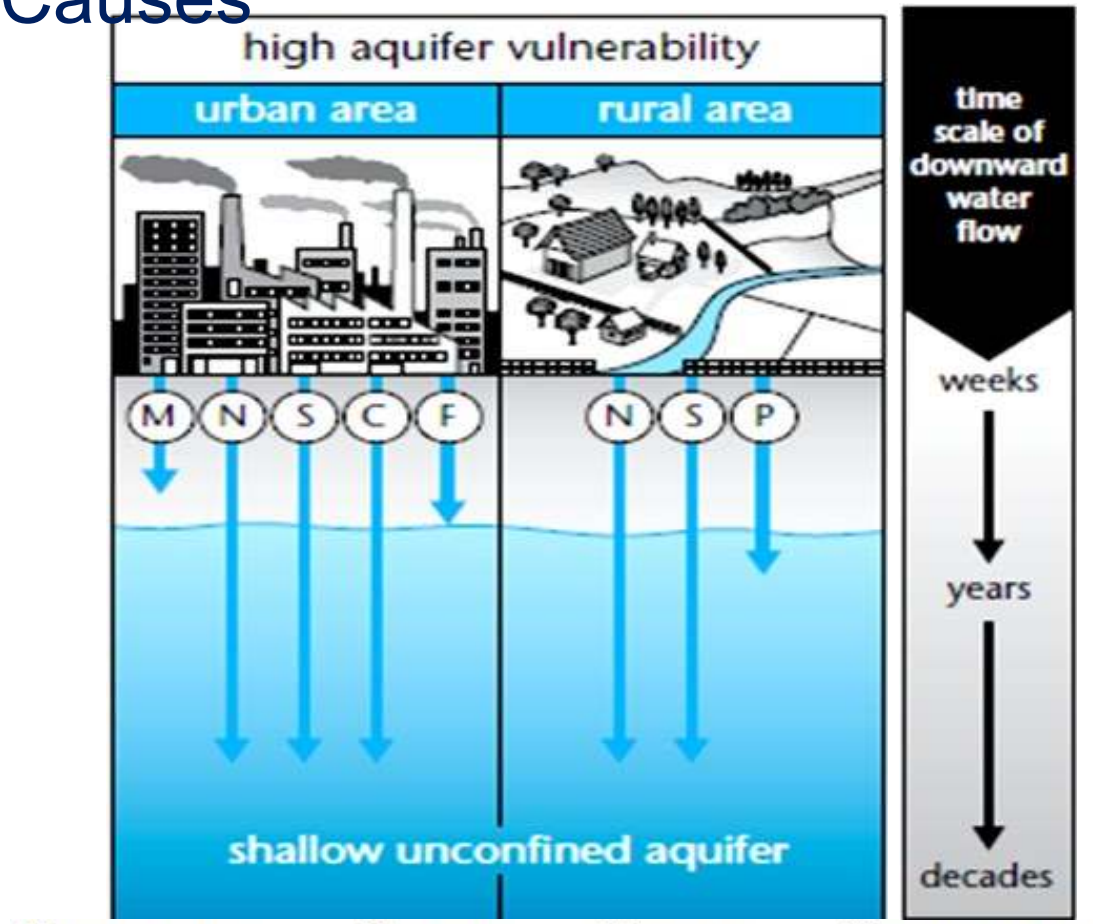



A
Major spillage
LNAPL
unsaturated zone
saturated groundwater flow
base of aquifer
water immiscible phase
water miscible phase
gaseous phase


B
Major spillage
saturated groundwater flow
DNAPL

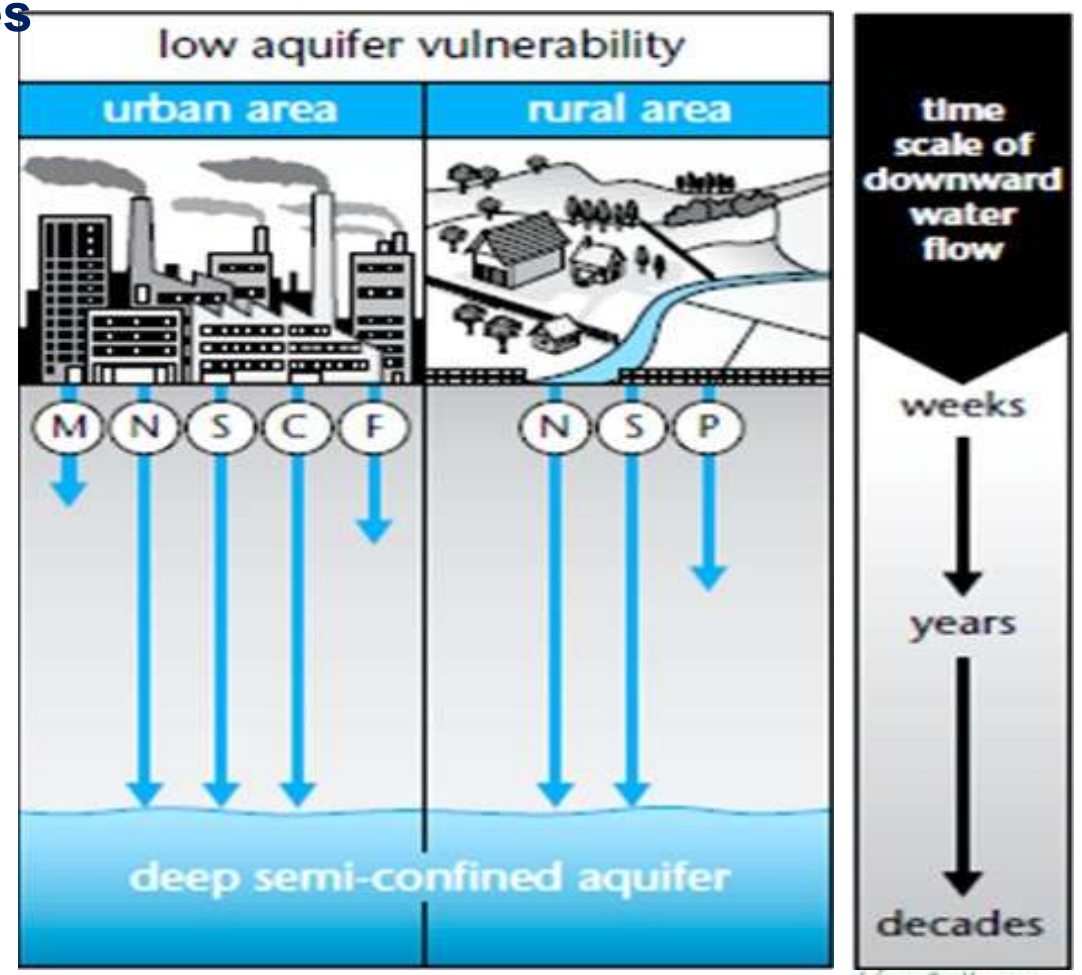
Groundwater Pollution: Causes

- Thin vadose zone & shallow water-table provides less natural attenuation,
- ∴ prone to pollution.



Groundwater Pollution: Causes

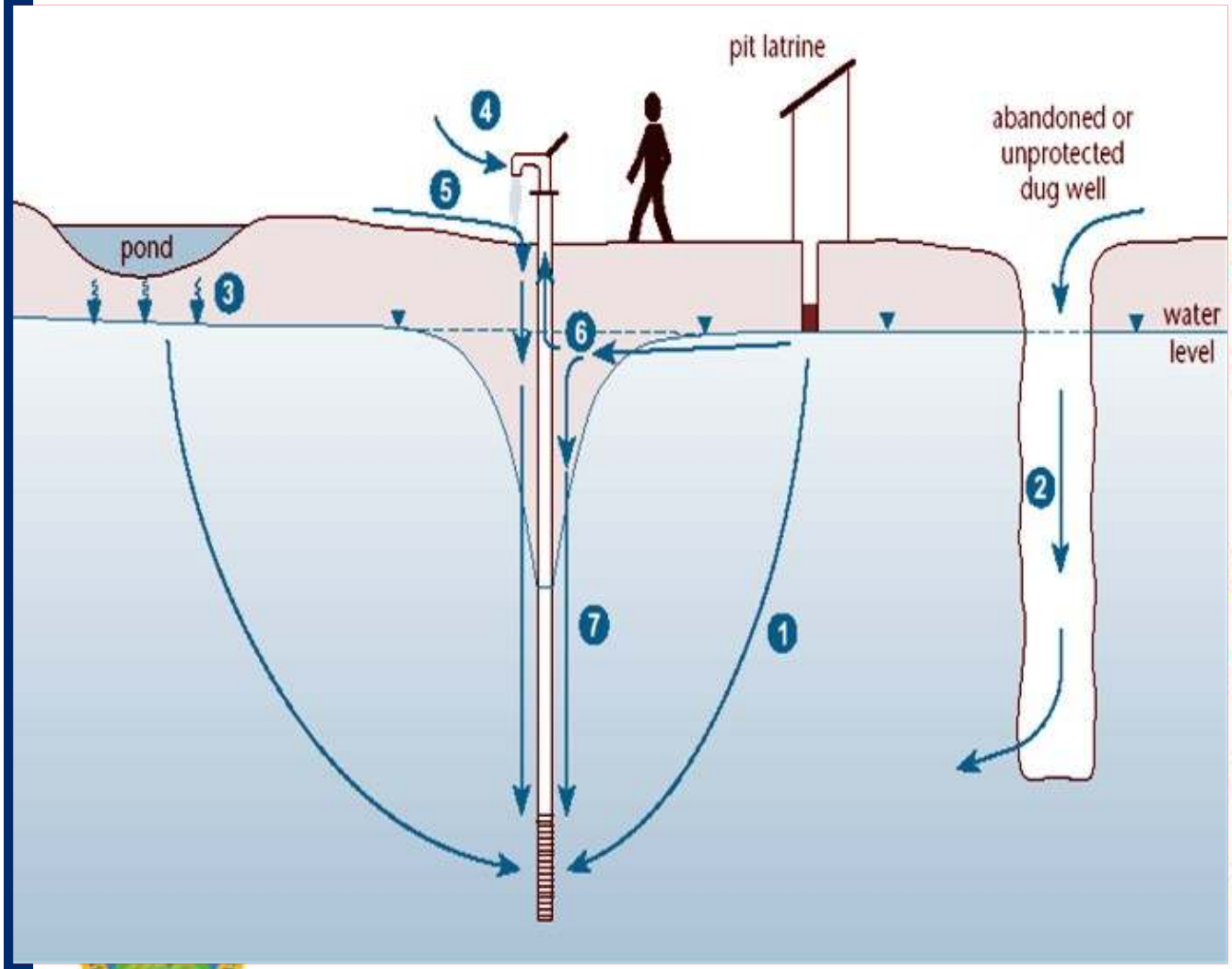
- Deeper and confined aquifers have much greater natural protection by the overlying ground.



(M) heavy metals (N) nitrate (S) salinity (C) organic carbon

(F) faecal pathogens (P) pesticides

Groundwater Pollution: Causes



Aquifer pollution pathways

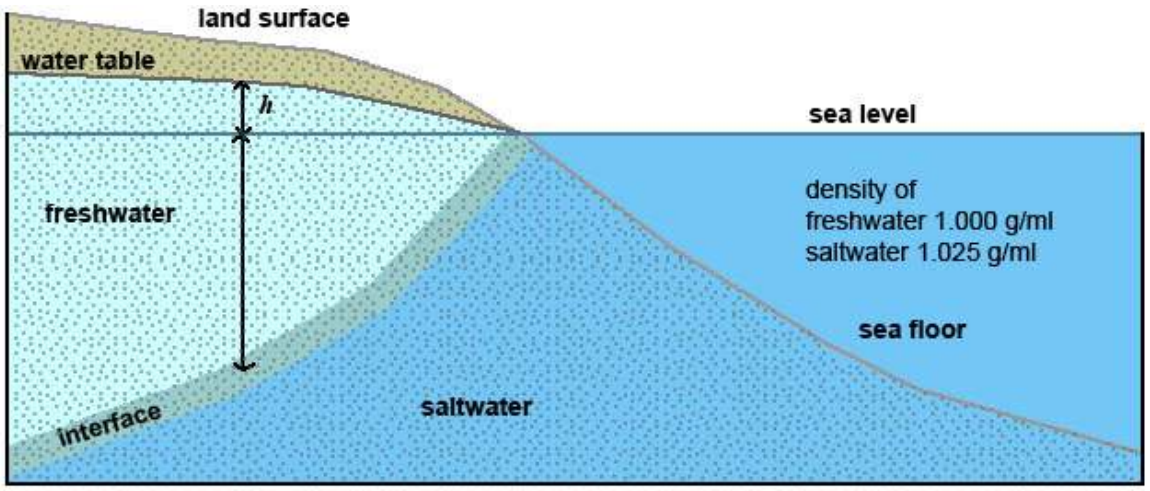
Pathways direct from pit latrine

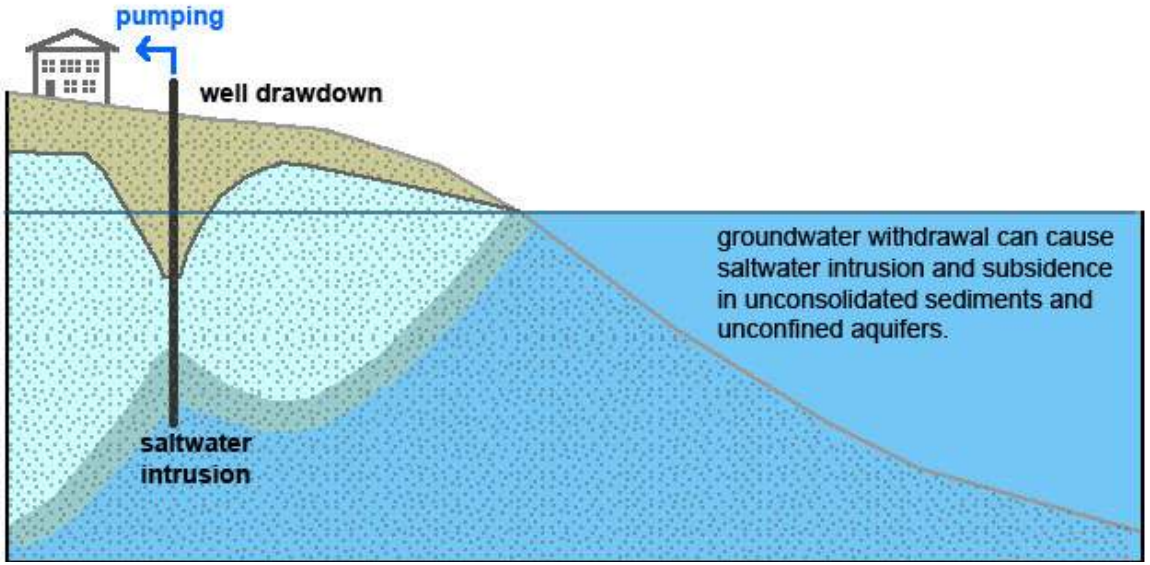
1. Deep penetration through strata
2. Contamination via abandoned/ unprotected dug well
3. Infiltration from a contaminated surface water body

Localised/indirect pathways

4. Direct contamination of spout (by dirty hands)
5. Surface water seepage behind tubewell casing
6. Lateral migration at water table and entry through defective casing
7. Lateral migration at water table and percolation behind the casing to the screen

Salt Water Intrusion





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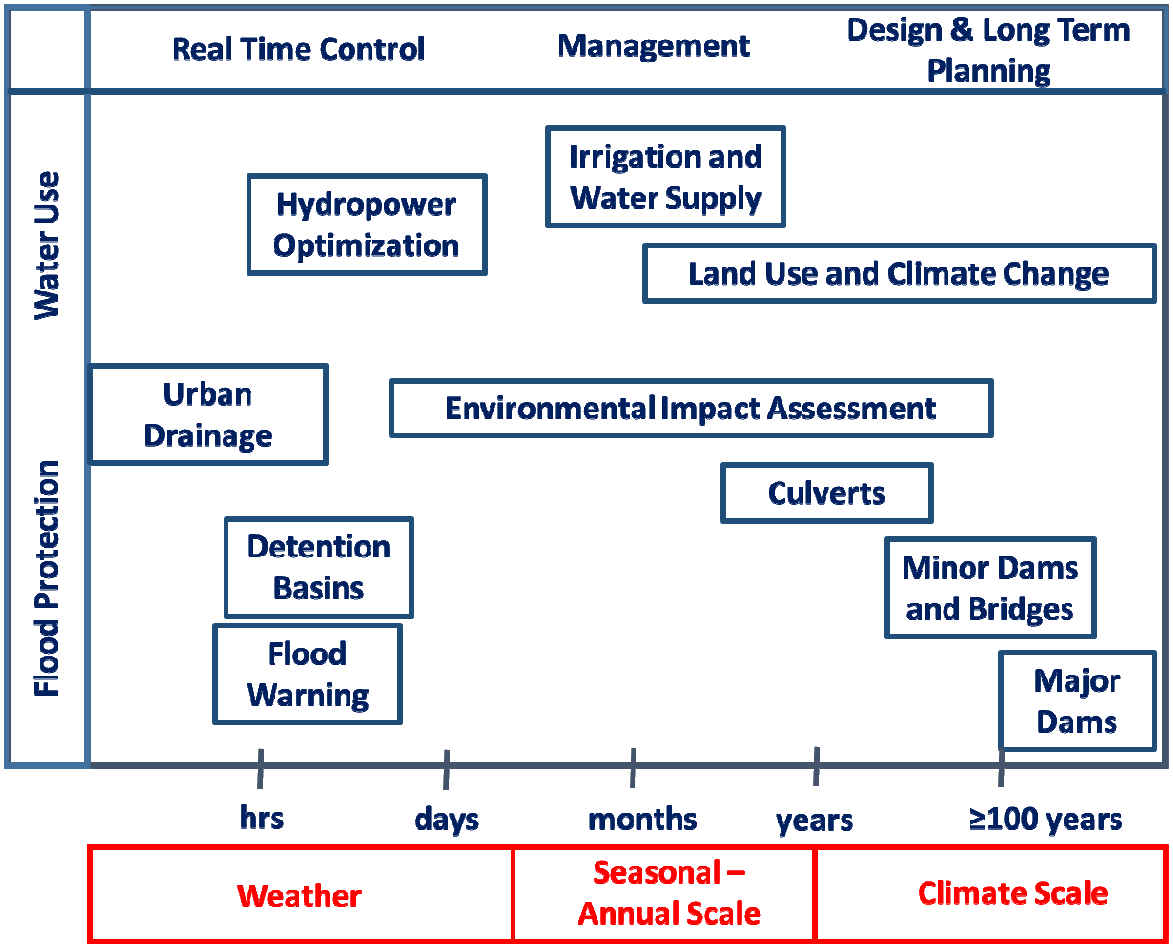
Issues in Water Resources Management

Lebanon Eco Movement

Scales in Water Resources Management



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Dublin Principles

- International Conference on Water and the Environment held in Dublin in 1992

- *IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.*

Dublin Principles

1. Freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment.

2. Water development and management should be based on a participatory approach, involving users, planners and policy makers at all levels.

3. Women play a central part in the provision, management and safeguarding of water.

4. Water has an economic value in all its competing uses and should be recognized as an economic good.

IWRM Criteria

1. *Equity*: The basic right for all people to have access to water of adequate quantity and quality for the sustenance of human well being;

2. *Environmental and ecological sustainability:* the present use of water resources should be managed in such a way that does not undermine the life - support system thereby compromising use by future generations of the same resource.

3. *Economic efficiency of water use:* Because of the increasing scarcity of water and financial resources, the finite and vulnerable nature of water as a resource and the demands on it, water must be used with maximum possible efficiency.

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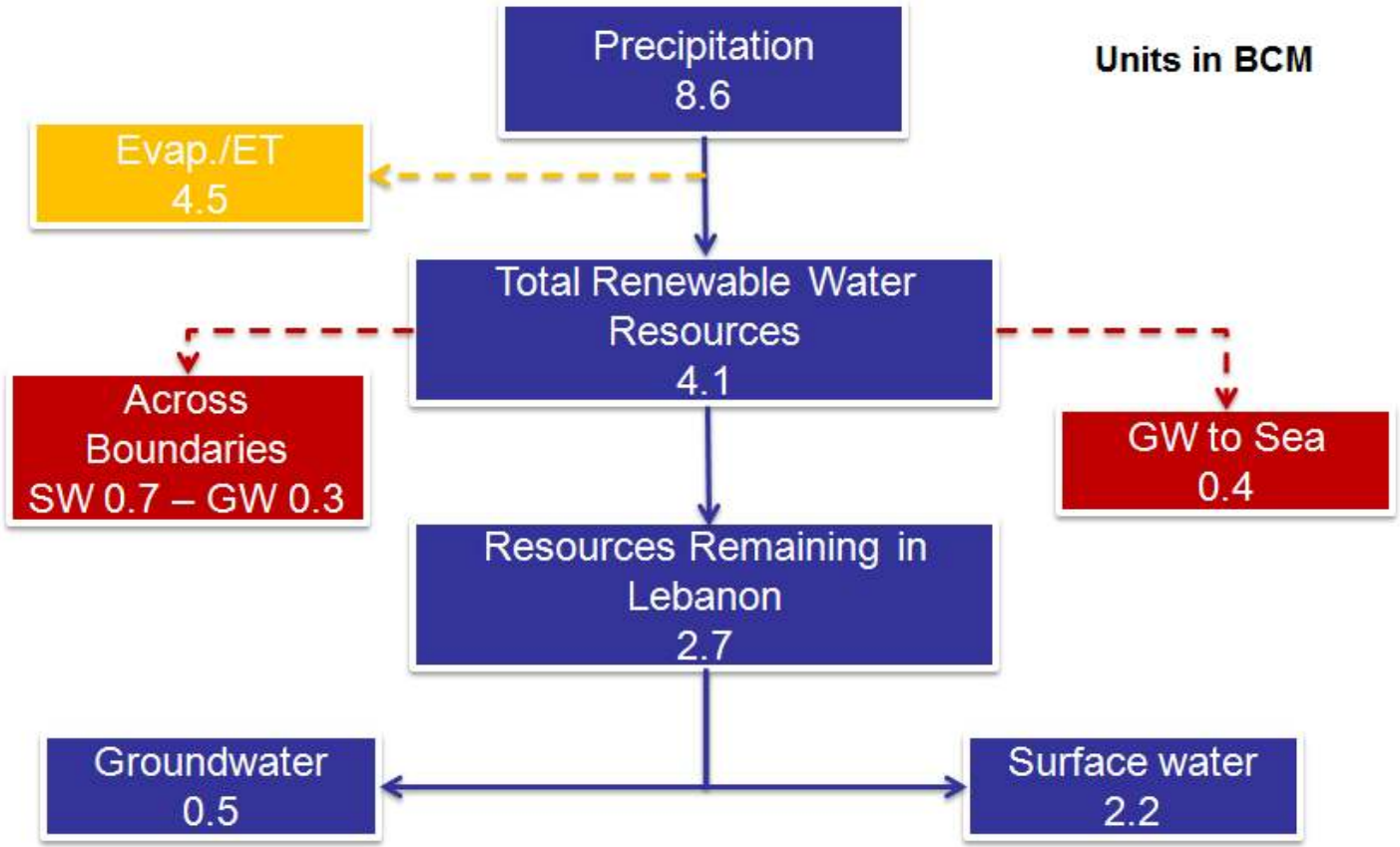
Precipitation
8.6
Units in BCM
Evap./ET
4.5
Total Renewable Water Resources
4.1
Across Boundaries
SW 0.7 – GW 0.3
GW to Sea
0.4
Resources Remaining in Lebanon
2.7
Groundwater
0.5
Surface water
2.2

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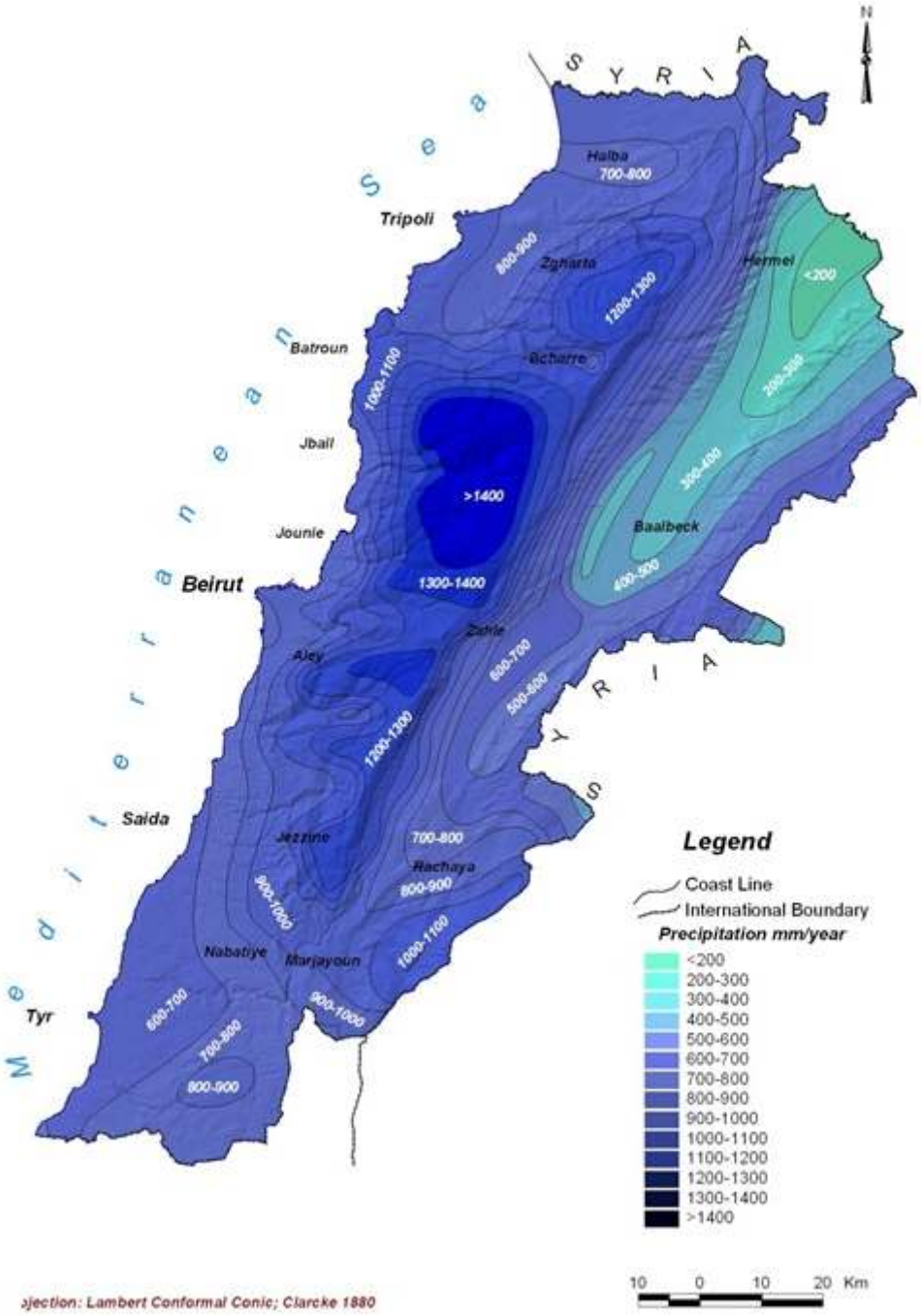
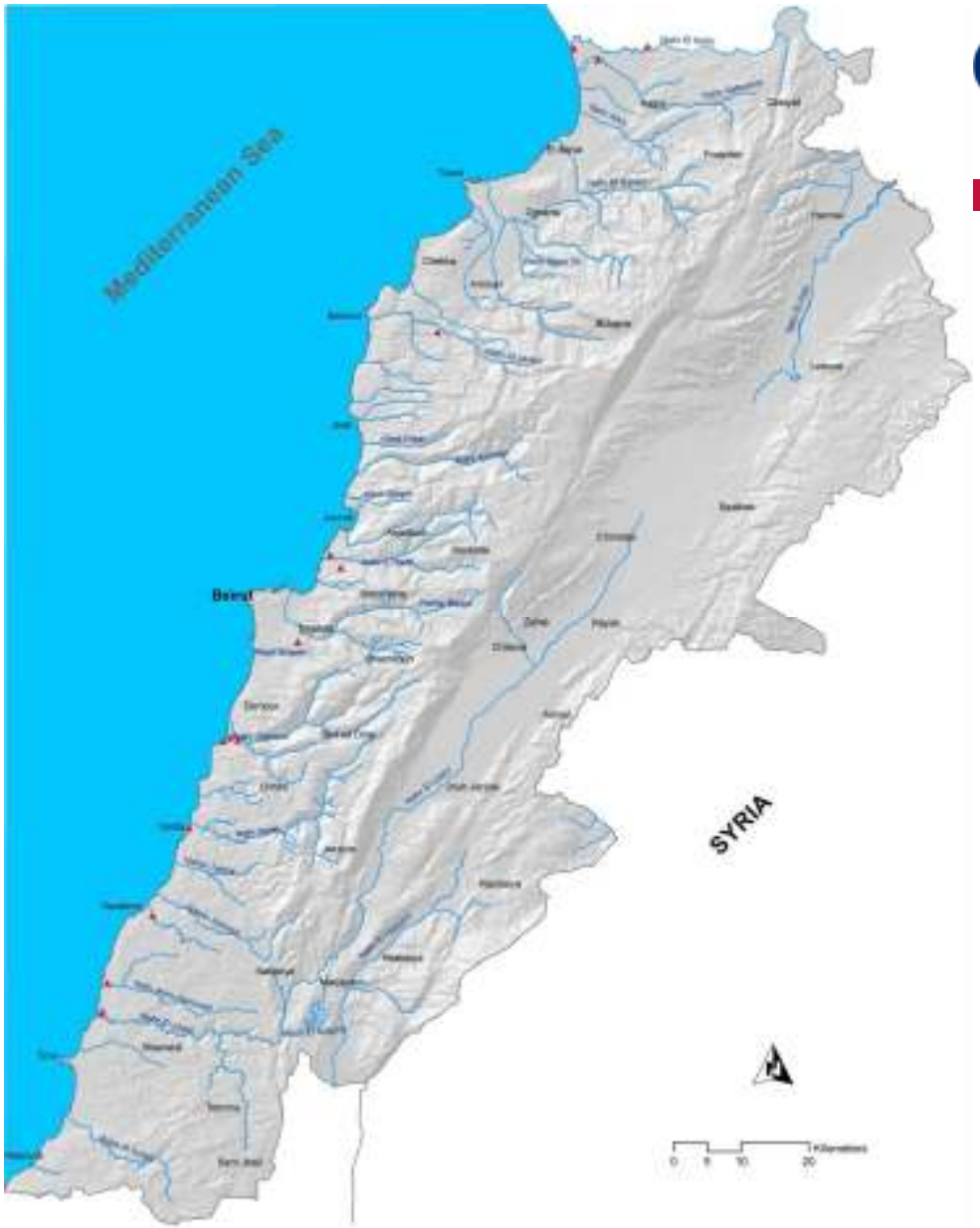
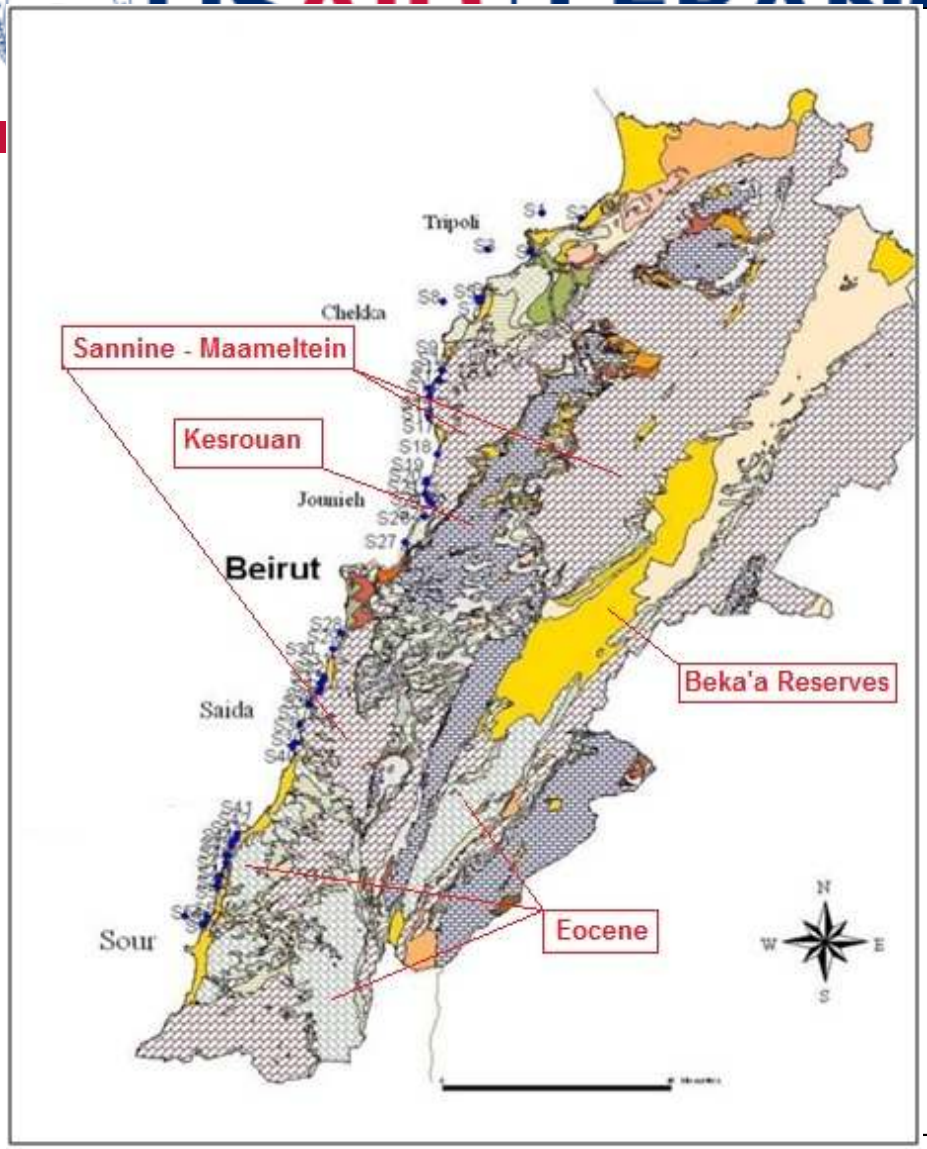
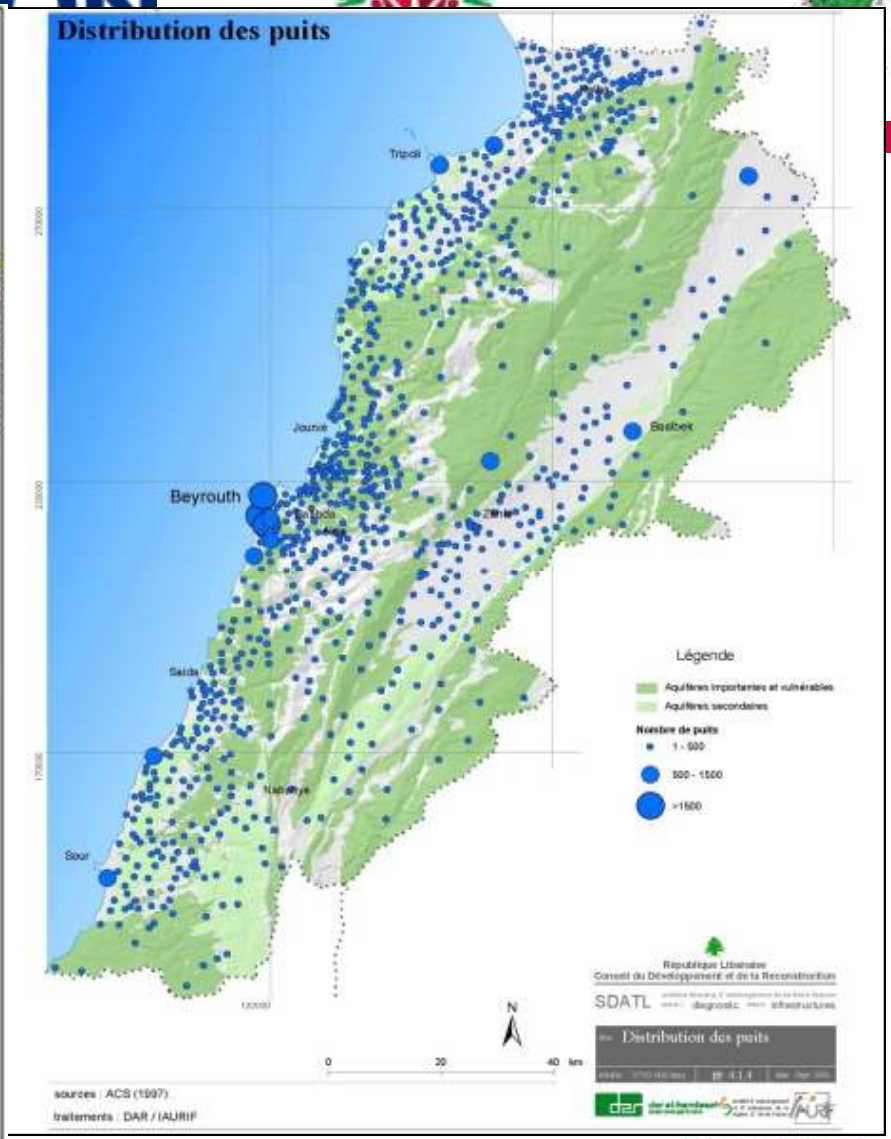
- Annual precipitation over Lebanon is about 8600 million m^3 (Mm^3) – mountains get most of it followed by coastal areas, the south and Beka'a





- Lebanon has 40 streams; 17 are perennial and 23 seasonal





Metni et al. 2003

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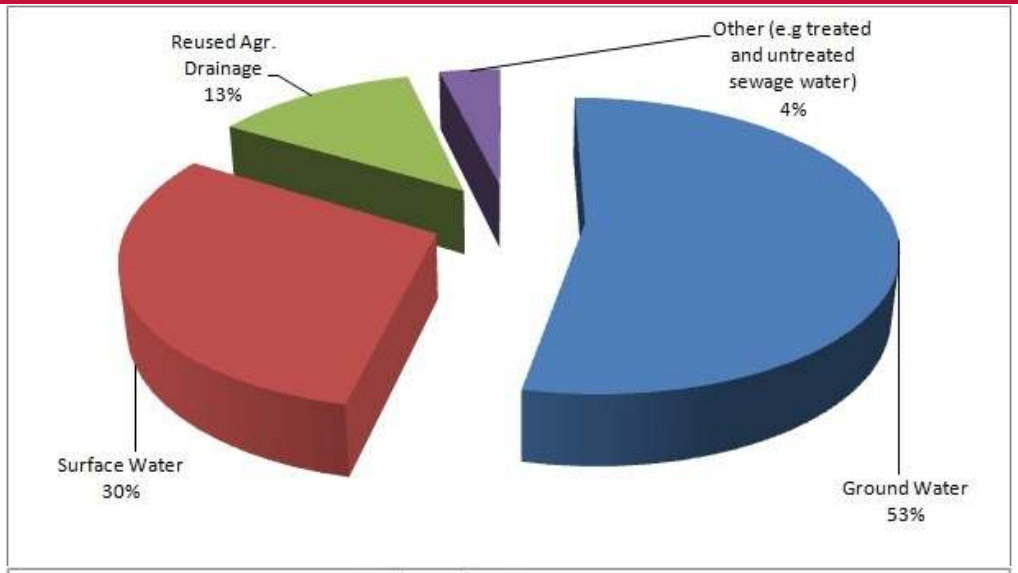
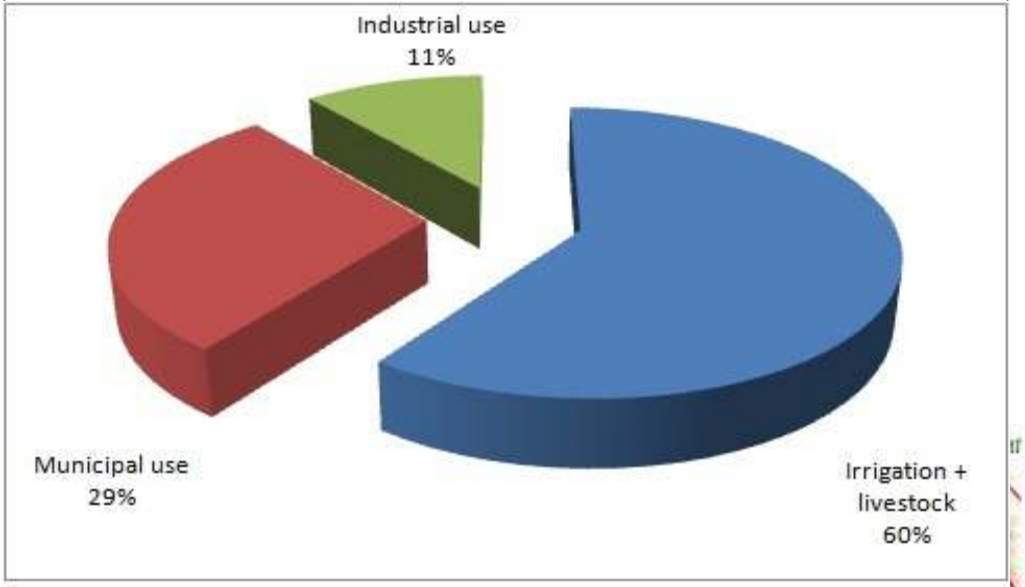
Sources



Demand – by Sector



Total: 1,473 - 1,530 Mm^3 /year

Major Stressors

- Growing Population
- Climate Change

- Estimated water demand 1,473 - 1,530 Mm^3 /year:
  - 61% going for agriculture,
  - 18% for domestic use and
  - 11% for industrial use

- Total annual renewable sources: 926m^3/person - lower than the benchmark of 1000m^3/person for water scarcity.

- By 2015, it was estimated that the individual share will drop to 839 m^3/person

- With the Syrian refugee influx, this has dropped to below 700 m^3/person

- Water infrastructure needs upgrade, almost half of the water distribution networks suffer from leakage – unaccounted for water ~ 48% nationally

- National Water Sector Strategy – plans to build dams to capture approximately 650 Mm^3/year

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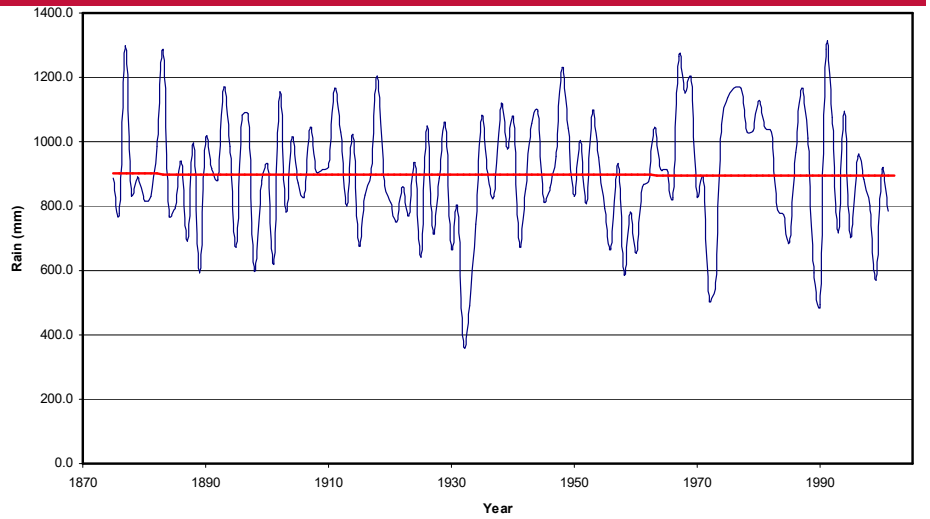
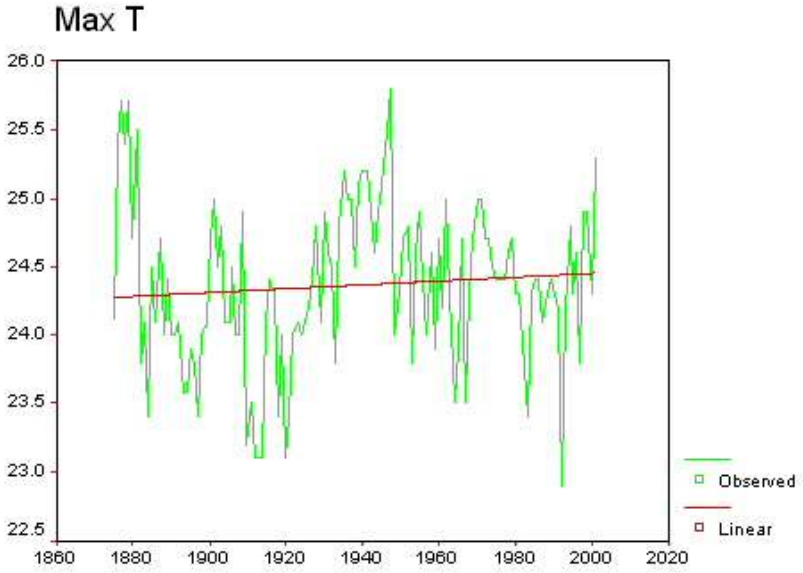
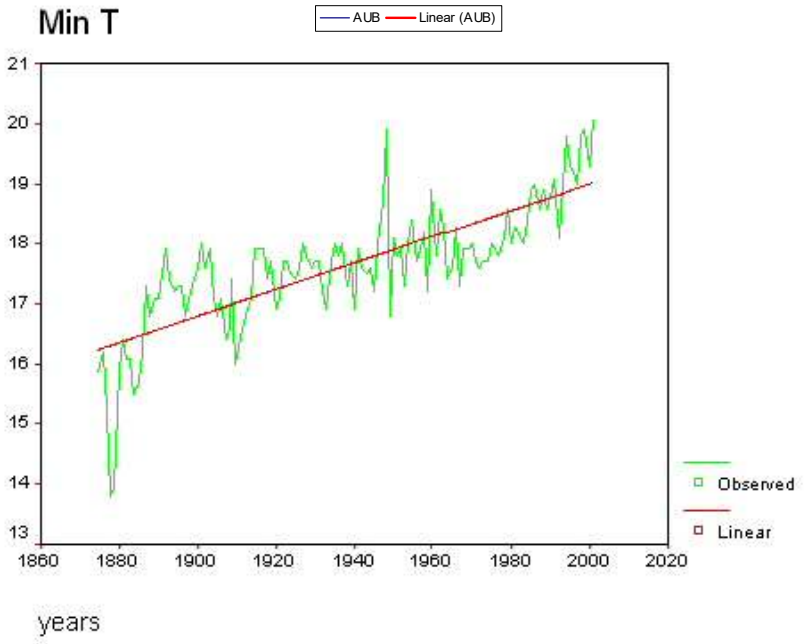
Climate Change and Water Resources Some Current Numbers – Beirut, Lebanon

Annual Rainfall in Beirut







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Water Resources and Climate Change

- Change in precipitation trends and patterns
- Rising temperature leading to decreased snow cover
- Increase in forest fires leading to decrease in ground cover

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Increase in storm severity

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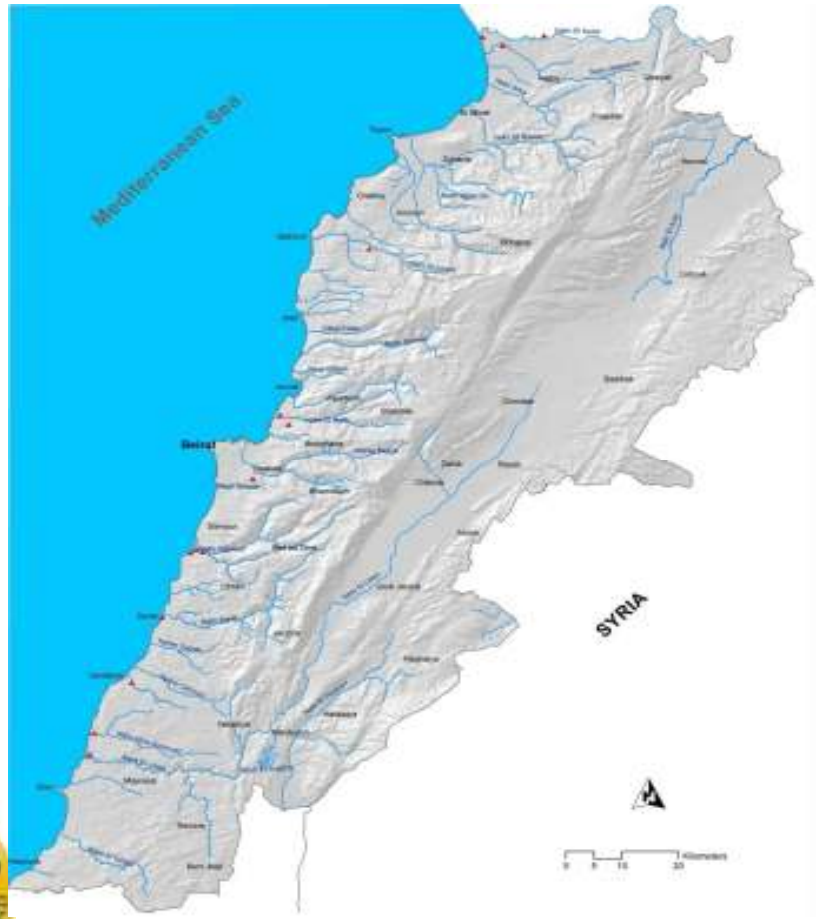
Flood Risk and Population Distribution



Source: MoE – SNC 2010

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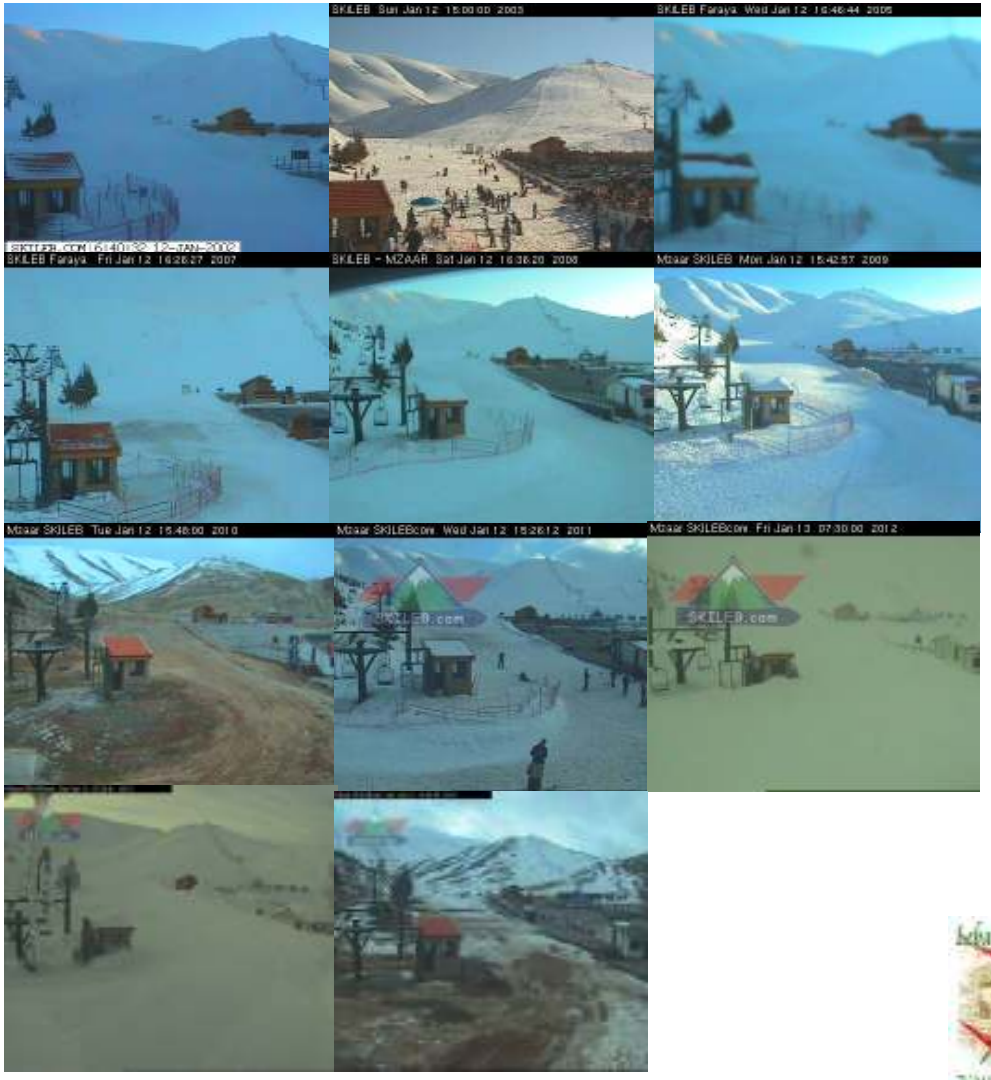
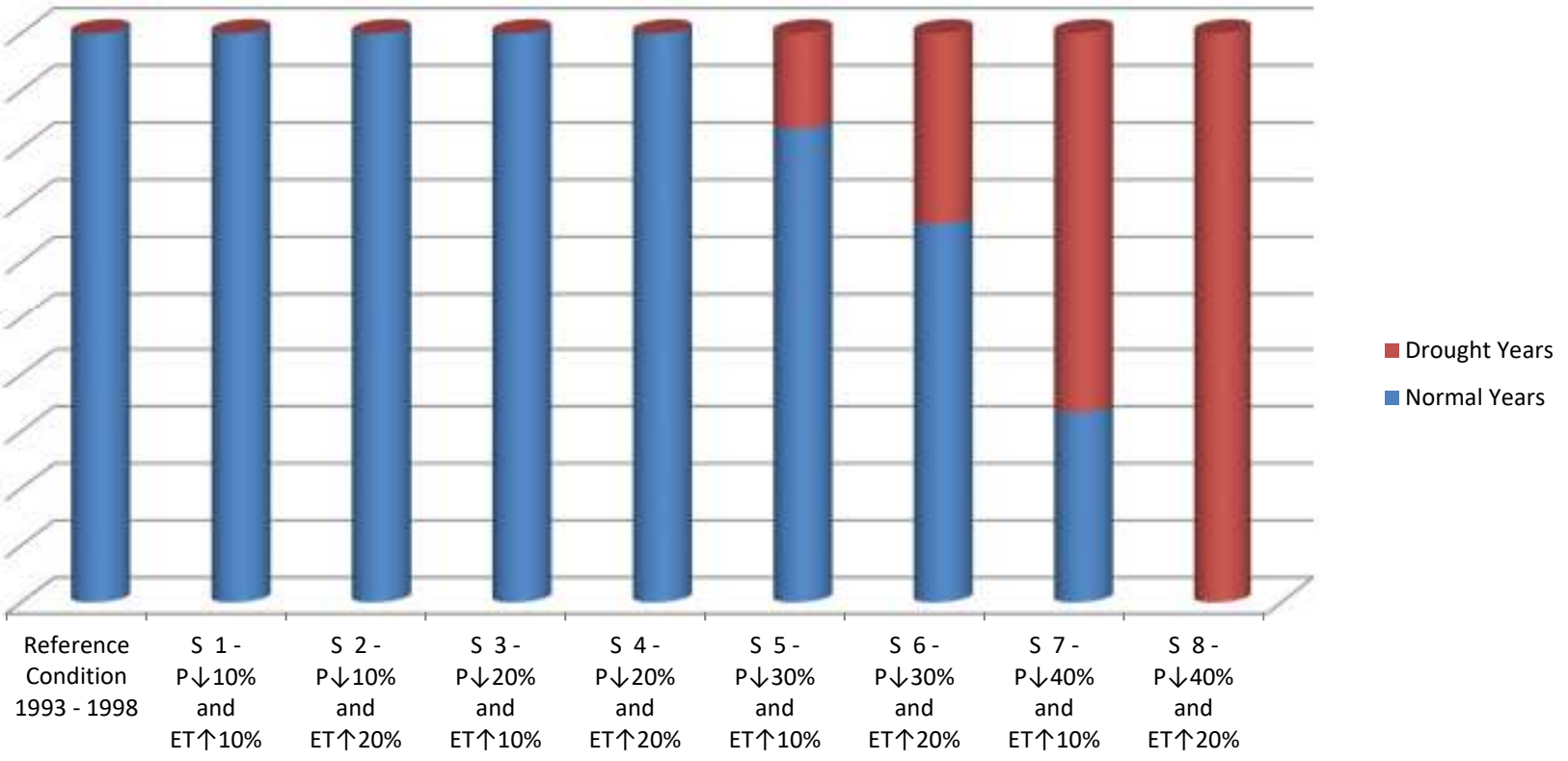
Decrease in snow cover



Lebanon Eco Movement

Increase in the occurrence and frequency of droughts

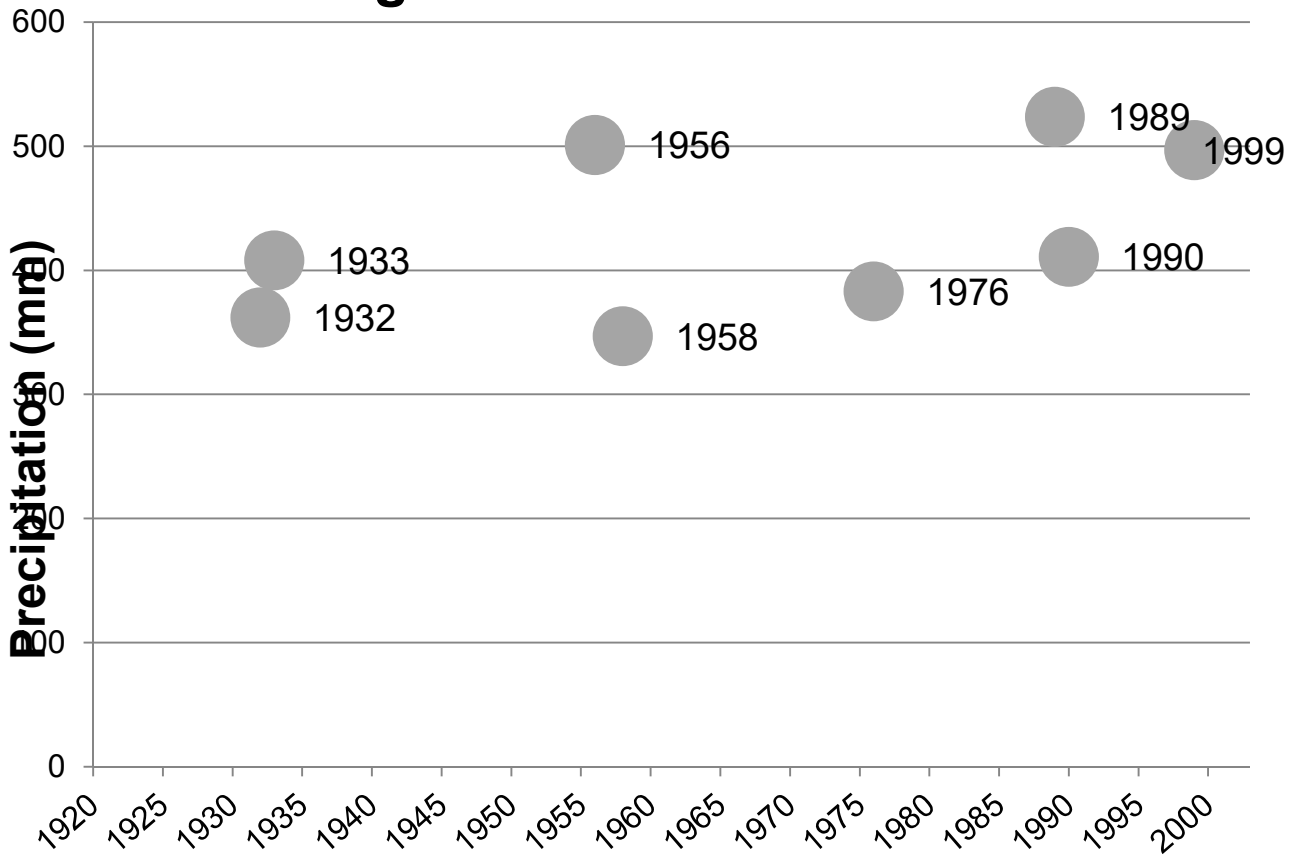


Rainfall and drought incidents

Year	Rainfall (mm)
1932	362.2
1933	408.3
1956	500.9
1958	346.9
1976	383.4
1989	523.7
1990	410.8
1999	496.9

In 2014, precipitation levels in Lebanon reached around 45% of the average annual precipitation nearly 370mm

Drought incidents since 1920



MEW considers drought conditions if rainfall is reduced by 40%

Decrease in groundcover

Current Situation

- National Water Sector Strategy – plans to build dams to capture approximately 650 Mm3/year
  - Two main dams
    - The Qaraoun reservoir on the Litani River - capacity of 220 Mm^3
    - The Chabrouh dam in Mount Lebanon - capacity of 9 Mm^3

- Water infrastructure needs upgrade, almost half of the water distribution networks suffer from leakage – unaccounted for water ~ 48% nationally

Current Situation

- Sewage connection is still an issue with the highest rate of connection to sewage networks being recorded in Beirut (96%) and the lowest in Batroun district (1%).

- 2 treatment plants are operational leading to the treatment of only 8% of wastewater.

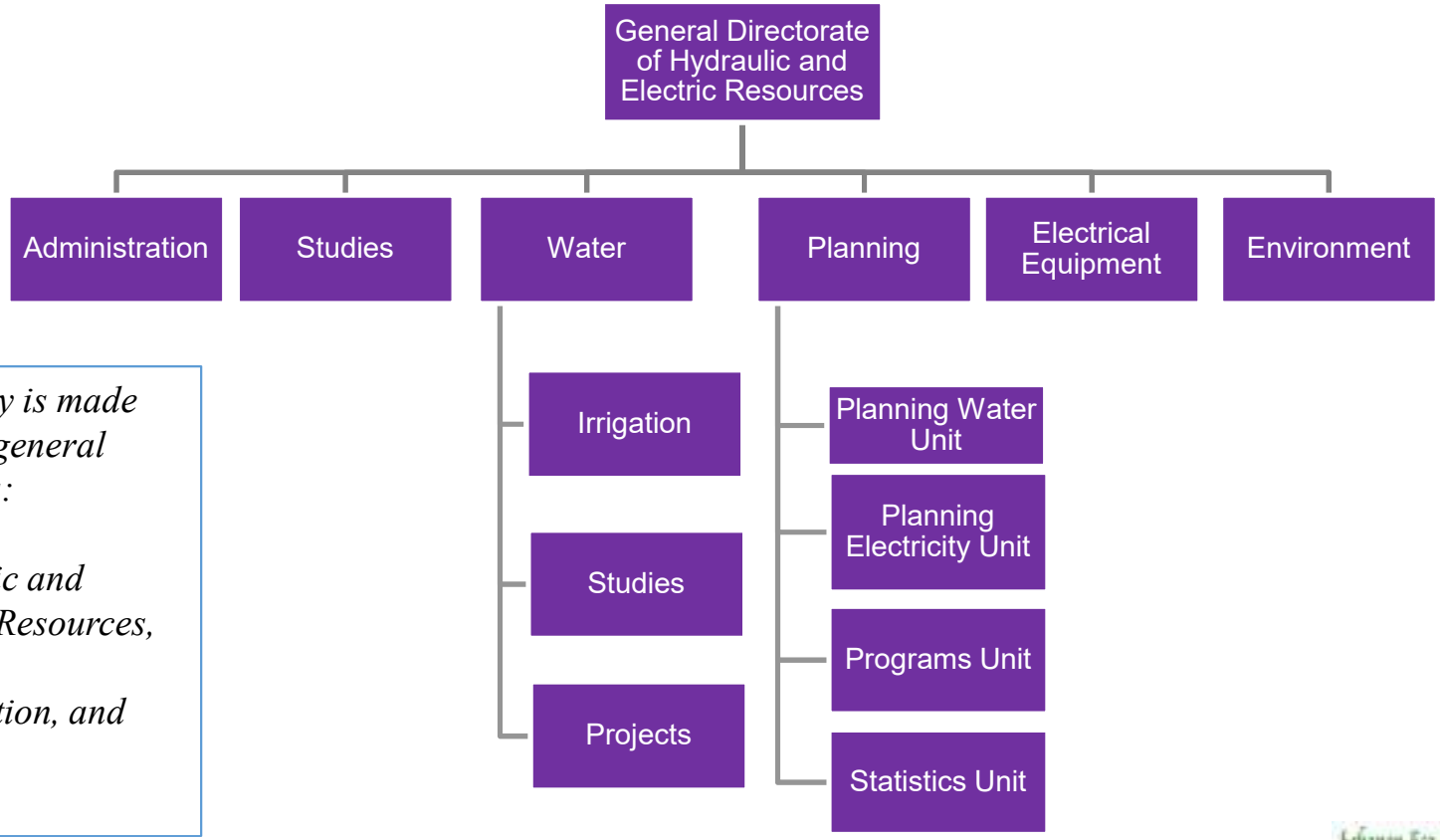
- About 80% of rivers are polluted by untreated sewage water and agricultural and industrial chemical pollution

Institutional Structure

Direct Line Ministries and related agencies	• Ministry of Energy and Water
	  • Regional Water Establishments
	  • Litani River Authority

Councils	• Council of the South • Municipalities • Local Committees
• Centers	• Lebanese Center for water and wastewater management • Lebanese water conservation center
• Indirect Ministries	• Ministry of Finance • Ministry of Agriculture • Ministry of Environment • Ministry of Public Health

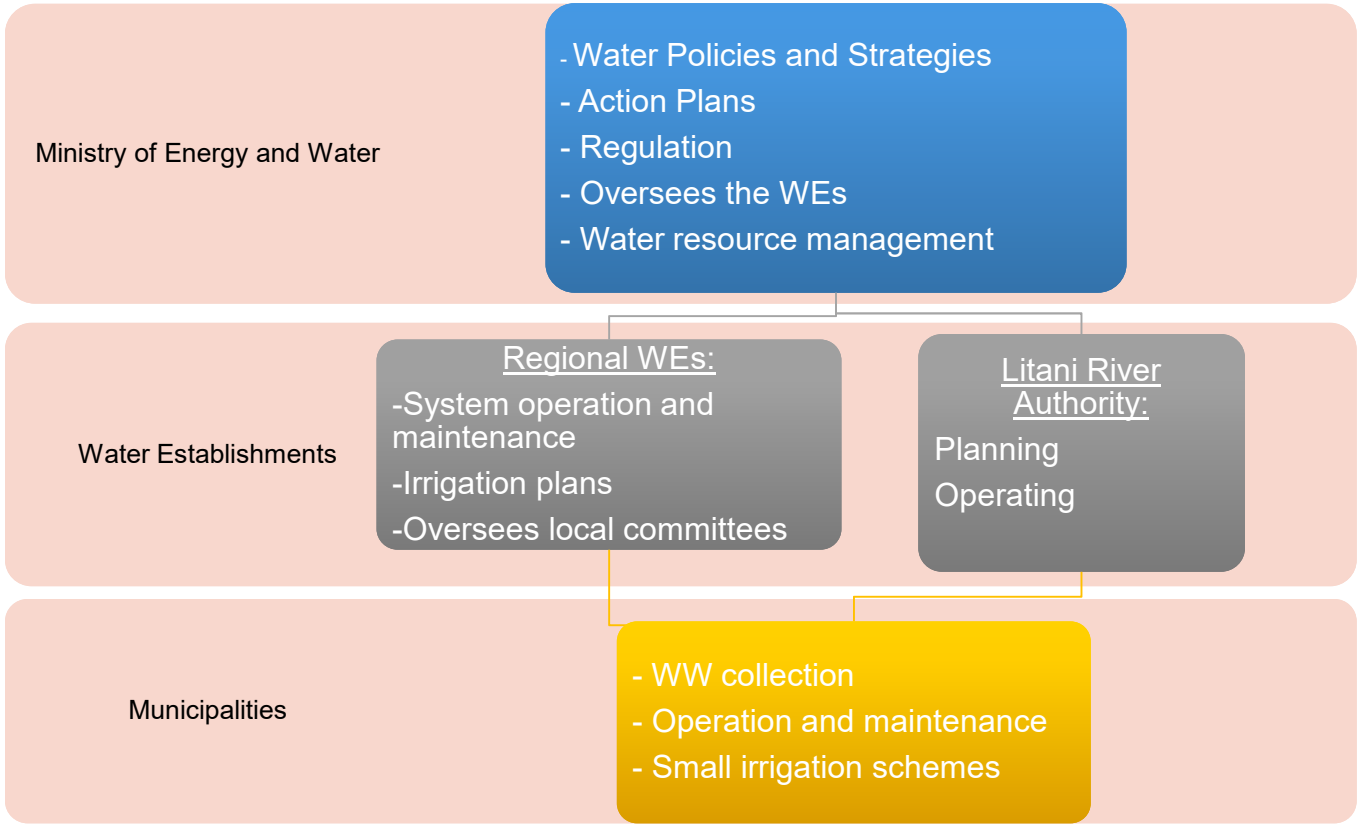
Institutions - MOEW



The Ministry is made up of three general directorates:

- *Hydraulic and Electric Resources,*
- *Exploitation, and*
- *Oil*

Institutions



Sector Policies Related to Water

- National Water Sector Strategy aims at providing continuous water supply for households and irrigation, and improving water treatment.
  - New plans to renew networks and complete distribution and transmission systems, new storage facilities, and optimization of surface water resources.
  - Artificial groundwater recharge to increase storage and to avoid or reduce salinization.
  - Wastewater plants - currently seven completed and only two operational.
  - Improve irrigation efficiency.
  - Reuse treated wastewater and sludge
  - Increased focus on demand management.
- Groundwater Assessment and Database project
- National Environmental Action Plan – Water Sector

Agriculture Sector Policies Related to Water

- Action Plans:
  - National Reforestation Plan
  - Safeguarding and restoring Lebanon's woodland resources
  - National Land Use Master Plan
  - Strategy for Forest Fire Management
  - Green Plan
    - Water reservoirs, Land Reclamation, Reforestation.
    - Hilly Areas Sustainable Agricultural Development Project.

Climate Change Sector Policies Related to Water

- MOE; Climate Change unit
- UNFCCC Conventions, Kyoto protocol
  - National Communications
  - NEEDS
  - TNA report
  - Nationally Appropriate Mitigation Actions (NAMAs)
- Country environmental analysis
- UNCCD Convention
  - National Action Plan to Combat Desertification; subprojects dealing with land planning, water supply, demand management, promotion of sustainable agriculture, soil and natural resources conservation.

Some Successes, Gaps, and Shortcomings

- First success is in having a National Water Sector Strategy (NWSS) but it has now fallen behind the times

- Gaps :
  - Law 221 amendment which prevents proper implementation of NWSS
  - Currently operating on a project basis

- Shortcomings
  - Political bickering
  - Very limited long term funding – from national budget
  - Reactive rather proactive actions
  - Lack of awareness at all levels
  - Lack of coordination amongst ministries and between relevant agencies
  - Current staff of WEs are mostly hired as contractors for temporary periods

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