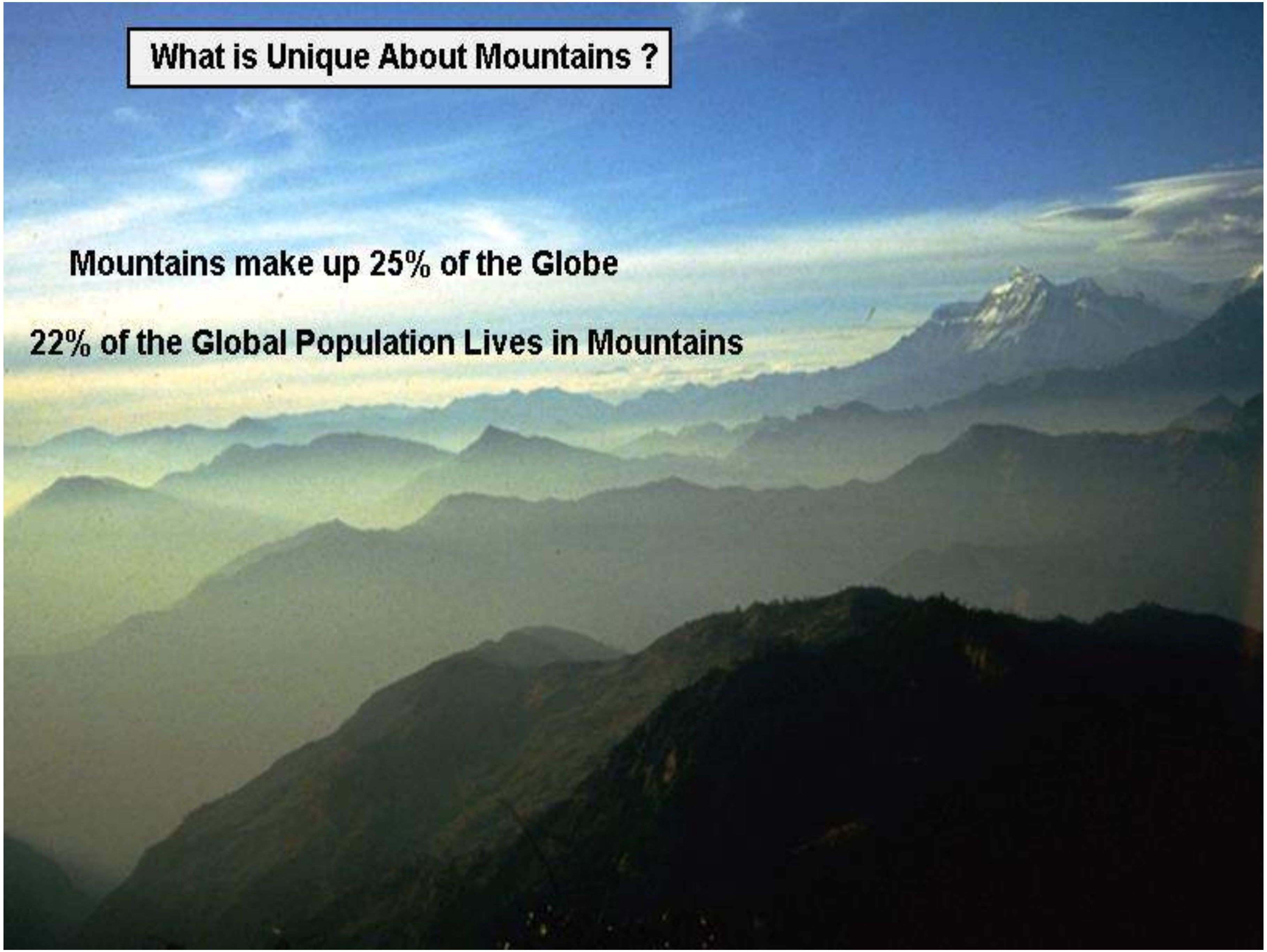
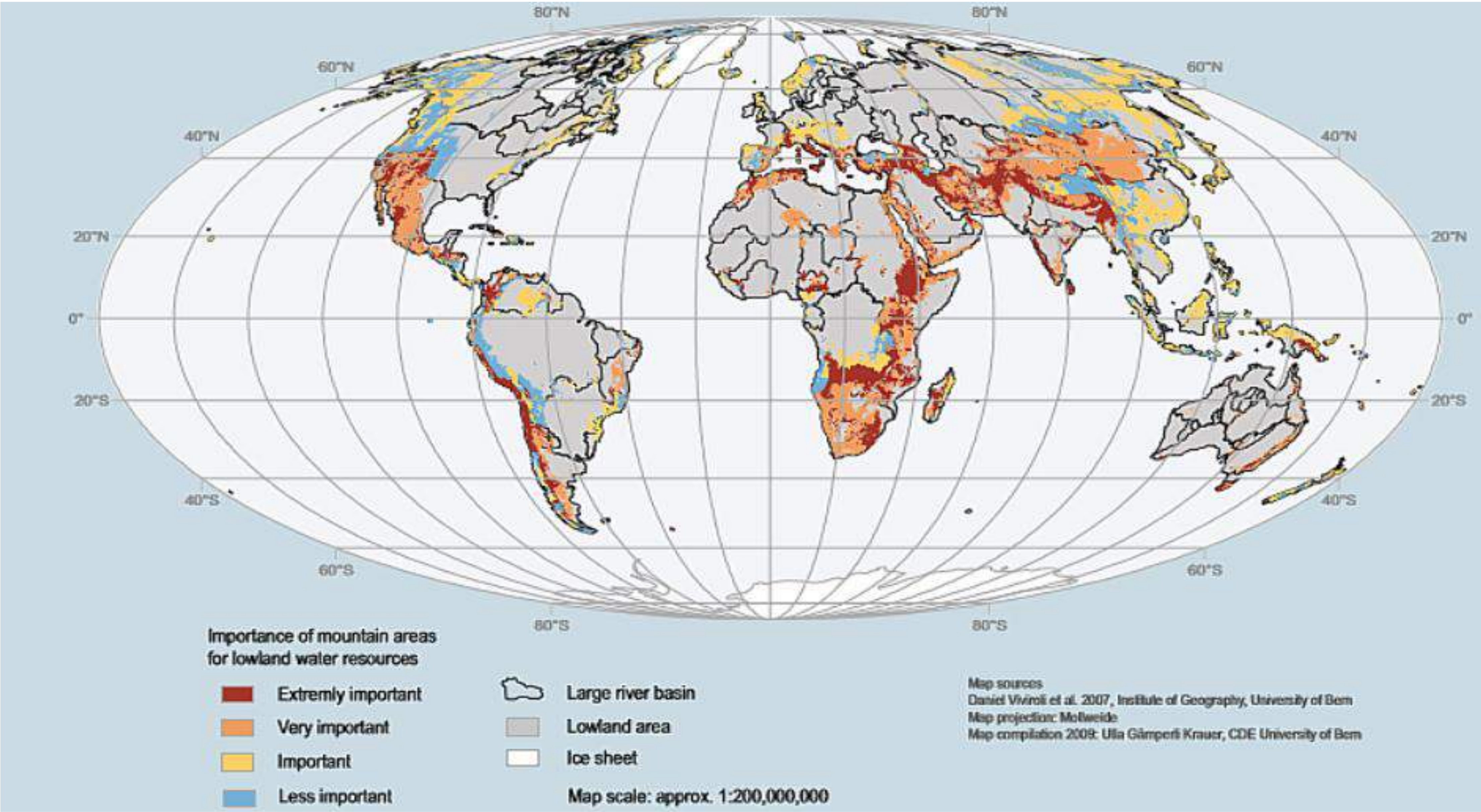
Introduction to Integrated Watershed Management

Hans Schreier, Land & Food Systems, Univ. of British Columbia, Canada


What is Unique About Mountains ?
Mountains make up 25% of the Globe
22% of the Global Population Lives in Mountains

Importance of Mountains for Lowland Water Resources



Advantages

Mountains are the Water Towers for Humanity

Mountains are Biodiversity Hotspot

Mountains as a Recreational Paradise

Mountains have Sacret and Spiritual Values

Constraints

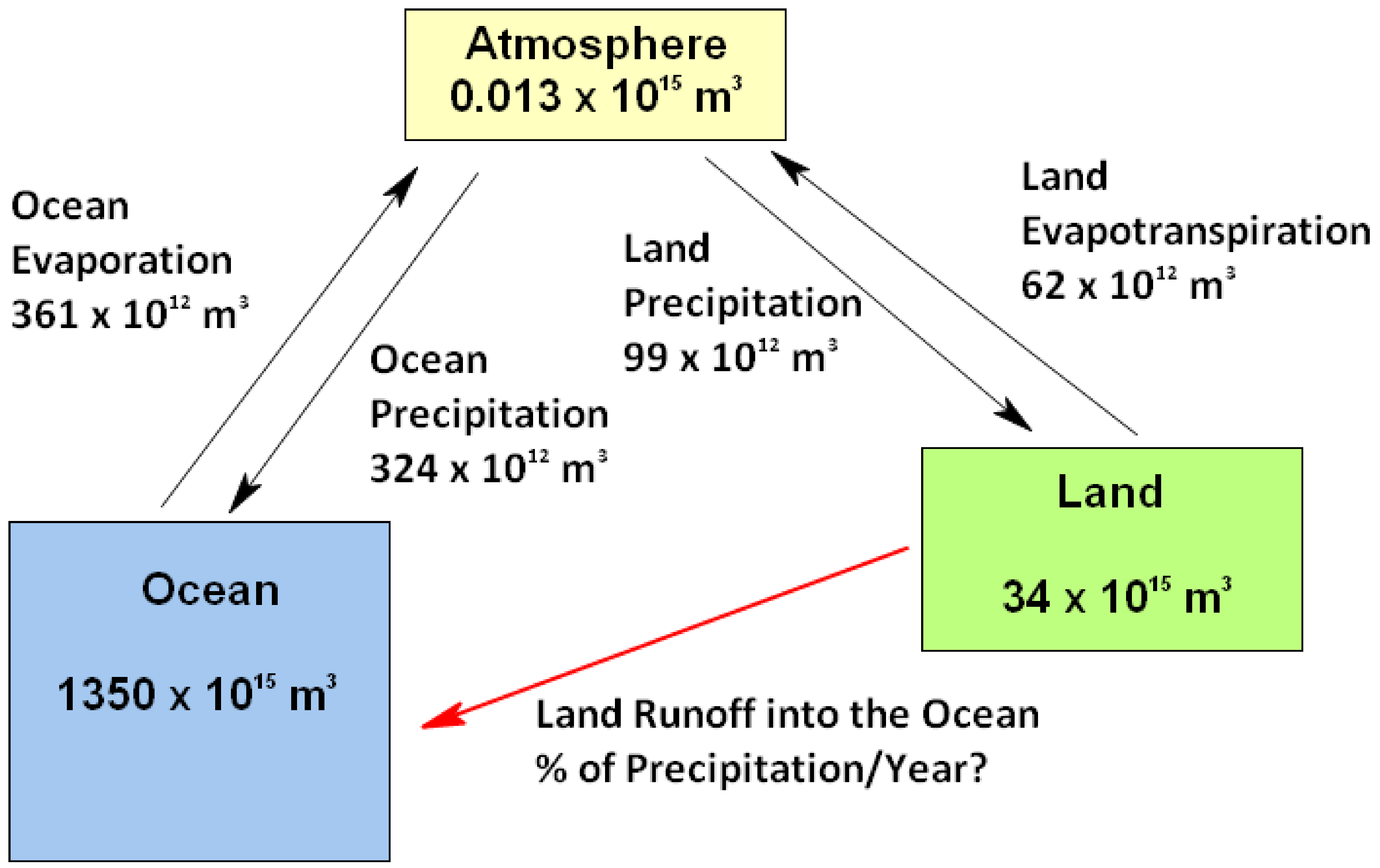
Mountains are Fragile, Hazardous and Have Low Resiliance

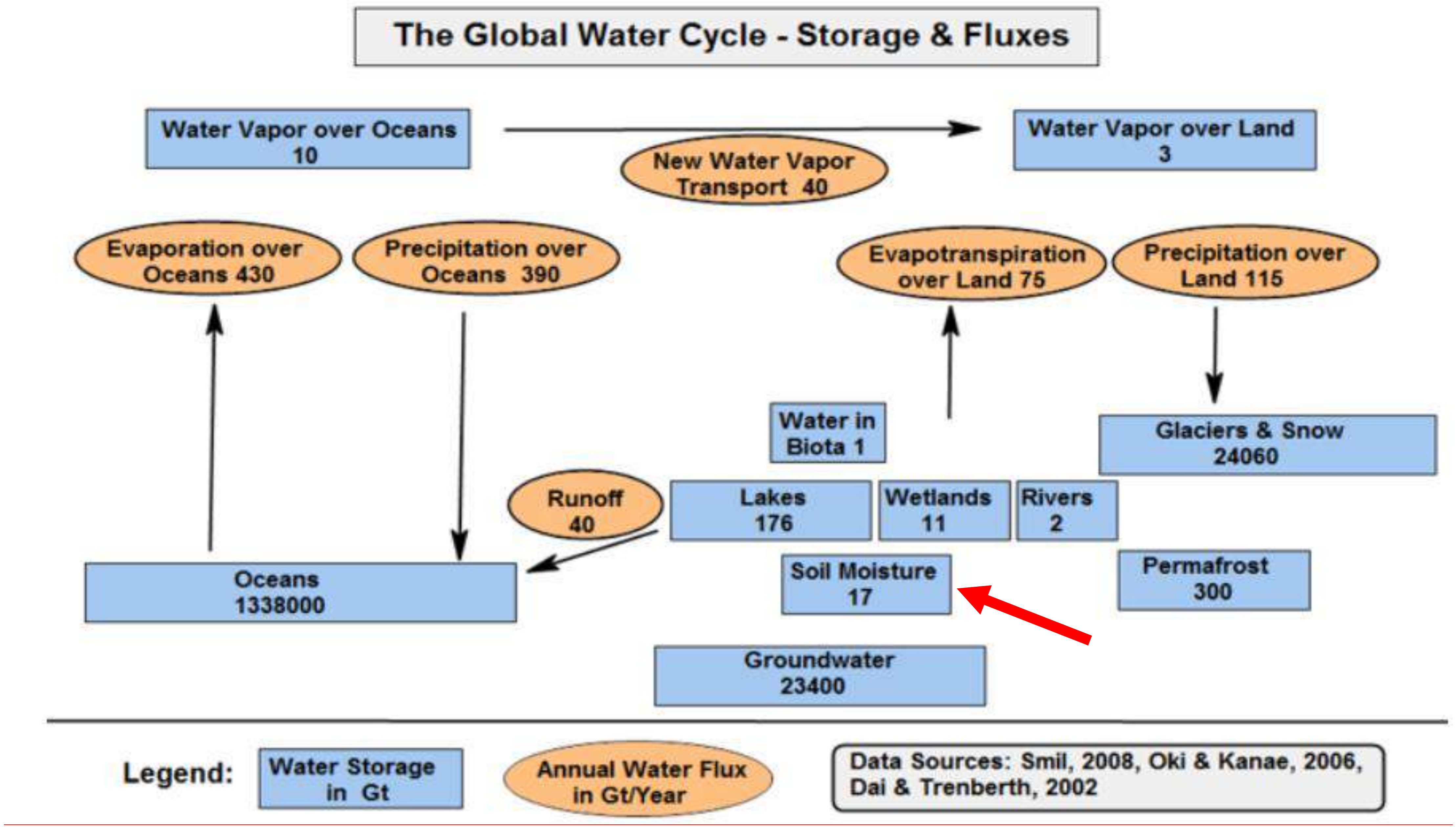
What Happens in Mountains can Have Very Large Impacts a Long Distance Downstream of Mountains

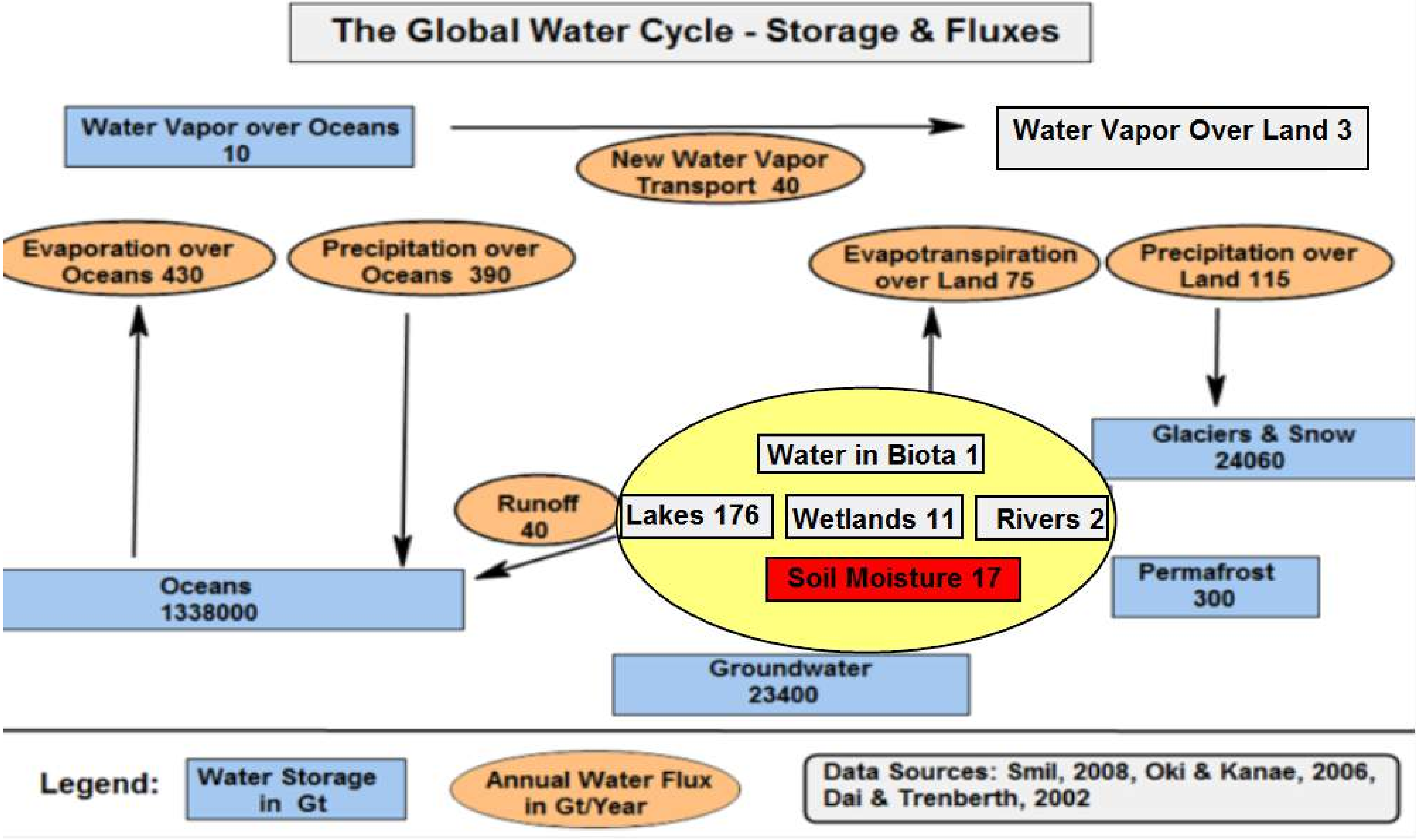
Mountain Areas Have Low Production Capacity and Transport in and out of Mountains is Difficult

Many Conflicts Originate in Mountains (Poverty Issues)

Global Water Cycle




The Global Water Cycle - Storage & Fluxes
Water Vapor over Oceans 10
New Water Vapor Transport 40
Water Vapor over Land 3
Evaporation over Oceans 430
Precipitation over Oceans 390
Evapotranspiration over Land 75
Precipitation over Land 115
Water in Biota 1
Glaciers & Snow 24060
Runoff 40
Lakes 176
Wetlands 11
Rivers 2
Oceans 1338000
Soil Moisture 17
Permafrost 300
Groundwater 23400
Legend:
Water Storage in Gt
Annual Water Flux in Gt/Year
Data Sources: Smil, 2008, Oki & Kanae, 2006, Dai & Trenberth, 2002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Oceans 1338000
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Water Storage in Gt
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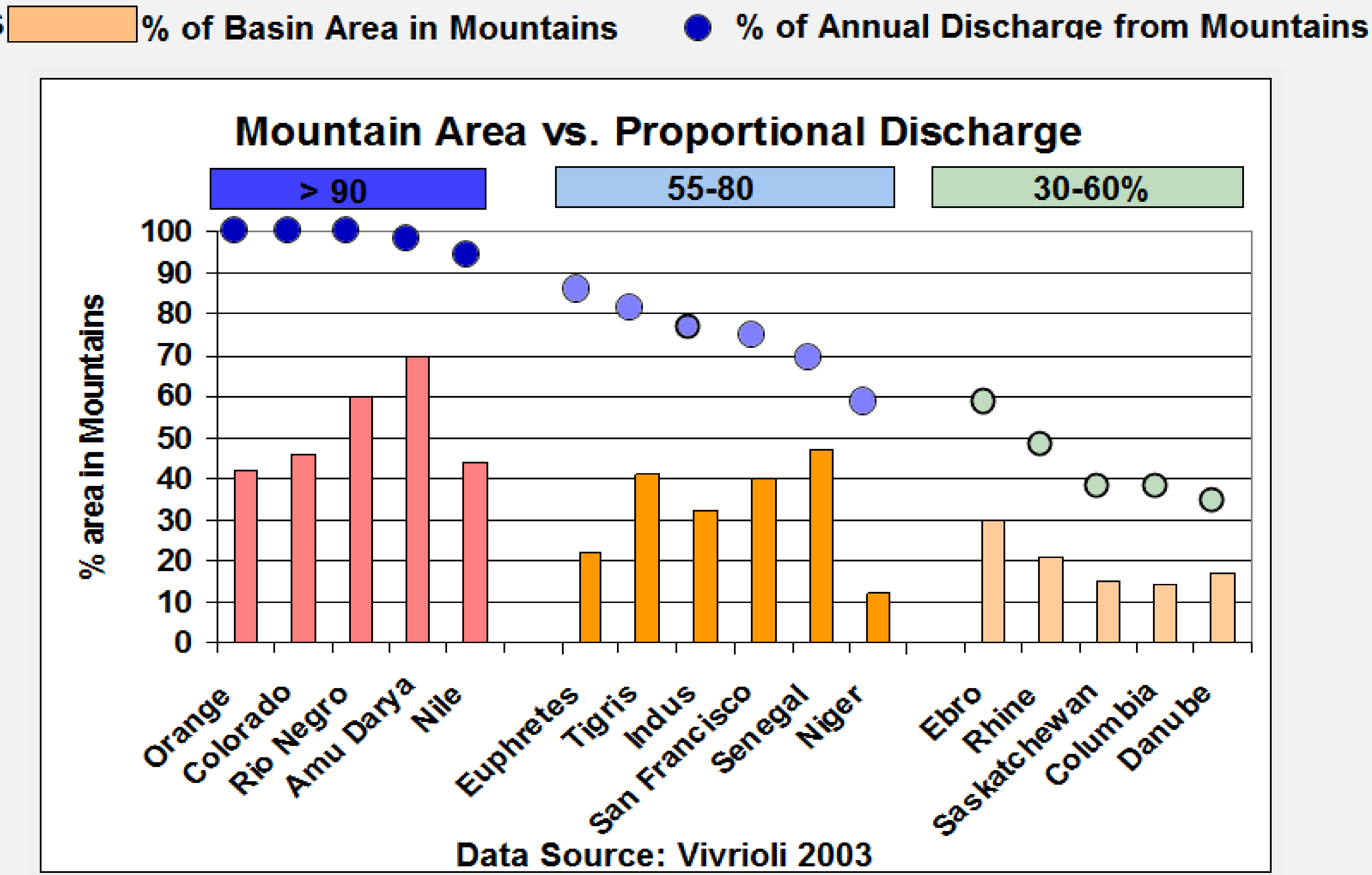
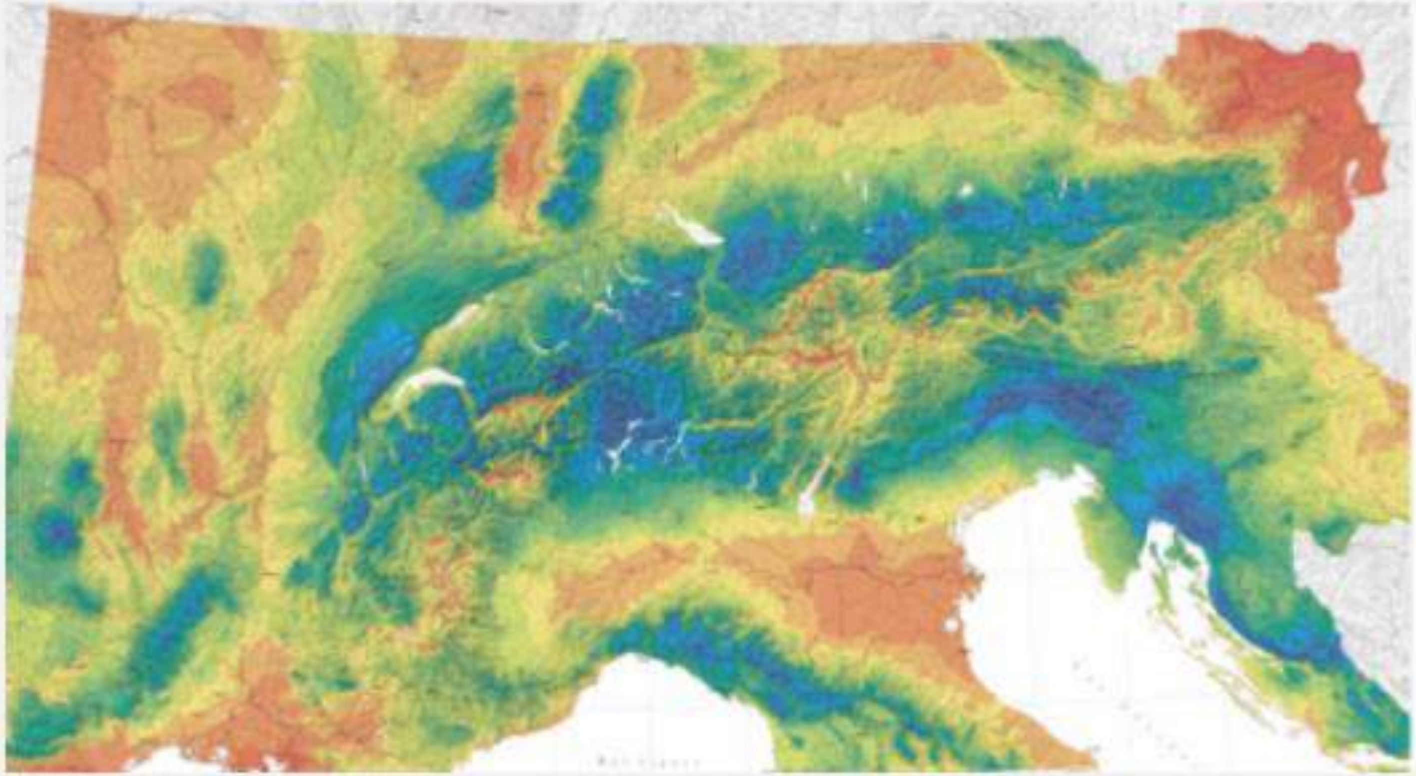
Proportional Discharge Contribution from Mountains in Major River Basins

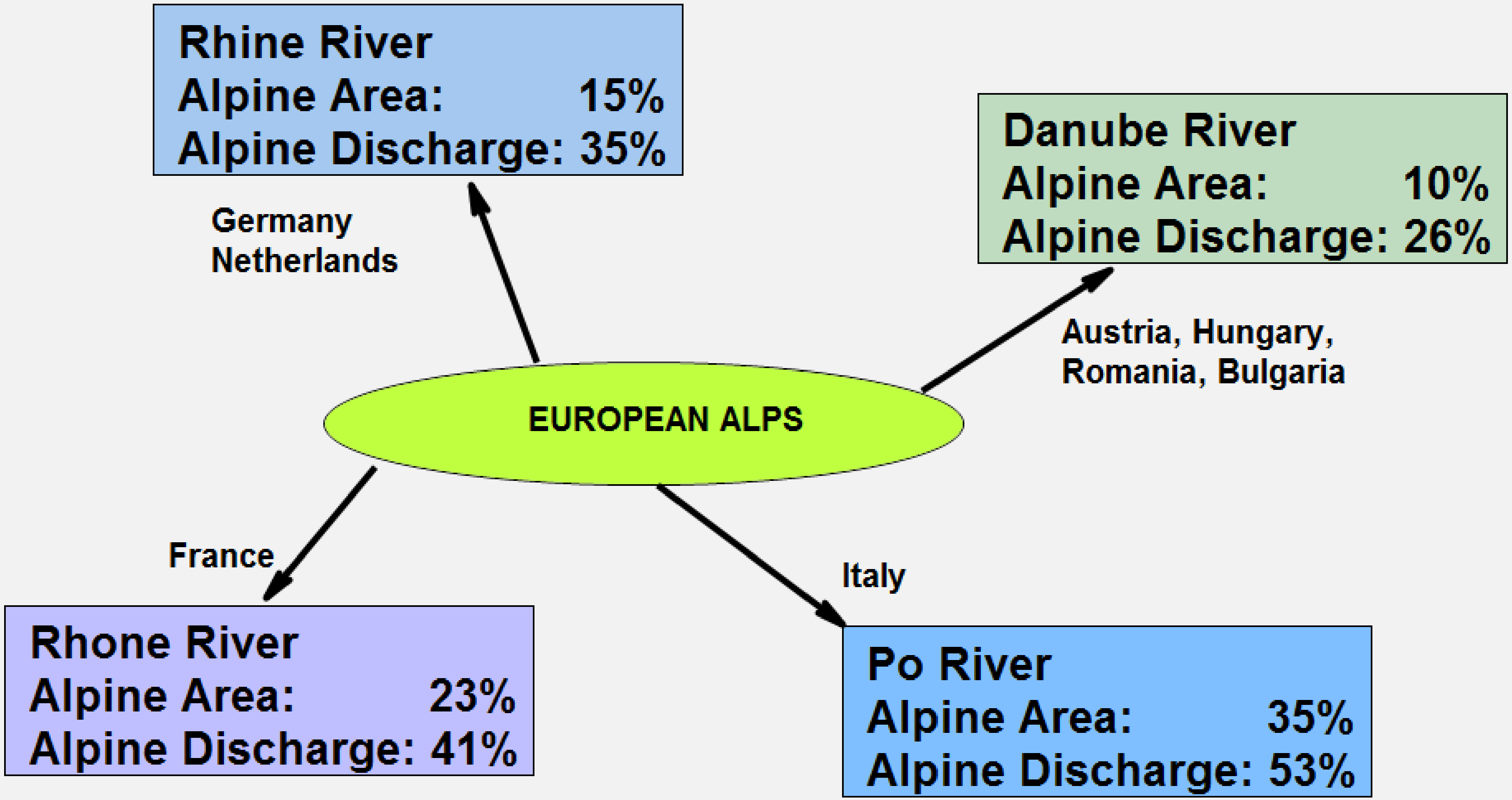


Runoff Surplus & Seasonal Supply

- Higher Rainfall and Lower Evapotranspiration than in Lowland
- Seasonal Redistribution: Accummulation & Melting of Snow
- Balancing Summer Effects in Lowland: Melting Snow & Ice

Annual Precipitation in Central Europe





Source: Viviroli & Weingartner 2004

Seasonal Impact

River Basins	Mountain Portion in Basin	Annual Contribution to Flow	Summer Contribution to Flow
Danube	10%	26%	36%
Po	35%	53%	80%
Rhine	15%	34%	52%
Rhone	23%	41%	69%

River Basins	Est. Basin Population Million	% in Mtn.	% Water from Mts	Monthly Discharge Billion m3/month Lowest	Highest	Mean
Ganges	500	33%	65%	10.9	128.5	43.1
Nile	450	44%	93%	2.3	80.5	29.6
Yellow	190	41%	50%	0.6	10.3	5.7
Indus	160	31%	75%	6.7	40.7	19.9
Niger	110	11%	58%	0.1	90.7	28.2
Mekong	60	48%	34%	0.4	107.9	41.1

200 Major Rivers

- 29 Decreased
  - Mississippi, Columbia
  - Uruguay, Parana
  - Congo, Niger,
  - Ganges, Yenisey
- 145 No change
- 26 Increased

Changes between 1948-2012 Precipitation & Runoff

Decreases in Precipitation & Discharge	Increases in Precipitation & Discharge
Africa, E & S Asia SE & NW USA, W & E Canada Part of Brazil	Argentina, Uruguay C & N USA C & N Europe, Russia

Modelled Projections to 2015 (Moderater Emissions)

Decreases 5-15% in Precipitation & Discharge	Increases 10-25% in Precipitation & Discharge
S-Europe N & S-Africa SW-USA, C-America	Asia, N-Europe, N-America SW-South America E-Africa

Why would the Runoff of Major Rivers Change?

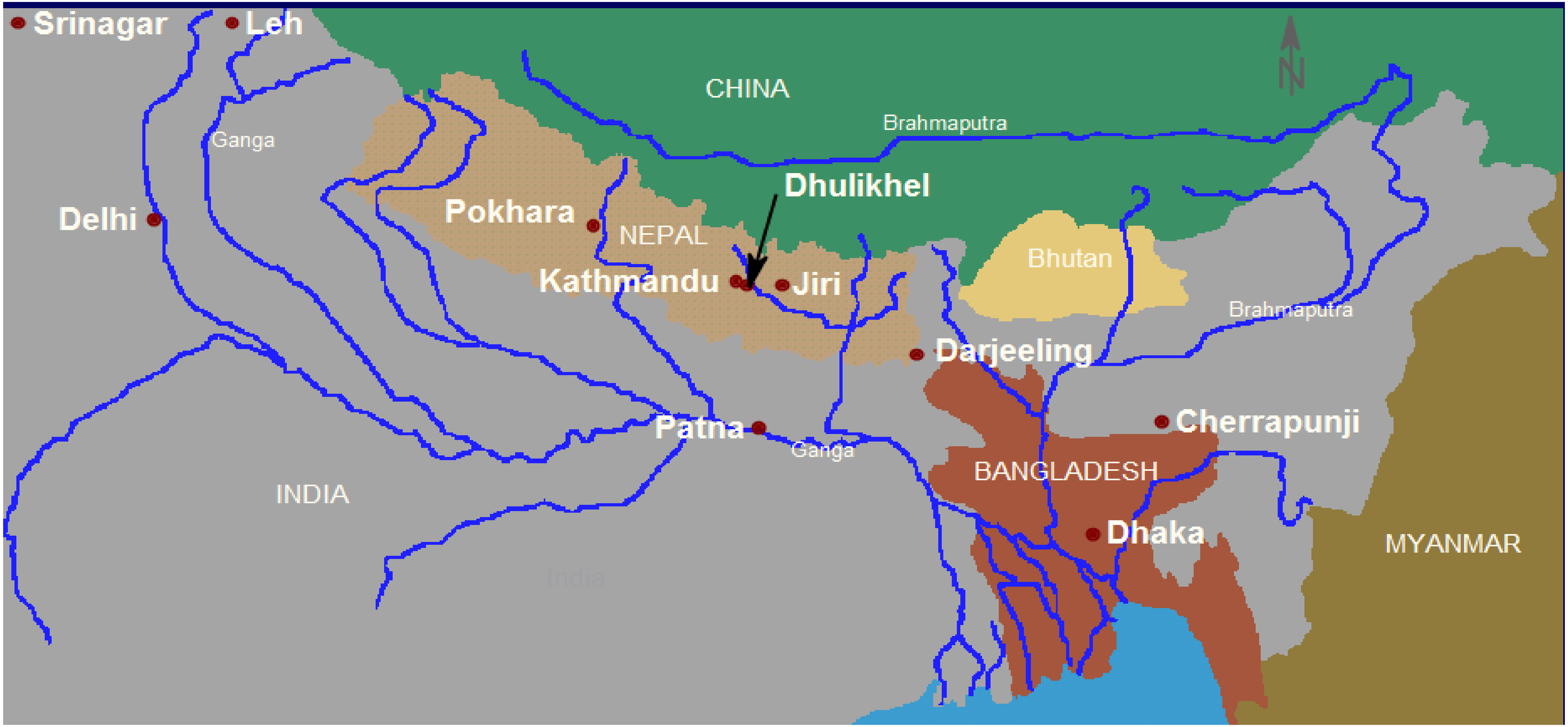
Possible Reasons for Changes in River Discharge

- Water used for Irrigation & Domestic Purposes
- Dams and Reservoirs
- Groundwater Mining
- Changes in Vegetation (Deforestation)

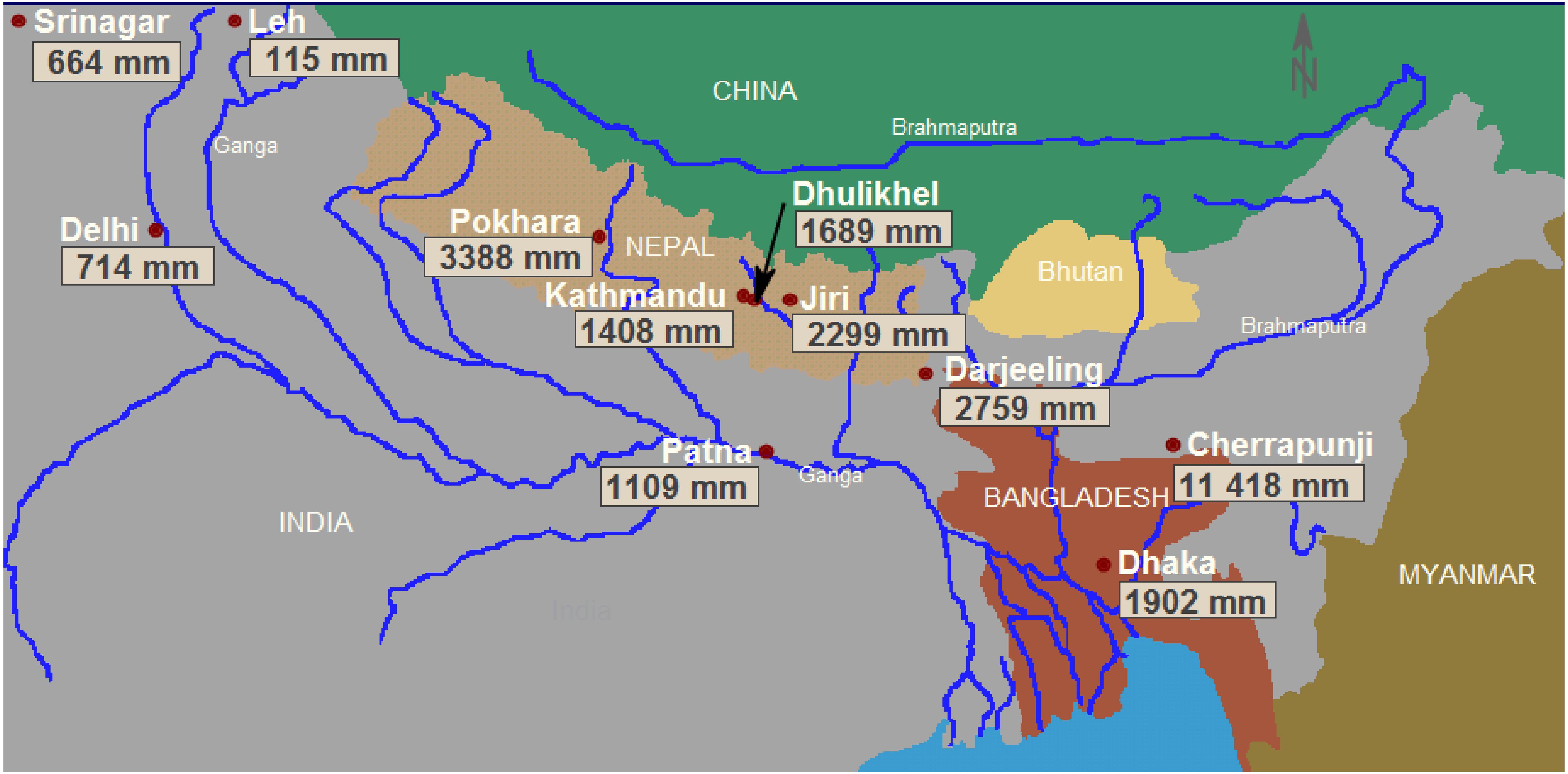
- Climate Change (Precipitation & Temperature)
- Glacial Melt

Dai et al. 2009. Changes in continental freshwater discharge 1948-2004. J. Climate 22
Dai, A. 2016. Historic & future changes in streamflow and continental runoff: A review. Chaper 2. Terrestrial water cycle & climate change, in Natural & Human induced impacts. Geophysical Monograph 221, John Wiley & Sons pp17-37

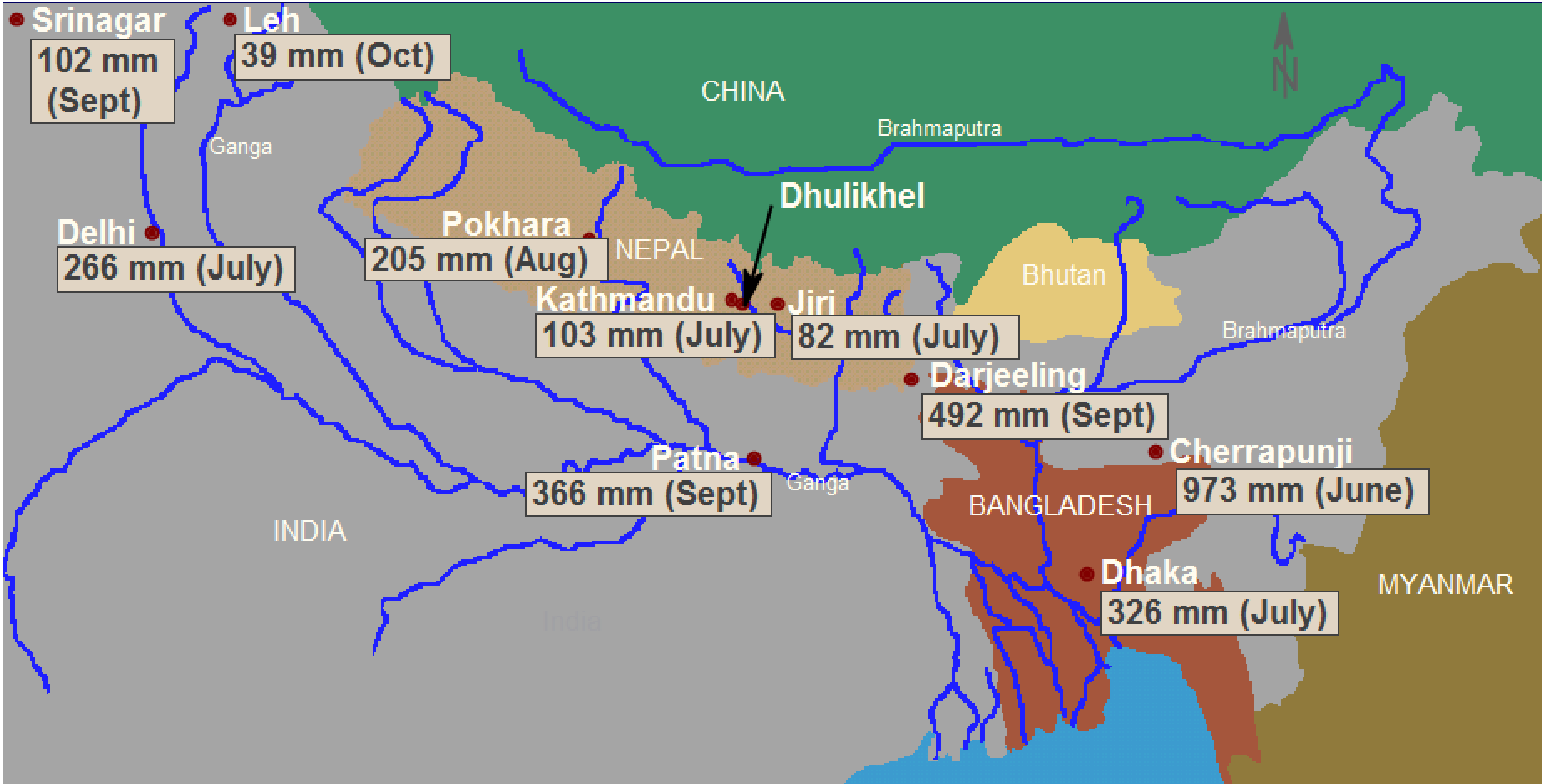
Himalayan Mountain Range



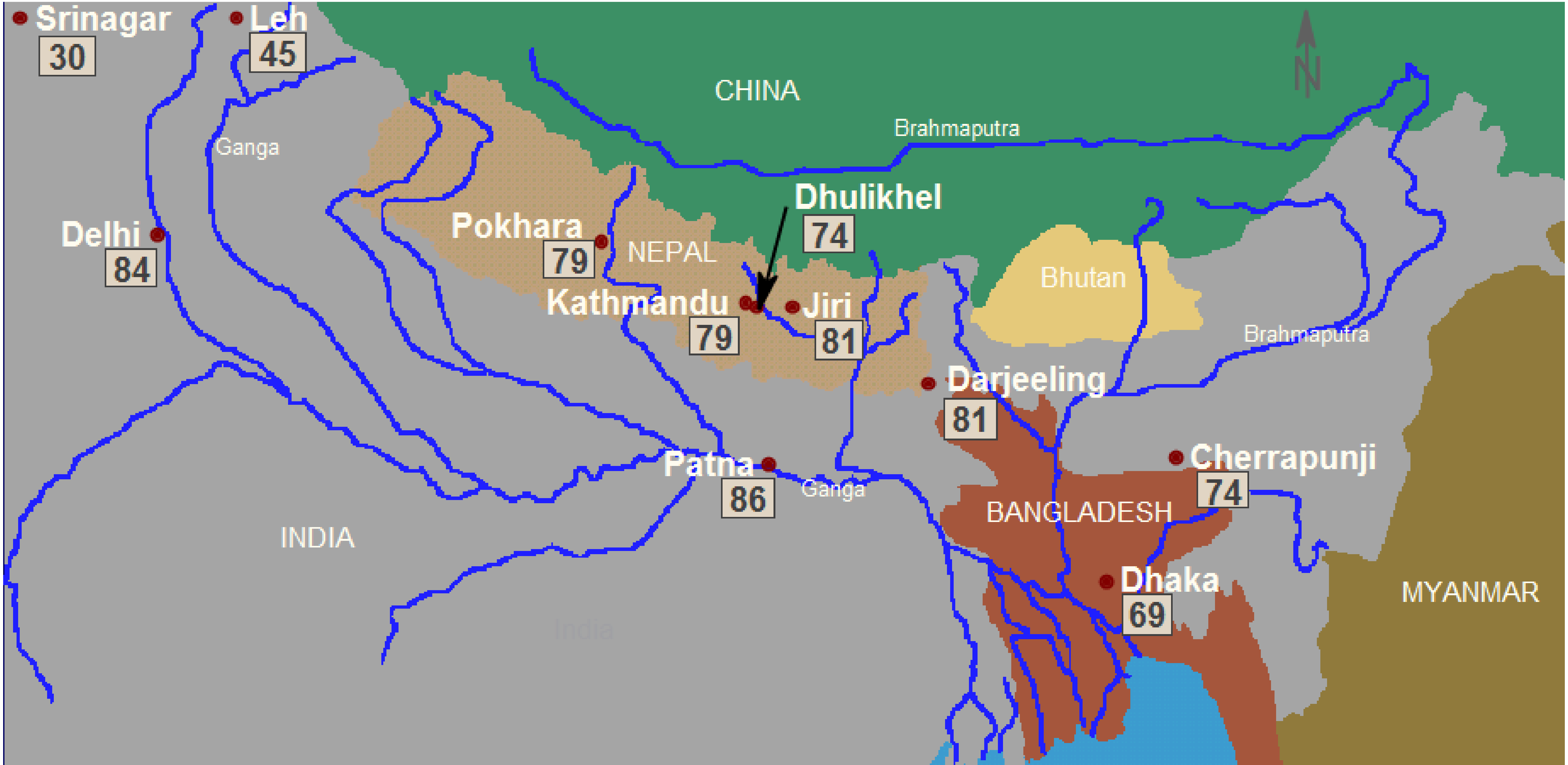
Variation in Annual Precipitation (in mm/Year)



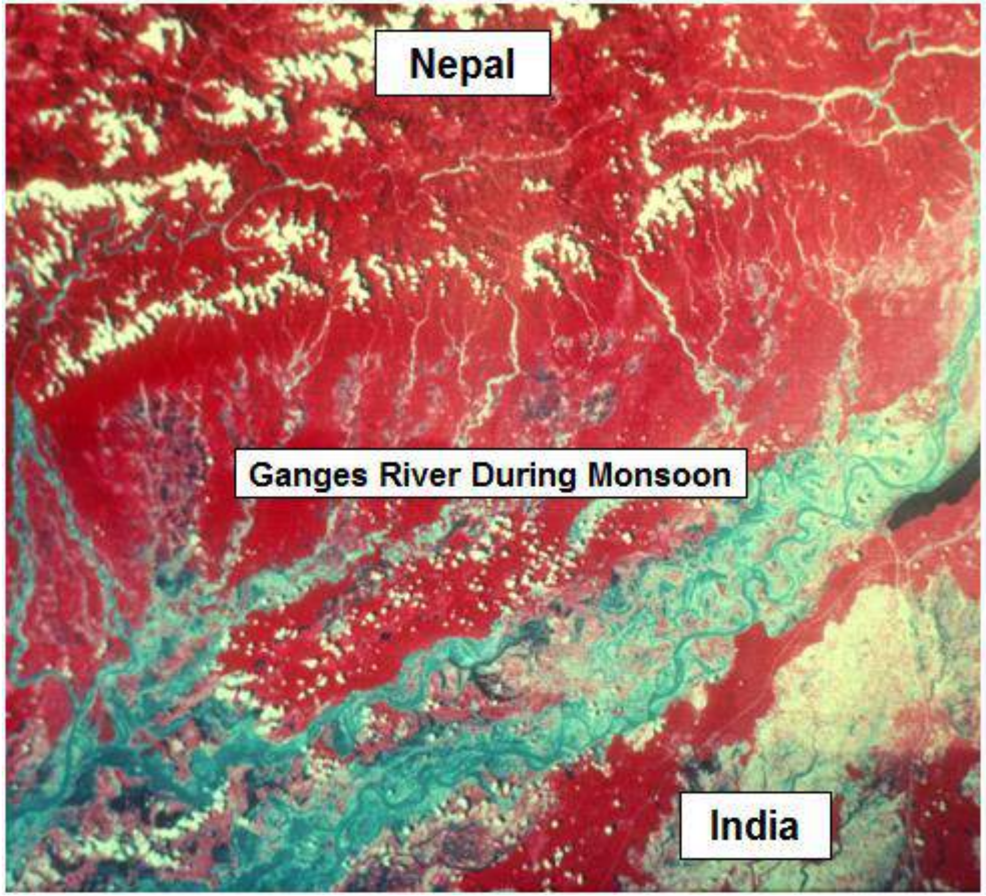
Variation in 24 Hours Rainfall Intensity (mm/24 hrs)



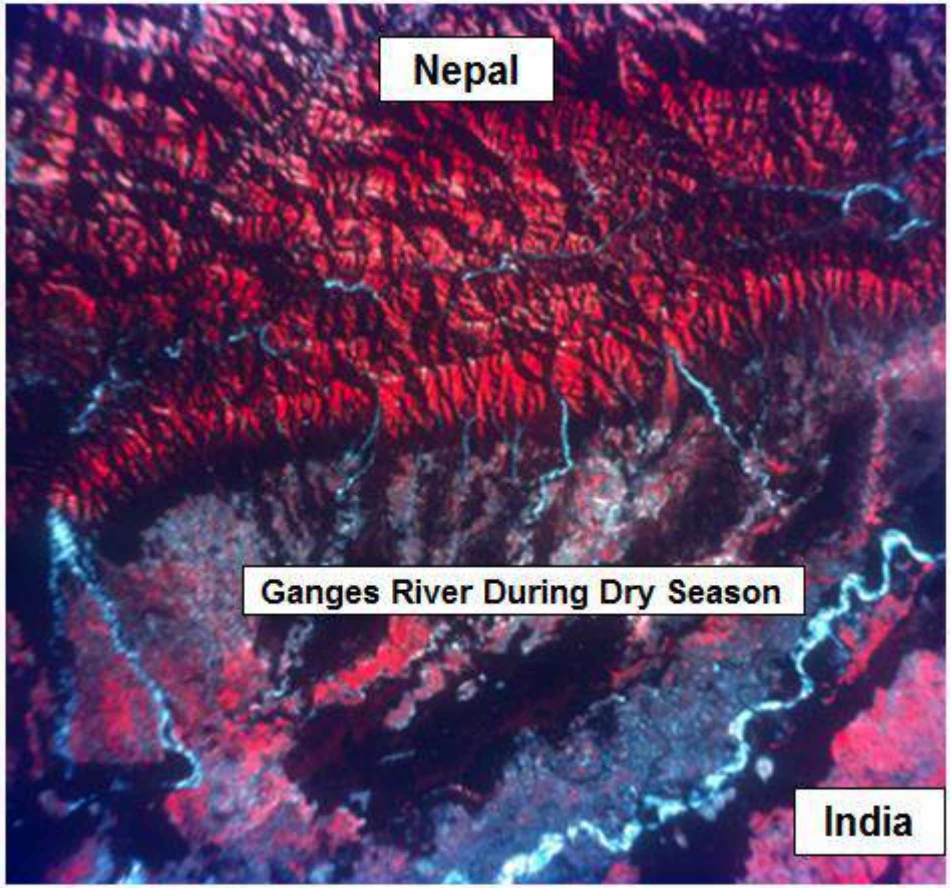
% of annual Rainfall Between May-Aug (Monsoon)



Wet Season



Dry Season



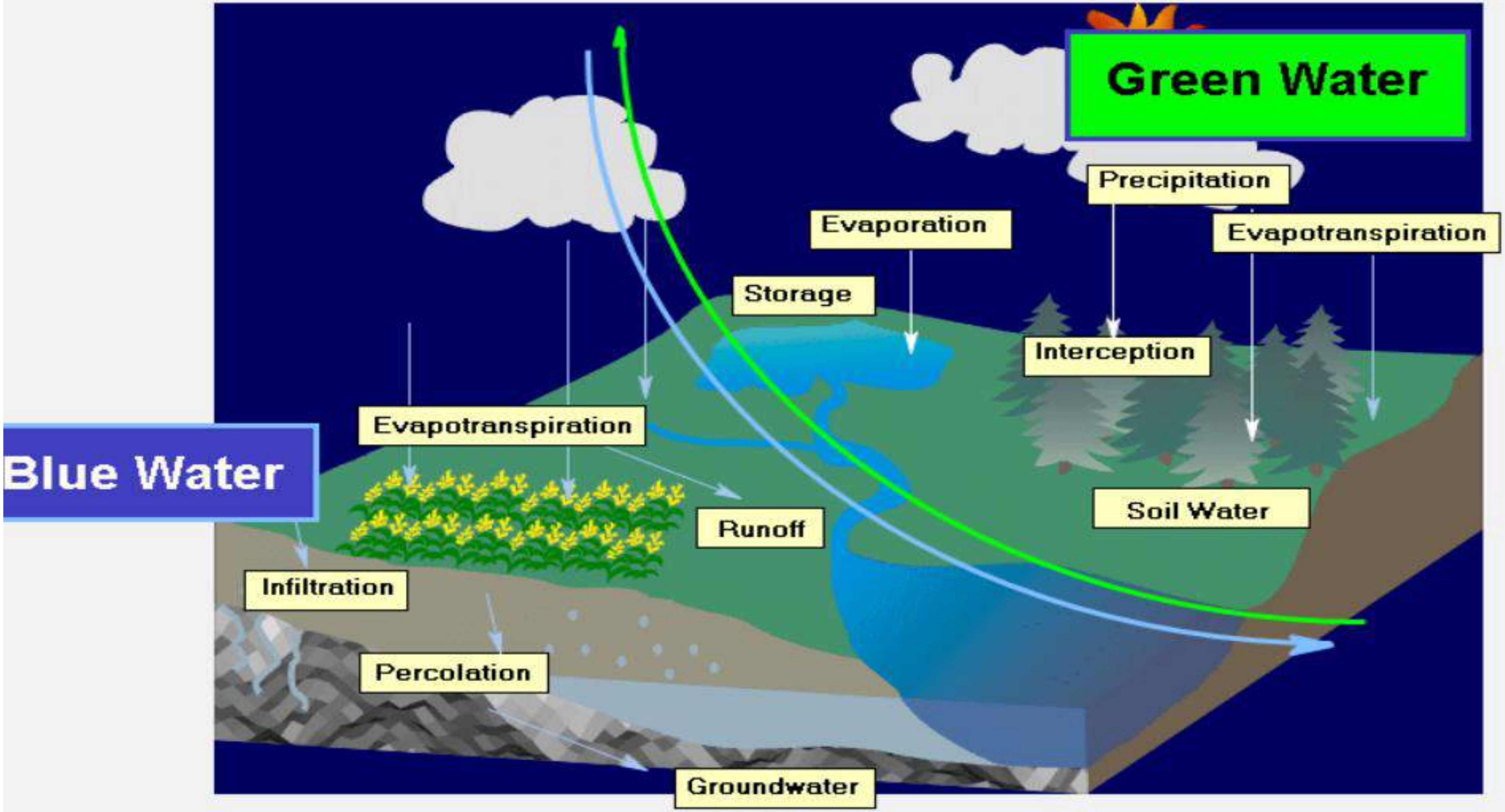
Variation in Annual Precipitation in Peru (mm/Year)

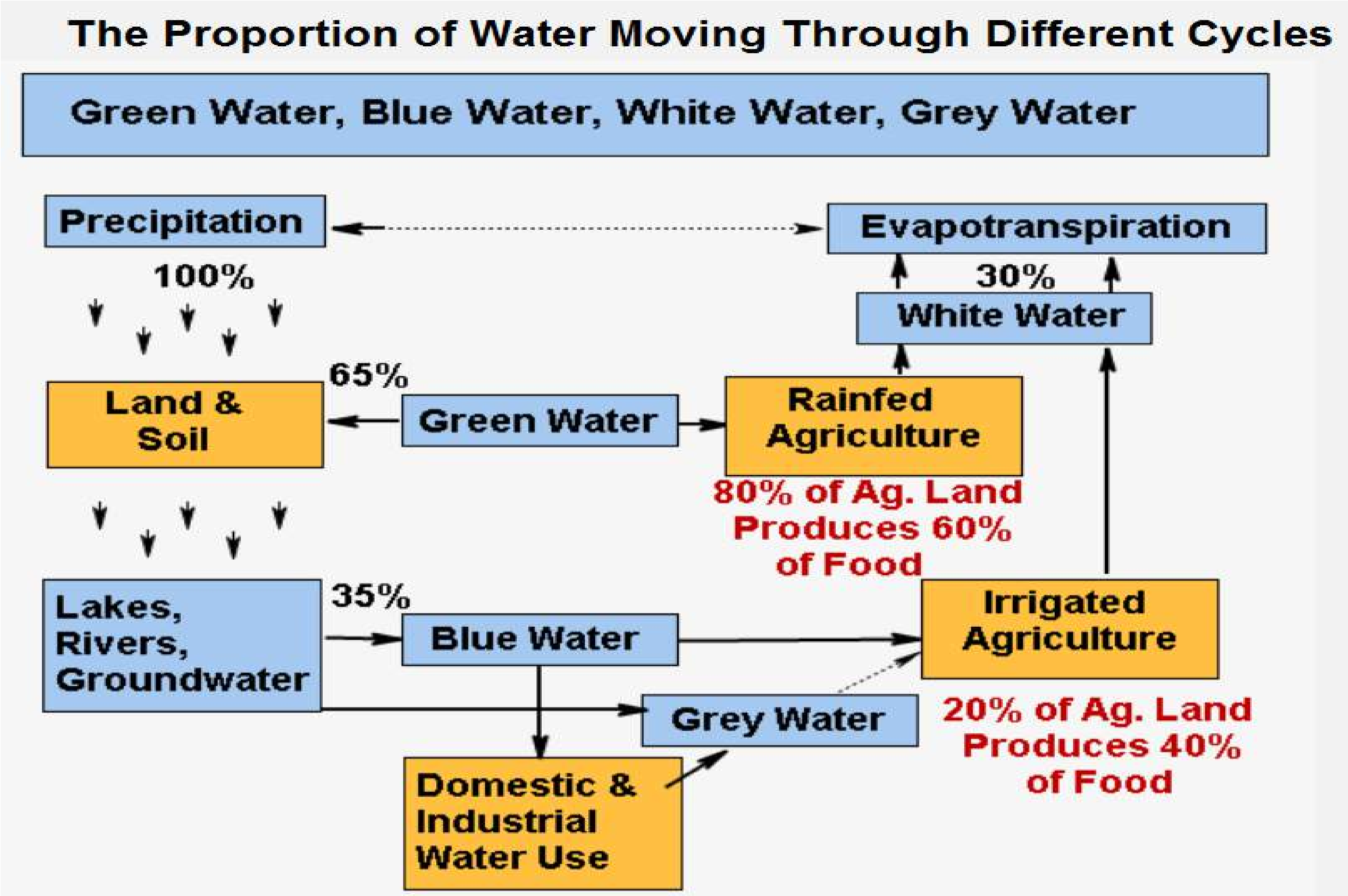
Great Variability in Peru's Climate

	Mean Temperatures	Annual Precipitation
Coast	21 °C	5-10 mm
Mountains	12 °C	400-700 mm
Tropics	32 °C	1900-3200 mm

More than 1/3 of the population lives in the coastal region (13 out of 35 Million)

The Blue and Green Hydrological Cycle





The Proportion of Water Moving Through Different Cycles
Green Water, Blue Water, White Water, Grey Water
Precipitation
Evapotranspiration
100%
30%
White Water
65%
Land & Soil
Green Water
Rainfed Agriculture
80% of Ag. Land Produces 60% of Food
35%
Lakes, Rivers, Groundwater
Blue Water
Irrigated Agriculture
Grey Water
20% of Ag. Land Produces 40% of Food
Domestic & Industrial Water Use

Projected Global Populations in Each Category by 2050

Blue Water	Green Water	
	Green Water Limited < 1300 m3/capita/yr	Green Water Sufficient > 1300 m3/capita/yr
Blue Water Limited < 1000 m3/capita/yr	46 %	14 %
Blue Water Sufficient > 1000 m3/capita/yr	21 %	19 %

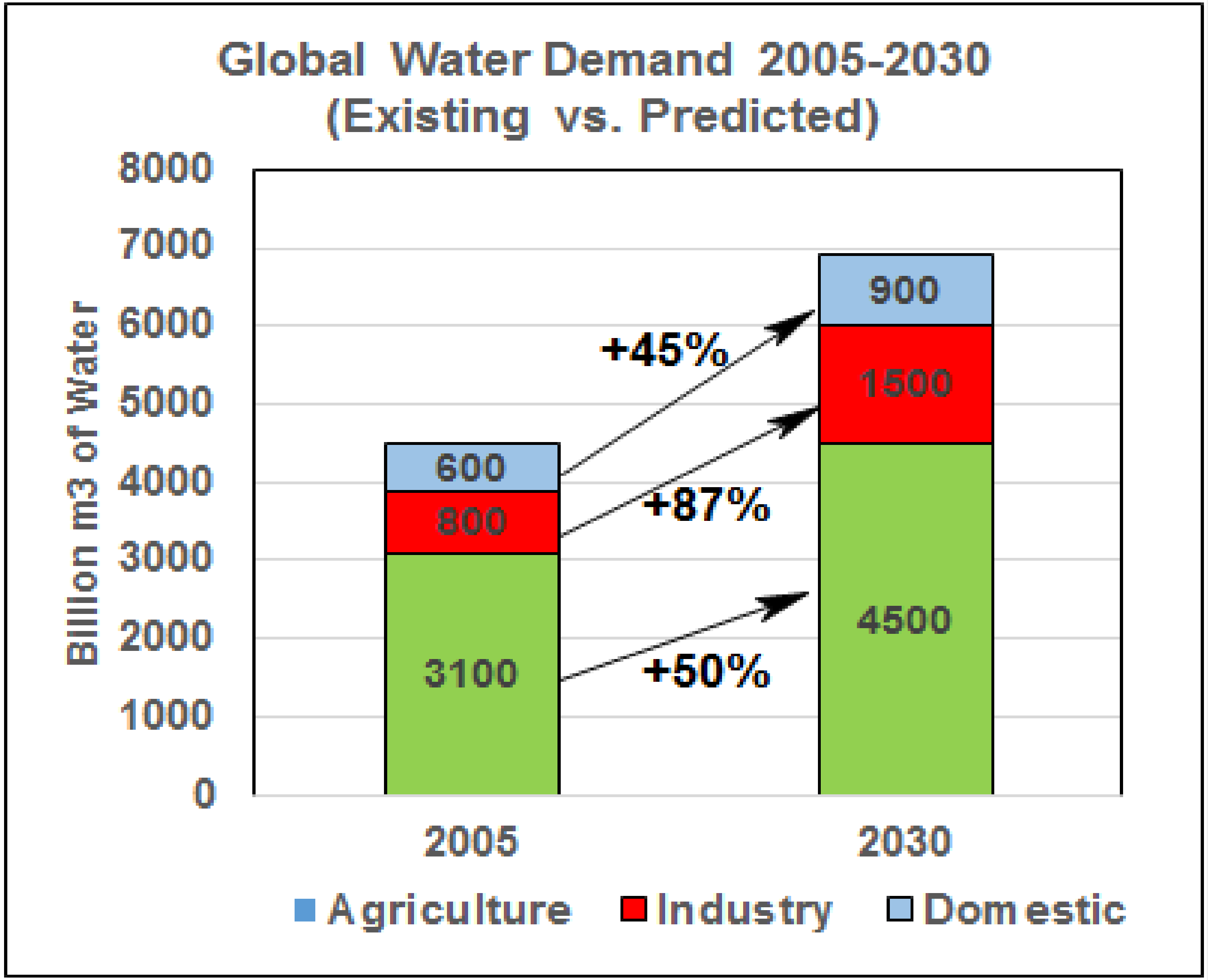
Data Source: Rockstrom et al. 2007, Falkenmark & Rockstrom, 2011

Example Countries by 2050

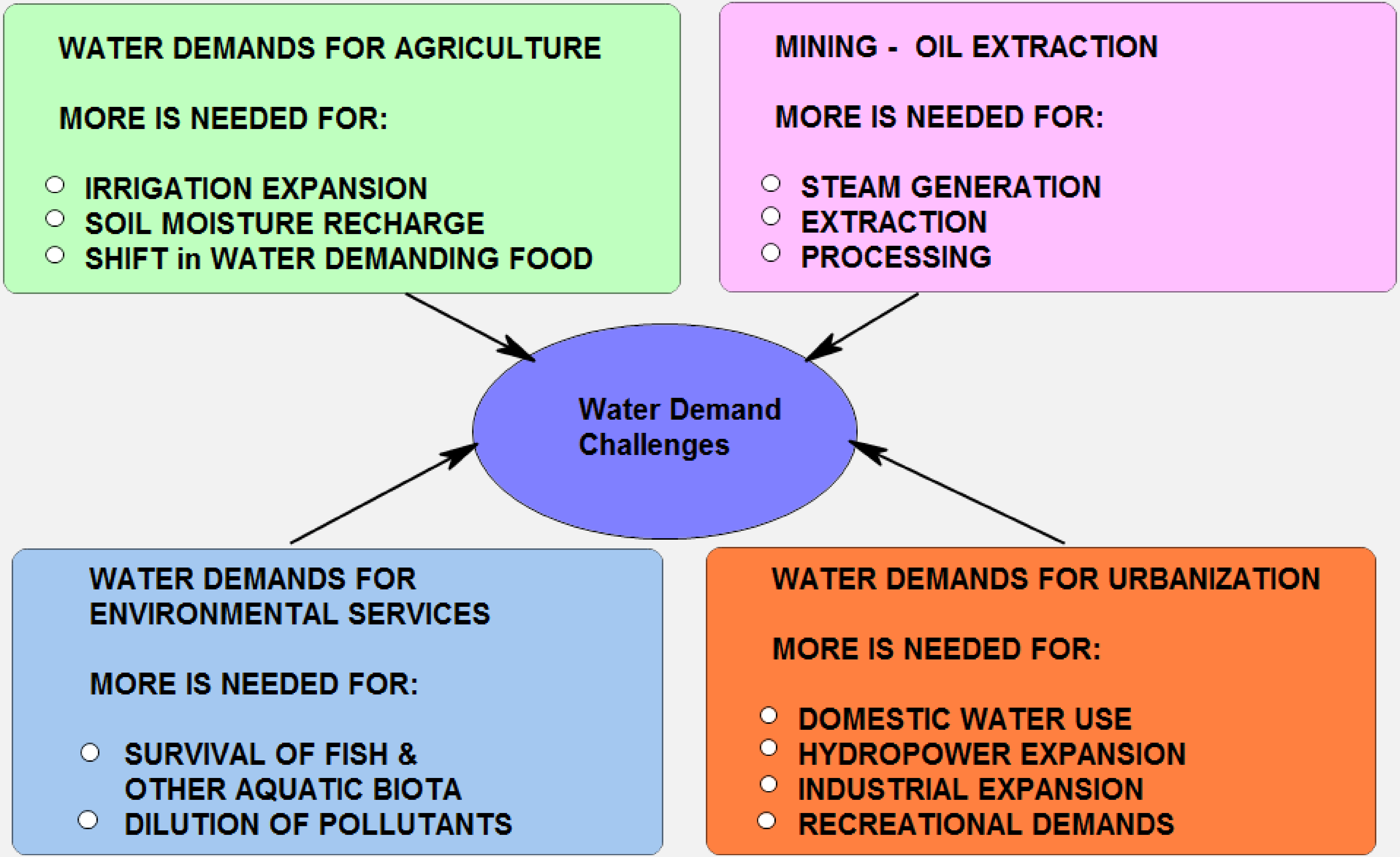
Blue Water	Green Water	
	Green Water Limited < 1300 m3/capita/yr	Green Water Sufficient > 1300 m3/capita/yr
Blue Water Limited < 1000 m3/capita/yr	Jordan, Egypt India, China	South Africa
Blue Water Sufficient > 1000 m3/capita/yr	Korea, Japan	Brazil, Canada

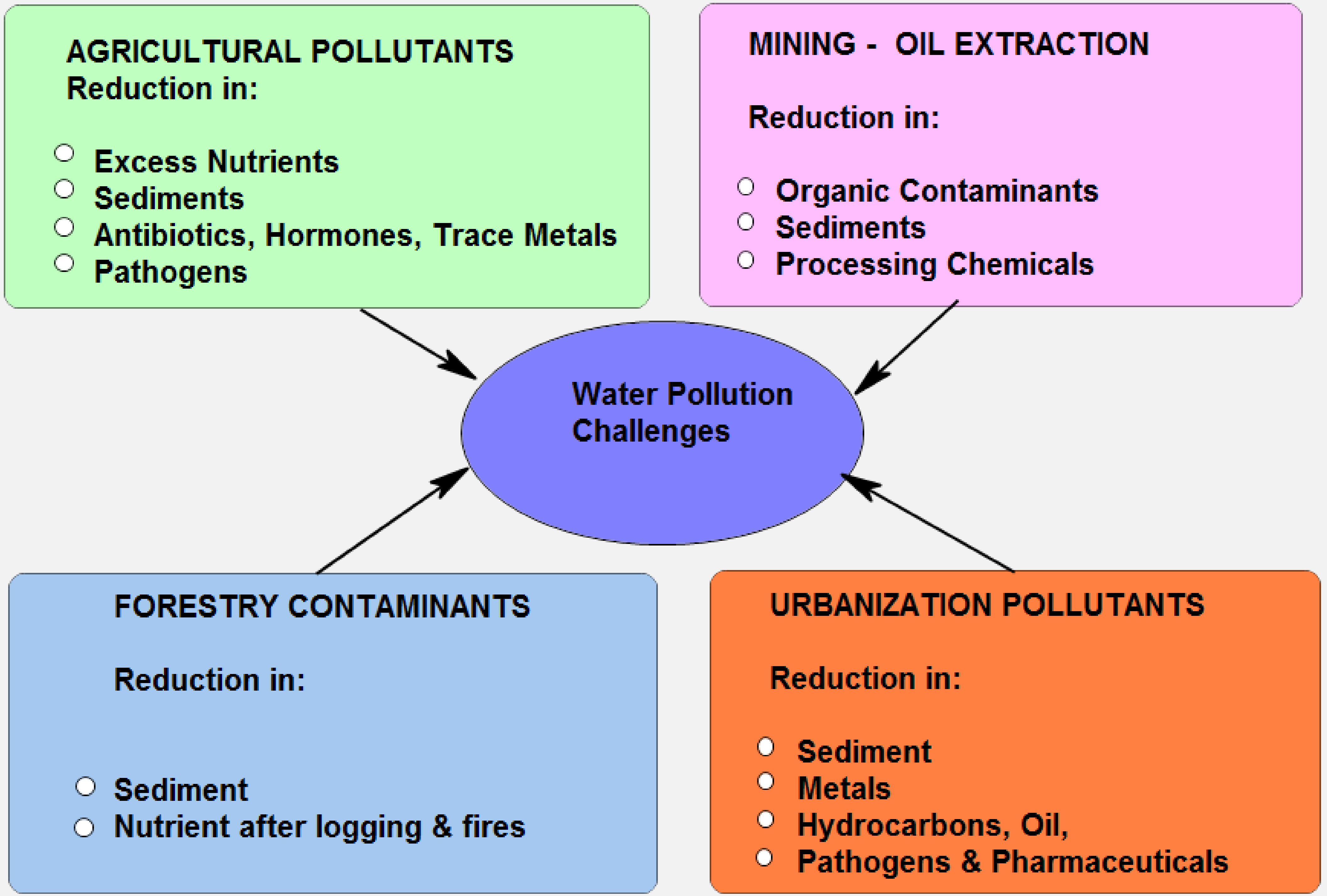
Data Source: Rockstrom et al. 2007, Falkenmark & Rockstrom, 2011

In 2010
69% of all
Water was
used for
Agriculture

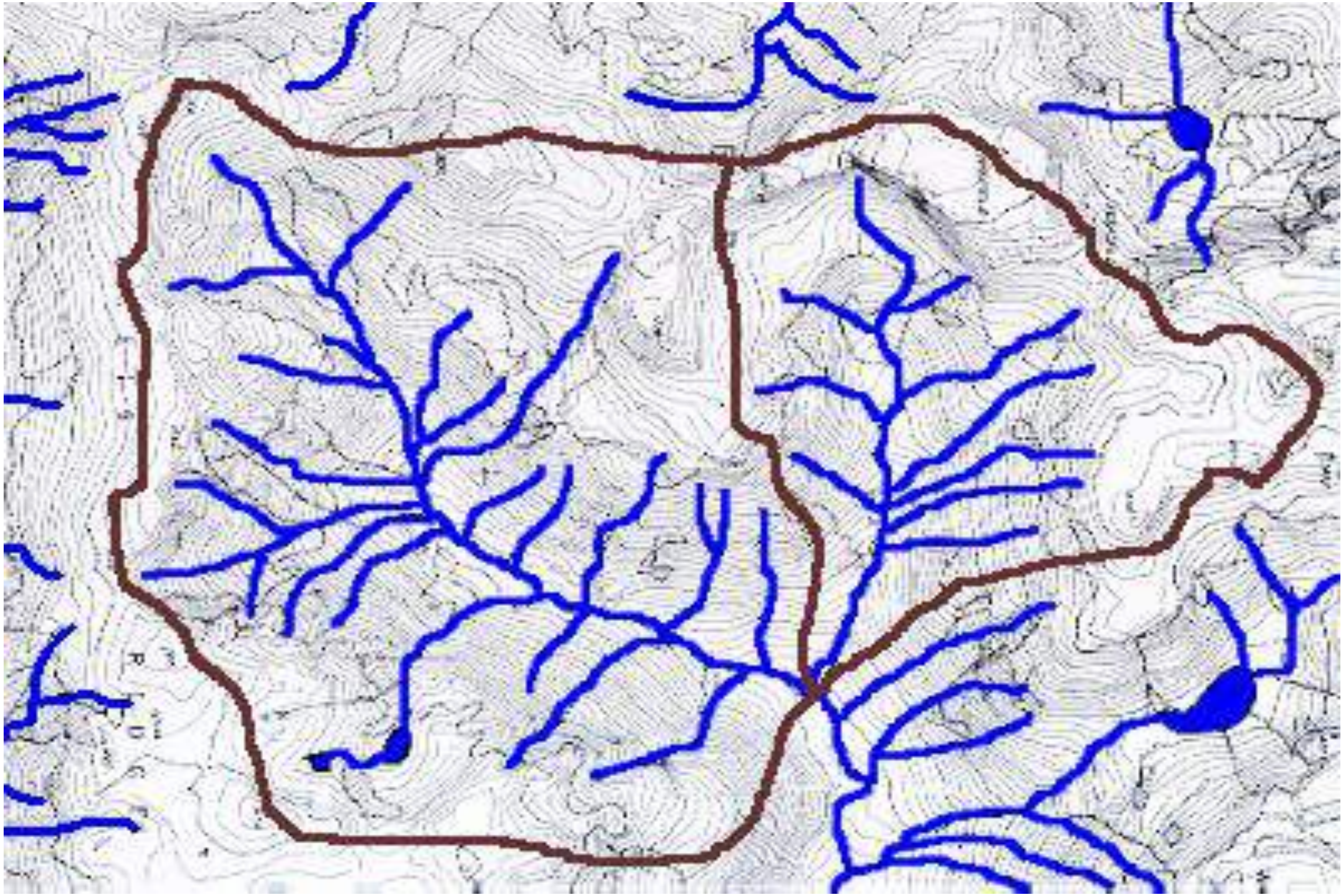


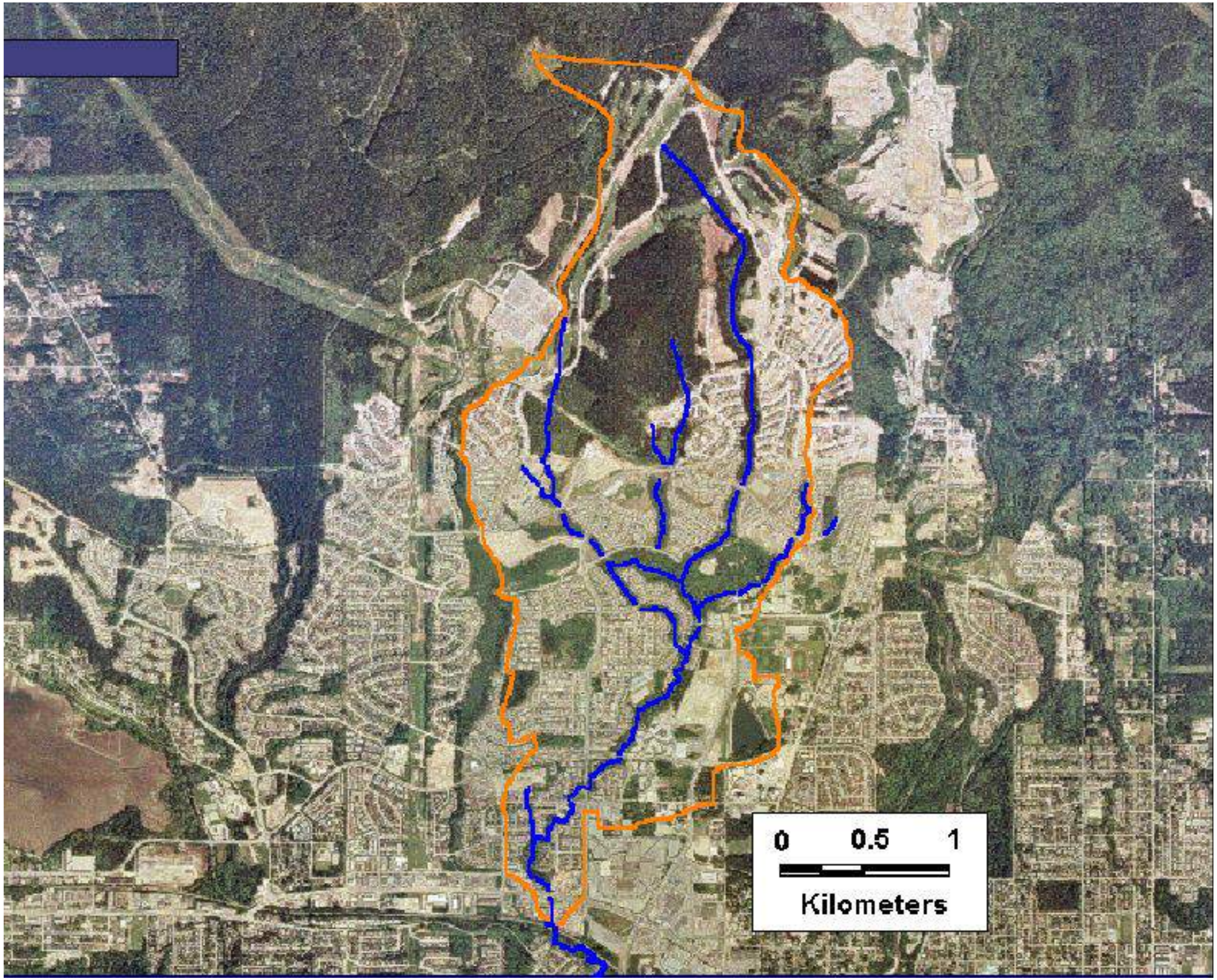
Data Source: McKinsey Corp. 2012

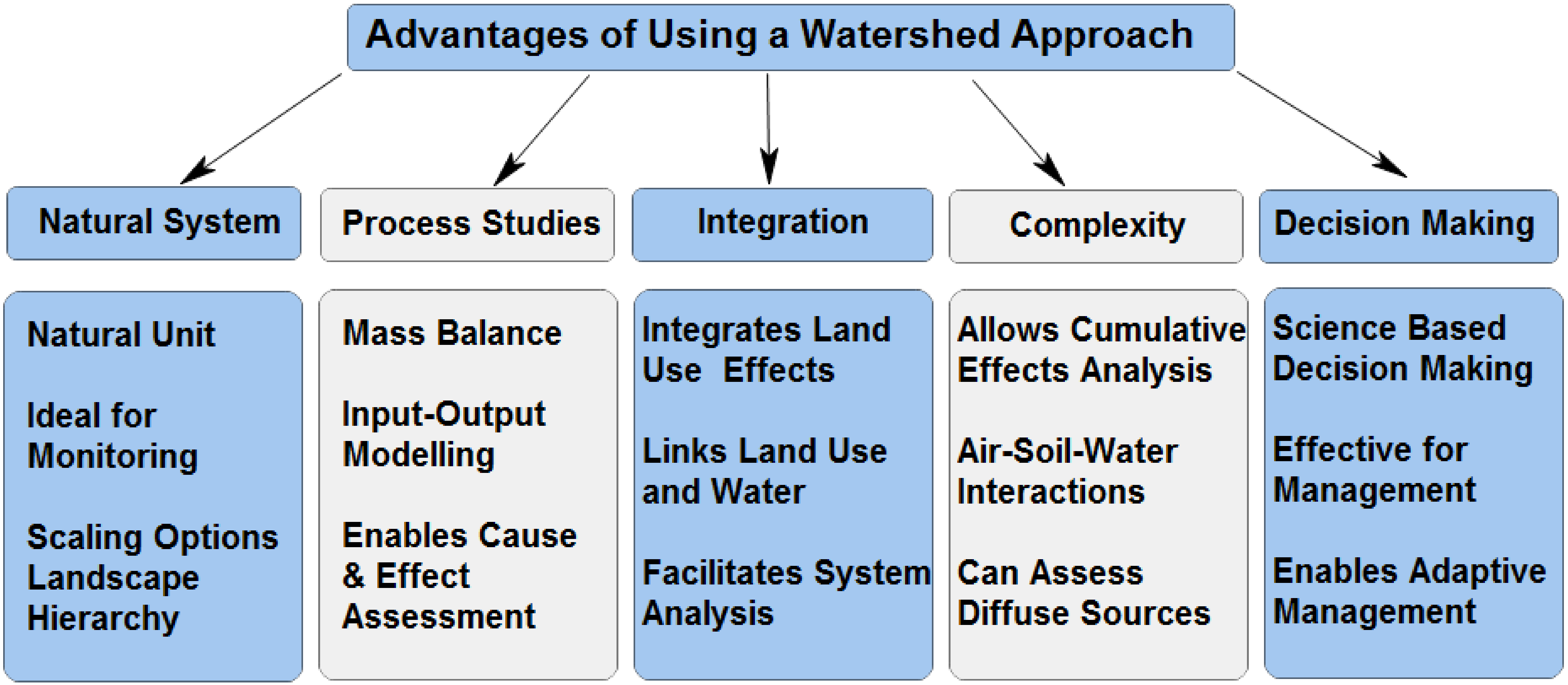

WATER DEMANDS FOR AGRICULTURE
MORE IS NEEDED FOR:
IRRIGATION EXPANSION
SOIL MOISTURE RECHARGE
SHIFT in WATER DEMANDING FOOD
MINING - OIL EXTRACTION
MORE IS NEEDED FOR:
STEAM GENERATION
EXTRACTION
PROCESSING
Water Demand Challenges
WATER DEMANDS FOR ENVIRONMENTAL SERVICES
MORE IS NEEDED FOR:
SURVIVAL OF FISH & OTHER AQUATIC BIOTA
DILUTION OF POLLUTANTS
WATER DEMANDS FOR URBANIZATION
MORE IS NEEDED FOR:
DOMESTIC WATER USE
HYDROPOWER EXPANSION
INDUSTRIAL EXPANSION
RECREATIONAL DEMANDS


AGRICULTURAL POLLUTANTS
Reduction in:
Excess Nutrients
Sediments
Antibiotics, Hormones, Trace Metals
Pathogens
MINING - OIL EXTRACTION
Reduction in:
Organic Contaminants
Sediments
Processing Chemicals
Water Pollution Challenges
FORESTRY CONTAMINANTS
Reduction in:
Sediment
Nutrient after logging & fires
URBANIZATION POLLUTANTS
Reduction in:
Sediment
Metals
Hydrocarbons, Oil,
Pathogens & Pharmaceuticals

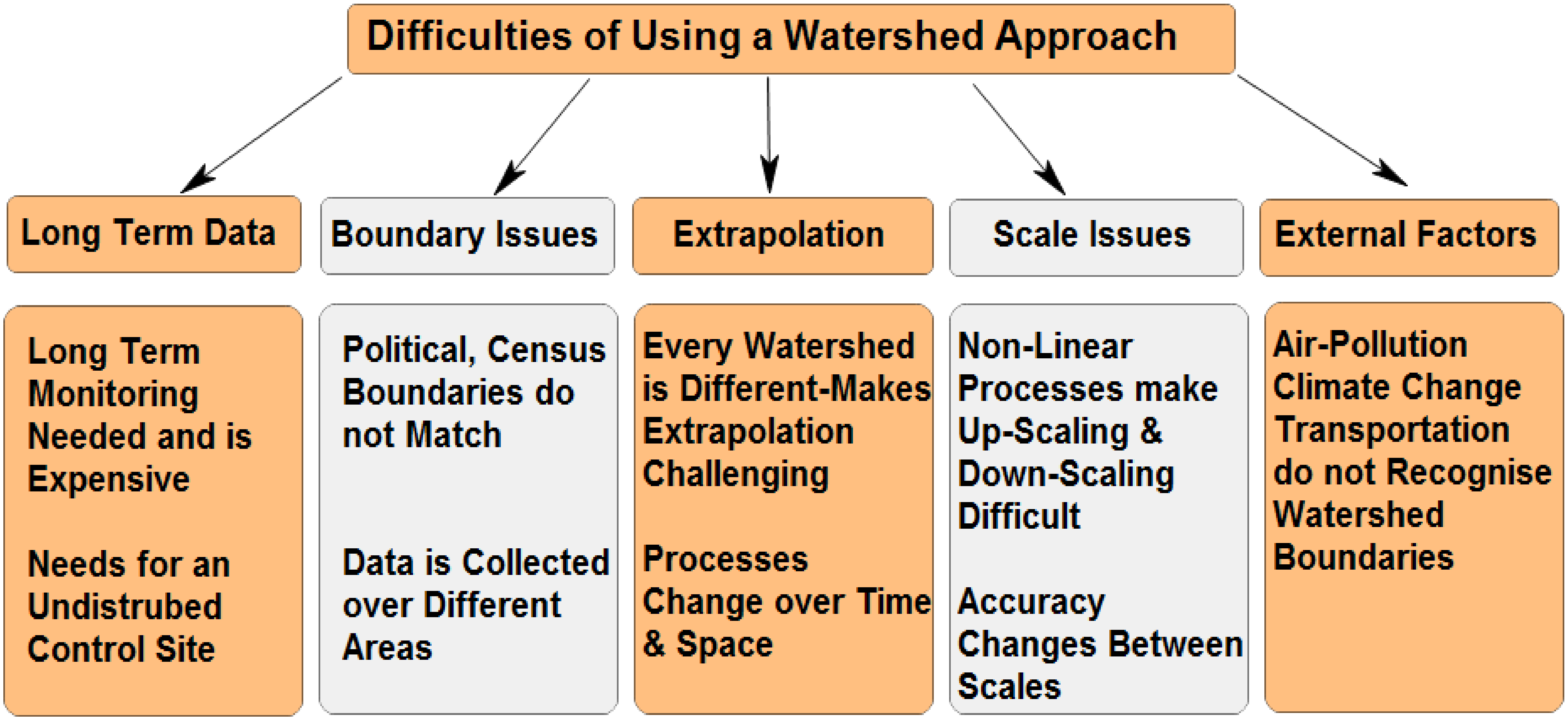
Why Integrated Watershed Management?




0 0.5 1
Kilometers



Advantages of Using a Watershed Approach
Natural System
Process Studies
Integration
Complexity
Decision Making
Natural Unit
Ideal for Monitoring
Scaling Options Landscape Hierarchy
Mass Balance
Input-Output Modelling
Enables Cause & Effect Assessment
Integrates Land Use Effects
Links Land Use and Water
Facilitates System Analysis
Allows Cumulative Effects Analysis
Air-Soil-Water Interactions
Can Assess Diffuse Sources
Science Based Decision Making
Effective for Management
Enables Adaptive Management


Difficulties of Using a Watershed Approach
Long Term Data
Boundary Issues
Extrapolation
Scale Issues
External Factors
Long Term Monitoring Needed and is Expensive
Needs for an Undistrubed Control Site
Political, Census Boundaries do not Match
Data is Collected over Different Areas
Every Watershed is Different-Makes Extrapolation Challenging
Processes Change over Time & Space
Non-Linear Processes make Up-Scaling & Down-Scaling Difficult
Accuracy Changes Between Scales
Air-Pollution Climate Change Transportation do not Recognise Watershed Boundaries

Land Use Change and Climate Change Interaction

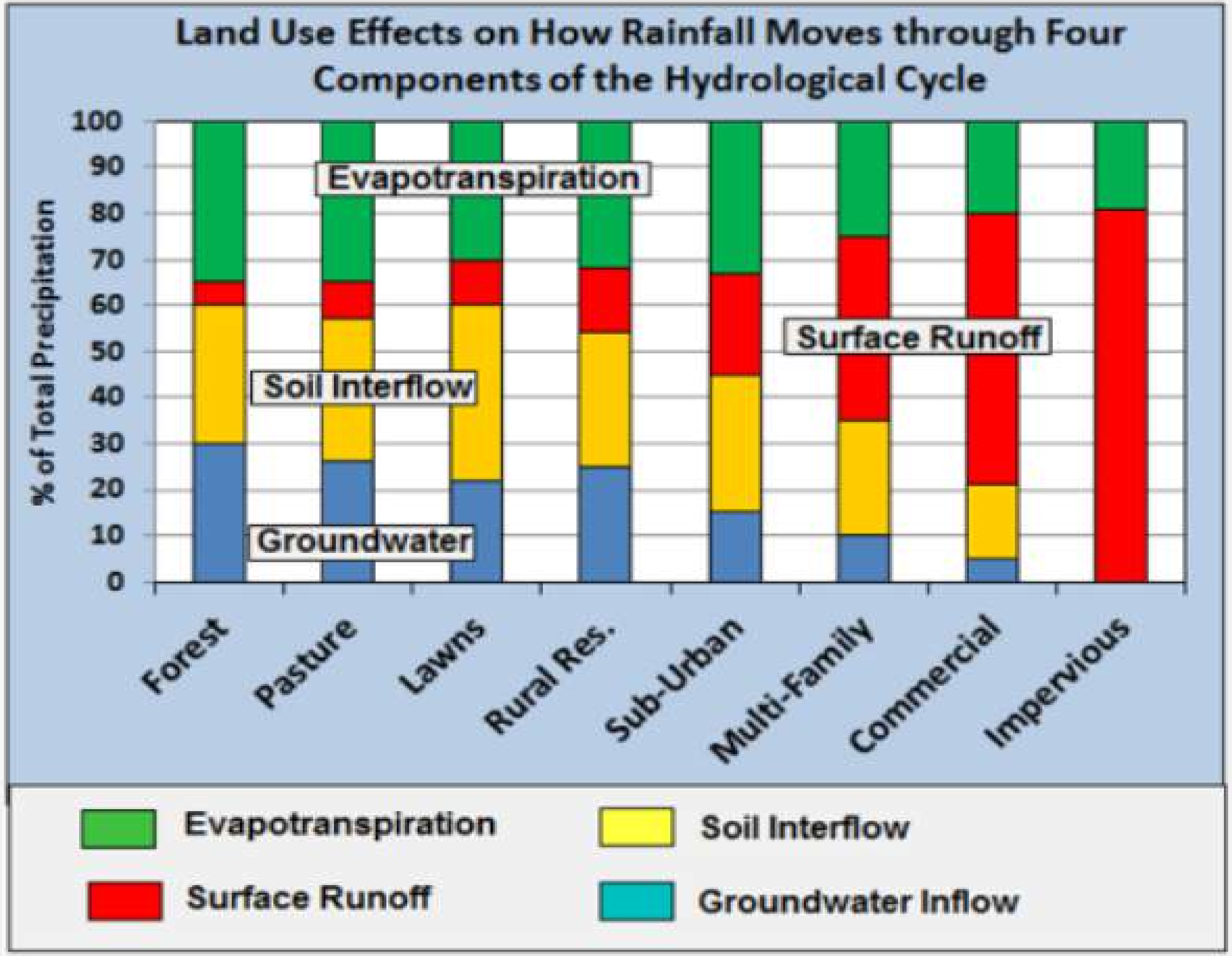
Evidence of increased Variability

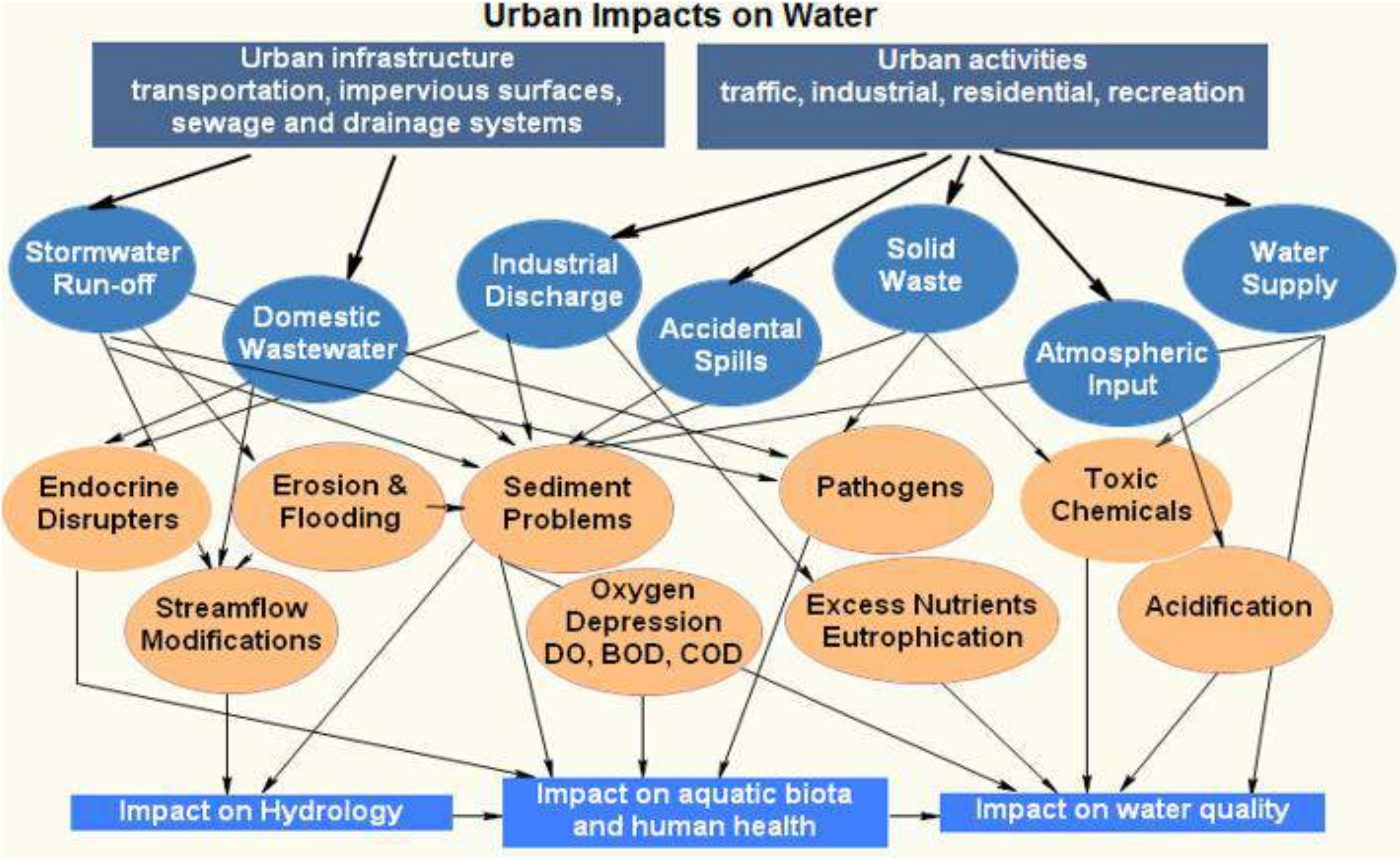
Increased Climatic Variability

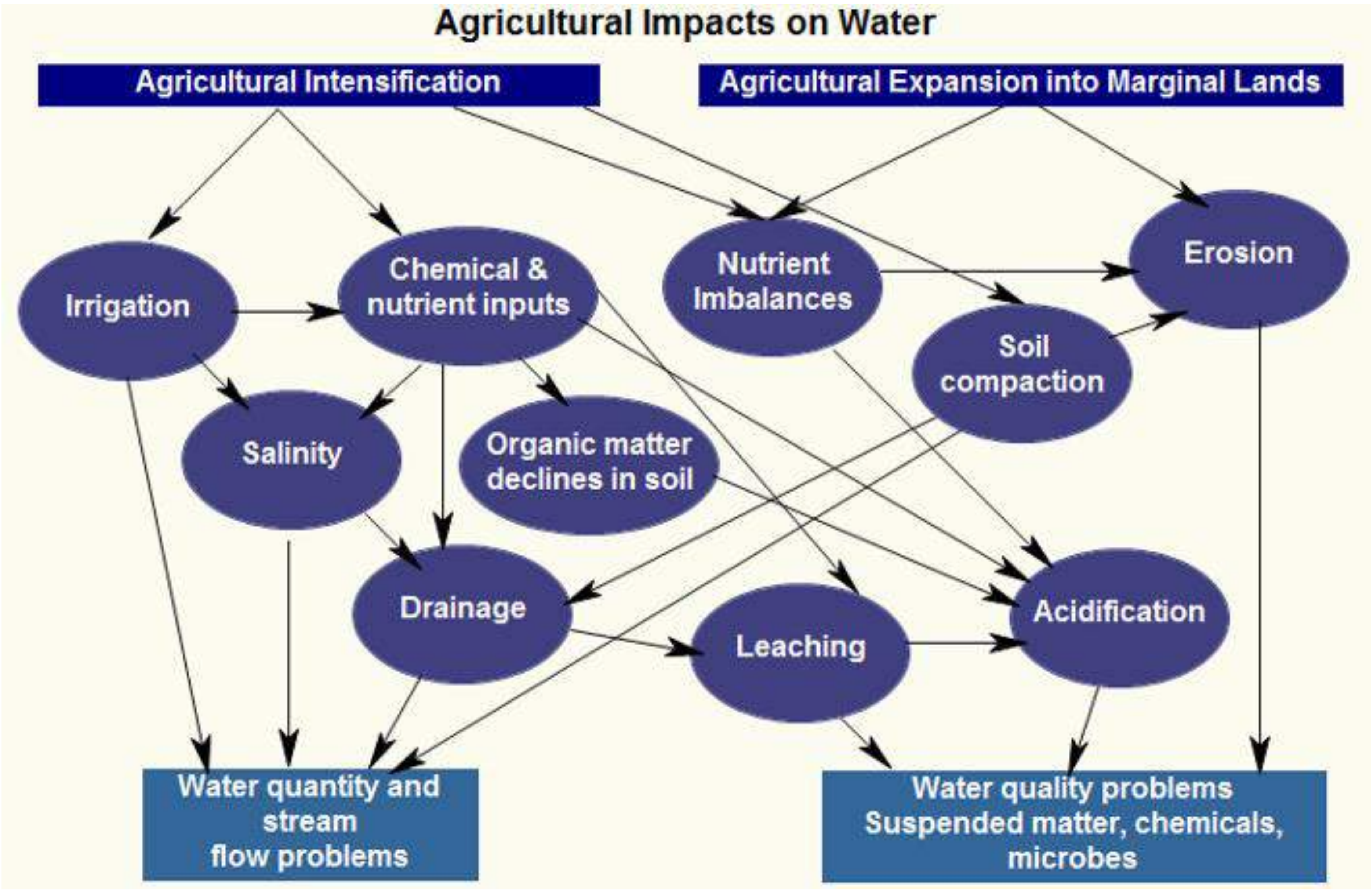
Increased Land Use Changes & Intensity

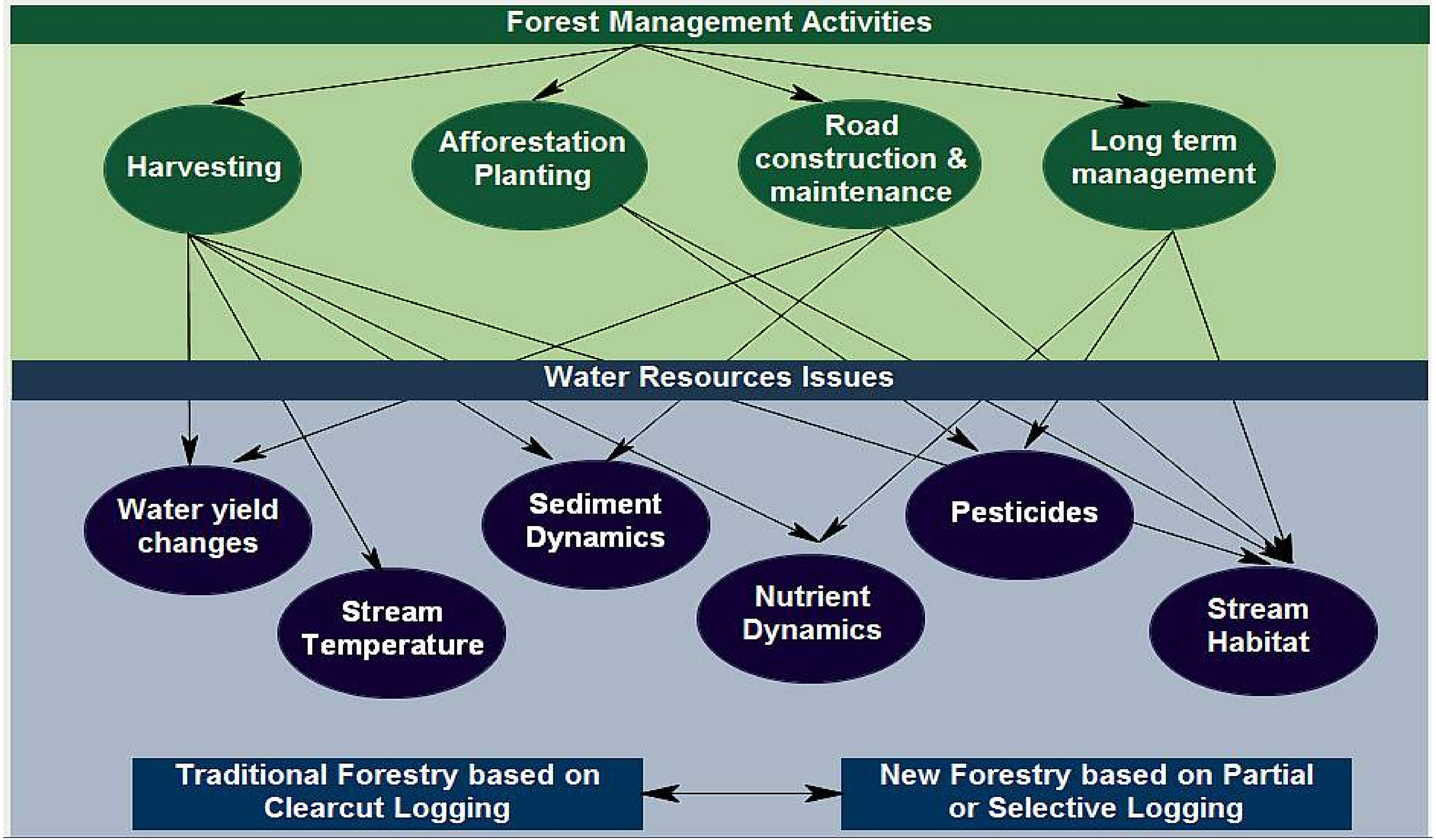
Rainfall Redistribution by Land Use

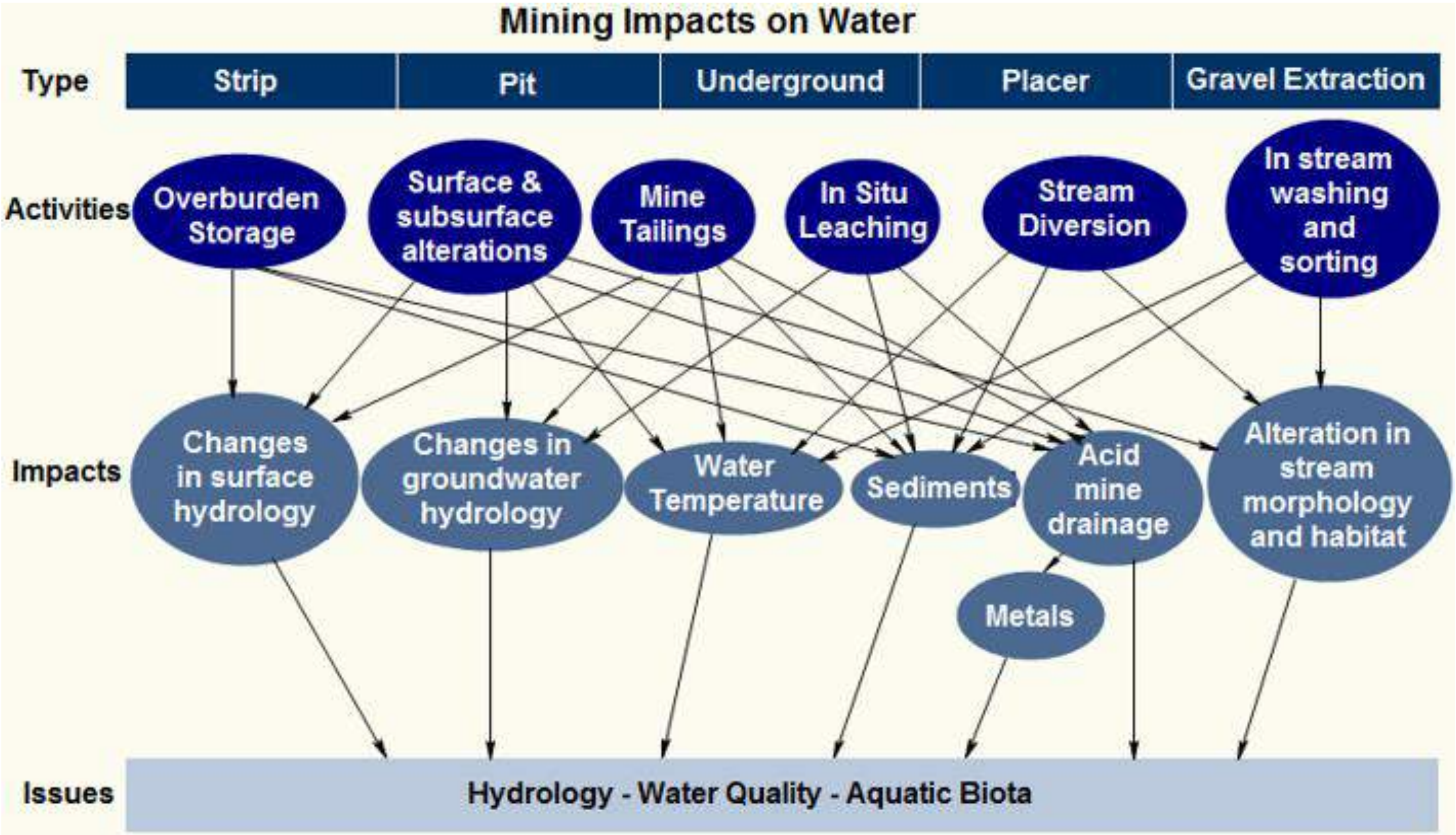
Note: Change in Surface Runoff as a result of land use changes (in Red)



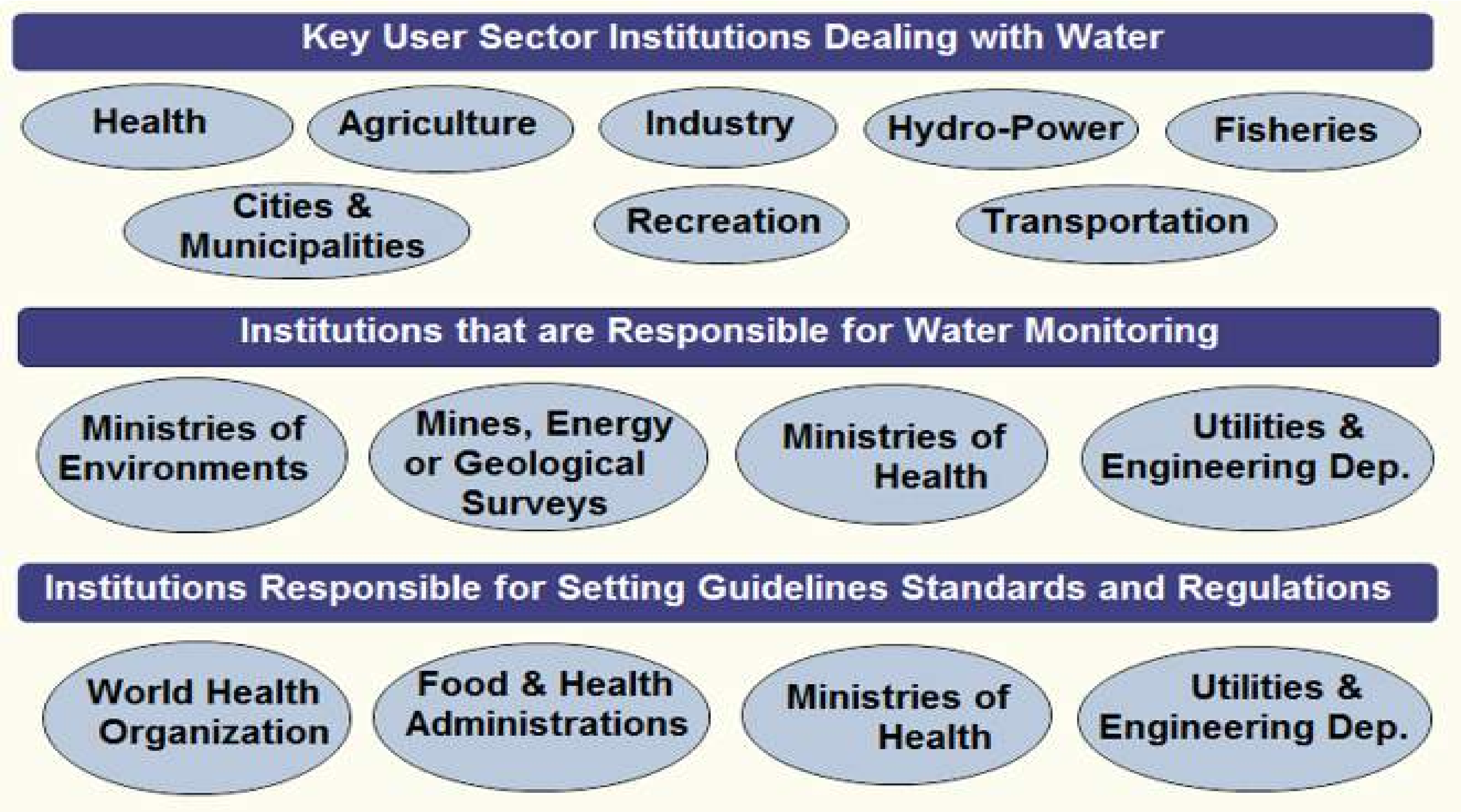

Urban Impacts on Water
Urban infrastructure
transportation, impervious surfaces,
sewage and drainage systems
Urban activities
traffic, industrial, residential, recreation
Stormwater Run-off
Domestic Wastewater
Industrial Discharge
Accidental Spills
Solid Waste
Atmospheric Input
Water Supply
Endocrine Disrupters
Erosion & Flooding
Sediment Problems
Pathogens
Toxic Chemicals
Streamflow Modifications
Oxygen Depression DO, BOD, COD
Excess Nutrients Eutrophication
Acidification
Impact on Hydrology
Impact on aquatic biota and human health
Impact on water quality


Agricultural Impacts on Water
Agricultural Intensification
Agricultural Expansion into Marginal Lands
Irrigation
Chemical & nutrient inputs
Nutrient Imbalances
Erosion
Soil compaction
Salinity
Organic matter declines in soil
Drainage
Leaching
Acidification
Water quantity and stream flow problems
Water quality problems Suspended matter, chemicals, microbes

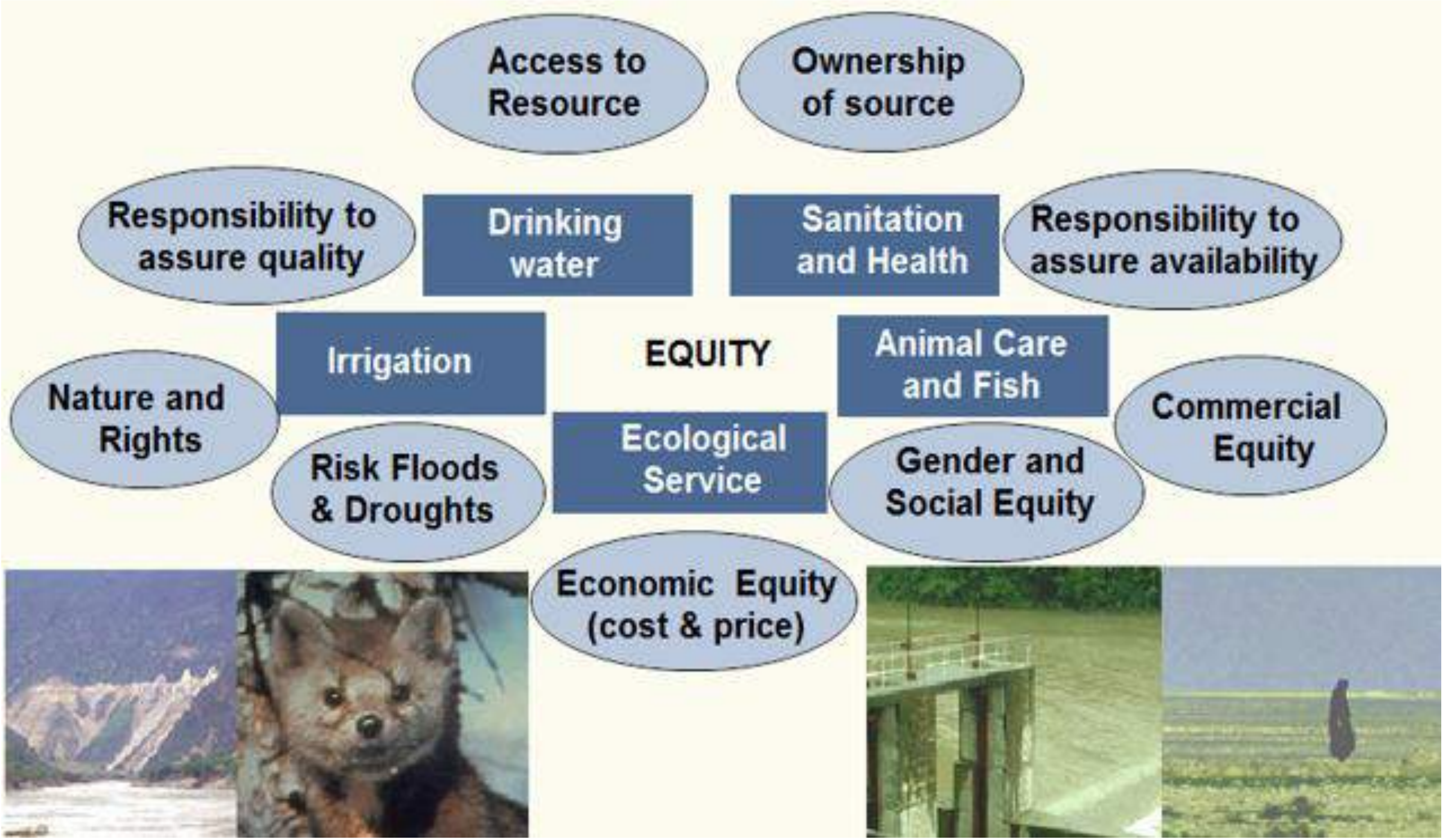

Forest Management Activities
Harvesting
Afforestation Planting
Road construction & maintenance
Long term management
Water Resources Issues
Water yield changes
Stream Temperature
Sediment Dynamics
Nutrient Dynamics
Pesticides
Stream Habitat
Traditional Forestry based on Clearcut Logging
New Forestry based on Partial or Selective Logging


Mining Impacts on Water
Type
Strip
Pit
Underground
Placer
Gravel Extraction
Activities
Overburden Storage
Surface & subsurface alterations
Mine Tailings
In Situ Leaching
Stream Diversion
In stream washing and sorting
Impacts
Changes in surface hydrology
Changes in groundwater hydrology
Water Temperature
Sediments
Acid mine drainage
Alteration in stream morphology and habitat
Metals
Issues
Hydrology - Water Quality - Aquatic Biota

Water Governance Issues



Water Access & Equity Issues



Why We Need for Water Conservation

What have we been doing?

Changing Course

What should we be doing?

Traditional Approach	Innovative Approach
Green Revolution (low Carbon Input)	Increase Soil Carbon
Intensive Land Use (Soil Compaction)	Minimize Soil Compaction
Minimizing Buffer Zones	Maximizing Buffer Zones
Draining Wetlands	Creating Wetlands
Excessive Drainage	Detaining Drainage Water
End of Pipe Treatment	Source Control
Point Source Pollution	Non-Point Source Pollution
Expanding Water Supplies	Controlling Demand (Water Smart)
Dealing with Single Pollutants	Cumulative Effects
Water Use for Human Activities	Water for Environmental Services
Flood Irrigation	Innovative Irrigation
Managing Blue Water	Managing Green Water

In Need of a Multi-Barrier Approach

Protective Measures:

1. Source Control - Reduce Input
2. Budget Accounting (N & P)
3. Large Riparian Buffer Zones
4. Wetland Preservation & Use
5. Beneficial Management Practices
6. Water Absorption & Infiltration
7. Limit Stocking Densities
8. Septic System Density
9. Tertiary Waste Water Treatment
10. Soil Erosion Control
11. Detention Ponds
12. Improved Manure Management

Impact Differences

Flood Impacts	Droughts Impacts
Flood impacts occur in individual watersheds Floodplains are the main impacted areas	Droughts cover very large areas The impact can be over large watersheds
The source of the flood water usually is long distance away from the flood impact	The impact is regional and not specific to floodplains
The impact is over relatively short time periods (Days-Weeks)	The impact is over longer periods (Months- Years)

How to Cope with Climate Extremes and Land Use Intensification and its Impact on Water

Densification = More Imperviousness

Climate Change = Increased Variability