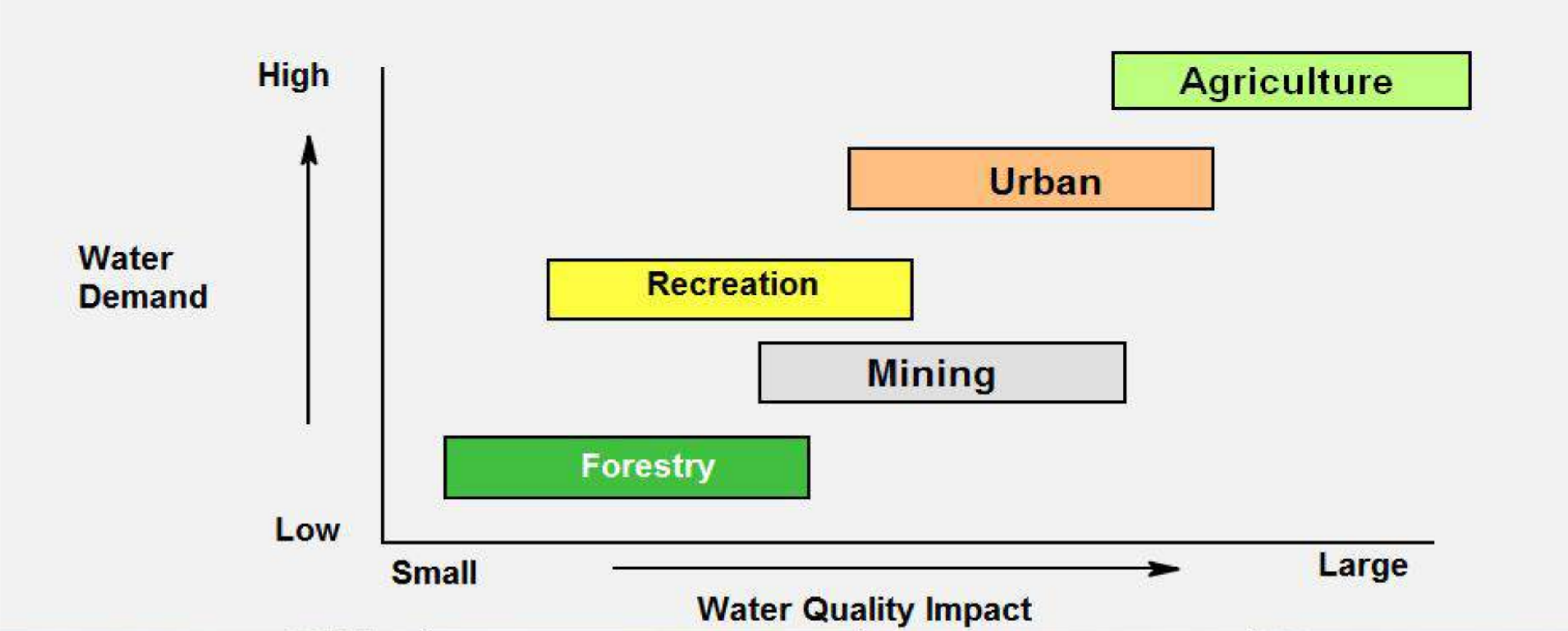
Land Use Impacts on Water Resources



Water Quality and Quantity Issues Associated with Different Land Uses

Urbanization	Flooding	= Densification & Impervious Surfaces
	Non-Point Sources	= Wide Range of Contaminants
	Water Demand	= Rapid Urban Growth
Agriculture	Water Demand	= More Irrigation & Change in Diets
	Water Pollution	= Eutrophication, Nutrients & Pathogens
Mining	Water Pollution	= Metals (Hg, Pb), Cyanide
	Sediments	= Surface Exposure, Tailings
Forestry	Stream Flow	= Logging, Forest Fires, Disease
	Sediments	= Logging Roads
Recreation	Water Pollution	= Pathogens, Pharmaceuticals, Sediments
	Water Demand	= Local, Peak Season

Key Water Issues

Urban Expansion

Increasing demand for safe drinking water
Increasing Waste Water
Increasing Non-point sources of pollution
Increase flooding during storms events

Agricultural Intensification

Greater water demand for irrigation
Non-point sources of pollution
Manure Management Problems
Virtual Water

Water & Environment

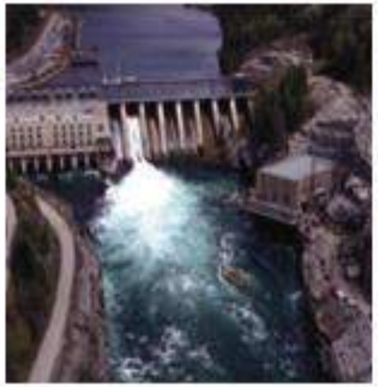
Increasing requirement to maintain sfficient flow during dry season to maintain biota and environmental services
Maintaining natural variability

Increased Climatic Variability

Higher and earlier peakflow
Lower baseflow
Warmer Temperatures
Glacier melt
Rain on snow events
More floods & droughts

Hydropower

Increasing demand for Green Energy
More hydro dams
More Run-of River Systems

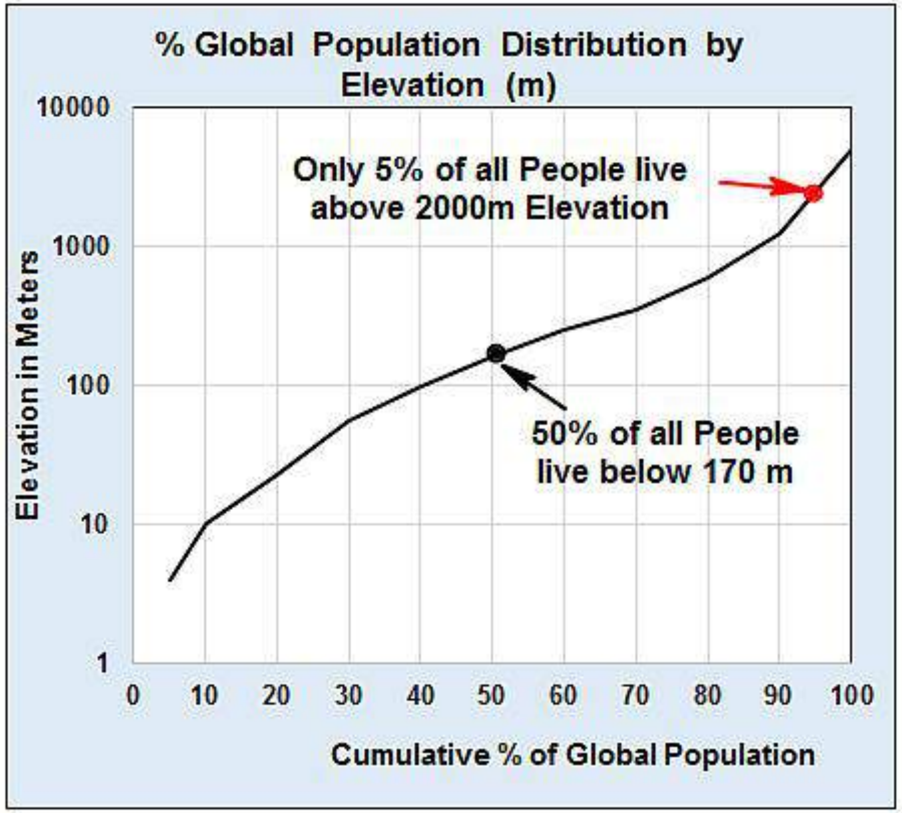


Water Quality Problems

NPS & cumulative effects
Pharmaceutical
Poor Wastewater Treatment
Eutrophication
Chemical interactions

Urban Issues in Mountains

Urbanization in Mountains

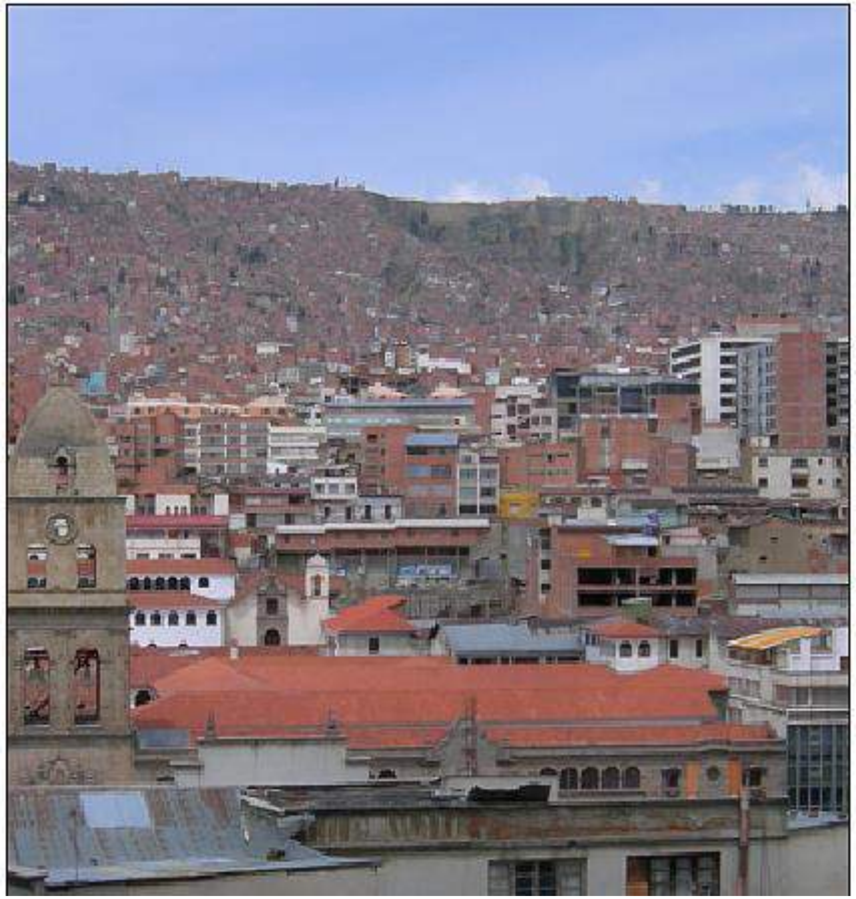


Data Source: B. Rankin 2016, Radical Cartography

Cities at High Elevations in Latin America

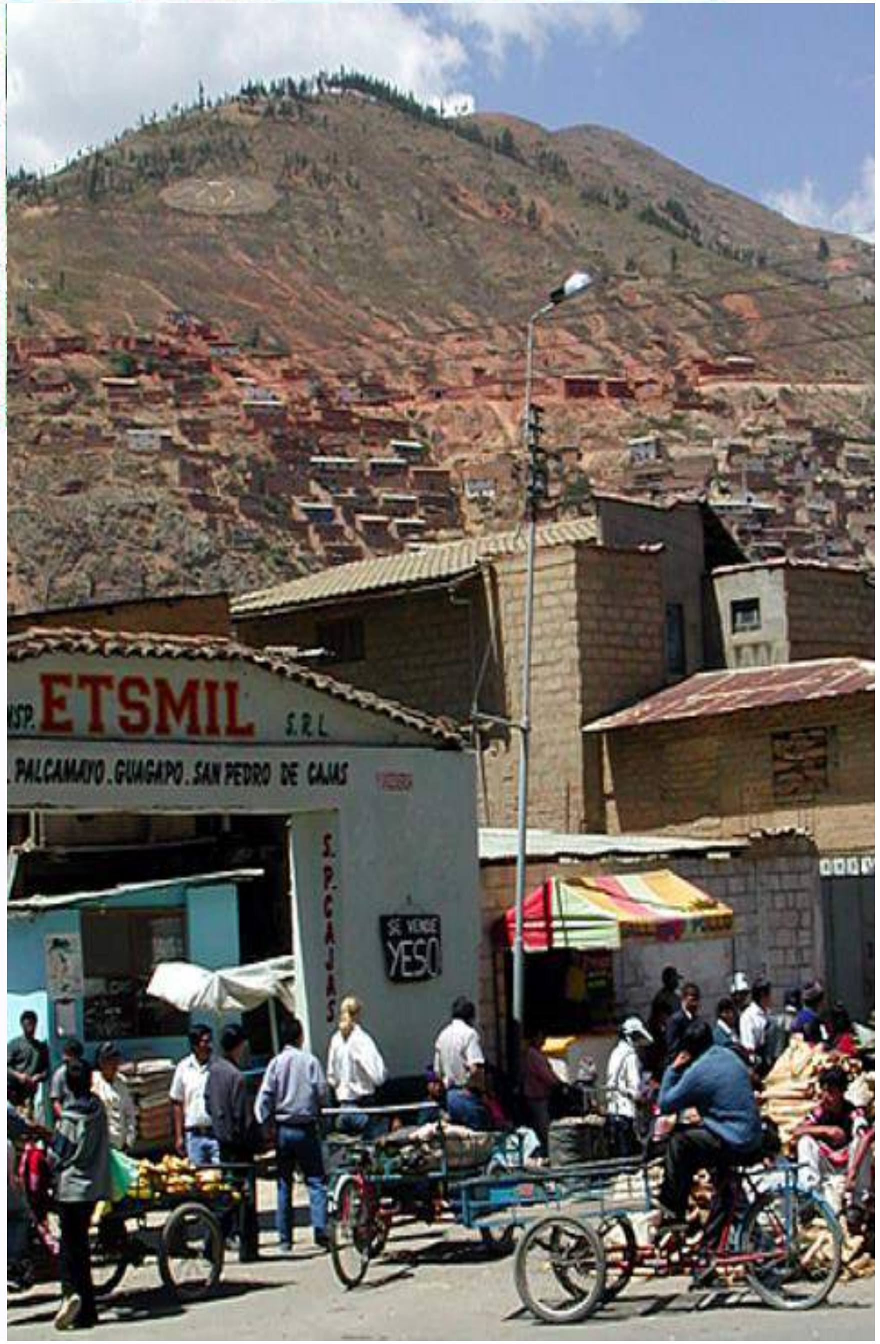
Quito, Bogota, Cali, Mexico City, La Paz etc.

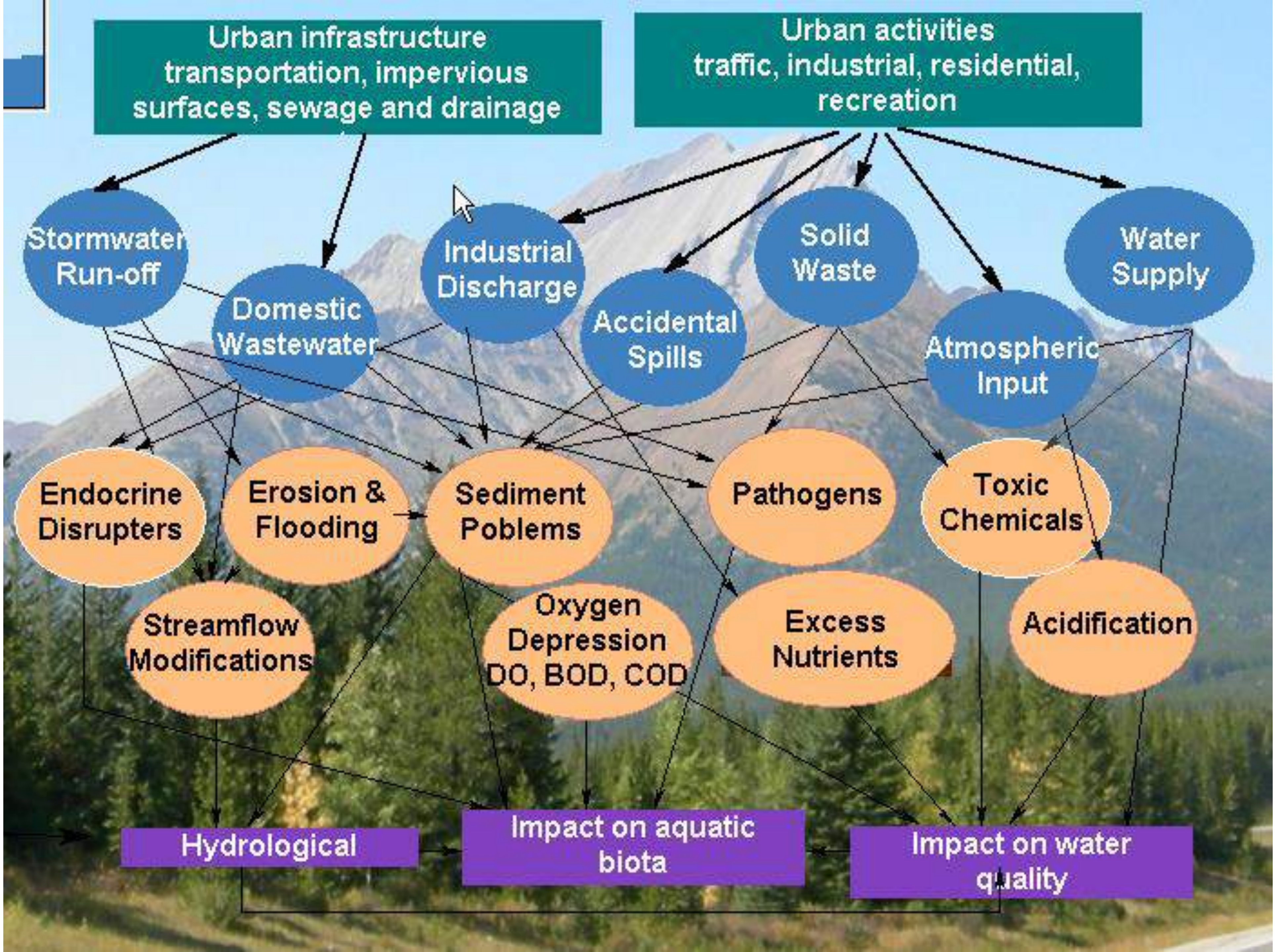
La Paz, Bolivia



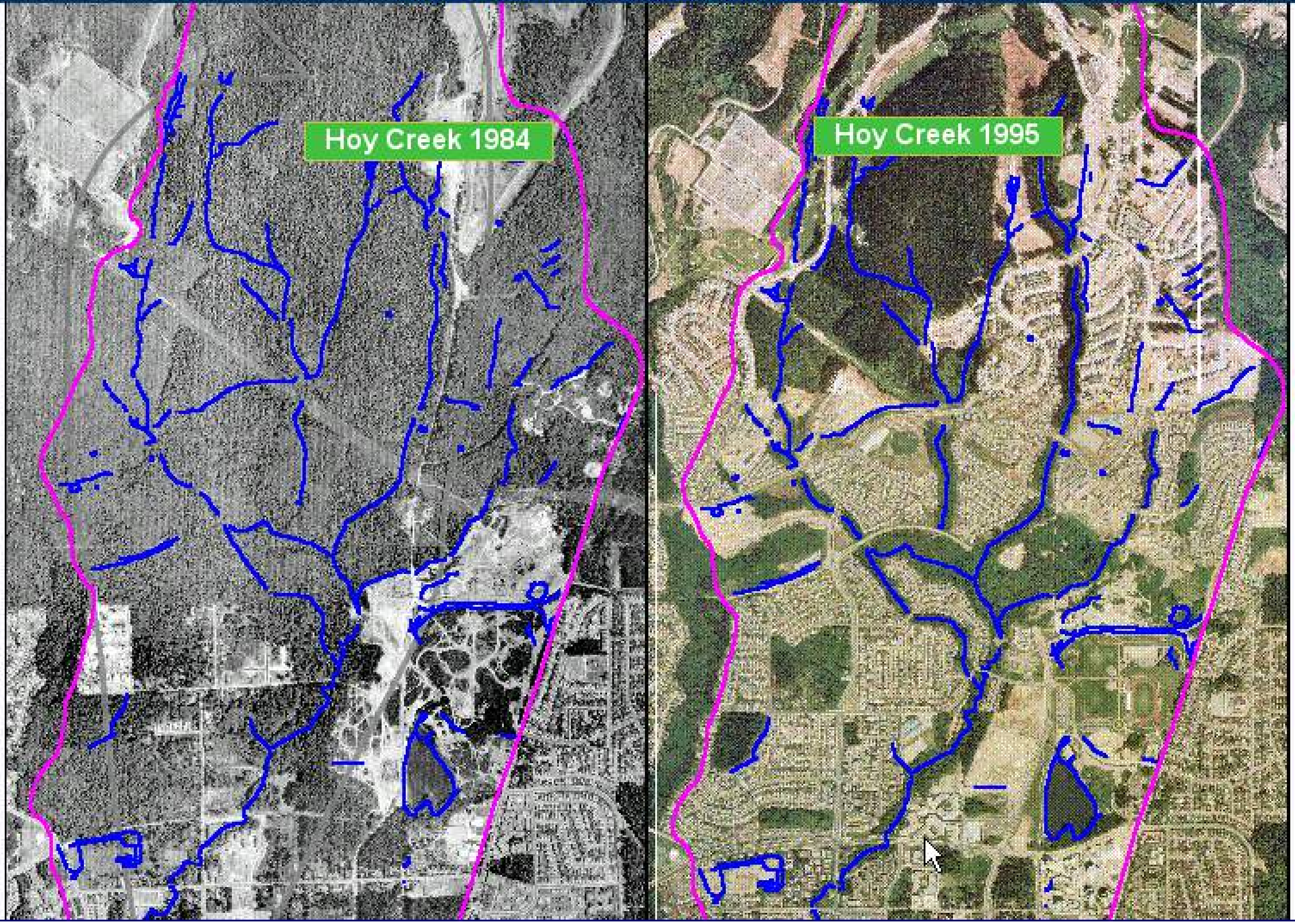
Mountain Population	920 Million	13% of World
Living above 1500m	450 Million	50% of Mt. People
Urban Mt. Population	280 Million	30% of Mt. People
Urban Mega Cities	25 Million	Cities 2-9 Million

Food Insecurity	330 Million	40% of Mt. People



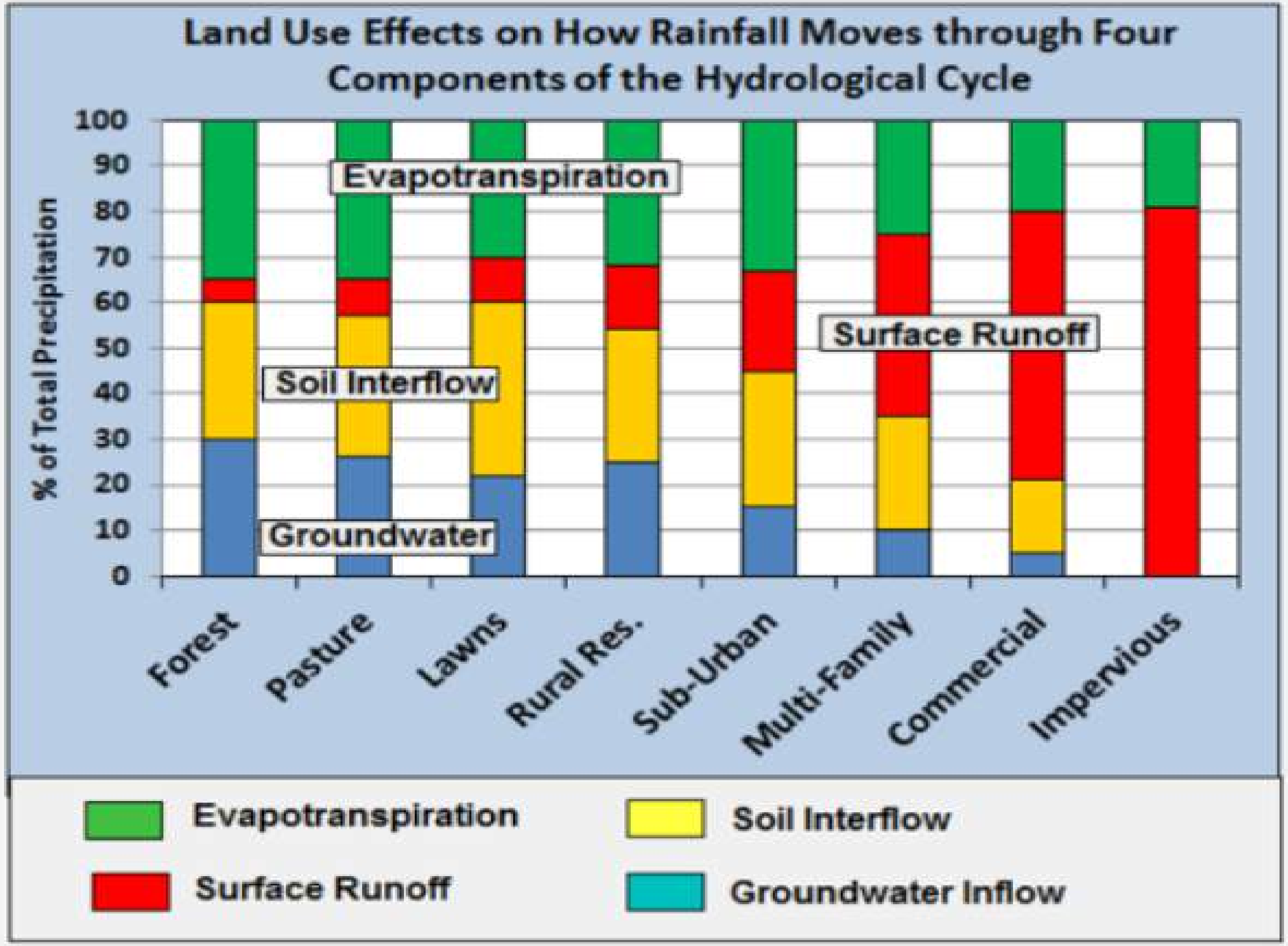

Urban infrastructure transportation, impervious surfaces, sewage and drainage
Urban activities traffic, industrial, residential, recreation
Stormwater Run-off
Domestic Wastewater
Industrial Discharge
Accidental Spills
Solid Waste
Atmospheric Input
Water Supply
Endocrine Disrupters
Erosion & Flooding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

Imperviousness & Soil Compaction

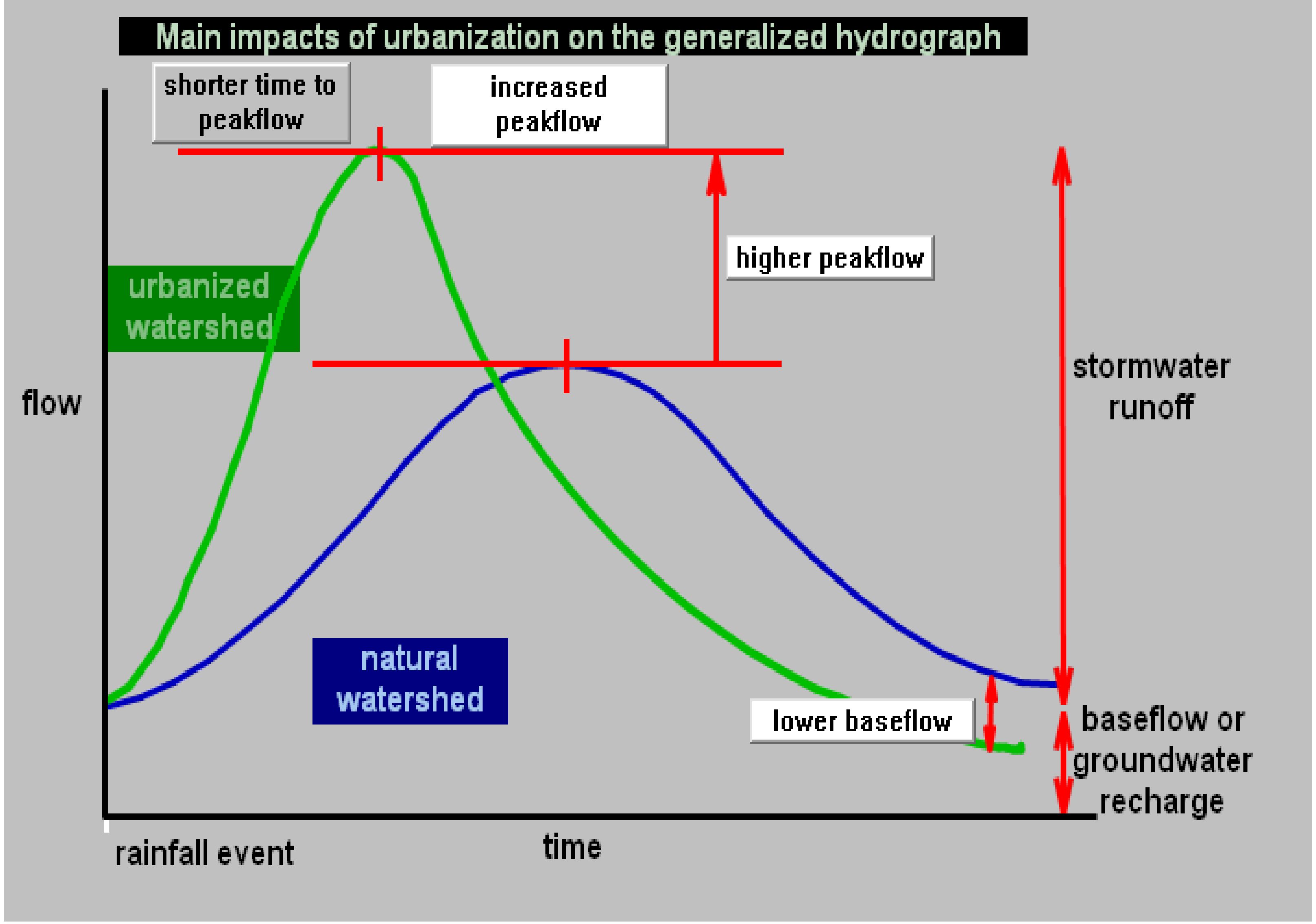


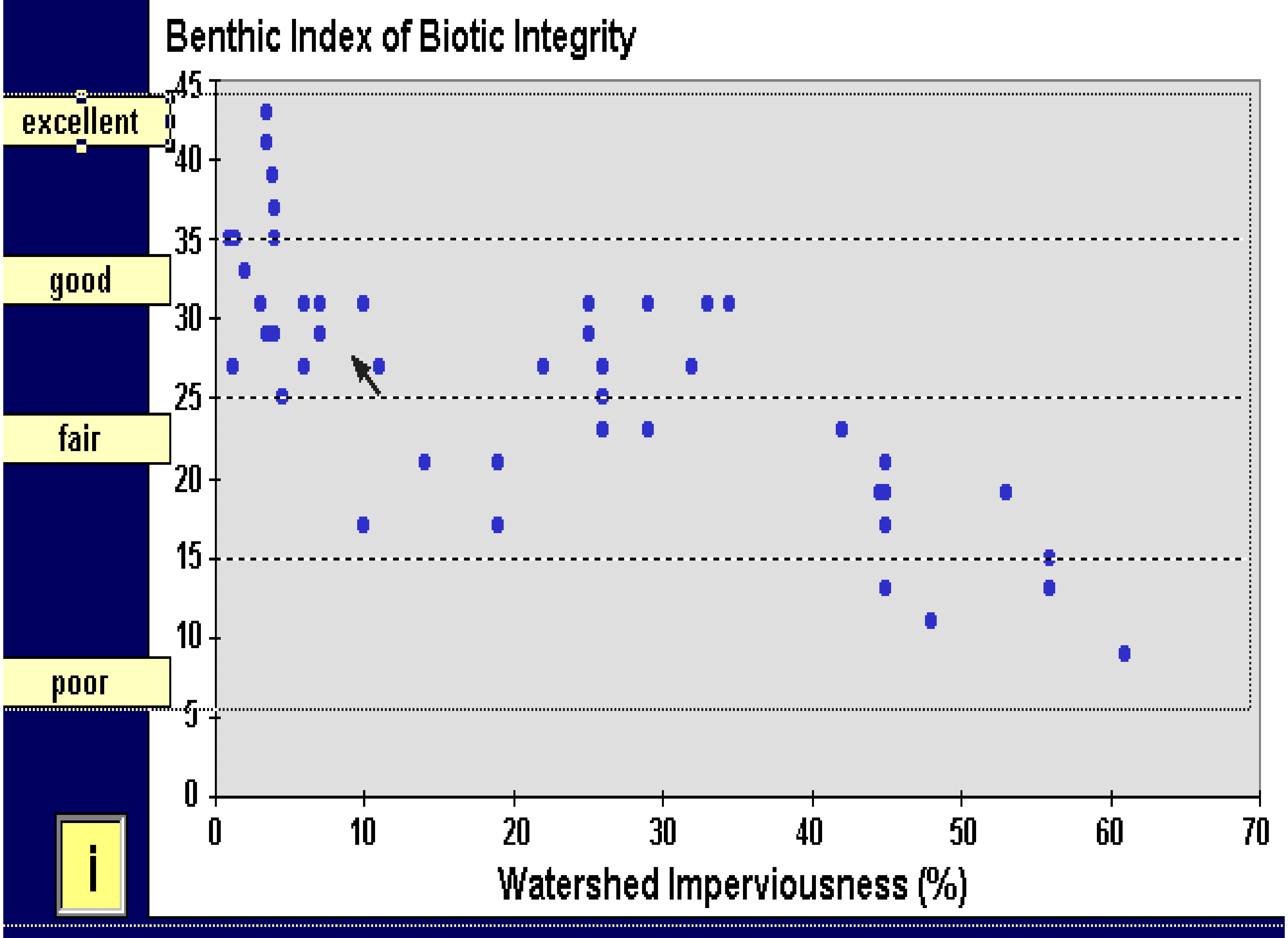
Rainfall Redistribution by Land Use

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



Streamflow Conditions





Benthic Index of Biotic Integrity
excellent
good
fair
poor
i
45
40
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
Watershed Imperviousness (%)

Impervious Surfaces and Conveyance Systems = Increases Pollution

Typical Non-Point Sources of Pollution (NPS)

Deposition of atmospheric pollutants (NO_x, SO_x)

Nutrient & Pesticides from applications to lawns, golf courses, right-of-ways

Land clearing and construction activities

Accidental spills and illegal dumping of waste

Vehicle traffic, wear and tear exhaust fumes and leaks in parking lots

Organic Materials and pathogens from animal wastes (pets & wildlife)

Combined sewers and septic systems discharges

Commercial and Industrial runoff and discharge

Water Supplies & Conservation

Domestic Water Sources

Reservoir

Groundwater

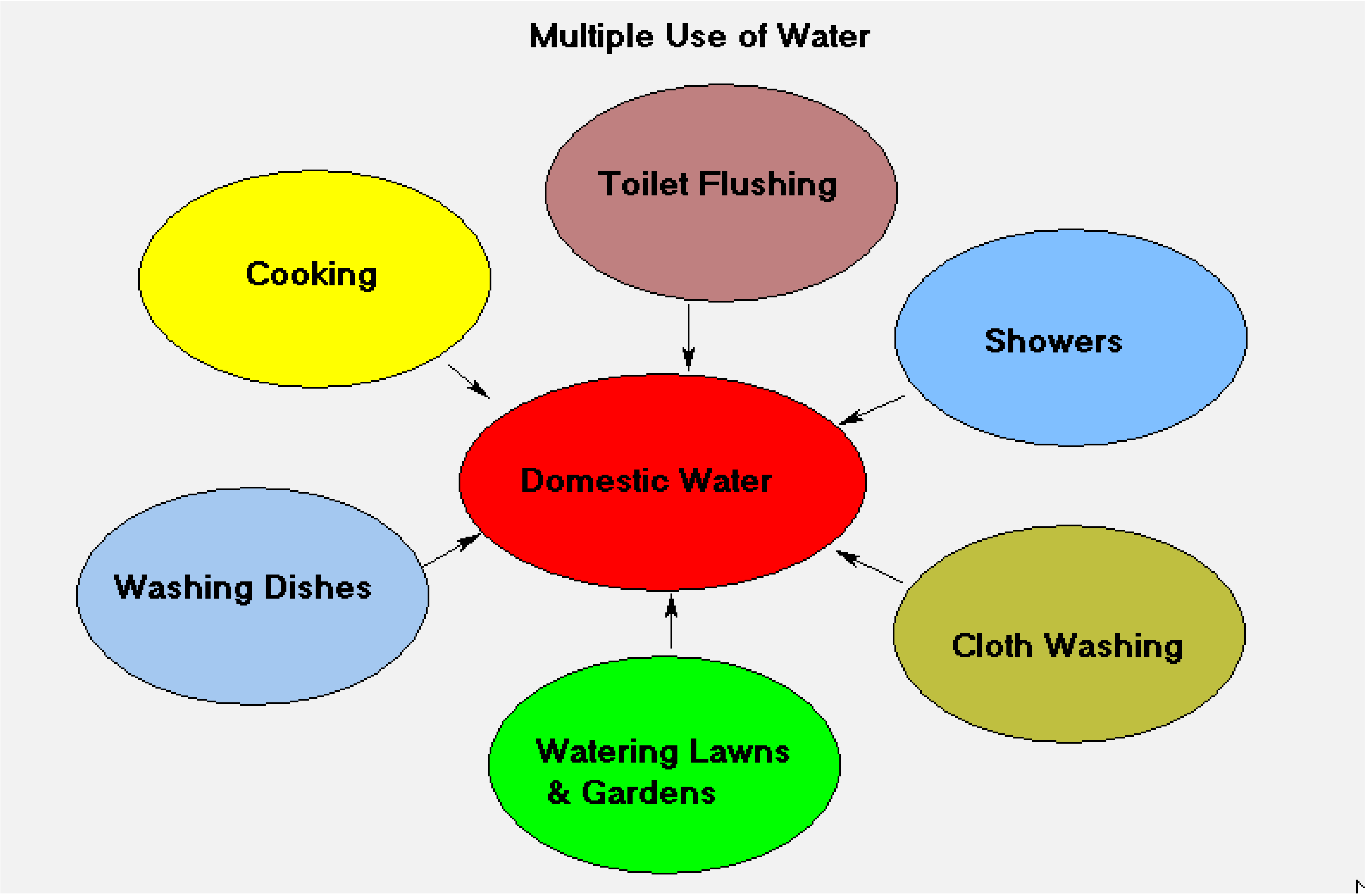
Rainwater Harvesting

Lake Water

Spring Water

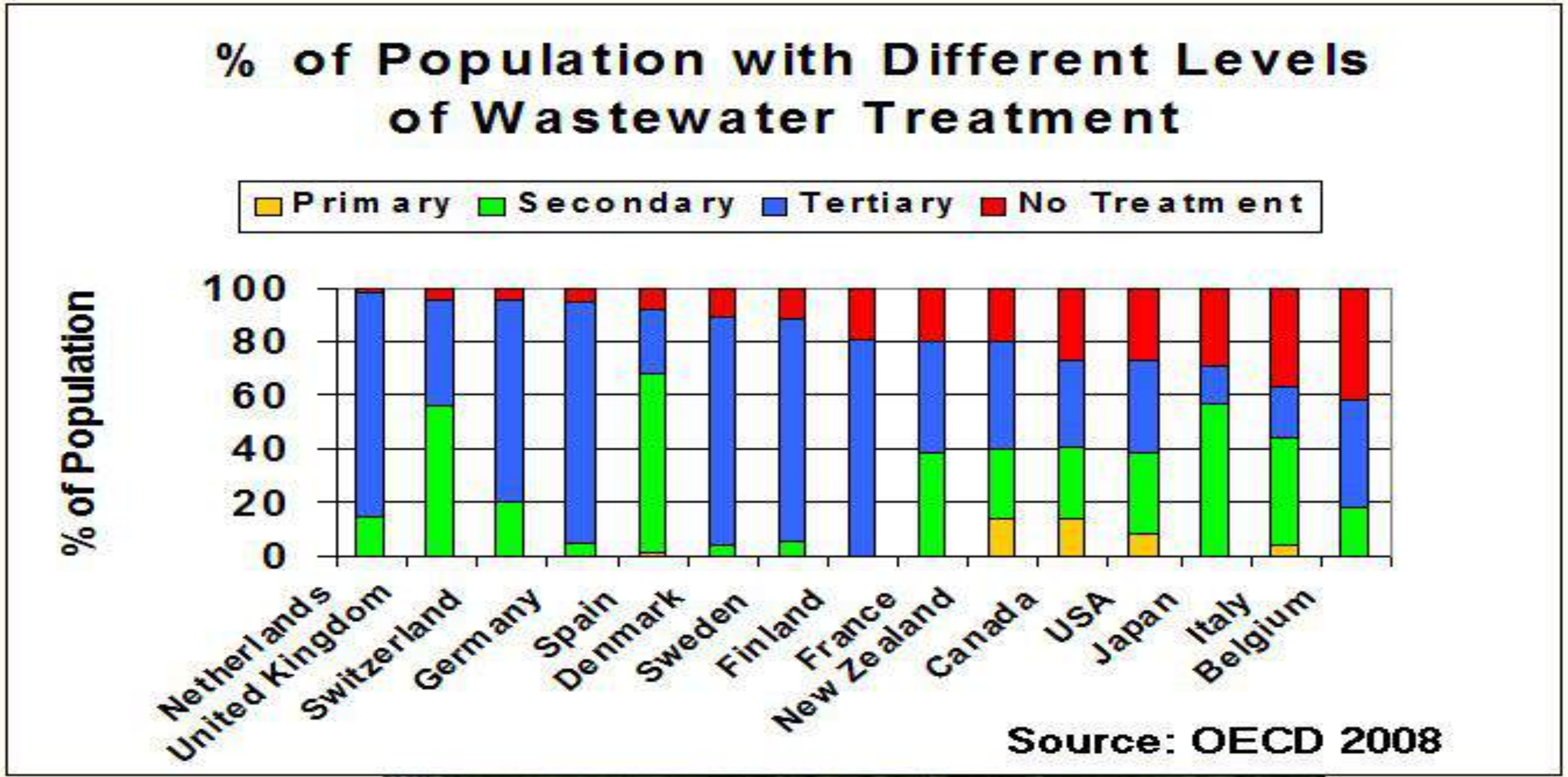
Streamwater

Examples:
Everest Water from Texas
Yosemity Water from LA Municipal Sources
Glacial & Arctic Water from Florida


Multiple Use of Water
Toilet Flushing
Cooking
Showers
Domestic Water
Washing Dishes
Cloth Washing
Watering Lawns
& Gardens

Wastewater

BLUE WATER	Rainfall that ends up into lakes, rivers & groundwater
GREEN WATER	Rain interception in soils & plants and evapotranspired
WHITE WATER	Water evaporated leaving the watershed (non-productive)
GREY WATER	Wastewater, polluted but usable for certain purposes
BLACK WATER	Wastewater, heavily polluted, not economically unusable

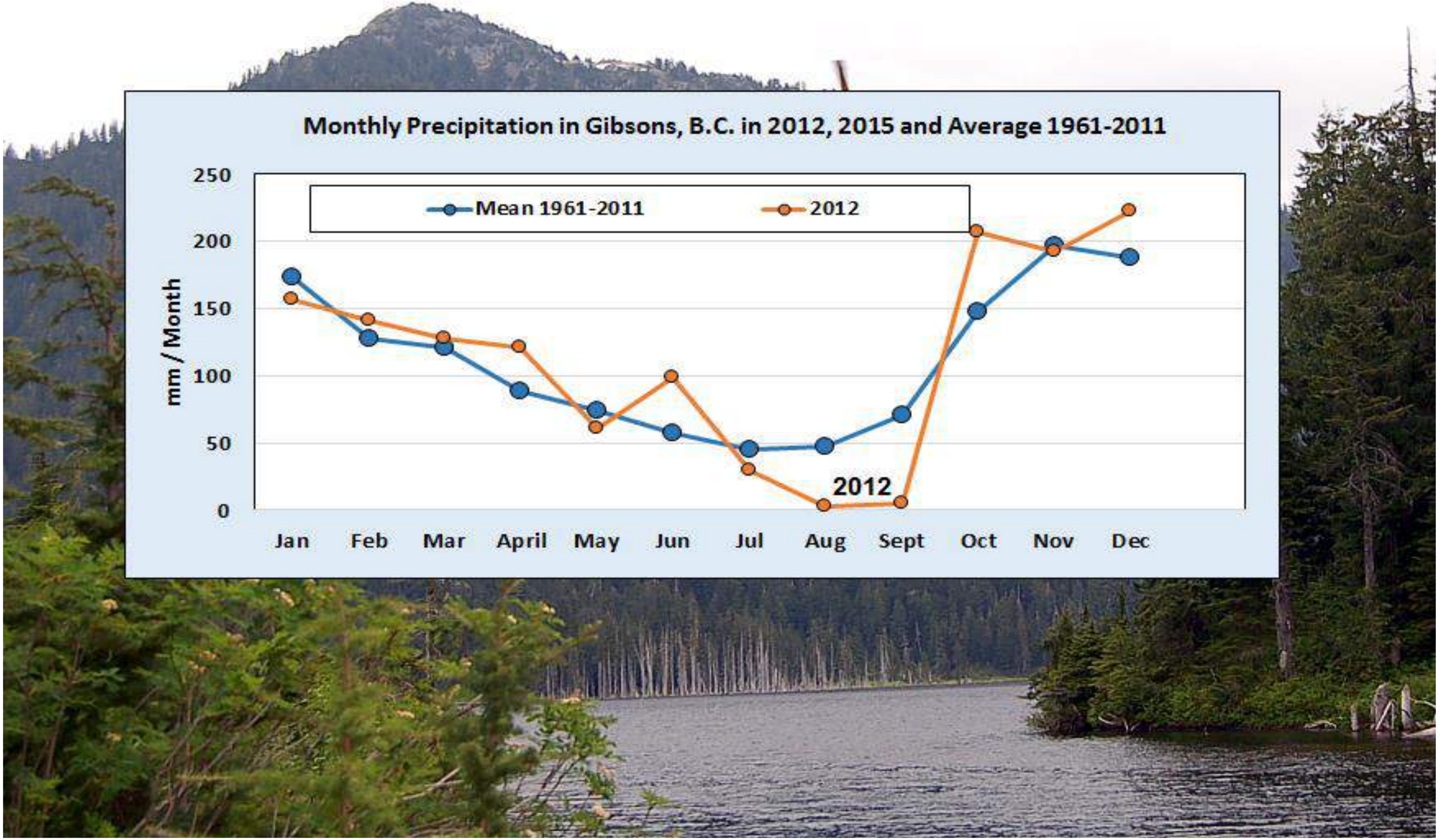

% of Population with Different Levels of Wastewater Treatment
Primary
Secondary
Tertiary
No Treatment
% of Population
100
80
60
40
20
0
Netherlands
United Kingdom
Switzerland
Germany
Spain
Denmark
Sweden
Finland
France
New Zealand
Canada
USA
Japan
Italy
Belgium
Source: OECD 2008


ACE

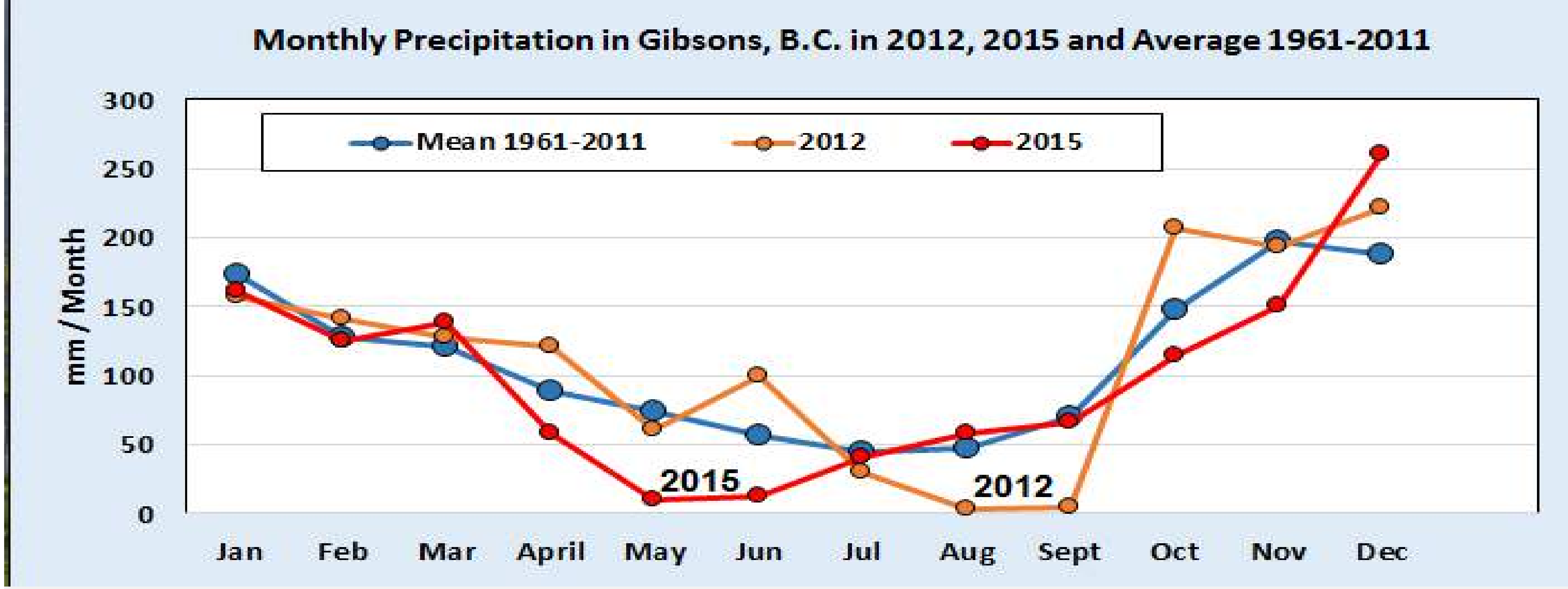
Chapman Lake; Water Supply for 28000 People on the Sunshine Coast, B.C.

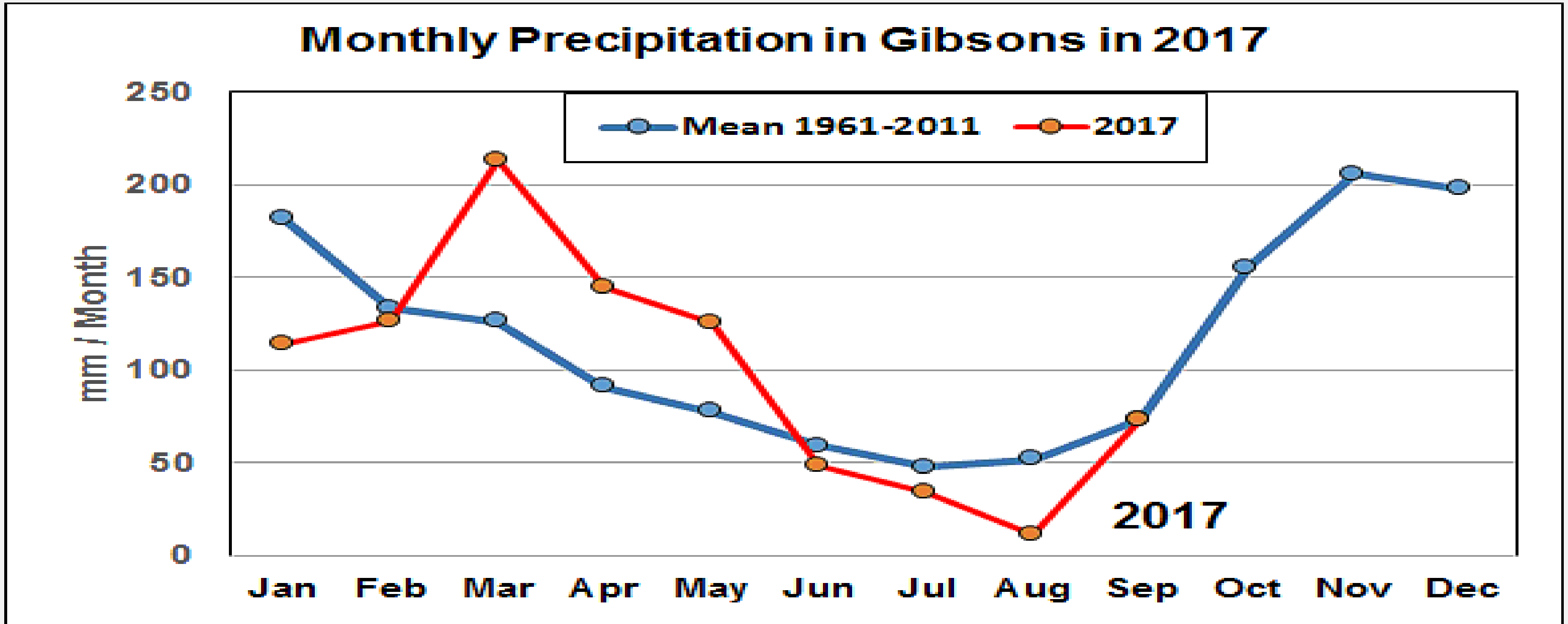
Chapman Creek Reservoir, Sunshine Coast, B.C.

Photo Sources:
Monte Staats 2014

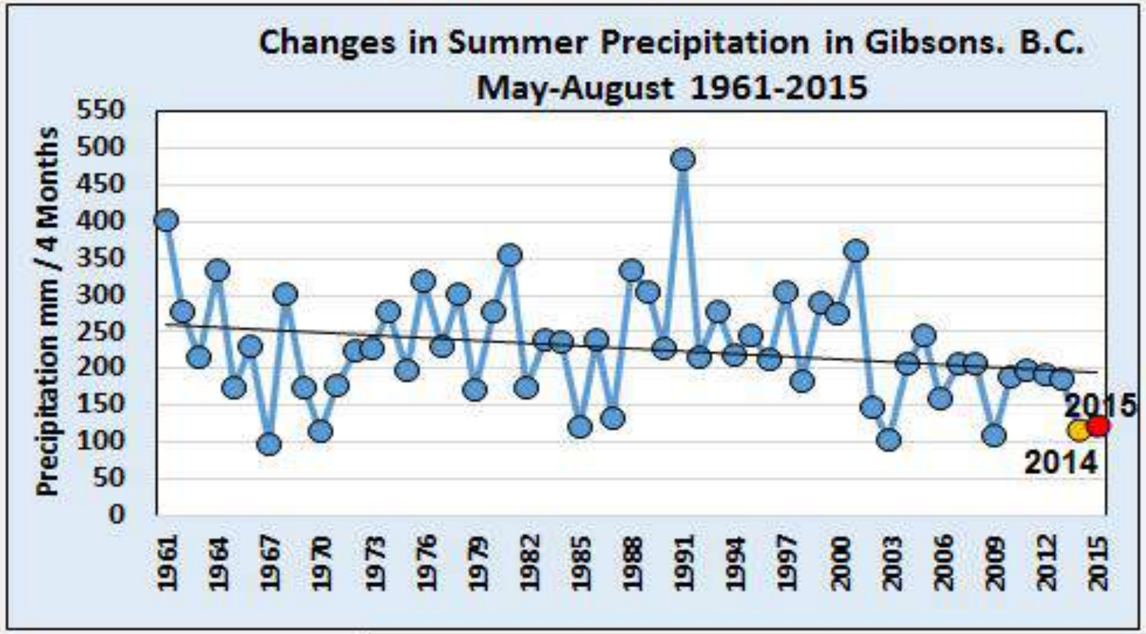


Monthly Precipitation in Gibsons, B.C. in 2012, 2015 and Average 1961-2011
Mean 1961-2011
2012
mm / Month
250
200
150
100
50
0
2012
Jan
Feb
Mar
April
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec

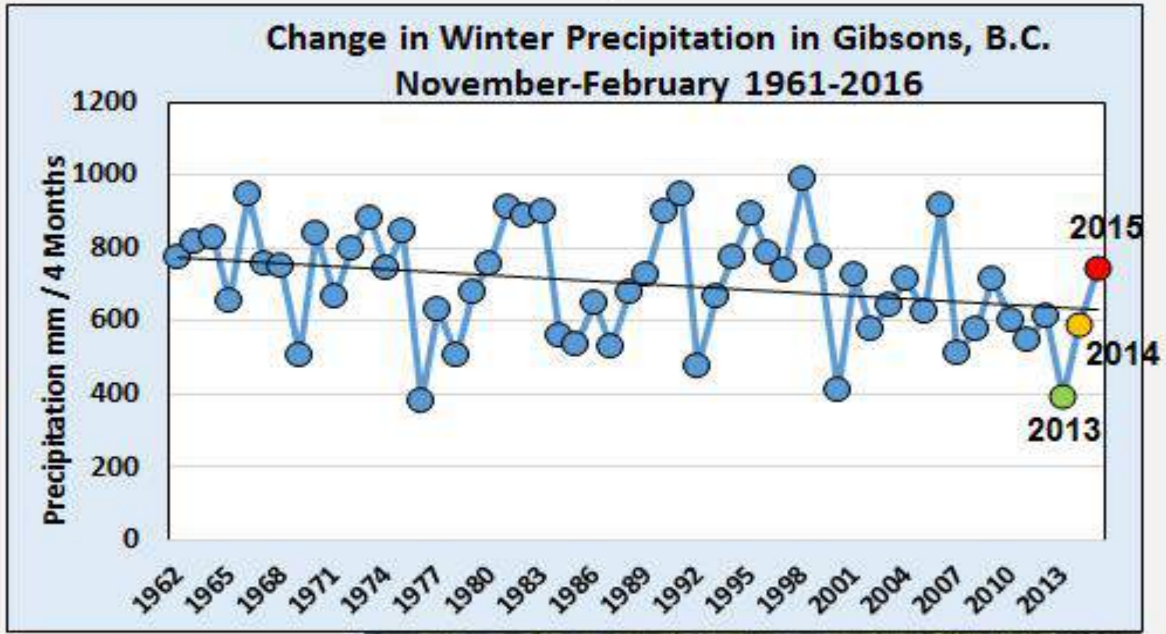

Monthly Precipitation in Gibsons, B.C. in 2012, 2015 and Average 1961-2011
Mean 1961-2011
2012
2015
mm / Month
300
250
200
150
100
50
0
2015
2012
Jan
Feb
Mar
April
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec


Monthly Precipitation in Gibsons in 2017
Mean 1961-2011
2017
mm / Month
250
200
150
100
50
0
2017
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

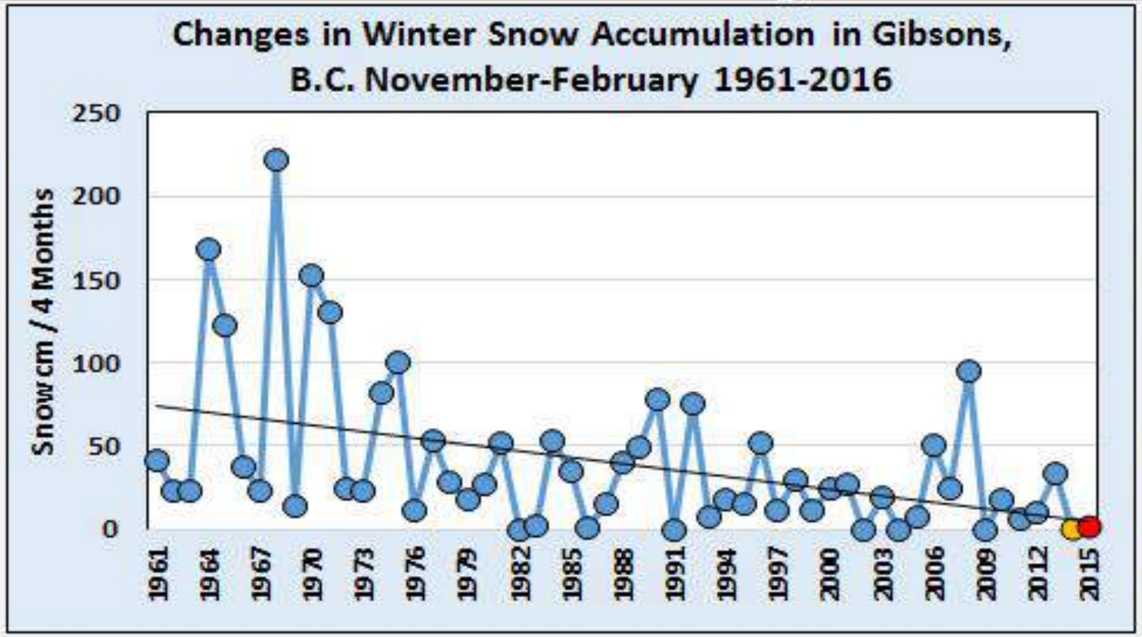
Summer Precipitation



Winter Precipitation



Winter Snow Accumulation



Urban Impacts on Water Resources

Urban Impacts	Reasons
Urban Water Demand > Supply	Increasing Urban Population Urban Heat Island & Droughts Neglected Infrastucture (leakages)
Urban Flooding is Increasing	Densification & Impervious Surfaces Stormwater Conveyance into Stream Channelizing Stream Channels
Urban Pollution	Urban Runoff without Treatment Insufficient Wastewater Treatment Traffic and Air Pollution

Water for Food: Are We Heading for a Crisis?

Projections:

50% increase food production is needed over the next 40 years.

Why?

2 Billion new pople
0.8 Billion have not enough
1 Billion is changing diets
10-20% of food biomass for ethanol & biodiesel

Water Use by Agriculture:

Agriculture uses about 70% of all fresh water

40% of all food comes from 19% irrigated land

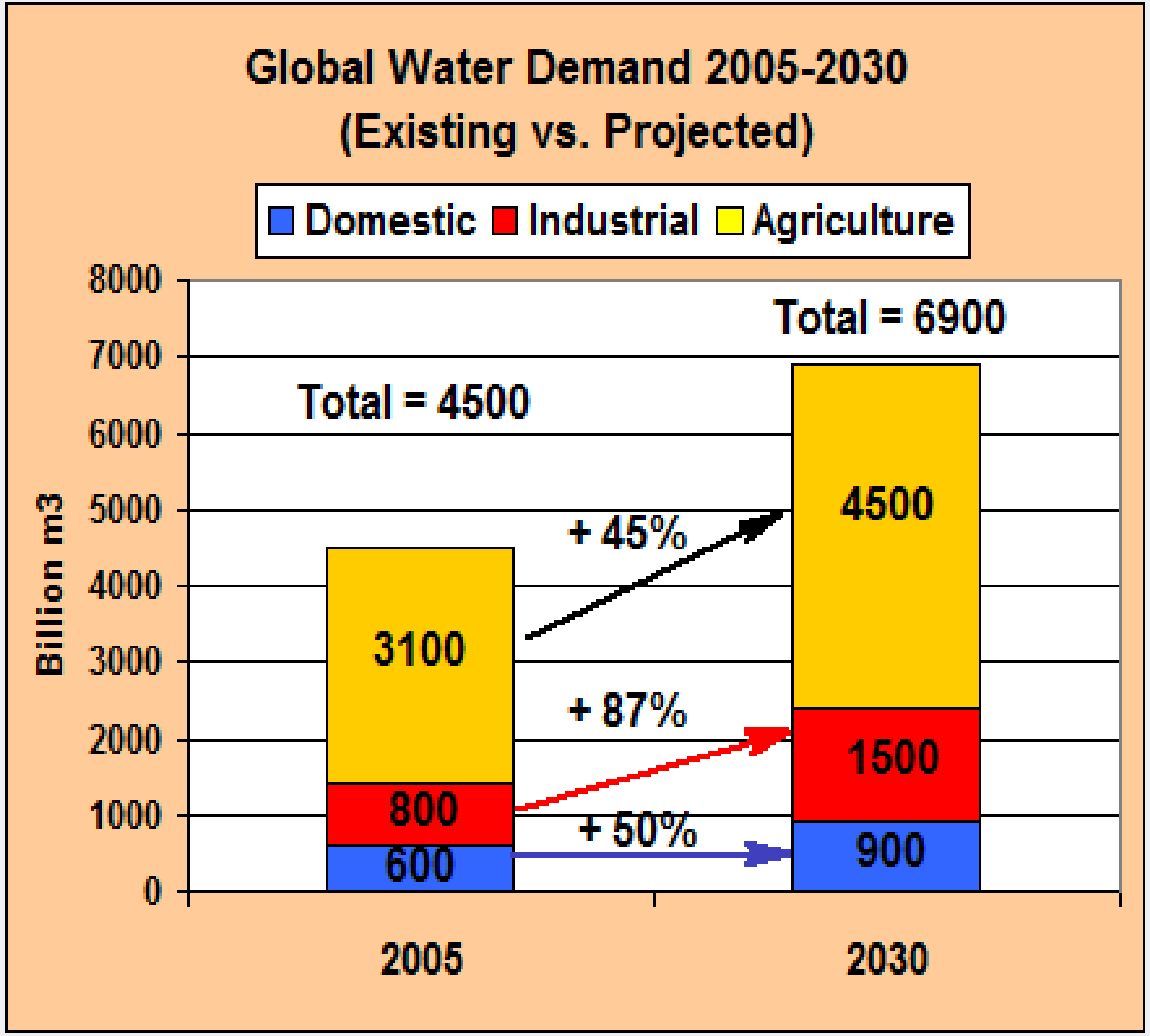


Can we increase the irrigated areas in agriculture ?

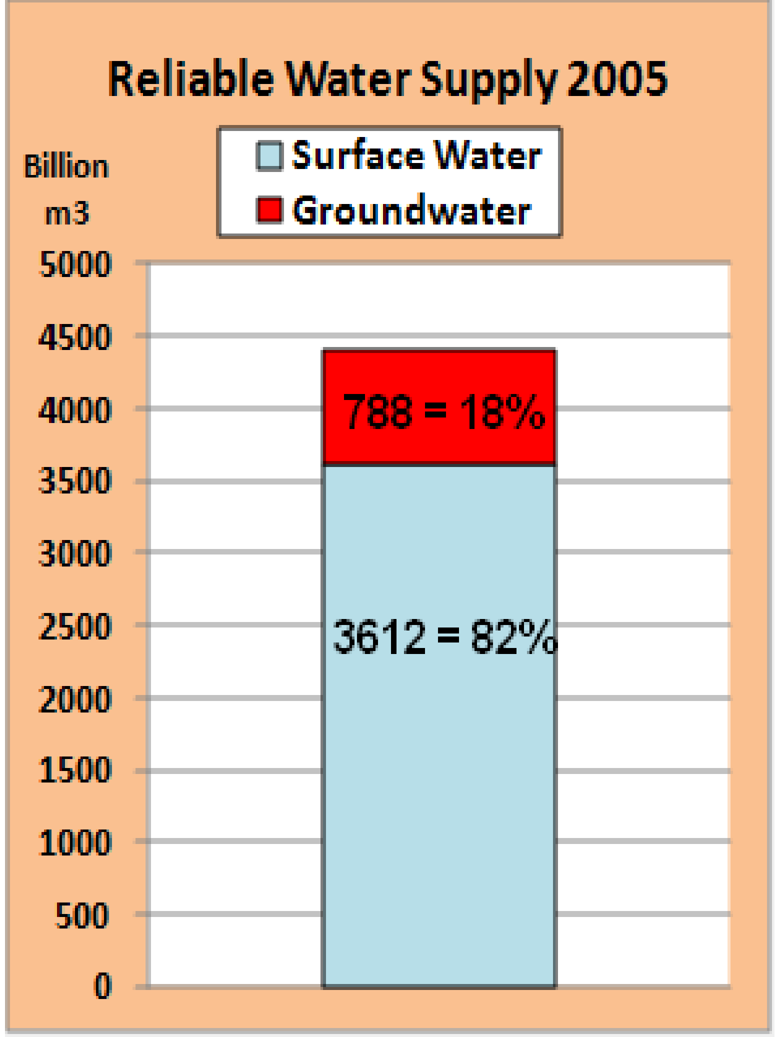
Can we produce more food from rainfed agricultural land ?

When:

1. Demand for water for other uses is increasing
2. The agricultural land base is shrinking
3. Climatic variability is increasing
4. Soil and water degradation problems are increasing
5. Energy problems are accelerating

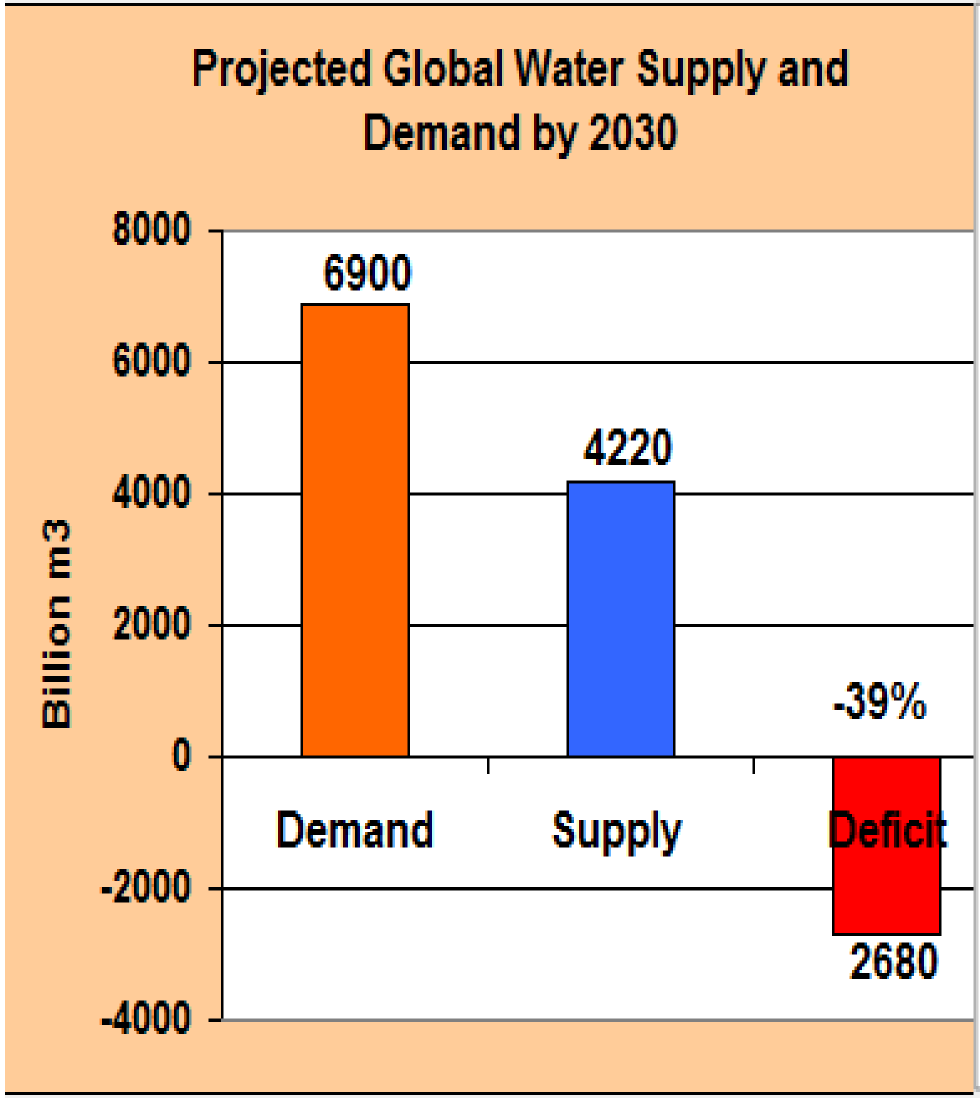



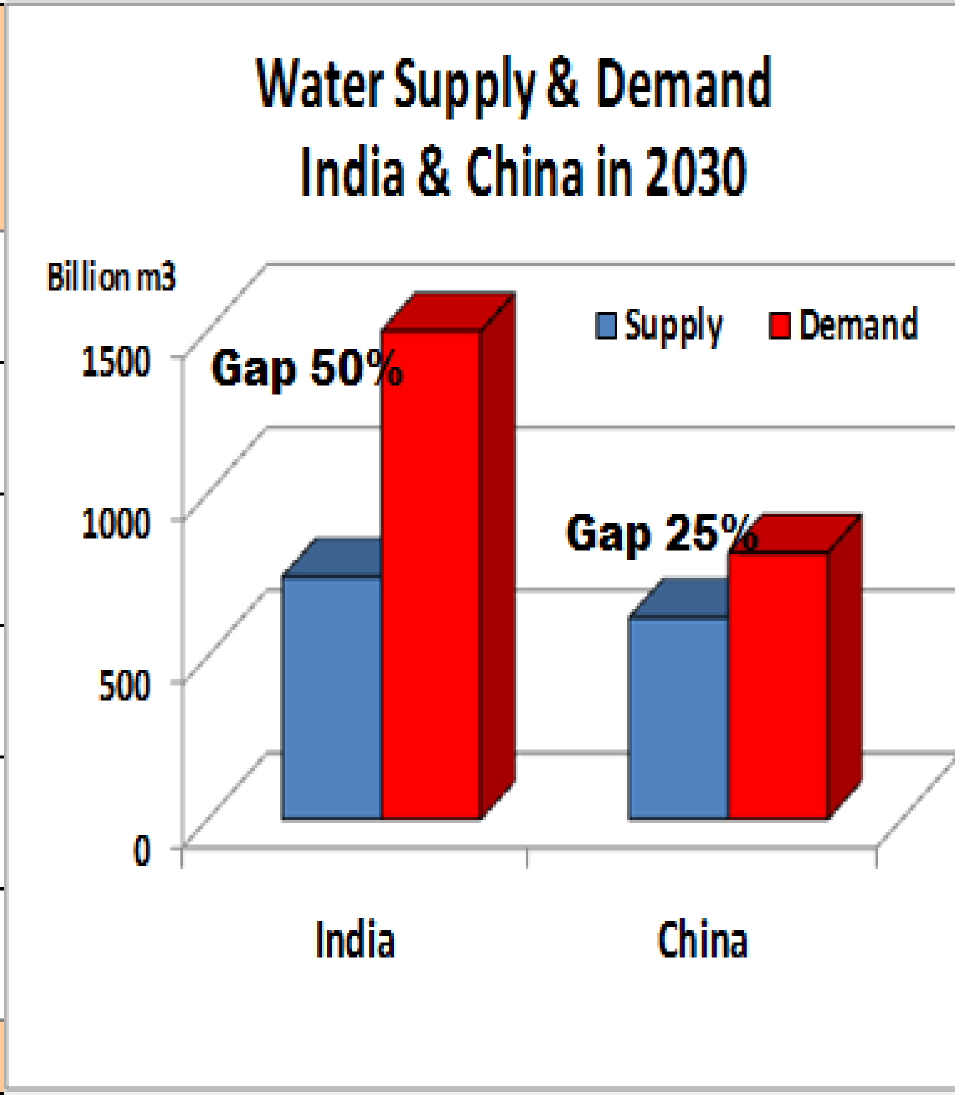
Without efficiency gains the water demand will increase by 64% between 2005-2030



Surface Water remains as the dominant water source for agriculture

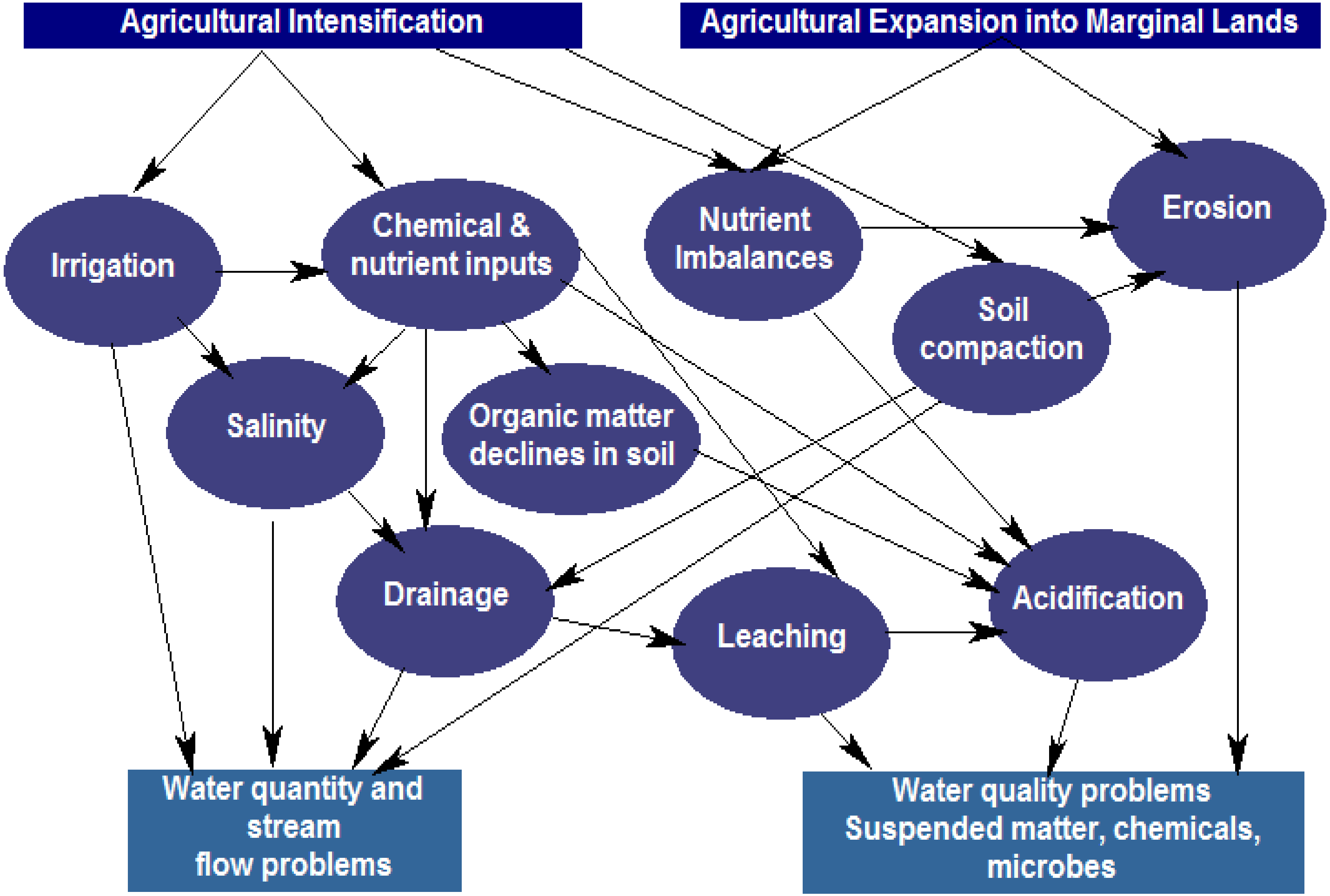
Source: Mckinsey Water Resource Group 2010. Charting our Water Future. Economic Frameworks to Inform Decision Makers
www.mckinsey.com/App_Media/Report/Water



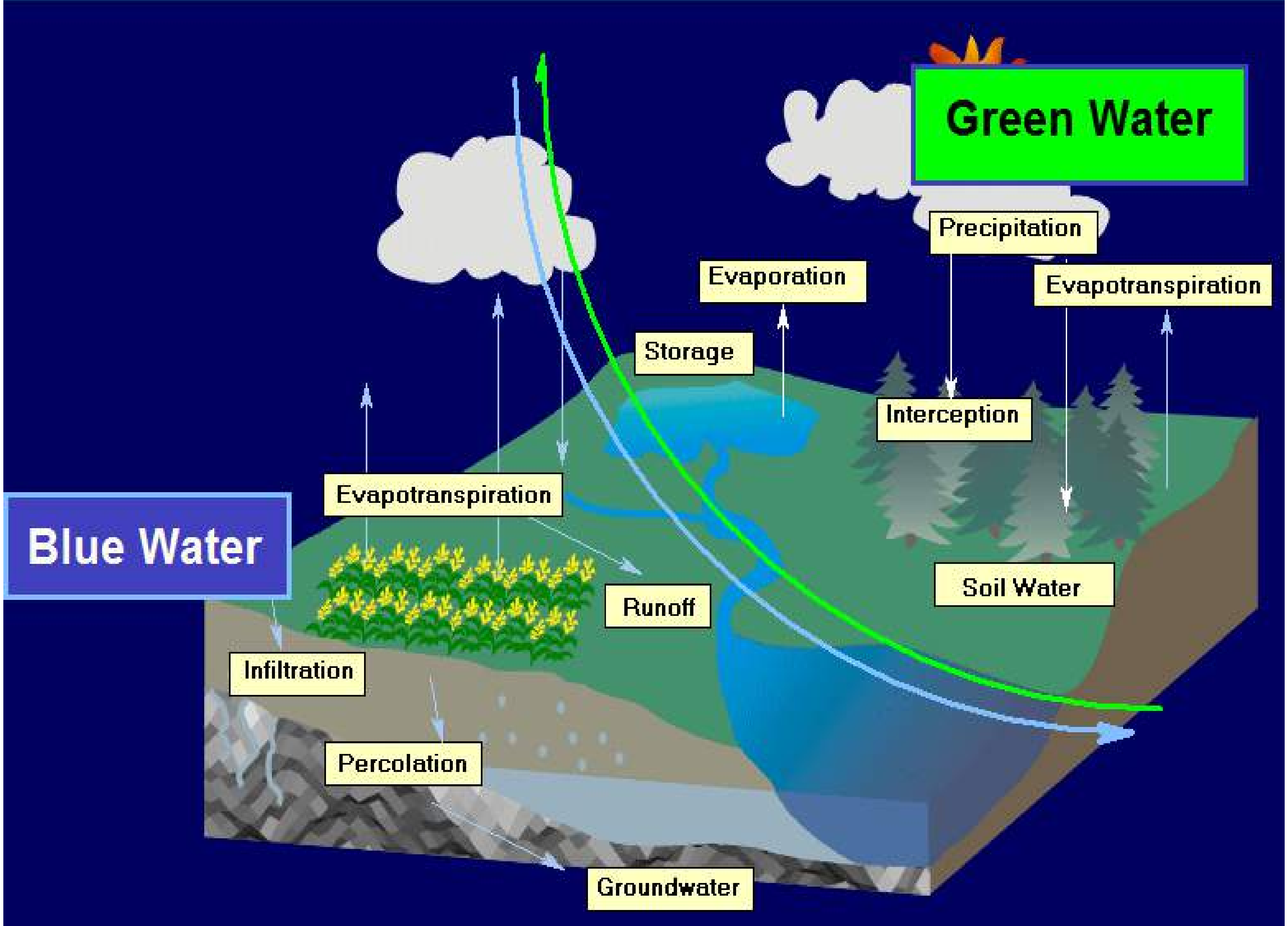


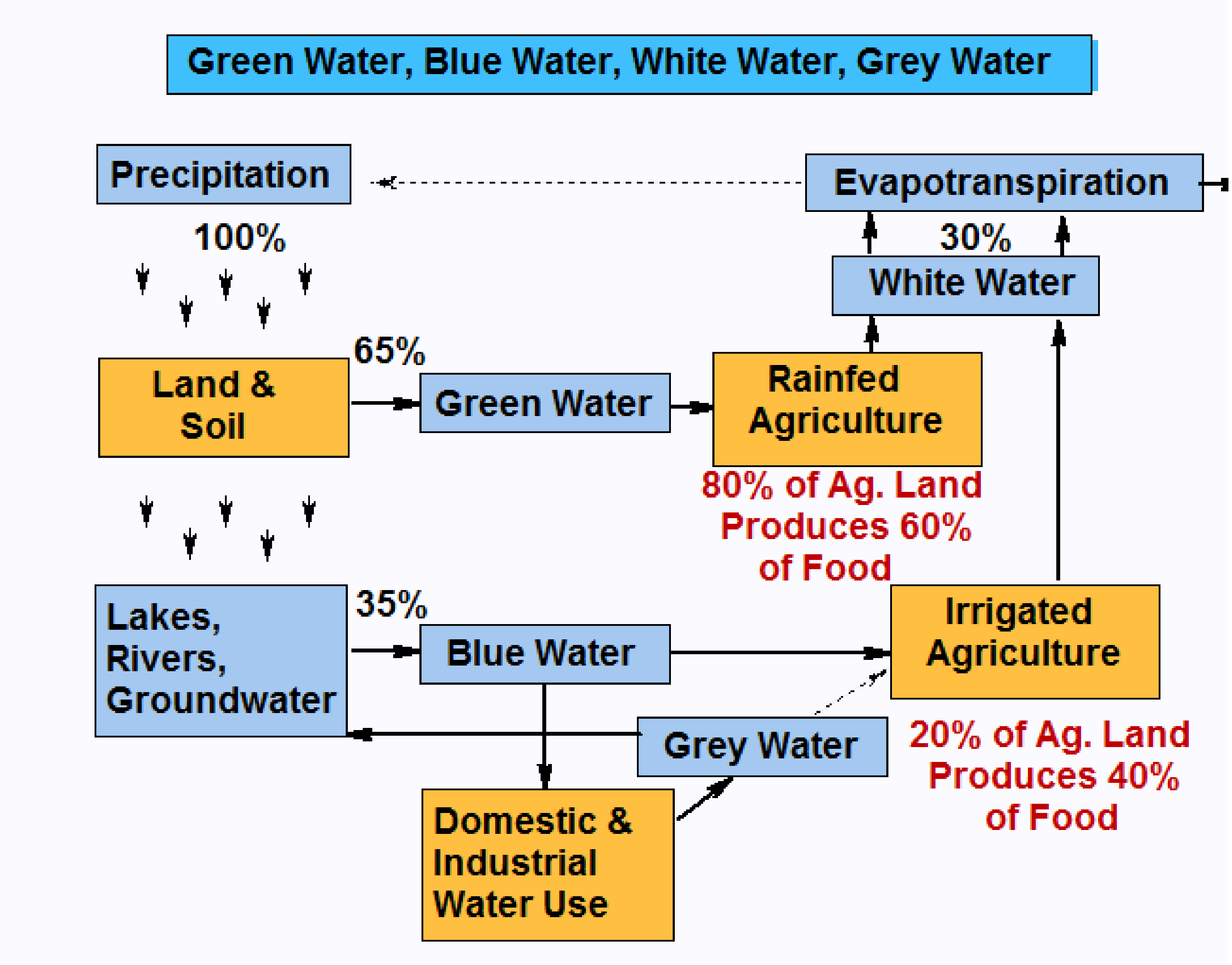
Source: Mckinsey Water Resource Group 2010. Charting our Water Future. Economic Frameworks to Inform Decision Makers
www.mckinsey.com/App_Media/Report/Water

Agricultural Impacts on Water Resources

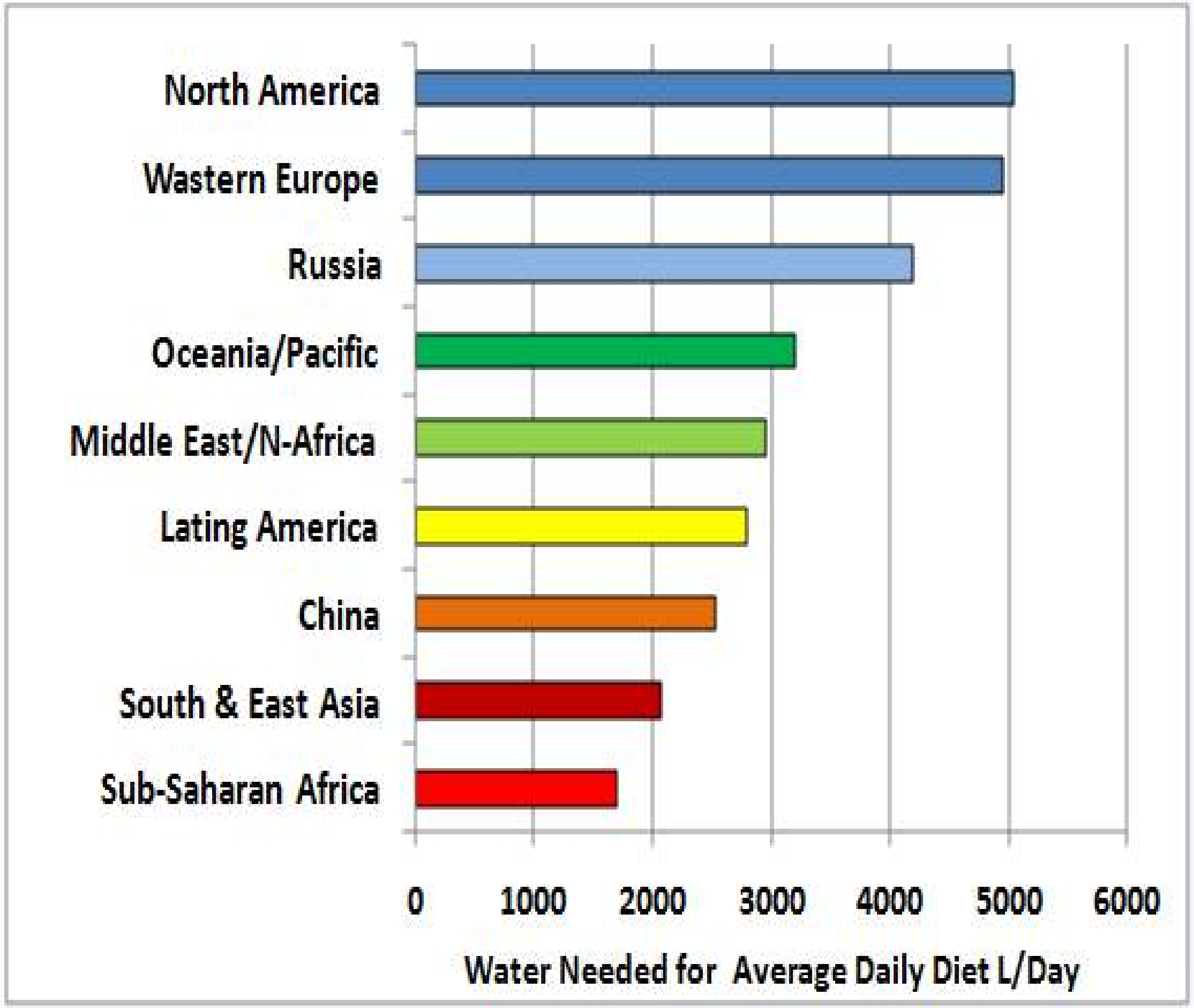


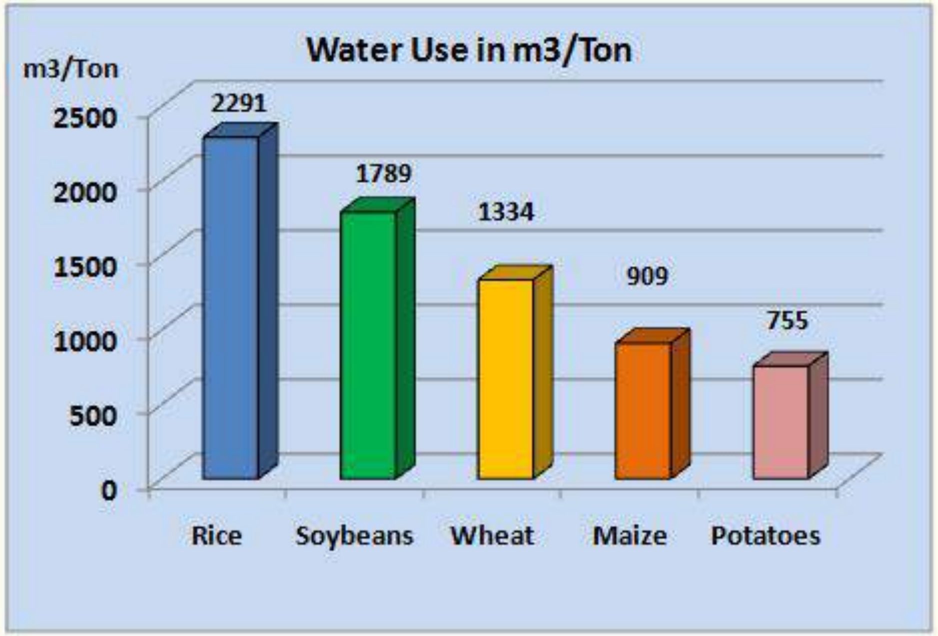
Hydrological Cycle

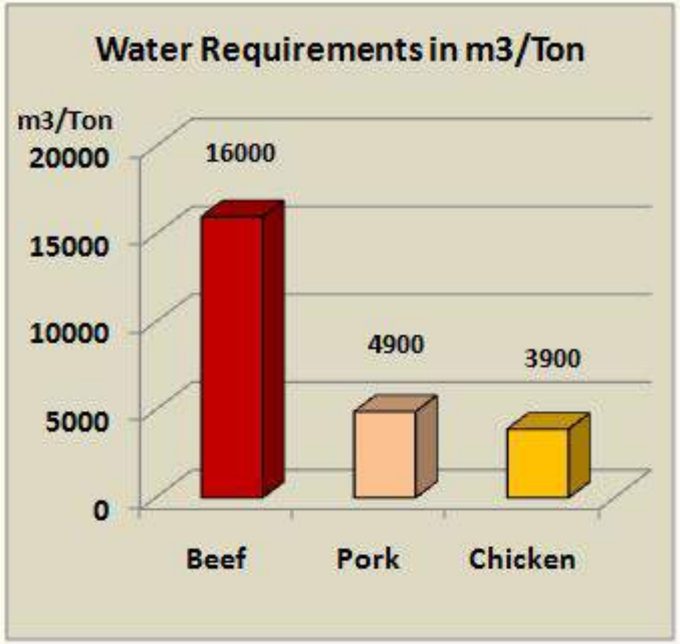


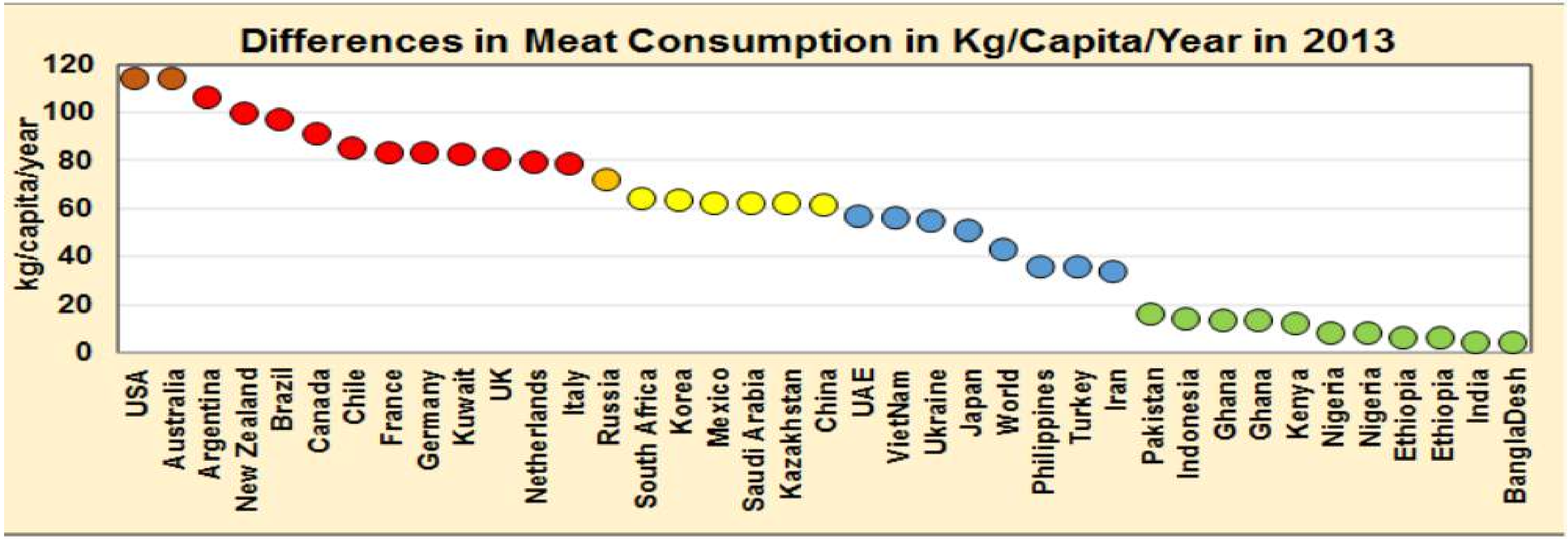

Green Water, Blue Water, White Water, Grey Water
Precipitation
Evapotranspiration
100%
30%
White Water
65%
Land & Soil
Green Water
Rainfed Agriculture
80% of Ag. Land Produces 60% of Food
35%
Lakes, Rivers, Groundwater
Blue Water
Irrigated Agriculture
Grey Water
20% of Ag. Land Produces 40% of Food
Domestic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

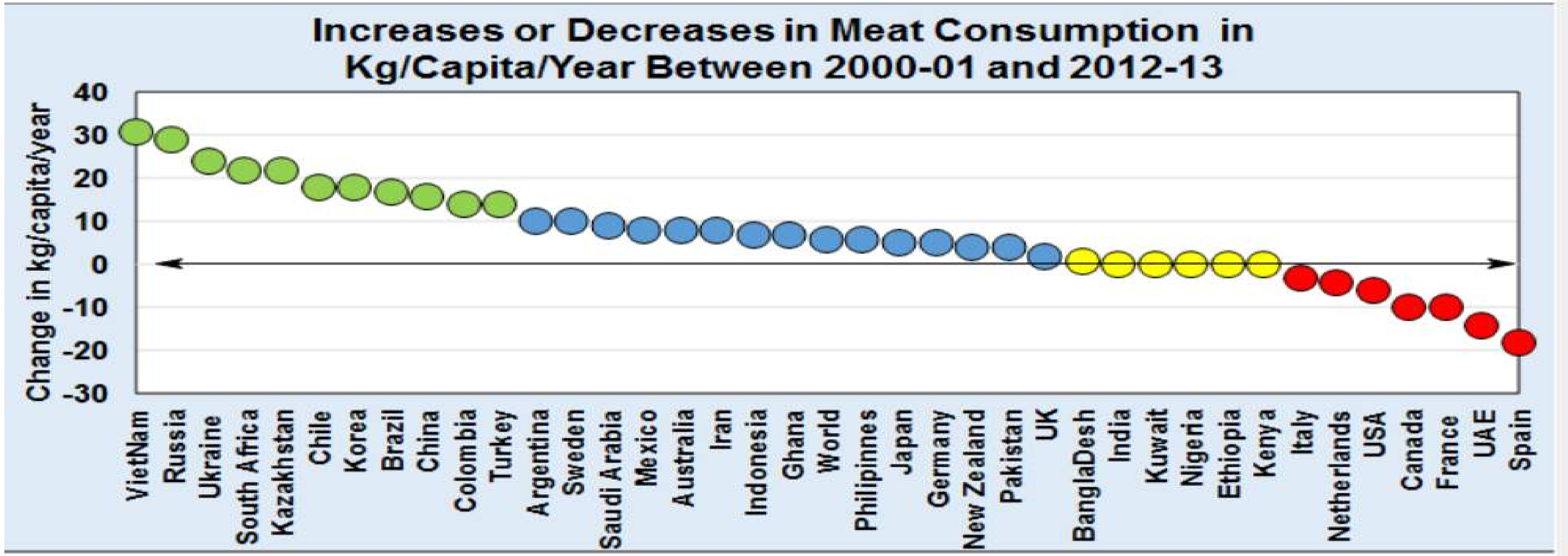
Water Requirements to Maintain Average Daily Diet




Water Use in m3/Ton
m3/Ton
2500
2000
1500
1000
500
0
2291
1789
1334
909
755
Rice
Soybeans
Wheat
Maize
Potatoes


Water Requirements in m3/Ton
m3/Ton
20000
15000
10000
5000
0
16000
4900
3900
Beef
Pork
Chicken


Differences in Meat Consumption in Kg/Capita/Year in 2013
kg/capita/year
120
100
80
60
40
20
0
USA
Australia
Argentina
New Zealand
Brazil
Canada
Chile
France
Germany
Kuwait
UK
Netherlands
Italy
Russia
South Africa
Korea
Mexico
Saudi Arabia
Kazakhstan
China
UAE
VietNam
Ukraine
Japan
World
Philippines
Turkey
Iran
Pakistan
Indonesia
Ghana
Ghana
Kenya
Nigeria
Nigeria
Ethiopia
Ethiopia
India
BanglaDesh


Increases or Decreases in Meat Consumption in Kg/Capita/Year Between 2000-01 and 2012-13
Change in kg/capita/year
40
30
20
10
0
-10
-20
-30
VietNam
Russia
Ukraine
South Africa
Kazakhstan
Chile
Korea
Brazil
China
Colombia
Turkey
Argentina
Sweden
Saudi Arabia
Mexico
Australia
Iran
Indonesia
Ghana
World
Philipinnes
Japan
Germany
New Zealand
Pakistan
UK
BanglaDesh
India
Kuwait
Nigeria
Ethiopia
Kenya
Italy
Netherlands
USA
Canada
France
UAE
Spain

% Changes in Livestock Numbers Between 2000 and 2014

	Cattle	Pigs	Sheep	Chicken	Human Population
World	13 %	15 %	13 %	49 %	18 %
Canada	-7 %	2 %	10 %	6 %	16 %
USA	- 10 %	14 %	-35 %	7 %	13 %
Australia	5 %	-8 %	-39 %	15 %	23 %
Brazil	57 %	20 %	19 %	57 %	17 %
China	5 %	22 %	49 %	29 %	8 %

Global Numbers in Billions 2014	Cattle	Pigs	Sheep	Goats	People
	1.47 Billions	0.99 Billions	1.19 Billions	1.01 Billions	7.3 Billions

Total Ruminants 4.7 Billions

Comparing Human & Livestock Waste

Nitrogen in Human Waste
= 4kg N /Person/Year

Number of People in the World
= 7 Billion

Nitrogen in Animal Manure
= 30-40 kg N /LUE/Year

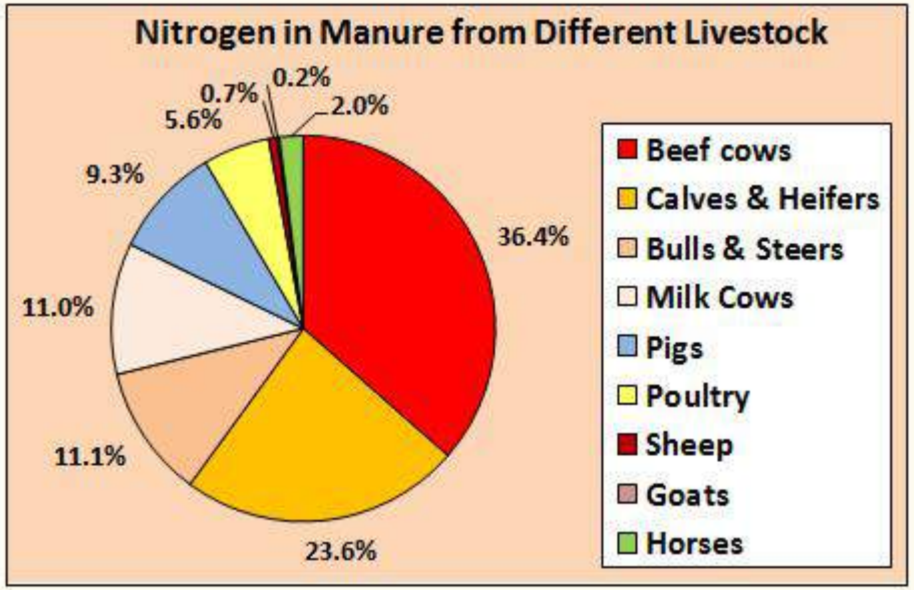
Number of LUE (Cow Equivalent)
= 3 Billion

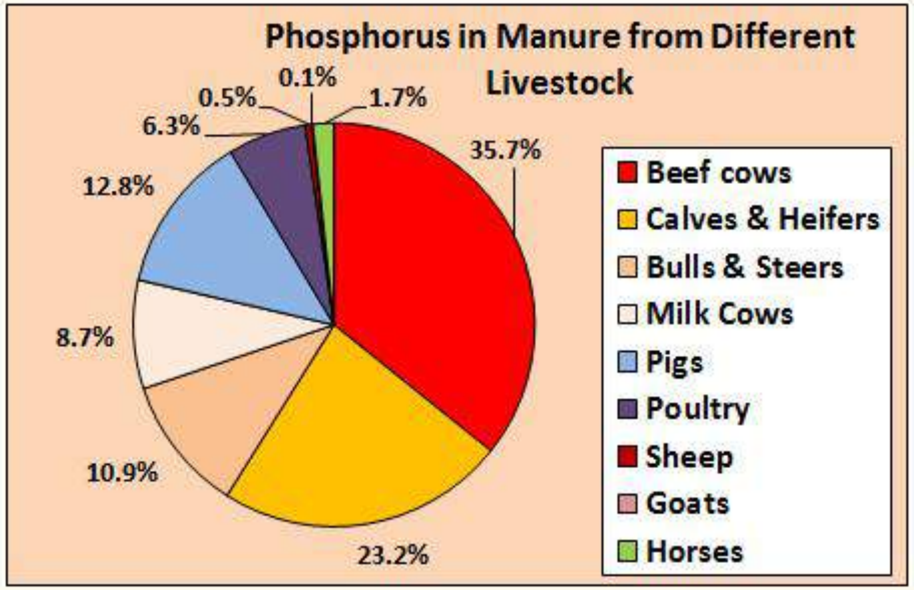
Cows generates 7 times the nitrogen in the waste that a human being

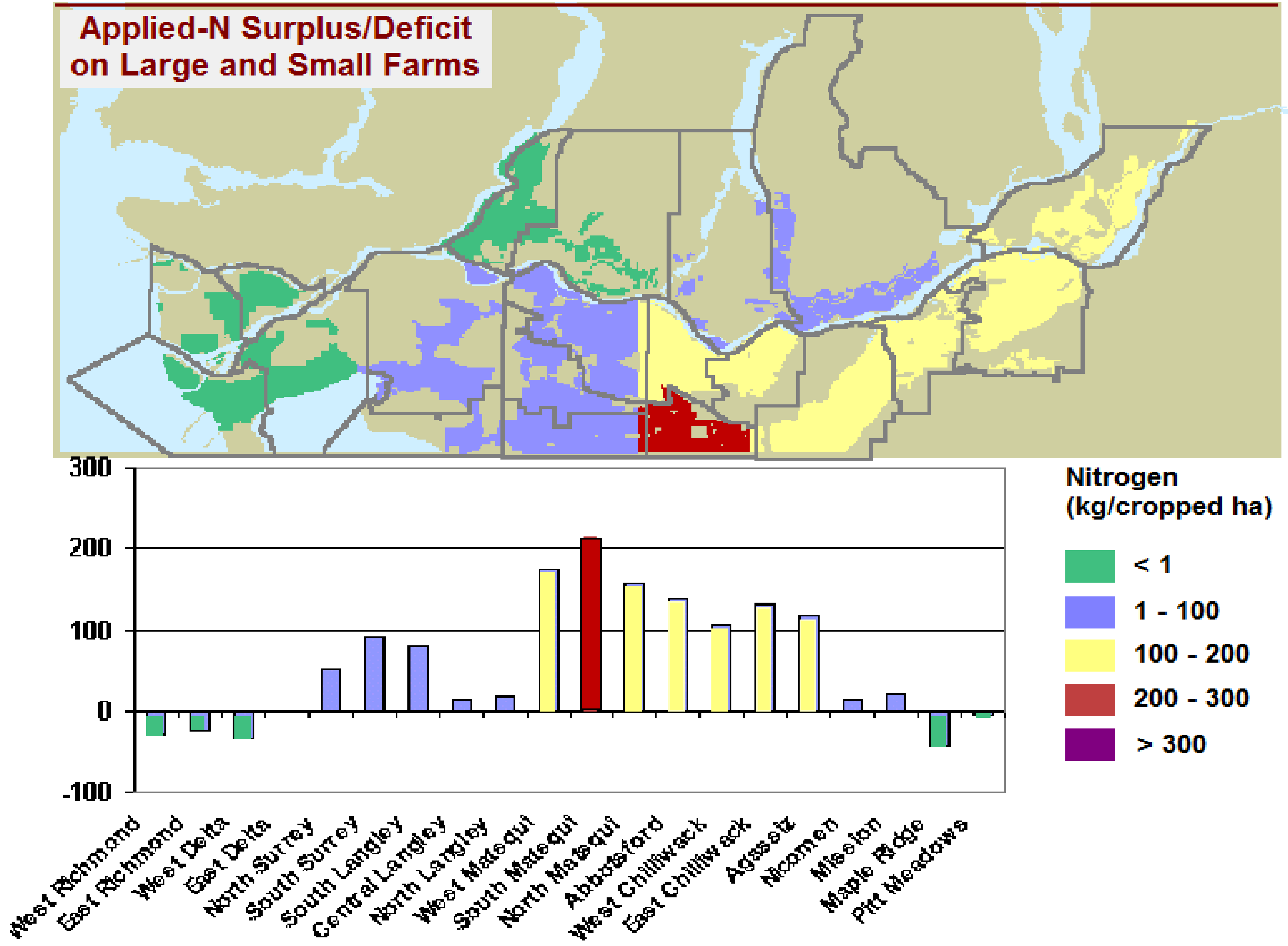
Global Nitrogen in Animal Waste = Equivalent to 21 Billion People

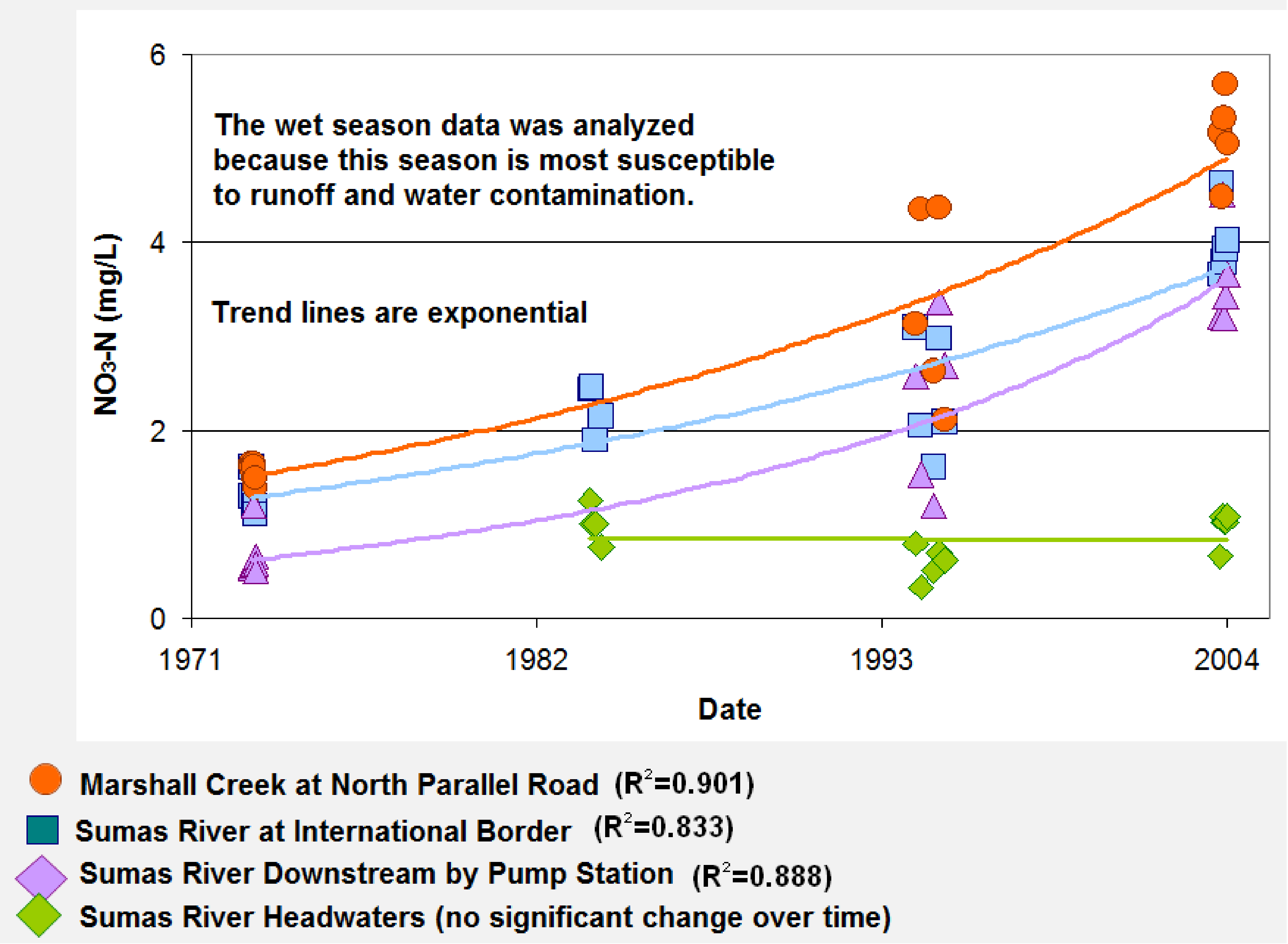
We try to treat Human Waste in the City
Why not treat Animal Waste in Large Operations

81% of all N and 75% of all P in Manure is from Cattle

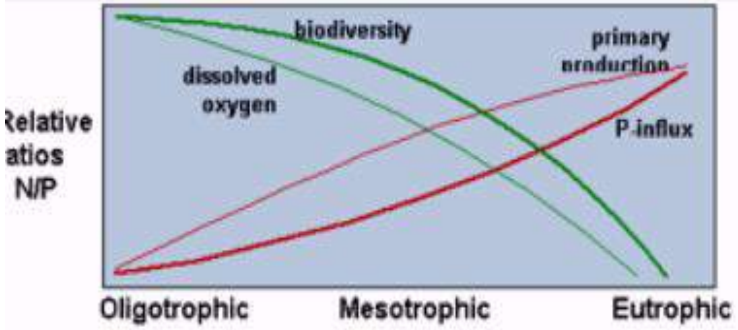





Applied-N Surplus/Deficit
on Large and Small Farms
300
200
100
0
-100
West Richmond
East Richmond
West Delta
East Delta
North Surrey
South Surrey
South Langley
Central Langley
North Langley
West Matsqui
South Matsqui
North Matsqui
Abbotsford
West Chilliwack
East Chilliwack
Agassiz
Nicomen
Mission
Maple Ridge
Pitt Meadows
Nitrogen
(kg/cropped ha)
< 1
1 - 100
100 - 200
200 - 300
> 300


6
4
2
0
NO_3-N (mg/L)
The wet season data was analyzed because this season is most susceptible to runoff and water contamination.
Trend lines are exponential
1971
1982
1993
2004
Date
Marshall Creek at North Parallel Road (R^2=0.901)
Sumas River at International Border (R^2=0.833)
Sumas River Downstream by Pump Station (R^2=0.888)
Sumas River Headwaters (no significant change over time)

Agriculture and Eutrophication



Low productivity	⟷	High productivity
Scarce littoral plants		Abundant littoral plants
Low nutrient levels		High nutrient levels
Oxygen in hypolimnion		Hypolimnion O depletion
Usually deeper lakes		Usually shallower lakes
Large diversity of plankton		Low diversity of plankton

Eutrophication

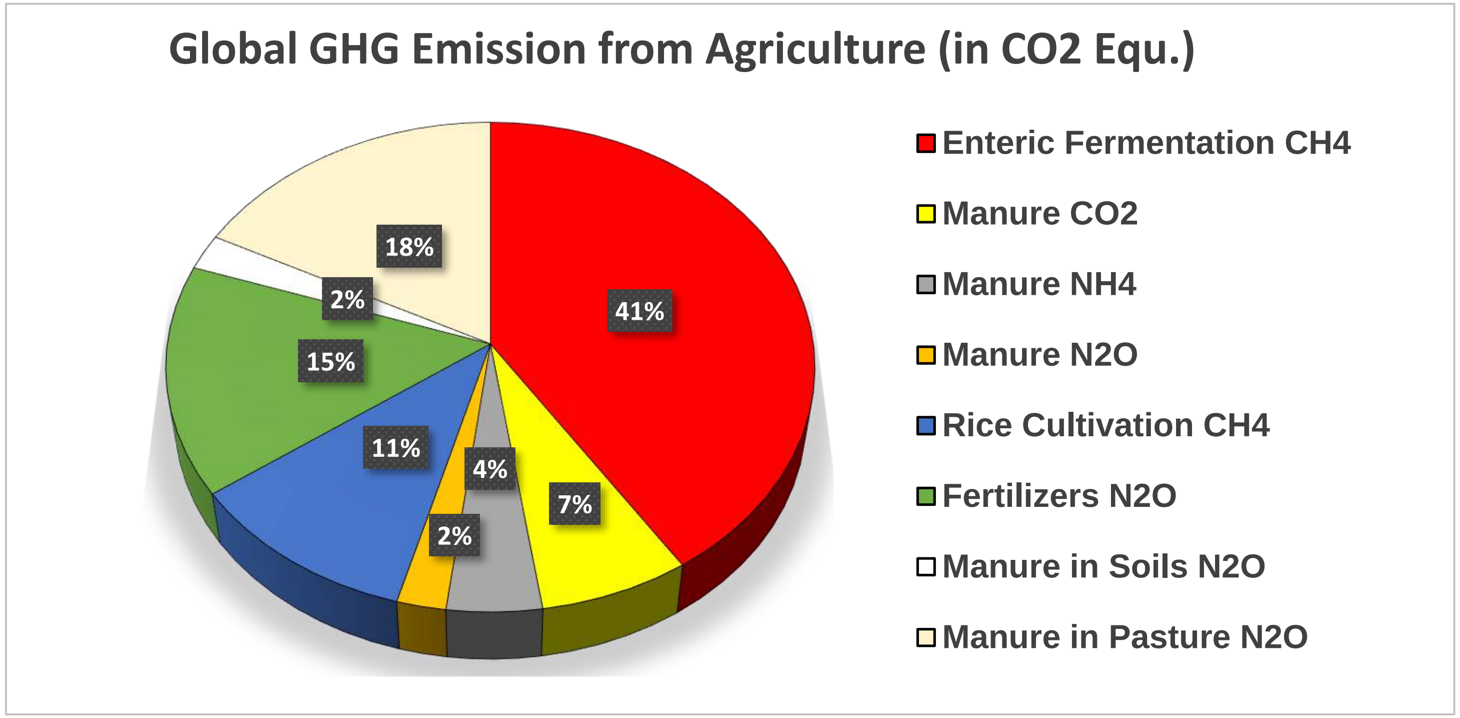
Control Nitrogen and Phosphorus Inputs (N/P)

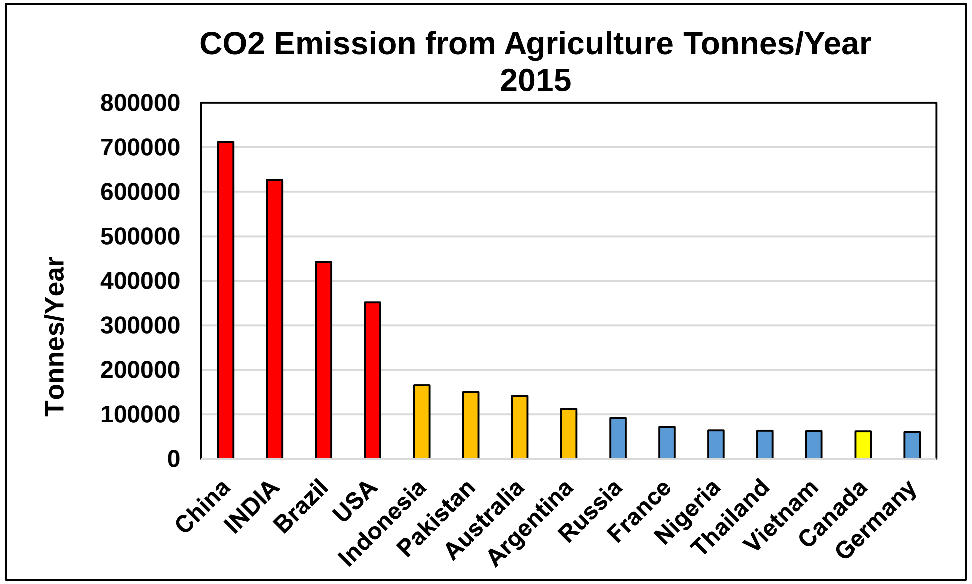
1. Annual Nutrient Budgets
2. Move Manure from Surplus Area to Deficit Areas
3. Precision Fertilization
4. Store Manure and only Apply to Land at Appropriate Time
5. Determine Soil Phosphorus Absorption Capacity
6. Animal Stocking Density Regulation based on Soil Absorption Capacity
7. Process Manure (Treatment with Nutrient Recovery)

Agriculture produces 13-14% of Global Green House Gases

65% CH_4 & N_2O

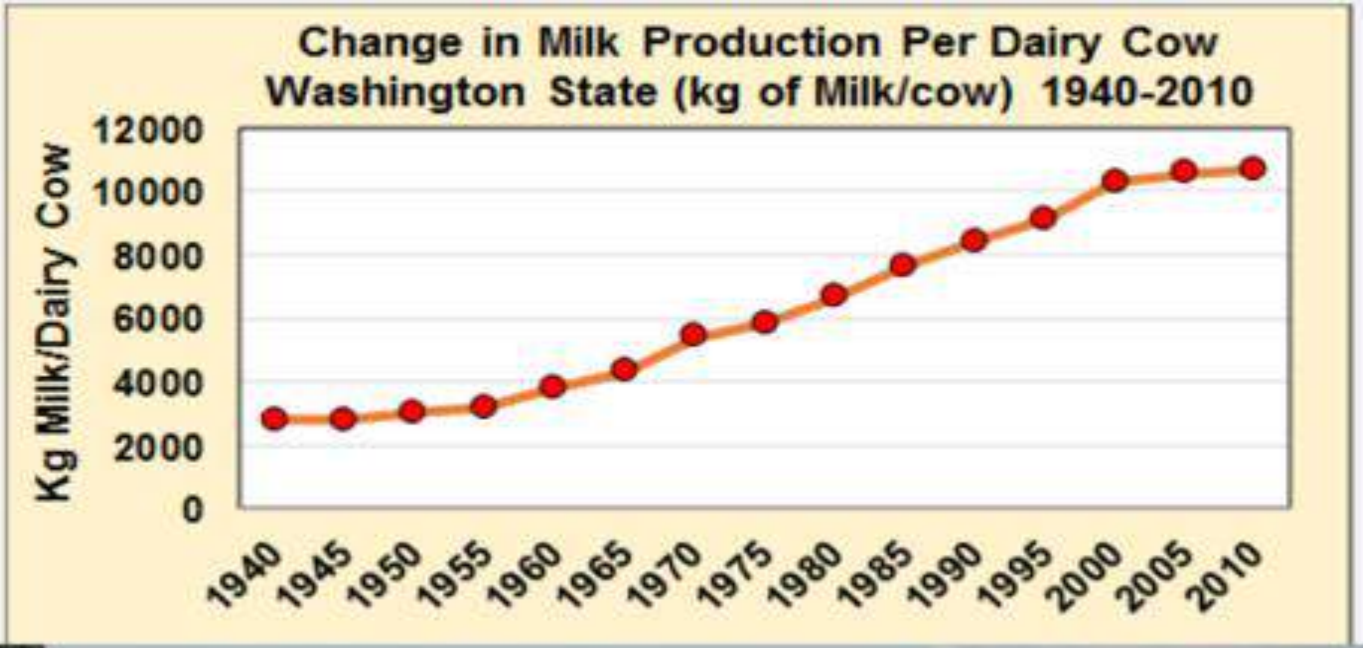
Increases between 1990-2010
8%

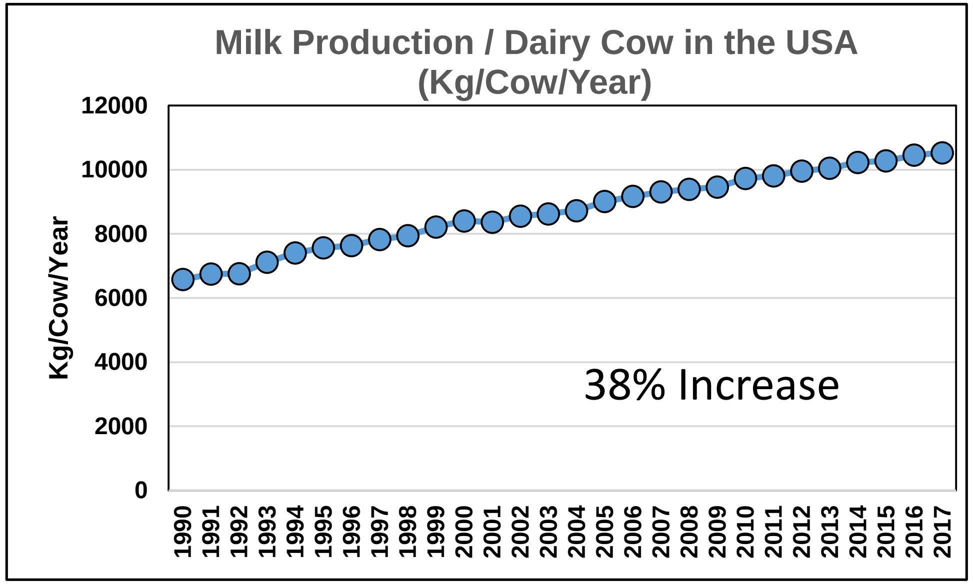


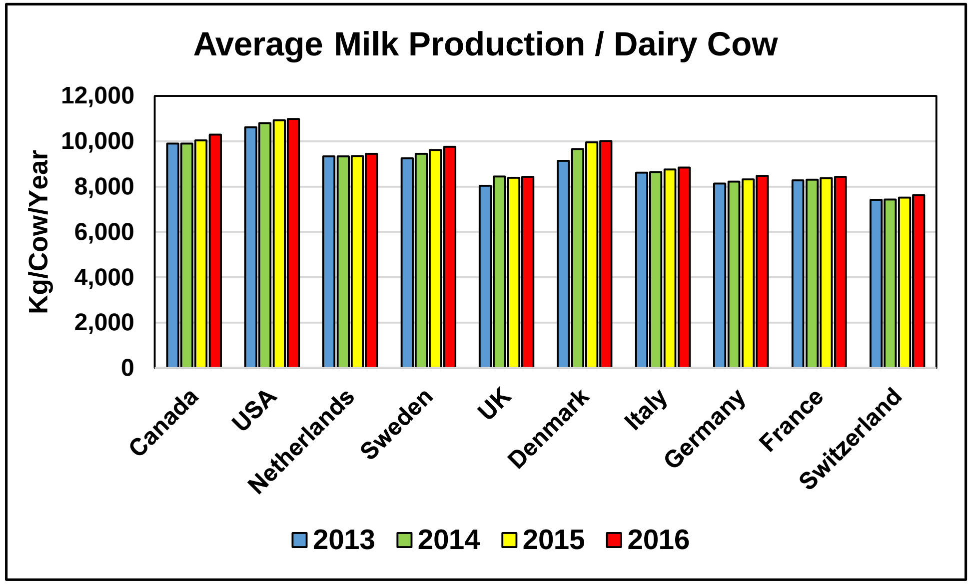


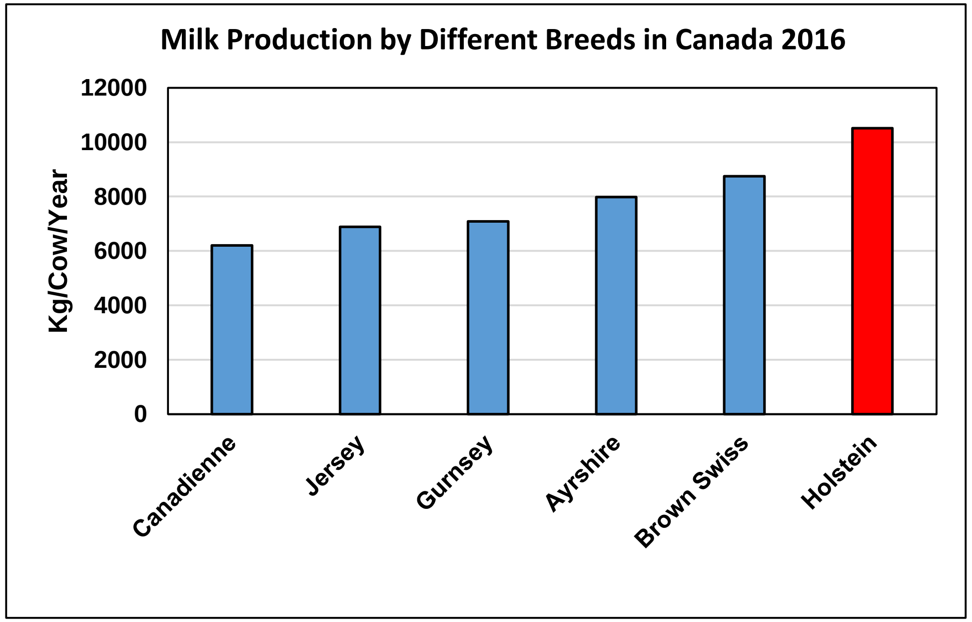
Cattle is the largest Contributor to GHG

Employs 1.3 Billion People
40% of Agricultural Output
Using about 30% of all Land


Change in Milk Production Per Dairy Cow
Washington State (kg of Milk/cow) 1940-2010
Kg Milk/Dairy Cow
12000
10000
8000
6000
4000
2000
0
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010







Dairy Cows are the most water consumptive Livestock
20000—30000 m3/year

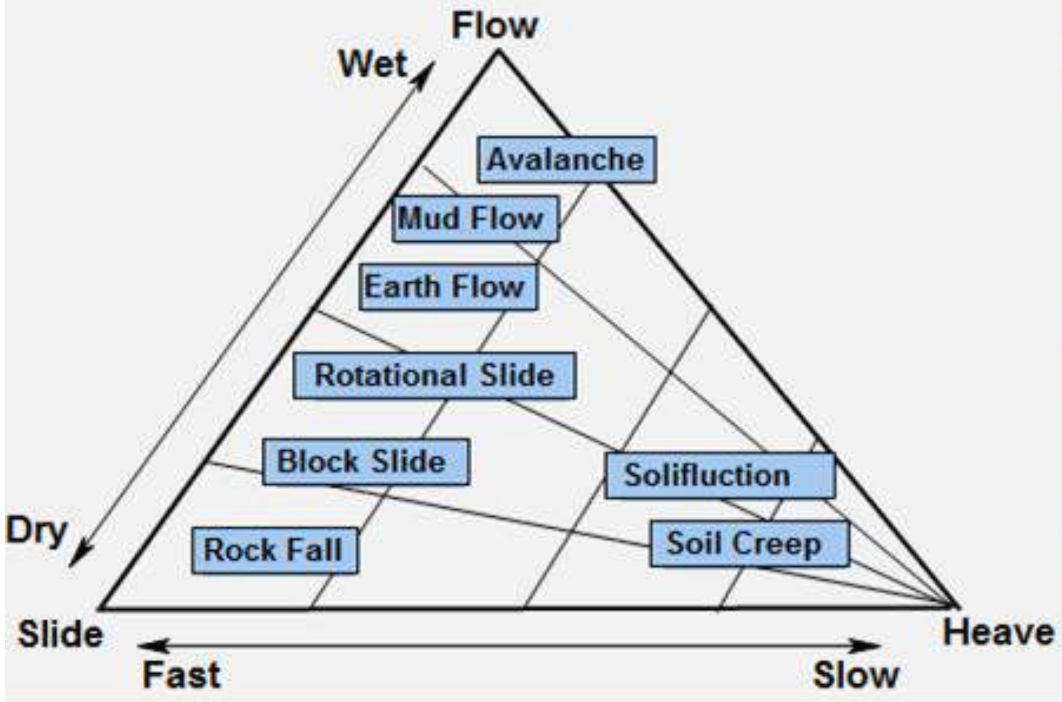
For every 1 kg of Milk they produce 1.7-2.6 kg of Manure (Holstein)


Herd: Main Herd
Group
Location

Manure Storage for 110 Dairy Cows

Soil Erosion

Typical Erosion	Rating
• 2- 5 t/ha/year	low
• 5-10 t/ha/year	moderate
• 10-15 t/ha/year	high
• 15-25 t/ha/year	very high
• 25-100 t/ha/year	excessive



Soil Erosion Processes

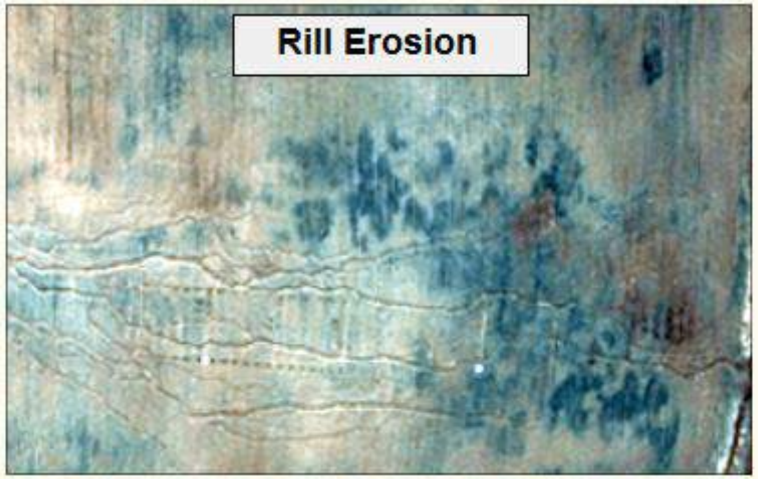
Inherent factors that influence erosion

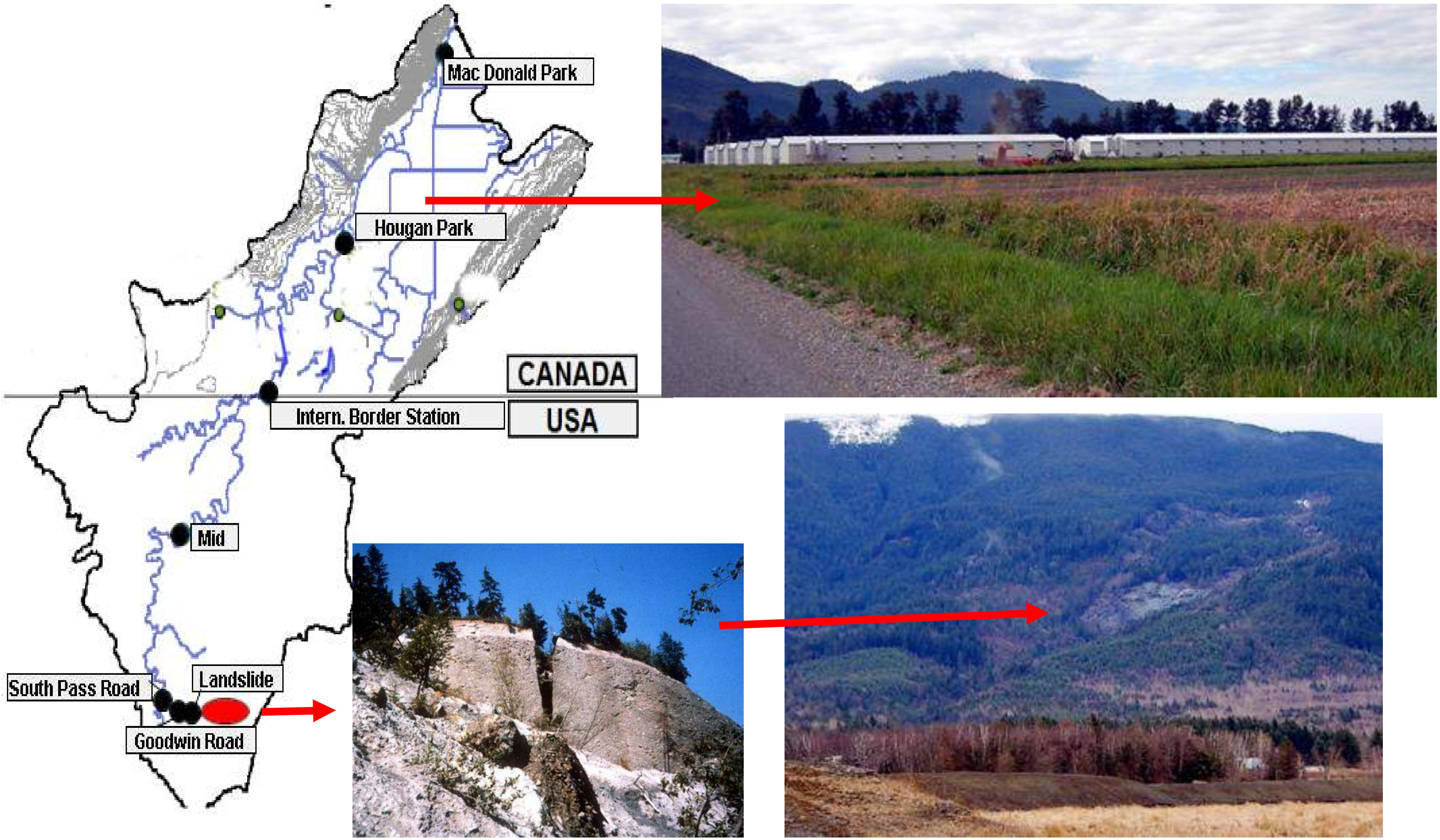
1. Type of Material (rocks & soil)
2. Soil texture and structure
3. Amount of swelling clays
4. Crusts and impervious layers
5. Infiltration and percolation rates
6. Topography and slope

External factors that influence erosion

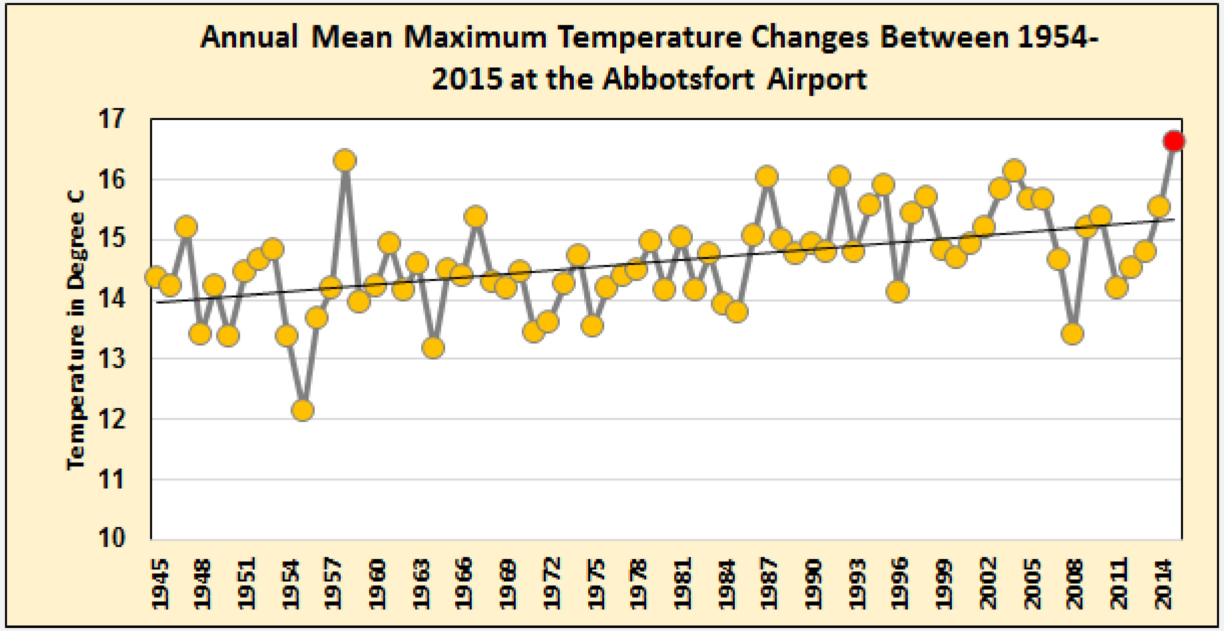
1. Rainfall intensity, duration & amount
2. Temperature
3. Change in surface conditions & cover
4. Change in soil moisture content
5. Vegetation cover, density & structure
6. Adjacent activities

Type of Erosion

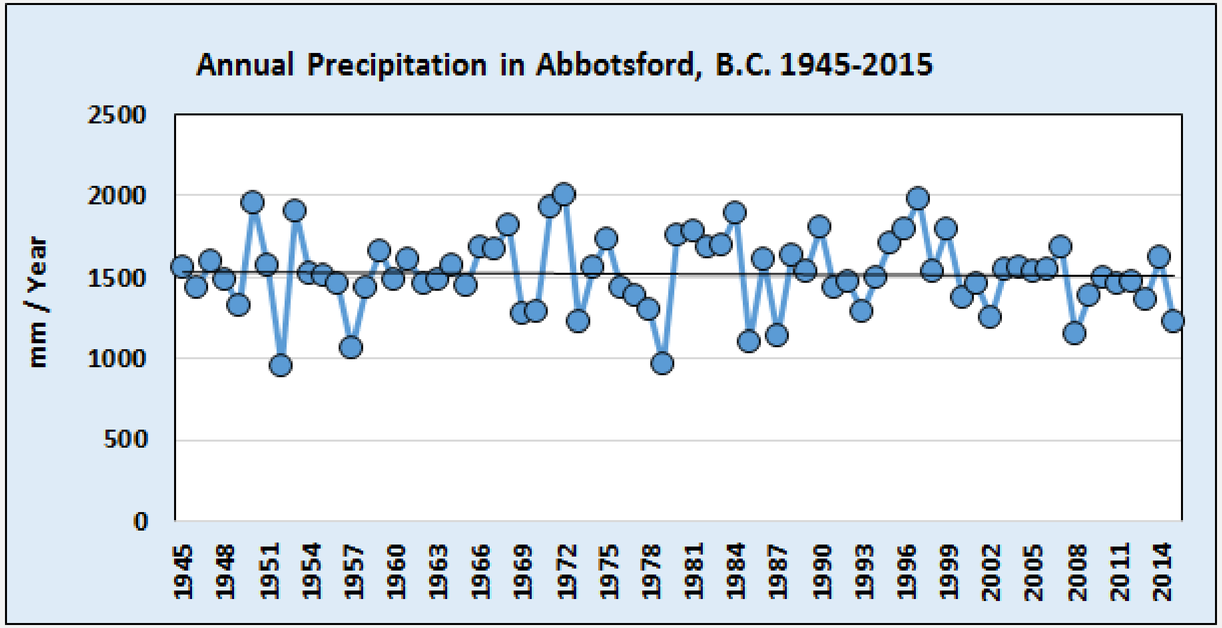



Mac Donald Park
Hougan Park
CANADA
Intern. Border Station
USA
Mid
Landslide
South Pass Road
Goodwin Road

The Impacts of Land Use Changes in the Sumas Watershed

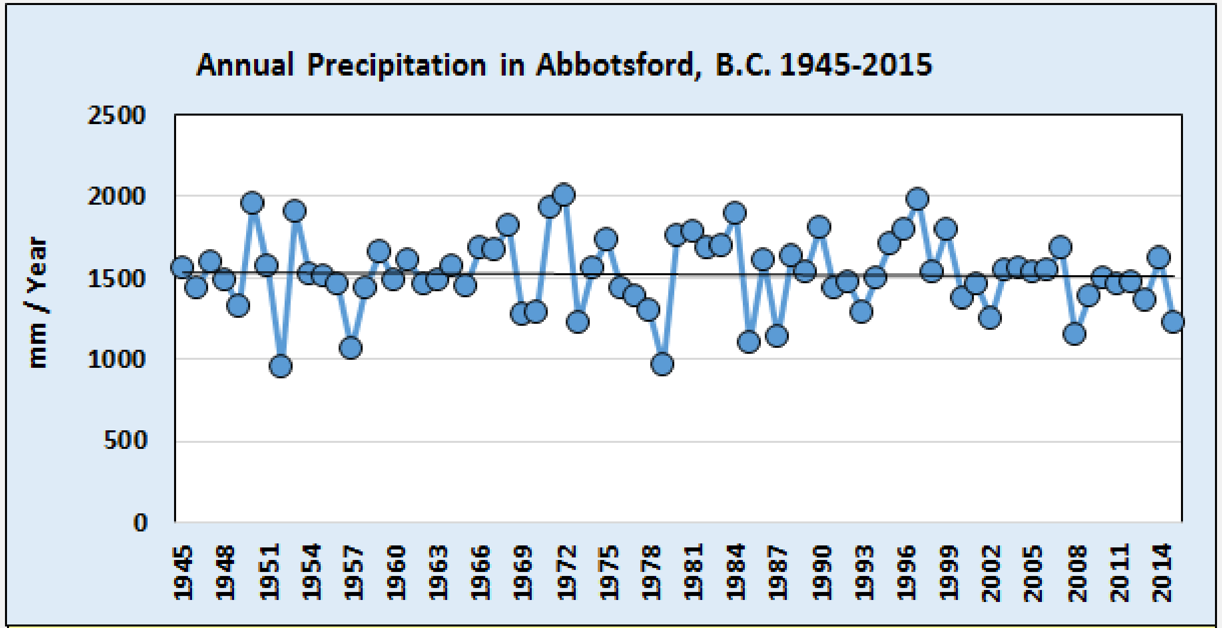


Temperature Increases

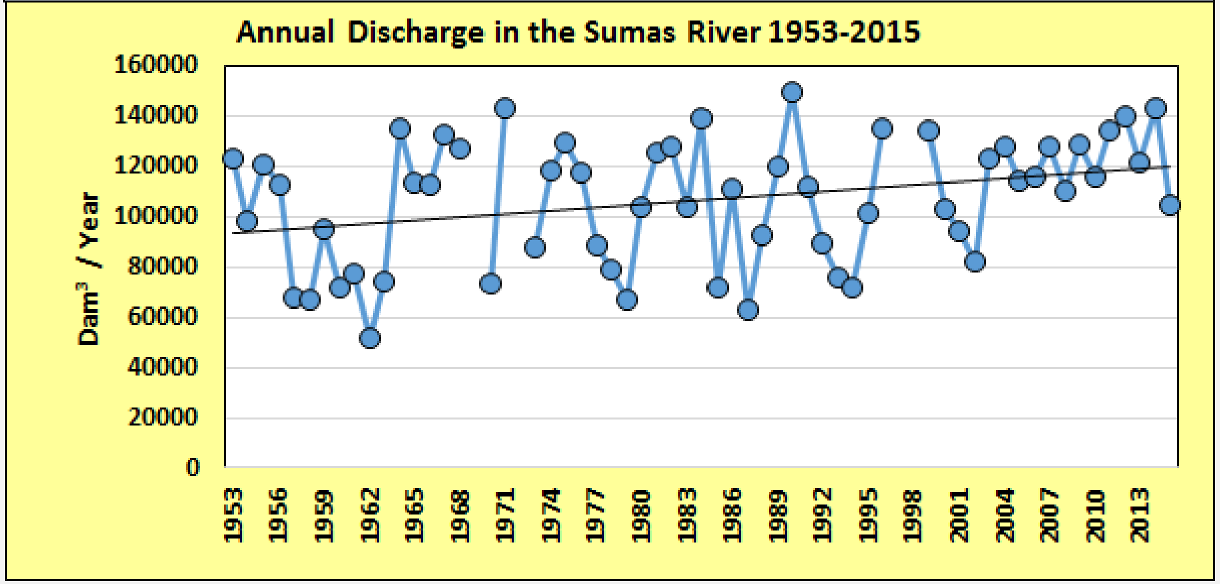


No Change in Precipitation

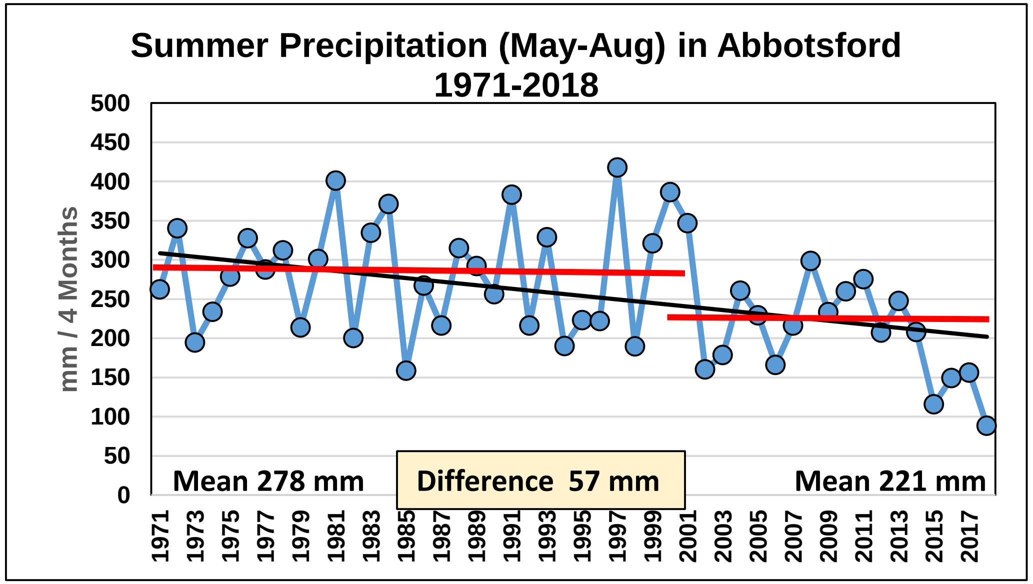
The Impacts of Land Use Changes in the Sumas Watershed

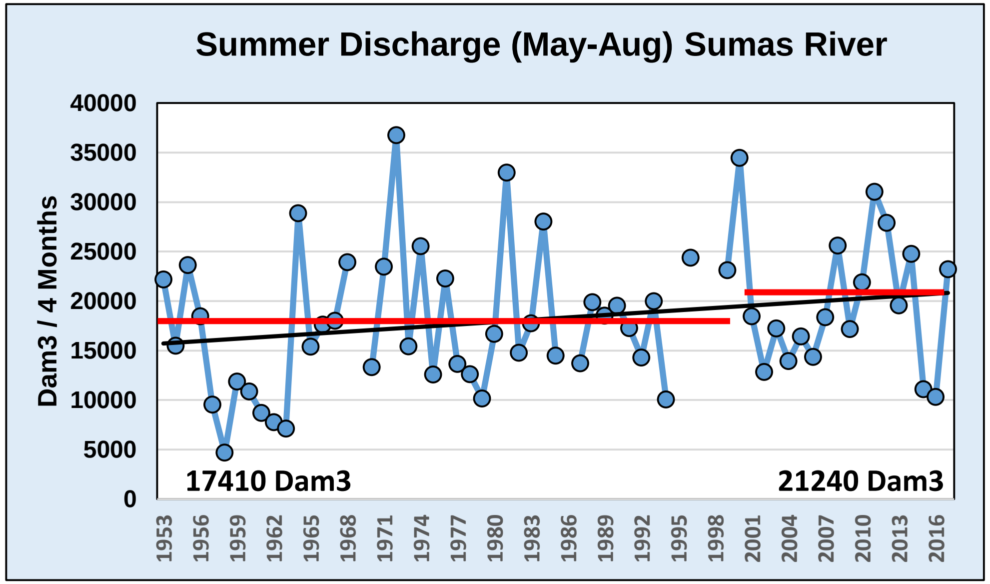


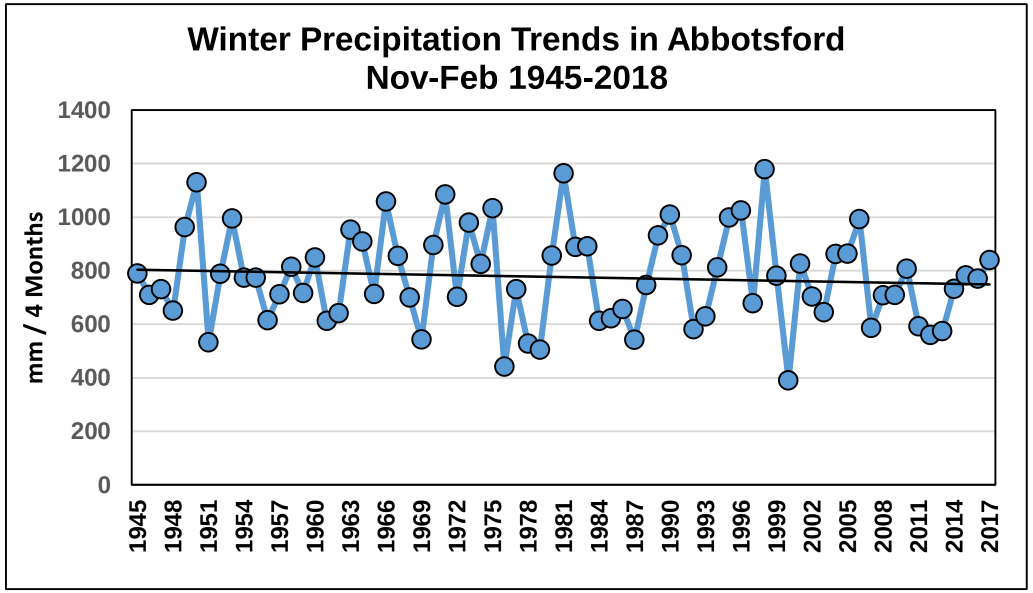
No Change in Precipitation

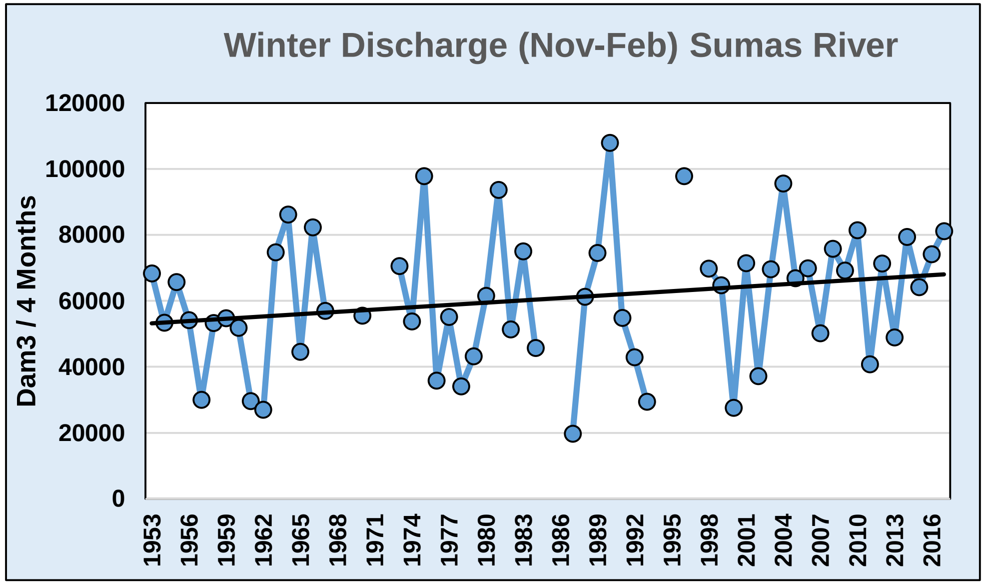


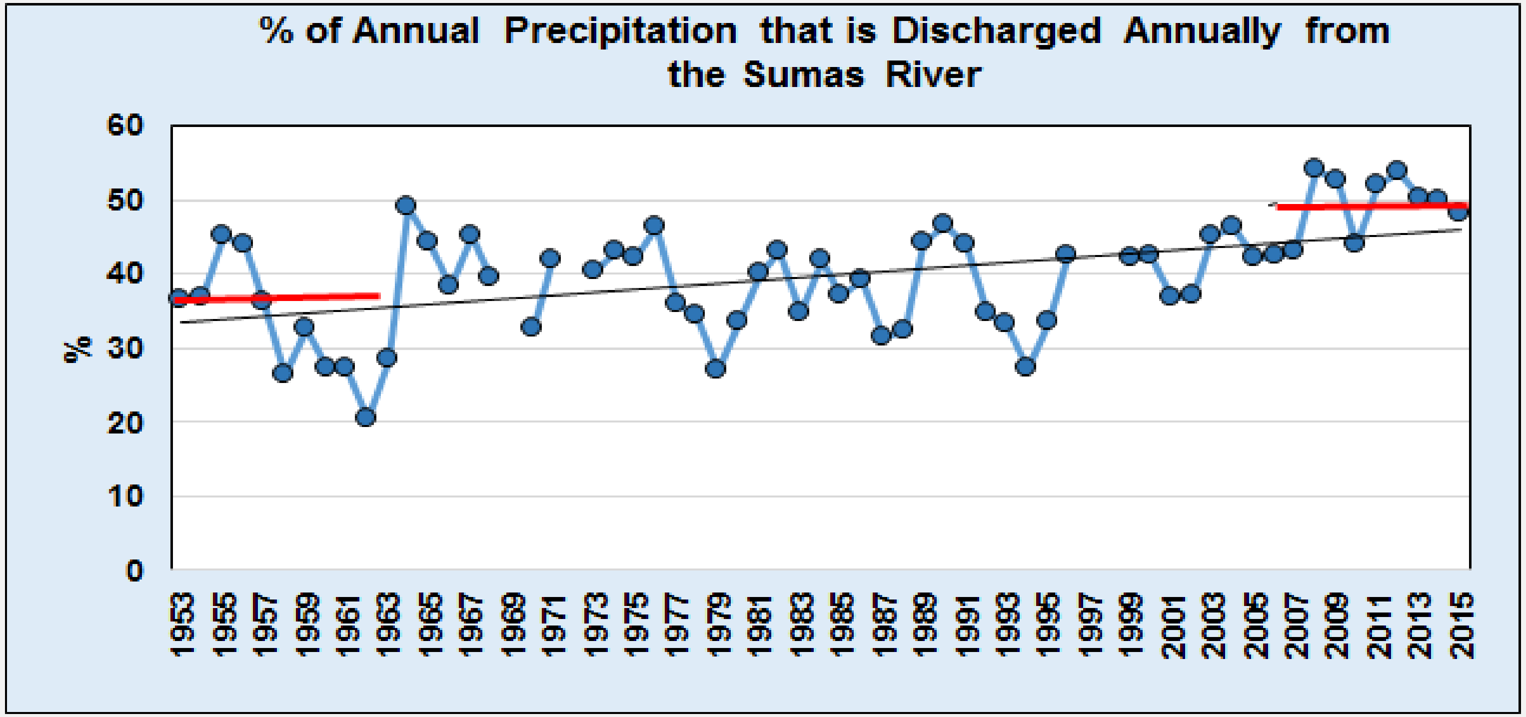
Increase in River Discharge


Summer Precipitation (May-Aug) in Abbotsford
1971-2018
mm / 4 Months
Mean 278 mm
Difference 57 mm
Mean 221 mm


Summer Discharge (May-Aug) Sumas River
Dam3 / 4 Months
17410 Dam3
21240 Dam3

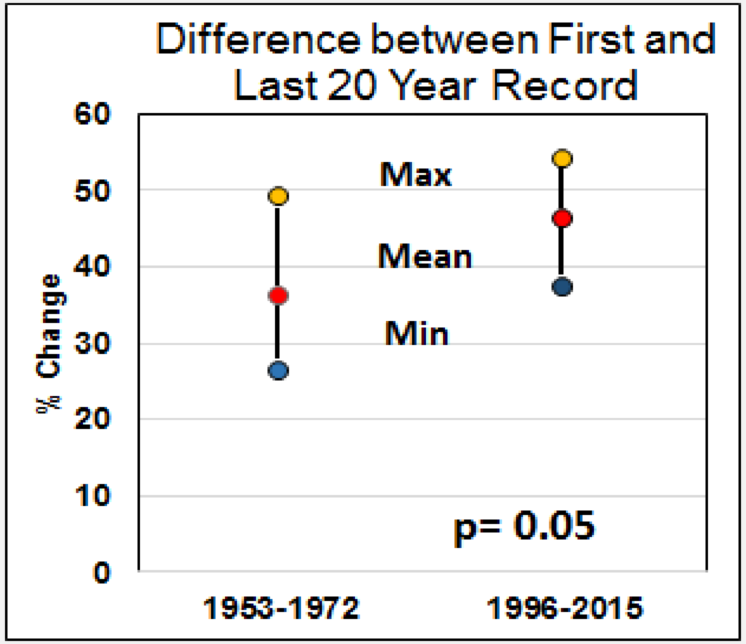

Winter Precipitation Trends in Abbotsford
Nov-Feb 1945-2018
mm / 4 Months


Winter Discharge (Nov-Feb) Sumas River
Dam3 / 4 Months



10 Year Comparison

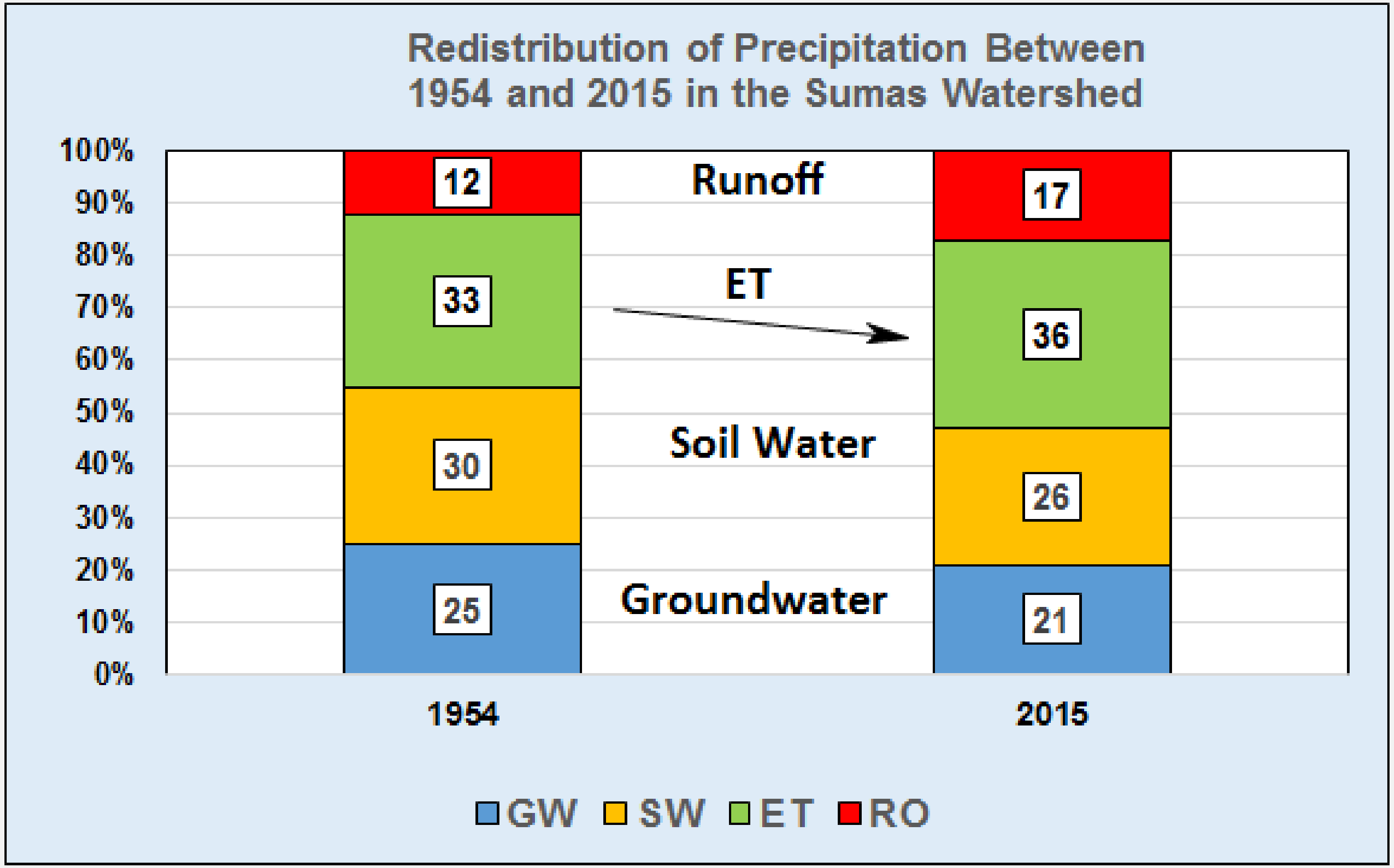
1953-1962 = 36%
2006-2015 = 49%



20 Year Comparison

1953-1972 = 36%
1996-2015 = 46%

Redistribution of Precipitation Between 1954 & 2015
Sumas River Watershed



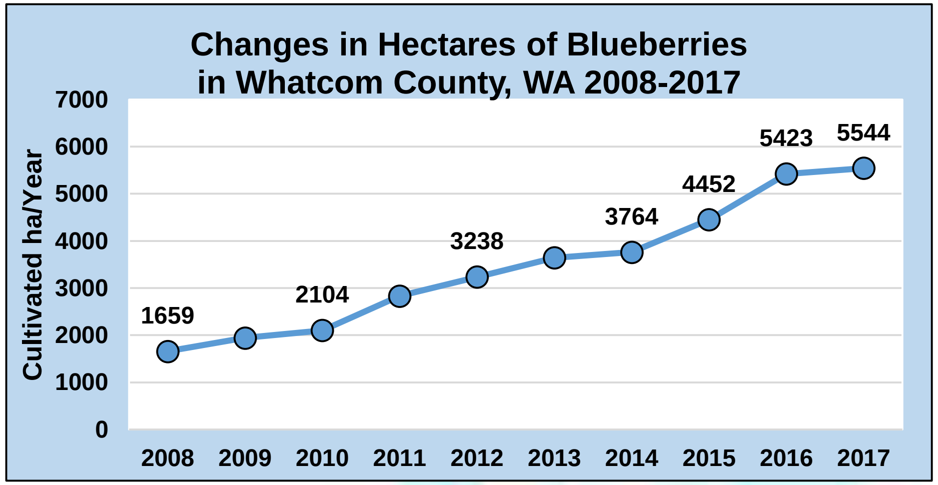
Water Balance

ET + SW + GW = P - Q

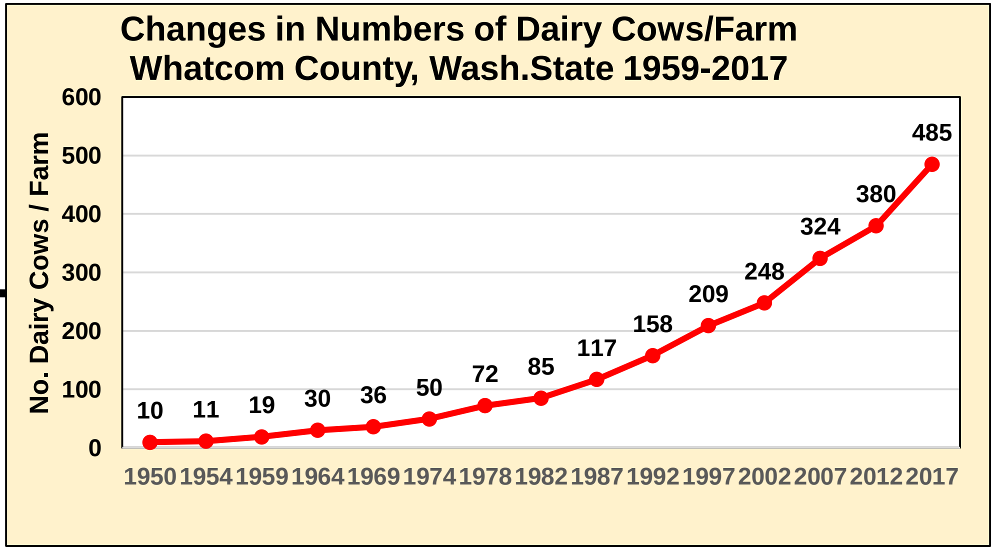
1. Soil Compaction
2. Drainage Increases
3. Increases in GW Use
4. More ET - Higher Temp.
5. SW & GW Recharge

SOIL Compaction

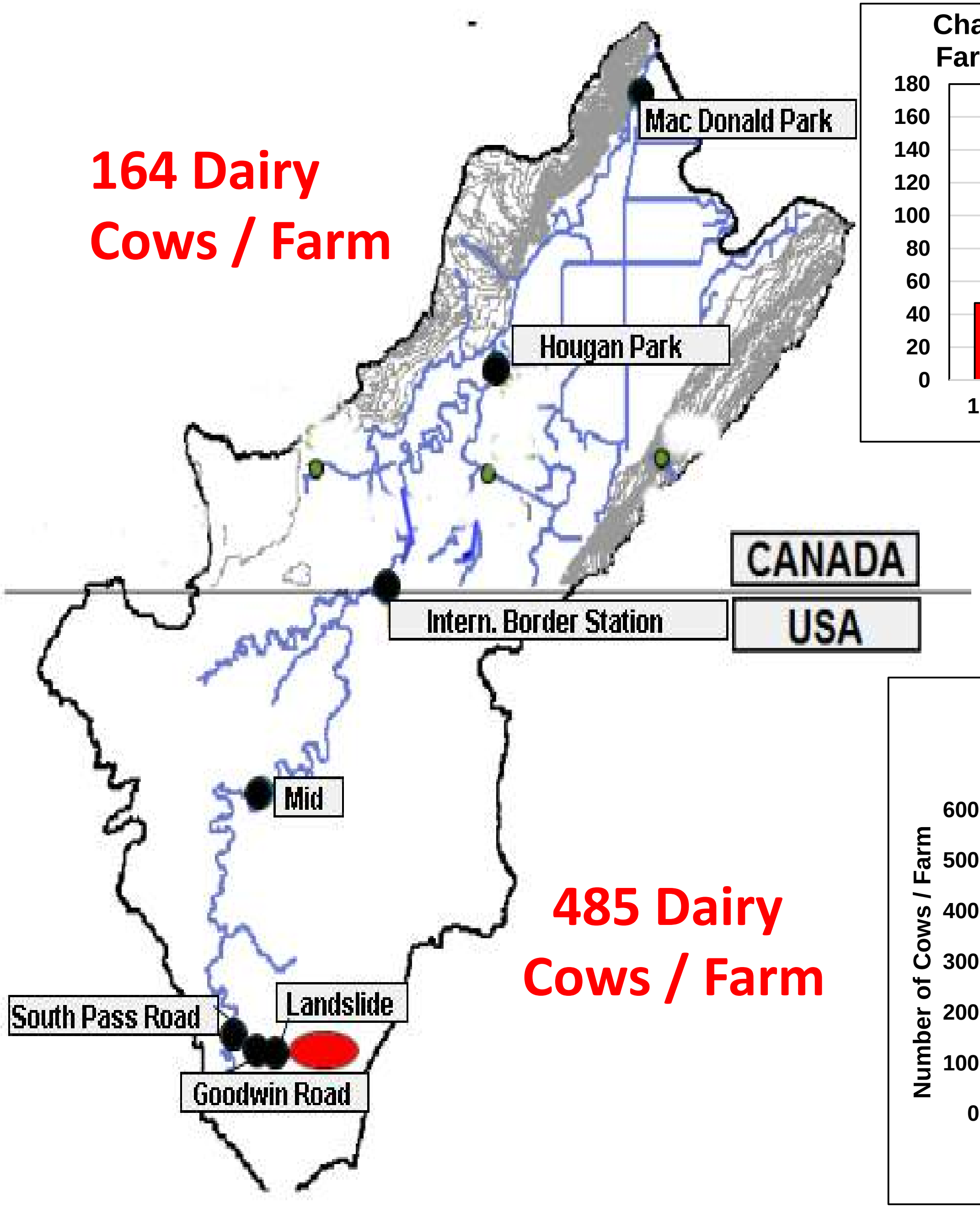
Dominant Land Use Activity in Watershed: Dairy, Raspberries, Blueberries

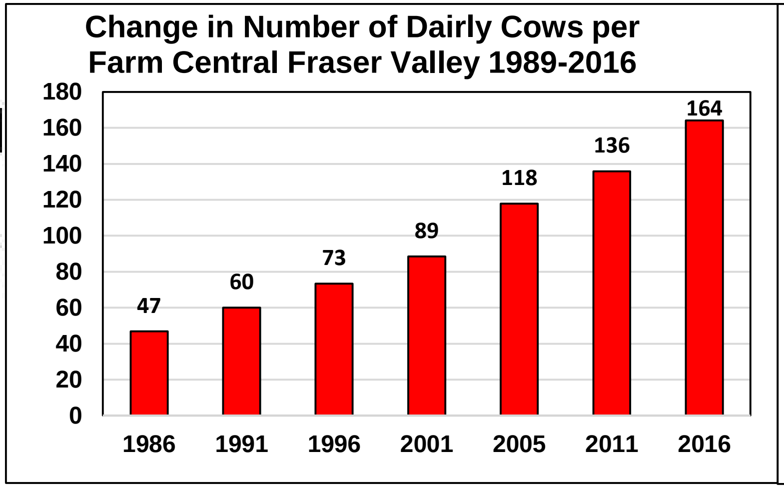


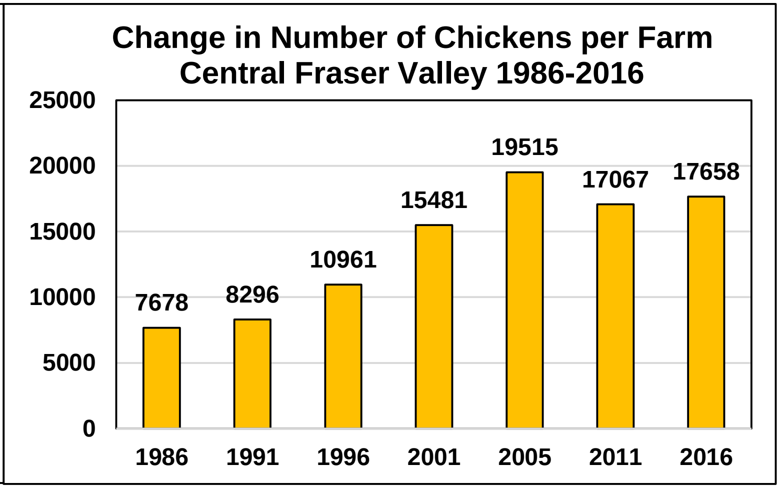
Whatcom County, WA

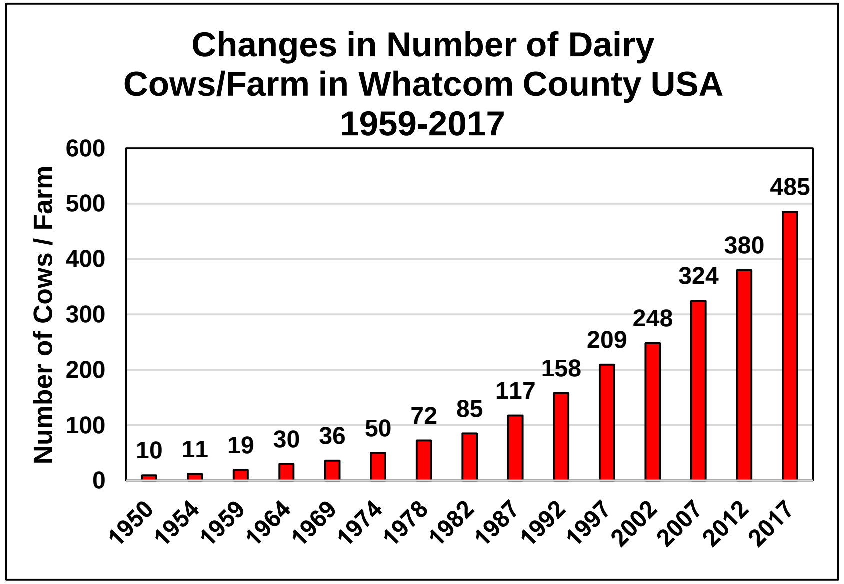


Soil Compaction and Impervious Surfaces = More Surface Runoff


164 Dairy Cows / Farm
Mac Donald Park
Hougan Park
CANADA
Intern. Border Station
USA
Mid
485 Dairy Cows / Farm
South Pass Road
Landslide
Goodwin Road


Change in Number of Dairly Cows per Farm Central Fraser Valley 1989-2016
180
160
140
120
100
80
60
40
20
0
47
60
73
89
118
136
164
1986
1991
1996
2001
2005
2011
2016


Change in Number of Chickens per Farm Central Fraser Valley 1986-2016
25000
20000
15000
10000
5000
0
7678
8296
10961
15481
19515
17067
17658
1986
1991
1996
2001
2005
2011
2016

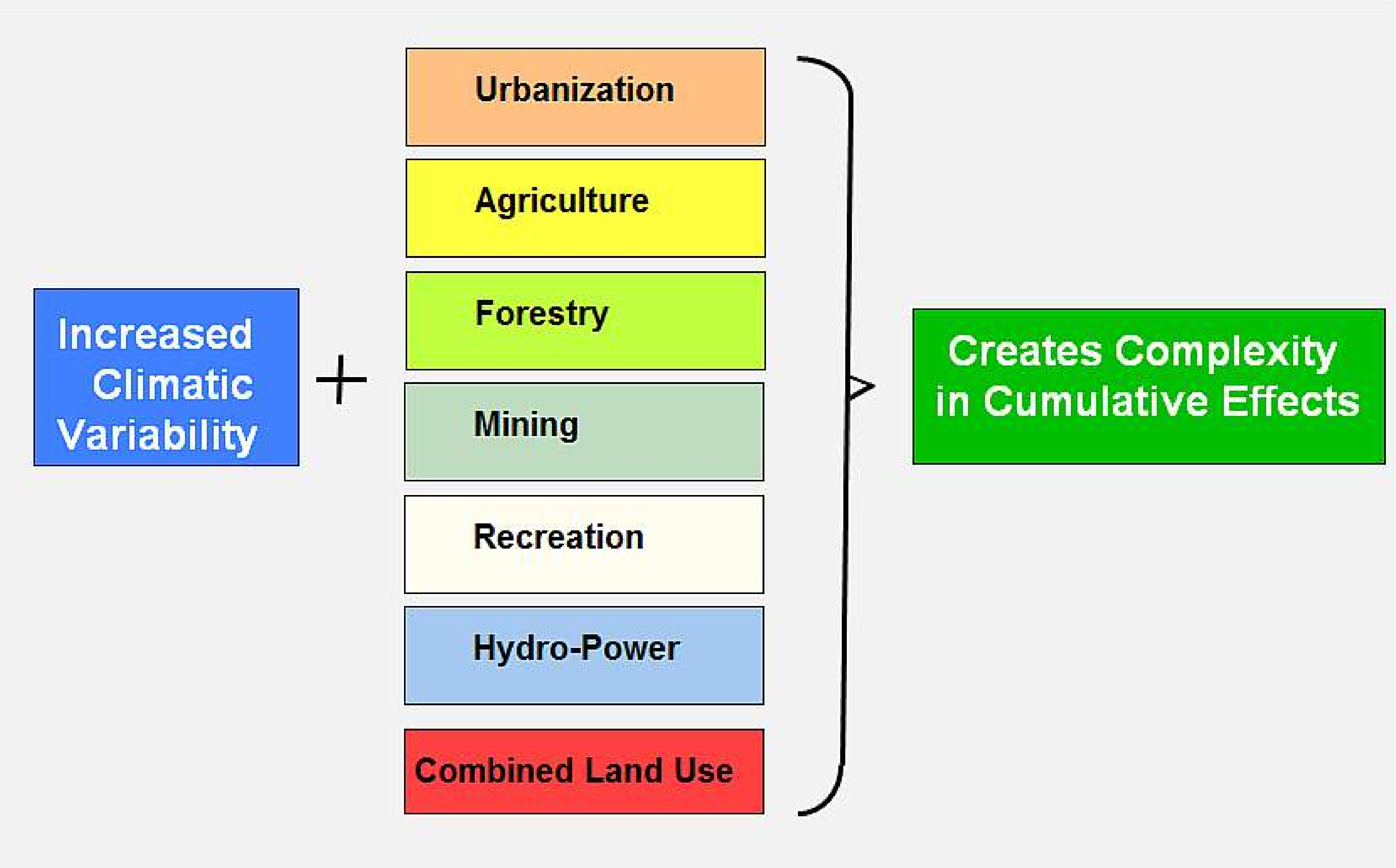

Changes in Number of Dairy Cows/Farm in Whatcom County USA 1959-2017
Number of Cows / Farm
600
500
400
300
200
100
0
10
11
19
30
36
50
72
85
117
158
209
248
324
380
485
1950
1954
1959
1964
1969
1974
1978
1982
1987
1992
1997
2002
2007
2012
2017

Number of Discharge Event Leading to Floods

	← Discharge in m3/Sec →			
	30-39	40-49	50-58	Total #
1953-1973	3	0	0	3
1974-1994	4	3	1	8
1995-2015	8	1	1	10
	← Minor Floods →	← Major Floods →		

Agricultural Impacts on Water Resources

Urban Impacts	Reasons
Increasing Water Demand	Need to Increase Production (>50%) Increases for Irrigated Agriculture Changes in Diets (Meat)
Increasing Pollution (NPS)	More Manure and Fertilizer Use Land Degradation (Erosion,Turbidity) More Pathogens (More Livestock)
Increasing Green House Gases	Large Increases in Ruminants (Manure) Intensive Cultivation (Soil OM Loss) Increases in Fertilzer Use


Increased Climatic Variability
+
Urbanization
Agriculture
Forestry
Mining
Recreation
Hydro-Power
Combined Land Use
Creates Complexity in Cumulative Effects

Land Use Activities	Water Demand & Use	Surface Runoff	Water Pollution
Urbanization	Increasing Demand Summer Peak Use	Increased Surface Runoff & Floods	NPS & Wastewater Discharge
Agriculture	More Irrigation	More Runoff due to Soil Compaction	Nutrient, Sediments Pathogen Leaching
Forestry	Water for Fire Fighting	Road and after Fire Runoff	Sediments
Mining	Fracking Water & Processing	Runoff from Tailing Failures	Metals & Organics Hg and Cyanide
Recreation	Water for Snow Increasing Peak Use	Changes in Sesonal Runoff	Pathogens & Sediments
Hydro-Power	More Reservoirs Pump Storage	Release during Peak Demand	Flushing during Summer
Combined Land Use	Cumulative Effect on Water Use, Runoff & Pollution		