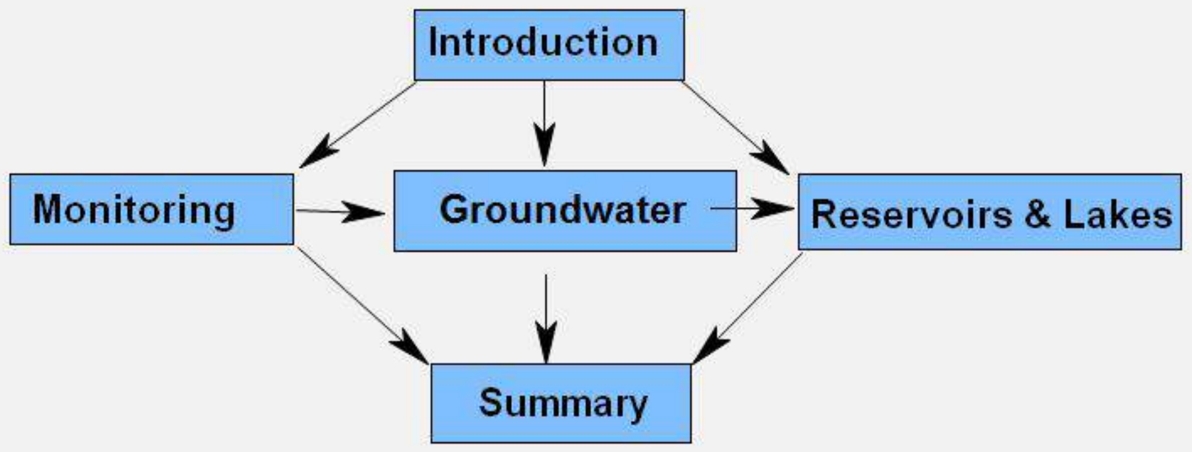
Source Water Protection

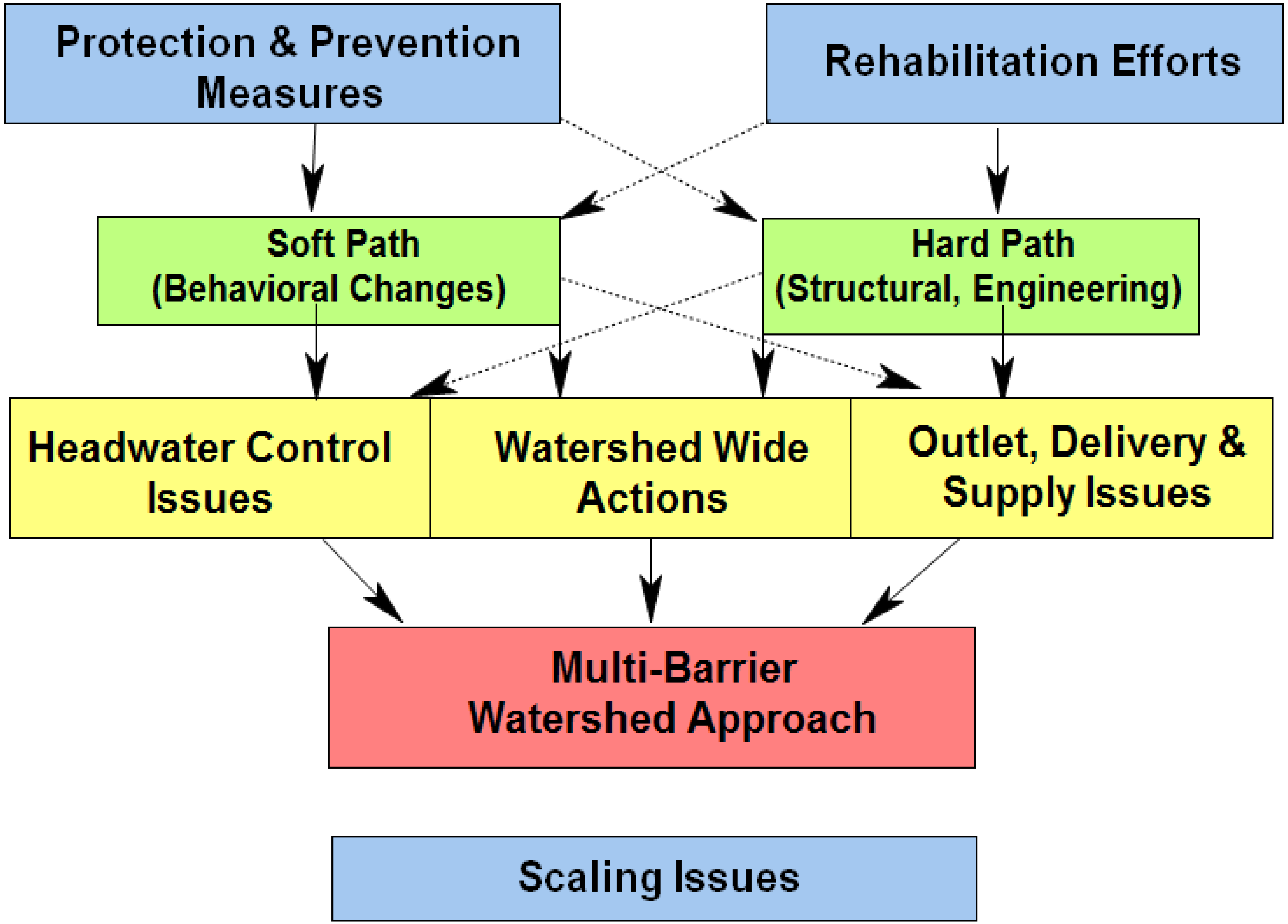
Hans Schreier, UBC, Vancouver, B.C.


Introduction
Monitoring
Groundwater
Reservoirs & Lakes
Summary

Options for Dealing with the Uncertainy of Water Supplies in Mountains Communities

Enhance Storage	Conservation	New Water Sources	Re-Use of Water
Expensive	Most Cost Effective Short Term Option	Difficult	Restricted Use Unless Treatment

A Multi-Barrier Approach to Watershed Management



Source Water Protection

Requires a Multi Barrier Approach

- Requires Source Protective Measures
- Comprehensive Water Treatment Options (active & passive)
- A Safe Supply Network
- A Monitoring Program in Place
- A Contingency Plan in Case of Failure

Different Water Sources Need Different Protective Measures

A 4 Step Process:

1. Delineate the Water Source
2. Identify the Potential Sources of Contamination
3. Determine the Suseptibility & Vulnerability
4. Prioritize Risk and Determine Capacity to Mitigate

Rivers & Streams

Groundwater

Springs

Reservoirs and Lakes

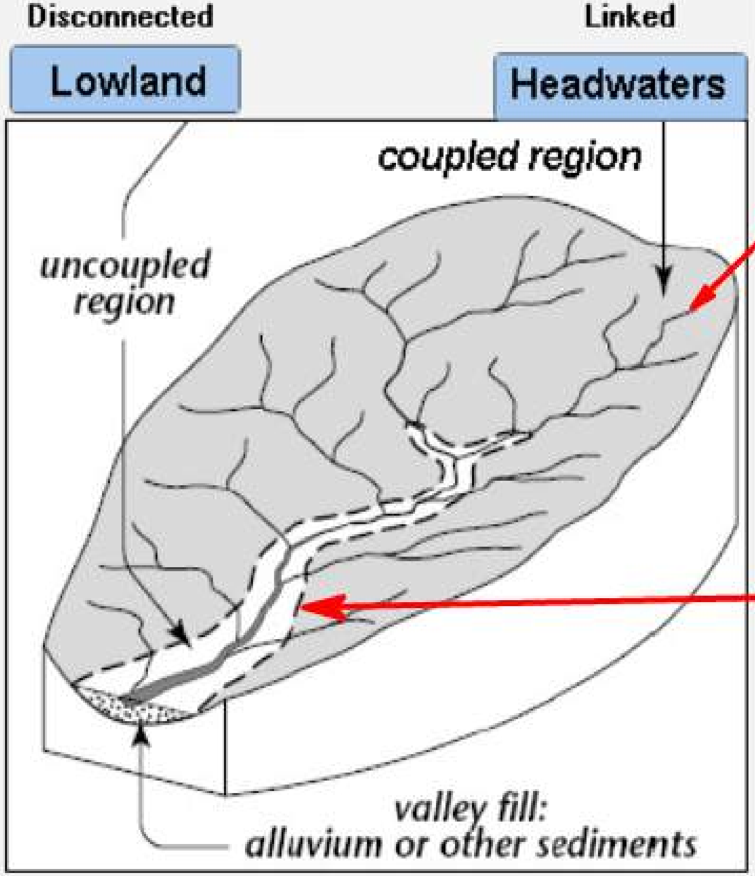
Rainwater Harvesting

Protecting Water Sources in Rivers

1. Delineating the Water Sources in a Watershed

Rivers & Streams

Land-Water Processes



Source: Church 2007

Processes are different between Headwaters & Lowlands

In the Headwaters Runoff and Subsurface Flow is Linked directly to the River

Example: Sediment Input and Transport is by Surface Erosion during storm events

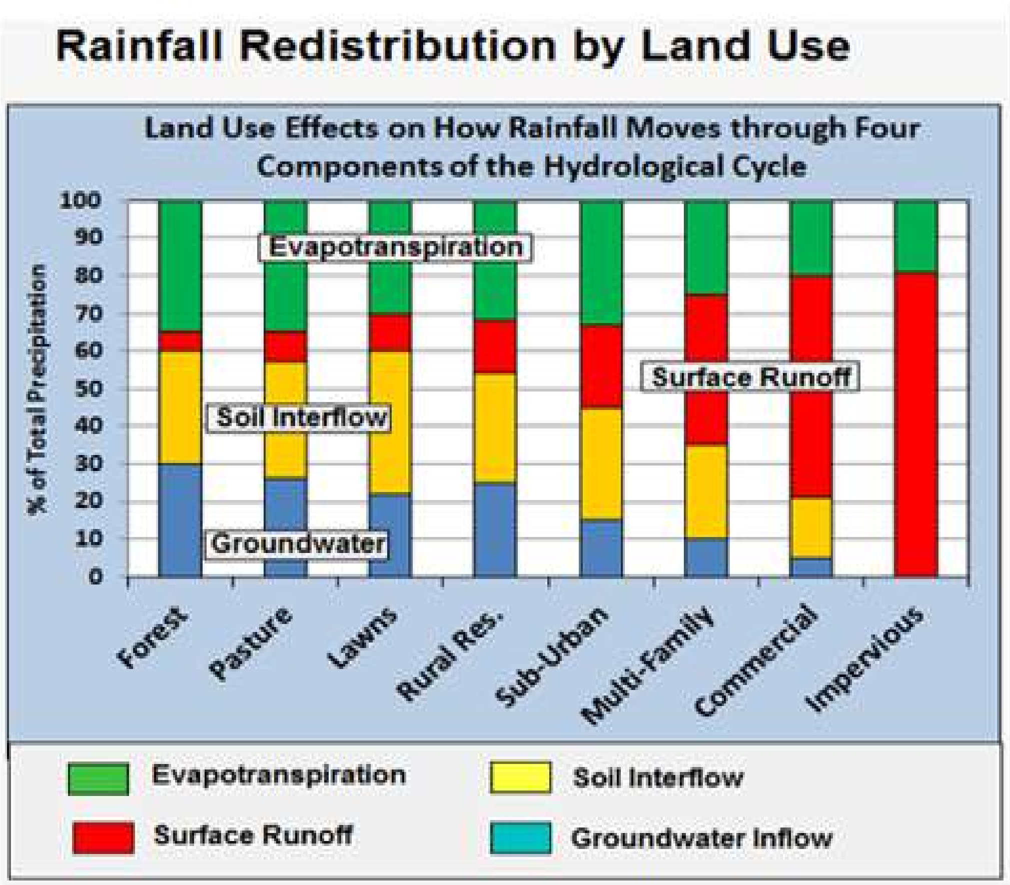
In the Lowland Surface Runoff into stream is less prominent (unless extensive drainage systems are in place)

Example: Sediment Transport is primarily by resuspension within the Floodplain and Bank Erosion

Water Source Inventory in Headwaters

Surface Runoff From Rain Snow and Ice	In Forested Headwaters Runoff from rain is usually small and primarily during peak storm events when rainfall intensity exceeds infitration rates.
Subsurface Flow in Soils	Water flows primarily through prefered pathways within the soil and enters the stream along the river channel
Groundwater Flow Contribution	Aquifers contribute to streamflow when surfical materials and geological stuctures are adjacent to the stream

In addition to the soil & geological conditions the land use in the headwaters affects the processes in the hydrological cycle as shown below



2. Identify Pollution Sources

Point and Non-Point Sources

	Sources	Main Contaminants	Origin & Pathways
Human Activities	Agriculture	Nutrients, Sediments, Pesticides, Organics, Pathogens	Excess Field Applications and Release Through Irrigation, Drainage and Surface Erosion
	Urbanization	Nutrients, Sediments, Metals, Pharmaceuticals, Organics, Pathogens, Petro-Chemicals	Stormwater Runoff from Impervious Surfaces, Wastewater Release, Spills, Solid Waste Management, Atmospheric Inputs,
	Forestry	Sediments, Nutrients, Organics	Soil Disturbance by Harvesting & Afforestation, Road Construction & Maintenance, Fire Disturbance, Pest Control
	Mining	Sediments, Metals, Organics	Metal Release from Extraction Processes, Tailing Ponds, In-Situ Leaching, Washing & Sorting, Acid Mine Drainage,
	Recreation	Pathogens,Sediments	Swimming, Pool Cleaning, Boat Activities Releasing Hydrocarbons, Chemical Use in Snow Making, Off-Road Vehicle Use
Natural Processes	Natural	Metals from Geological Sources As, Cu, Zn etc, Organics	Natural Acid Mine Drainage, Hotsprings, Drainage from Volcanic Rocks & Hydrothemal deposits, Sediment Releases after Major Storm Events or Earthquakes, Plant Organic Matter

The Focus should be on Chemical, Physical and Biological Contaminants

Examples of Contamination of Concern from Human Activities

Nutrients

Manure
Fertilizer
Human &
Livestock Waste
Air Pollution

Nitrate
Phosphate

Pathogens

Human Waste
Livesock Waste
Wildlife
Recreation

Giardia
Cryptosoridium
E. coli
Campylobacter

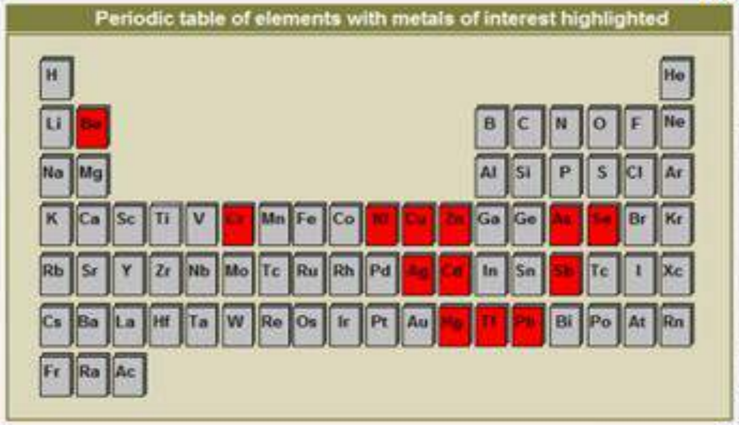
Sediments

Sediments from Land Use
Activities & Fires

Turbidity
Color
Fe, Mn

Metals

Road Transport Zn & Cu



Hydrocarbons & Organics

Hydrocarbon
Long Distance
Transport by Air

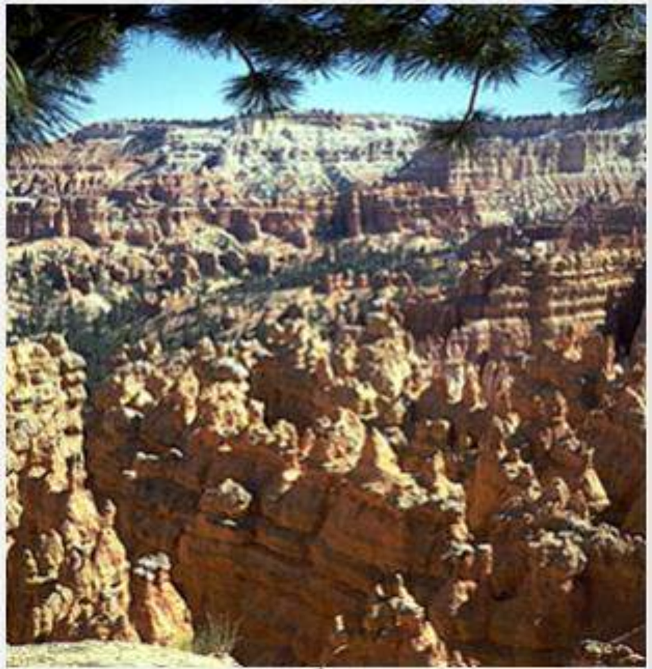
Chloninated Organics
Pesticides
Exotic Chemicals

Natural Processes Influencing Source Water

Influence of Bedrock on Water Quality

Igneous Rocks

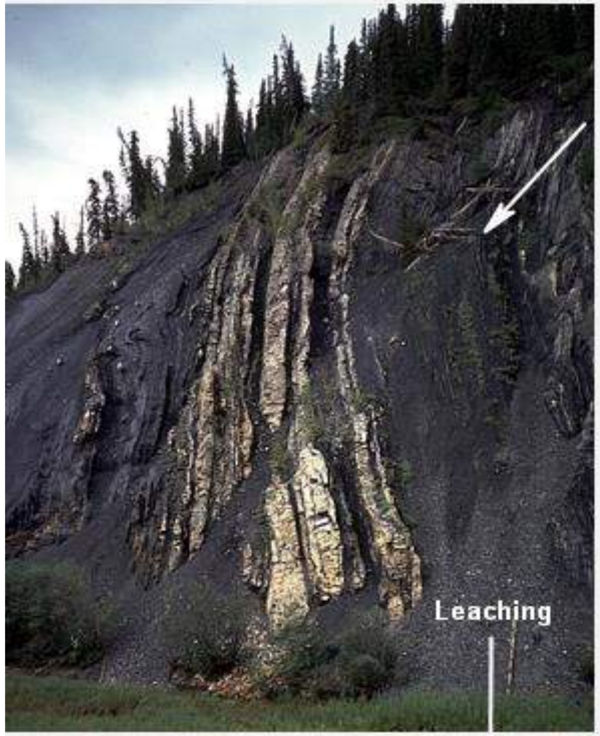
Granite (light Color)	Soft Water, Slightly Acidic, Low Nutrient Content
Volcanic (dark Color)	High in Nutrients and Cations, Variable pH



Limestone

Sedimentary Rocks

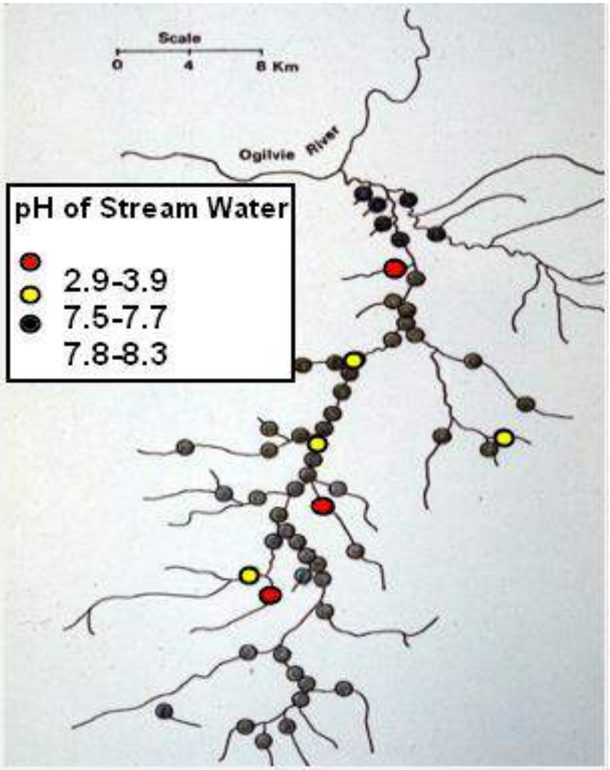
Sandstone	Soft Water, Slightly Acidic, Low Nutrient Content
Shale	Variable pH, High Nutrients, High Buffer and Exchange Capacity
Limestone	Hard Water, Alkaline, High Ca, Mg-Carbonate, High Buffer Capacity



Black Shale
Contains Pyrite (FeS)

Oxidizes into H_2SO_4
when exposed to Air

Spatial Distribution
of Streamwater pH



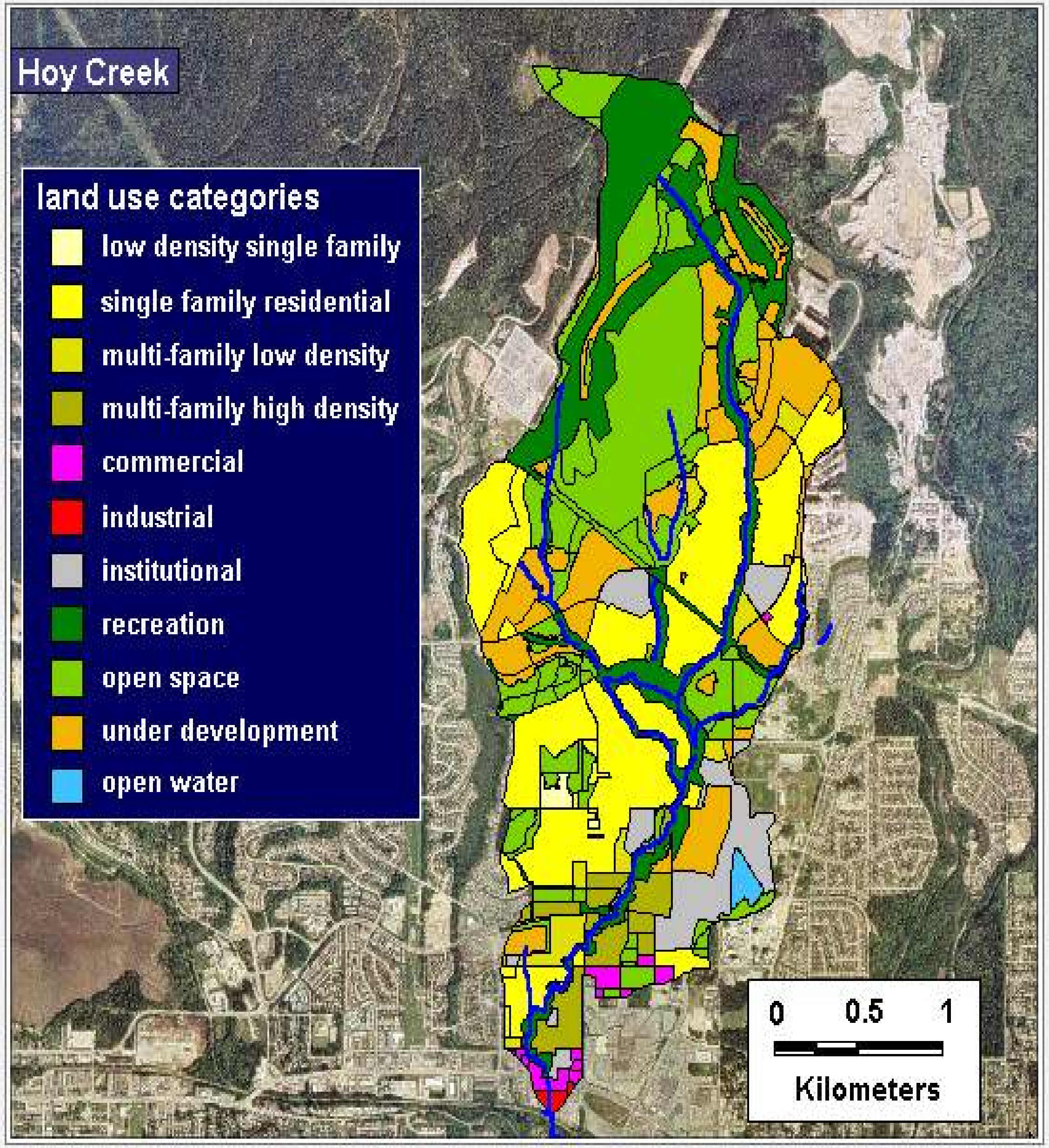
Limestone in
Adjacent Mountains

Chemical Interactions


Capilano Watershed
Seymour Watershed
Coquitlam Watershed
Lower Seymour Conservation Reserve
Metro Vancouver Watersheds
metro vancouver

Conduct an Inventory of Pollution Sources in the Watershed

- Requires Land Use Mapping of the Watershed with a focus on the Type of Land Use and Intensity of Use
- Differentiate between Point and Non-Point Sources
- Produce a Digital Elevation Model of the Watershed
- Incorporated into a Geographic Information System (GIS)



3. Determine Suspetibility and Vulnerability

Requires good understanding of surfical materials
Water Flow passways to the stream
Activities in Proximity to the stream channel
Chemical input to the land

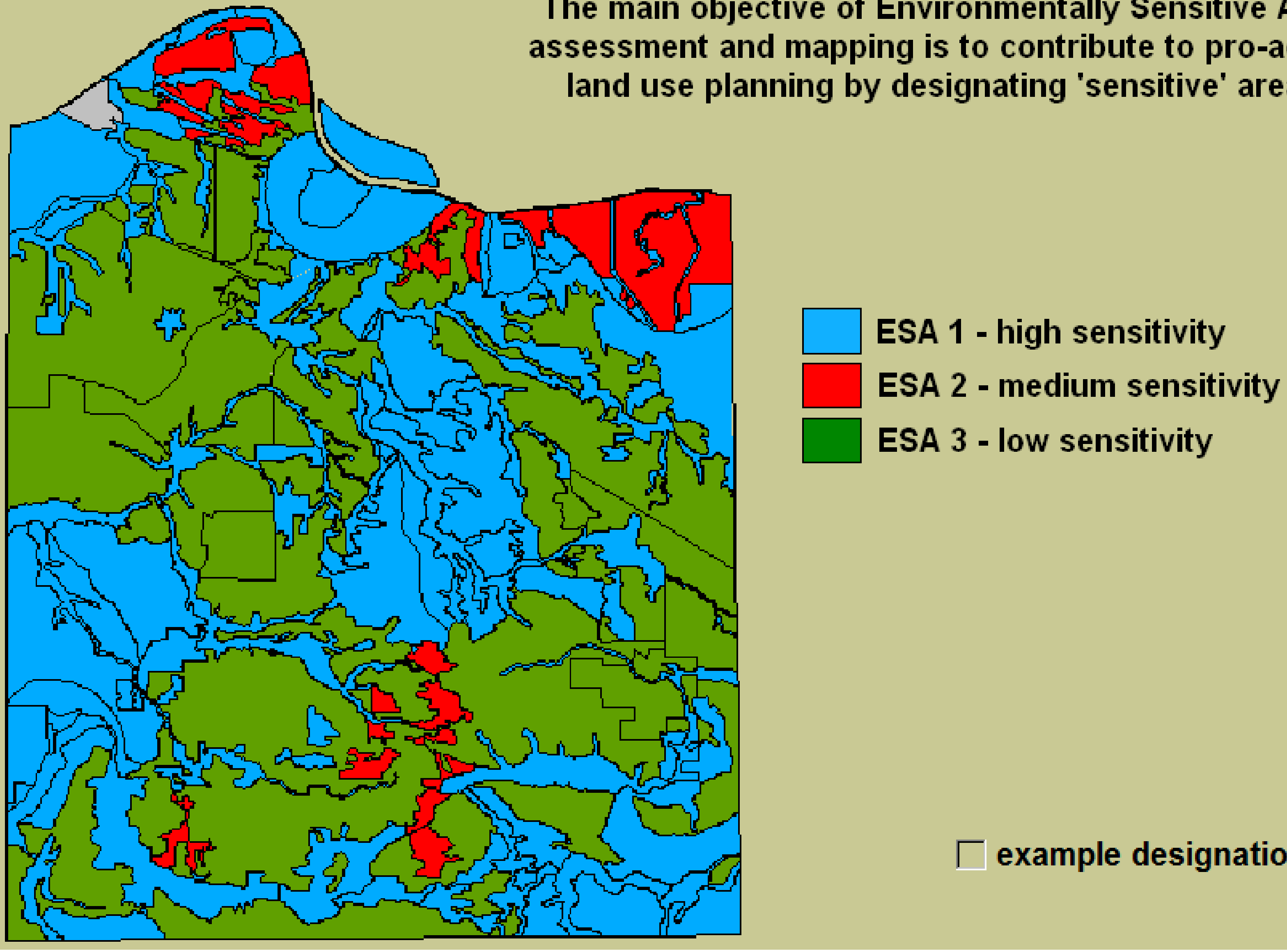
Determine Environmentally Sensitive Areas (ESA)

ABC Method:

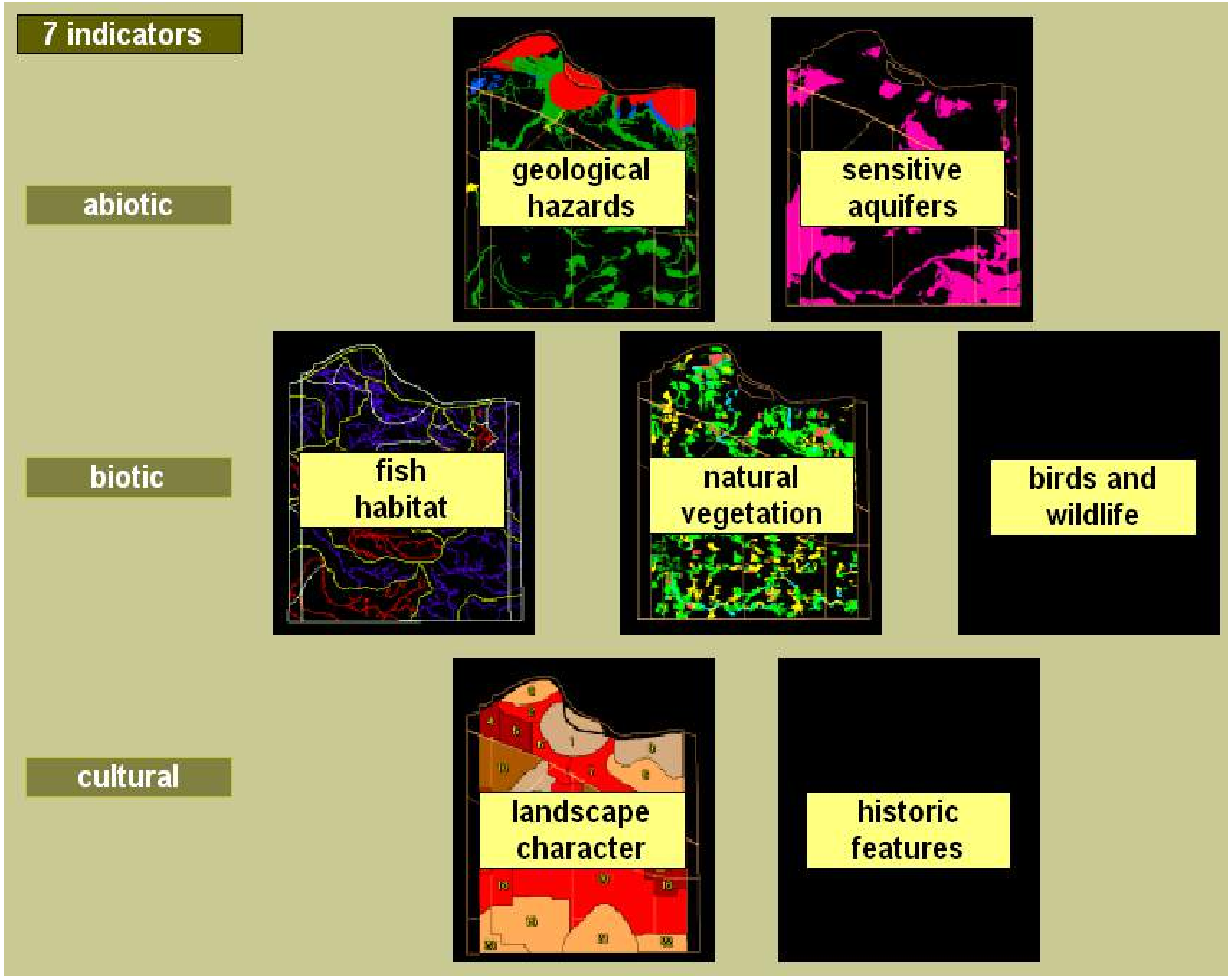
Incorporates: Abiotic, Biotic & Cultural Factors

Role of ESA

The main objective of Environmentally Sensitive Area assessment and mapping is to contribute to pro-active land use planning by designating 'sensitive' areas



example designations


7 indicators
abiotic
biotic
cultural
geological hazards
sensitive aquifers
fish habitat
natural vegetation
birds and wildlife
landscape character
historic features

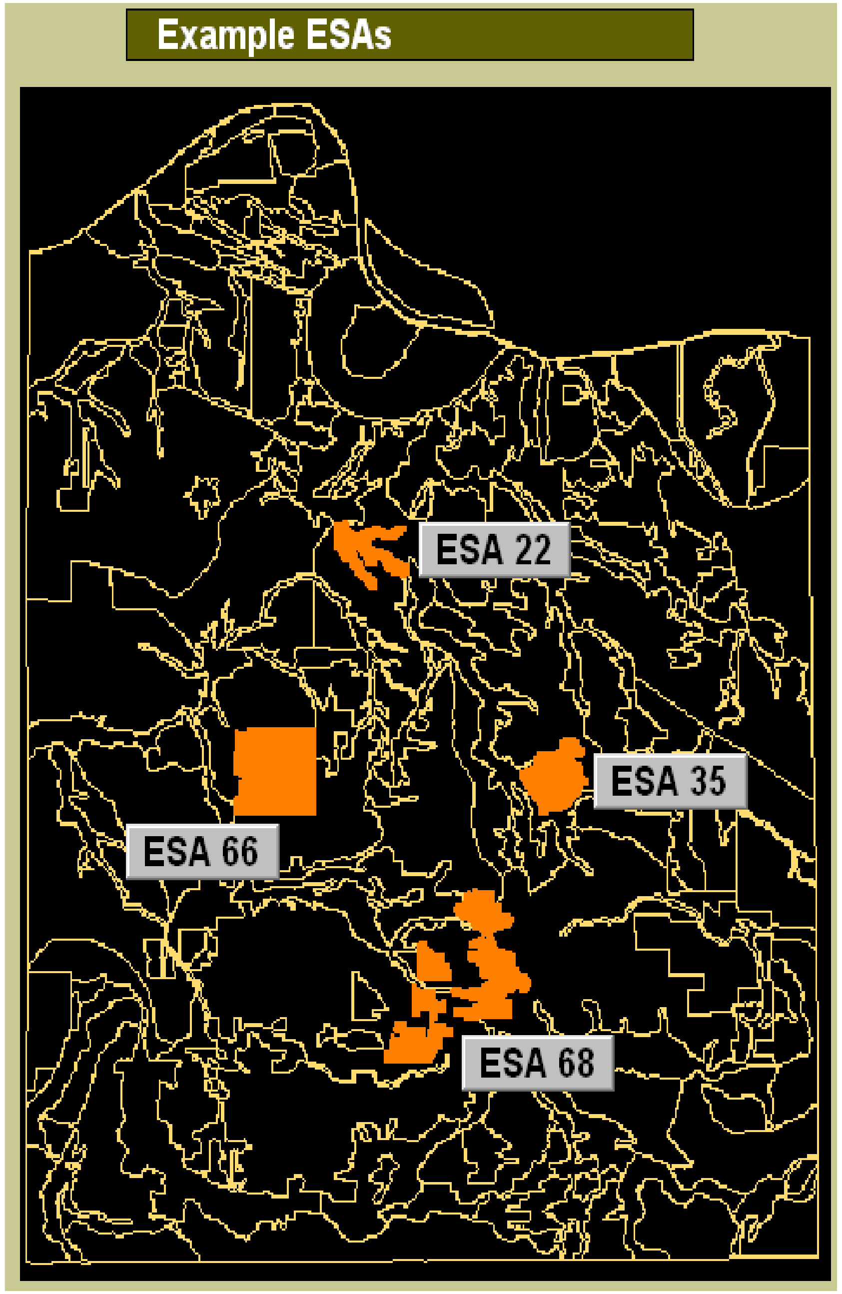
Applying criteria

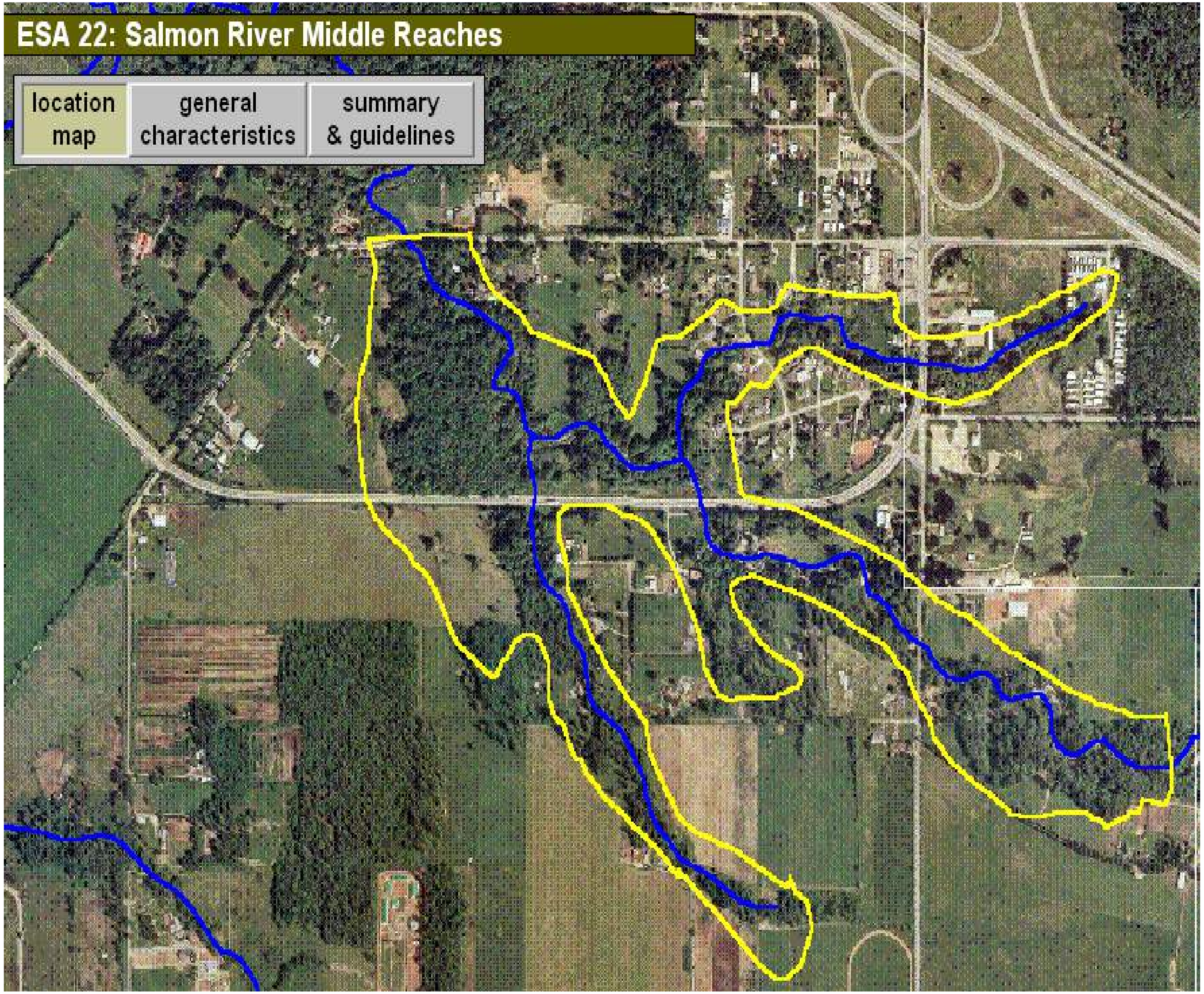
one of these 3 criteria or 4 or more criteria in total

this criterium or 3 more criteria in total

one or two criteria not highlighted under ESA 1 or 2

	ESA 1	ESA 2	ESA 3
public health	✓		
cultural landscape value			
heritage / historic site			
geological hazards		✓	
rarity of landforms/species	✓		
size			
location (adjacency)			
connectivity (wildlife)			
fragility	✓		
diversity			
representativeness			


Example ESAs
ESA 22
ESA 35
ESA 66
ESA 68


ESA 22: Salmon River Middle Reaches
location map
general characteristics
summary & guidelines

ESA 22: Salmon River Middle Reaches

location map	general characteristics	summary & guidelines

General	ESA desig'n	ESA 1
	type	watercourse, forest
Abiotic	landform	dissected stream system
	surficial	marine
	groundwater	-
	slope	2 - 5% undulating to 30 - 60% hilly
	size	70.5 ha
Biotic	vegetation	mixed forest; riparian
	birds	birds of prey - high, songbirds - high
	fish	salmonids = 3, other = 2, total = 5 habitat for salmonid spawning and rearing
Cultural	land use	stream system
	visual zone	06 - Upland Rural Residential Zone 12 - Nickomekl Headwaters
Criteria fulfilled	fragility	permanent watercourse
	fragility	erosion along watercourse

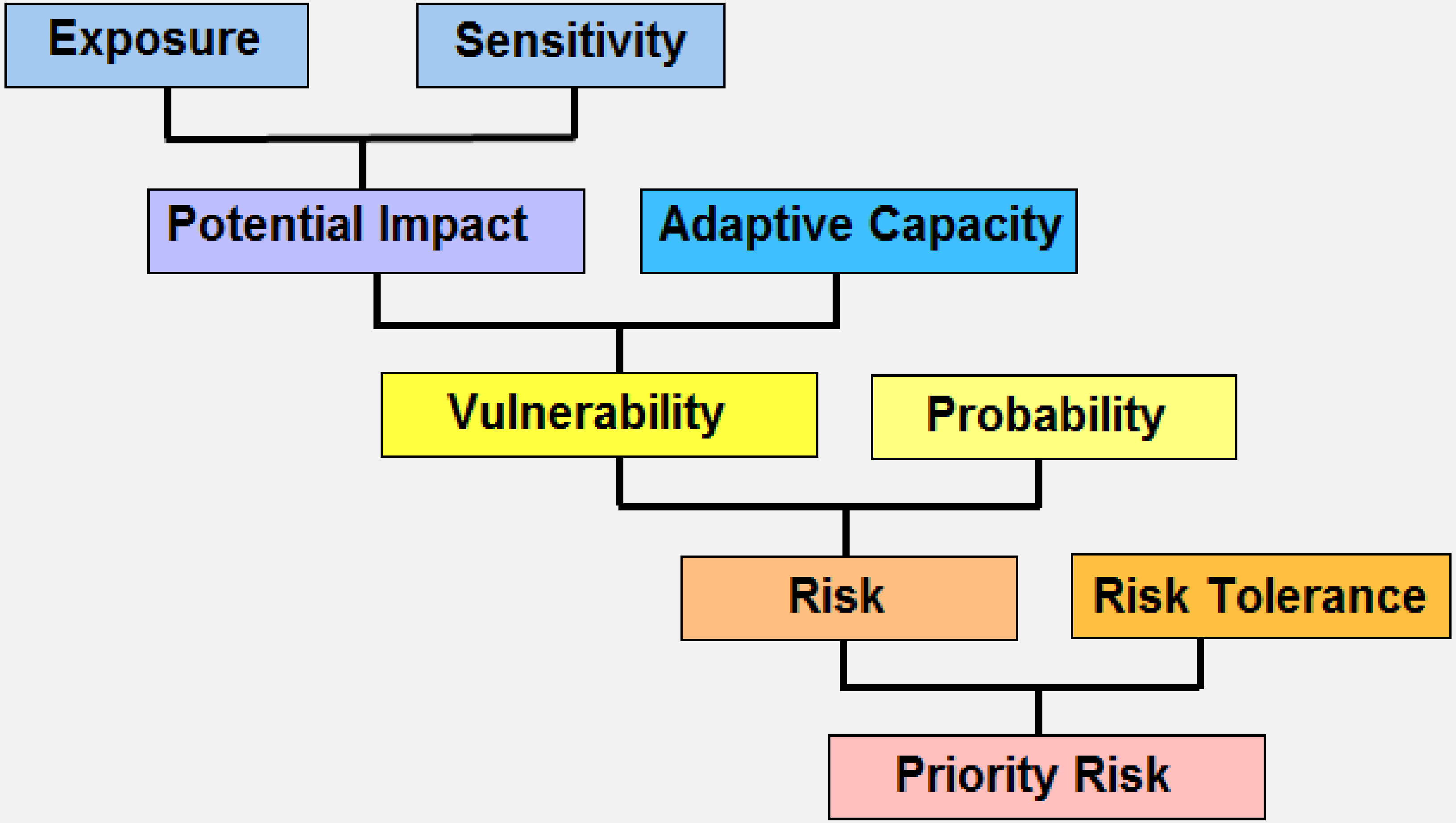
ESA 22: Salmon River Middle Reaches

location map	general characteristics	summary & guidelines

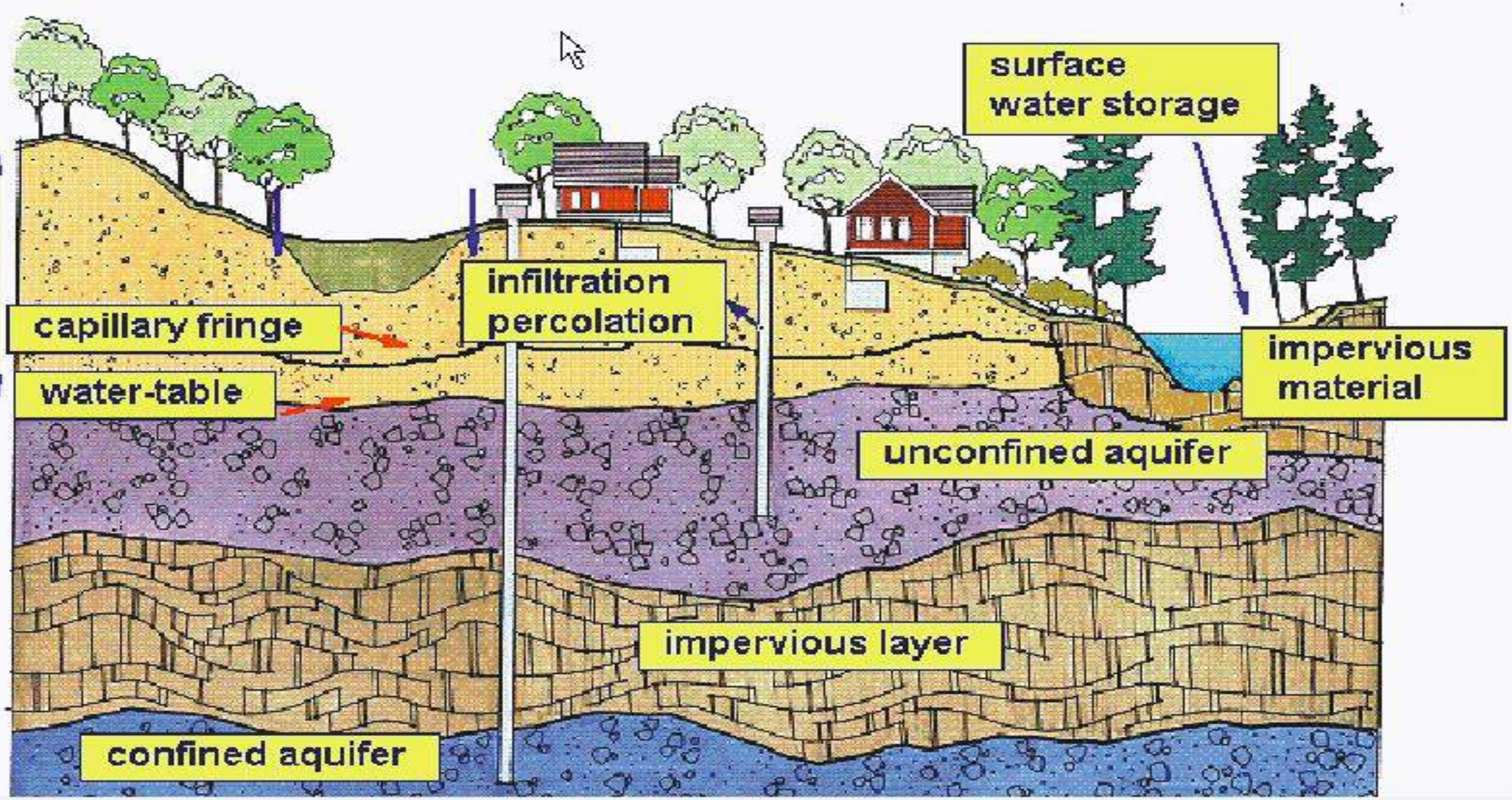
Summary	The middle reaches of the Salmon River include the mainstem and associated tributaries from 72 Avenue to approximately 236 St, flows over marine deposits and the vegetation adjacent to the river is primarily mixed forest. The diversity of songbirds and birds of prey is estimated to be very high. The land use surrounding this section is mostly agriculture with some rural residences. The river provides excellent spawning and rearing habitat for salmonids. A few non-salmonid fishes reside in mainstem and tributaries.	
Management guidelines	watercourse	maintain a leavestrip of natural vegetation (30 m in high density urban, otherwise 100 m) from the top of the slope break of a permanent watercourse
		maintain a leavestrip of natural vegetation on either side of the intermittent watercourses
		restrict access by livestock to watercourse to provent nutrient additions, distrubance of bank and vegetation and siltation of the watercourse
		restrict residential development adjacent to watercourse to protect high value salmonid spawning/rearing habitat
	fish habitat	protect riparian habitat (i.e. streamside vegetation)
		remove or reduce the detrimental effects of barriers to fish migration (i.e culverts, pumping station)

Protecting Water Sources in Rivers

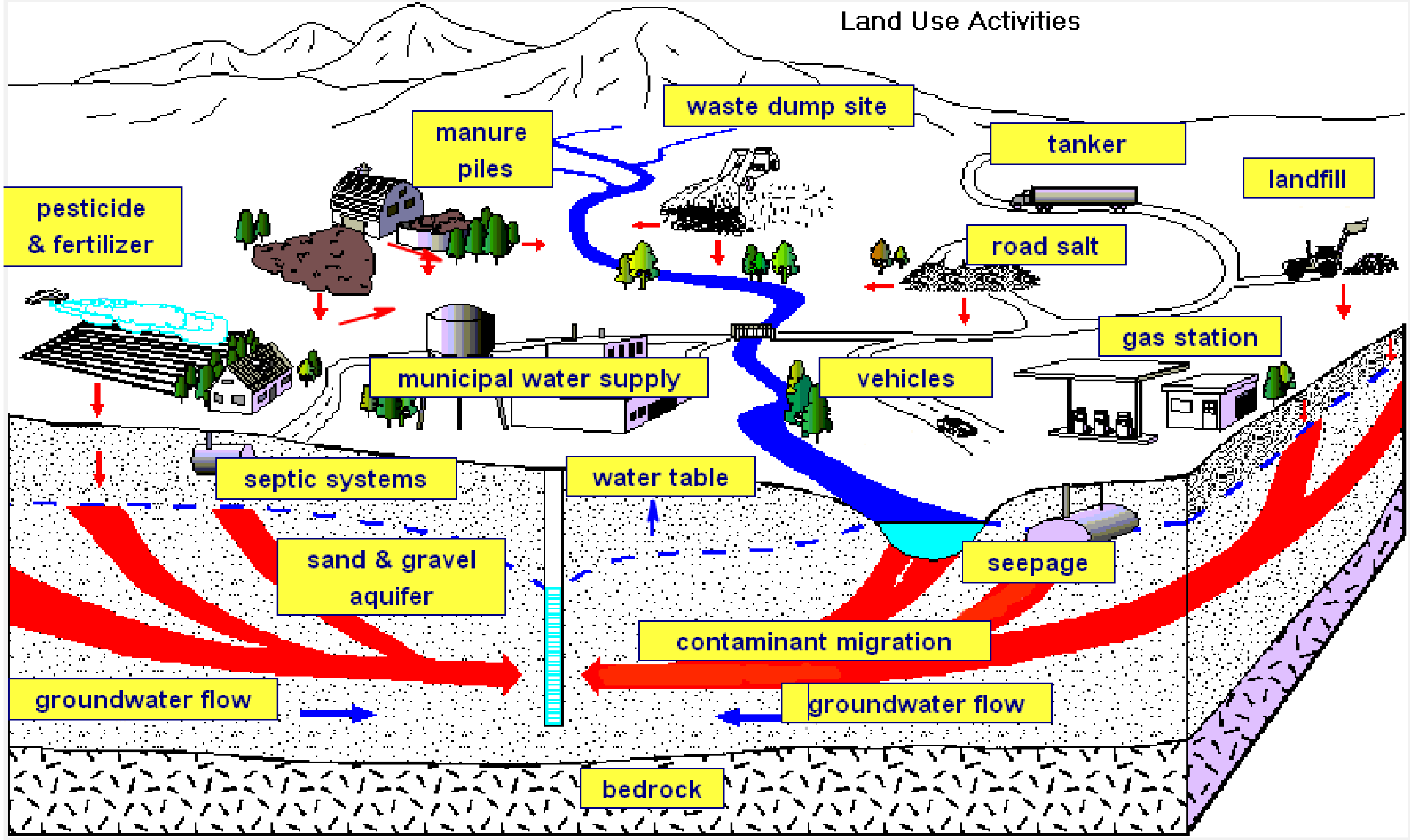
4. Prioritize Risks

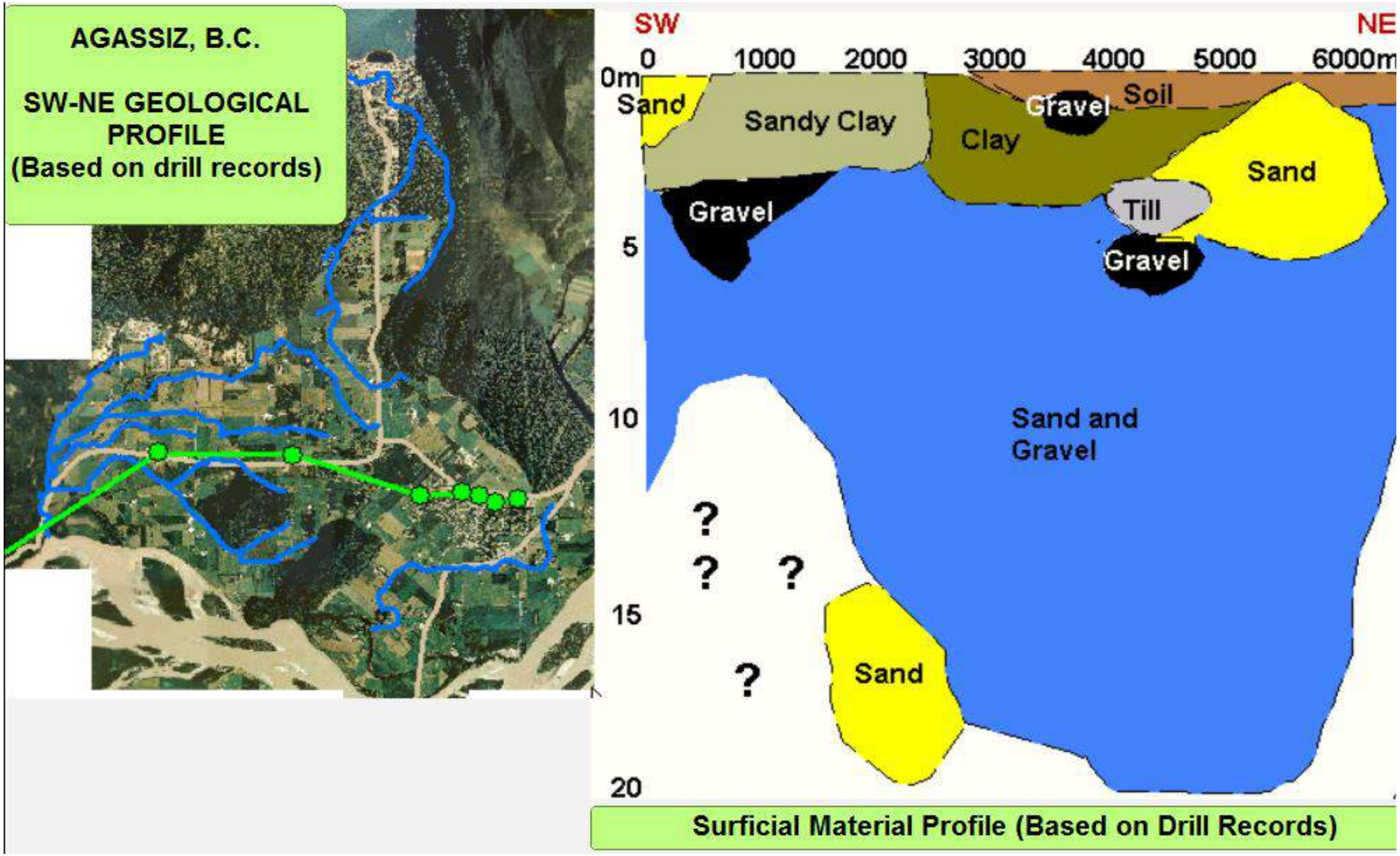


Groundwater Aquifer Management is more Difficult than Surface Water Management

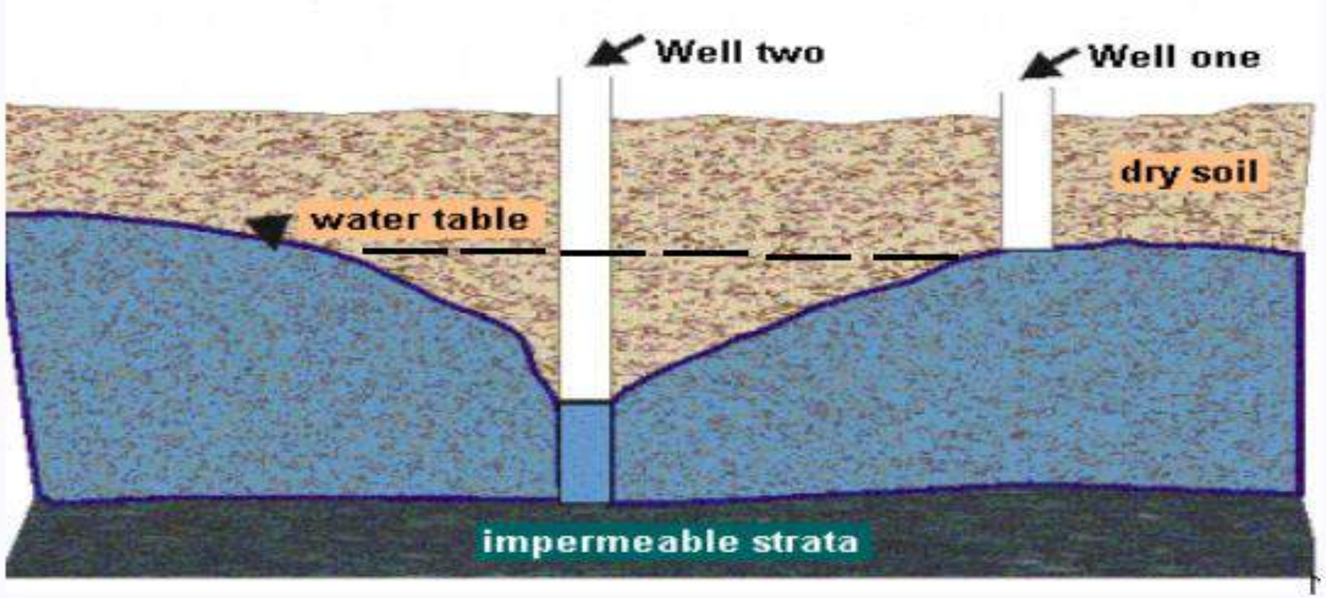


Source Water Protection - Groundwater

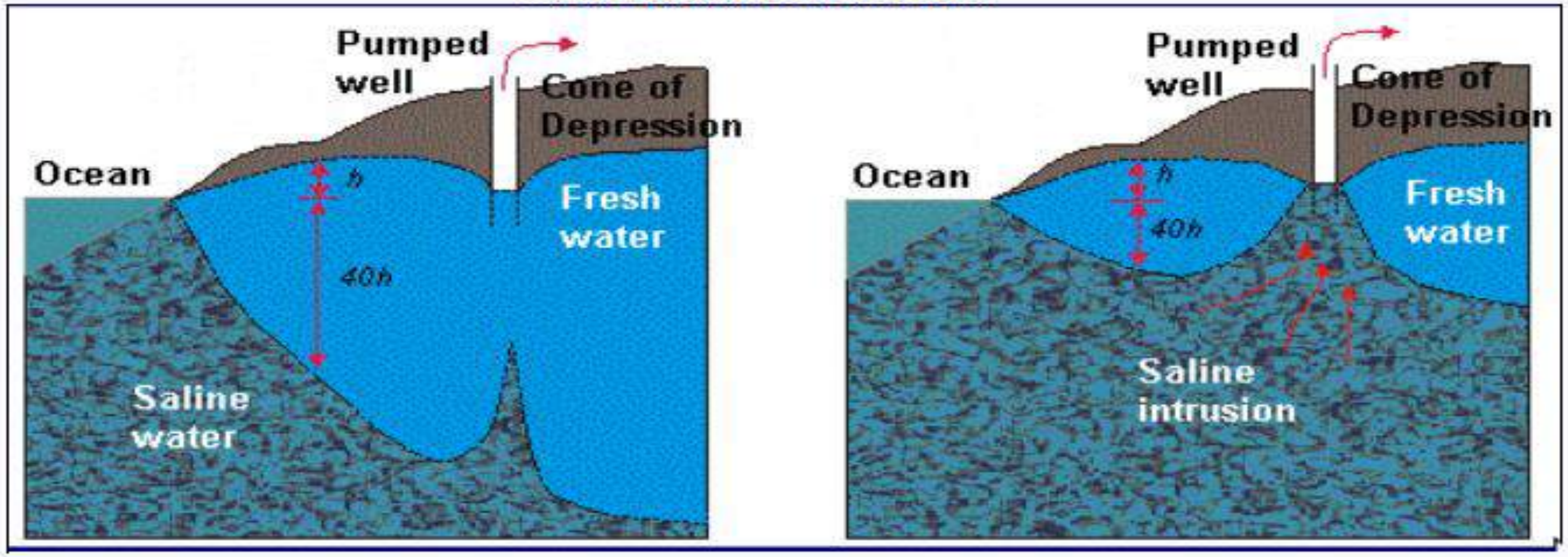


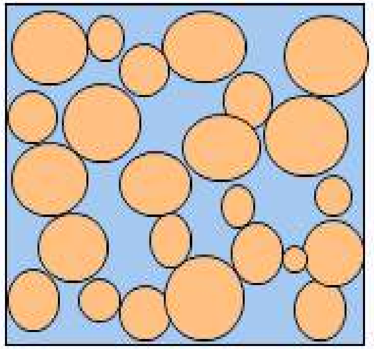

AGASSIZ, B.C.
SW-NE GEOLOGICAL PROFILE
(Based on drill records)
SW
NE
0
1000
2000
3000
4000
5000
6000m
0m
5
10
15
20
Sand
Sandy Clay
Clay
Gravel
Soil
Sand
Till
Gravel
Gravel
Sand and Gravel
?
?
?
?
Sand
Surficial Material Profile (Based on Drill Records)

Pump Test

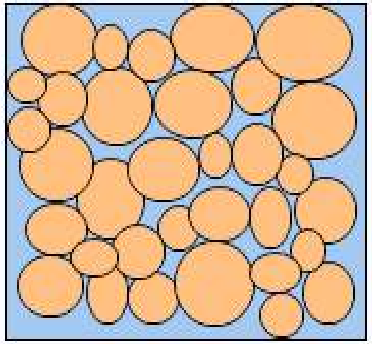


Salt Water Intrusions





Large Pore Space



Small Pore Space

Hydraulic Conductivity = $K = Cd^2 \frac{pg}{u}$

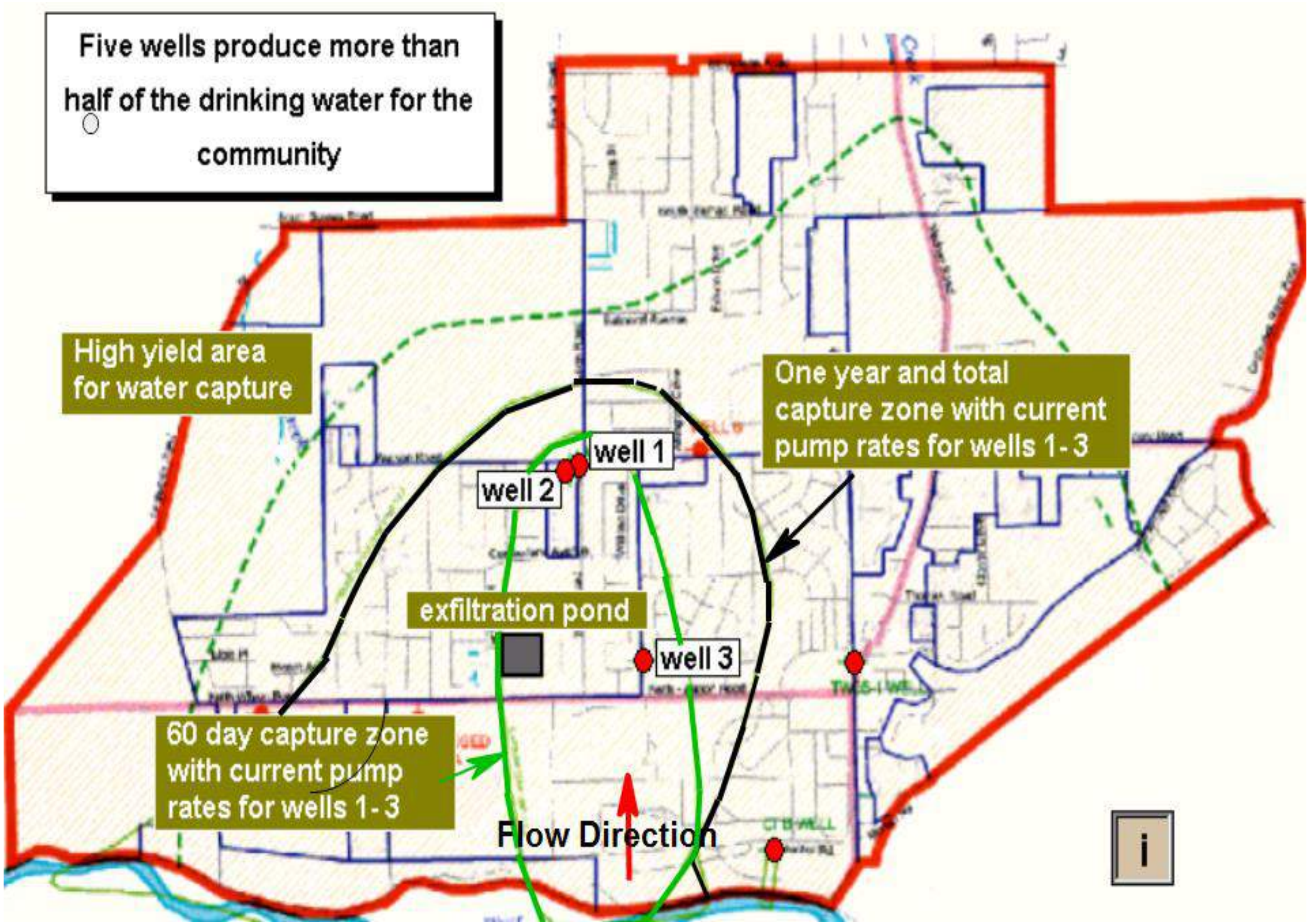
where: permeability = k = Cd^2 (properties of the medium only)

and pg/u (properties of the fluid only)

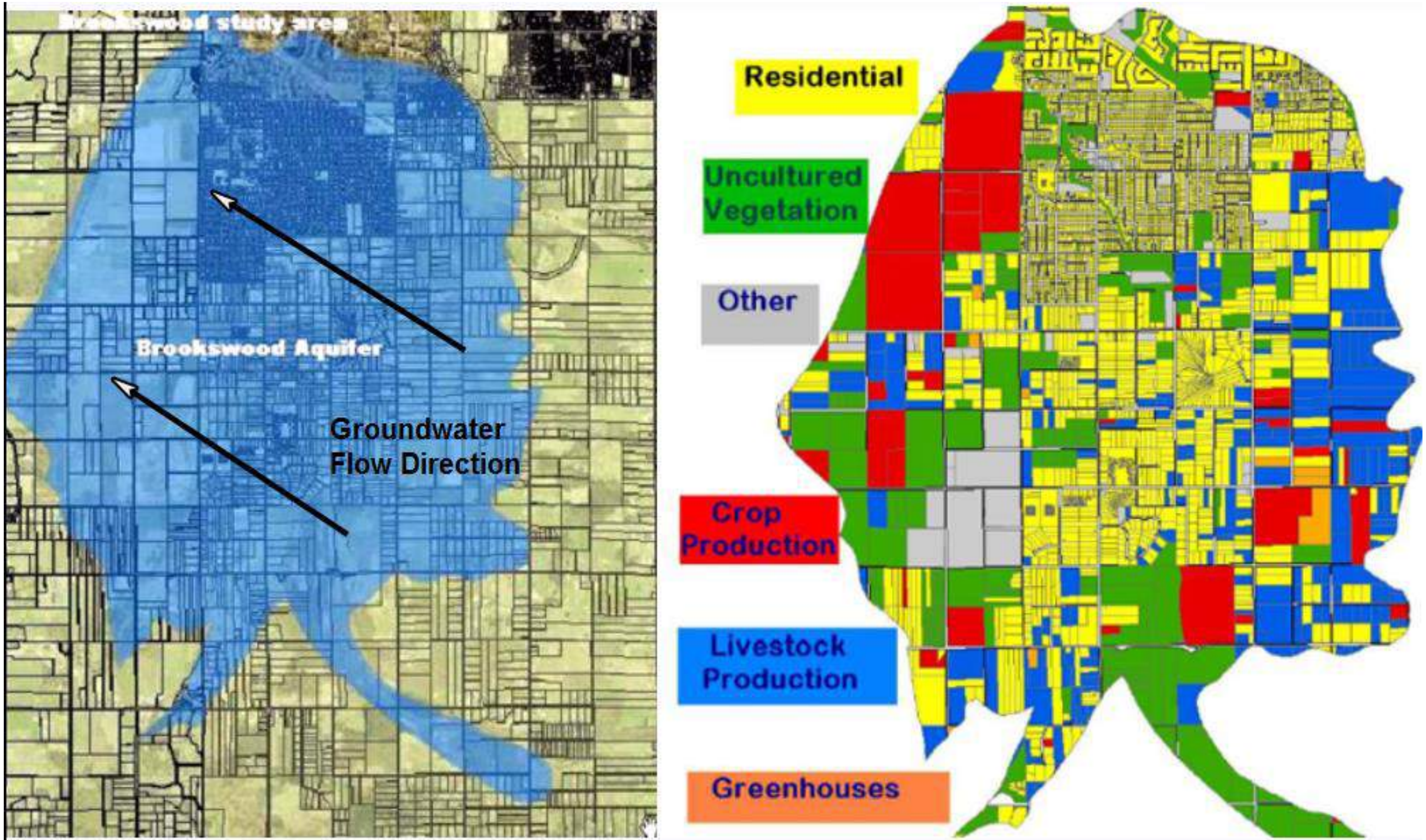
p = density, u = viscosity, g = gravity, d = average grain size, C = constant of proportionality that represents the effects of the porous medium upon the flux.

Conductivity changes with fluid, temperature, and density (salt water). Thereby when we are interested in studying fluids other than water, flow through a medium we have to talk about Conductivty rather than Permeability.

Material	Hydraulic Conductivity, K (m/s)
Gravel	10^{-1} to 1
Clean Sand	10^{-3} to 10^{-2}
Silty sand	10^{-5} to 10^{-1}
Glacial till	10^{-10} to 10^{-4}
Unfractured clay	10^{-10} to 10^{-7}
Unfracture igneous rocks	$<10^{-12}$ to 10^{-3}
Fractured igneous rocks	10^{-6} to 10^{-2}
Limestone	10^{-7} to 10^{-3}
Karst limestone	10^{-4} to 1



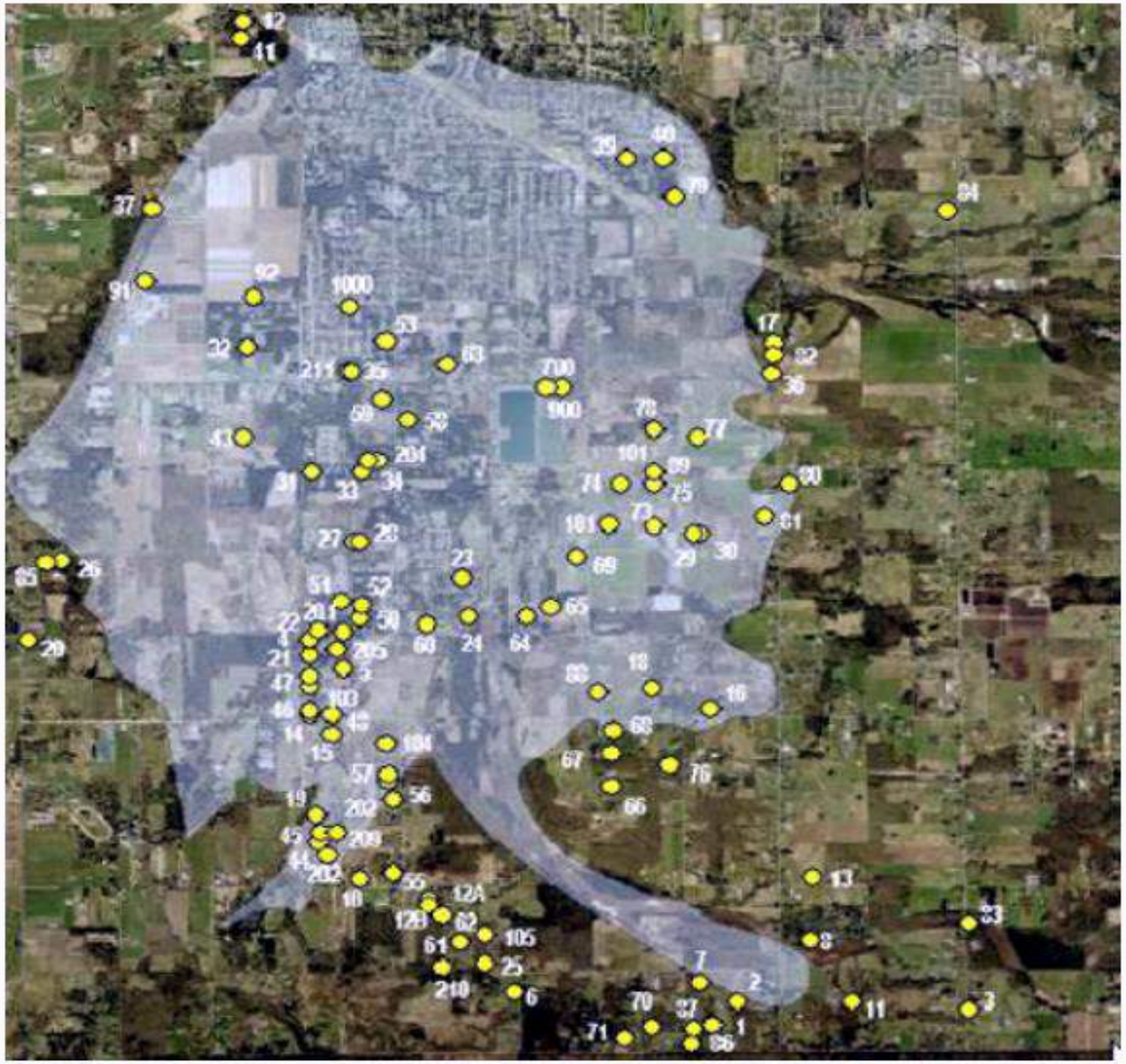
Five wells produce more than half of the drinking water for the community
High yield area for water capture
One year and total capture zone with current pump rates for wells 1- 3
well 1
well 2
well 3
exfiltration pond
60 day capture zone with current pump rates for wells 1- 3
Flow Direction
i



**Brookswood Aquifer:
Flow Direction and Land Use**

Brookswood Aquifer

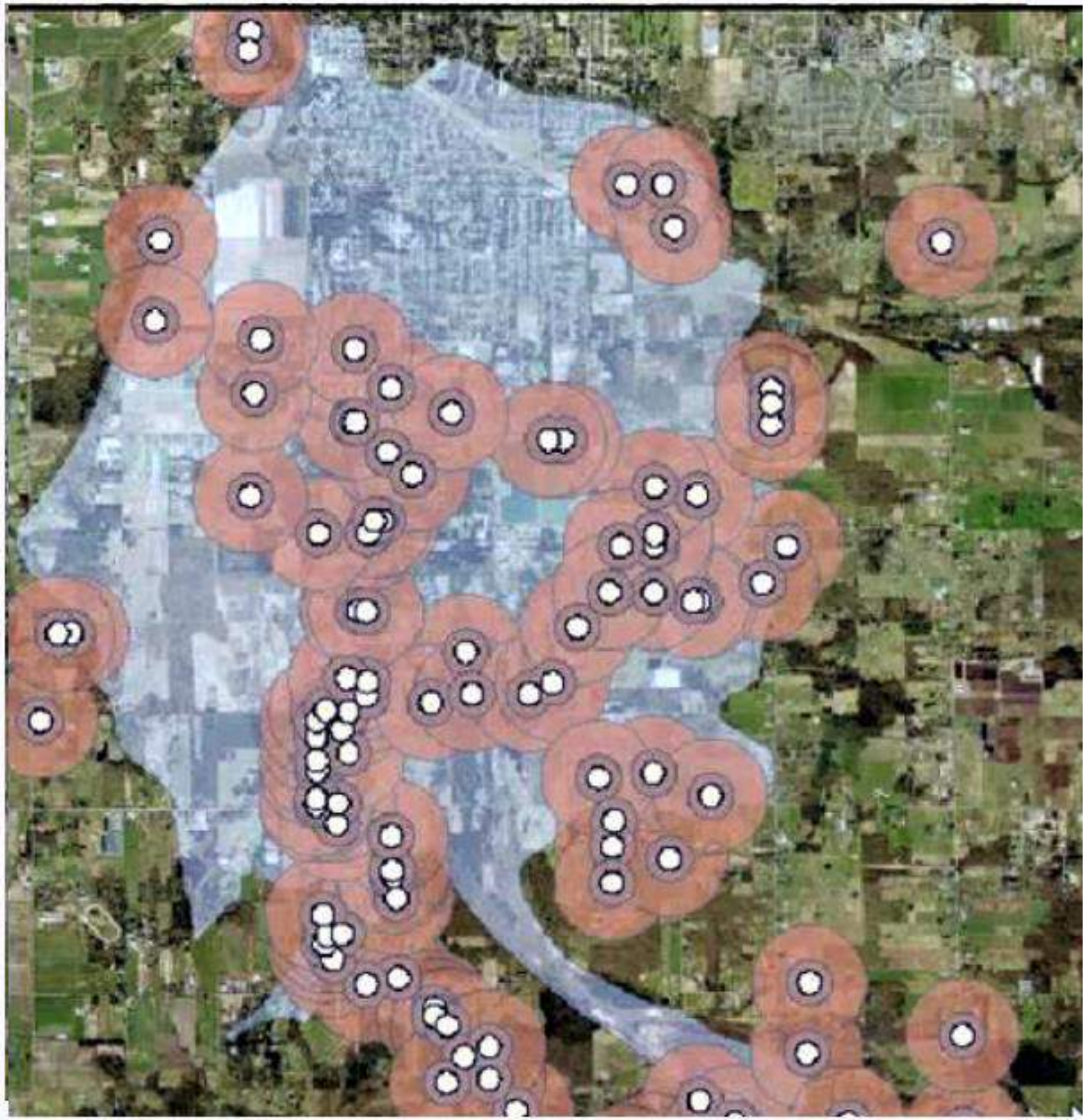
Well Water Sampling Stations



Wells
Buffer
Fan Buffer

Brookswood Aquifer

Buffer Zone Around Wells 100, 200, & 500 m



Wells
Buffer
Fan Buffer

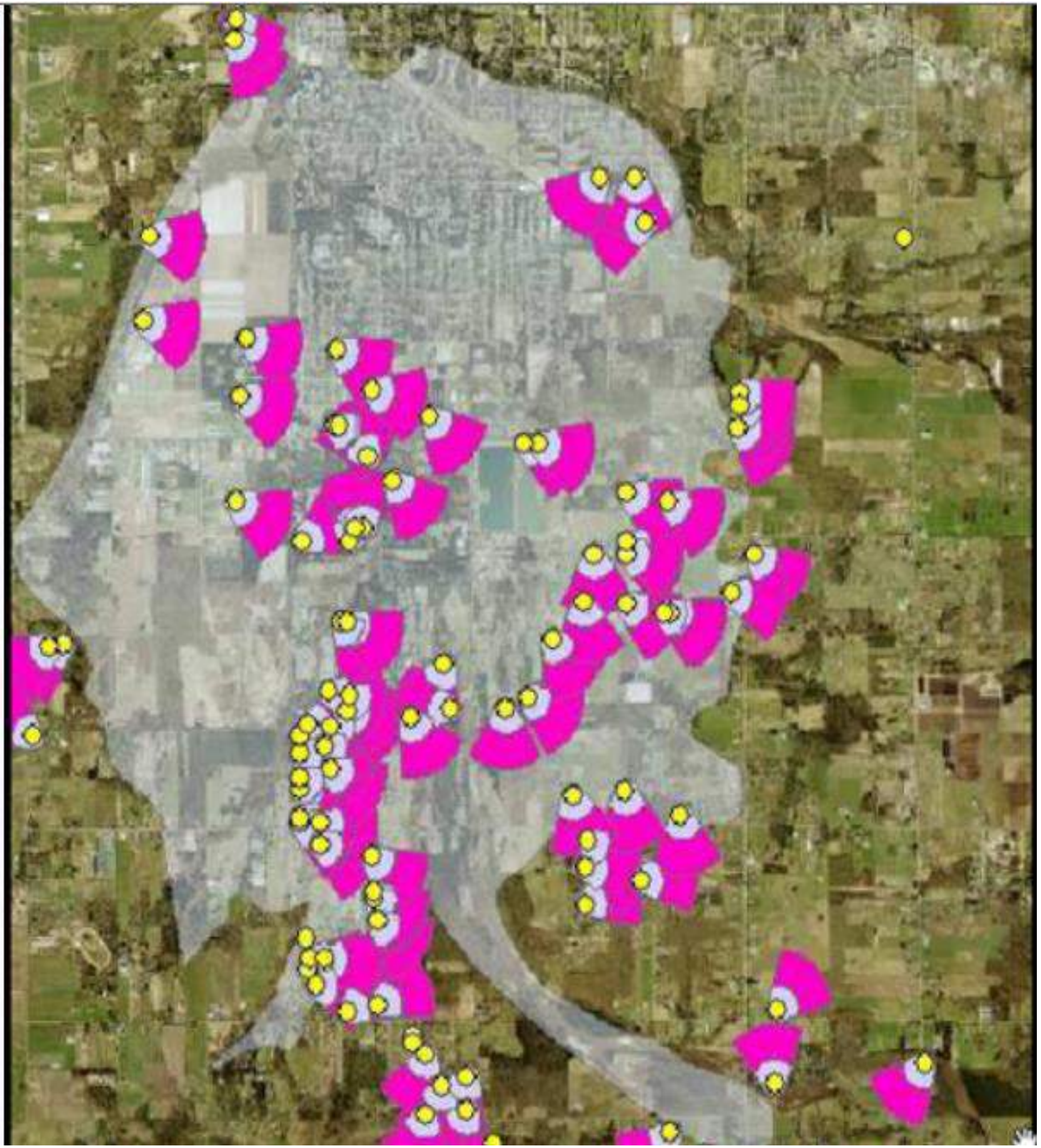
Brookswood Aquifer

Fan Shaped Buffer Zone Around Wells 100, 200 & 500 m (Zone of Greatest Influence)

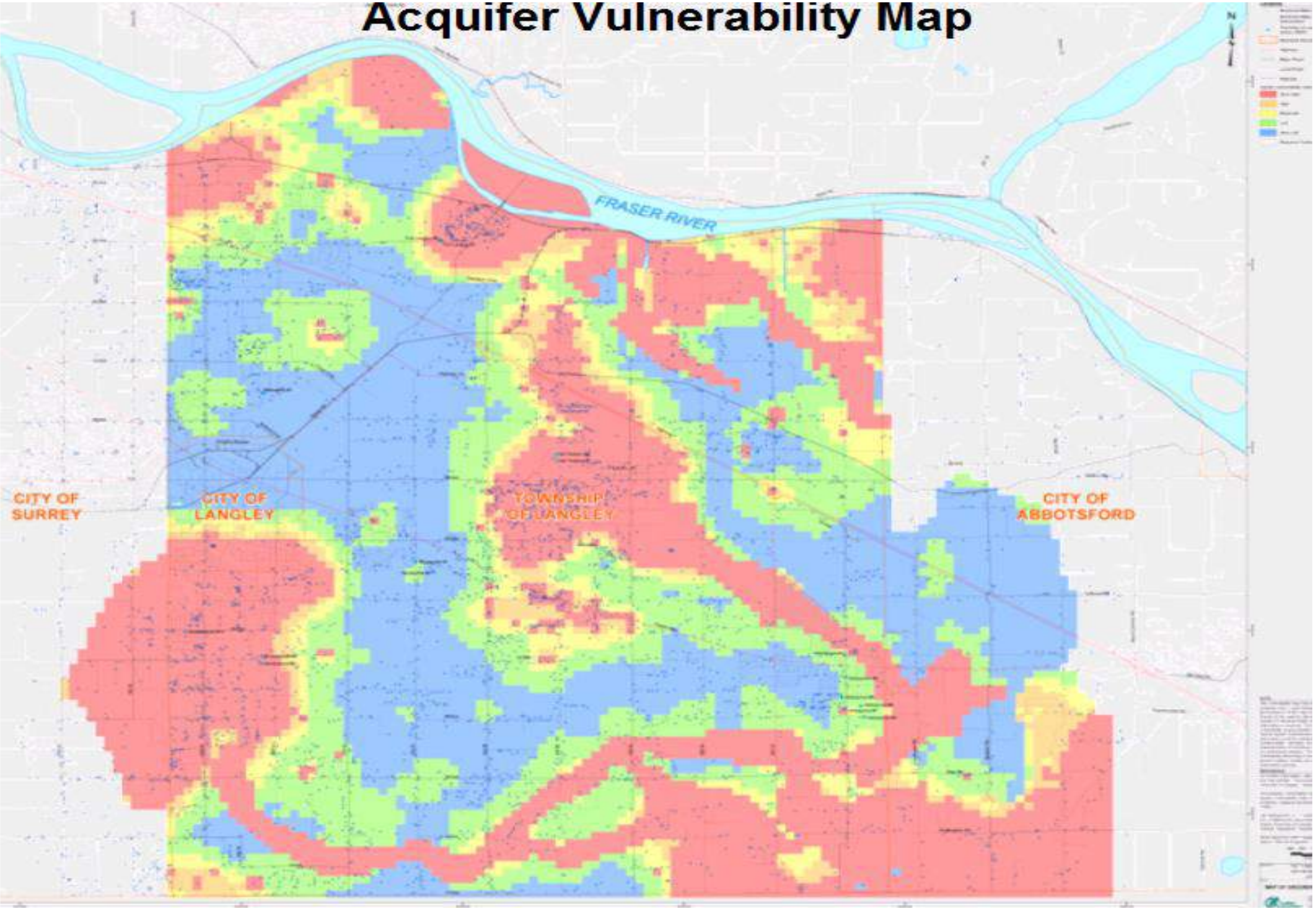
Wells

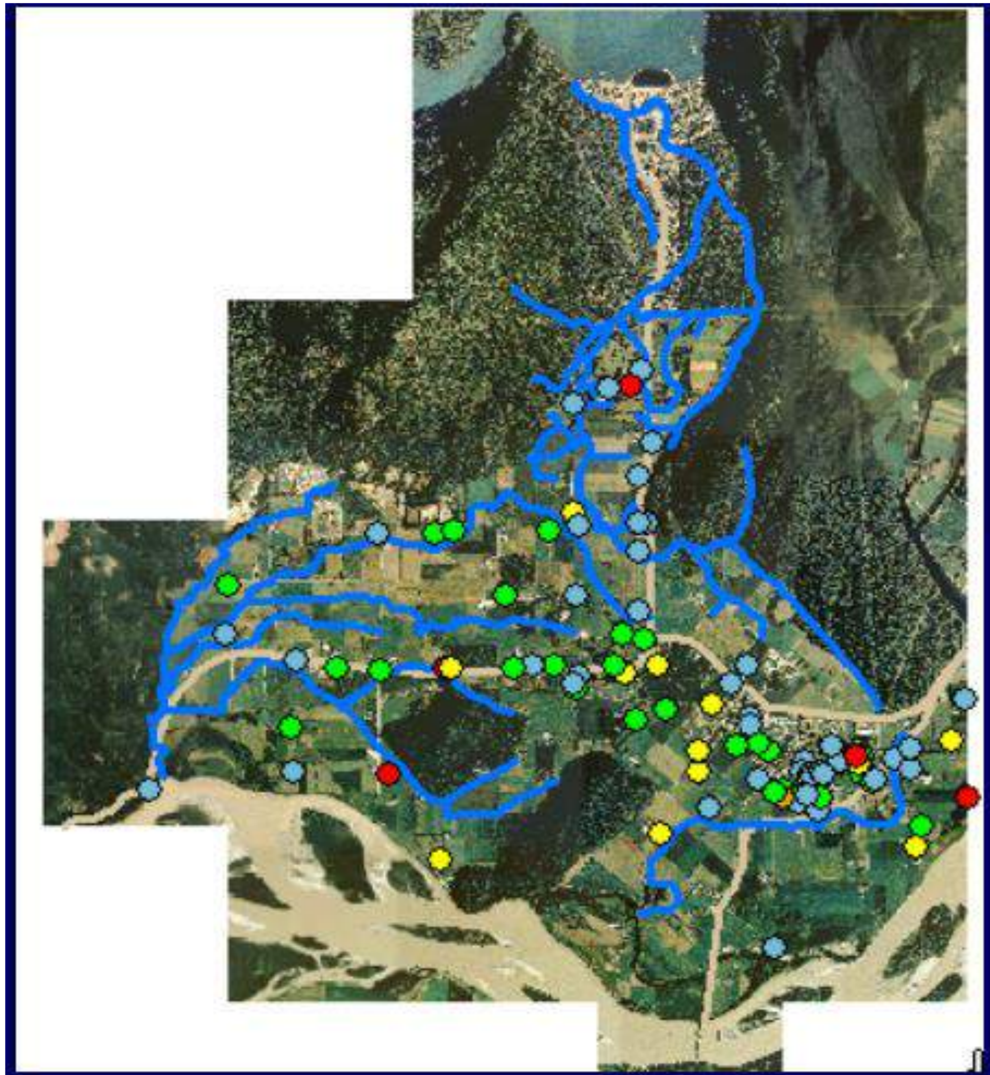
Buffer

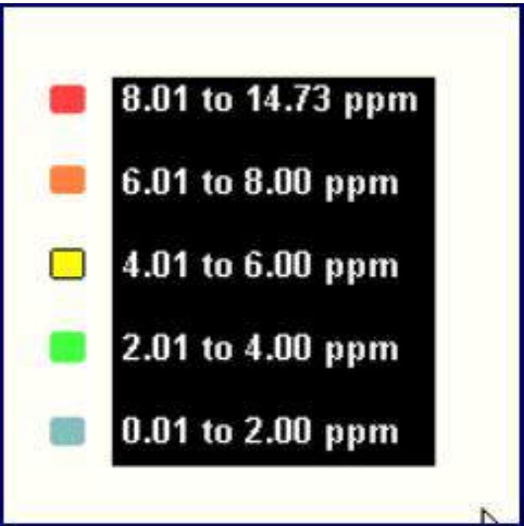
Fan Buffer

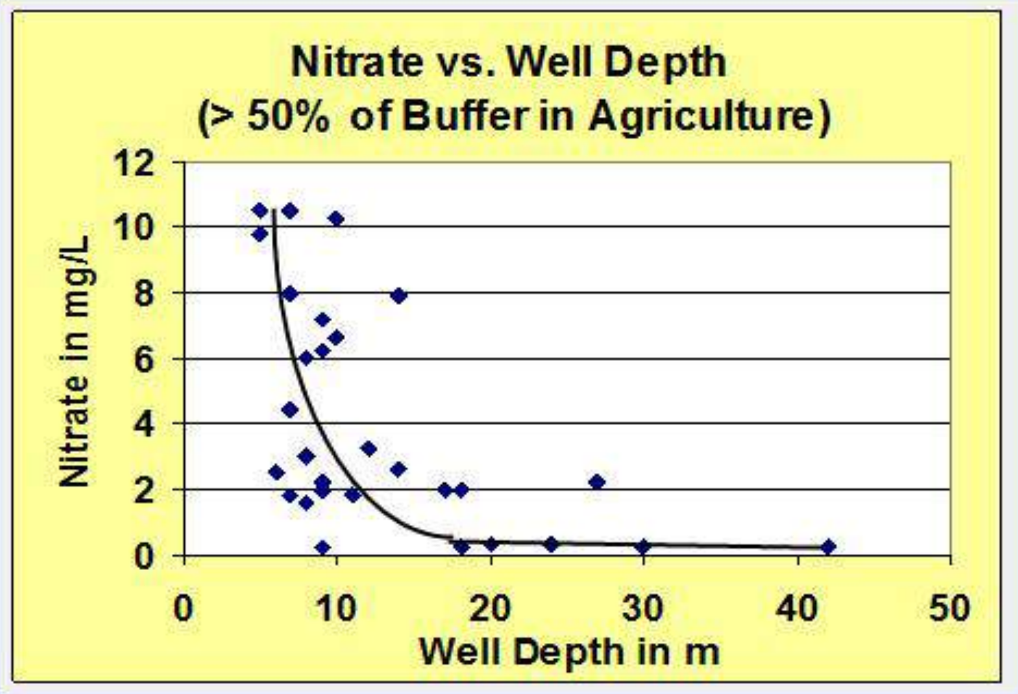


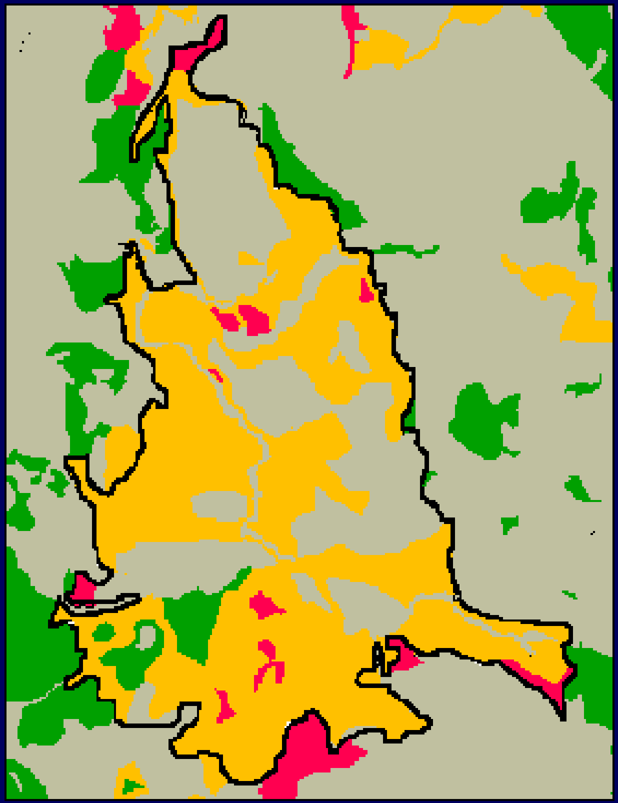
Acquifer Vulnerability Map






8.01 to 14.73 ppm
6.01 to 8.00 ppm
4.01 to 6.00 ppm
2.01 to 4.00 ppm
0.01 to 2.00 ppm

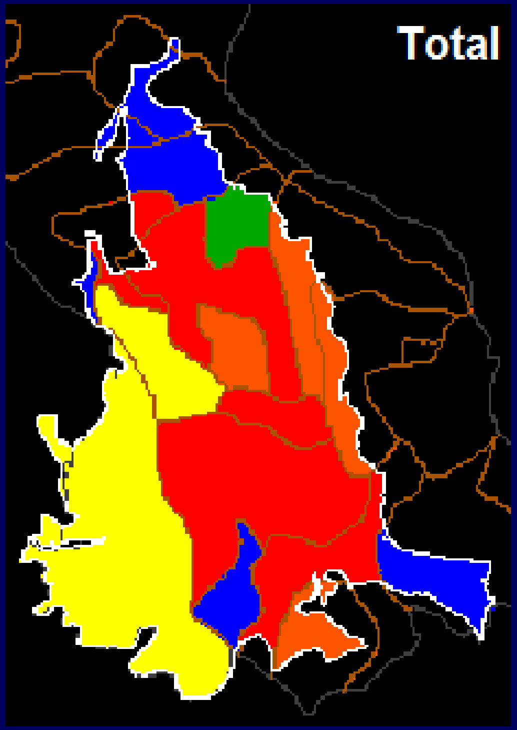

Nitrate vs. Well Depth
(> 50% of Buffer in Agriculture)
Nitrate in mg/L
Well Depth in m
0
2
4
6
8
10
12
0
10
20
30
40
50



- highly permeable
- permeable
- moderately permeable
- low permeability

Nitrogen Surplus/Year

(above what is needed by plants)



kg/ha/year

- 0 - 20
- > 20 - 40
- > 40 - 60
- > 60 - 80
- > 80

Surplus Nitrogen Applied

	Rate in kg/ha/year	Percentage of Surplus
From Hobby Farms	12.2	18.0%
From Commercial farms	33.1	48.8%
From Septic Systems	22.5	33.2%
Overall Total	67.8	100.0%

Protecting Mountain Lakes

Characteristics of Mountain Lakes:

Lakes are primarily oligotrophic (Low nutrient content)
High Biodiversity in Aquatic Organisms
(Many different algal and invertebrate species)
Highly sensitive to nutrient input

What are the Issues about Mountain Lakes?

- Rapid Increases in Temperature
- Airborne Deposition in Dust & Rain
- Changes in Organic Matter Input
- Alterations due to Glacial Retreat

Rapid Increases in Temperature in Mountain Lakes

Temperatures in Mountain Lakes are increasing rapidly

According to Hampton et al. 2016, Mountain Lakes Around the World are increasing more rapidly than Air, Ocean & Lowland Land Temperatures:

Mtn. Lakes Temperatures	**= 0.34°C / Decade**
Air Temperatures Increases	**= 0.25°C / Decade**
Ocean Temperature Increases	**= 0.12°C / Decade**

Depends on region, size and shape of lakes. Shallow lakes increase up to 0.55°C/ Decade, Large lakes up to 0.36 °C/ Decade

Source: Hampton, S. et al. 2016. Rapid and highly variable warming of Lake surface around the globe. Mountain Views, CIRMOUNT, Vol 10(1): 5-8

Factors Responsible for Temperature Increases and the Resulting

Factors Responsible for Temperature Increases:

Depends on Air Temperatures
Solar radiation
Winter Ice Cover
Decreasing Cloud Cover

Reasons for Temperature Increases:

Warming can decrease cloud cover which increased Radiation.
Decline in Duration of ice cover (Ice insulates)
Temperatures increase evaporation =
Temperatures increases in shallow lakes

Impact of increased temperatures on Lake Ecosystems:

Higher water temperatures hold less oxygen
Decreases algal growth = less food for fish
Changes water quality (increases concentrations due to evaporation)
Changes food web processes and results in shift on aquatic organisms
Favors different species and increases primary productivity

What is more important is the interactions between Temperature Increases and Alterations in nutrient and Cabon Inputs!

Water Temperature

Temperature impact on Dissolved Oxygen

Increased temperatures decrease the solubility of dissolved oxygen
Stress imposed by oxygen demanding waste increases with temperature

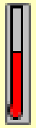
Temperature Effects on Biochemical and Physiological

Temperatures govern many biochemical processes in aquatic organisms
Increased temperatures can increase metabolic and reproductive rates throughout the food chain

Temperature Effects on Abiotic Chemical Processes

Affects many chemical processes such as re-aeration rates, sorption of organicchemical to particles, and volatilization rates
Increased temperatures lead to increased stress form toxic compounds .
The dissolved fraction is usually most bioactive.

Temperature Impact on Fish and Invertebrates



- High summer temperatures can be lethal
- Accelerated development of embryos in gravel
- Earlier emergence in spring
- Inhibition of migration
- Increased susceptibility to disease
- Higher respiration rate, reduced metabolic efficiency
- Changes in competitive advantage

Airborne Dust & Nutrient Deposition

- Airborne Dust from desertification, mining operations, agricultural and construction activities is resulting in deposition of phosphorus, metals and organic chemicals into remote mountain lakes that changes the chemistry of these sensitive oligothrophic lakes
- Nitrogen in airpollution from fertilizers, manure application and transportation activities is enriching the lakes with an essential nutient that changes the lake chmistry and the aquatic food web.

Impacts:

- **The combined input of nutrients (N & P) results in a shift form an oligotrophic state into a meso-trophic state, which increases to production of blue-green algae at the expense of diatoms.**
- **Oligotrophic lakes have little buffer capacity and the Nitrogen enriched precipitation is d acidifying lakes and shift the nutrient regime to promote Eutrophication.**

Alterations due to Glacial Retreat

Factors Responsible for Changes in Lake Ecosystems from Glacial Retreat

Factors Responsible for Change:

Increases Loss of Glacial Mass
Alters the Water Supply
Shift from Ice Melt to Snow Melt
Changes in Sediment Delivery

Reasons for Lake Impacts:

Change in Seasonal Hydrological Input
Alterations of Sediment Sources
Changes in the Thermal Regime
Shift from Inorganic to Organic Inputs over Time (Vegetation Encroachment)

Impact of Glacial Retreat on Lake Ecosystems:

Seasonal Changes in Hydrology Affects Temperature & Supply (Evaportion)
Increase or Decrease in Sediments that Affects Transparency & Productivity
Increases Productivity and Changes the Distribution of Aquatic Organisms

Challenges in Protecting Mountain Lakes

Mountain Lakes are excellent indicators of climate change and environmental Impacts
Sediment cores provide the history of changes (Fossil Records & Chemical Changes)

Problems:

- Most Mtn. Lakes are oligotrophic and are higly sensitive to changes in flow & inputs
- More than 50% of pristine mountain lakes have been stocked with fish & mysis.
- Long Distance Transport of Air Pollution is difficult to control
- Climate warming is affecting temperatures which interact with vegetaion changes
- Glacier fed lakes will lead to flow alterations & changes the sediment regime

Options:
Reduce Air Pollution Globally (Difficult)
Enhance Wetlands in Heawaters
Consider Liming Lakes (Limestone Pebbles)
Monitor Changes

Dilemma: Assist in speeding up the natural processes or let nature do the work over time

To Protect Lakes, Rivers, Groundwater, Springs Requires Different Approaches

Rivers:	**Riparian Buffer Zones Protection and Minimize Land Use Inputs**
Lakes:	**Reducing Atmospheric Pollution and Climate Factors**
Groundwater:	**Water Balance (Maintain Recharge) & Minimize Pollution Inputs**
Springs:	**Grounwater Surface Water Interactions and Land Use Restriction**

Wetlands:	**Protection & Enhancement to Store & Purify Water**