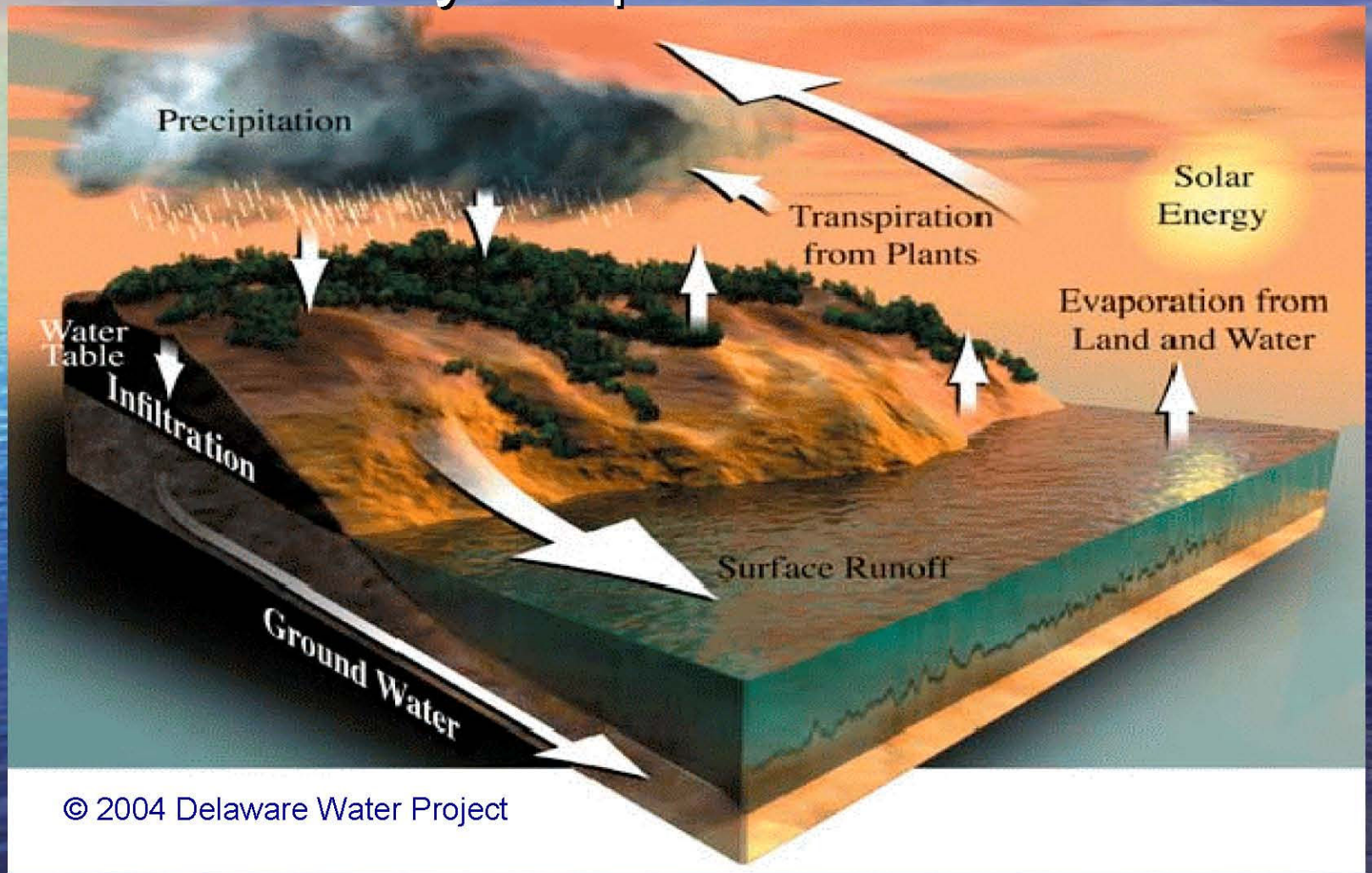
Water Resources on PEI: an overview and brief discussion of challenges

The Water Cycle can be used to describe the movement of water in and between different portions of the Hydrosphere

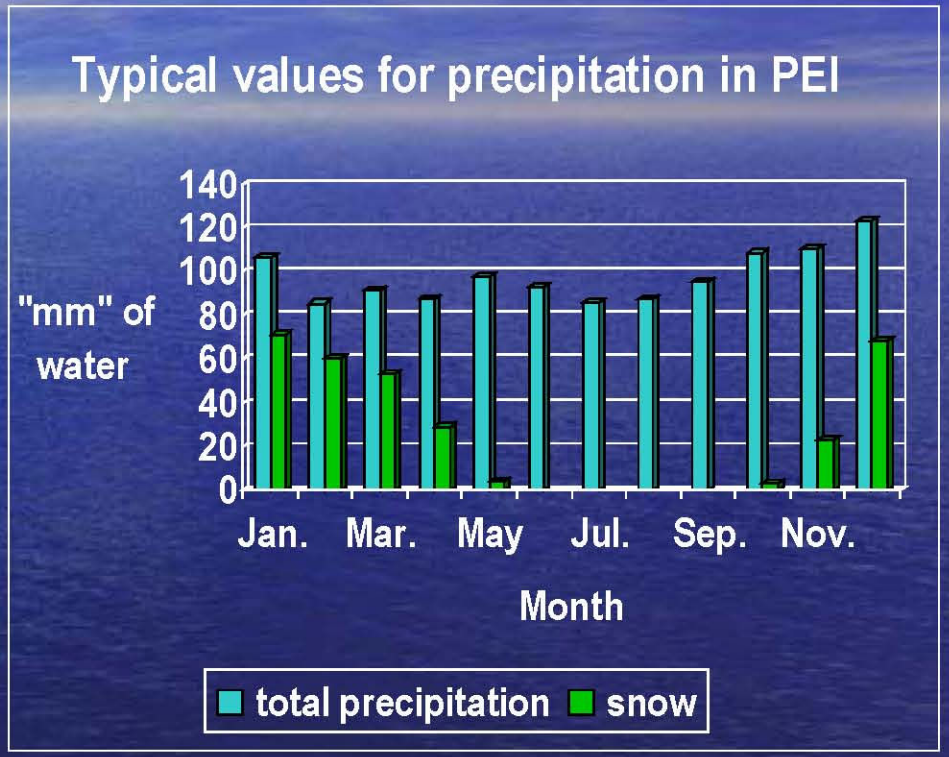


Components and links

- Components:
  - Atmospheric water
  - Surface water (including glacial water)
  - Groundwater
- Links:
  - Precipitation (atm > surface water/ soil water/groundwater)
  - Evapotranspiration (surface water or soils> atmosphere)
  - Runoff (surface soils>streams etc.)
  - Infiltration/recharge (surface soils> groundwater)
  - Discharge (groundwater to surface water)

Precipitation

- Water is “precipitated” from the atmosphere as rain or snow. In an average year, about 1,100 mm of precipitation falls on Prince Edward Island. About 25% of total precipitation falls as snow.

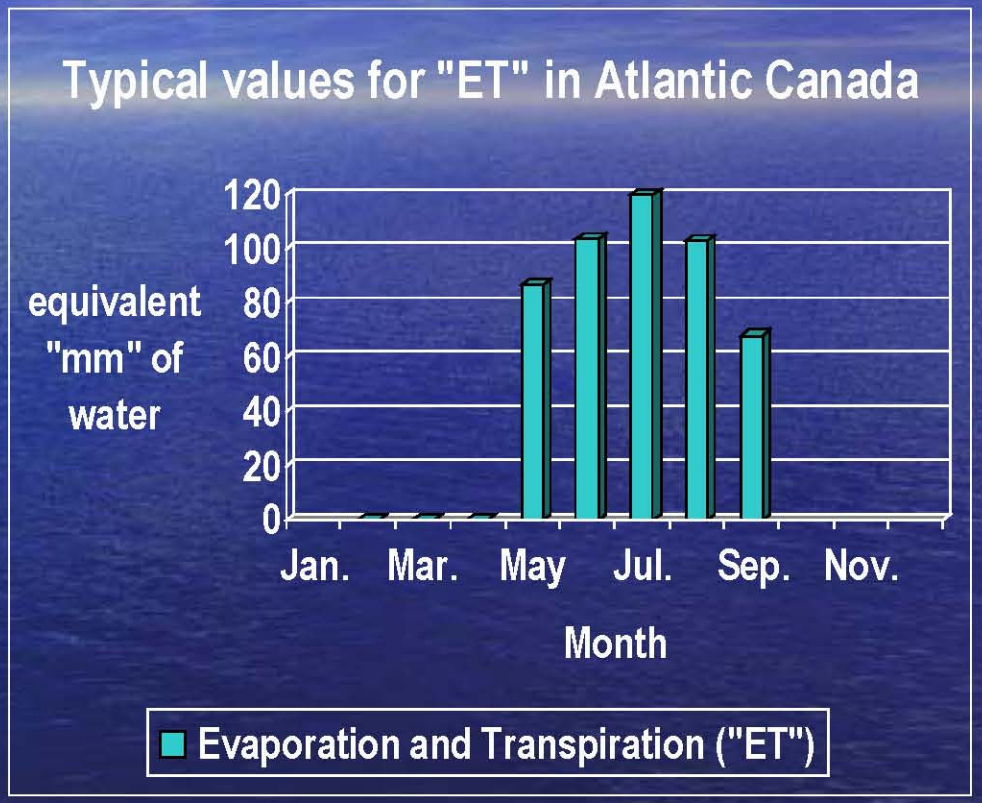


* In the graph above, snowfall has been converted to its liquid equivalent. 1 cm of snow represents about 1 mm of water.

Evaporation and Transpiration

(evapotranspiration – ET)

- Evaporation and transpiration of moisture into the atmosphere require relatively warm temperatures; significant effects on PEI are normally limited to the period from late spring to early fall.



Surface water: streams, rivers and estuaries

- On PEI we have many small rivers and streams but relatively few lakes or natural ponds.
- Our rivers tend to be short, and a good portion of their length contains *brackish* water - a mixture of fresh water and salt water from the ocean. These areas of mixed fresh and salt water are called *estuaries*. They are highly productive areas for shell fish and fin-fish.

Stream flow:

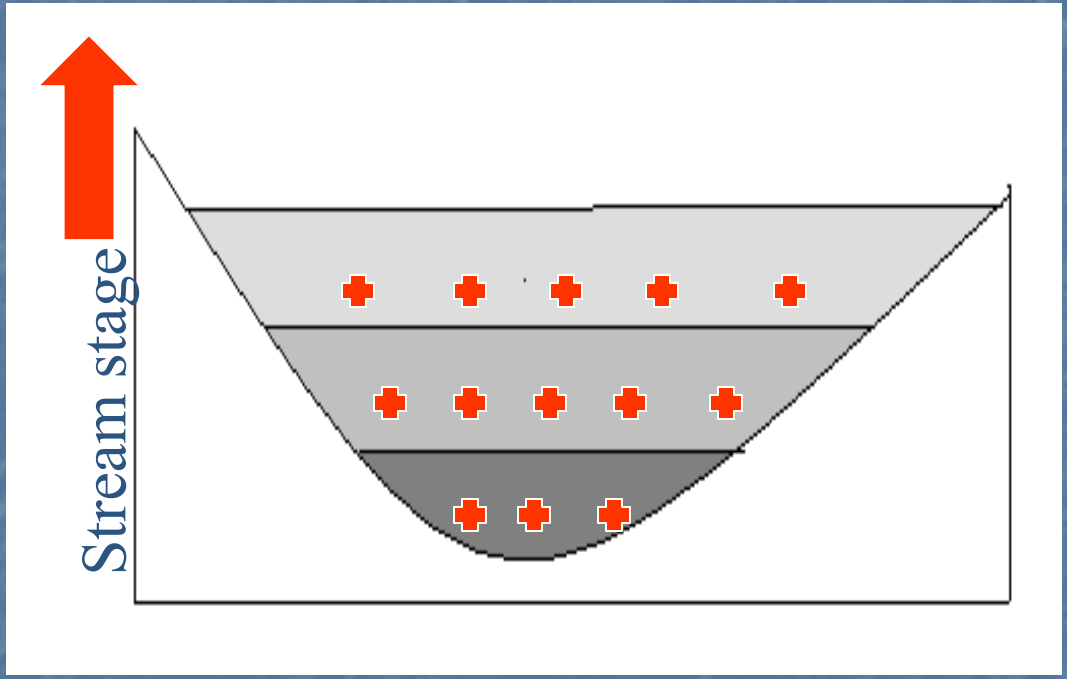
- Stream flow is comprised of baseflow (groundwater discharge) and direct run-off

- "Total" Stream flow can be measured directly:
  - Using profile of stream and velocities at representative points across the stream profile and converted to a flux by the use of a rating curve (instantaneous measurement in m^3/sec) .

- Stream flow can be estimated using regional equations for response of stream flow to precipitation using depth of precipitation (mm) and the area of the catchment (km^2)
  - Approach depends on time frame (ie annual basin yield (simple), or short term responses for maximum or minimum flows with a given return period) more complicated

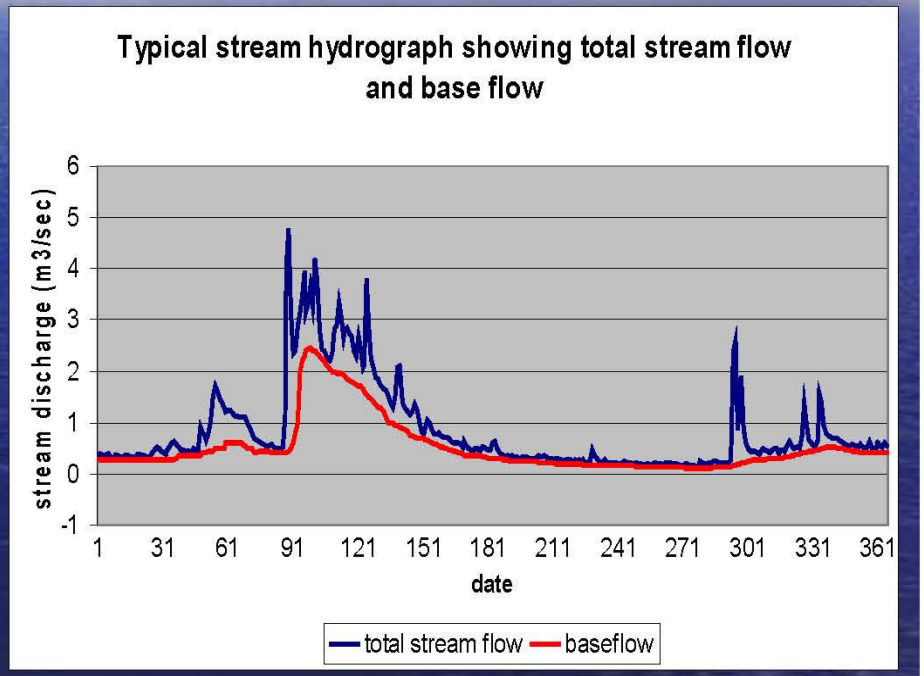
Direct measurement of stream flow

- A rating curve is constructed by measuring the relationship between stream stage (elevation) and stream discharge at different times of the year.
- Using stream stage (usually continuously) and the rating curve, stream flow can be determined



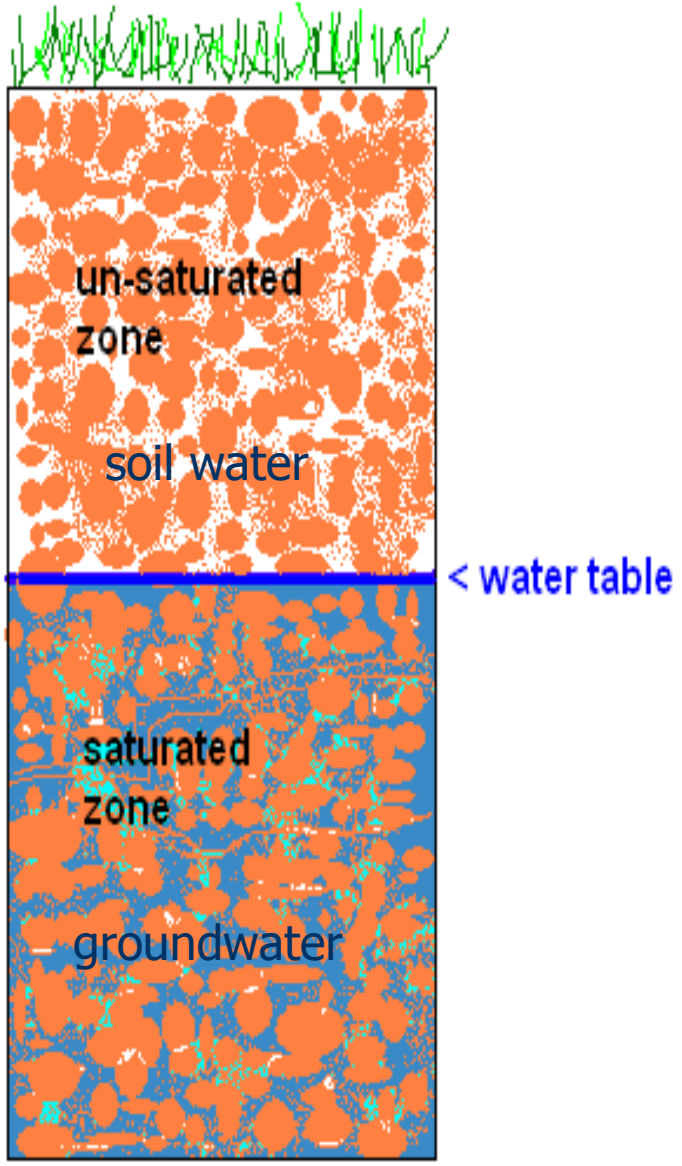
Fresh Water Flow in Island Streams

- The surface water we see in fresh water streams comes from two sources:
  - Water that runs over the ground surface to streams such as after a rain storm or snow melt, and
  - Groundwater discharge from springs.



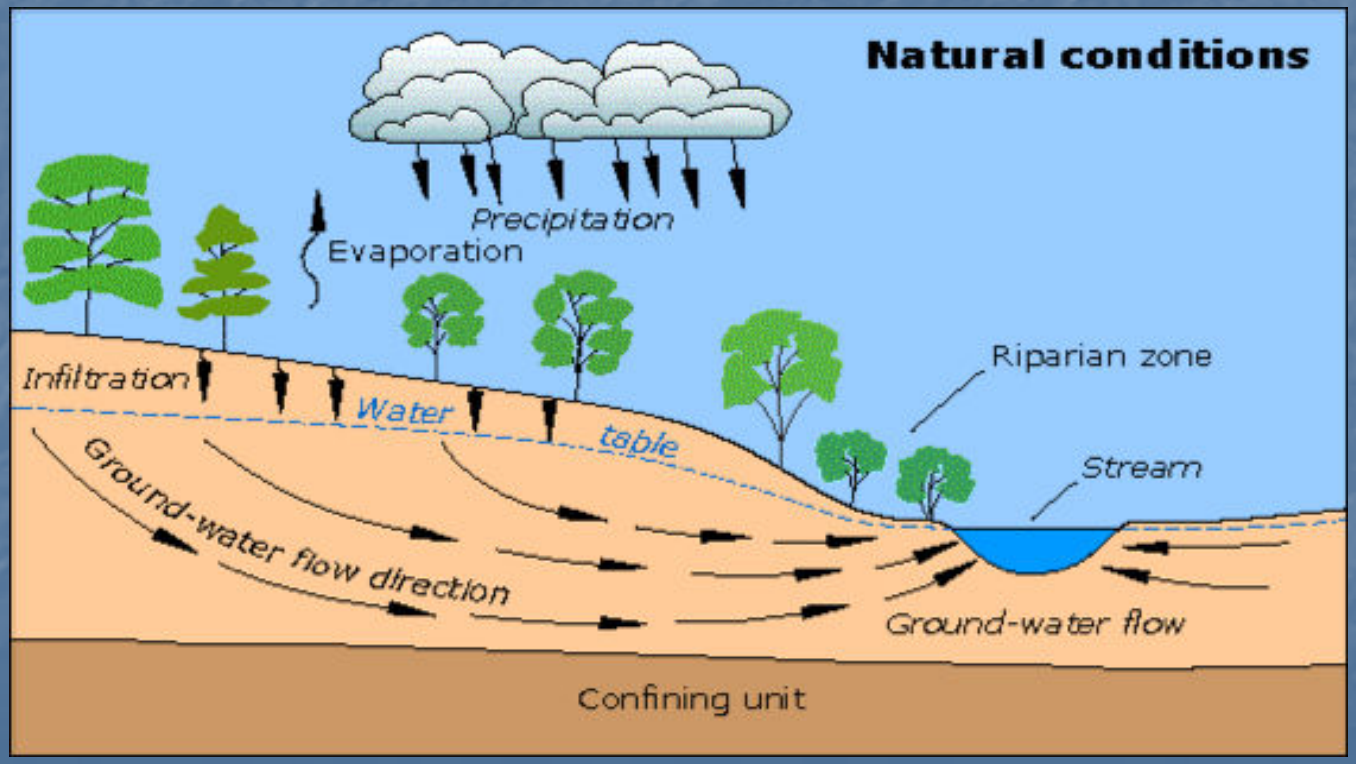
Groundwater: what is it?

- The area below the ground surface can be divided into two zones:
  - Un-saturated zone where pore spaces and fractures in rocks and soil are partially filled with air, and partially filled with water.
  - Saturated zone where these void spaces are completely filled with water. This is what we refer to as "groundwater"
- The water table is the boundary between the un-saturated and saturated zones.
- A geological formation containing useable quantities of groundwater is called and "aquifer"

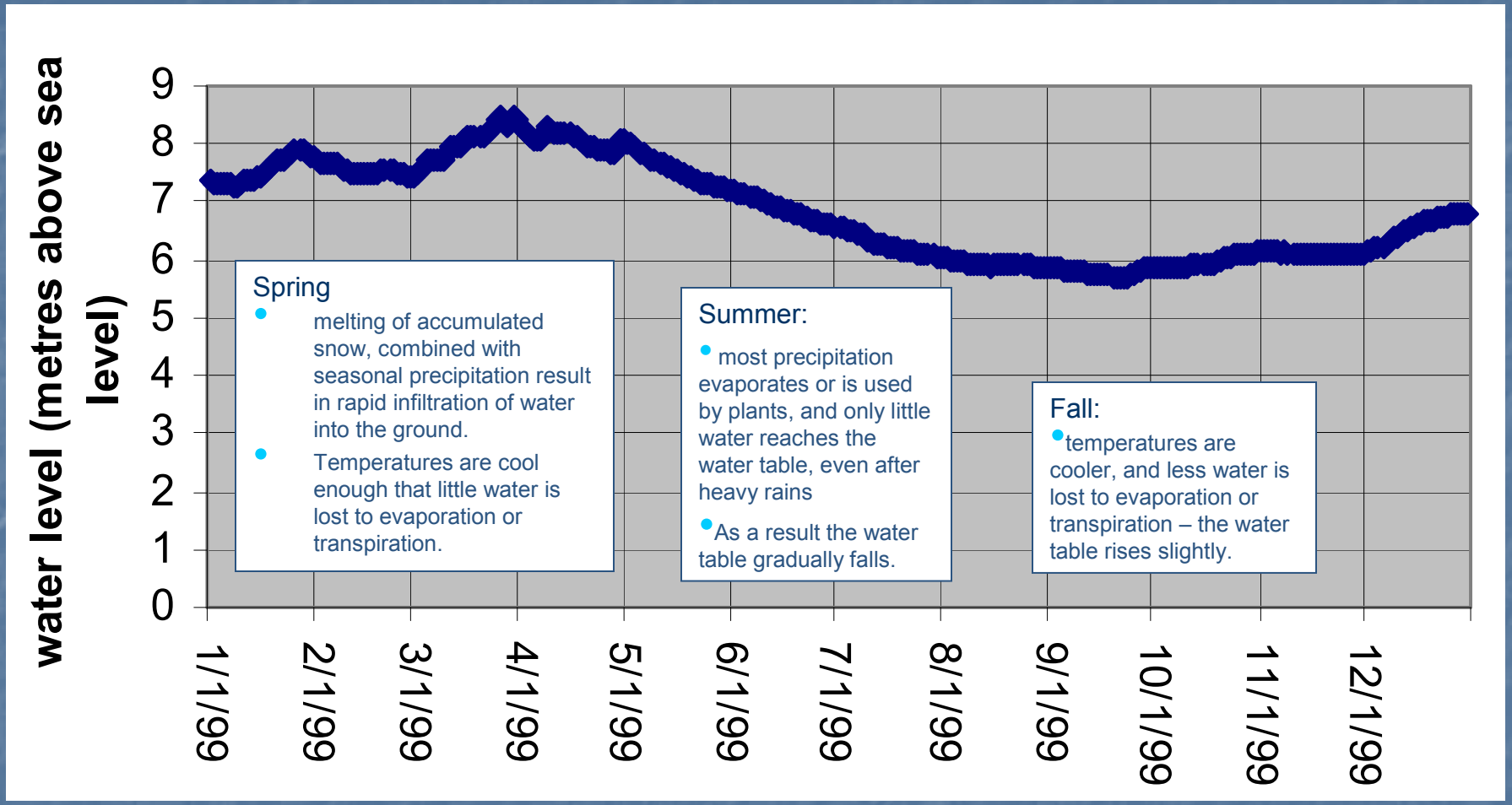


Seasonal Trends in the Water Table

- The elevation of the water table rises and falls throughout the year depending on the *relative* rate at which groundwater is *recharged* and *discharged*.

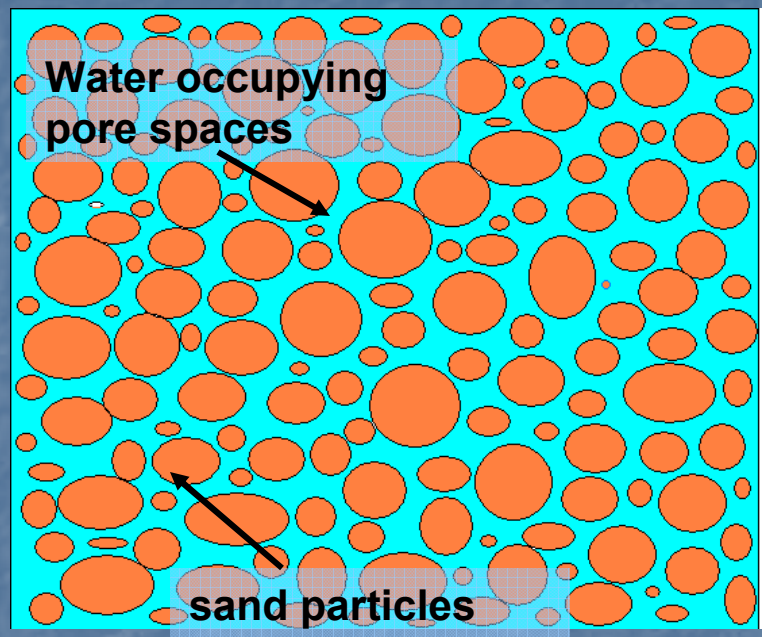


Water Table Elevation, Sleepy Hollow Well 1999



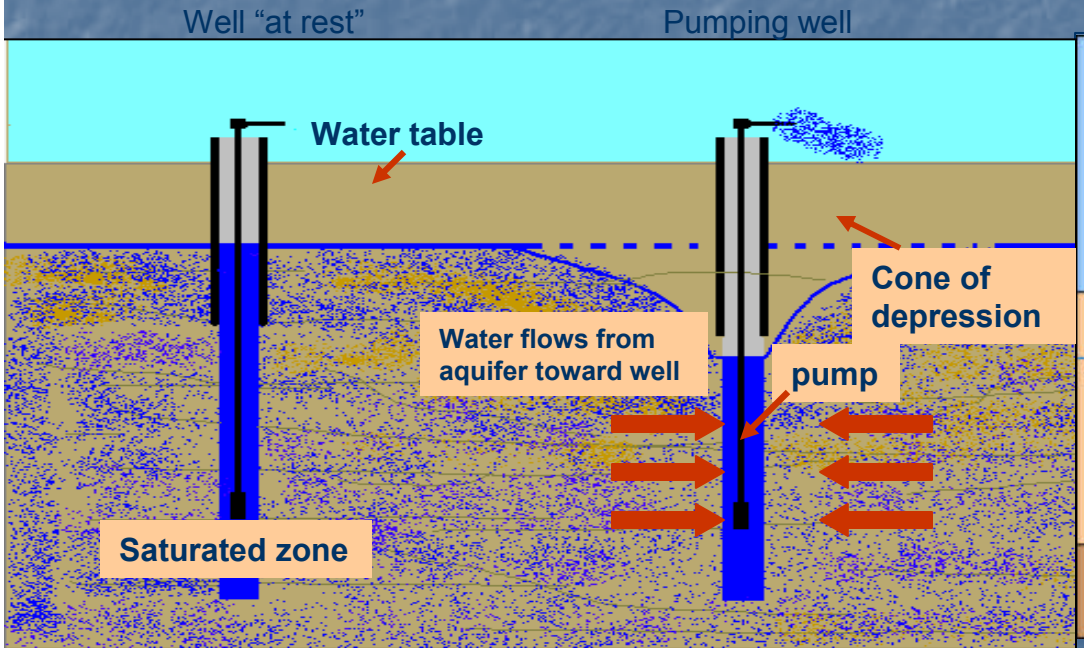
Aquifers: Reservoirs of Fresh Water

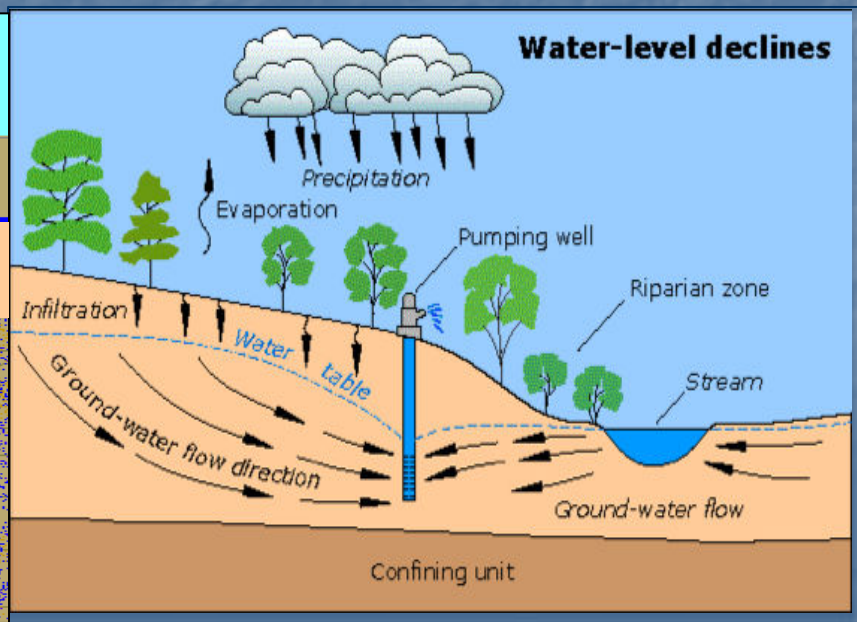
- Aquifers can store vast amounts of water. The aquifer underlying PEI is a good example.
- While the sandstone bedrock below us looks pretty solid, it is actually filled with many tiny *pore spaces* and fractures. The area occupied by these void spaces is referred to as *porosity.*
- On Prince Edward Island these spaces make up about 15% of the total volume of the rock, and we would say that the porosity of the rock is 15%.
- In some other types of geological formations:
  - Porosity may be greater (sand & gravel deposits), or
  - Much lower (shales, metamorphic rocks, volcanic rocks etc.) and may be mostly as a result of fractures in the rock



Using Wells to Access Groundwater

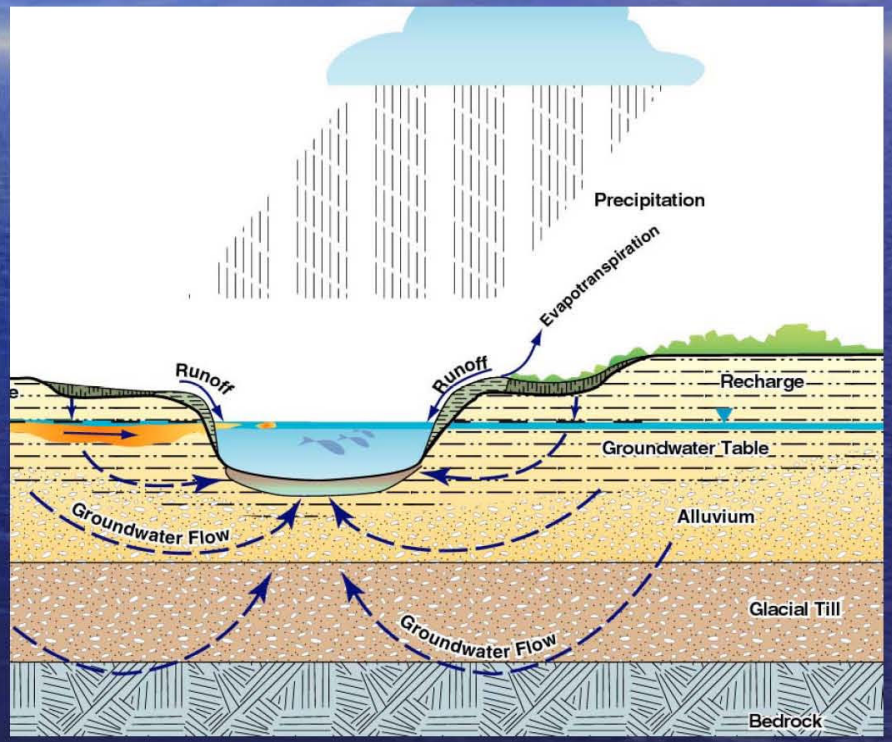
- Wells provide a means of tapping groundwater stored in the "saturated zone" or "aquifer"
- When a well is not pumping, the water level in the well is the same as the water table elevation.
- When a well is pumping, the water level in and immediately around the well drop, forming what is called a "cone of depression".
- The size and shape of the cone of depression depend on the pumping rate, the duration of pumping and the characteristics of the aquifer.
- When a well is located near a stream, heavy pumping may draw water from the stream into the well.





The Groundwater Cycle

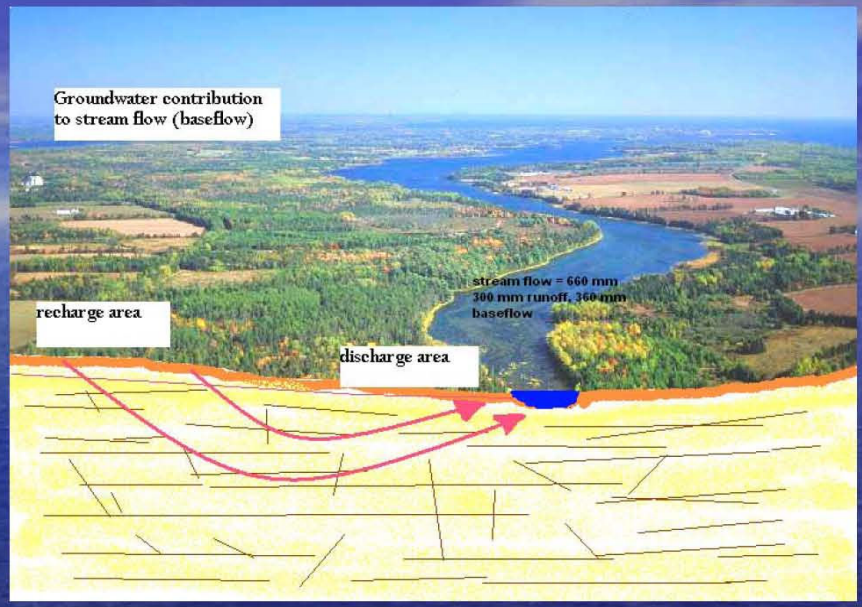
- While surface water flows quite rapidly, groundwater flows very slowly, often only a few metres to tens of metres per day.
- The process by which water seeps through the soil and reaches the water table is called *recharge*.
- Once water reaches the water table it moves away from areas of higher elevation, called *recharge areas*, toward areas of lower elevation called *discharge areas*.



Environmental Protection Agency

Groundwater: An Important Contributor to Stream Flow

- Groundwater which is *discharged* through springs and *seeps* to rivers or the shore is often called "base-flow"
- Base-flow accounts for 55-65% of the average annual stream flow.
- In dry summer months when there is little direct precipitation run-off, almost all the water we see in Island streams is groundwater discharge.



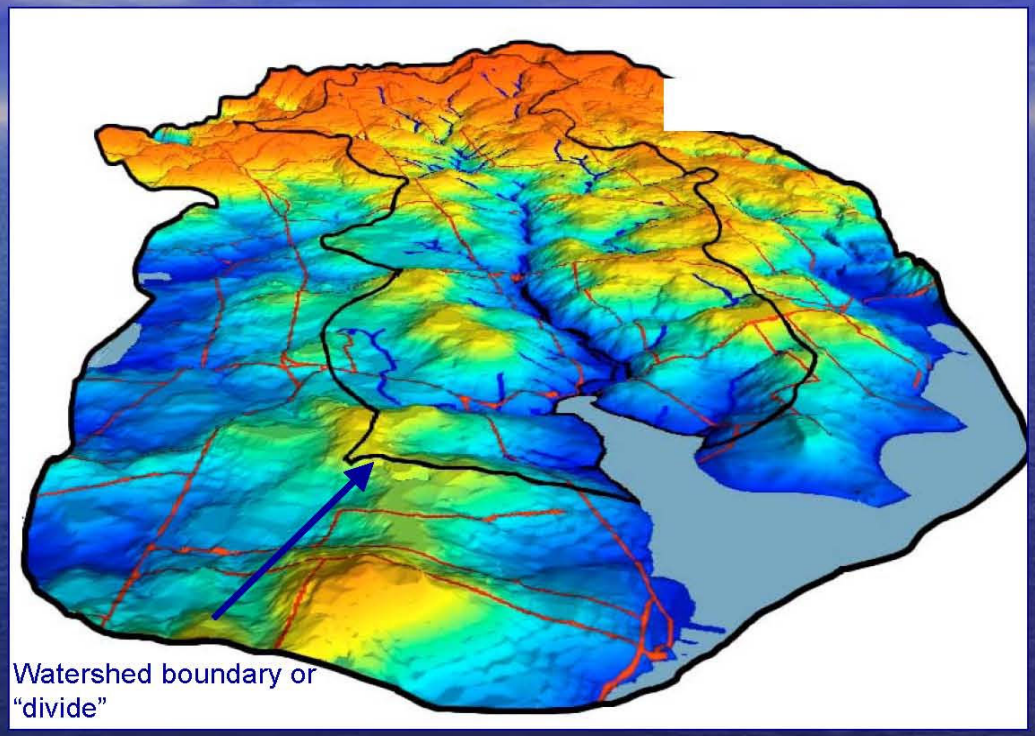
Spring discharging groundwater to a small stream. This is a fairly unusual example, and most springs are barely noticeable to the casual observer.

Putting the pieces together

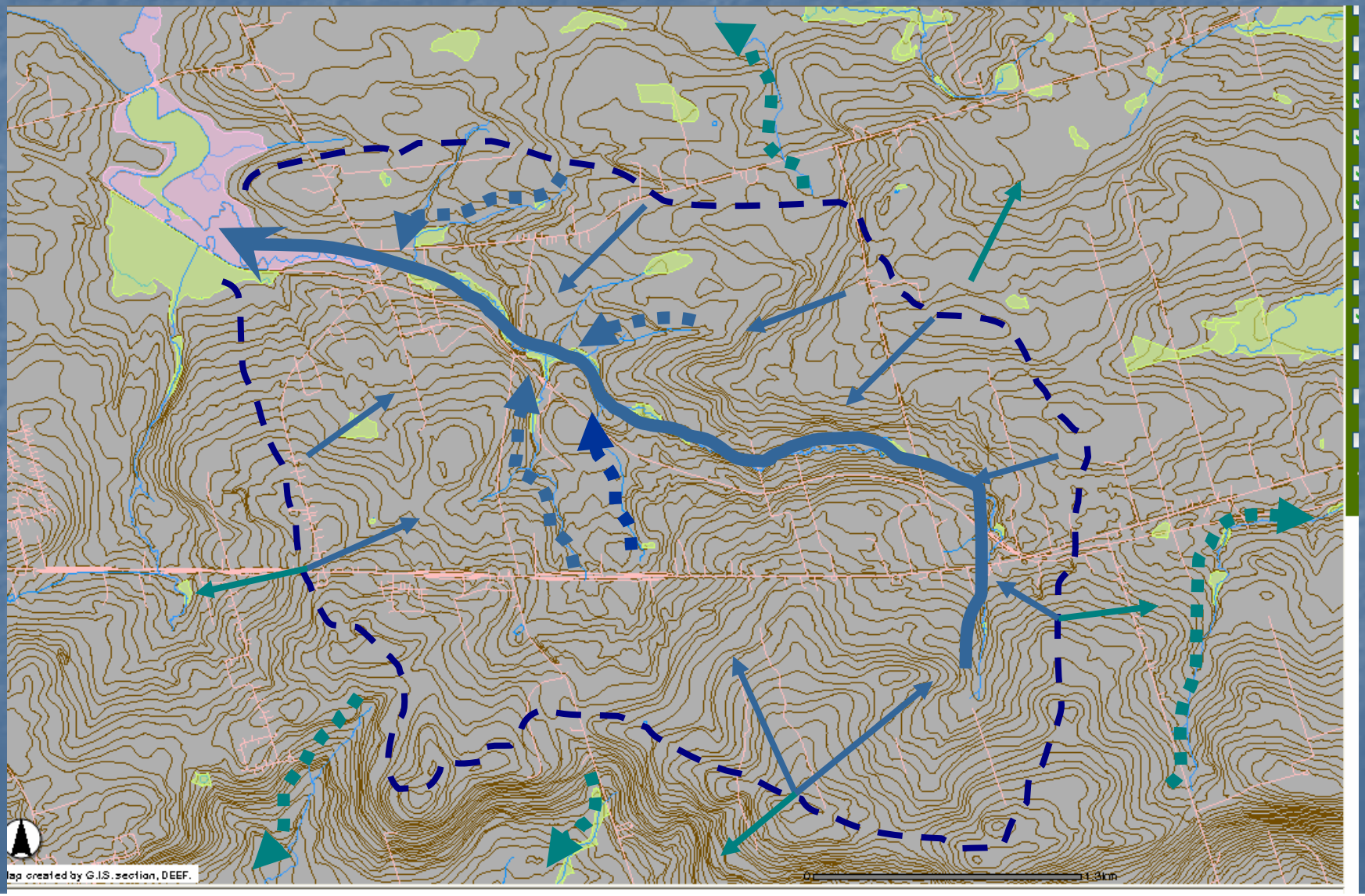
- Watersheds as the basic unit of study
- The water balance as a basic way of accounting for the movement of water
  - In to the watershed
  - Out of the watershed
  - Within components of the watershed

Watersheds: A Useful Tool in the Study of Water

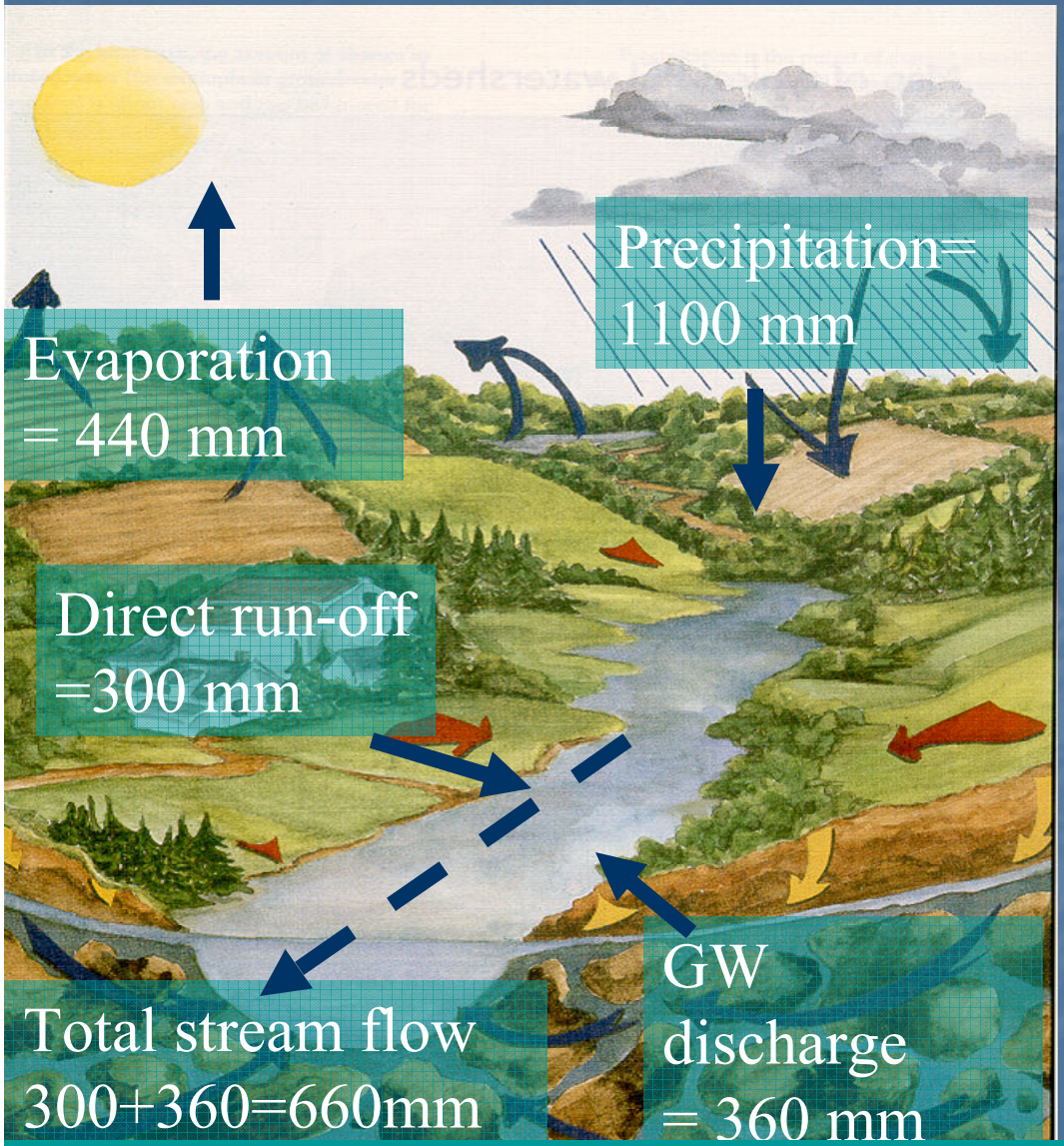
- A *watershed* is the area of land over or under which water flows toward a stream, river or the ocean. Regardless of where you are, you're in a watershed!
- For many issues relating to water, we use watersheds to define the physical boundaries of the area of interest.



Topographic "control" of watershed boundaries



The "Water Cycle" & a "typical" PEI water budget



- The water cycle starts with precipitation. On PEI we normally receive about 1100 mm of precipitation annually.
- Water that falls on the ground will follow one of three processes:
  - evaporate and return to the atmosphere (440 mm)
  - run directly over the land surface to streams (300 mm)
  - soak into the ground and become groundwater (360 mm)
- Groundwater flows slowly from areas of higher elevation to lower elevation and eventually discharges to surface water bodies such as streams, ponds etc.
- Surface water evaporates and returns to the atmosphere to complete the cycle.

Water Balance: $P = Q_{run\text{-}off} + Q_{groundwater\ discharge} + ET$ +/- change in Storage

The "Water Cycle" & "Water Quality"

- Water quality is determined by the materials that water comes in contact with as it passes through various phases of the "hydrologic" or "water" cycle .

Precipitation is slightly acidic but has only a small amount of dissolved constituents

Water soaking into the ground (groundwater) moves very slowly, and dissolves many of the minerals it comes in contact with, or any other soluble compounds in or on the ground.

When groundwater "discharges" to streams it carries these dissolved constituents with it.

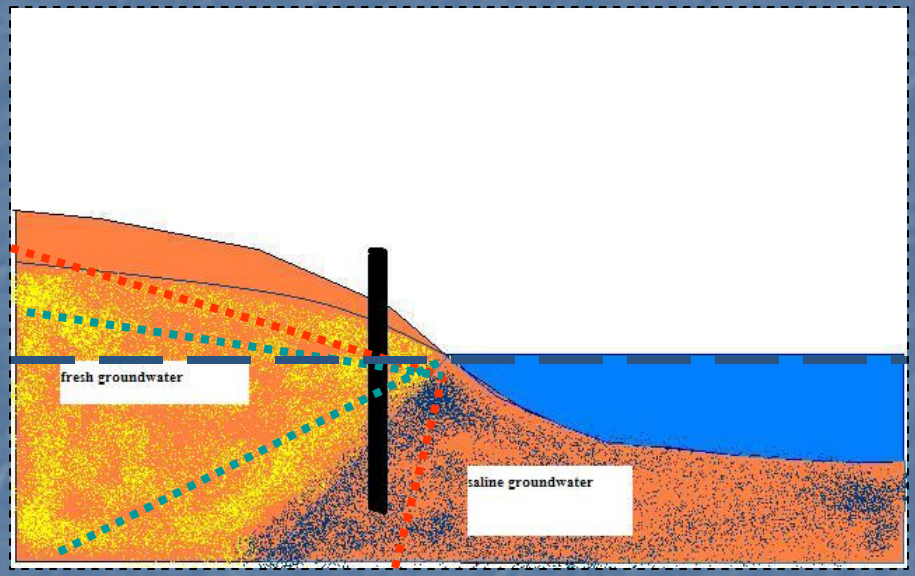
This discharging groundwater (called base-flow) makes up about 2/3 of our fresh surface water on an annual basis, and nearly 100% during dry periods.

"clean" water is not "pure" water

- All natural waters contain some level of dissolved constituents. In addition, foreign materials may be suspended in water.
- Water can be considered "contaminated" when levels of naturally occurring or man-made constituents are present at levels that can threaten health or other uses of the water.
- Water that may be considered "contaminated" for some uses may be quite acceptable for other uses.

Salt water intrusion

- In some coastal areas, marine waters "intrude" inland beyond the coast.
- The position (depth) between overlying fresh groundwater, and deeper saline water depends in large part on the elevation of the fresh water table:
  - Where the water table is elevated well above sea level the depth the fresh water /saltwater interface will be quite deep
  - Where the water table is closer to sea level, the depth to salt water will be shallower



Link between land use and the health of our water resources

- Water quantity issues
- Water quality issues

Water quantity issues

- Groundwater Extraction and affect on other groundwater users
- Impact of groundwater on extraction surface water resources
- Potential impact of climate change

Sustainable groundwater extraction rates

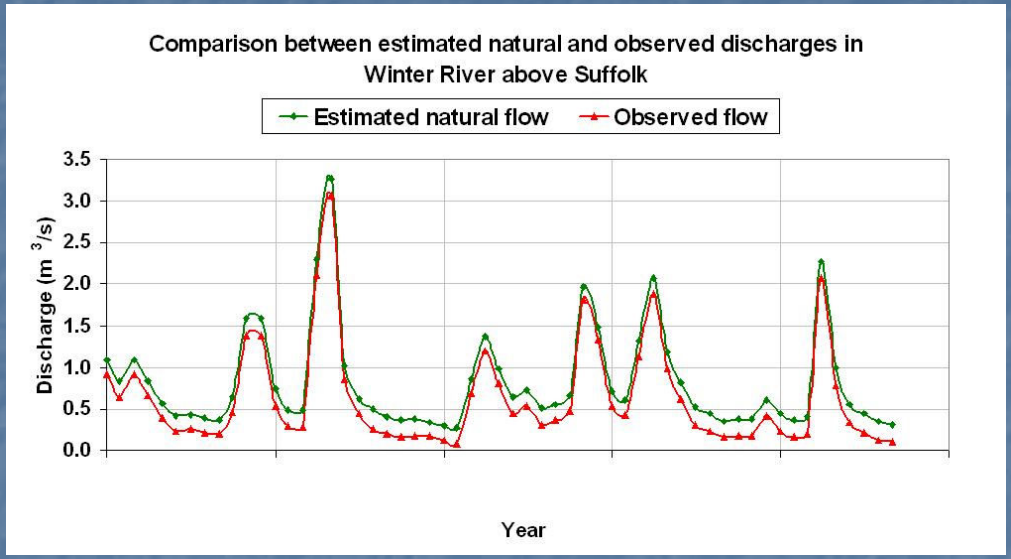
- No single definition for "sustainable" extraction rates… depends to some degree on what is considered:
  - Changes in water table elevations/interference with other wells
  - Affect on stream flow (not as frequently considered)
  - Relationship to recharge rates
    - Any pumping will affect the local hydrologic cycle and water table elevations
      - If extraction rate is less than recharge rate a stable "steady state" is reached
      - If extraction rates are greater than recharge rates, water levels will continue to decline indefinitely (called groundwater mining)
  - Groundwater mining is a serious issue in many areas with high water demand +/or low recharge rates.
  - In coastal areas, excessive groundwater extraction can result in salt water intrusion problems

Groundwater extraction and impact on stream flow

- Overall groundwater extraction in the Province amounts to about 2% of annual recharge of the aquifer, but
  - Extraction is very un-evenly distributed among watersheds
  - Stream flow can be significantly impacted by groundwater extraction
  - Annual water budgets to not necessarily reflect more important seasonal impacts of withdrawals on stream flow (ie during low flow periods).

Groundwater development: Winter River watershed

- Pumping utilizes:
  - ~35% of mean annual recharge
  - ~48% of the recharge of 2001
- Heavy pumping has significantly reduced the stream flow.



Month	Reconstructed Stream flow (f<5%, m^3/s)	Simulated base flow reduction (under current pumping rate)	Simulated base flow reduction (under peak capacity)
August	0.293	60%	67%
September	0.300	58%	65%

Water conservation and water reuse

- Conservation of water resources make sense anywhere (even in areas with abundant water, if nothing else, it reduces energy consumption)
- Reduction of water use (low flow fixtures, water metering and appropriate water rates) can be more cost effective and environmentally friendly than developing additional water supply
- Emerging technologies allow us to re-use water, using reclaimed water for uses where quality is less of a concern (flushing toilets, irrigation etc.)

Flooding and Storm Water Management

- An important element of watershed planning (especially in areas with highly variable or intense rainfall events) is storm water management.
  - Flooding can cause a great deal of damage to property, as well to water and wastewater supply infrastructure
    - Walkerton (flooding was a big part of the problem)
    - New Orleans
  - Storm water (run-off) can carry sediment and nutrients that can degrade surface water quality

Climate change and PEI water resources – quantity considerations

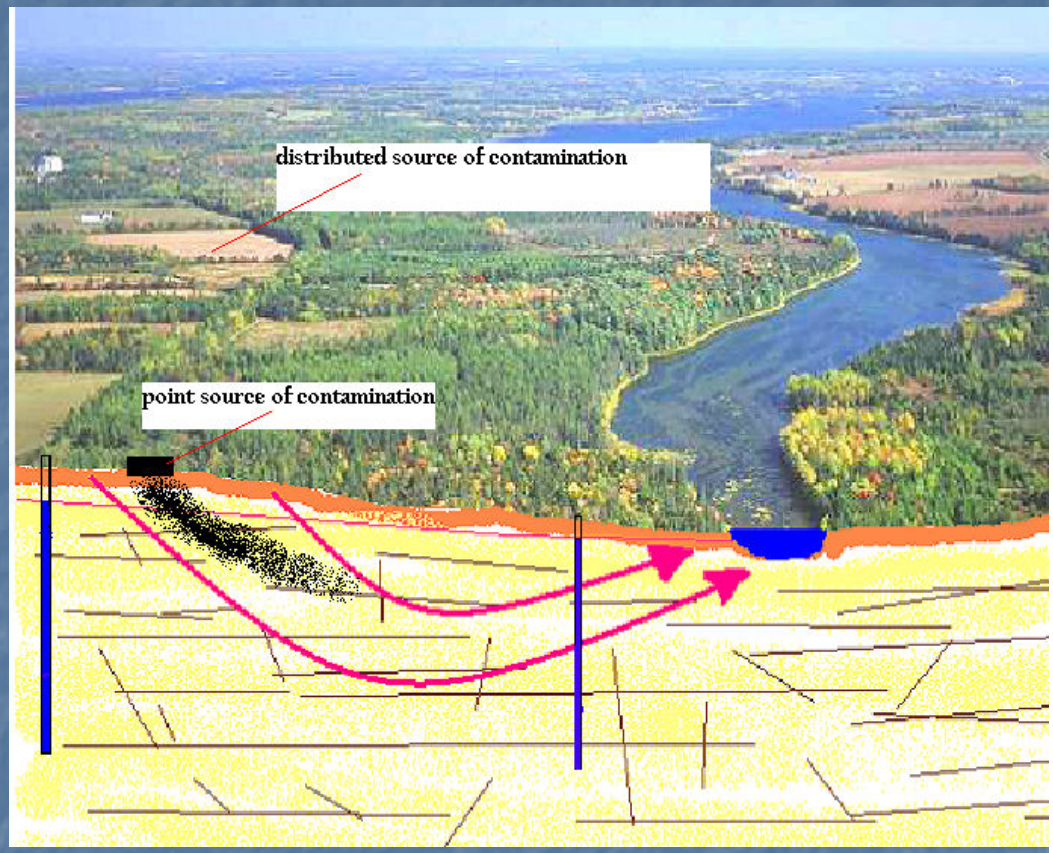
- Long term changes in precipitation amounts and patterns, and temperatures may affect:
  - Groundwater recharge rates
  - Water table elevations
  - Stream flow regimes
  - Run-off characteristics during extreme weather events

Water quality issues

- Link between land use and water quality
- Bacterial contamination
- Chemical contaminants
  - General considerations for drinking water
  - Nutrients… a special challenge for PEI

Man-made influences on water quality

- Any activity occurring on or near the ground surface can influence surface or groundwater quality
- Contamination may be from "point" sources or "distributed" sources
- For some parameters, there is a strong link between groundwater and surface water quality



Link between water quality and land use

- Water quality is determined by the materials it comes into contact with on its journey through the water cycle, including:
  - Naturally occurring compounds (most but not all, of no health or ecological concern)
  - Man-made contaminants, many of potential health or ecological concern
- Generally it is only the influence of man-made contaminants for which we can protect the quality of water resources….compounds released by activities at the ground surface, as part of land use:
  - Sewage & solid waste disposal, fuel storage, agricultural and industrial activities etc.
  - We can minimize the impact of these activities by controlling land use
- To protect municipal drinking water supplies we can resort to well field protection.
- Many of the same measures that can also protect surface water resources – thus well field protection and watershed protection have many features in common

Nutrients & the Water Cycle: concerns & pathways

Nitrogen (principally nitrate and ammonia)

- Nitrate
  - Highly soluble, not bound well to soils, most stable form of N in the environment
  - readily transported by groundwater flow
  - Concern in relation to drinking water at a **concentration** > 10 mg/L
  - Fresh water habitat CCME guideline **concentration** of 2.9 mg/L
  - N **loading** of estuaries…no specific concentration…..overall **mass** of N

- Ammonia
  - relatively unstable form of N in the environment
  - Main N species in wastewater, fresh manure
  - Rapidly oxidized to nitrate in an oxygen rich environment

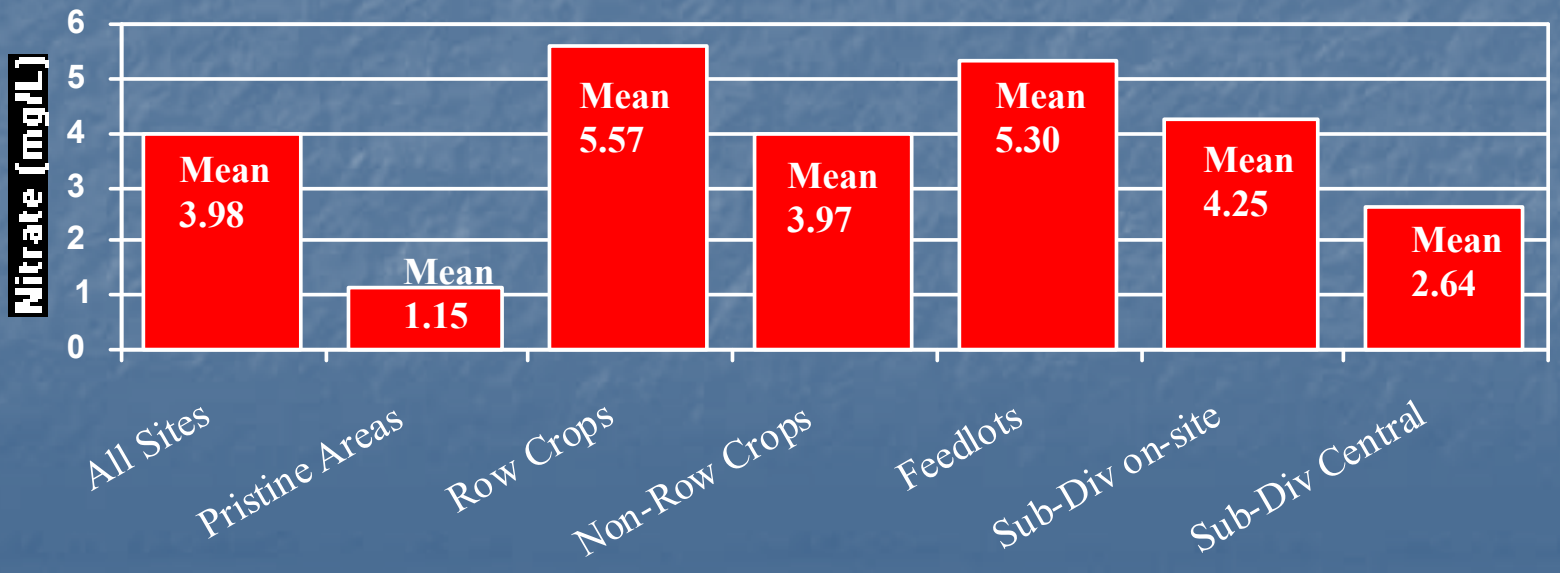
Phosphorous

- Binds well to soil particles
- Transported by overland runoff to water in association with soil erosion
- Not an issue for groundwater or drinking water quality
- Principally associated with eutrophication in fresh water bodies

An example of land-use impacts on groundwater and surface water quality - Nitrate

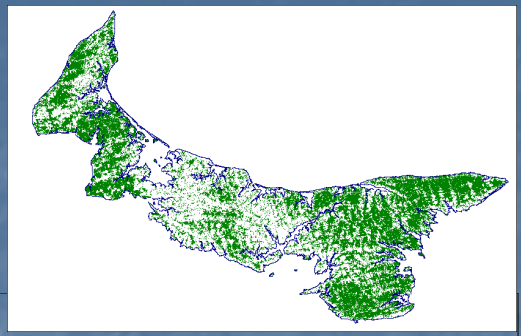
- Principle nitrogen sources:
  - Fertilizer
  - Manure and septic tanks
  - Soils (organic matter from plant residues)
  - Wastewater
  - Atmosphere

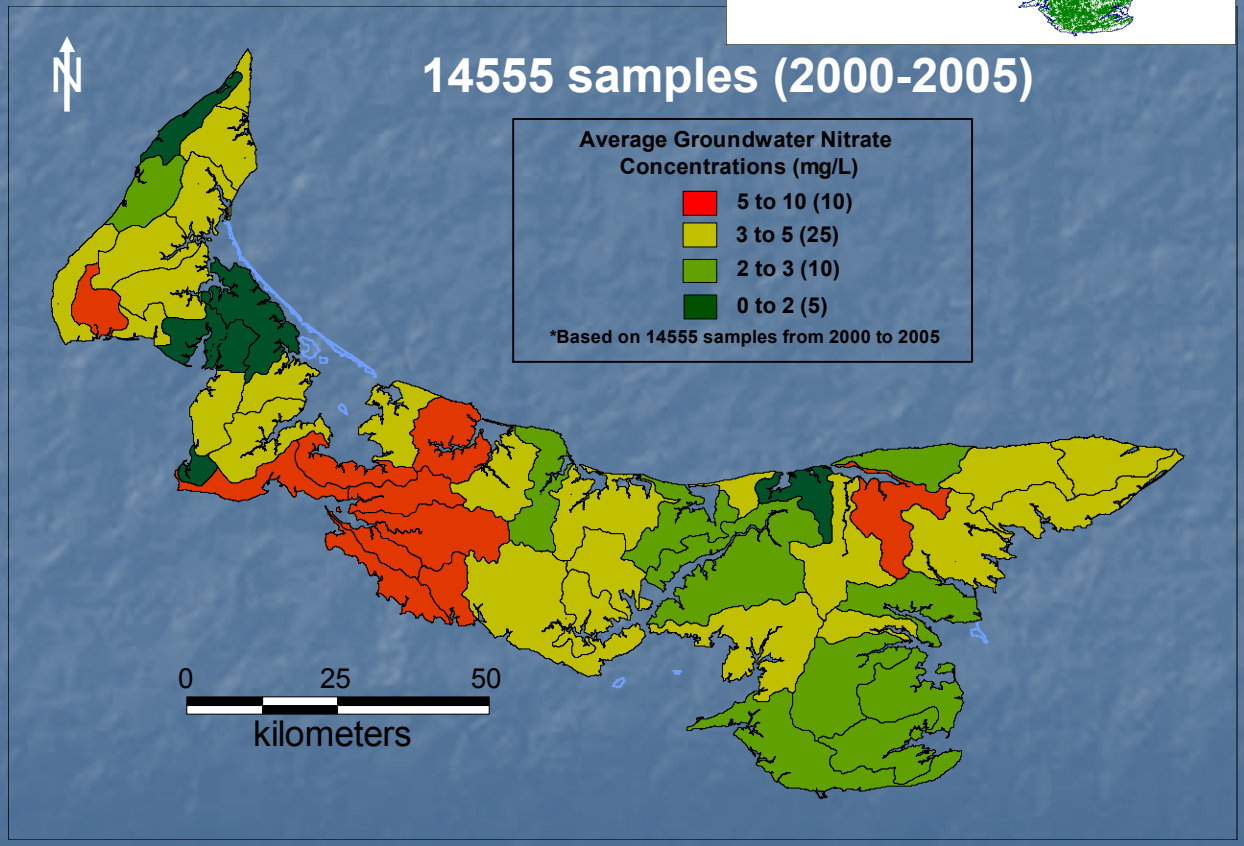
- An early PEI study (1988-1991): Nitrate concentrations in groundwater (private wells) and land use:



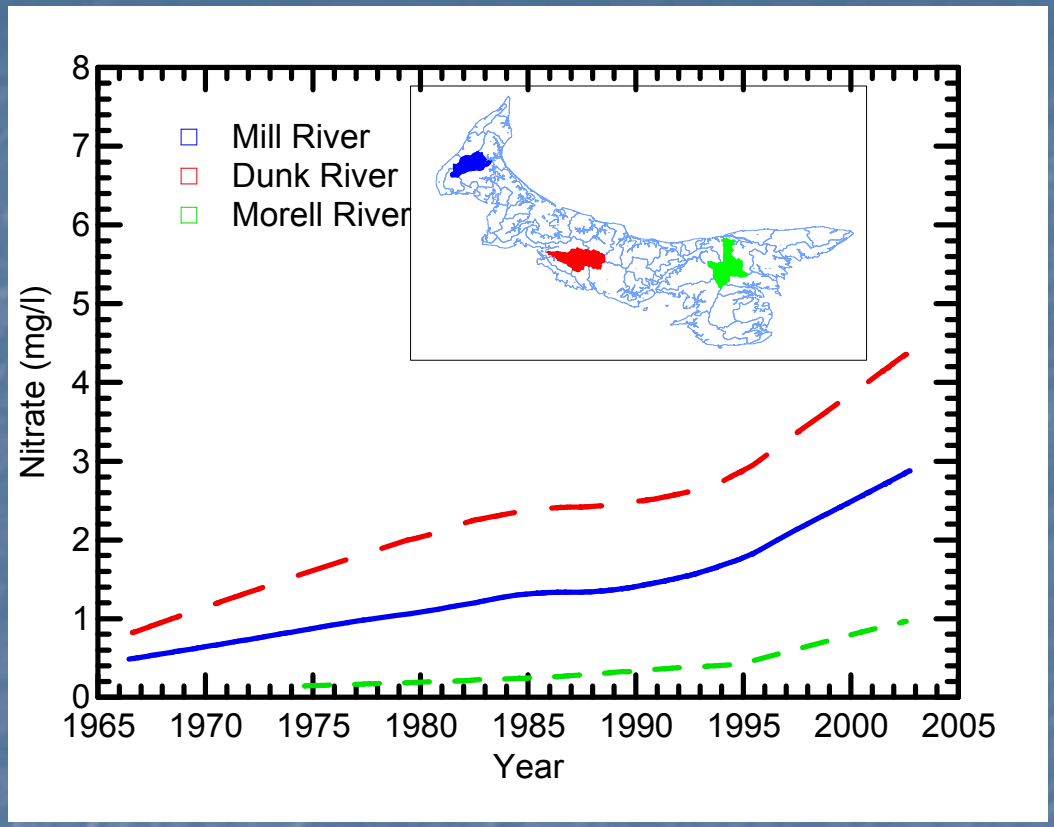
Nitrate contamination in groundwater

- GW nitrate levels of 90% watersheds exceed background.
- 4.5% wells exceed 10 mg/l and island-wide ave. is 3.7 mg/l.
- Elevated nitrate is associated with greater agricultural intensity.





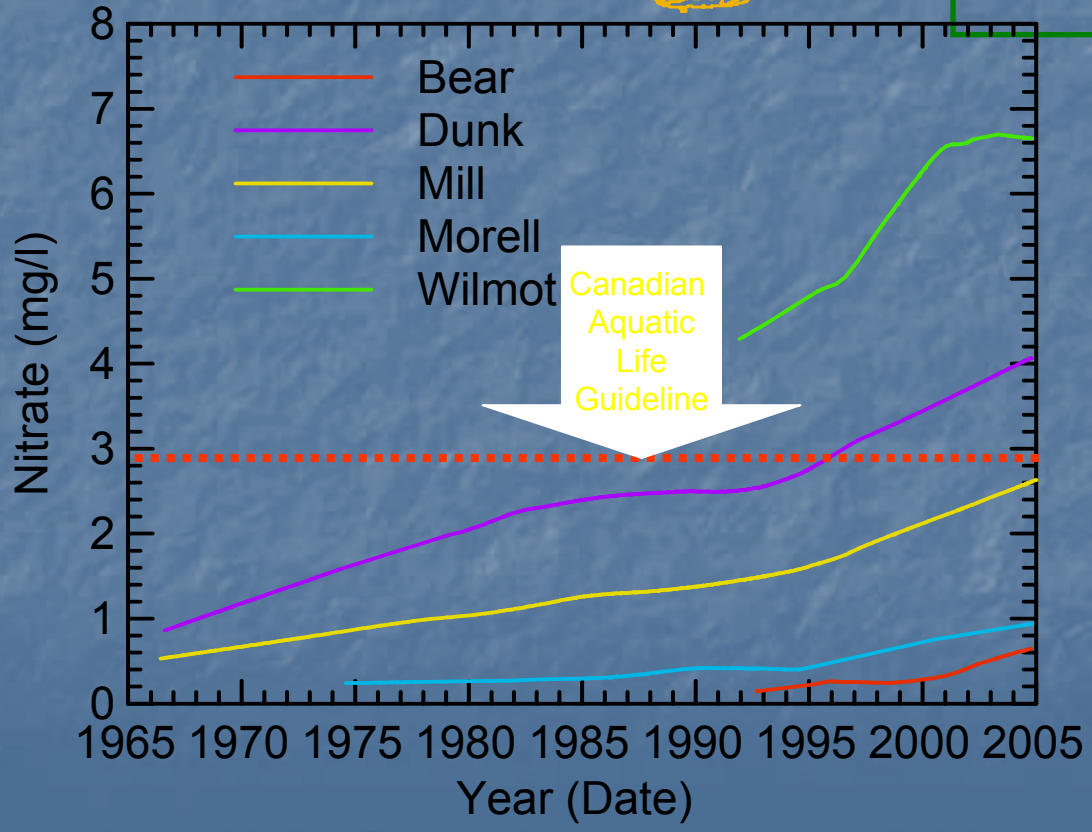
Historical GW trends- evidence from "baseflow"



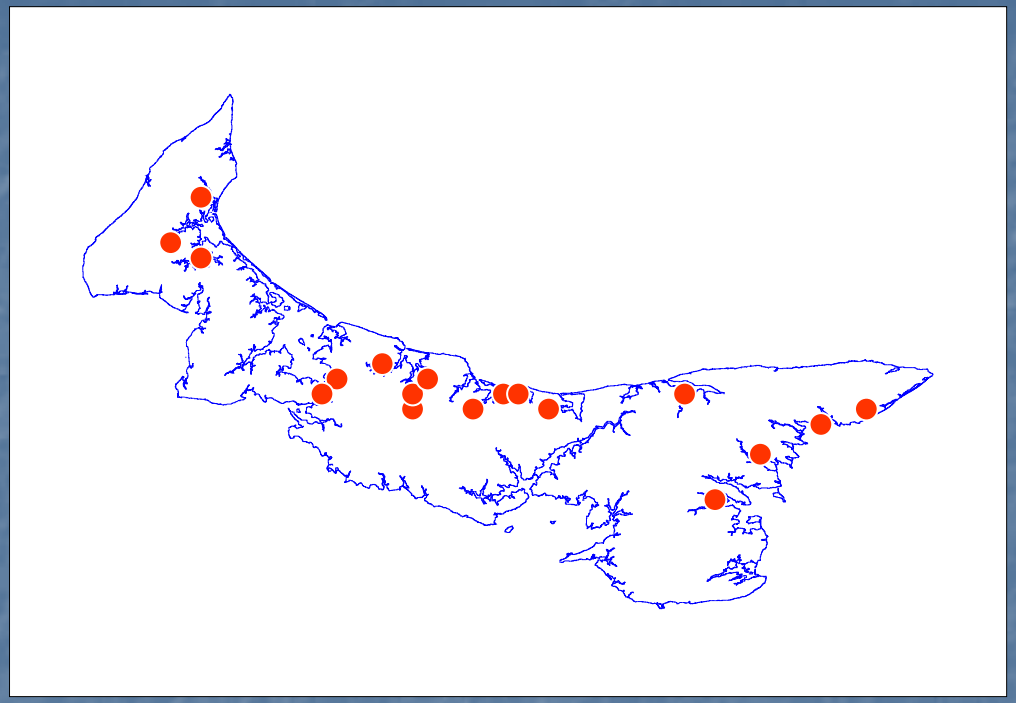
- The quality of base-flow provides a good average sample of GW quality for the watershed
- The quality of base-flow ***also*** gives us some idea of the amount of nitrate being transferred from groundwater to fresh surface waters and to our estuaries.

Nitrate contamination in surface water

- **SW nitrate levels increased over time and exceeded the Canadian aquatic life guideline in some cases.**
- **Excessive nitrate contributed to eutrophication in some estuaries.**



Eutrophication



- **Severe eutrophication / anoxia is a routine issue in 18 estuaries.**
- **Anoxic events seem to be occurring both earlier & later in year and lasting longer**
- **The south shore can stand higher loading, probably because it has higher tide than the north.**