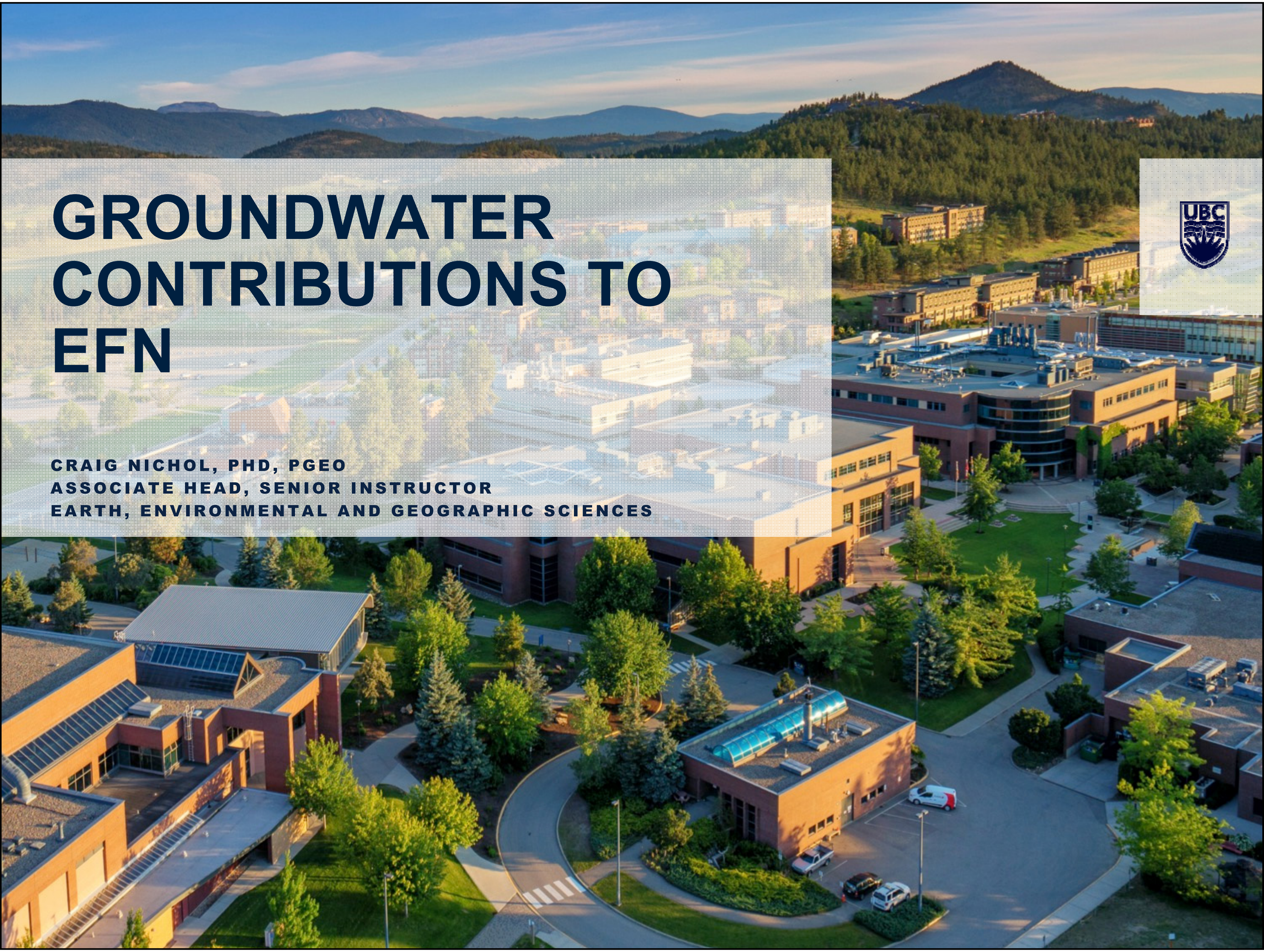

GROUNDWATER CONTRIBUTIONS TO EFN

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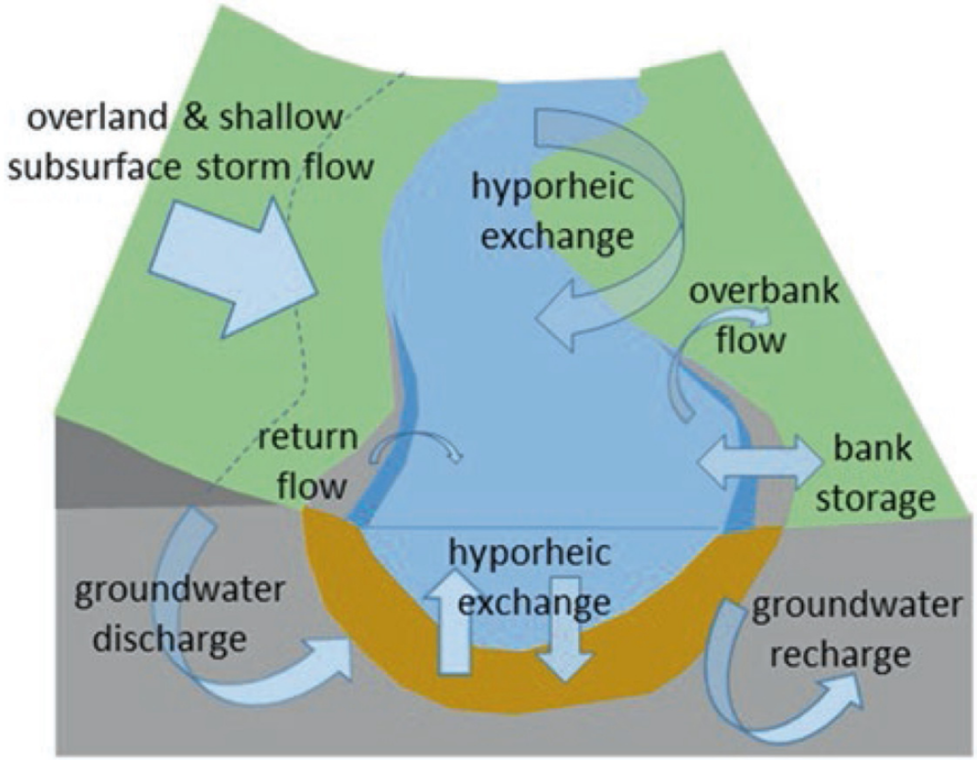
RECOMMENDED READING:

Barlow, P.M., and Leake, S.A., 2012, Streamflow depletion by wells—Understanding and managing the effects of groundwater pumping on streamflow: U.S. Geological Survey Circular 1376, 84 p.
Available at:
http://pubs.usgs.gov/circ/1376/



Wohl, E. 2018. Sustaining River Ecosystems and Water Resources. Springer, 151 pp.

OUTLINE:

- **Review of groundwater basics:**
  - Groundwater Head, Conductivity/Permeability, Recharge & Discharge
  - Groundwater and streamflow: Interflow, Groundwater, Streamflow, Bank Storage, Hyporheic Flow
- **Effects of groundwater on hydrographs used in EFN setting methods**
  - Groundwater contributions to the hydrograph
  - Groundwater delayed effects on surface flow: location and timing
  - Allocations and EFN setting challanges
- **Groundwater, the hyporheic zone and the river corridor.**
  - The role of the hyporheic zone in stream ecosystem health
  - The effect of groundwater extraction on the river corridor
- **The challenges of groundwater / surface water interaction measurements**
  - Physical methods: Piezometers, seepage meters, differential stream flow.
  - Chemical methods: Mixing models
  - Heat methods: Local, reach scale
  - Reconciling measurements at different scales
- **Summary: Key messages**

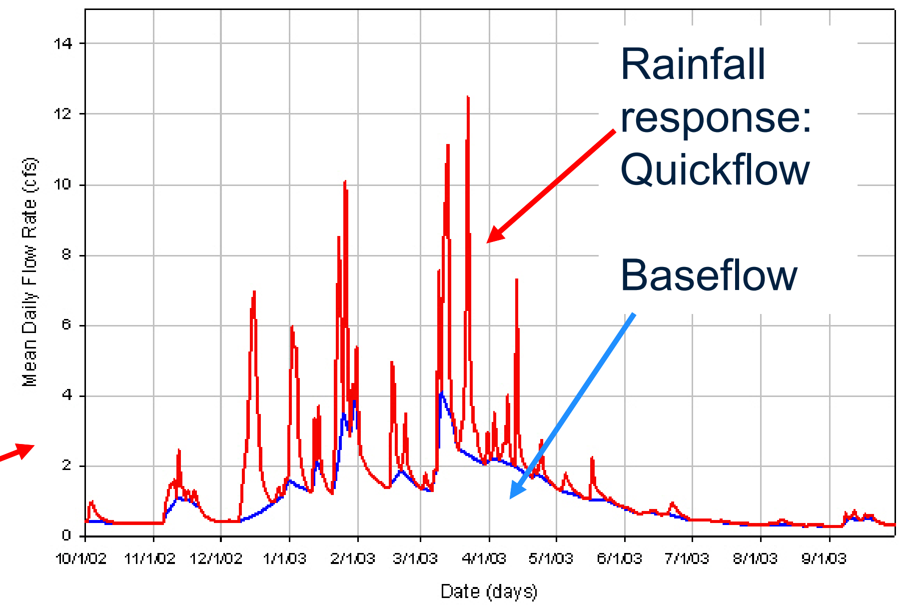
COMPONENTS OF STREAMFLOW HYDROGRAPHS

Rainfall leads to over ground Runoff, and to soil Interflow. Together, these make up Quickflow, which is the fast response to rain events.

When there has been no recent precipitation the hydrograph is supported by baseflow. Groundwater is the dominant component of baseflow

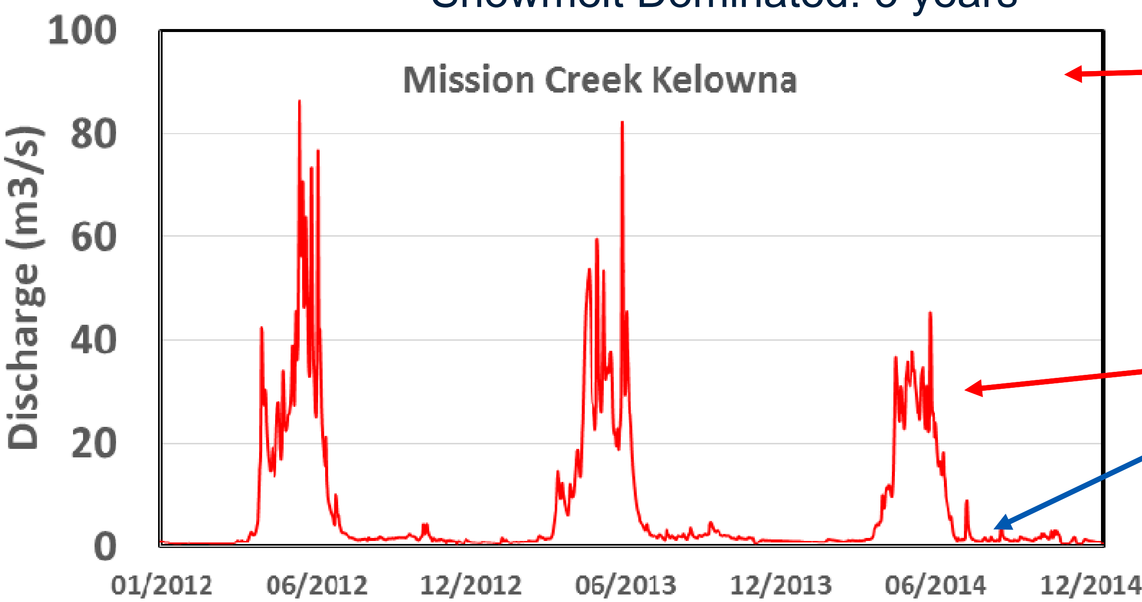
In rainfall dominated systems, quickflow and baseflow are present year round.

Rainfall Dominated: 1 year



https://www.mathworks.com/matlabcentral/fileexchange/36387-hydrograph-separation-using-hydsep

Snowmelt Dominated: 3 years



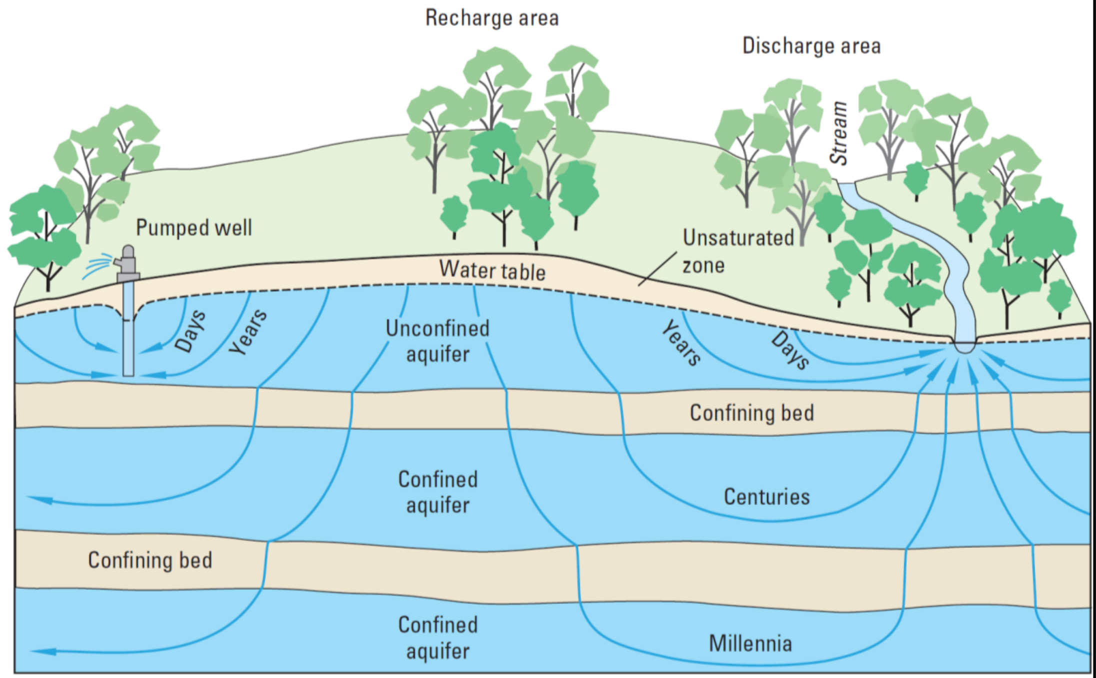
In dry, snowmelt dominated systems like the Okanagan, baseflow conditions dominate outside of the freshet season.

Spring Snowmelt - Freshet

Baseflow

GROUNDWATER FLOW BASICS

Groundwater is present everywhere under the ground in the pore spaces and fractures. There are no “underground rivers”. Water flows from locations where water has high energy to places where there is lower energy.



USGS Circular 1376

Groundwater Head: Water’s energy can be gravity (height) energy, or it can be energy stored as water pressure. Groundwater Head combines these two energy sources. The elevation of the water inside a well is a measure of the groundwater head (total energy) of the groundwater outside the well screen.

Conductivity / Permeability: Sediments like gravel have big pores, and groundwater flows easily (high hydraulic conductivity or permeability) and are aquifers . Clay or dense bedrock may have very small pores, or few pores (low conductivity or permeability, termed aquitards, or confining layers)

Recharge from Rainfall: Rain and snow falling on the ground surface infiltrates into the ground. Within the soil, or unsaturated zone, pores have both water and air in them. Water may flow sideways in the soil to a stream (interflow), or get used by plants (evapotranspiration). Water that makes it deep into the ground reaches the water table (where the pore spaces are 100% full of water) to become groundwater. This is known as groundwater recharge.

Recharge from Streams: In some locations, the water level in a stream is higher than the surrounding water table and stream water flows out and becomes recharge to the groundwater.

Discharge to streams and Lakes: The water table typically slopes towards streams and lakes, and groundwater discharges to surface water. This may take days, to 1000’s of years.

Groundwater pumping: Human extraction of groundwater from wells.

INTERFLOW VS GROUNDWATER & HYPORHEIC FLOW

Flow	Description	Spatial Scales	Temporal Scales	Chemistry	Effect on EFN?
Stream Flow	Water flowing in the stream	ms to 100s kms	Hrs to Weeks	Typically well oxygenated. Temperature fluctuates daily. Lower dissolved ions	Short term (hours) to long term (season) fluctuations. Extractions, diversions, discharges, dam operations.
Groundwater	Water flowing below the water table. May be flowing towards streams or lakes and adding to surface water (baseflow), or may be flowing away from stream (recharge). Pumping may reverse flow away from stream (induced recharge) Generally unidirectional over short times.	ms to 100s kms	Hours to Millennia	Long contact with sediments, may be reduced oxygen. Stable temperature at depth = annual average air temperature. Typically higher dissolved ions than surface water.	Continuous process. Inflow: Supplies baseflow. Increases with rainfall, and seasonally. Natural recharge driven by geometry, not small scale stream water levels. Induced recharge variable.
Hyporheic Flow	Bidirectional: Water flowing from the stream, into the bed, and back to the stream. No net effect on stream flow rate.	cms to 10s of metres.	Seconds to Days	Increases oxygen in bed at inflow, reduces stream temperature at outflow, important nutrient cycling in bed.	Pattern affects spawning preferences. Pattern may change with stream depth, and with groundwater changes.
Bank Storage	Water flowing out of the stream through the banks of the channel and into local groundwater system during high storm events or snowmelt season. Some proportion later returns to the river.	ms to 100s metres	Hrs to Months	Moderate contact with sediments, mixing with groundwater. May come back chemically more similar to groundwater.	Extends high flows after storms, and after snowmelt freshet season.
Interflow	Water flowing in the soil zone near the stream	ms to 100s of m.	Minutes to Days	Short contact with soil zone: weathering of soil minerals	Typical in rainfall events
Overbank Flow	During high water, water that flows over the top of the channel banks and out across the landscape. This may later return	ms to Kms.	Minutes to Months	Infiltrates otherwise unsaturated soils. Returning chemistry may vary from groundwater	Extends high flows after storms, and after snowmelt freshet season.

*There is a distinction between the time scales over which changes in flow propagate, and the residence time of water in a system. Time scale here refers to the rate at which changes propagate, which is much faster than the actual residence time. For example, infiltration during a rainstorm may cause interflow which appears a the water table or streams in hours, but the actual residence time of water in the soil zone might be years. Aquifers in the North Okanagan contain water 1000's of years old, but pumping might change the water levels across the aquifer in weeks.

SURFACE WATER – GROUNDWATER INTERACTIONS IN THE UPLANDS

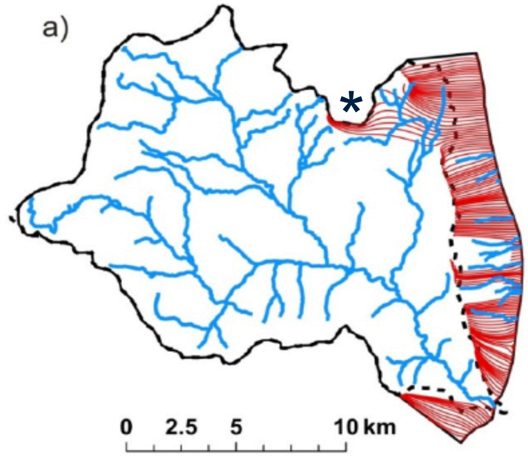
Groundwater flow may separate into local flow systems, intermediate flow system and regional scale systems.

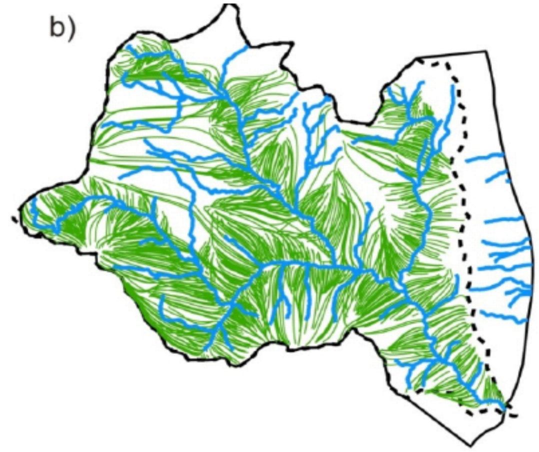
Local: Groundwater mostly flows to the closest stream down gradient (b, green traces).

Intermediate: Sometimes water flows under the closest stream and discharges to another stream reach (c, blue traces) further downgradient in the watershed.

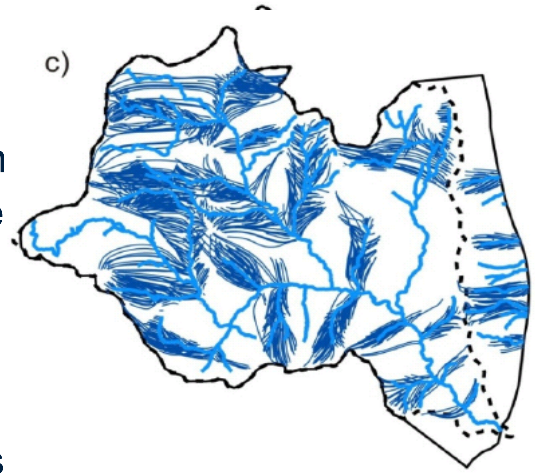
Regional flow: Flow that reaches deep within the aquifer system, to reappear at a much lower elevation, having bypassed several opportunities to discharge to surface water.

In the Okanagan, some groundwater flows directly from the bedrock uplands to the aquifers in the middle of the valley (e.g.: map a, red traces). Mostly this is from the slopes on the valley edge, but some flows from deeper in the watershed (e.g.: map a, red traces below the *). ~90% of the water rechargeing groundwater in the uplands watersheds returns to surface water in the bedrock watershed.

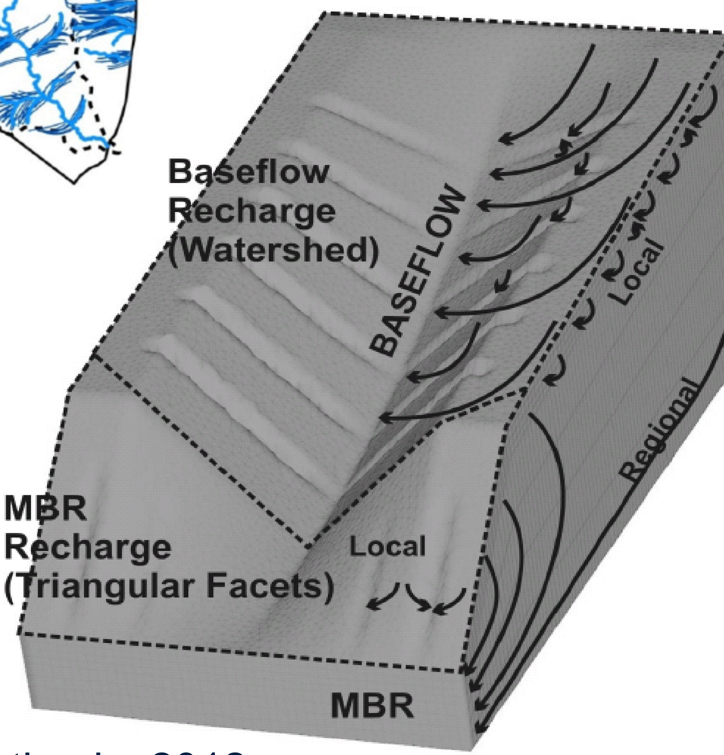




Lambly Creek Watershed
West side of Okanagan Lake



Hypothetical
Bedrock
Watershed



L. Welch, SFU PhD thesis, 2012

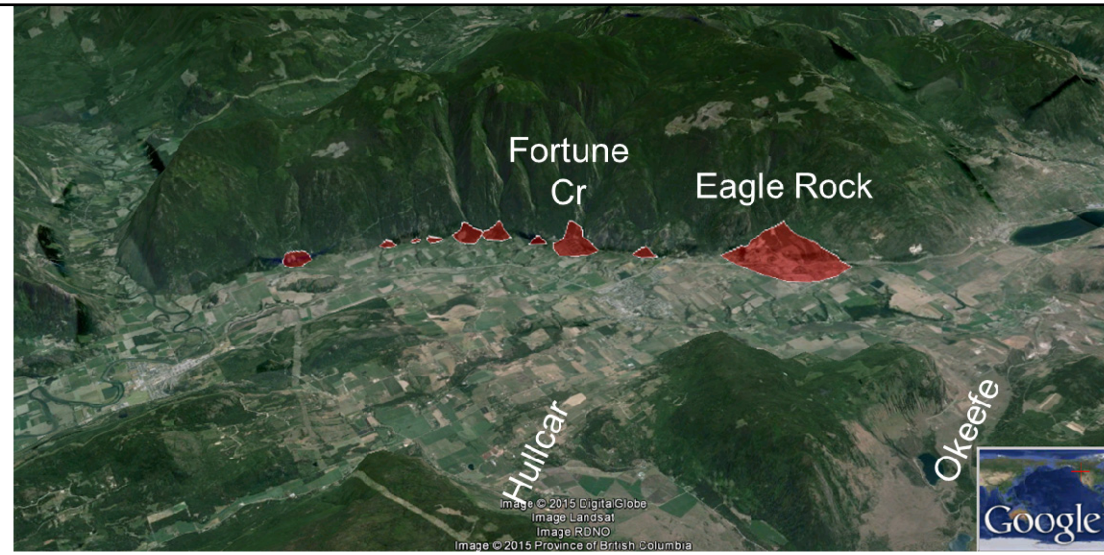
SURFACE WATER – GROUNDWATER INTERACTIONS IN THE VALLEY FLOOR

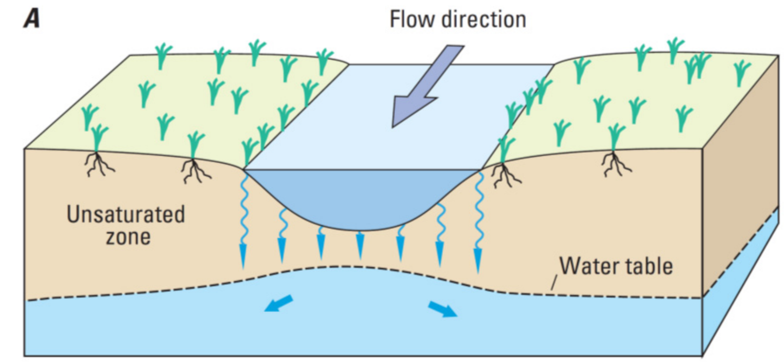
In the Okanagan streams change character at the bedrock to valley floor transition. Typically, there is an alluvial fan built up where streams leave the bedrock portion of the watershed.

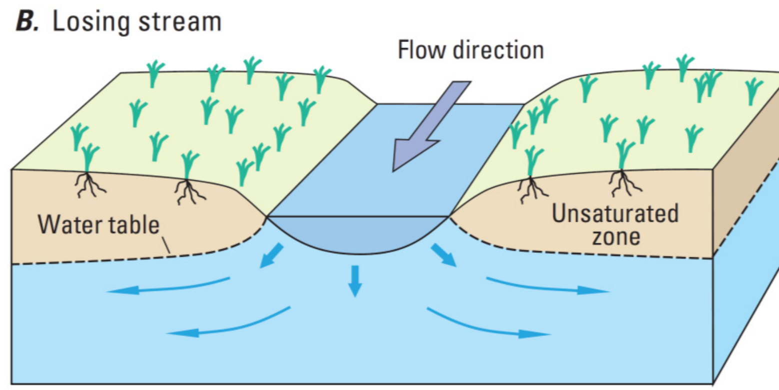
Across these fan, the stream elevation in the fan may be above the water table (A), or connected to the water table, but higher (B). On the valley floor, streams may gain (C) or lose (B) groundwater.

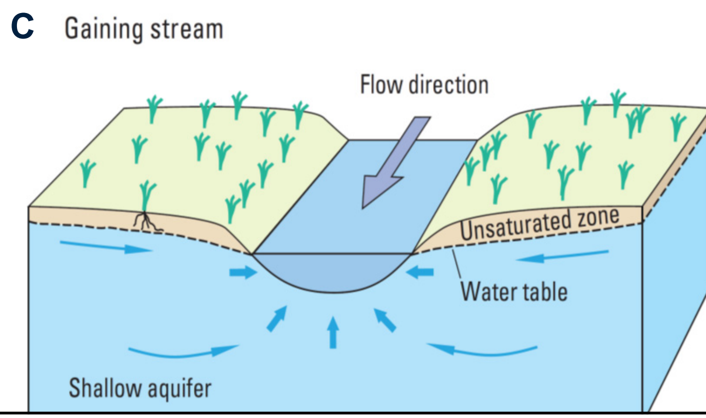
Recharge of groundwater at the valley edge by losses from streams is an important source of recharge

Typically, most groundwater pumping occurs in the valley floor.

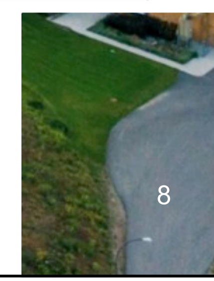








USGS Circular 1376



WHERE DOES GROUNDWATER PUMPING COME FROM?

Storage: Groundwater pumping creates a “cone of depression” in the water table around the well. Some groundwater is permanently removed from storage as the cone of depression is created.

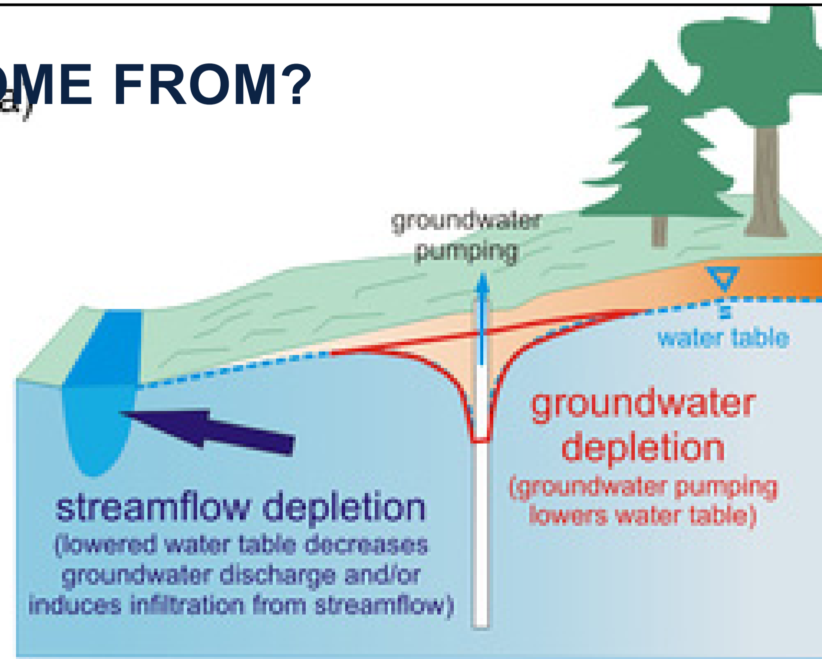
> *“All water discharged by wells is balanced by a loss of water somewhere. This loss is always to some extent and in many cases largely from storage in the aquifer. Some groundwater is always mined.” Theis (1940).*

Streamflow Depletion or Streamflow Capture: This is the dominant source of groundwater. As time progresses, the water comes from either (a) intercepting water on its way to becoming baseflow to surface water somewhere else or (b) the pumping lowers the water table compared to surface water, and water starts flowing out of surface water back into groundwater, termed induced recharge. :

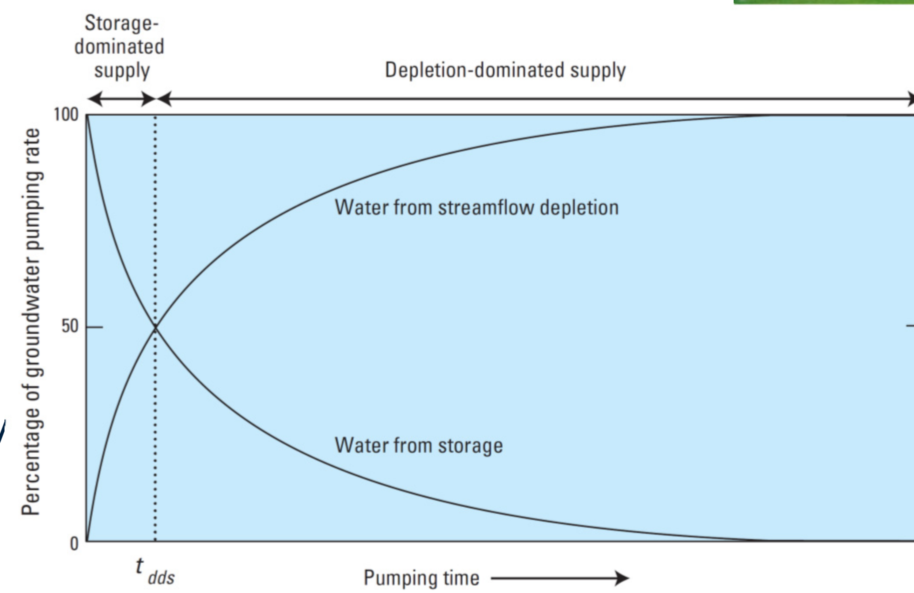
> *“Overall 85% of long-term pumping is derived from stream capture” (Konikow & Leake, 2014).*

The effect of pumping on streams is time lagged. Some wells may affect flow in hours, or summer pumping may affect fall streamflow. In very large aquifers, the effects of pumping may take decades to affect the streamflow.

Evapotranspiration Reduction: Lowering the water table may prevent this water from being available to vegetation to use for evapotranspiration. This is particularly true near wetlands and riparian areas. This water would have been “discharged” from the watershed by the vegetation, rather than discharge in streamflow



Gleeson, T. and B. Richter (2018) How much groundwater can we pump and protect environmental flows through time? Presumptive standards for conjunctive management of aquifers and rivers, River Research and Applications, 34, (1): 83-92, DOI: (10.1002/rra.3185)



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GROUNDWATER PUMPING: DELAYS IN AND LOCATIONS OF STREAMFLOW DEPLETION

The time it takes for streamflow depletion to outweigh storage depletion is the “time of full capture. Well head protection zones are designed around actual travel time of water calculations, and typically consider 1, 5 and 10 year travel times. Groundwater in aquifers may be decades to millennia old. In contrast, the rate of propagation of a change in flow rate is much faster. For example, the time for pumping in typical Okanagan aquifer to reach 95% of long term effect ranges between < 1 or up to ~3 years (max distance between well and river ~2.5 km; aquifer 4a and 4b; 95% reached at 3*stream depletion factor).

The simplest model is based on: $\tau = \frac{L^2}{(T/S)}, L\ is\ length\ scale, T\ is\ transmissivity\ and\ S\ is\ storativity$

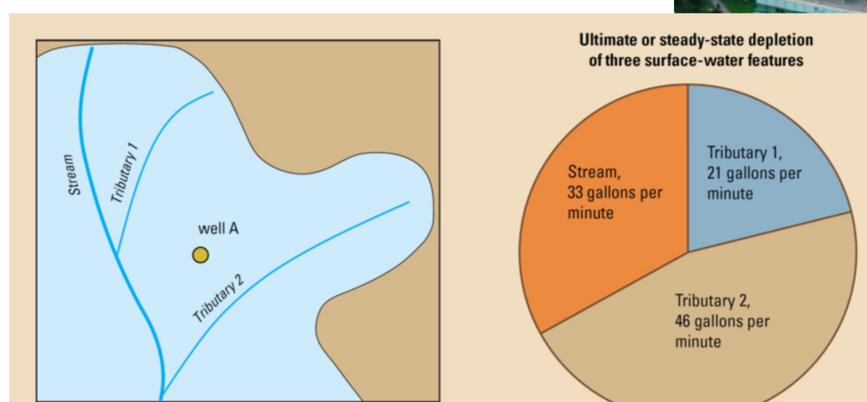
Aquifer Type	Transmissivity T	Storativity S	Diffusivity D	Stream Depletion Factor (days) Distance between pumping and surface water (m)				
				"Close"				Ok. Max.
	m2/day		m2/day	100	300	500	1000	2500
1a - Unconfined or partially cofined fluvial and glaciofluvial aquifers along high-order rivers	4500	0.2	22500	0.4	4.0	11.1	44.4	277.8
1b - Unconfined or partially cofined fluvial and glaciofluvial aquifers along moderate-order rivers	1800	0.14	12857.1429	0.8	7.0	19.4	77.8	486.1
2 - Unconfined deltaic aquifers formed in river deltas	1000	0.07	14285.7143	0.7	6.3	17.5	70.0	437.5
3 - Unconfined alluvial fan aquifers	420	0.02	21000	0.5	4.3	11.9	47.6	297.6
4a - Unconfined aquifers of glaciofluvial origins	650	0.04	16250	0.6	5.5	15.4	61.5	384.6
4b - Confined aquifers of glaciofluvial origins	340	0.00044	772727.273	0.01	0.1	0.3	1.3	8.1

Modified from: Rathfelder, 2016, Modelling tools for estimating effects of groundwater pumping on surface waters. Water Science Series, BC Ministry of Forest, Lands, Natural Resource Operations and Rural Development.

Therefore it is likely that all historical Okanagan pumping is already having effect on surface water.

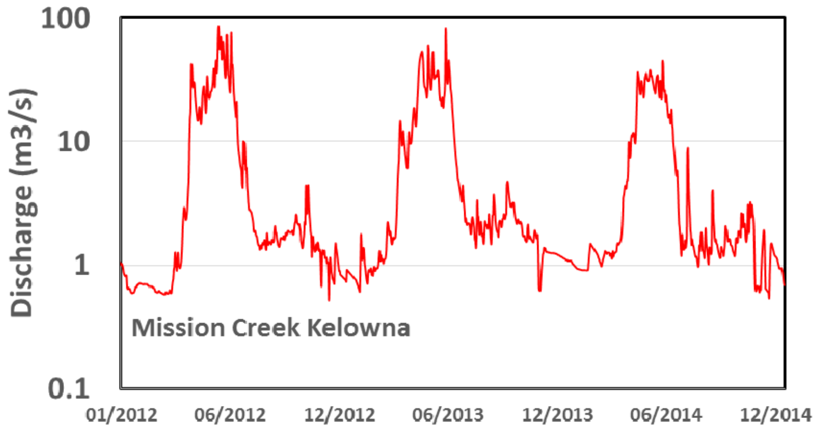
The delay for a confined aquifer (4b, a silt or clay layer between the aquifer and the stream) may be

The physical location of where streamflow is depleted in a multi-stream situation can be estimated from various analytical formulas or determined from computer models.



Plan view of portion of aquifer around well A (fig. 42). In this example, well A is assumed to pump at a rate of 100 gallons per minute.

"NATURAL" VS "NATURALIZED" HYDROGRAPHS



The assumption is that stream ecosystems adapted to natural variations in streamflow within years, or between years prior to human contact. Human activities that reduce flow place additional stress on the system by making natural dry years occur more frequently

The "natural hydrograph" or a "naturalized hydrograph" is the starting point for EFN determination methods. However, these seem to have no agreed meaning in common usage, nor a legal one in BC or Federal law.

*"….**natural hydrograph**…the hydrograph that would have occurred if no development was present within the watershed (a calculated, "naturalized" hydrograph). Alberta Regional Aquatics Monitoring Program.*

Natural here means "no development". The "calculated" includes both restoring surface and groundwater impacts. Many stream channels and watersheds in the valley floor areas were heavily modified from "natural" by channelization, dyking and land use change prior to the collection of any streamflow data. Many uplands have been logged. A "natural hydrograph" should mean the stream and watershed prior to any human alterations to channel morphology, watershed character, or flows. Hydrographs from valley floor stations are typically for the current modified channel and conditions. So, any calculations based on measured data are for the "current channel" and are not "natural".

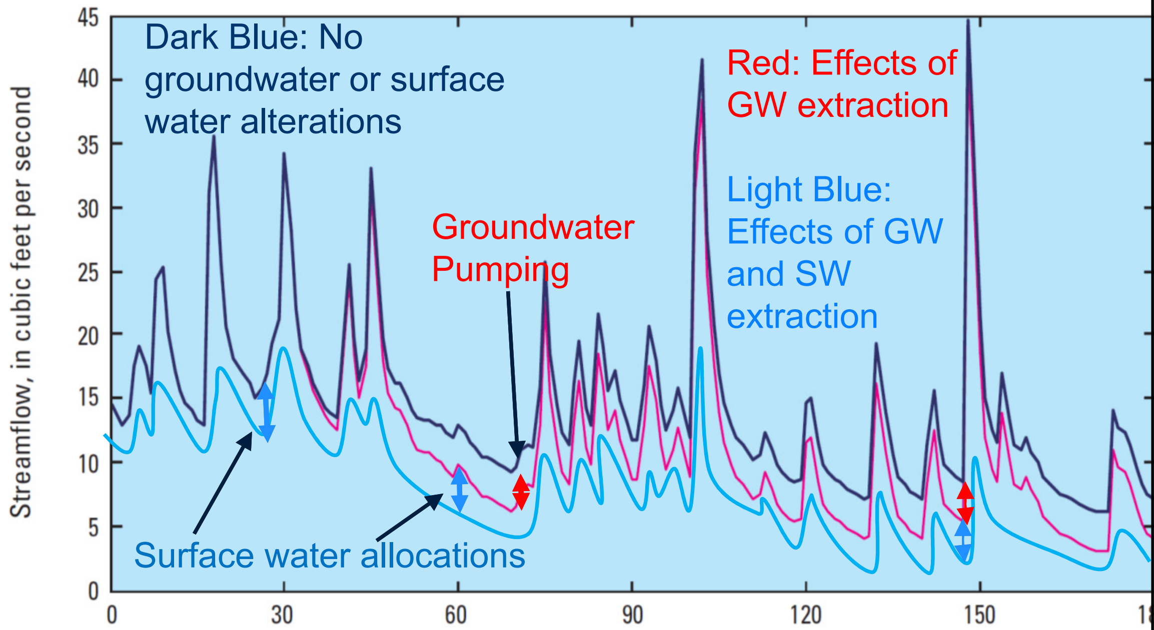
***"Naturalized flow:** Measured flows that are adjusted for upstream water licenses or uses to approximate the flows that would occur in the absence of regulation and extraction." ESSA Technologies & Solander Ecologial Research, 2009. Instream Flow Needs Analysis for the Okanagan Water Supply & Demand Project*

This description accepts that the channel and/or watershed are no longer "natural", but seeks to determine flows as may exist now in the modified watershed. This version of "naturalized flow" is calculated from the current measured hydrograph data + surface water extractions – surface water discharges +/- effects of reservoir operations. This hydrograph is perhaps better described as a "surface water usage compensated current hydrograph" as it includes the current channel and land use, but does not include any effects of groundwater on the hydrograph.

Some policies are ambiguous as to what type of hydrograph is to be considered: *"Key aspects of the **natural hydrograph** should be maintained by restricting hydrologic alterations to within a percentage-based range around <u>natural</u> or <u>historic</u> flow variability (DFO, 2013)" BC Govt. EFN Policy March 2016.*
"Natural" seems to mean actually natural, but "historic" implies measured hydrographs that are likely not natural.

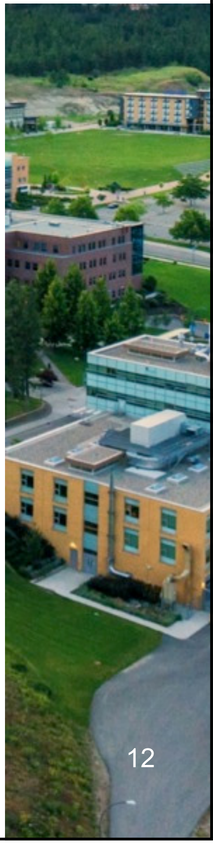
GROUNDWATER EFFECTS ON HYDROGRAPHS

Consider a hypothetical watershed where the channel and land use has been changed. Hydrographs are collected in the valley bottom where groundwater pumping exists. The light blue line is the current measured hydrograph. When the known surface water alterations are accounted for, the red "naturalized" hydrograph is produced. However, this hydrograph is affected by ongoing historical groundwater pumping which lowers the "non affected" blue hydrograph down to the red hydrograph. In the past, groundwater effects on hydrographs have not been explicitly corrected for and so the streamflow hydrograph used for setting surface water extraction would have been the historical records of measured streamflow data (light blue) corrected for surface extractions (red).
Streamflow allocation decisions would therefore have been partially compensated for groundwater usage, as they started from a lowered hydrograph (red). This does creates some difficulties:



USGS Circular 1376

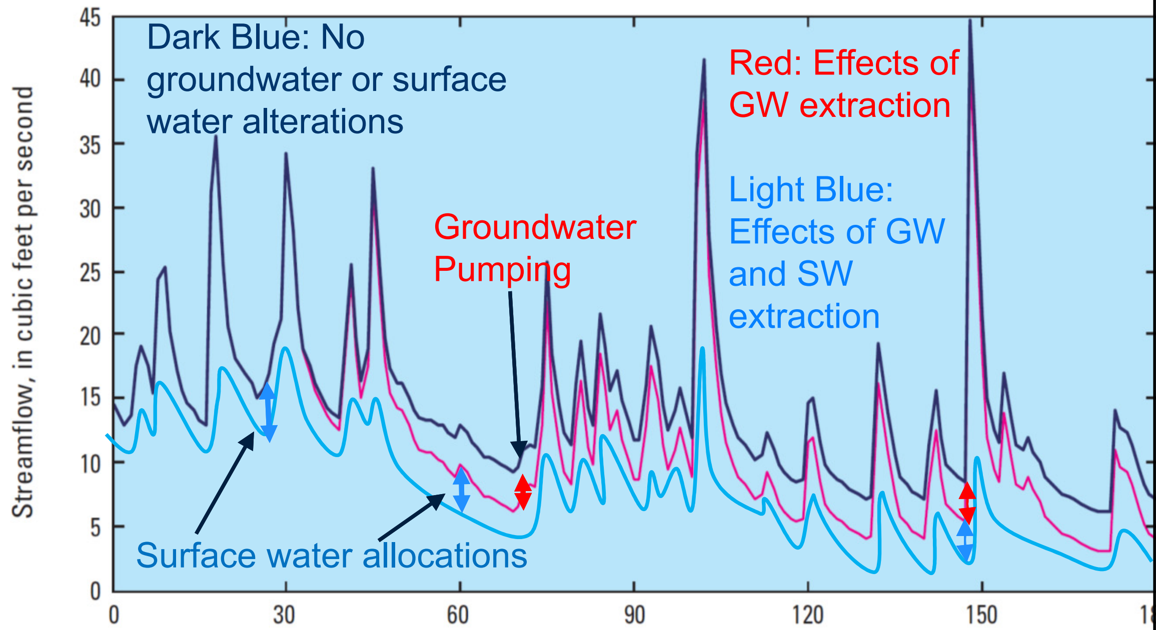
(1) If groundwater extractions significantly changed during the observation period, then the difference between no extraction (dark blue) and groundwater affected (red) would not be constant. The historical statistics of the red hydrograph from multiple years will not be representative.
(2) The "naturalized hydrograph" is found from the currently observed hydrograph (light blue), compensated for surface water effects, and would represent the groundwater affected hydrograph (red). As groundwater effects may be seasonal (as above) or significantly delayed, calibrating a hydrology model to the red hydrograph would be matching to the dark blue line in winter, but the red line in summer. This may misrepresent the watershed "productivity'.
(3) Decisions often must be made in unmonitored watersheds. The calibrated properties of hydrology models calibrated to watersheds with groundwater pumping may not directly apply to watersheds without groundwater pumping, as they would likely underestimate water flows by recreating a "red" hydrograph, not the dark blue hydrograph.



HYDROGRAPHS FOR GROUNDWATER ALLOCATIONS AND EFNS

The difference between the dark blue and red hydrographs, and between the red hydrograph to the light blue have both been growing over time.

When licensing existing groundwater pumping, it should not be further subtracted from the light blue line as a new extraction, as this may double count prior groundwater extraction (already accounted for in difference of dark blue to red). New groundwater extractions are not accounted for in the red hydrograph and should be subtracted from the light blue line, but with consideration to the time delay.

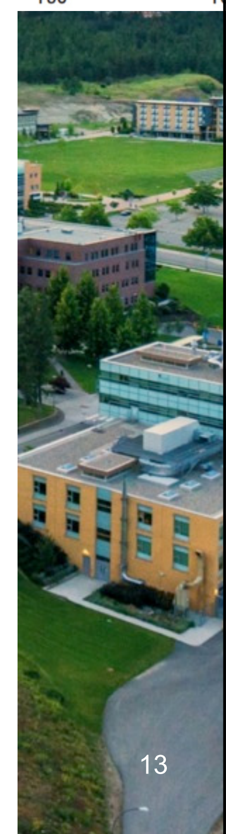


USGS Circular 1376

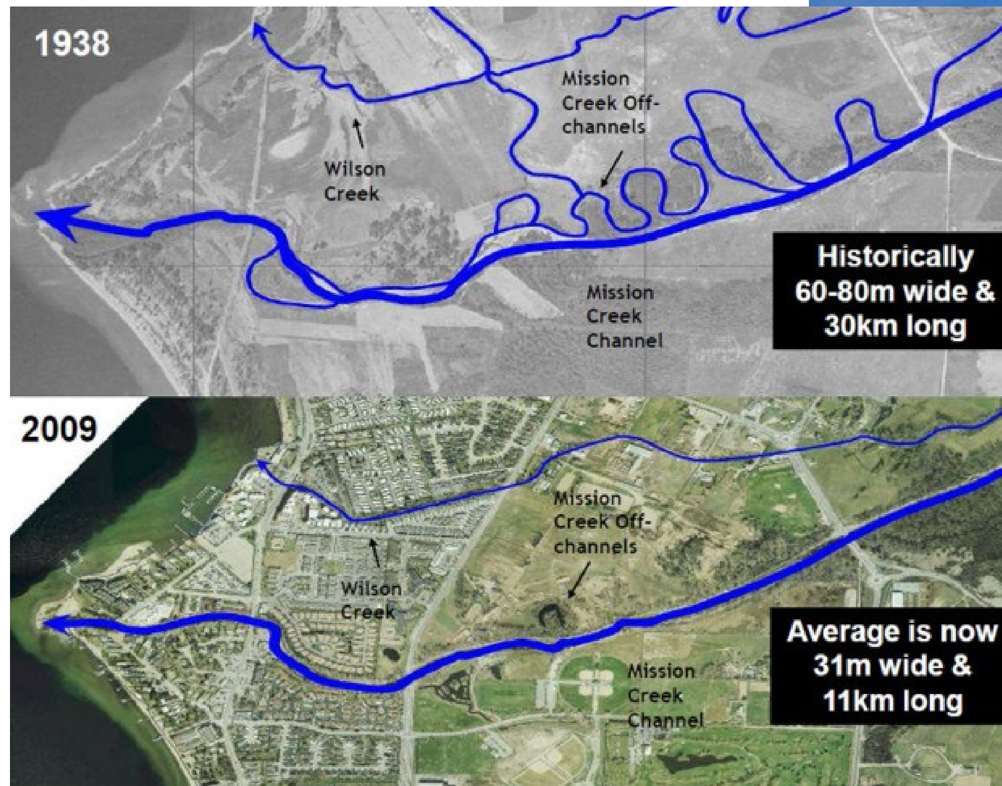
Integrated SW and GW licensing decisions would best be done by determining the dark blue hydrograph by (1) restoring all surface water alterations and (2) restoring all groundwater alterations to the appropriate timing in the hydrograph. Usage (2) may be affected by delays of days to decades. The lack of historical groundwater pumping data presents significant challenges to actually doing this.

An "All usage compensated current hydrograph"= current and historical measured hydrographs that represent the existing channel and land use patterns + surface water extractions – surface water discharges +/- reservoir operations. ***+/- effects of groundwater pumping on streamflow, appropriately timed.***

The setting of Environmental Flow Needs also needs to acknowledge that a most naturalized or surface water usage compensated current hydrographs (red) are already a reduced flow due to historic groundwater pumping. The starting point for EFN setting for the existing channel and land uses should be the "all usage compensated current hydrograph" (dark blue). Measures such as a percentage fraction of mean annual discharge, or statistics of flows (e.g.: the 1 in X year drought flow or flood flow) should be taken from the dark blue hydrograph, otherwise the EFN would be underestimating the flow needs.



“ALL USAGE COMPENSATED CURRENT HYDROGRAPH” VS “NATURAL” VS “RESTORED”



The “all usage compensated current hydrograph” is still not a “natural” hydrograph, if natural is taken to be “not influenced by any anthropogenic effects”. Hence, the inclusion of the word “current” which is used to imply that it refers to the stream and watershed in its current state.

An all usage compensated current hydrograph is still affected by:

1. Changes in upland forest hydrology due to timber harvesting
2. Changes in upland forest hydrology due to changes in fire frequency/size under natural conditions, indigenous fire management or current fire management.
3. Stream geometry alterations in the valley floor due to channelization and dyking.
4. Changes in lowland hydrology due to forest clearing, agricultural land management, and urbanization.
5. Changes in hydrographs due to lake level control (in the Okanagan).

Hydrographic data for most of BC has been collected primarily after 1950, which is after the start of uplands timber harvesting, major valley land use and lake level alterations, and channel modification (e.g.: after the1948 flood year). The raw measured hydrograph data for determining an “all usage compensated current hydrograph” already includes the majority of these effects, and represents the hydrograph for that “current” channel and watershed configuration, as opposed to a truly “natural” or pre-anthropogenic watershed and channel configuration.

Setting an EFN from an all usage compensated current hydrograph accepts that the goal is to provide the best possible ecosystem conditions for the modified stream and watershed. It does not seek to compare that ecosystem health or character to that which would have existed in the past under natural conditions, nor does it consider the potential ecosystem character and watershed characteristics created in future by any restoration efforts (an “all usage compensated restored hydrograph”

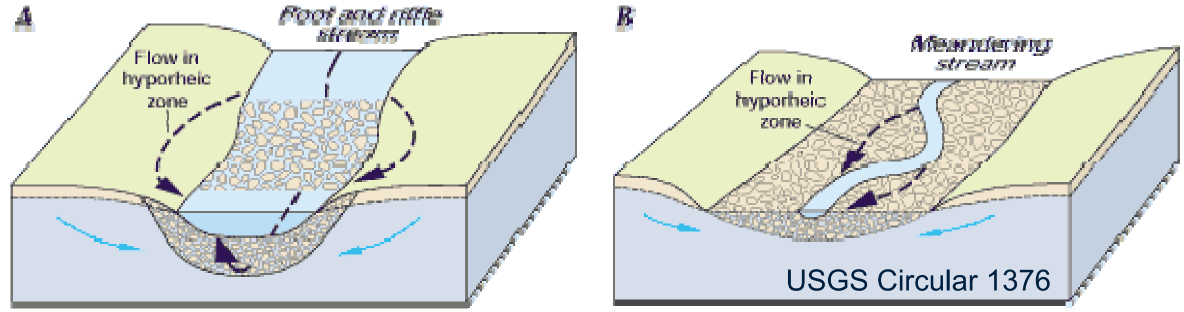
HYPORHEIC FLOW AND GROUNDWATER FLOW

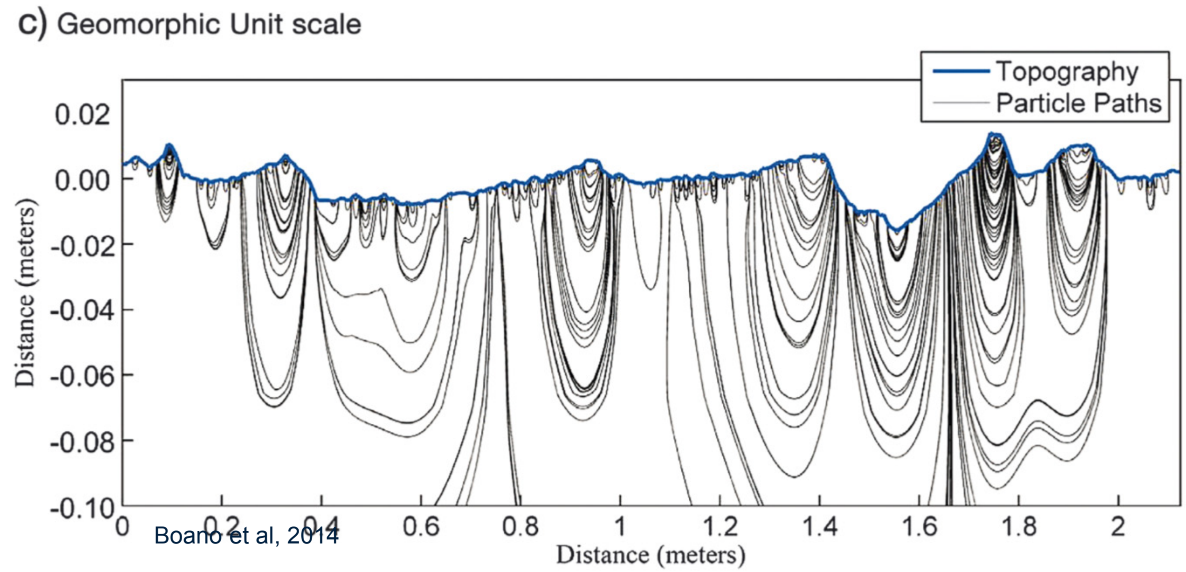
Hyporheic flow is water that leaves the stream channel, flows temporarily in the stream bed, and then returns to the stream. Flows are driven by:

A. Changes in stream height like riffles and pools (cm to m's). Flows tend to increase when water is lower, and bed topography causes more dramatic changes in water surface.

B. Lateral channel meanders (ms to 10s of ms

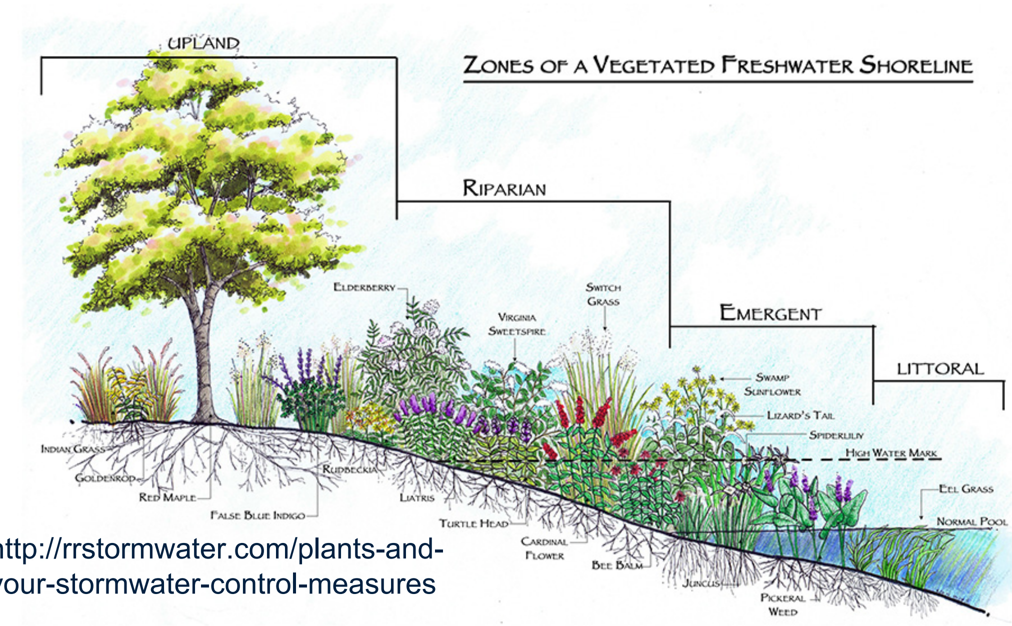
C. Small scale changes in stream bed character – rocks, pieces of wood, transient bedforms like ripples, meander bends, bar forms, pool-riffle sequences. Higher pressure generated upstream where water piles up, and lower pressure downstream in the flow shadow (cms). Flow depth typically to ~0.8 size of feature.





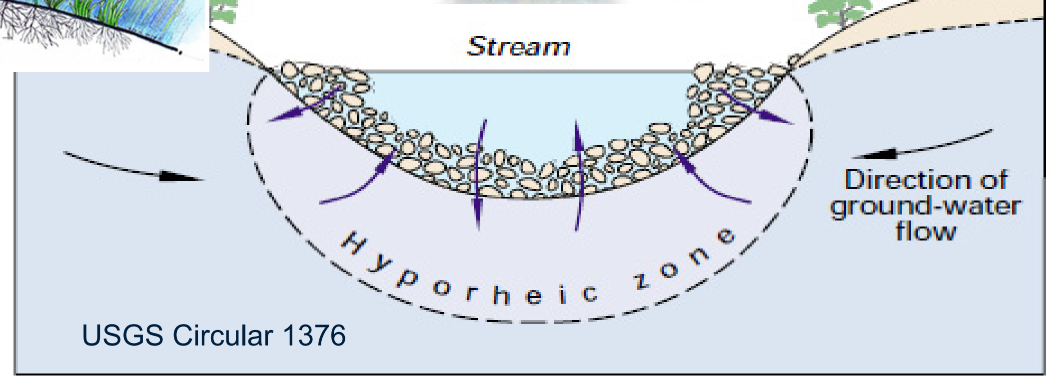
Flow rates at groundwater discharge locations can vary by 2 orders of magnitude, even in fairly uniform sand bottomed rivers (eg: Rosenberry et al, 2016). The focussed discharge locations can be driven by heterogeneity in the underlying aquifer, or can be due to differences in streambed material. These discharge locations might be static – e.g.: the intersection of bedrock with a stream. They might be semi-dynamic - e.g.: the intersection of an old stream channel with a stream acting as a focussed discharge. Or, these can be dynamic – e.g.: differences in the stream bed material, and hence its permeability. These latter groundwater components may move spatially due to changes in the bedforms between low and high flows– erosion of fines, deposition of fines, migration of bars and channels over time.

STREAM ECOSYSTEMS AND THE STREAM CORRIDOR



http://rrstormwater.com/plants-and-your-stormwater-control-measures

Water Column



USGS Circular 1376

EFNs in BC are typically designed around macrofaunal life cycles (e.g.: salmonids.). Streamflow is used as the master variable. The presumption being that if they are healthy, then the supporting ecosystem will be healthy enough as well.

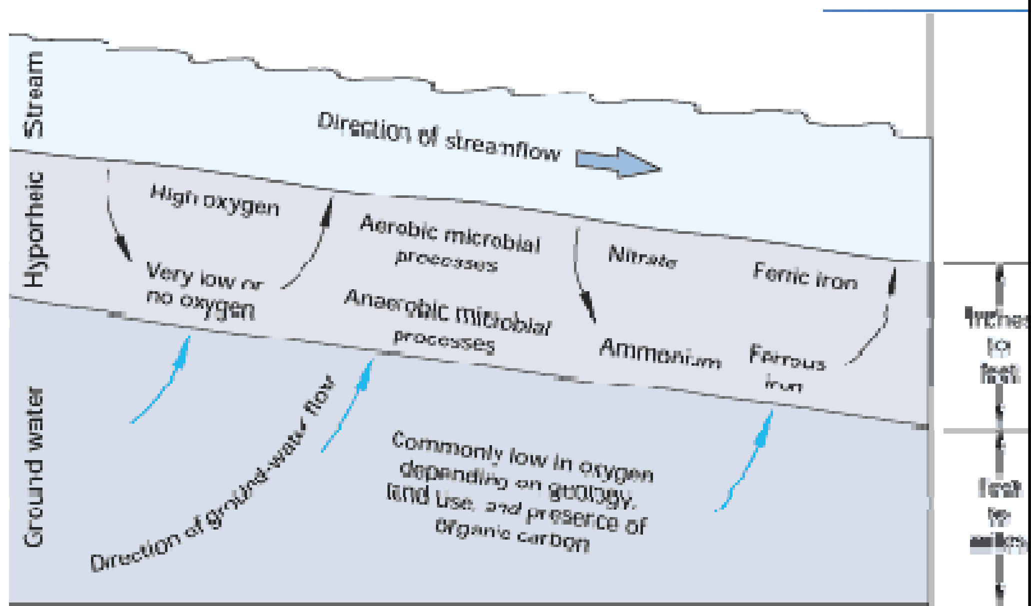
The ecosystem and biochemical functioning of a stream or river includes the stream water, the hyporheic zone, the instream vegetation and riparian vegetation which together make up the "stream corridor". Riparian or bank side vegetation along stream beds depends on the depth of the hyprorheic zone. Its rooting depth often matches the hyporheic zone. Vegetation outside channel may rely on the height of the water table for its water supply. Groundwater extraction may reduce water table elevations and alter the size of the hyporheic zone.

HYPORHEIC ZONE FLOW AND GROUNDWATER FLOW.

Streamwater flowing into the bed to become hyporheic flow has higher dissolved oxygen, high exposure to light, variable temperature, typically lower dissolved ions. May be high in nutrients. May be bacterially compromised.

Groundwater flowing out to streamflow has lower dissolved oxygen, no exposure to light, stable temperature, higher dissolved ions.

Increased mixing leads to higher microbial activity, more oxidation of dissolved organic carbon, more mineralization of nutrients, denitrification (removes excess dissolved nitrate (NO_3-)., more removal of metals as metal oxides, degradation of organics.
Increased O_2 in beds increases macroinvertebrates..



USGS Circular 1139

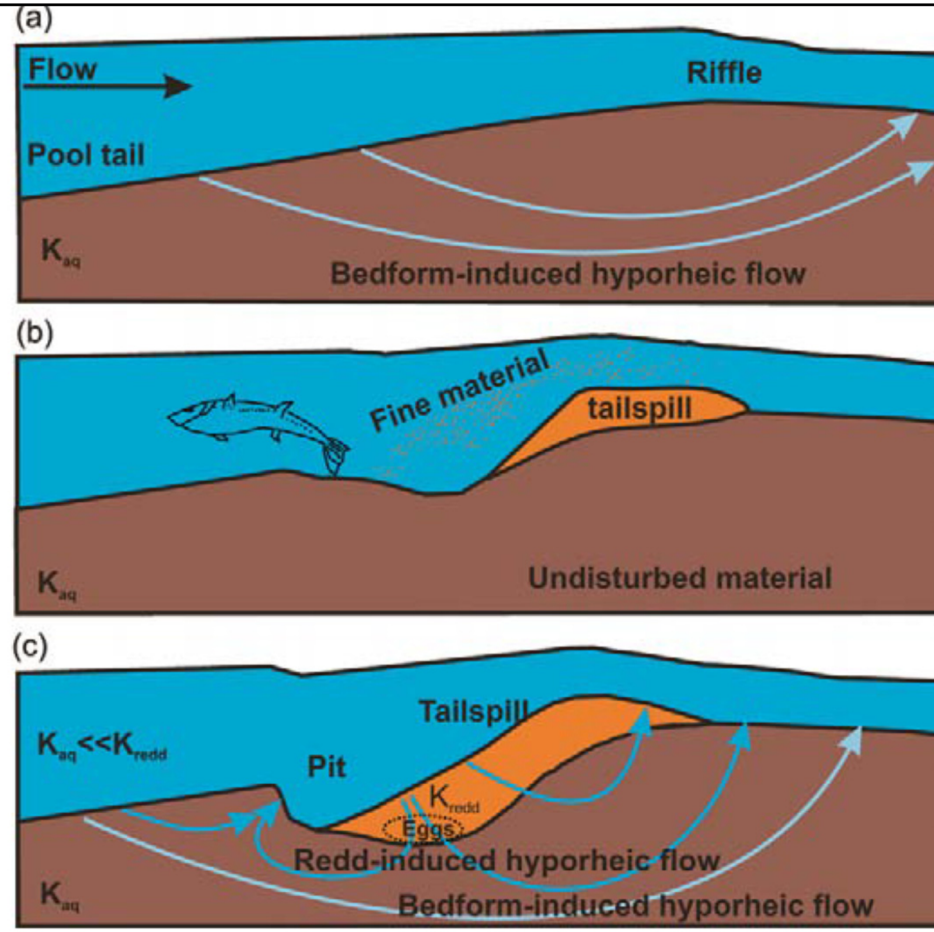
In general, the hyporheic zone increases in size in dry periods, and contracts in higher groundwater discharge conditions (Boano et al, 2014). Periods of flooding may increase the hyporheic zone by creating bigger bedforms. Nearby pumping of groundwater may help increase the size of the hyporheic biozone (by reducing groundwater inflows), or may reduce the size of the hyporheic zone.
Pumping enough to reverse gradients and induce recharge changes the biochemistry of the hyporheic zone, and may draw contaminants from surface water down like bacteria or excess nutrients into the groundwater.

HYPORHEIC FLOW AND SALMONID SPAWNING

Salmon dig redds in gravel river beds. Digging creates localized hyporheic flow conditions. The dominant effect of digging is that it removes the fines, increases conductivity increases hyporheic flow and increases oxygen reaching the eggs. Incoming cold water allows water to carry more oxygen and reduces metabolic rates.

Sockeye – spawn anywhere
Coho – spawn at mixed GW/SW
Neither pick hyporheic flow locations
(N. Neumann, 2013)

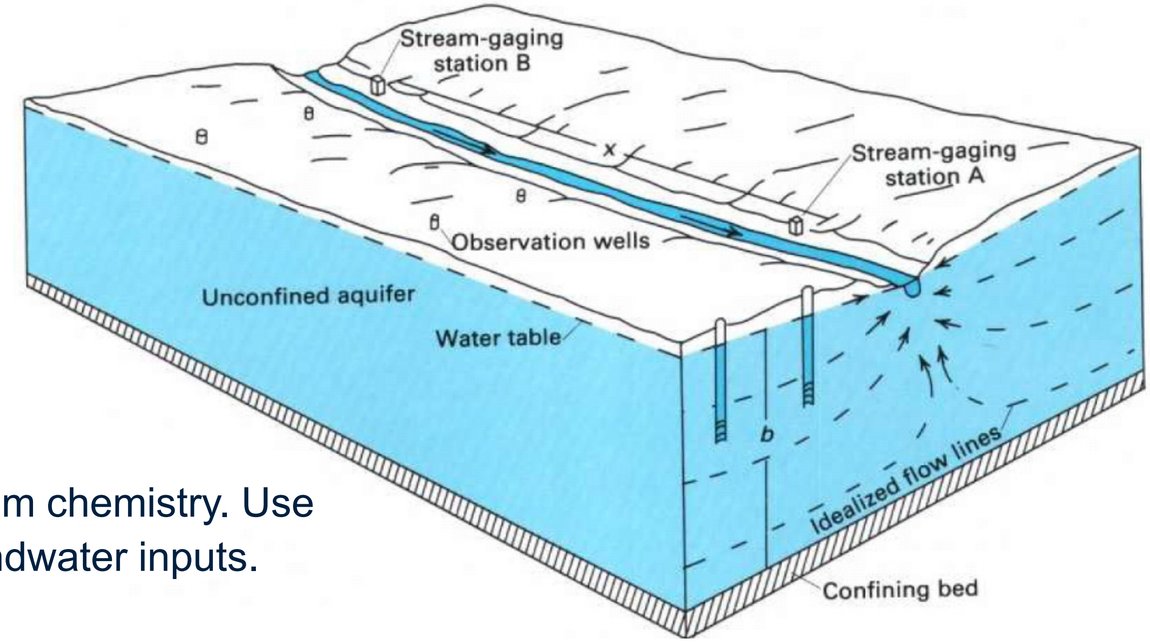
Chinook see upwelling zones when spawning (Geist et al 2002)



Tonina, D., and J. M. Buffington (2009b), A three-dimensional model for analyzing the effects of salmon redds on hyporheic exchange and egg pocket habitat, Can. J. Fish. Aquat. Sci., 66, 2157–2173.

Alterations in groundwater flow change the patterns of groundwater inputs, and change the locations and character of hyporheic flows.

QUANTIFYING GROUNDWATER INFLOWS AND OUTFLOWS

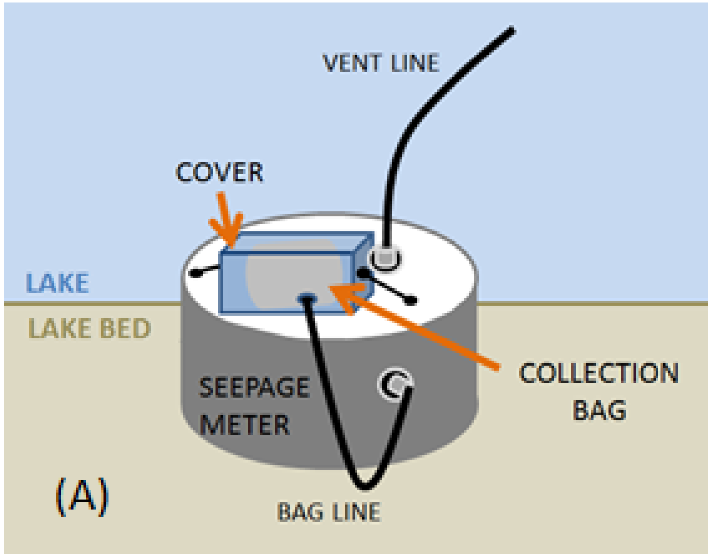


Physical methods:
Measure groundwater heads near the stream.
Measure streamflow upstream and downstream.
Measure flow cross the stream bed:
Seepage meters

Chemical Methods:
Measure groundwater chemistry, stream chemistry. Use mixing calculations to determine groundwater inputs.

Temperature Methods: Groundwater temperature is the average air temperature. Groundwater discharges cool streams in summer and warm streams in winter. Measure temperatures in stream or in stream bed.

Considerations:
Water flow across sediment interface at any given location could be either hyporheic flow or groundwater flow.
Groundwater discharge can be localized. Can vary by up to 10x to 100x between locations.
Flows may change seasonally, or with pumping.
Locations of focussed discharge can change as stream depth and groundwater pumping changes.



Seepage Meter

PHYSICAL MEASUREMENTS OF FLOW EG: MISSION CREEK:

Physical measurements are critical for calibrating model, but can be costly, and labour intensive.

Measure heads: Groundwater pumping may decrease groundwater levels near streams, but not actually reverse flow. Separating groundwater pumping influence from seasonal variations in water levels likely not possible without long records from before and after pumping

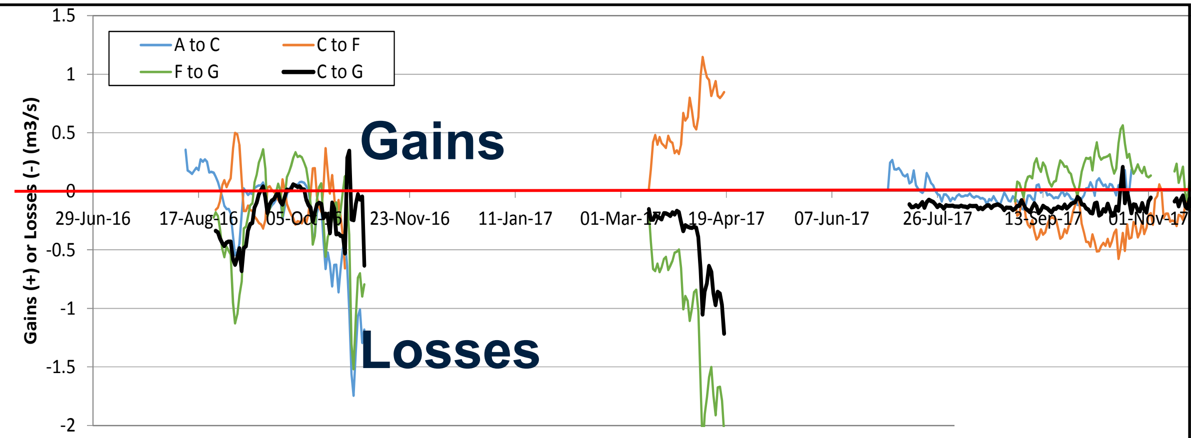
Measure upstream and downstream: Measure all known flows in-between. Measurement is not affected by hyporheic flow. Residual is groundwater inflow or outflow. Limited by the accuracy of flow data.

Excellent = +/- 2%

Good = +/- 5%

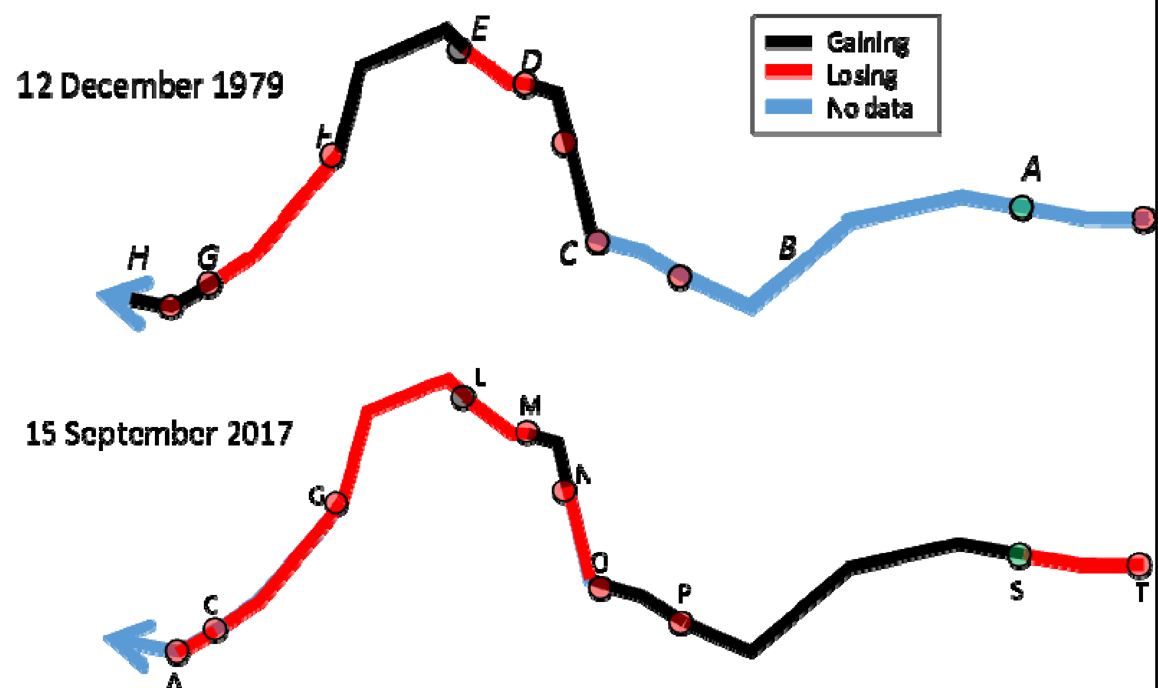
Poor = +/- 8%

Example: Mission Creek: Two years of data. Required streamflow, all surface water extractions, spring flows, diversions out and back in, tributary flows. Discovered many previously unconsidered inflows and outflows. Required 20 stations.



Gains and losses in streamflow

Stream segments that **Gain** or **Lose** groundwater



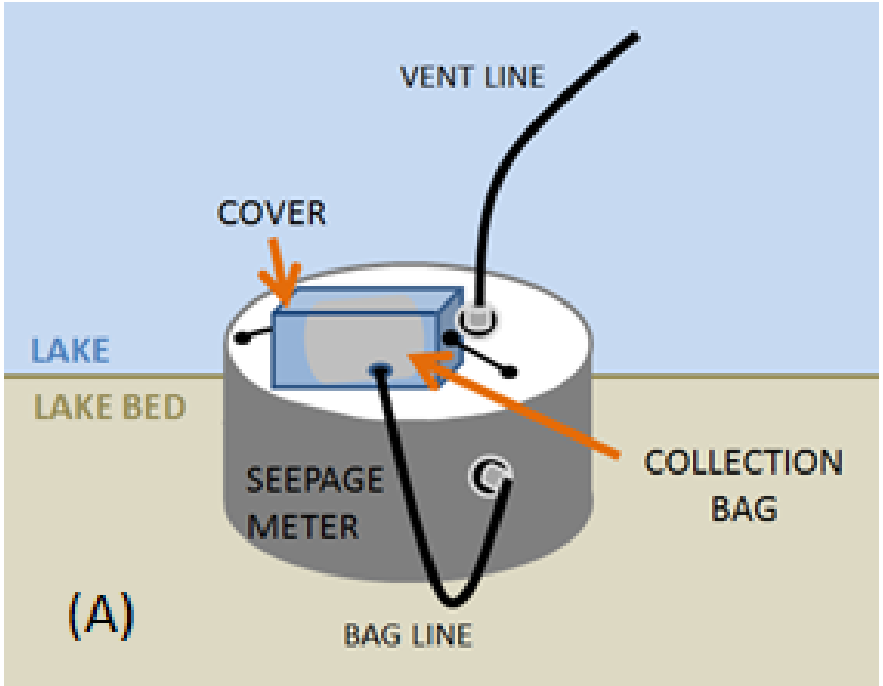
DIRECT INFLOW/OUTFLOW MEASUREMENT: SEEPAGE METERS

Method:
Chamber placed on stream, lake or ocean bottom, with sides pushed into the sediment / water interface.

Start with collection bag filled with known volume and measure the gain or loss from the bag after 24 – 72 hours. Calculate upwards or downwards flow across the sediment surface.

Issues:
Simple technology works well in lakes but needs special designs to be used effectively in most streams
Determines gains or losses.

Labour intensive
Cannot be used in coarse gravelly sediments
Could be measuring either hyporheic flow, or groundwater flow.
Takes a single measurement at a single point in space and time.



CHEMICAL METHODS: REACH SCALE

In stream mixing modelling:

Dissolved ions: Measure isotopes, chloride, cations (in some circumstances), electrical conductivity.

Gases: Some gases arefound in groundwater, but not surface water eg: Helium, Radon / Radium, Chlorofluorocarbons.

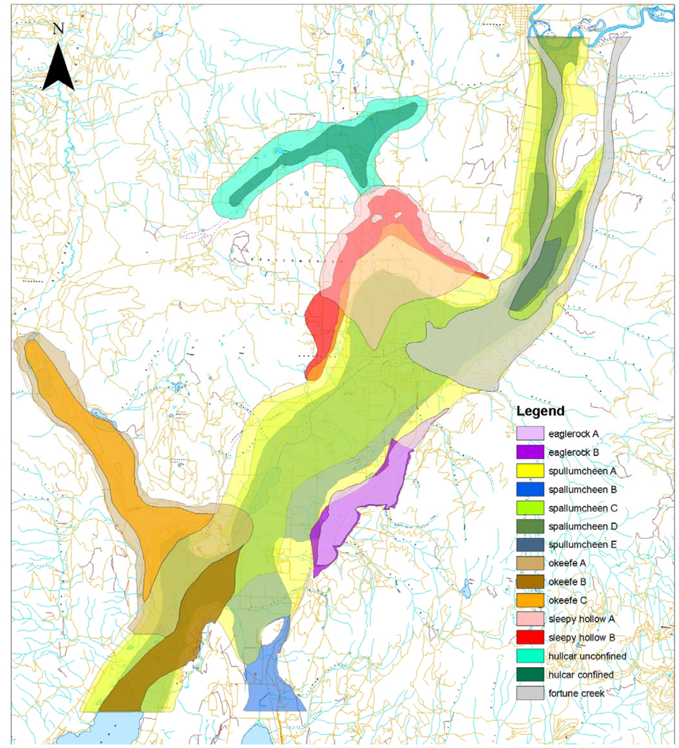
Regional mixing modelling:

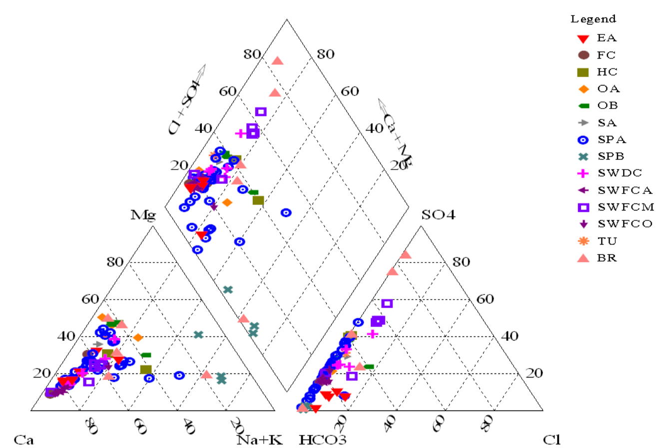
e.g.: North Okanagan.

Measure groundwater chemistry and surface water chemistry. Use groundwater geochemistry modelling programs to examine surface water chemistry upstream and downstream, and determine how much groundwater must have been added to create the changes in chemistry along the reach.

Methods detect net gains in water, and cannot determine losses.

North Okanagan Mapping Project Aquifer Delineations (Monahan, 2006)
and NOGWCA Survey Well Locations

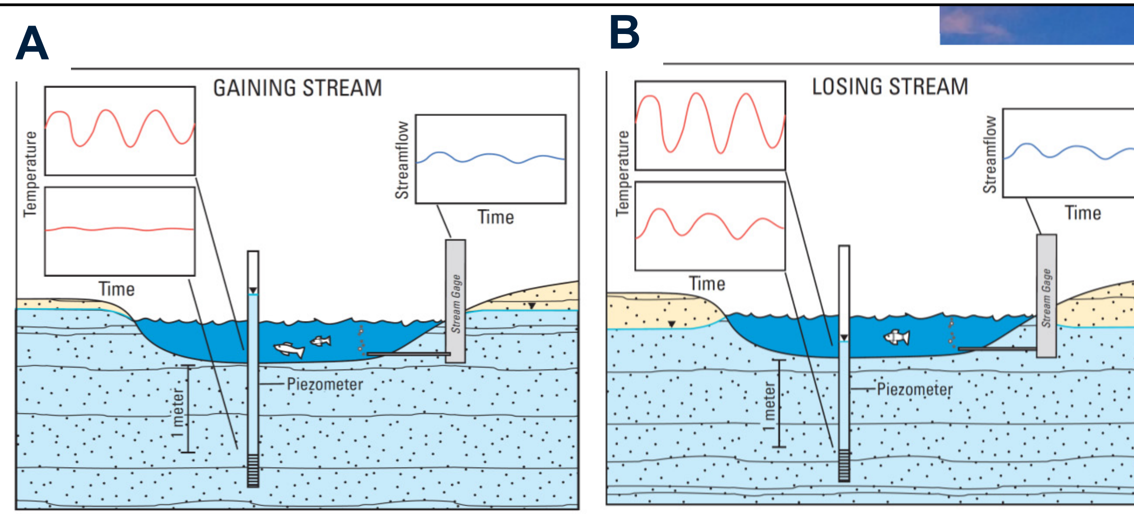




Piper Plot for all waters

THERMAL METHODS

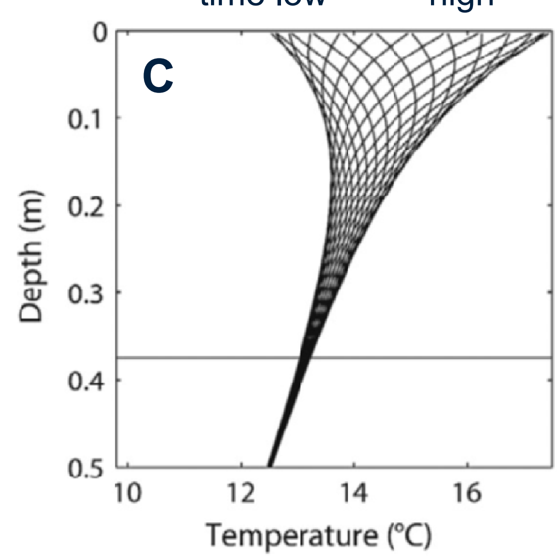
Groundwater is a constant temperature close to annual average air temperature. Streamflow varies on a day to day, and season to season basis. Groundwater inflows stabilize streamflow temperatures (A), provide temperature refugia (cold in summer, unfrozen in winter).



U.S. Geological Survey Circular 1260

Short term: Upstream and downstream reach measurements. Detects groundwater flow to stream only. Must be corrected for any surface heating

Medium term: Stream bed temperature profiles. Measure temperatures, and model water and heat flow. Example of temperatures during summer day at right.
Quantifies inflows and outflows.
Only measures at a point. Measures both hyporheic and groundwater flow



Long term: Using whole aquifer and streamflow temperature measurements as part of a full scale groundwater models.

KEY MESSAGES

Groundwater and hydrographs for allocation and EFNS

- In most of the interior of BC, the time for groundwater pumping to have an effect on surface water is likely in the range of days to < decade.
- Hydrographs for allocations or EFNs must account for the amount and timing of groundwater pumping.
- Not accounting for past groundwater flow likely leads to underestimating the productivity of watersheds and setting of EFNS that are too low.

The stream corridor, groundwater and hyporheic flows

- EFNs are more than just a flow rate: Flow rate is a proxy for a whole series of processes: Temperature, oxygen, velocity, scour, sediment transport, location and type of flow exchange with the bed.
- Hyporheic flow / groundwater mechanisms are part of stream health / fish habitat selection The stream ecosystem extends to the base of hyporheic zone, which is critical in nutrient cycling, habitat, benthic micro and macrofauna, plants, and ultimately, macrofauna like fish etc.

Measuring groundwater – surface water interactions

- Physical measurements:
- Chemical methods:
- Locations of discharge are part of stream health/fish habitat selections

THANK YOU