CANADIAN MOUNTAIN NETWORK | RÉSEAU CANADIEN DES MONTAGNES

BUILDING RESILIENCE DURING DROUGHT: A SHARED LEARNING OPPORTUNITY

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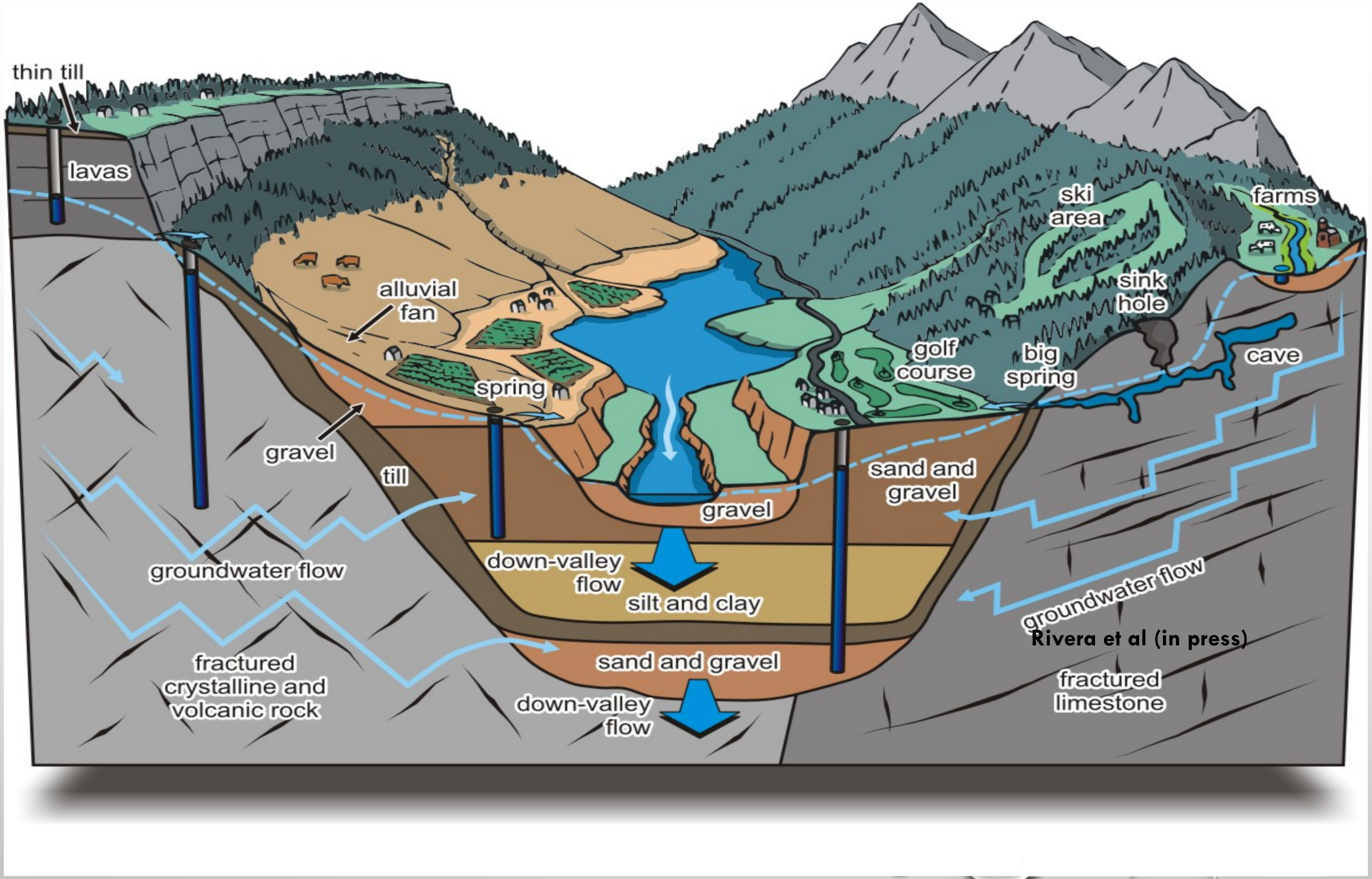
FEBRUARY 5, 2020

CMN ANNUAL MEETING, OTTAWA

GROUNDWATER IN MOUNTAIN REGIONS



Rivera et al (in press)

DROUGHT

"FOR SUCCESSFUL DROUGHT RISK MANAGEMENT,

1. OUR UNDERSTANDING MUST INCLUDE THE PROCESSES LEADING TO DROUGHT (CAUSES) AND THE IMPACTS OF DROUGHT (CONSEQUENCES). IN THIS WAY, DROUGHT PREDICTIONS CAN BE MADE AND EFFECTIVE MEASURES TAKEN TO MITIGATE DROUGHT SEVERITY AND TO REDUCE DROUGHT IMPACTS"……..

2. NATURAL AND HUMAN PROCESSES NEED TO BE FULLY INTEGRATED INTO DROUGHT DEFINITIONS, PROCESS UNDERSTANDING, AND ANALYSIS APPROACHES."

VAN LOON ET AL. (HESS, 2016)

THE TEAM

- PROJECT LEAD - DIANA ALLEN, PROFESSOR, SIMON FRASER UNIVERSITY
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CANADIAN MOUNTAIN NETWORK PROJECT

GOAL 1: DEVELOP QUANTITATIVE DROUGHT INDICATOR THRESHOLDS FOR GROUNDWATER LEVEL

GOAL 2: EVALUATE THE PERFORMANCE OF INDICATORS AND REGULATORY TOOLS THAT ARE USED DURING WATER SCARCITY IN THE OKANAGAN BASIN

GOAL 3: IDENTIFY WHICH AQUIFERS ARE SUSCEPTIBLE TO DROUGHT IN THE OKANAGAN BASIN

WORKSHOP AND FIELD TRIP GOAL AND OBJECTIVES

- **GOAL:** TO IMPROVE OUR UNDERSTANDING OF DROUGHT IMPACTS IN OKANAGAN BASIN
- **OBJECTIVES:**

  WHAT ARE THE ISSUES, WHAT ARE YOUR CONCERNS?

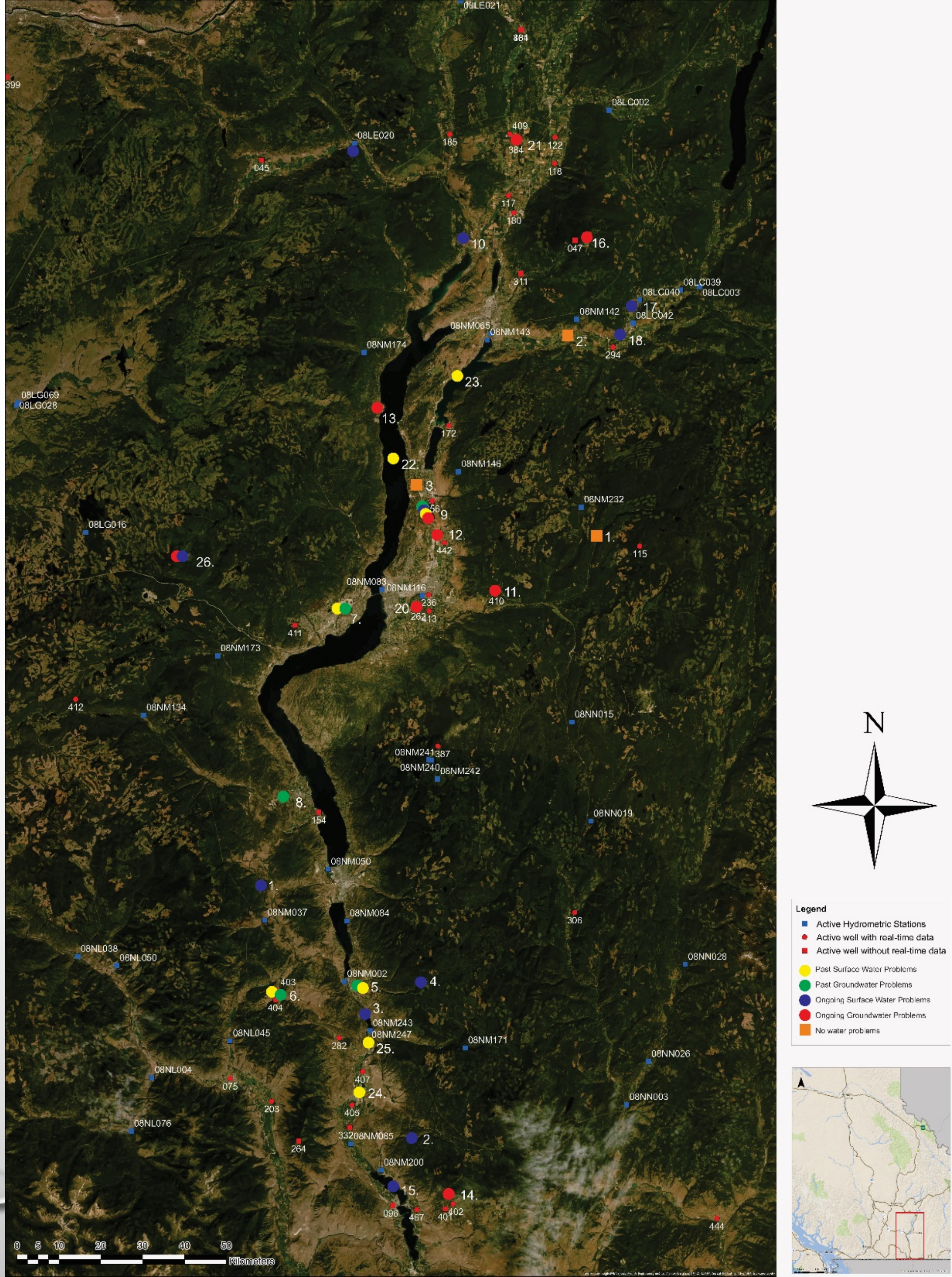
  WHAT ARE DROUGHT IMPACTS?

  WHERE HAVE DROUGHT IMPACTS BEEN OBSERVED?

  WHAT RESEARCH IS NEEDED TO ADDRESS CONCERNS RAISED?

WORKSHOP OUTCOMES

Number on Map	Dot Colour	Location name	Notes
1	blue	Shingle Creek	headwatters have reservoirs, has water use changed? Expanding agriculture?
2	blue	Inkaneep Creek	
3	blue	Vaseaux Lake	
4	blue	Shuttleworth Creek	sandy gravel stream bottoms, lots of new GW use in the lower watershed
5	yellow, green	Okanagan Falls	
6	yellow, green	Twin Lakes	
7	yellow, green	West Kelowna	GW drought
8	green	West of Summerland	
9	blue, yellow, green, red	Ellison Lake	
10	blue	Okanagan Indian Band - Vernon	lower flows than previous years, fish
11	red	Joe Rich	Chronic GW deficits
12	red	Airport	
13	red	Fintry	
14	red	Anarchist Mtn	
15	blue	Osoyoos Lake	high temperatures, lack of runoff
16	red	Silver Star	
17	blue	Bessette Creek	
18	blue	Duteau Creek	
19	blue	Faulkland	Salmon River
20	red	OW 262	
21	red	OW384	
22	yellow	Okanagan Lake	Water use from lakes not huge
23	yellow	Kalamalka Lake	
24	yellow	Okanagan River	Penticton -> Oliver -> Osoyoos; chain of effects
25	yellow	McIntyre Dam	Oliver takes water from here - reliant on river
26	blue, red	Pennask Plateau	replants from forestry are not surviving -> logging -> becoming more grasslands
No Water Problems			
1	orange square	Upper Mission Creek	
2	orange square	Lavington	*Where there are no OW there tends to not be any problems*
3	orange square	Bewteen Windfield and Okanagan Lake	springs



FIELD TRIP OUTCOMES

RESEARCH OUTCOMES

Characterization of Aquifer-Stream Systems and Preliminary Groundwater Drought Indicators in the Okanagan Basin, BC

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Introduction

A groundwater level record from an observation well can potentially be used as an indicator of drought. However, the magnitude and timing of the groundwater level changes depend not only on the climate, but also the location of the observation well - i.e. the type of aquifer and its proximity to a stream. Understanding how and why groundwater levels respond the way they do under natural climate conditions is critical for understanding how they might change during drought conditions.

Defining the **aquifer-stream system type** is a useful way to understand the mechanisms that drive the groundwater level response. Two end-member types have been identified (Allen et al. 2010):
Recharge driven systems: the groundwater level increases due to recharge by precipitation (diffuse recharge) and groundwater discharges into the stream (Fig. 1a).
Streamflow driven systems: the rise and fall of the stream discharge drives the rise and fall of the groundwater level (Fig. 1b).

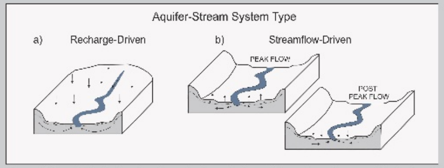


Figure 1. Schematic diagram showing the two end-member aquifer-stream system types. Recharge-driven systems are controlled by the recharge of precipitation over the aquifer footprint which, in turn, drives the streamflow. Streamflow-driven systems are controlled by the streamflow which, in turn, drives the groundwater level (Modified from Allen et al. 2014).

Objectives

The main purpose of this study is to **explore** how the different aquifer-stream systems can be used to develop and test **groundwater** drought indicators in the Okanagan Basin. These tools and resources may be used to **aid** and inform drought management across BC. The objectives of the study are:

1. To create a groundwater observation well and aquifer database.
2. To define the aquifer-stream system types in the Okanagan Basin
3. To develop and test quantitative groundwater drought indicators for the Okanagan Basin.

Aquifer-Stream System Methodology

Groundwater (GW) level records from 23 provincial observation wells in the Okanagan Basin and surrounding area were analysed (Fig. 2).

Hysteresis plots (GW level vs stream discharge) were plotted for each, using the data from the nearest hydrometric station[1].

The hysteresis plots were used to characterize the aquifer-stream system type according to Allen et al. (2010) and examined for the general hysteresis direction (clockwise or counter clockwise) to identify the leading process.

[1] If the nearest hydrometric station was judged not be hydraulically connected to the aquifer, an alternative station was used for the analysis.

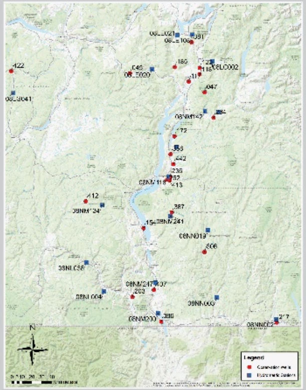


Figure 2. Locations of the observation wells and hydrometric stations in the Okanagan region used in the analysis.

Aquifer-Stream System Results

- Hysteresis plots (Figs. 3 and 4) are colour-coded according to year, and each month (1-12) has a unique symbol.
- A loop structure is evident in many of the wells, except for wells 203, 302, 412, 413, and 442. Arrows indicate if the hysteresis loop is positive (clockwise) or negative (counter clockwise).
- The hysteresis loops are similar in shape from year to year and may be a function of the connectivity between the aquifer and the stream (Allen et al 2010).
- The streamflow driven systems tend to be type 1a, 1b, 1c, and 4a aquifers. These aquifer types tend to be situated in valley bottoms or tributary channels and found along streams (Wei et al. 2009).
- The recharge driven systems are mostly type 4b aquifers. These are confined glacio-fluvial sand and gravel aquifers (Wei et al. 2009).

Table 1. Observation wells, hydrometric stations, aquifer properties, and the hysteresis loop direction used to characterize the aquifer-stream systems.

Observation Well		Hysteresis Loop Direction	Aquifer Number	Aquifer Type	Aquifer System Type
045	Westwold	CCW	289	4a	stream driven
096	Osoyoos	CCW	193	4a	stream driven
117	Armstrong	CW	1158	4b	recharge driven
118	Armstrong	CW	1158	4b	recharge driven
122	Enderby	CW	1158	4b	recharge driven
154	Summerland	CCW	297	2	stream driven
172	Oyama	CCW	346	4a	stream driven
185	Salmon River	CCW	97	1a	stream driven
203	Cawston	MESSY	259	1a	stream driven
217	Grand Forks	CCW	158	1b	stream driven
236	Rutland	CW	464	4b	recharge driven
262	Kelowna	CW	464	4b	recharge driven
294	Lumby	CCW	316	1c	stream driven
302	Malakwa	MESSY	307	1b	stream driven
306	Beaverdell	CCW	482	1c	stream driven
356	Winfield	FLAT	344	4b	possibly no connection
381	Canoe Creek Shallow	MESSY	108	4a	stream driven
407	Oliver	CCW	255	1a	stream driven
412	Summerland	MESSY	n/a	bedrock	recharge driven
413	SE Kelowna	MESSY	464	4b	recharge; possibly no connection
422	Logan Lake	CW	n/a	bedrock	recharge driven
442	Kelowna	MESSY	464	4b	recharge driven

Recharge Driven

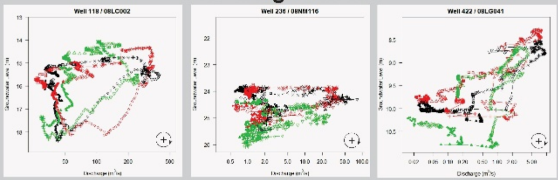


Figure 3. Hysteresis plots showing the positive (clockwise) hysteresis loop. The stream discharge lags behind the groundwater level creating a positive hysteresis loop.

Streamflow Driven

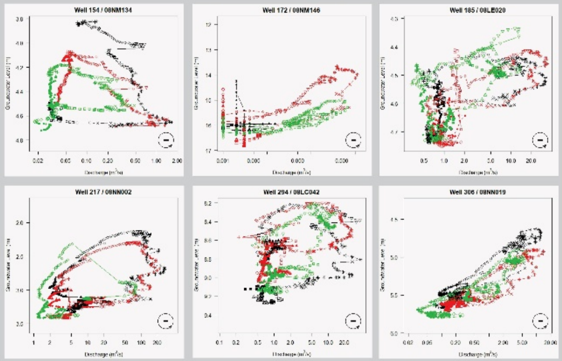


Figure 4. Hysteresis plots showing the negative (counter-clockwise) hysteresis loop. The aquifer provides water to the stream and the stream recharges the aquifer during periods of high flow.

Drought in British Columbia and the Okanagan Basin

- The British Columbia (BC) Drought Response Plan uses four core drought indicators:
  1. Basin snow measurements,
  2. Seasonal volume runoff forecasts
  3. 7-day average streamflow
  4. 30-day percent of average precipitation

  as well as supplemental indicators such as aquifers levels.
- On April 1st, 2015 the snow water equivalent average for BC was 73% of normal, the second lowest in 31 years of record (BC River Forecast Centre, 2015).

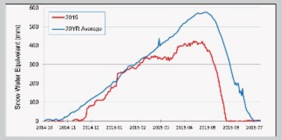


Figure 5. Snow water equivalent for the 2015 water year and the 20 year average at Mission Creek (BC Ministry of Environment and Climate Change Strategy, 2019).

Table 2. Drought levels for the Okanagan and surrounding basins in 2015. The Okanagan-Kettle Basin was separated into two basins on July 23 (Source: BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development 2019)

Basins	15-May	28-May	25-Jun	03-Jul	09-Jul	15-Jul	21-Jul	23-Jul	05-Aug	06-Aug	20-Aug	03-Sep	17-Sep	01-Oct
South Thompson	1	1	2	2	3	3	3	4	4	4	4	4	3	2
Okanagan-Kettle	2	2	2	2	3	3	3	3	4	4	4	4	3	3
Kettle (separated July 23)								4	4	4	4	4	3	3
Nicola	2	2	2	2	3	3	4	4	4	4	4	4	3	2
Similkameen	2	2	2	2	3	3	3	4	4	4	4	4	3	2

- The below average snow pack, coupled with above average temperatures, and below average precipitation resulted in Level Four Drought being declared in the North Thompson, South Thompson, Okanagan, Kettle, Nicola, Similkameen, Skagit, Lower Fraser, South Coast and Vancouver Island basins by August 20th 2015 (Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2019; BC River Forecast Centre, 2015).

Preliminary Groundwater Drought Indicator

Groundwater is an important water supply to streams during periods of low flow for both streamflow driven systems and recharge driven systems. However, groundwater level data is currently only used as a secondary indicator of drought in BC. A groundwater drought indicator may be useful in water use decision making prior to or during periods of drought.

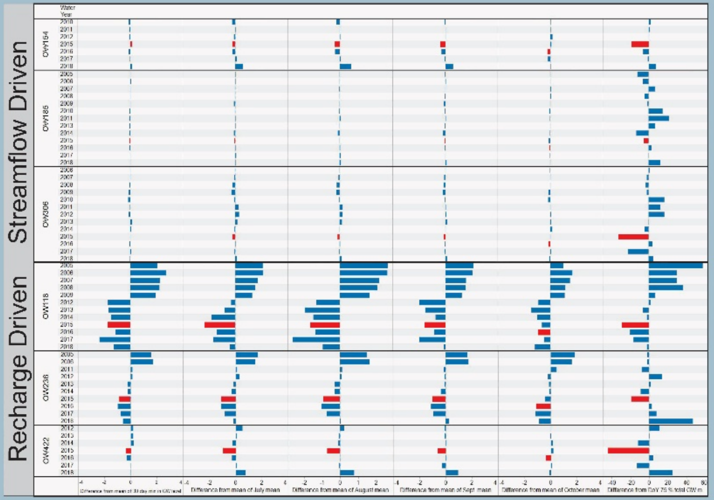
The groundwater levels in the Okanagan were examined to find irregularities before and during the 2015 water year that could signify that the 2015 drought had a negative impact on groundwater levels.

Methodology

- Groundwater levels statistics were explored by water year. A water year starts on October 1st of the previous year and ends on September 30th of the water year.
- Difference from mean or median graphs were made for 30 day minimum groundwater levels - i.e. the yearly minimum 30 day rolling average. Each 30 day minimum value was subtracted from the mean of the yearly values for each well.
- Difference from mean or median graphs were also made for monthly means (July, August, September, and October) - i.e. each monthly mean was subtracted from the mean of the monthly means for each well.

Acknowledgments

I would like to thank Paul Whitfield for providing the R scripts to produce the hysteresis plots and for and introduction to cross correlation in R. This project was funded by Natural Sciences and Engineering Research Council (NSERC) via an Undergraduate Student Research Award (USRA).



Preliminary Drought Indicator Results

Difference From Average of 30 Day Minimum Groundwater Level
- Wells that have minimum groundwater levels in the late winter or early spring **tended** to have a 30 day minimum groundwater level higher than the average during the 2015 drought year (Well 047, 154, 302, 306, 311, 356, 381, 387, and 412).
- Wells 118, 185, 236, 384, 401, 402, 411, and 422 had 30 day minimum groundwater levels lower than the average during the 2015 drought year.

Difference from Average of Monthly Means
- Wells 118, 236, and 411 have mean groundwater levels at least 1 m below average from July to October 2015, and all have yearly minimums between late summer to early fall.
- The largest drop (-2.35 m) in monthly mean for the 2015 drought year occurred in well 118 in the month of July.

Difference from Median of date of 75 Percent Level
- The difference from the median of the date of 75 percent level shows the timing of the hydrologic regime. Negative numbers show that the groundwater levels raised earlier in the water year, whereas a positive number indicates that the groundwater levels raised later in the water year.
- Wells 47, 118, 154, 236, 302, 306, 402, 403, 407, 410, 412, and 422 had DoY 75 % total values at least 14 days earlier than the median during the 2015 drought year.

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SFU

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Okanagan Basin WATER BOARD

BRITISH COLUMBIA

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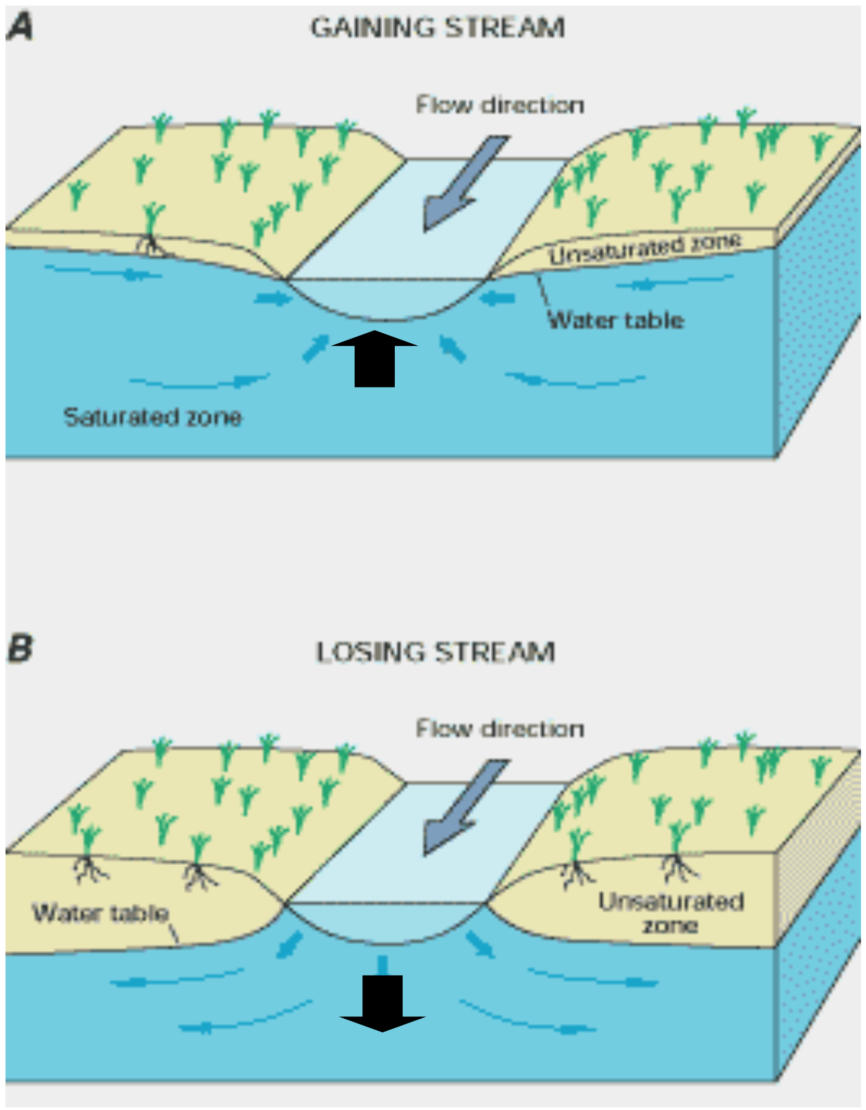
University of Victoria

GROUNDWATER-SURFACE WATER INTERACTIONS



From Alley et al., USGS Circular 1186,

A. Gaining – groundwater contributes to stream

- Upwelling water has relatively constant temperature and contains nutrients from underground, but is lower in dissolved oxygen

B. Losing – surface water contributes to groundwater

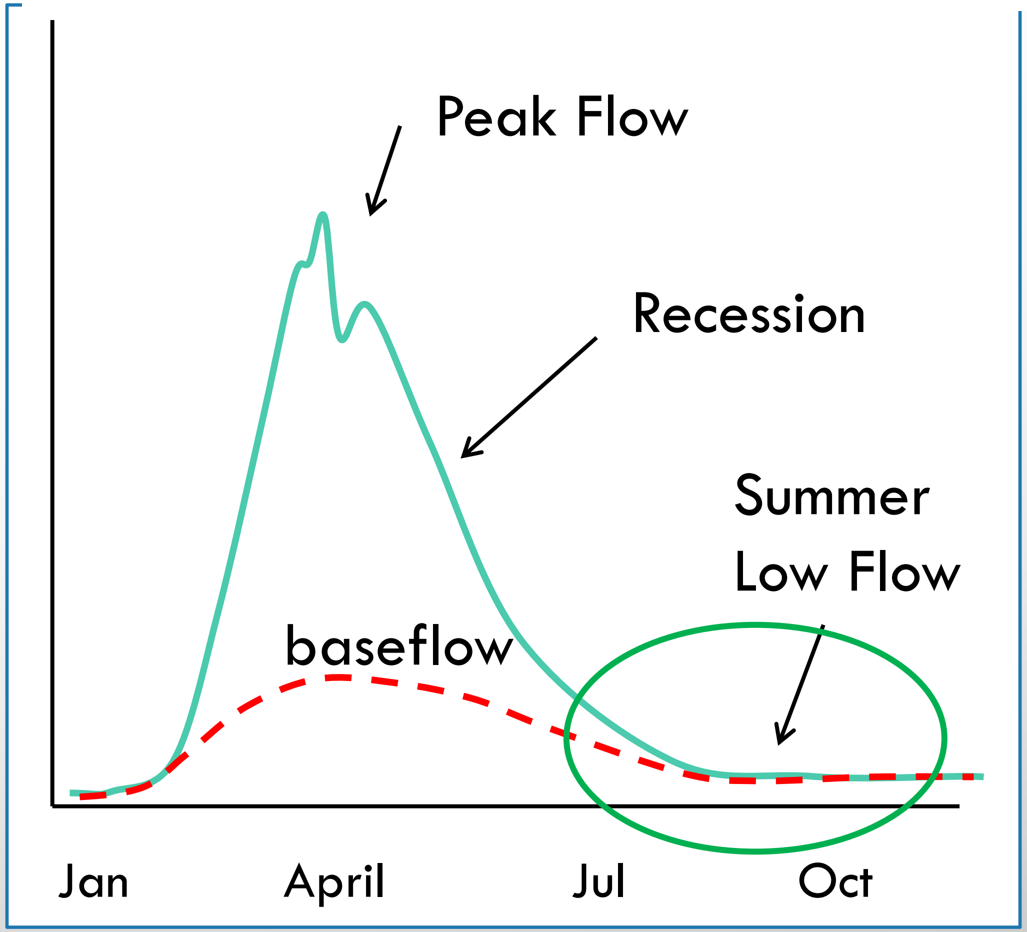
- Downwelling water is high in dissolved oxygen but temperature varies daily and seasonally

Streams may <u>gain</u> groundwater in some reaches and <u>lose</u> in others, and the patterns can <u>change seasonally</u>.

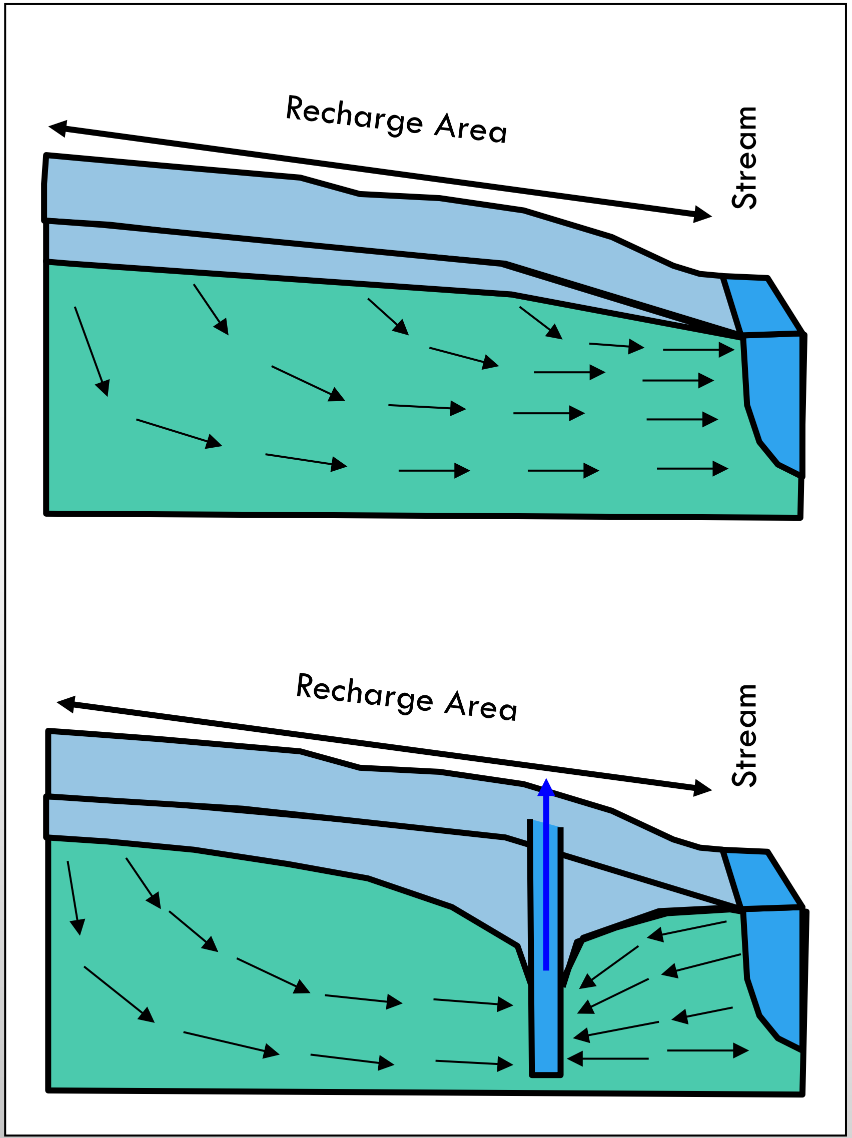
GROUNDWATER AND LOW FLOWS

- STREAMS OFTEN GAIN WATER FROM GROUNDWATER AS BASEFLOW
- DURING THE SUMMER LOW FLOW PERIOD, BASEFLOW MAY BE THE ONLY CONTRIBUTION.
- IF WE ALTER THE GROUNDWATER SYSTEM, THEN THE INTERACTION WITH SURFACE WATER CAN CHANGE

Hydrograph – Snowmelt-dominated Regime



EFFECT OF PUMPING NEAR STREAMS



Pumping can reverse direction of water movement.

The stream becomes a losing stream.

What is the impact of pumping on a stream during drought conditions?

What if the groundwater recharge is reduced?