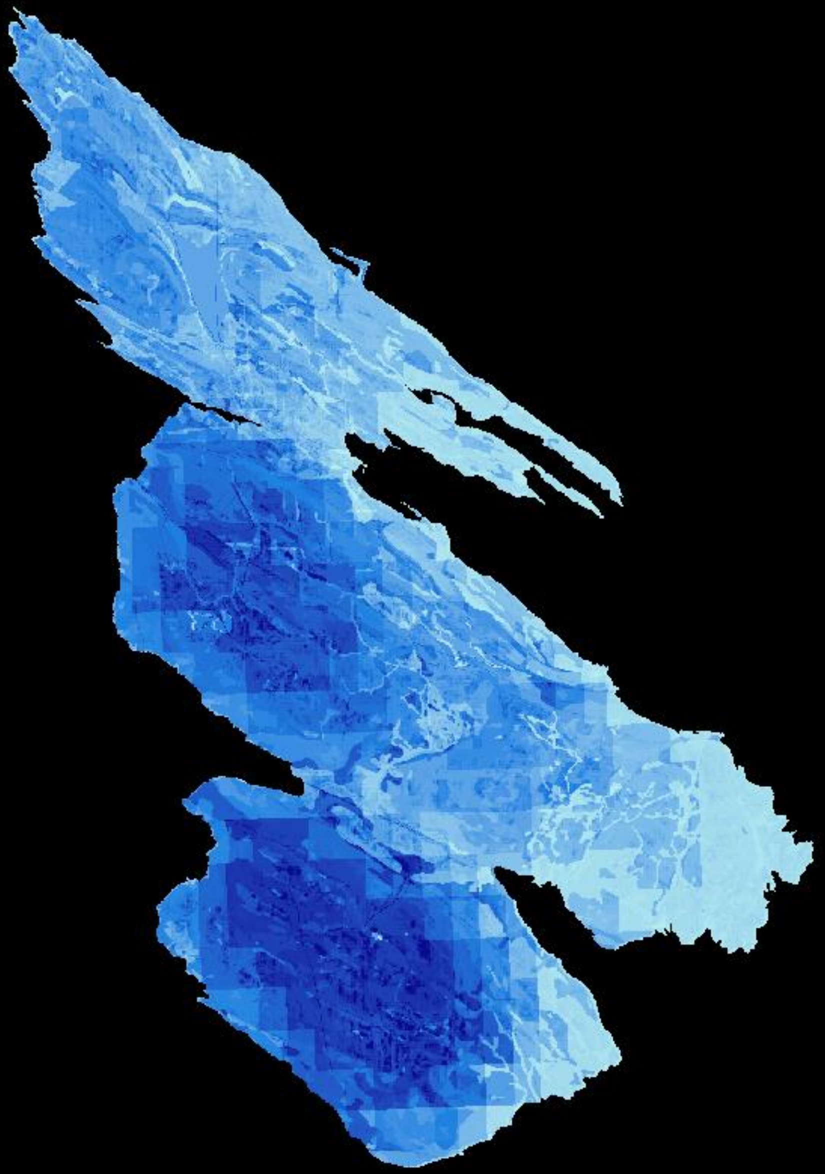
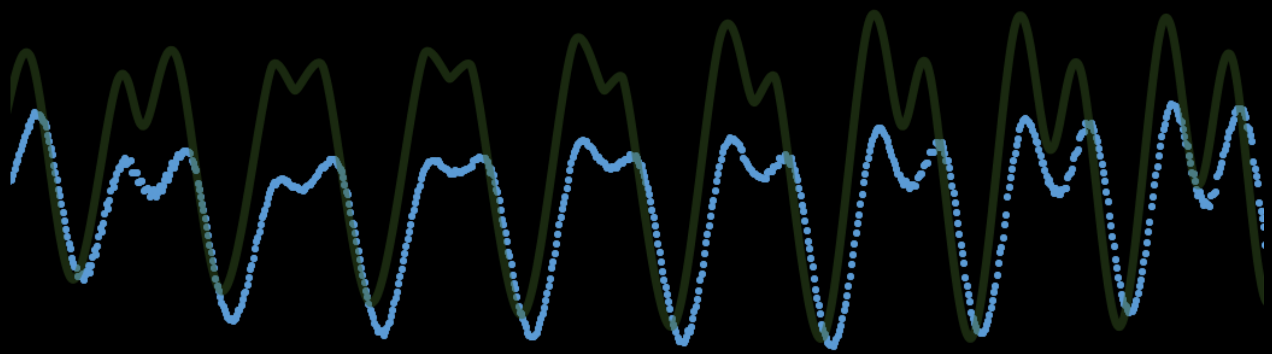




# Salt Spring Island Groundwater Well Monitoring

December 2020
Salt Spring Island Library

WILLIAM SHULBA, P.GEO
SENIOR FRESHWATER SPECIALIST
LICENSED SCIENCE OFFICER
ISLANDS TRUST

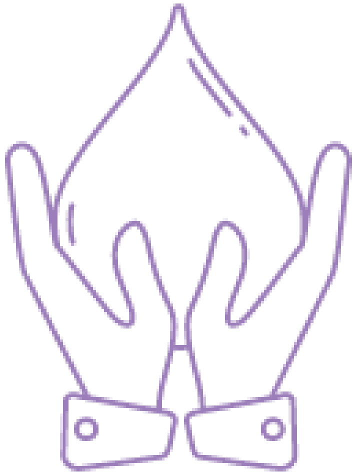
# Global Groundwater Statement

A global group of scientists, practitioners, and experts calling for action to ensure groundwater benefits society now and into the future.

GroundwaterStatement.ORG

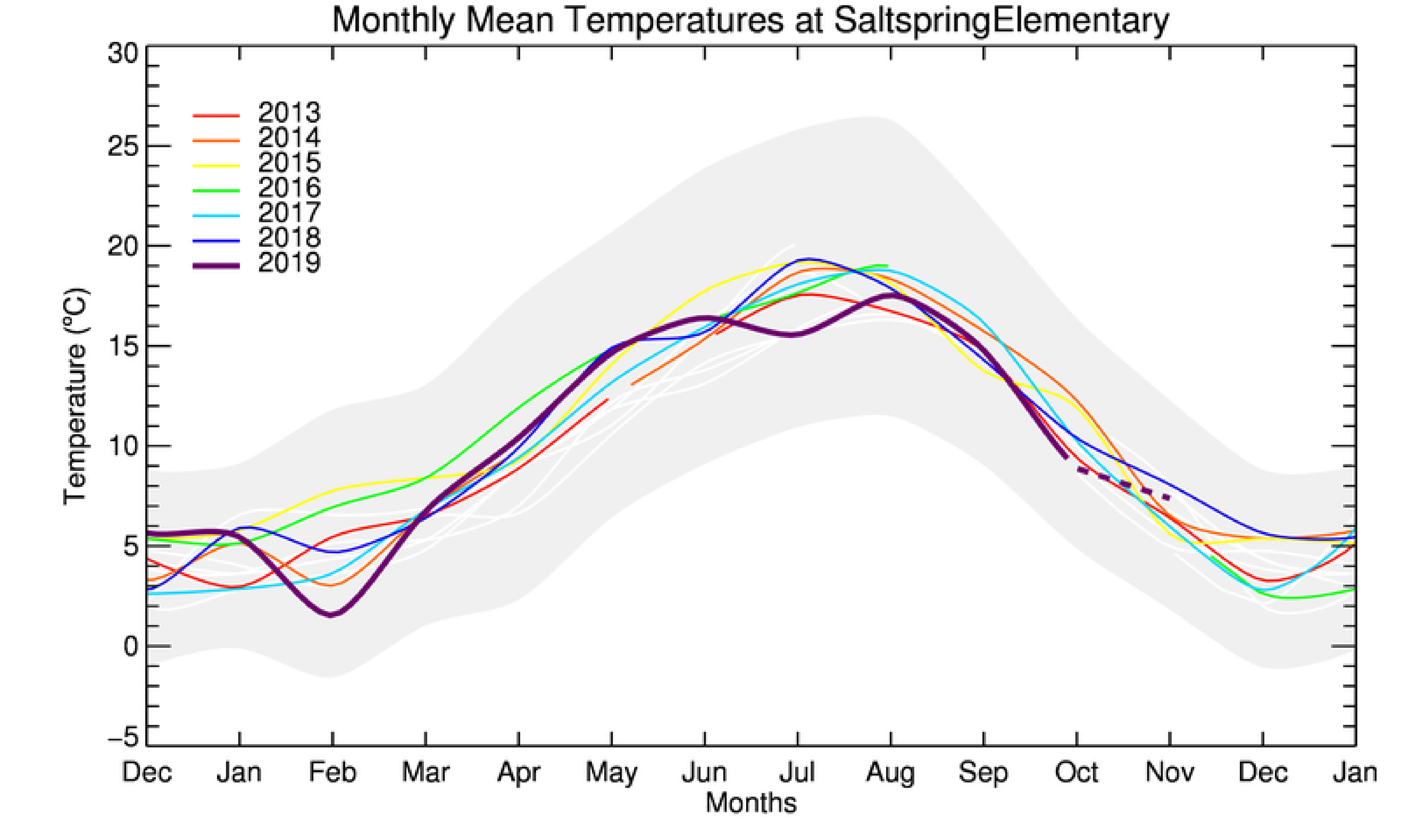
Put the spotlight on global groundwater sustainability

Manage and govern groundwater sustainability from local to global scales

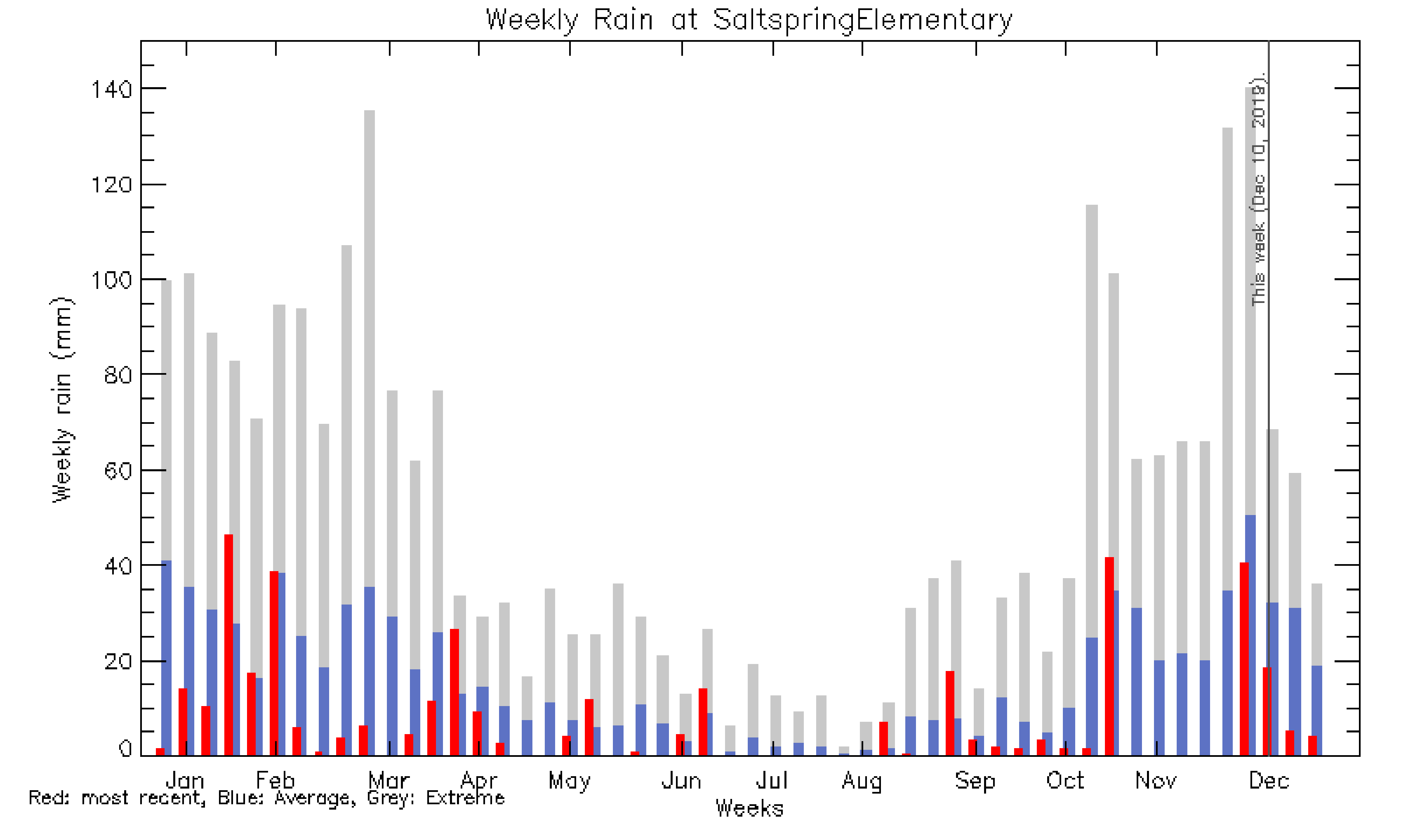


Invest in groundwater governance and management

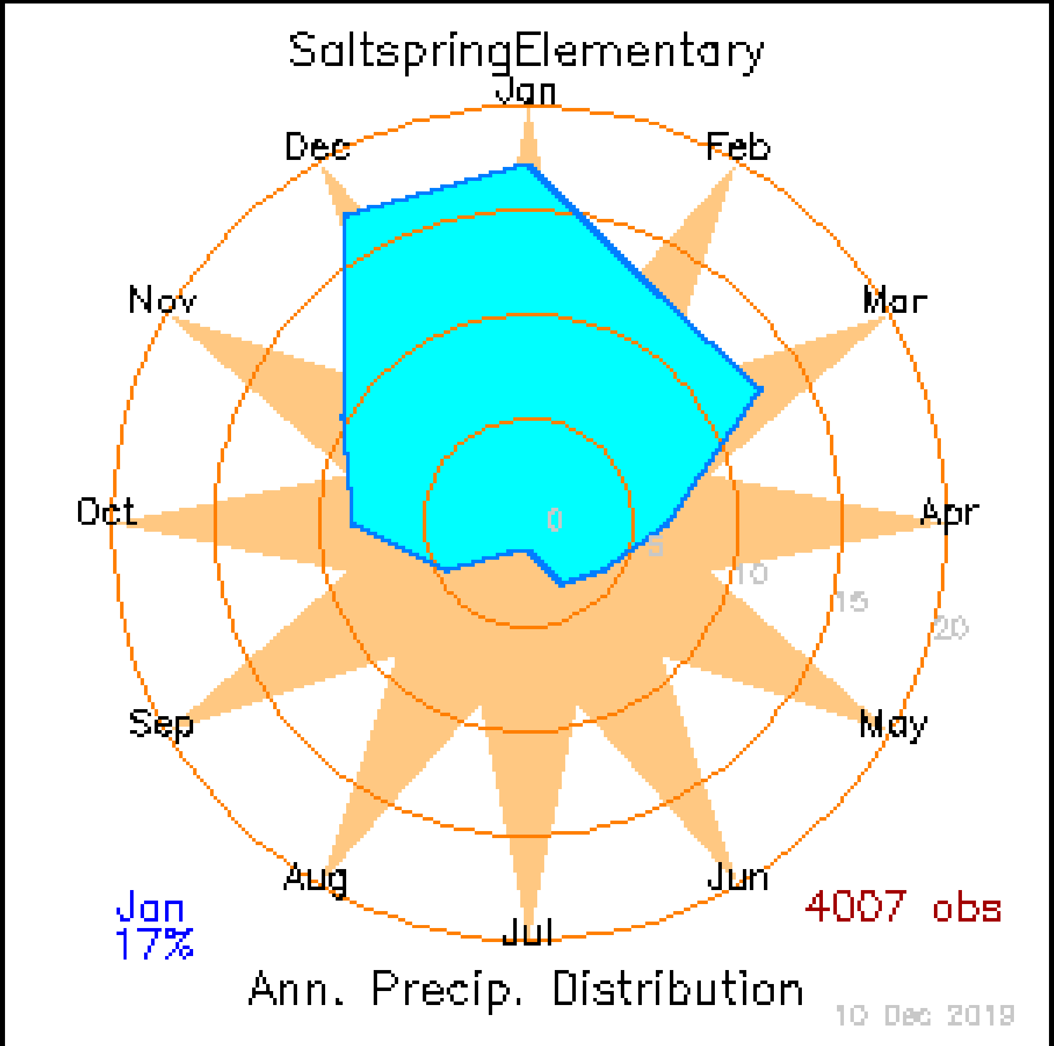
GroundwaterStatement.ORG

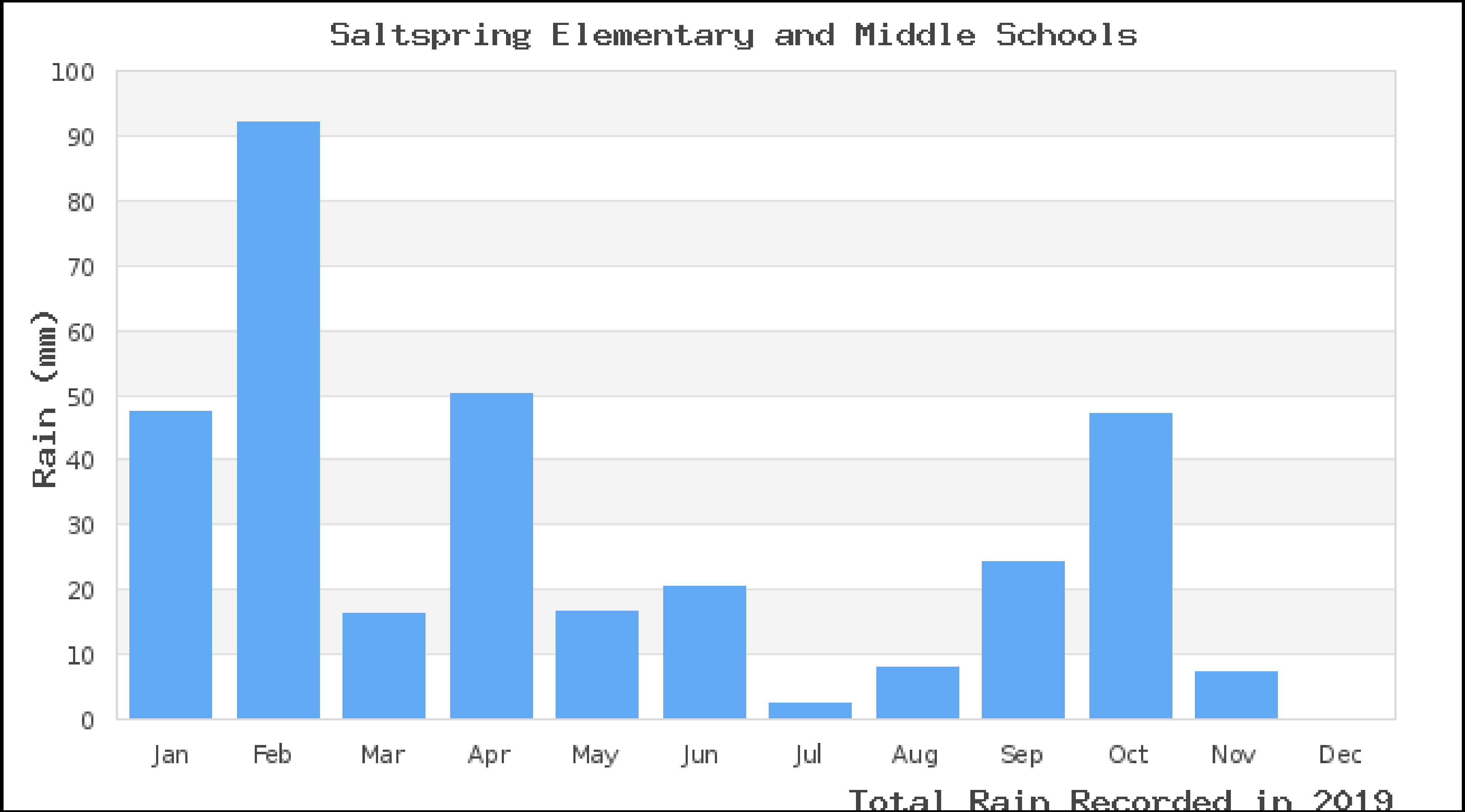


Monthly Mean Temperatures at SaltspringElementary
30
25
20
15
10
5
0
−5
Temperature (°C)
2013
2014
2015
2016
2017
2018
2019
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Months

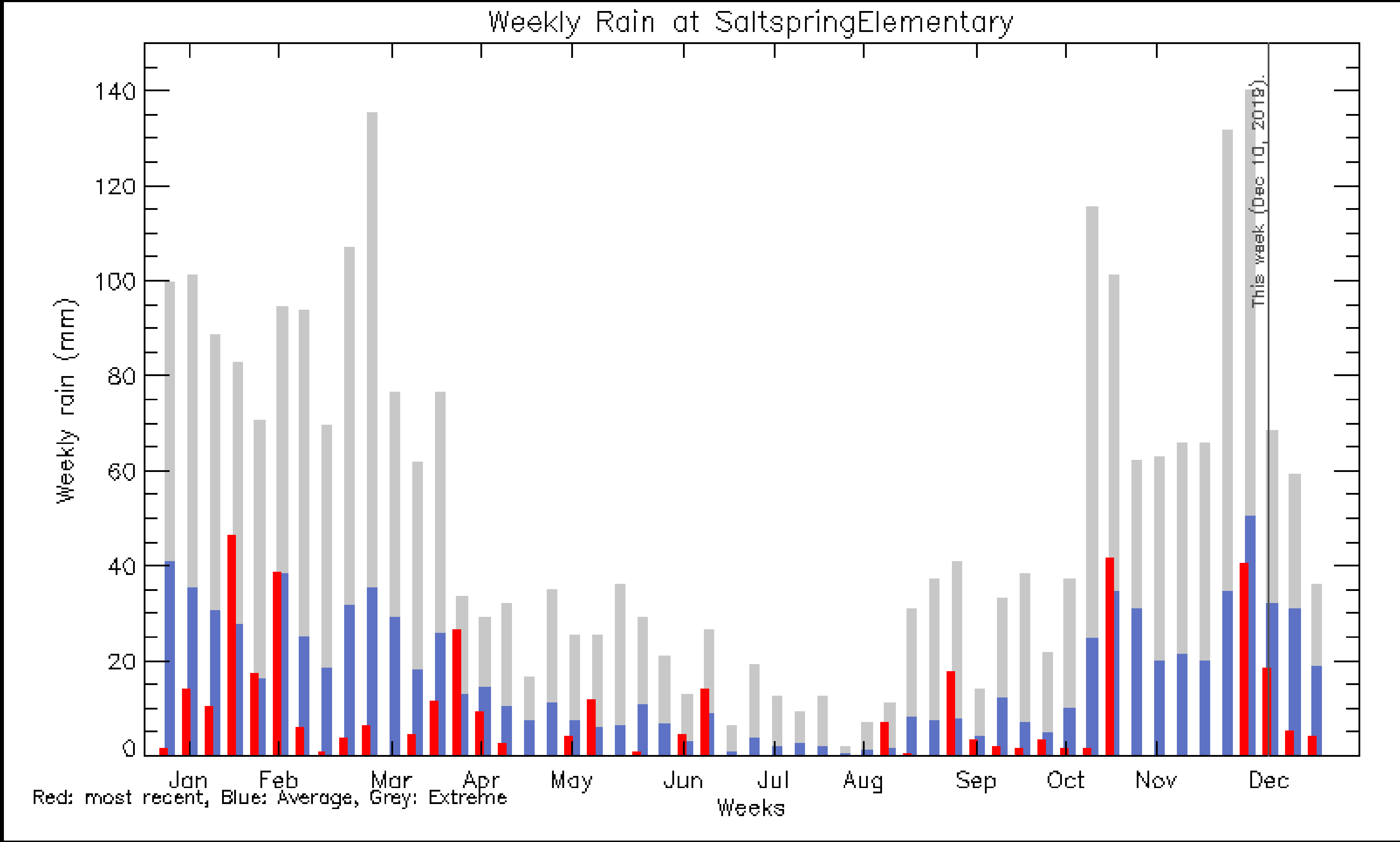


Weekly Rain at SaltspringElementary
Weekly rain (mm)
140
120
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Weeks
Red: most recent, Blue: Average, Grey: Extreme
This week (Dec 10, 2018).


SaltspringElementary
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0
5
10
15
20
Jan
17%
4007 obs
Ann. Precip. Distribution
10 Dec 2019



Saltspring Elementary and Middle Schools
Rain (mm)
100
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Total Rain Recorded in 2019

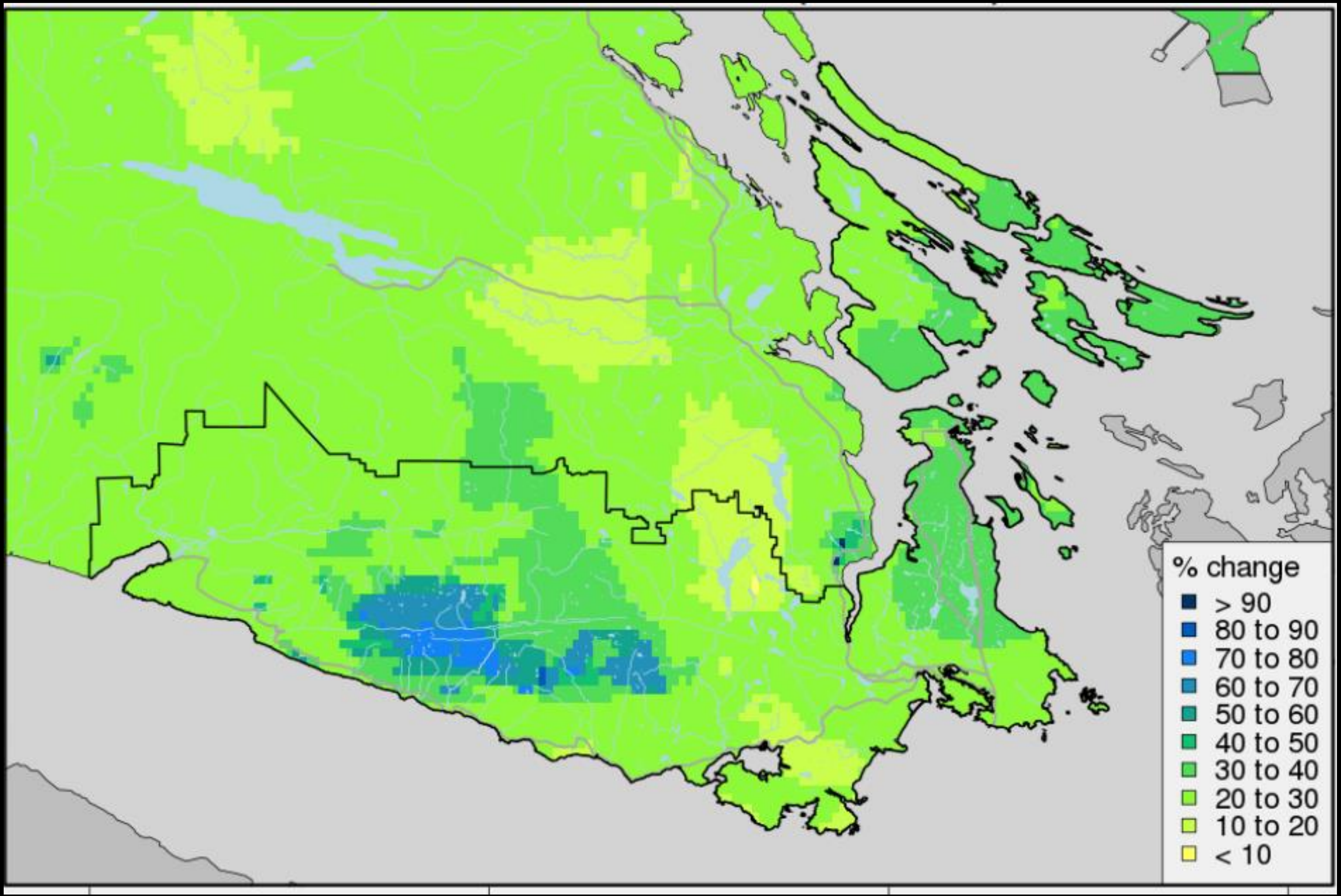


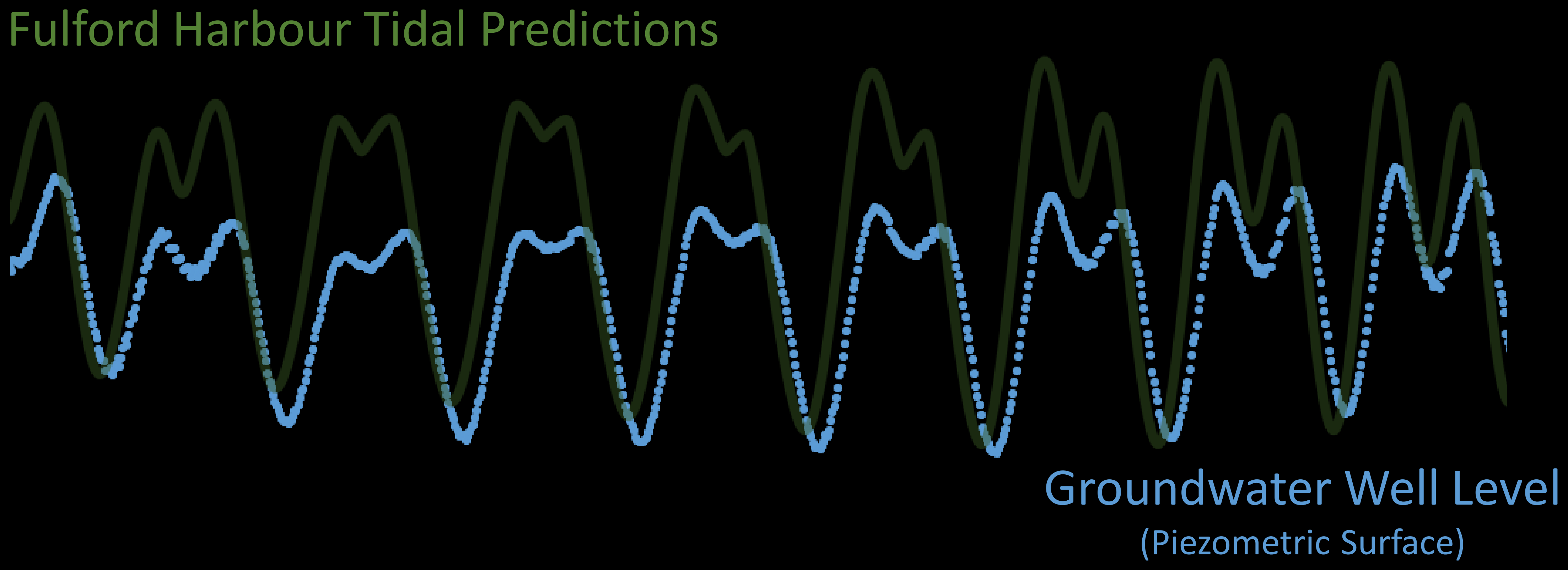
Weekly Rain at SaltspringElementary
Weekly rain (mm)
140
120
100
80
60
40
20
0
This week (Dec 10, 2018).
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Weeks
Red: most recent, Blue: Average, Grey: Extreme

## Rain Days by Month at Salt Spring Elementary and Middle Schools

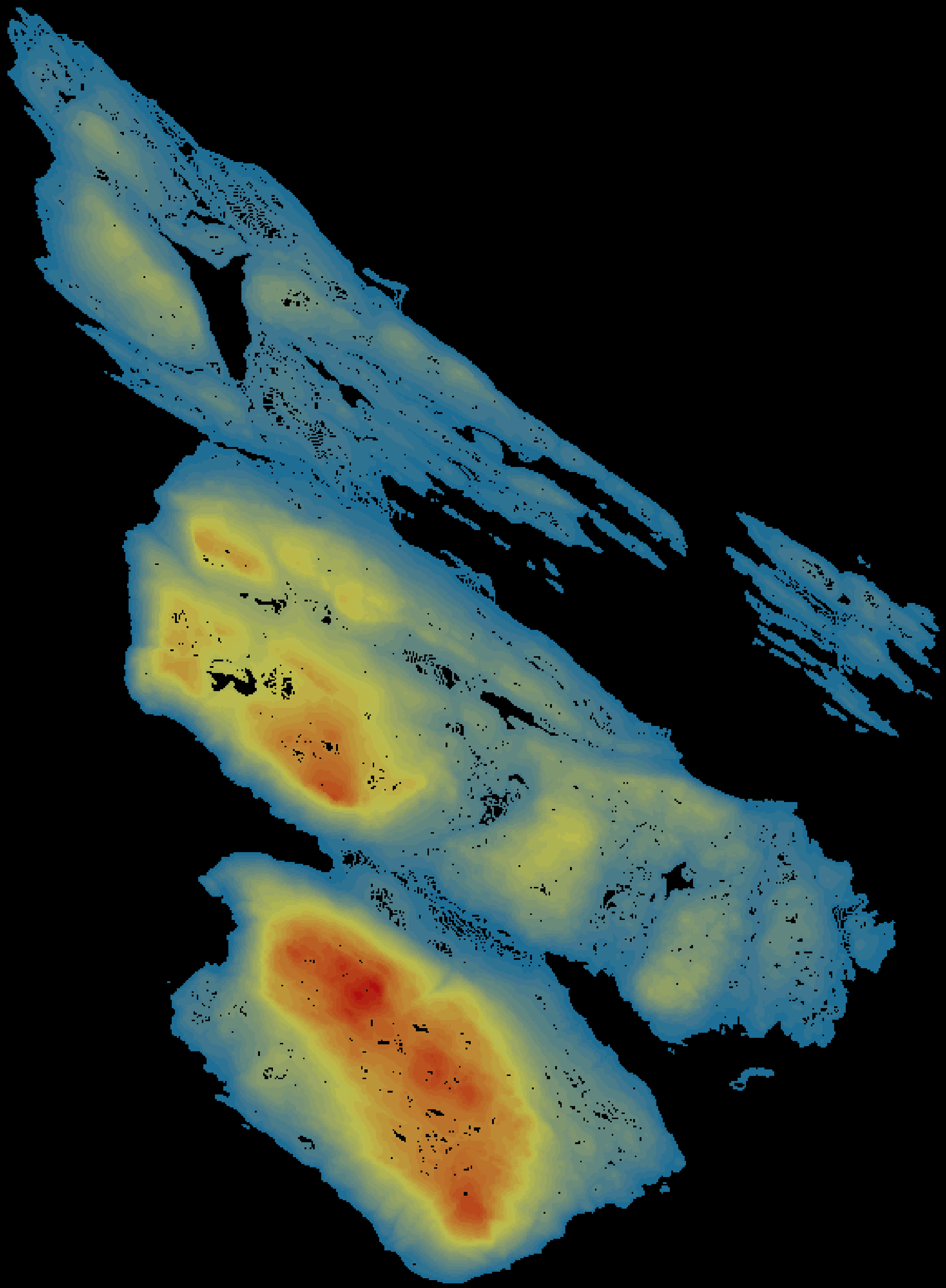
| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2019 | 30 | 18 | 12 | 14 | 8 | 4 | 1 | 3 | 19 | 28 | 4 | | |
| 2018 | 28 | 16 | 16 | 18 | 3 | 8 | 3 | 3 | 19 | 18 | 11 | 29 | **172** |
| 2017 | 13 | 15 | 26 | 20 | 10 | 5 | 2 | 3 | 9 | 13 | 17 | 18 | **151** |
| 2016 | 24 | 26 | 21 | 13 | 7 | 7 | 8 | 4 | | | | 21 | |
| 2015 | 29 | 25 | 23 | 14 | 4 | 4 | 5 | 6 | 22 | 23 | 25 | 28 | **208** |
| 2014 | 20 | 19 | 21 | 15 | 6 | 11 | 8 | 6 | 12 | 25 | 23 | 24 | **190** |
| 2013 | 29 | 10 | | | 11 | 8 | | 9 | 18 | 18 | 24 | 16 | |
| 2012 | 28 | 19 | 2 | 21 | 8 | 15 | 5 | 4 | 6 | 20 | 12 | 5 | **145** |
| 2011 | 20 | 15 | 26 | 13 | 14 | 5 | 7 | 1 | 7 | | 8 | 31 | |
| 2010 | 26 | 24 | 19 | 18 | 16 | 5 | | | | 12 | 19 | 22 | |
| 2009 | 21 | 19 | 21 | 8 | 12 | 4 | 4 | 4 | 6 | | | 13 | |
| 2008 | 23 | 12 | 28 | 16 | 9 | 6 | 3 | 10 | 6 | 5 | 19 | 20 | **157** |
| 2007 | | | | | | | | 1 | 11 | 10 | 20 | 19 | |
| **Average** | 24 | 18 | 20 | 15 | 9 | 7 | 5 | 5 | 12 | 17 | 17 | 21 | **170** |
| **Std Dev** | 5 | 5 | 7 | 4 | 4 | 3 | 2 | 3 | 6 | 7 | 7 | 7 | **24** |
| **Year** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** | **Total** |

## Projected Change in 20-Year Annual Maximum One Day Precipitation



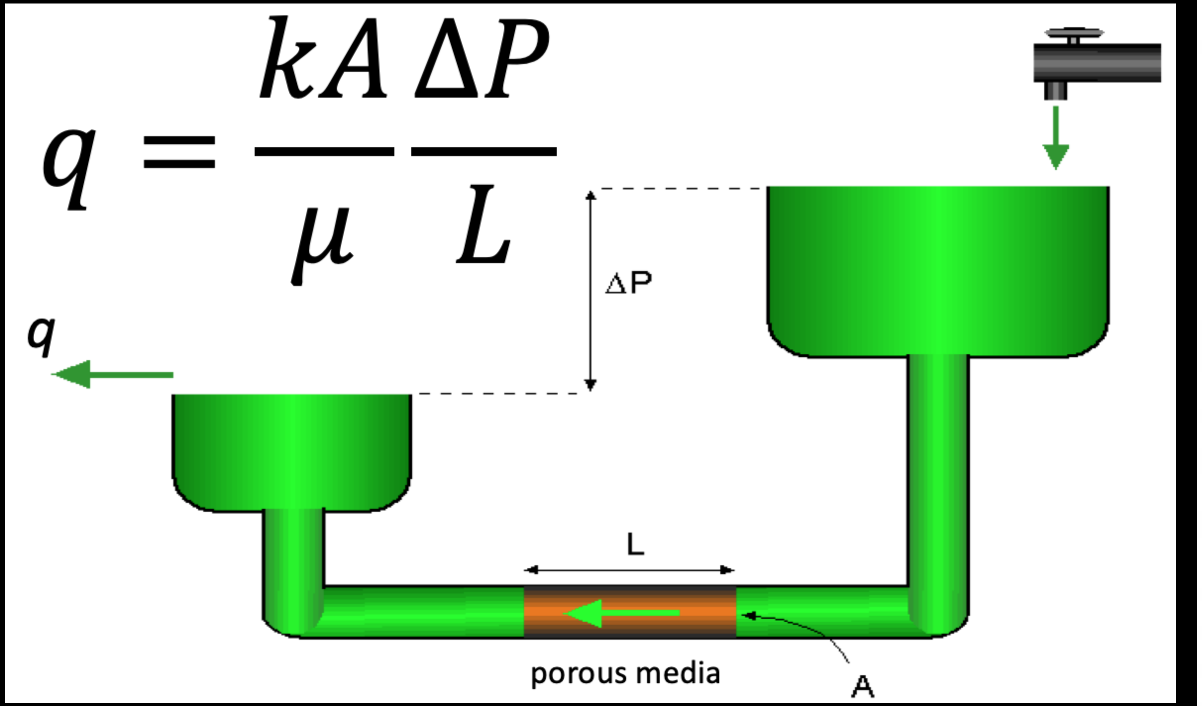

# HYDRAULIC CONTINUITY

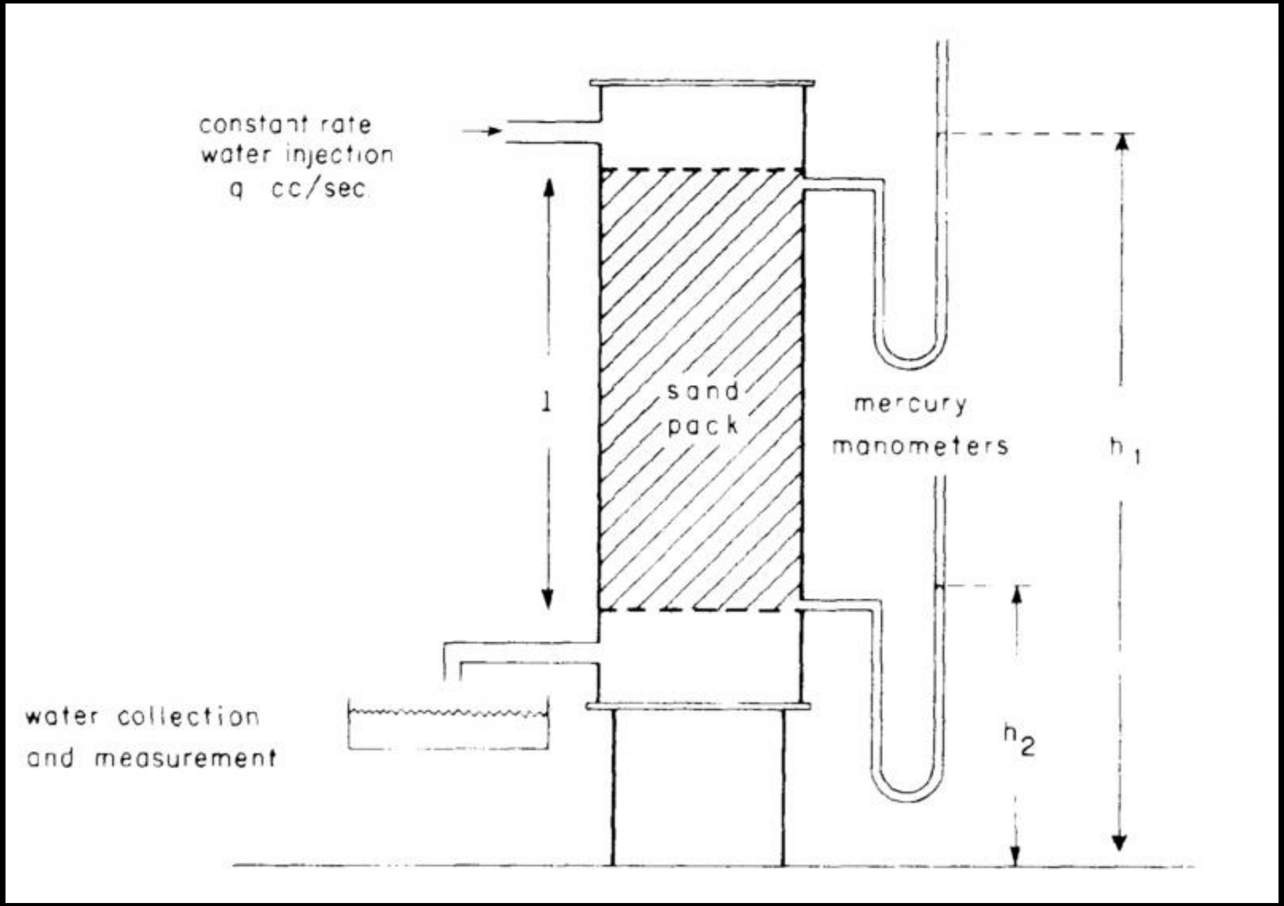


Groundwater flows in a gravity driven freshwater network of *Hydraulic Continuity*

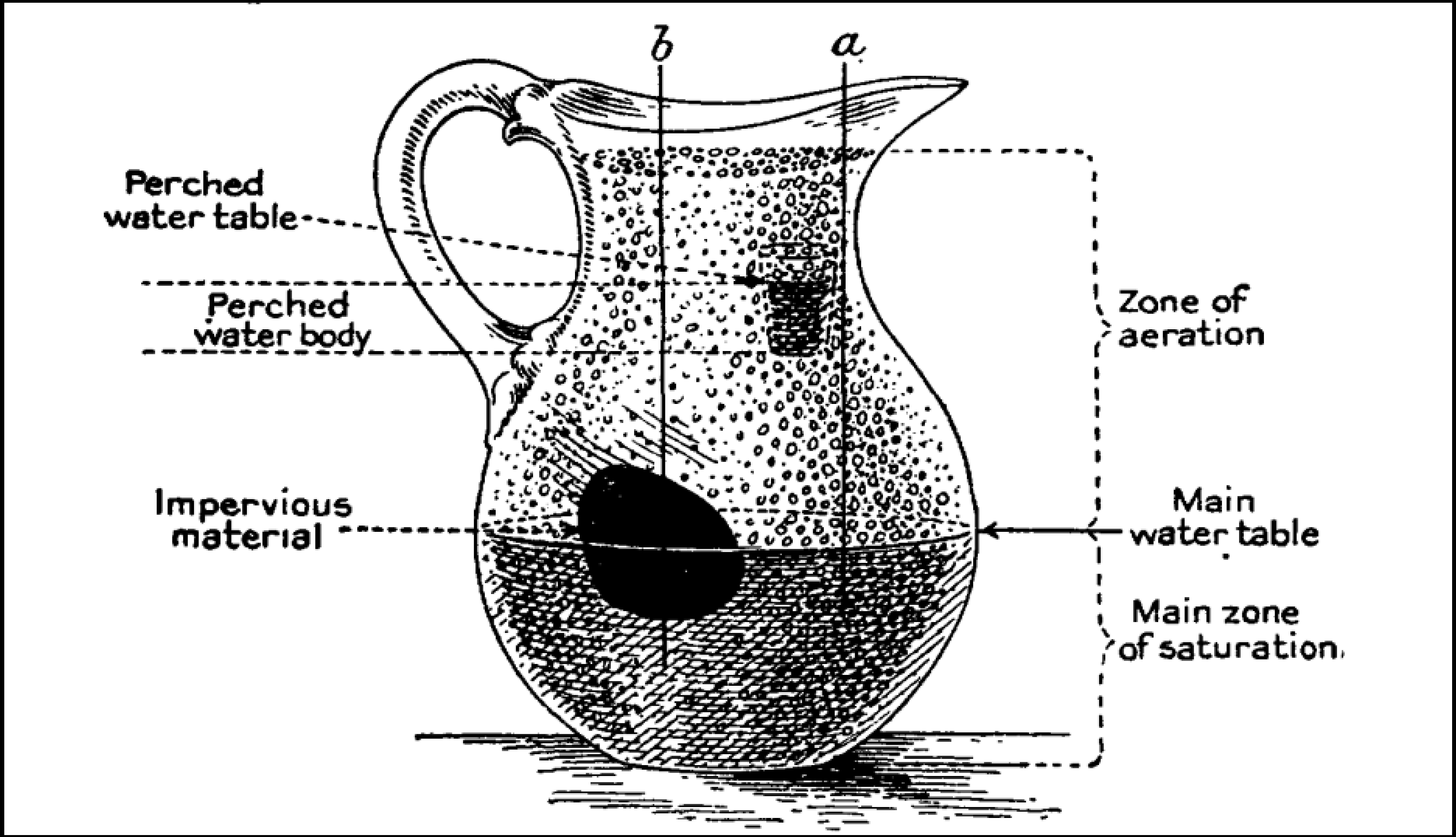
Digital Elevation Model
Islands Trust Information Services

# Darcy's Law, 1856

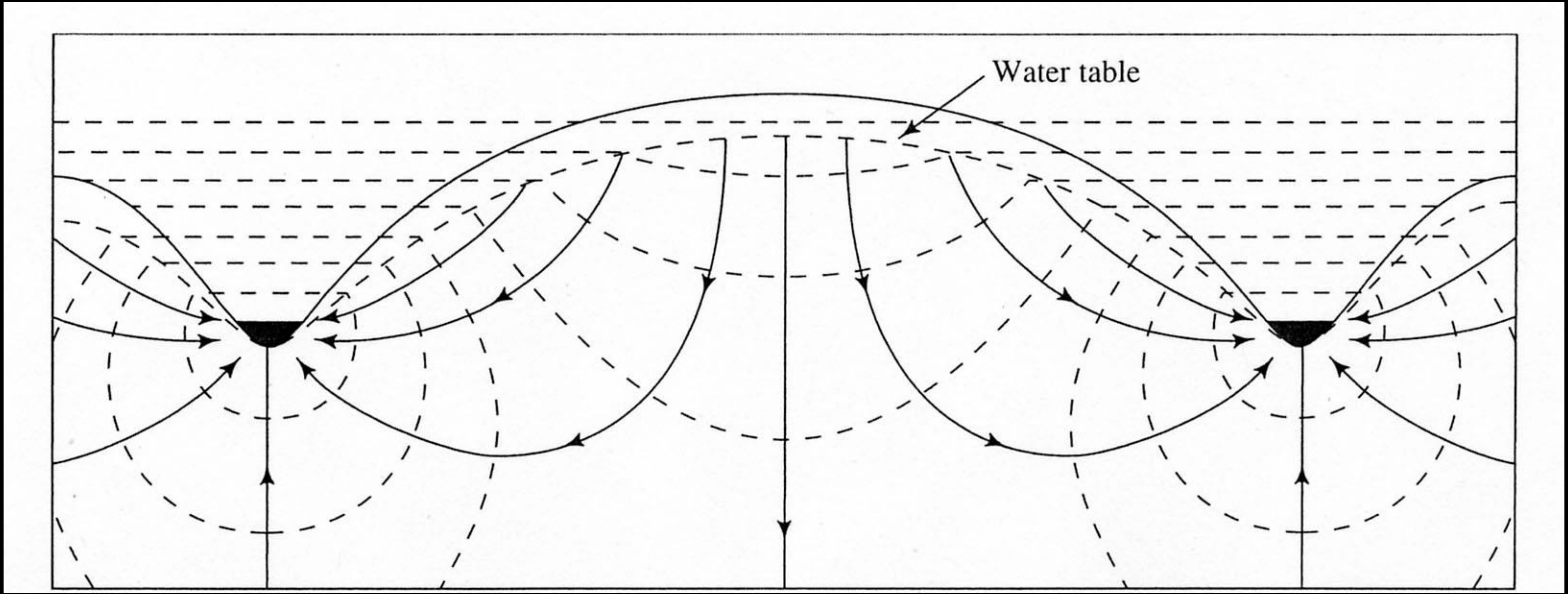


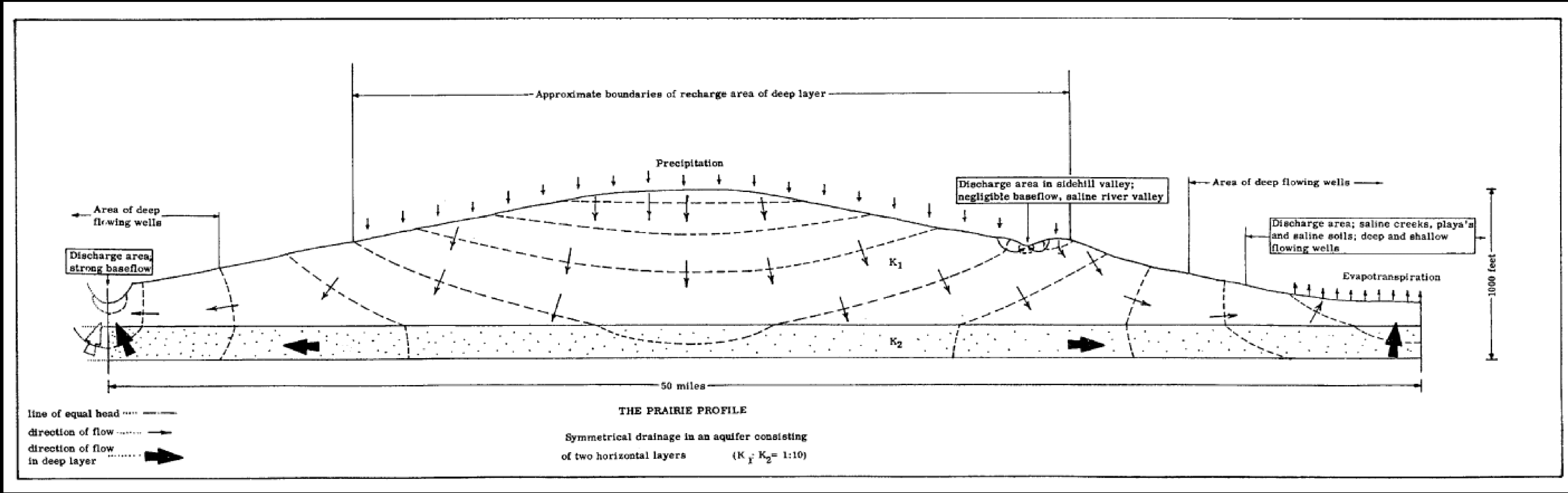
# Meinzer, USGS, 1923

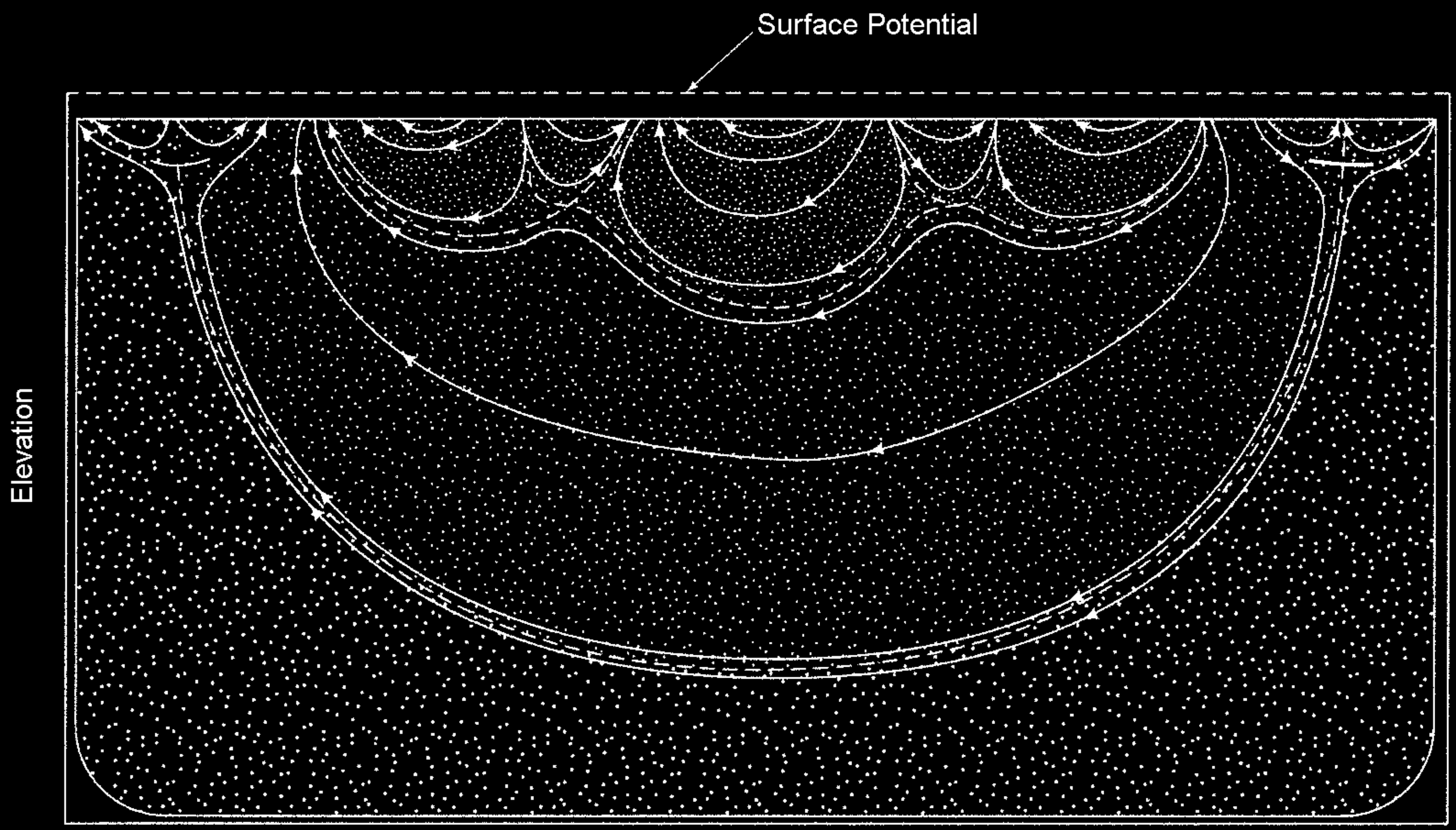


# Hubbert, USGS, 1940



# The Prairie Profile, Mayboom, 1962

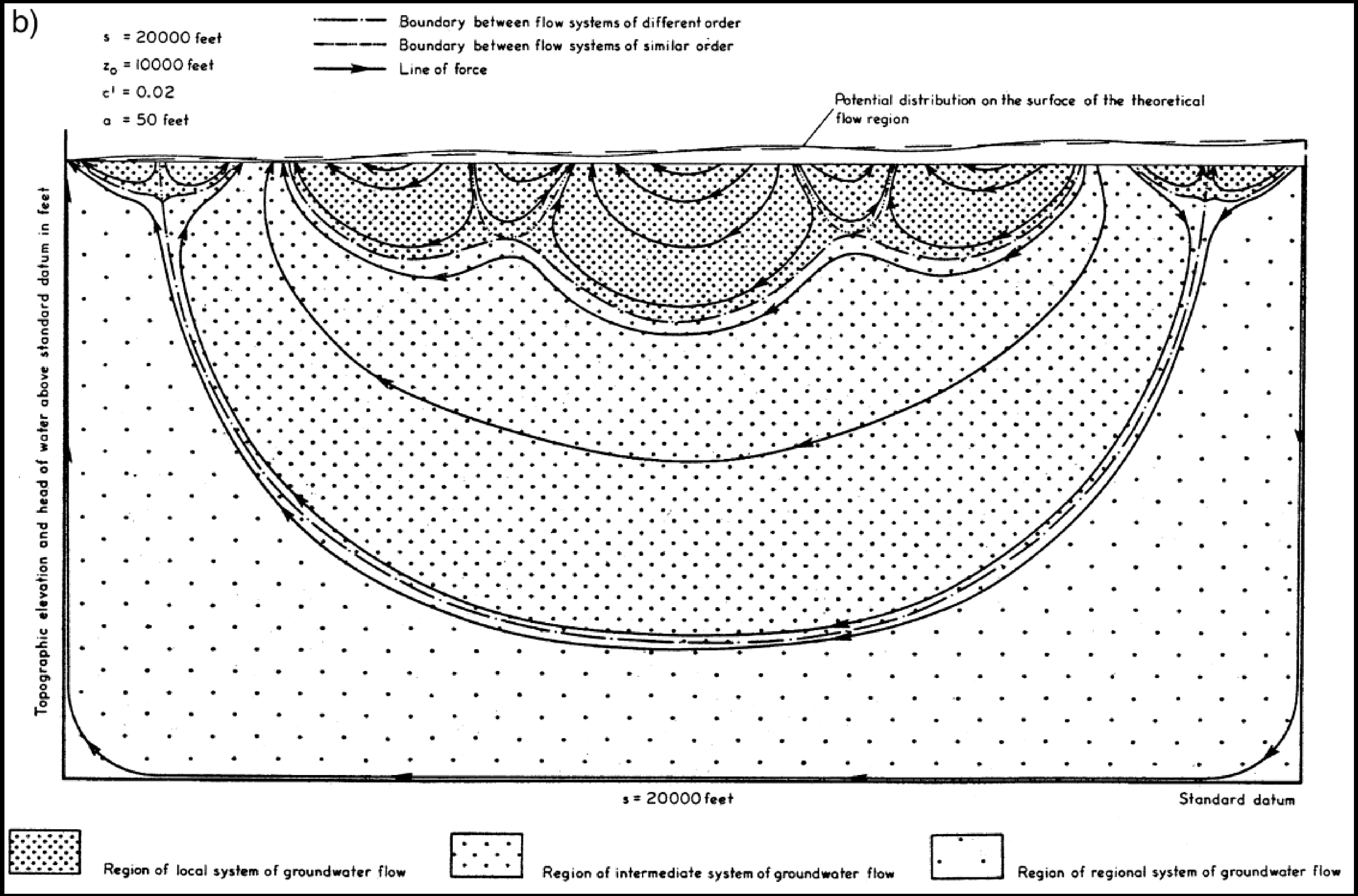


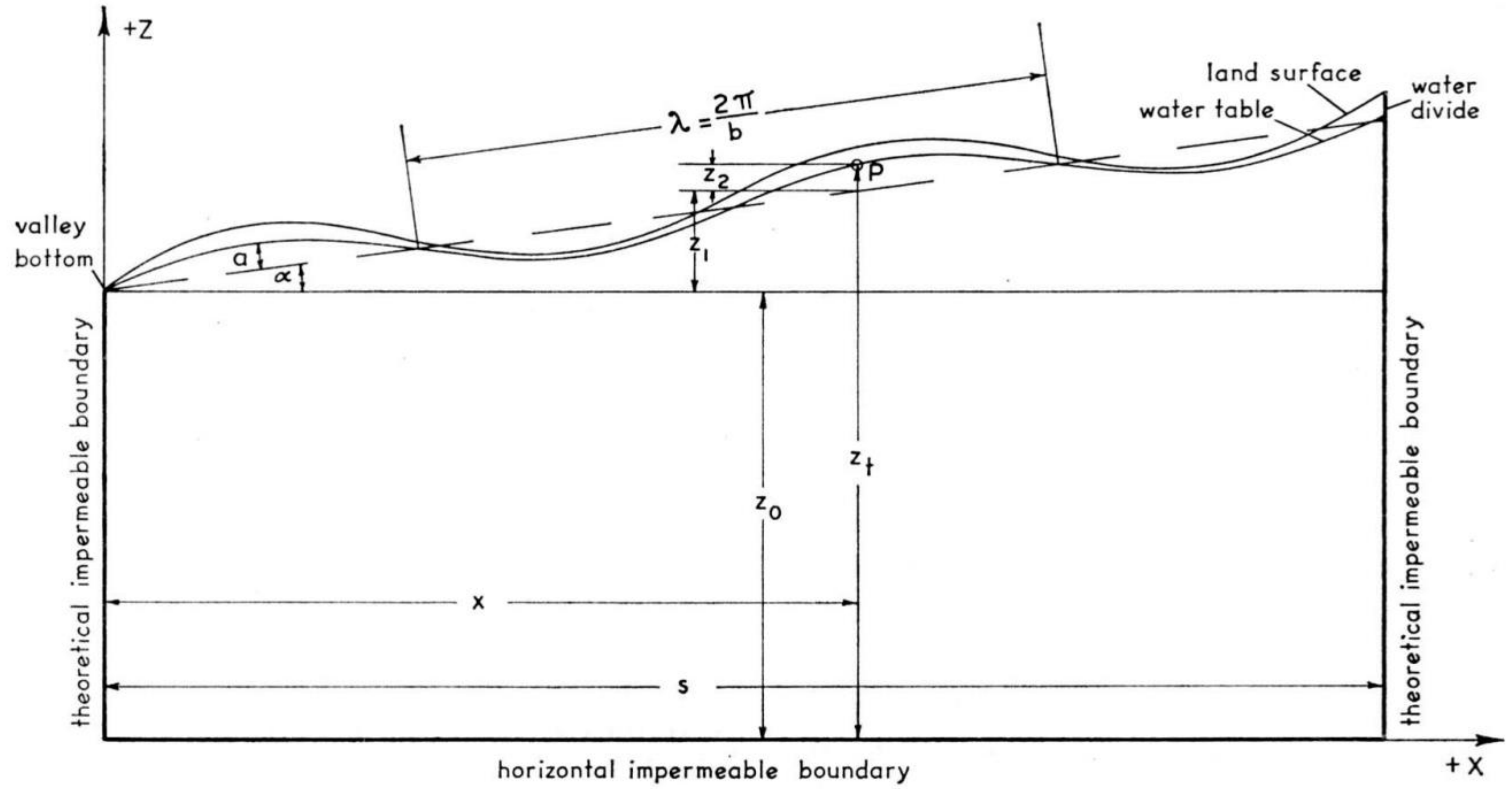



# Groundwater flows in a gravity driven freshwater network of *Hydraulic Continuity*

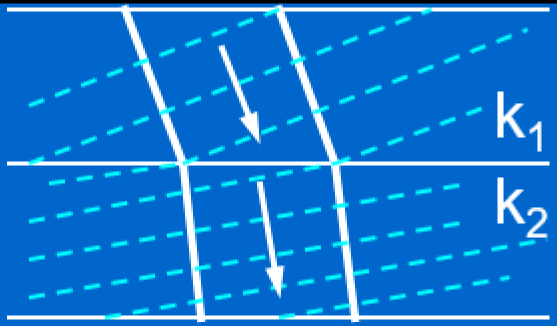
Groundwater Unit Basin (1963)
Dr. Jozef Toth

# The Unit Basin, Toth, 1963

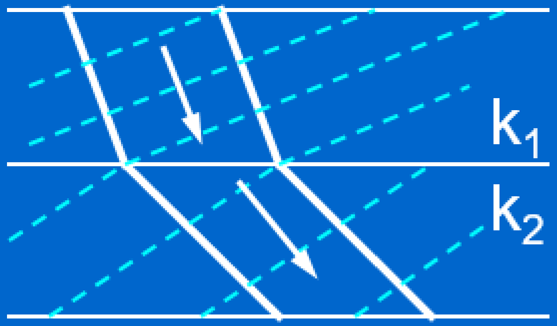




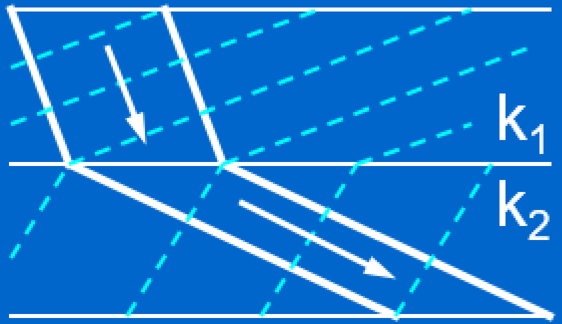
+Z
land surface
water divide
water table
$\lambda = \frac{2\pi}{b}$
$z_2$
P
valley bottom
a
α
$z_1$
theoretical impermeable boundary
theoretical impermeable boundary
$z_t$
$z_0$
x
s
horizontal impermeable boundary
+X




$k_1 > k_2$

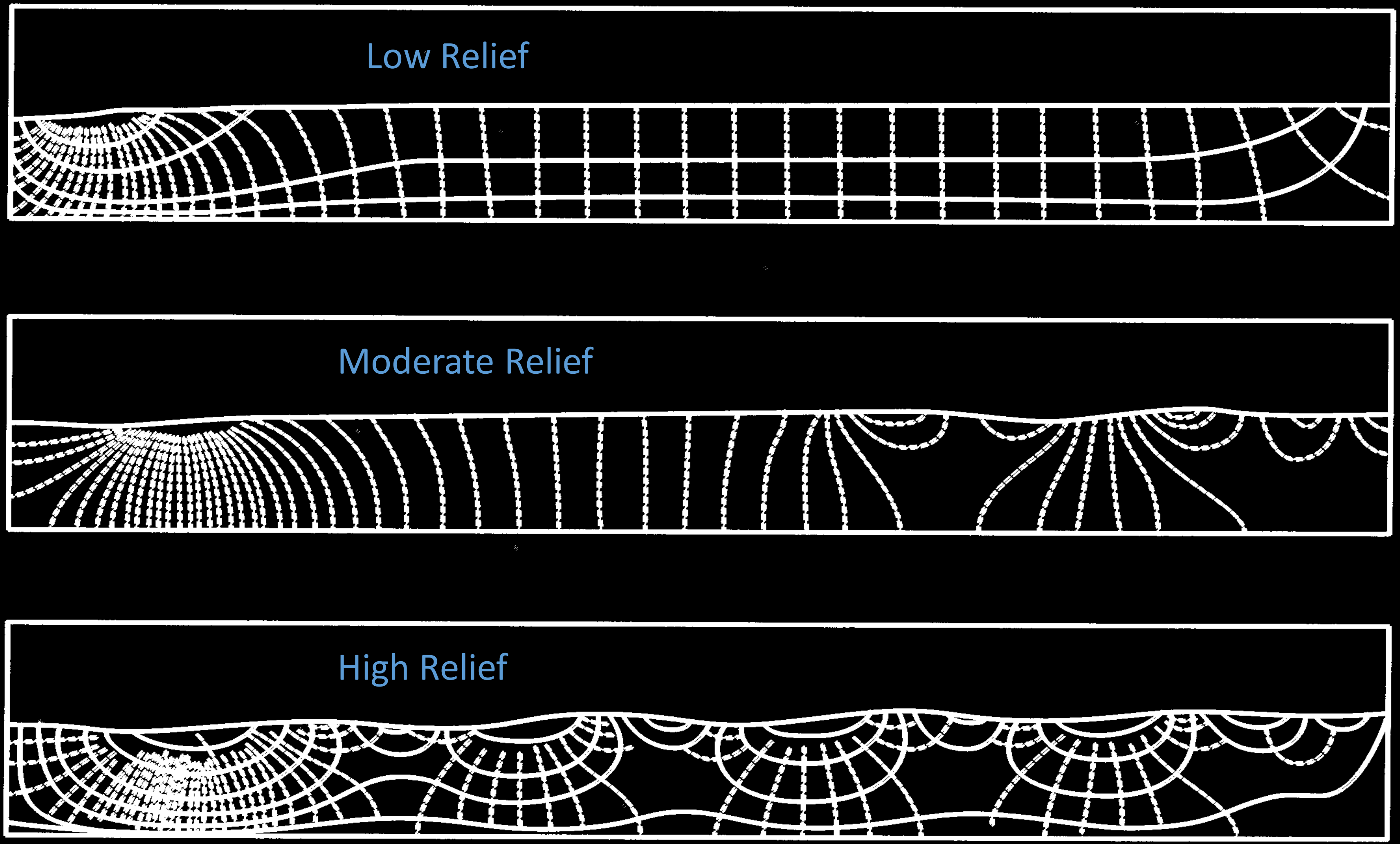



$k_1 < k_2$



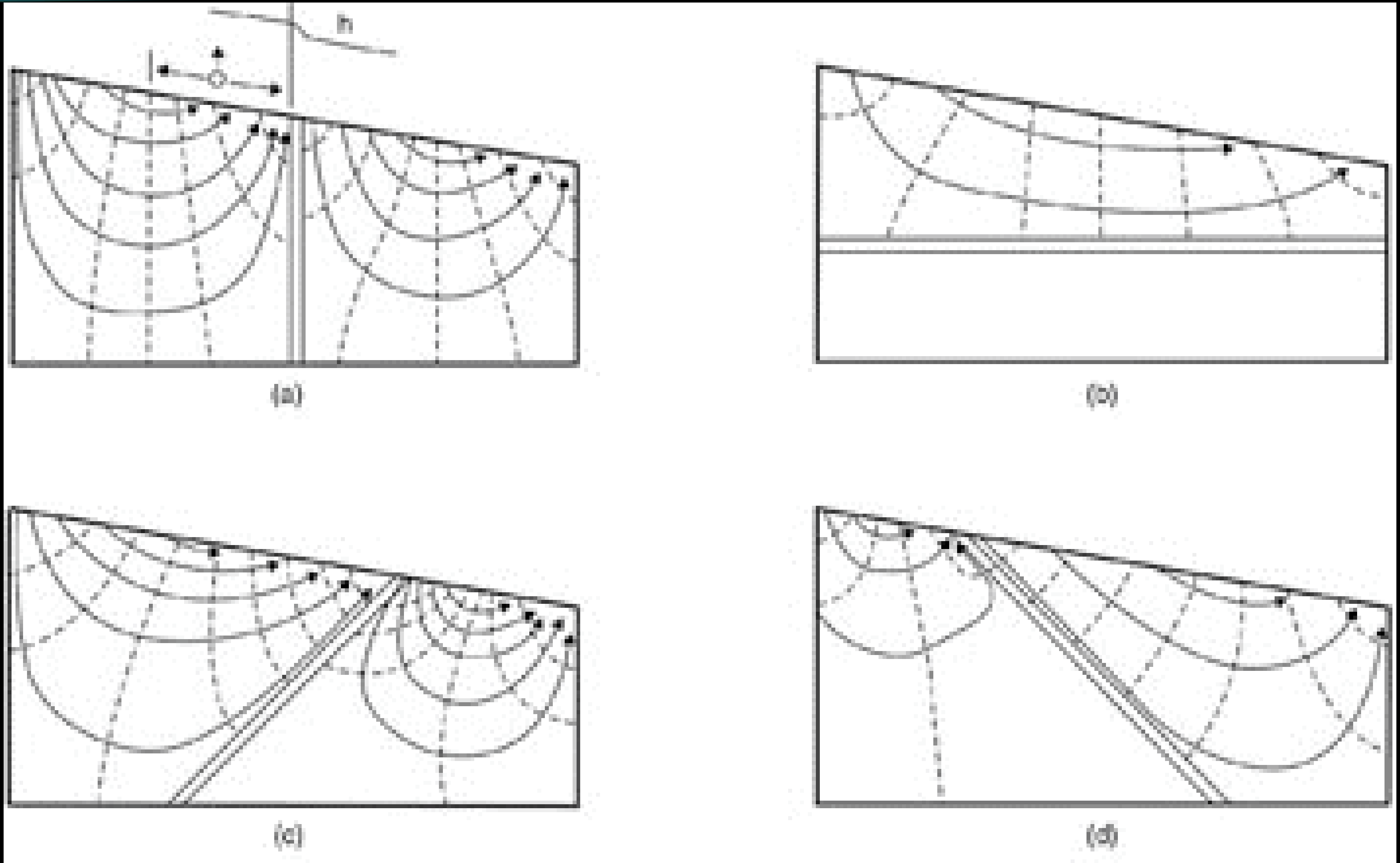

$k_1 << k_2$

- If hydraulic continuity decreases with depth, piezometric potentials crowd and flow becomes more vertical
- If hydraulic continuity increases with depth, piezometric potentials spread apart and flow becomes more horizontal
- If hydraulic continuity increases significantly with depth, piezometric potentials are widely spaced and flow becomes sub-horizontal

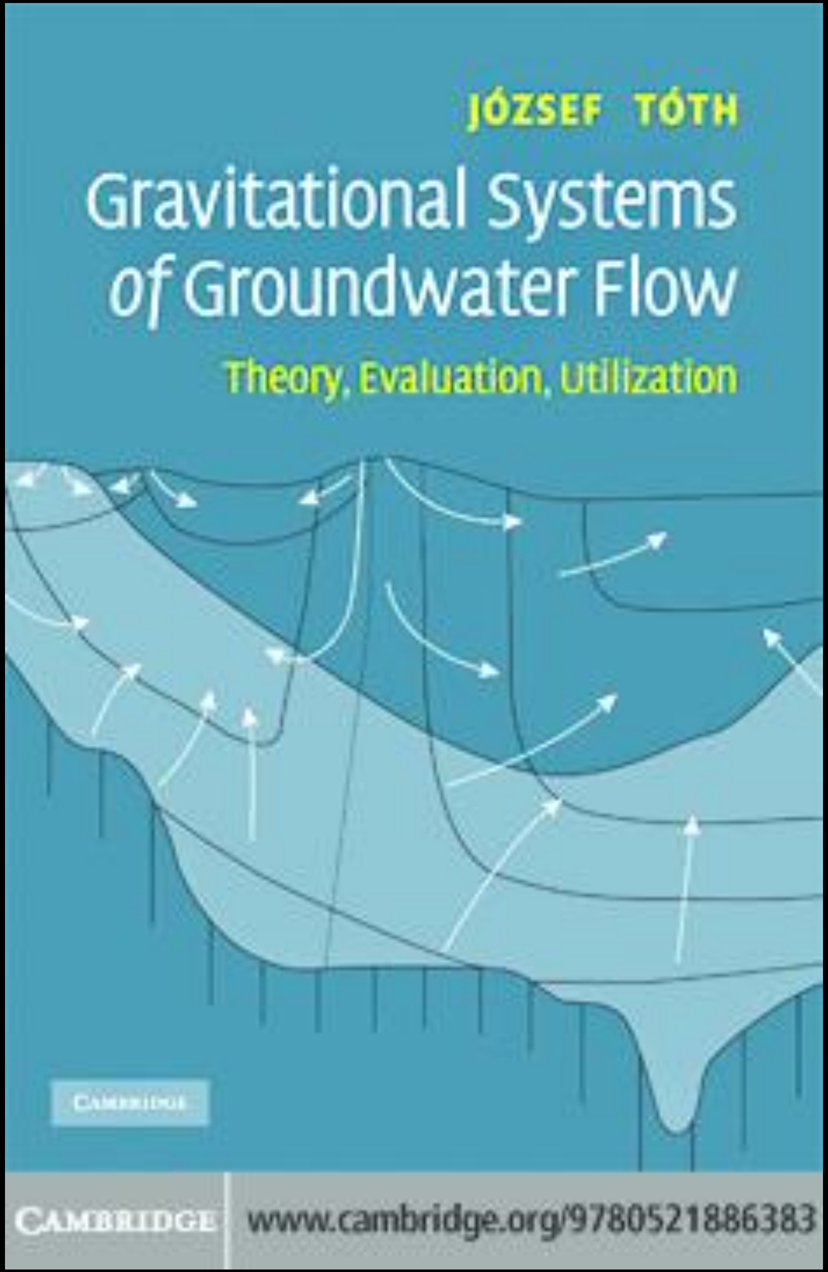



Groundwater flows in a gravity driven freshwater network of *Hydraulic Continuity*

Groundwater Unit Basin (1963)
Dr. Jozef Toth
Professor of Hydrogeology

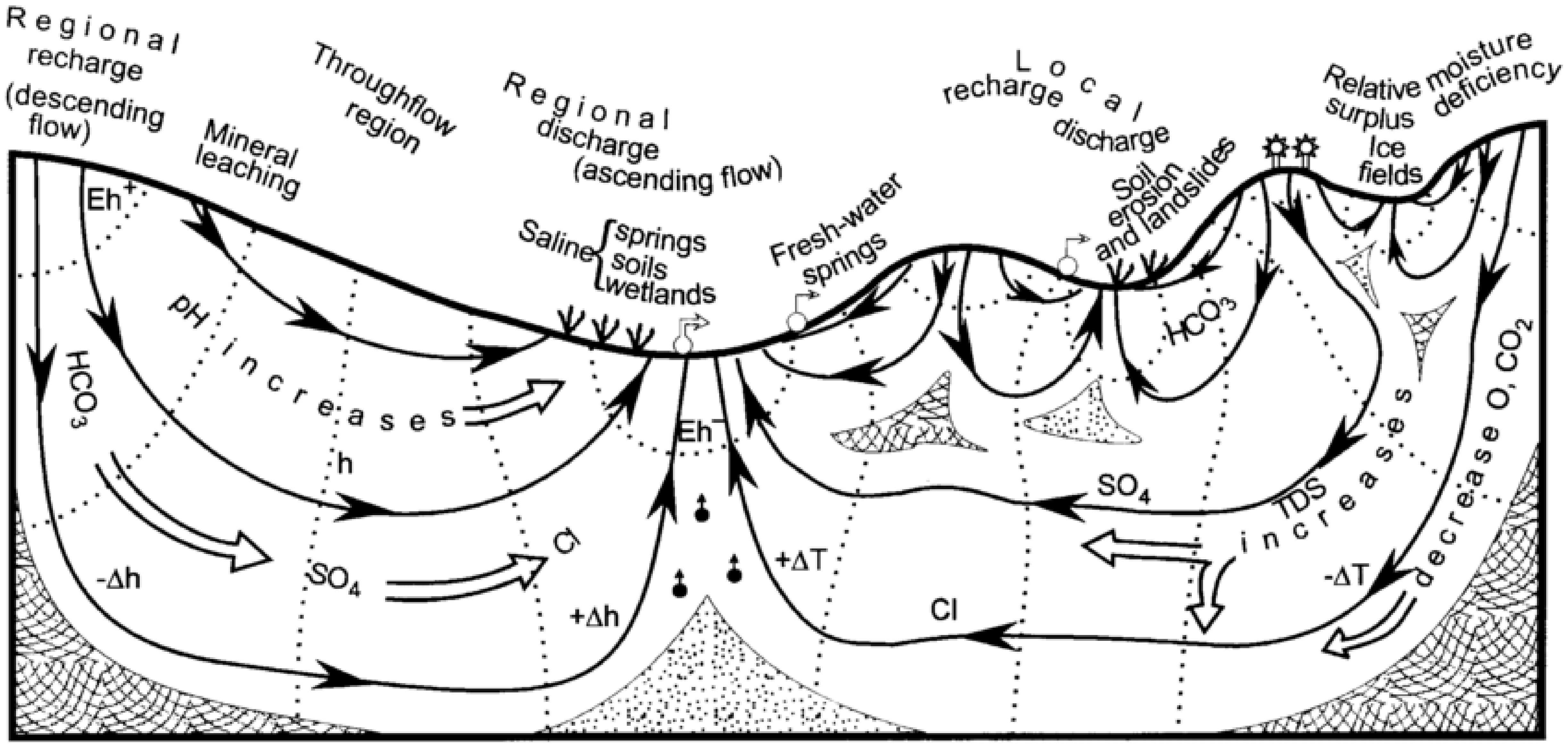


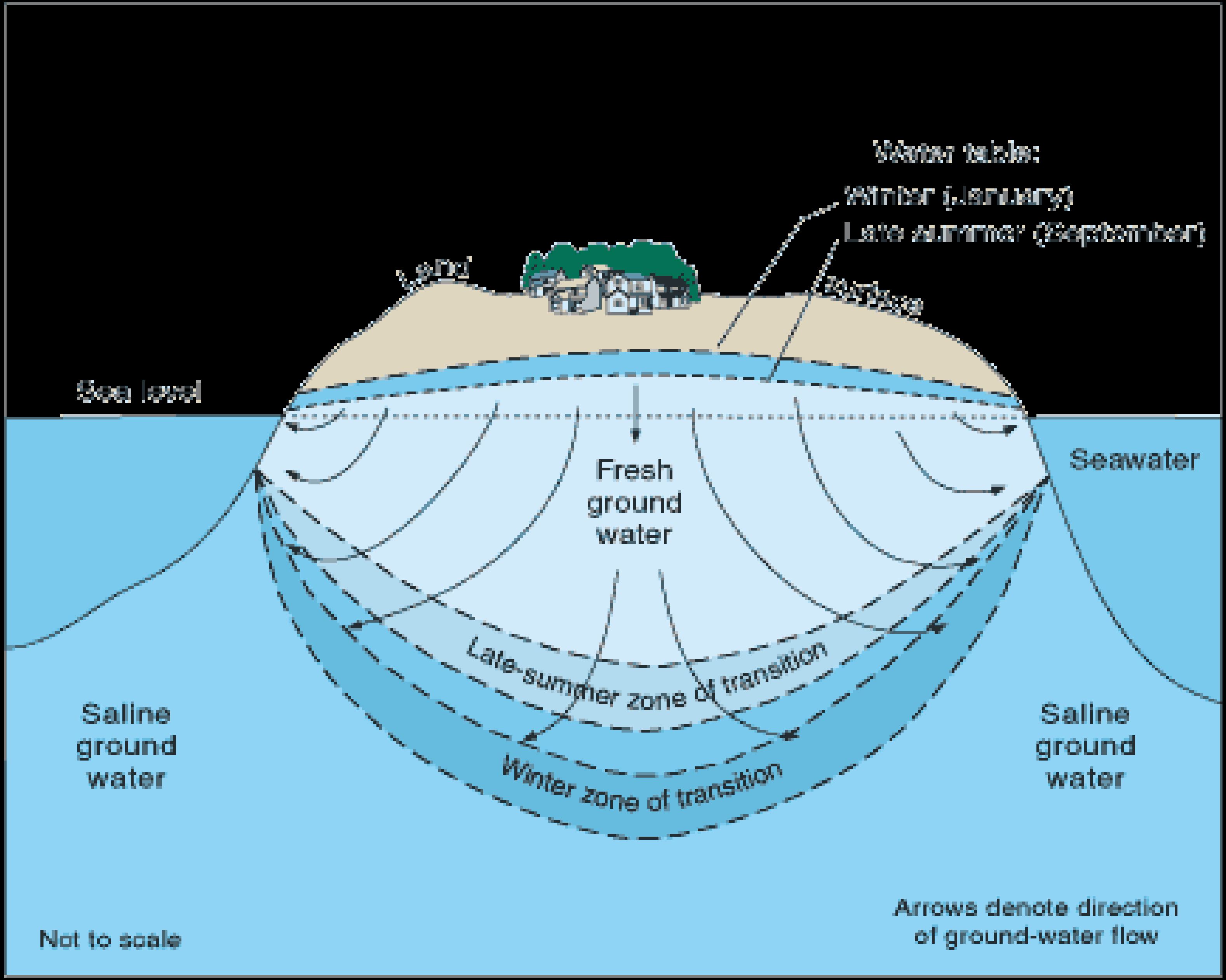

Toth, Jozef (1963)
A Theoretical Analysis of Groundwater Flowin Small Drainage Basins




Groundwater flows in a gravity driven freshwater network of *Hydraulic Continuity*

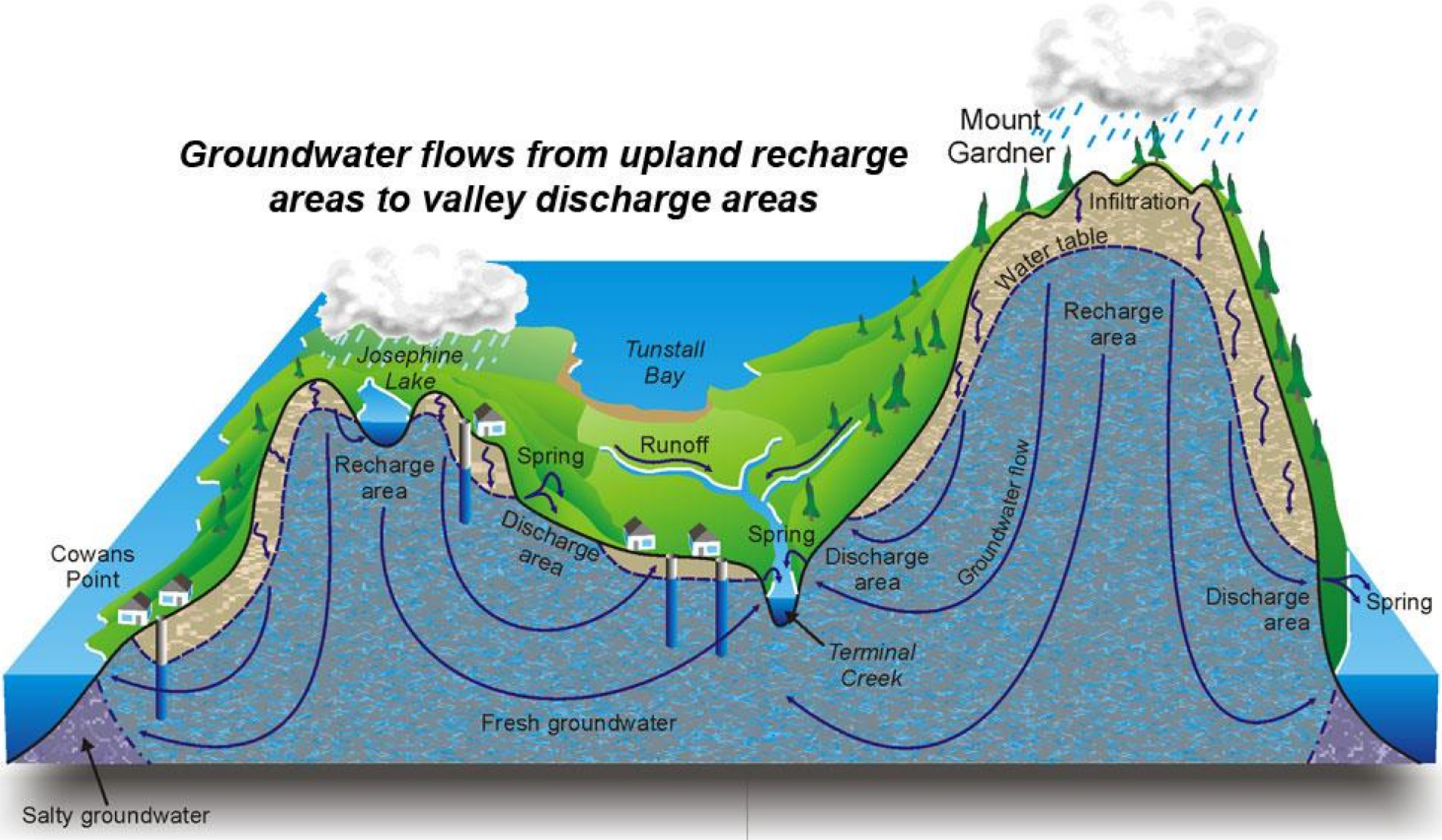
# Groundwater as a Geologic Agent, Toth, 1999





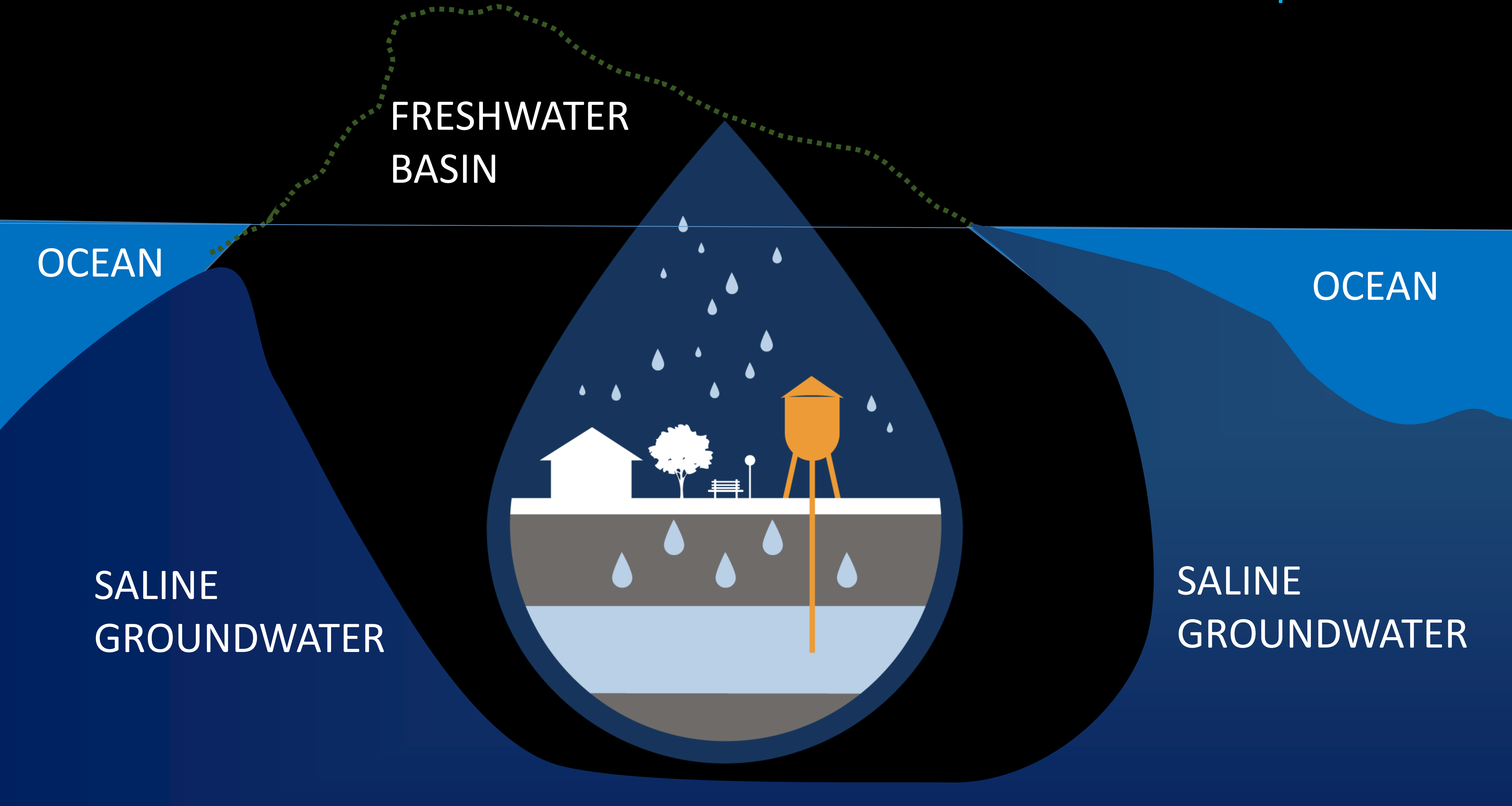
Water table:
Winter (January)
Late summer (September)
Land
surface
Sea level
Seawater
Fresh ground water
Late-summer zone of transition
Winter zone of transition
Saline ground water
Saline ground water
Not to scale
Arrows denote direction of ground-water flow

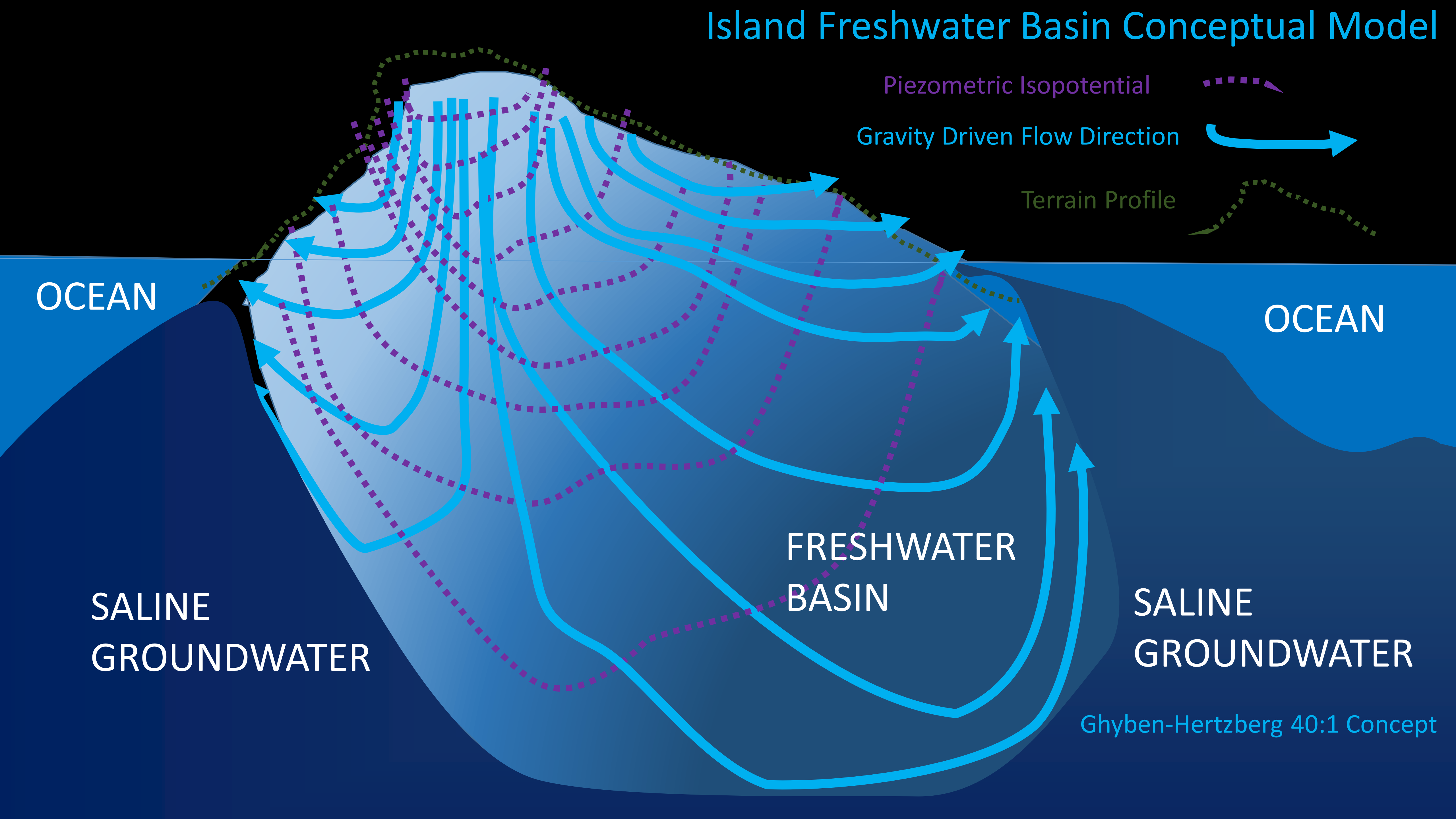
## *Groundwater flows from upland recharge areas to valley discharge areas*

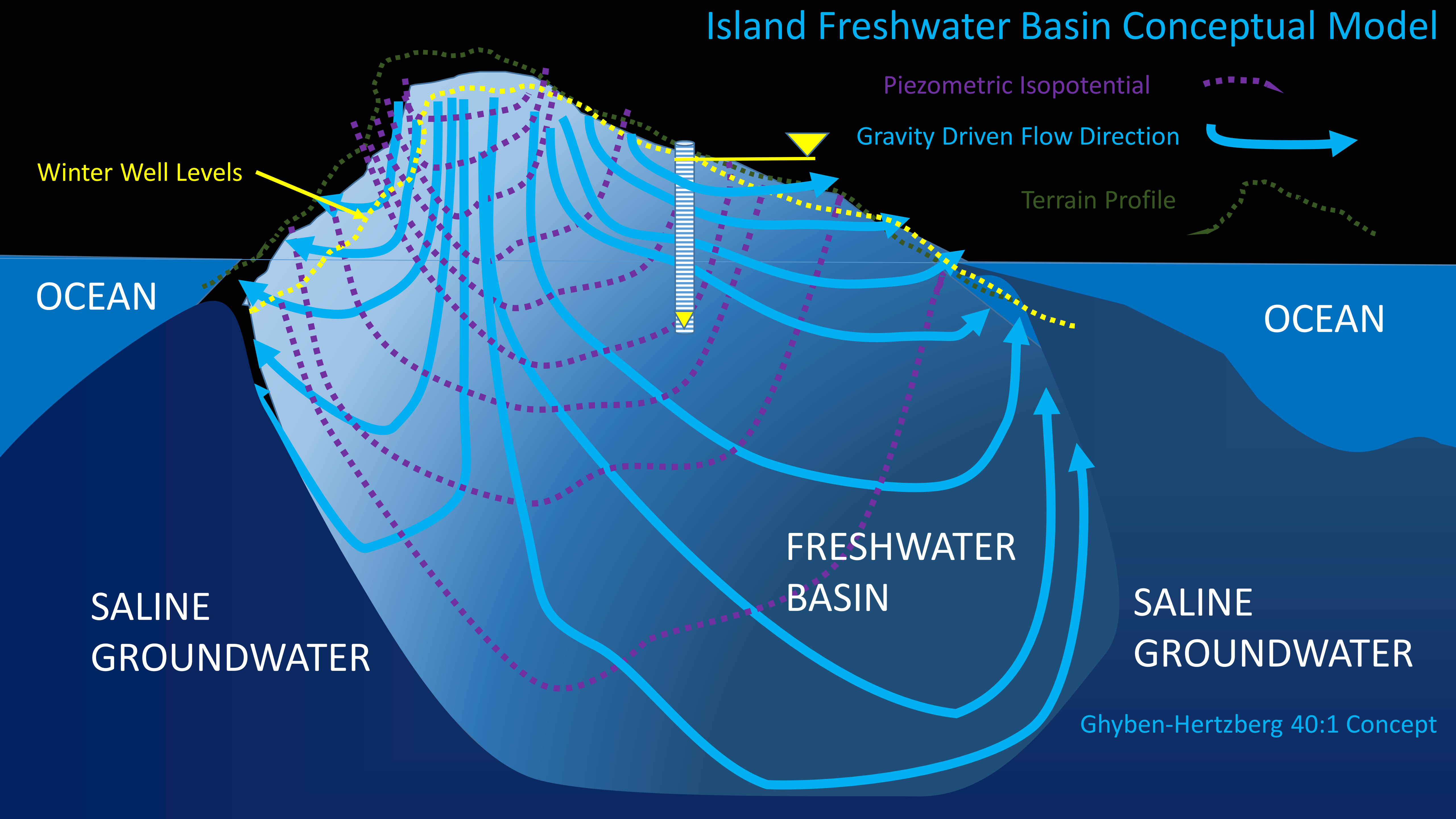


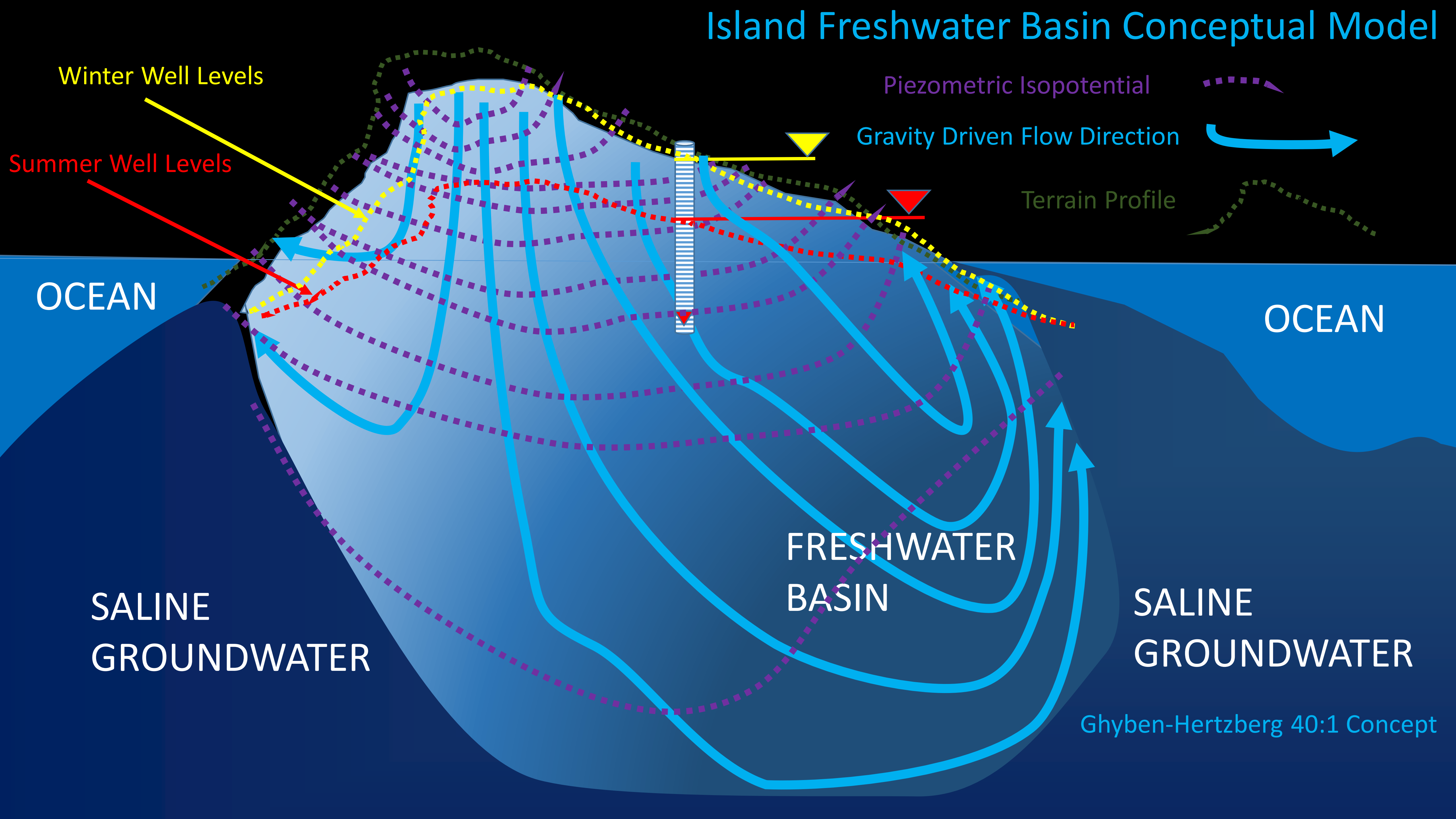

WATER

# Island Freshwater Basin Conceptual Model

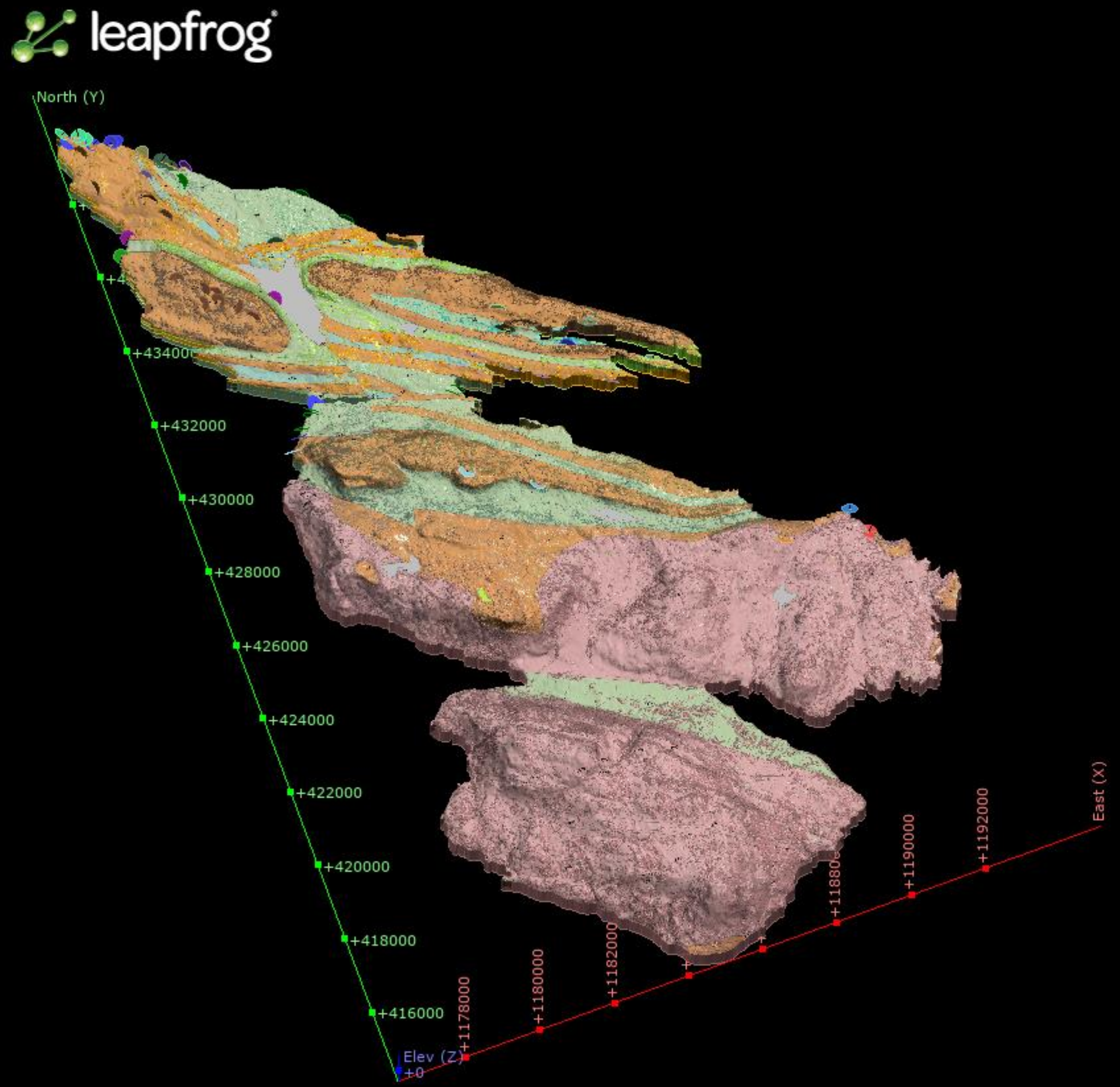



Island Freshwater Basin Conceptual Model
Piezometric Isopotential
Gravity Driven Flow Direction
Terrain Profile
OCEAN
OCEAN
FRESHWATER
BASIN
SALINE
GROUNDWATER
SALINE
GROUNDWATER
Ghyben-Hertzberg 40:1 Concept


Island Freshwater Basin Conceptual Model
Piezometric Isopotential
Gravity Driven Flow Direction
Terrain Profile
Winter Well Levels
OCEAN
OCEAN
FRESHWATER
BASIN
SALINE
GROUNDWATER
SALINE
GROUNDWATER
Ghyben-Hertzberg 40:1 Concept



Island Freshwater Basin Conceptual Model
Winter Well Levels
Summer Well Levels
Piezometric Isopotential
Gravity Driven Flow Direction
Terrain Profile
OCEAN
OCEAN
FRESHWATER
BASIN
SALINE
GROUNDWATER
SALINE
GROUNDWATER
Ghyben-Hertzberg 40:1 Concept

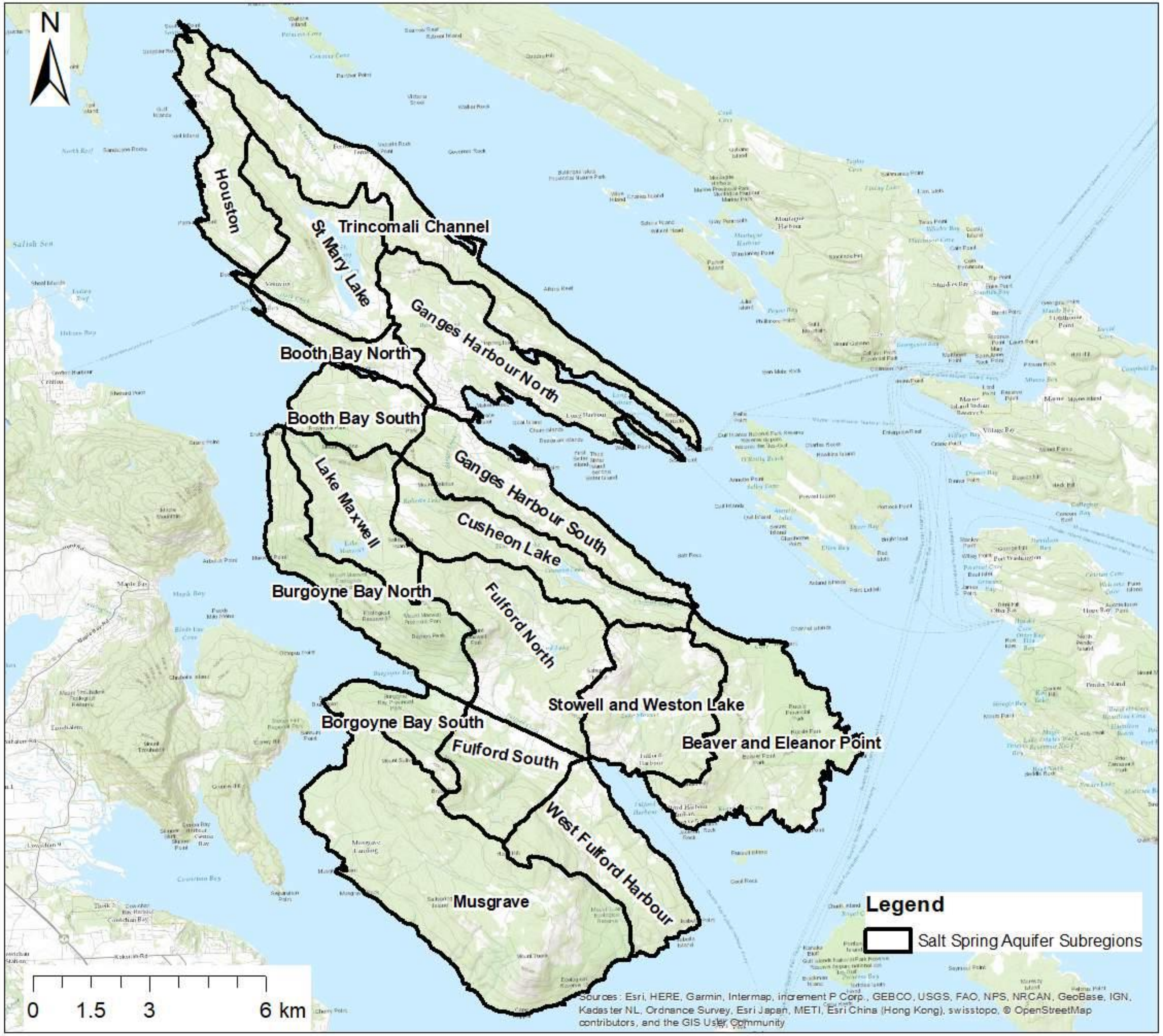


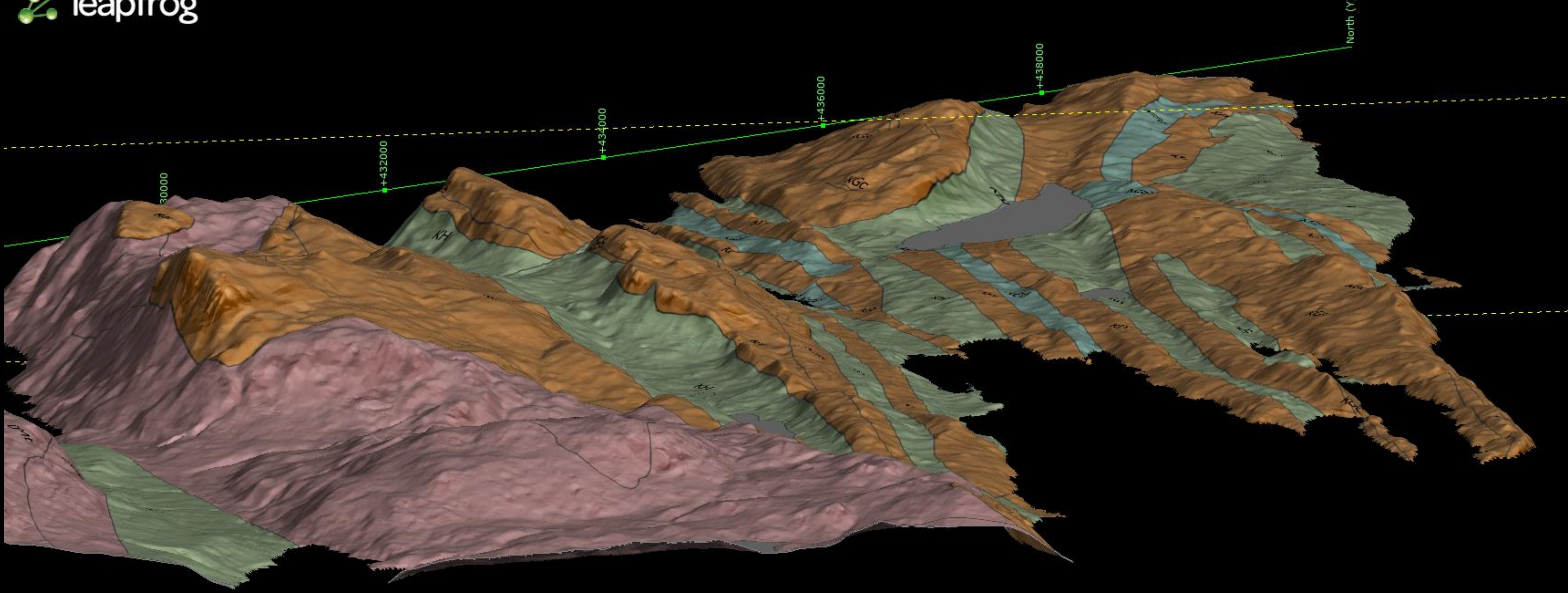

# Three Dimensional Hydrogeological Conceptual Model of Salt Spring Island

GW Solutions (2019)


# Geology of Saltspring Island

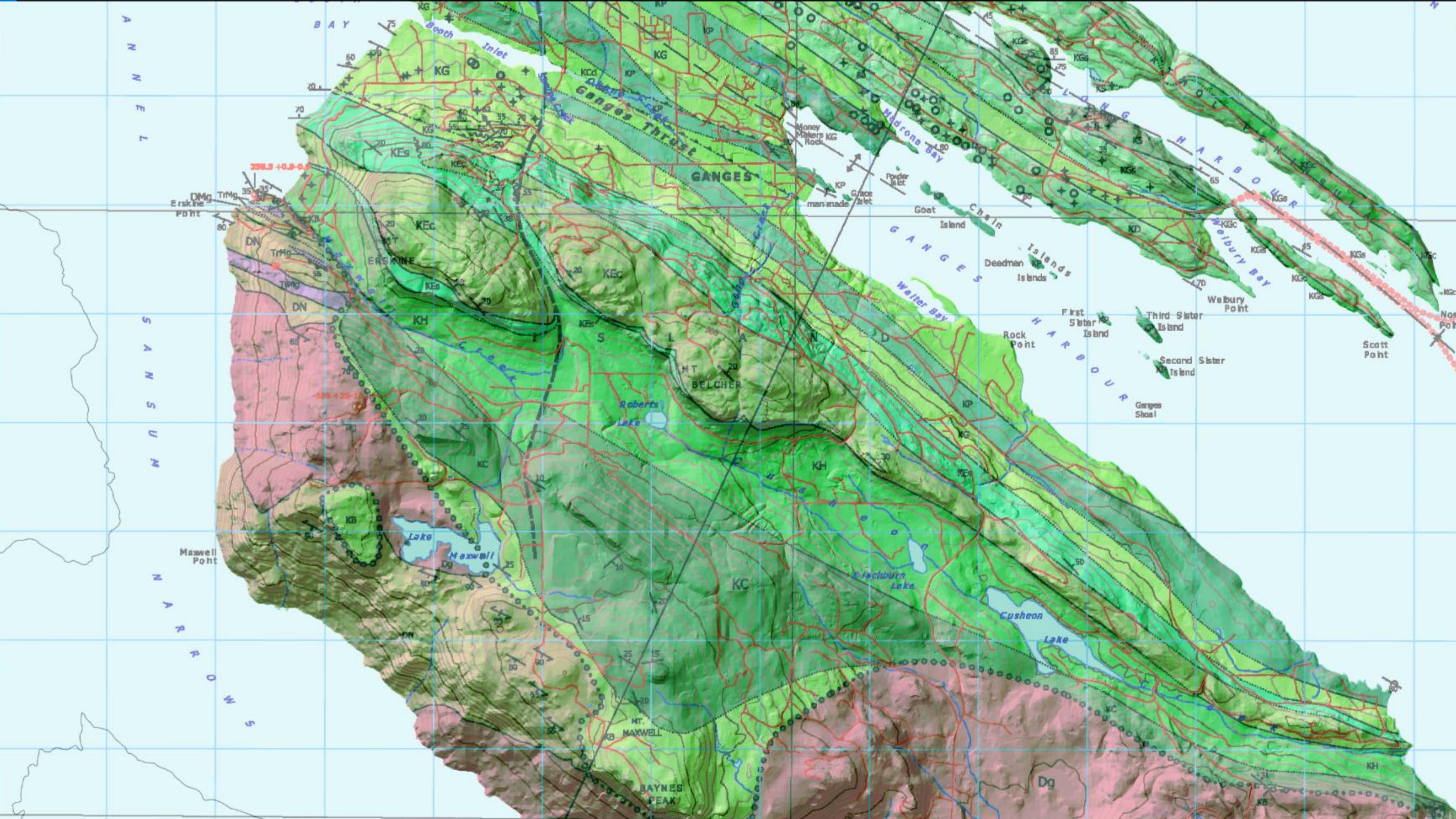
Greenwood, H.J (2009):Open File 2009-11
Ministry of Energy, Mines, and Petroleum Resources

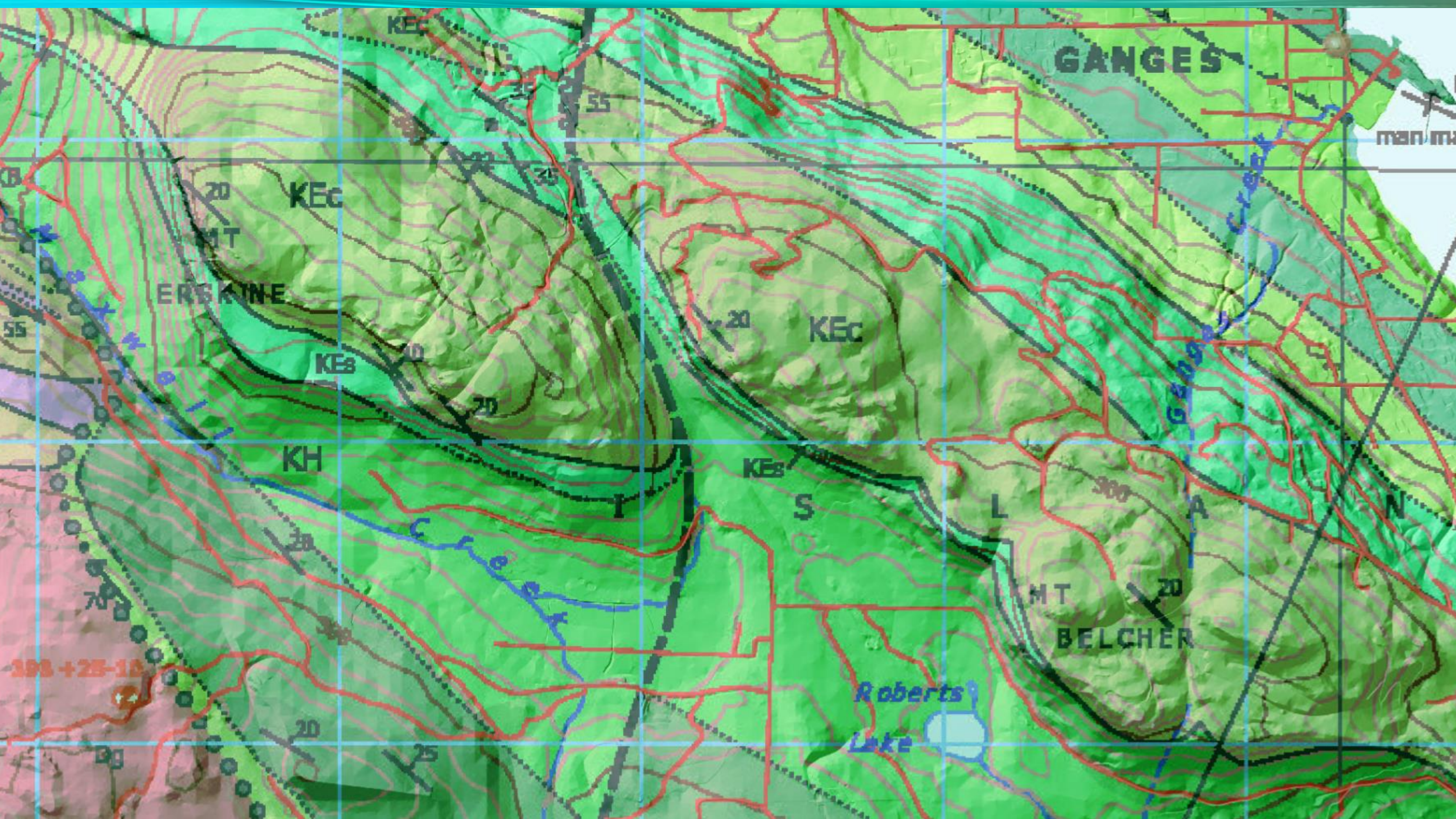

N
Houston
Trincomali Channel
St Mary Lake
Booth Bay North
Ganges Harbour North
Booth Bay South
Lake Maxwell
Ganges Harbour South
Cusheon Lake
Burgoyne Bay North
Fulford North
Stowell and Weston Lake
Borgoyne Bay South
Beaver and Eleanor Point
Fulford South
West Fulford Harbour
Musgrave
Legend
Salt Spring Aquifer Subregions
0 1.5 3 6 km
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community



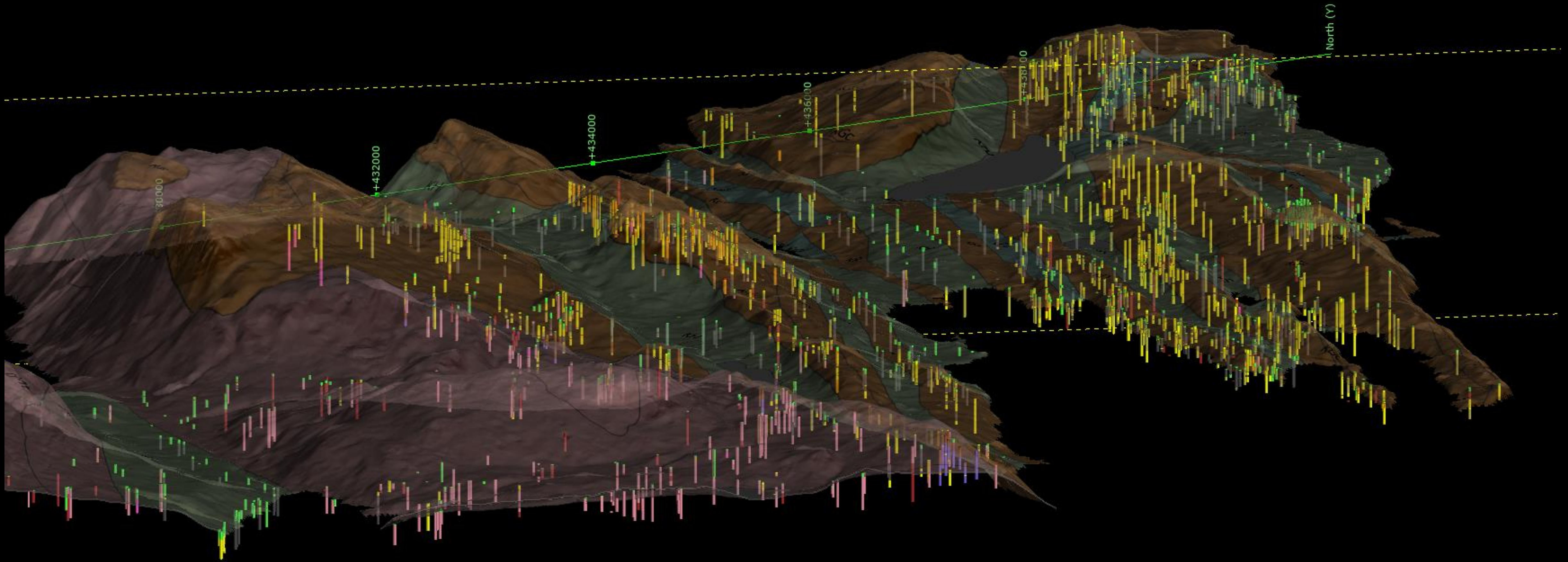

# Digital Elevation Model

Islands Trust Information Services


Booth Inlet
GANGES
Ganges Thrust
Madrona Bay
Goat Island
Chain
Deadman Islands
Walter Bay
GANGES HARBOUR
LONG HARBOUR
Welbury Bay
Welbury Point
First Sister Island
Third Sister Island
Second Sister Island
Scott Point
Rock Point
Ganges Shoal
Erskine Point
ERSKINE
SALT SPRING ISLAND
MT BELCHER
Roberts Lake
Blackburn Lake
Cusheon Lake
Lake Maxwell
Maxwell Point
MT. MAXWELL
BAYNES PEAK
SANSUM NARROWS
Powder Islet
Grace Islet
Money Makers Rock

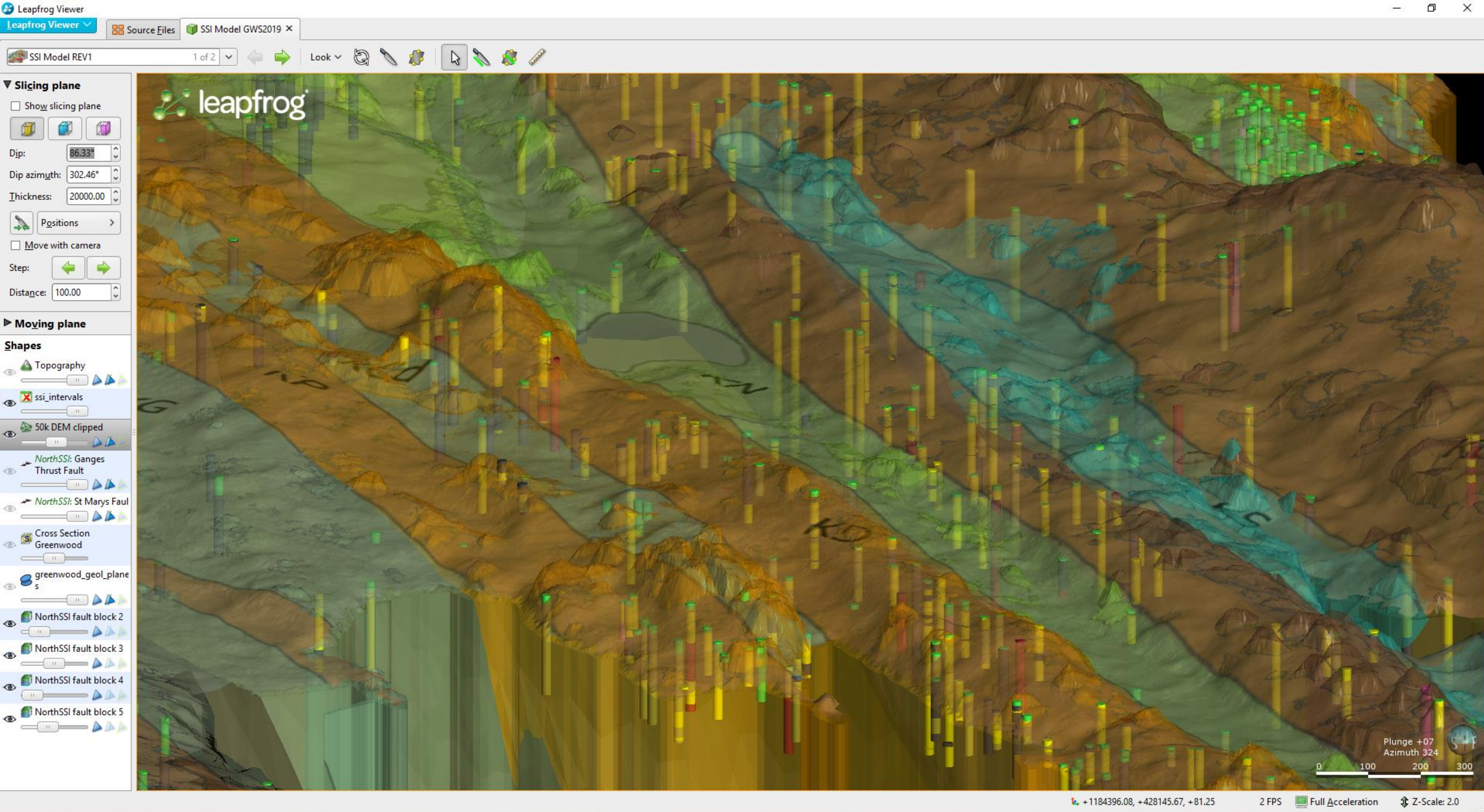


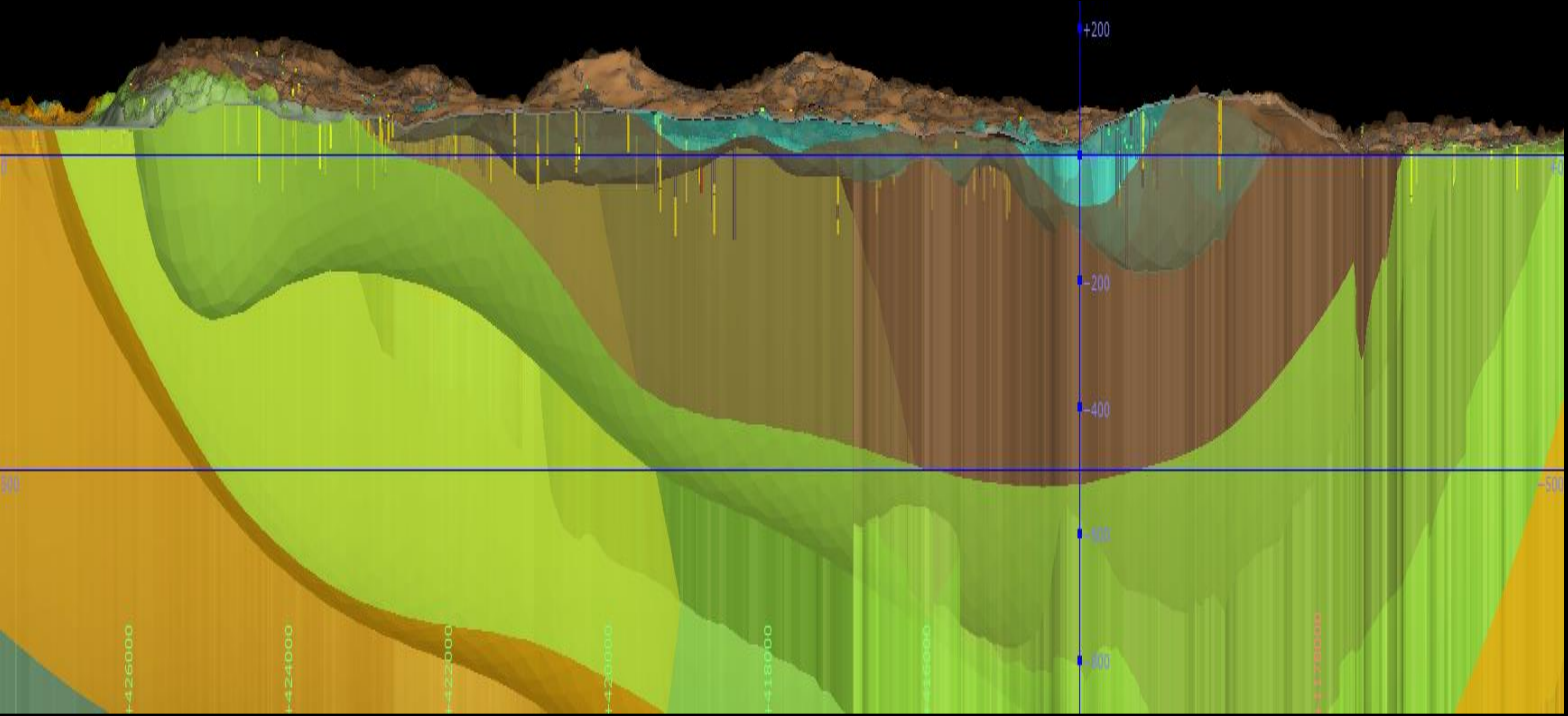
GANGES
KEc
KEc
KEc
MT
ERSKINE
KEs
KEs
KH
S
L
A
N
I
MT
BELCHER
Roberts
Lake
Creek
Ganges
Creek

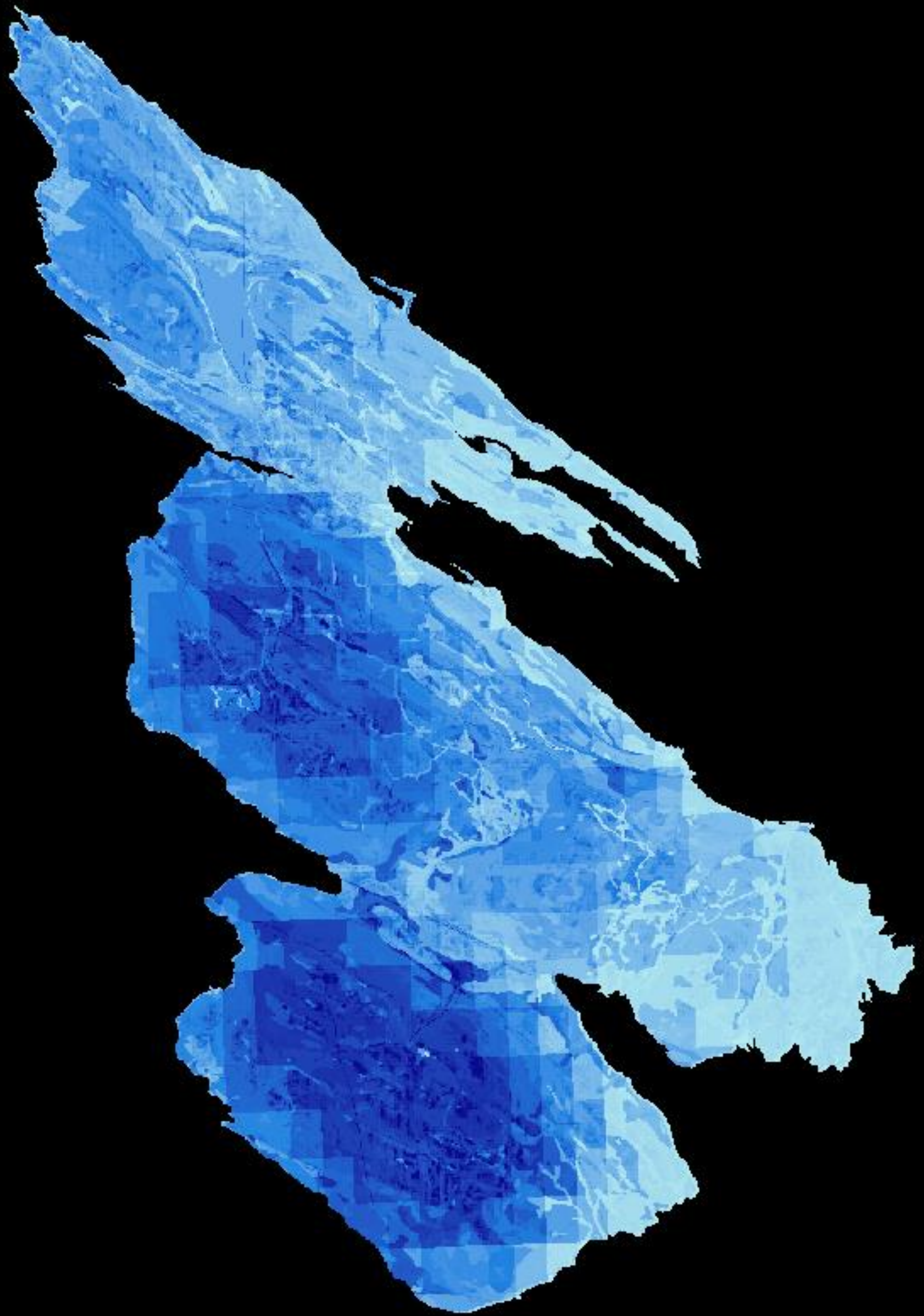



# Groundwater Well Records

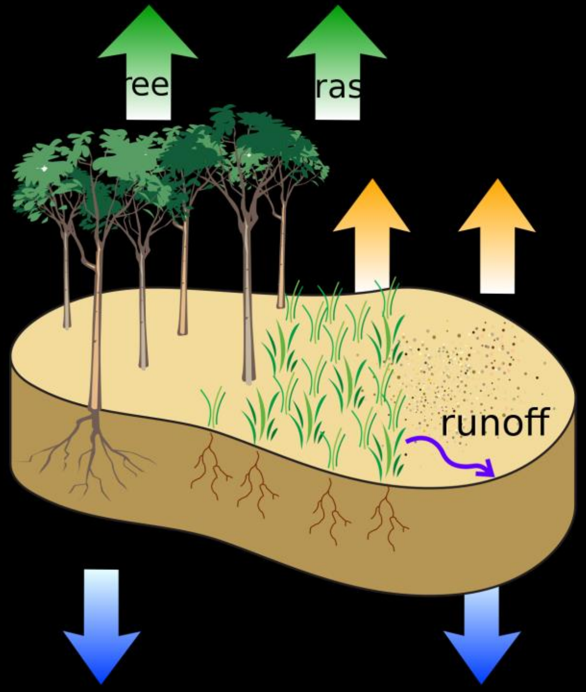
Ministry of Environment and Climate Change Strategy


Leapfrog Viewer
Leapfrog Viewer
Source Files
SSI Model GWS2019
SSI Model REV1
1 of 2
Look
Slicing plane
Show slicing plane
Dip:
86.33°
Dip azimuth:
302.46°
Thickness:
20000.00
Positions
Move with camera
Step:
Distance:
100.00
Moving plane
Shapes
Topography
ssi_intervals
50k DEM clipped
NorthSSI: Ganges Thrust Fault
NorthSSI: St Marys Faul
Cross Section Greenwood
greenwood_geol_planes
NorthSSI fault block 2
NorthSSI fault block 3
NorthSSI fault block 4
NorthSSI fault block 5
leapfrog
Plunge +07
Azimuth 324
0
100
200
300
+1184396.08, +428145.67, +81.25
2 FPS
Full Acceleration
Z-Scale: 2.0


+200
-200
-400
-500
+4260000
+4240000
+4180000



# Meteoric Recharge



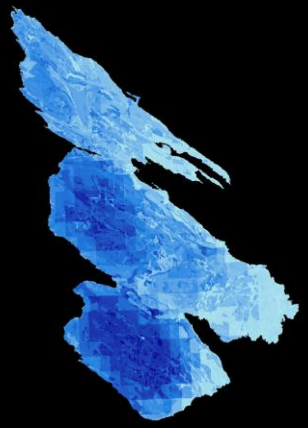

Groundwater Recharge Potential Model
Completed for Islands Trust by GW Solutions

| Value | Description | Group | Infiltration Factor |
|---|---|---|---|
| 0 | No Data | No Data | 0 |
| 11 | Cloud | Cloud | 0 |
| 12 | Shadow | Shadow | 0 |
| 20 | Water | Water | 0 |
| 31 | Snow/Ice | Non-Vegetated Land | 0 |
| 32 | Rock/Rubble | Non-Vegetated Land | 0.1 |
| 33 | Exposed Land | Non-Vegetated Land | 0.08 |
| 34 | Developed | Non-Vegetated Land | 0.01 |
| 52 | Shrub - Low | Shrubland | 0.15 |
| 81 | Wetland Treed | Wetland | 0.05 |

| Value | Description | Group | Infiltration Factor |
|---|---|---|---|
| 82 | Wetland Shrub | Wetland | 0.05 |
| 83 | Wetland Herb | Wetland | 0.05 |
| 100 | Herb | Herb | 0.14 |
| 110 | Grassland | Herb | 0.13 |
| 121 | Annual crops | Herb | 0.12 |
| 122 | Perennial crops and Pasture | Herb | 0.12 |
| 211 | Coniferous - Dense | Forest/Trees | 0.2 |
| 212 | Coniferous - Open | Forest/Trees | 0.19 |
| 213 | Coniferous - Sparse | Forest/Trees | 0.18 |
| 221 | BroadLeaf - Dense | Forest/Trees | 0.17 |
| 222 | BroadLeaf - Open | Forest/Trees | 0.16 |
| 223 | BroadLeaf - Sparse | Forest/Trees | 0.15 |
| 233 | MixedWood - Sparse | Forest/Trees | 0.14 |

| Group | Code | Description | Factor |
|---|---|---|---|
| Drain | P | Poorly Drained | 0.1 |
| Drain | I | Imperfectly Drained | 0.15 |
| Drain | MW | Moderately Well Drained | 0.2 |
| Drain | W | Well Drained | 0.3 |
| Drain | R | Rapidly Drained | 0.4 |
| Texture | SICL | Silty Clay Loam | 0.1 |
| Texture | SIL | Silt Loam | 0.15 |
| Texture | SL | Sandy Loam | 0.2 |
| Texture | L | Loam | 0.3 |

| Group | Code | Description | Factor |
|---|---|---|---|
| Texture | LS | Loamy Sand | 0.35 |
| Texture | S | Sand | 0.4 |
| Geology | | Anthropogenic | 0.01 |
| Geology | | Bedrock | 0.2 |
| Geology | | Colluvium | 0.2 |
| Geology | | Fluvial | 0.3 |
| Geology | | Glacio Fluvial | 0.4 |
| Geology | | Glacio Marine | 0.2 |
| Geology | | Ice | 0 |
| Geology | | Lacustrine | 0.1 |
| Geology | | Marine | 0.1 |
| Geology | | Moraine | 0.1 |
| Geology | | Organic | 0.1 |
| Geology | | Undefined | 0.01 |
| Geology | | Undifferentiated | 0.2 |



| Groundwater recharge potential | Slope degree | Infiltration factor |
|---|---|---|
| Minimum | >24.04 | 0.01 |
| Very poor | 8.46 - 24.04 | 0.02 |
| Poor | 4.51-8.46 | 0.05 |
| Moderate | 2.7-4.51 | 0.1 |
| Good | 1.8-2.7 | 0.15 |
| Very good | 0.22-1.8 | 0.2 |
| High | <0.22 | 0.3 |

| Groundwater recharge potential | TWI range | TWI Recharge Potential |
|---|---|---|
| Low | < 8 | 0.25 |
| Moderate | 8 - 11 | 0.5 |
| High | 11 - 14 | 0.75 |
| Very High | 14 - 21 | 1 |

| Groundwater recharge potential | Surplus range (mm) | Recharge Potential |
|---|---|---|
| Minimum | < 560 | 0.15 |
| Poor | 560 - 610 | 0.35 |
| Moderate | 610 - 650 | 0.5 |
| Good | 650- 710 | 0.65 |
| Very good | 710 - 790 | 0.8 |
| High | 790 - 960 | 1 |

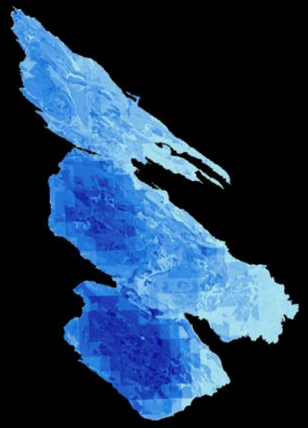
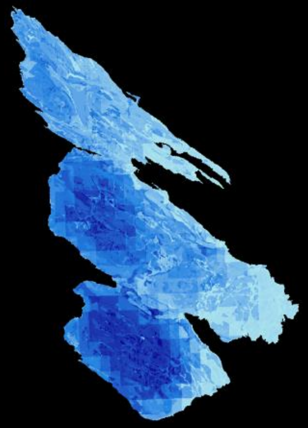


Table 7. Relationship between recharge potential and groundwater amplitude

| Observation well | Groundwater amplitude | Recharge potential | Recharge potential group |
|---|---|---|---|
| OW281 | 0.7 | 0.06 | Low |
| OW438 | 5 | 0.2 | Moderate |
| OW373 | 6.5 | 0.35 | High |

$$q = \frac{P * Clp}{Clgw}$$

where q is groundwater recharge flux (mm/year), P is average annual precipitation (mm/year), Clp average precipitation-weighted chloride concentrations (1.313 mg/L for precipitation on Saturna Island) and Clgw is the average chloride concentration in groundwater (mg/L). Using this method, the calculated aquifer recharge flux for Salt Spring varies from 9 to 285 mm/year, suggesting that the mechanism for recharge on Salt Spring is complex and spatially variable.



## 4.3 Recharge Potential

In most systems, the sum of slope, soil and land cover factors will determine the percentage of surplus that will recharge the groundwater systems. However, in a bedrock dominant environment, the faults, geologic contacts and lineaments will also play an important role. GW Solutions proposes the following equation to estimate the groundwater recharge potential:

$$RP=[85\%*(IF_{soil}+IF_{landcover}+IF_{slope})+15\%*(IF_{faults})]*SI$$

Where:

RP= Recharge potential (0.0 - 0.73)

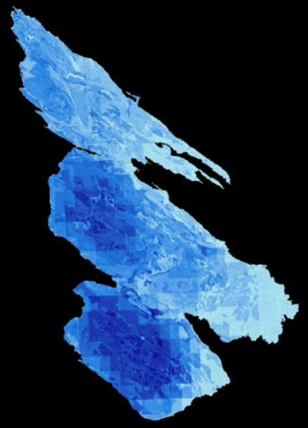
$IF_{soil}$ = Soil infiltration factor (0.0 - 0.4)

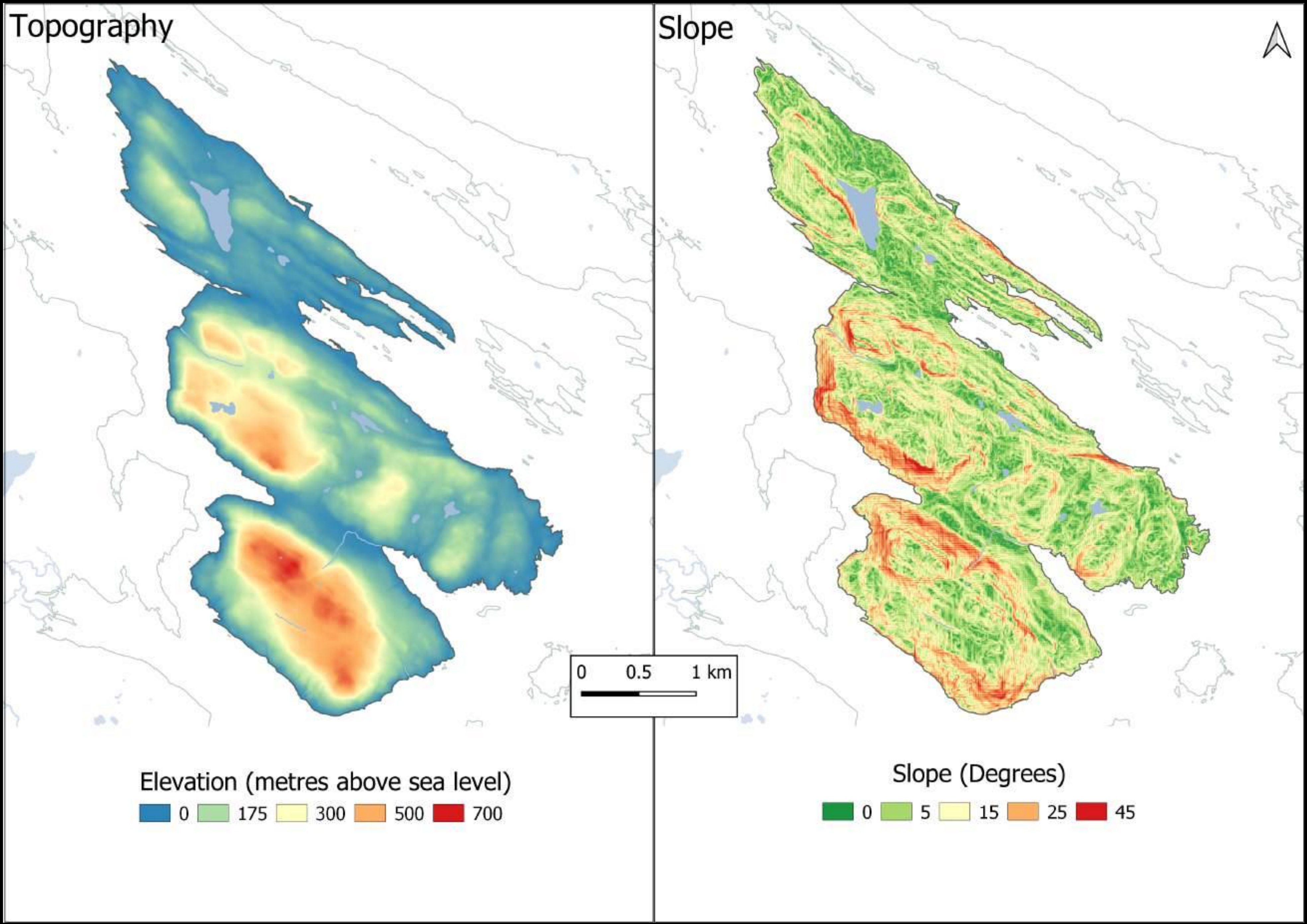
$IF_{landcover}$ = Land cover infiltration factor (0.0 - 0.2)

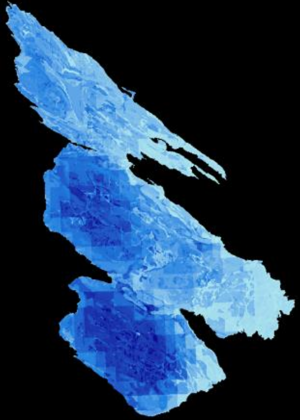
$IF_{slope}$ = slope infiltration factor (0.01 - 0.3)

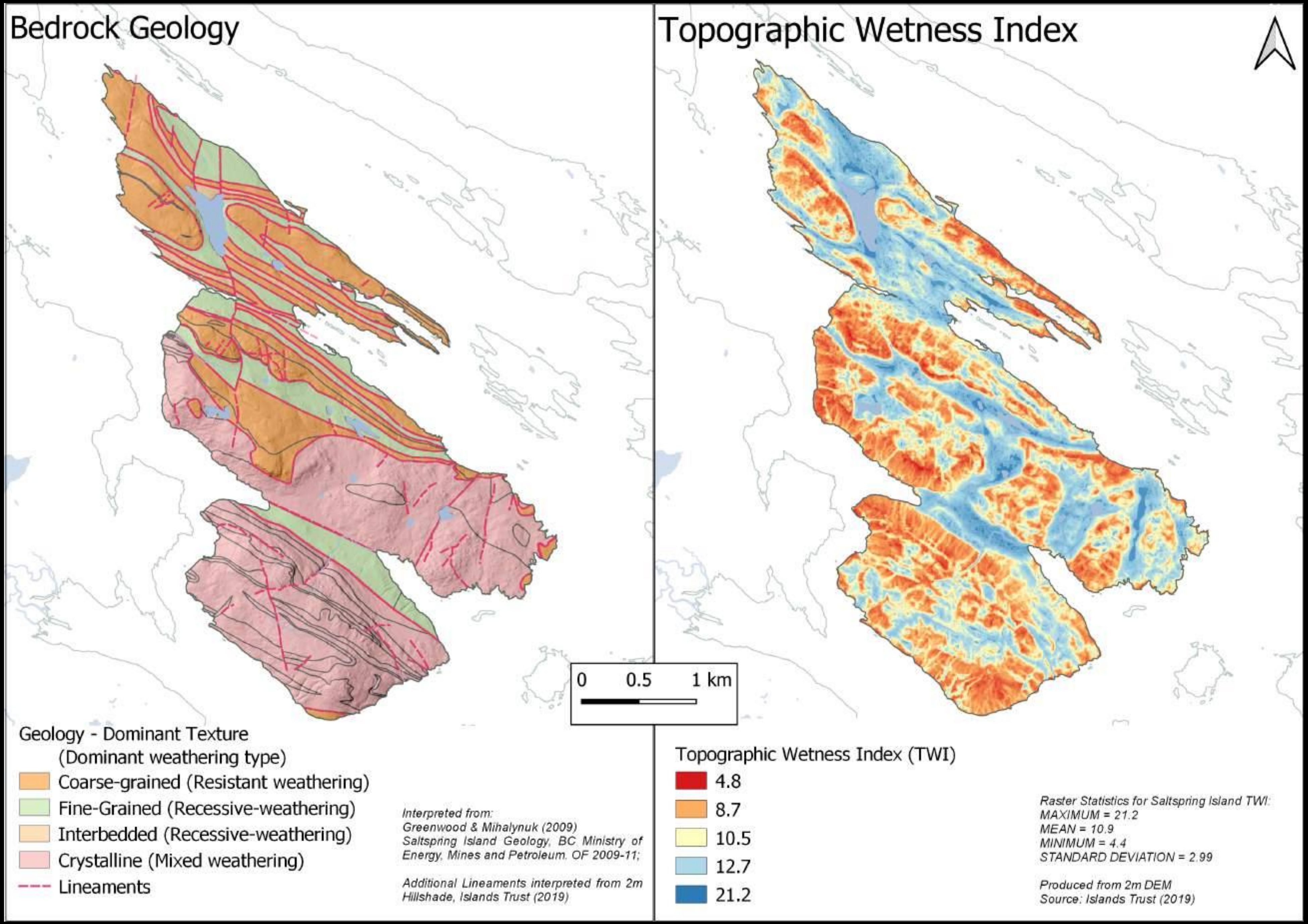
$IF_{faults}$ = bedrock contacts/lineaments infiltration factor (0.25 - 1.0)

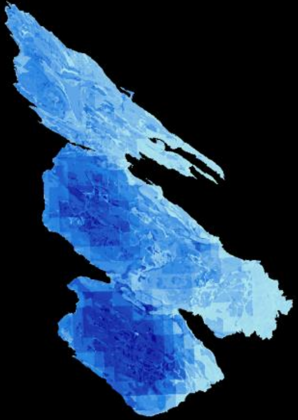
SI = Surplus Index (0.15 - 1.0)



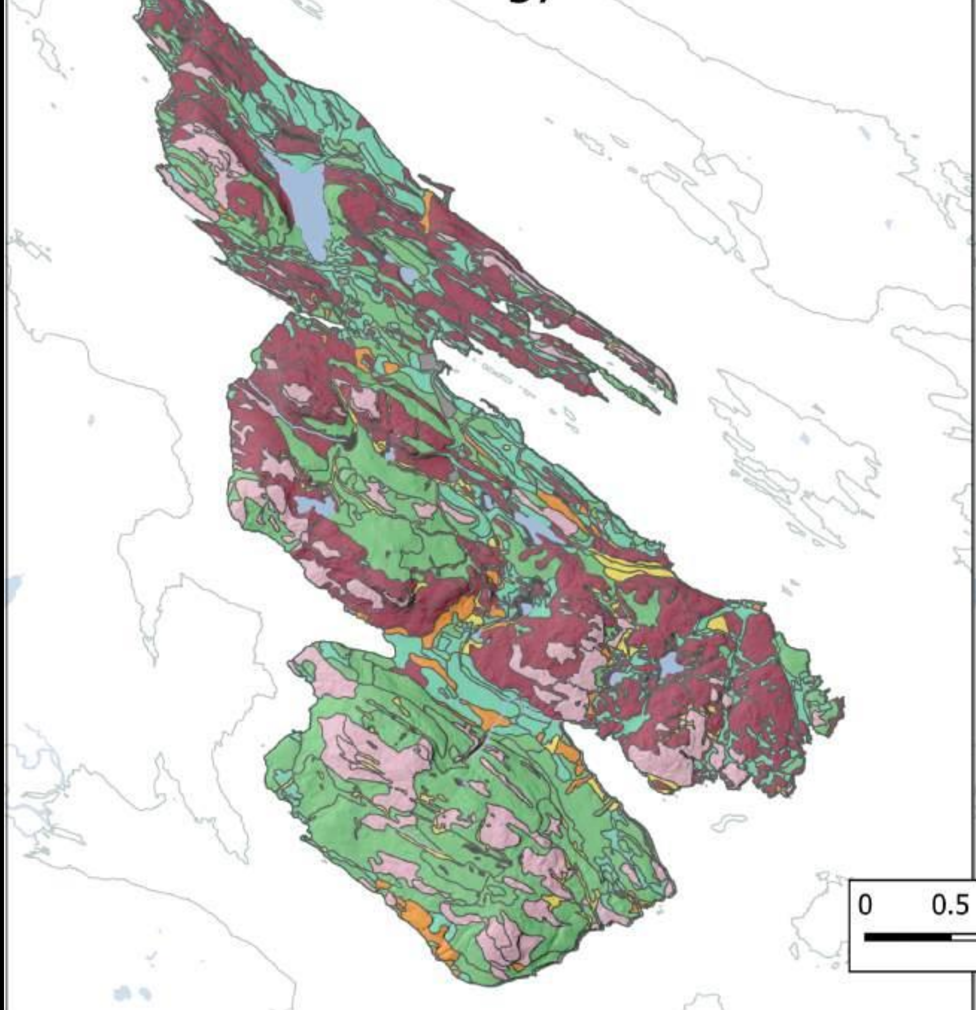

Topography
Slope
0 0.5 1 km
Elevation (metres above sea level)
0 175 300 500 700
Slope (Degrees)
0 5 15 25 45




Bedrock Geology
Topographic Wetness Index
0 0.5 1 km
Geology - Dominant Texture
(Dominant weathering type)
Coarse-grained (Resistant weathering)
Fine-Grained (Recessive-weathering)
Interbedded (Recessive-weathering)
Crystalline (Mixed weathering)
Lineaments
Interpreted from:
Greenwood & Mihalynuk (2009)
Saltspring Island Geology, BC Ministry of Energy, Mines and Petroleum. OF 2009-11;
Additional Lineaments interpreted from 2m Hillshade, Islands Trust (2019)
Topographic Wetness Index (TWI)
4.8
8.7
10.5
12.7
21.2
Raster Statistics for Saltspring Island TWI:
MAXIMUM = 21.2
MEAN = 10.9
MINIMUM = 4.4
STANDARD DEVIATION = 2.99
Produced from 2m DEM
Source: Islands Trust (2019)



## Soils & Surficial Geology

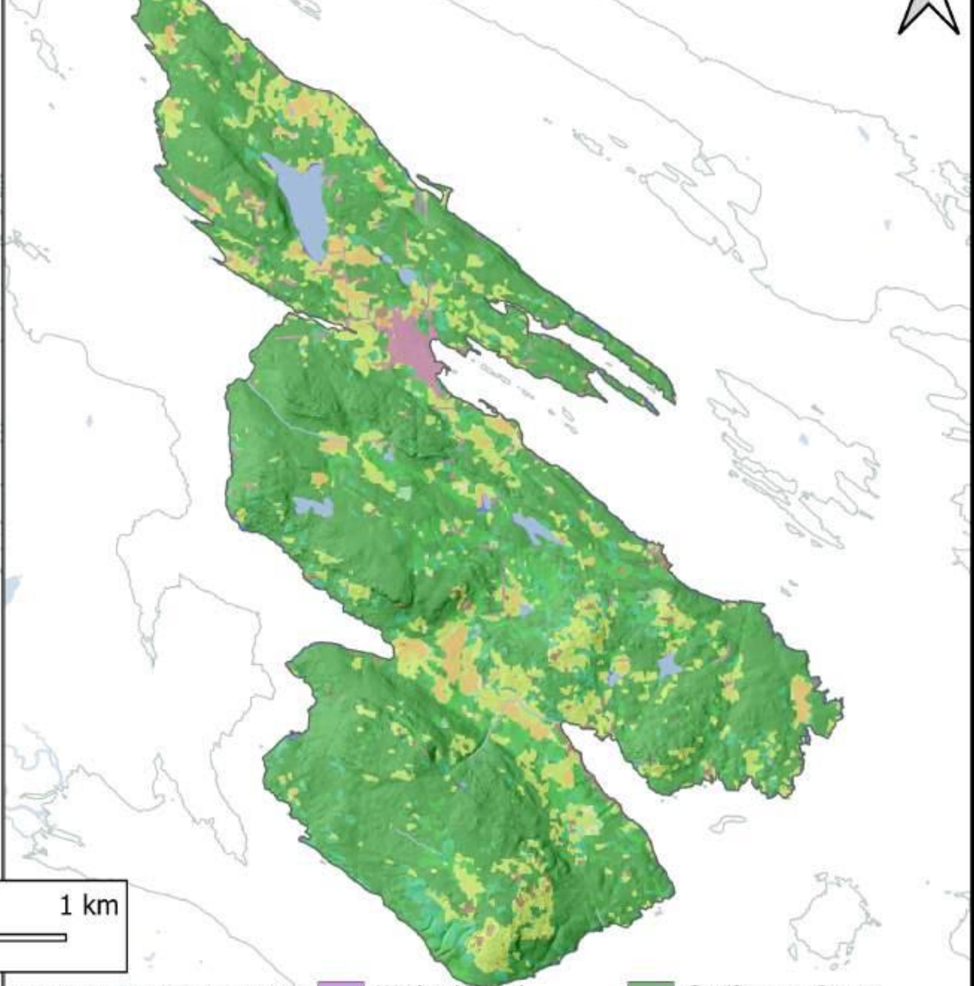


### Soils - Parent Geologic Material

| | | |
|---|---|---|
| Anthropogenic | Glacio Fluvial | Moraine |
| Bedrock | Glacio Marine | Organic |
| Coluvium | Lacustrine | Undefined |
| Fluvial | Marine | |

*Source: Soils of the Gulf Islands, BC, Vol 1 Saltspring. Report No.43 Vol 1. BC Soil Survey 1987 Agriculture Canada.*

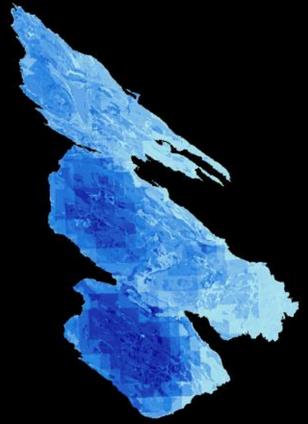
## Land Cover

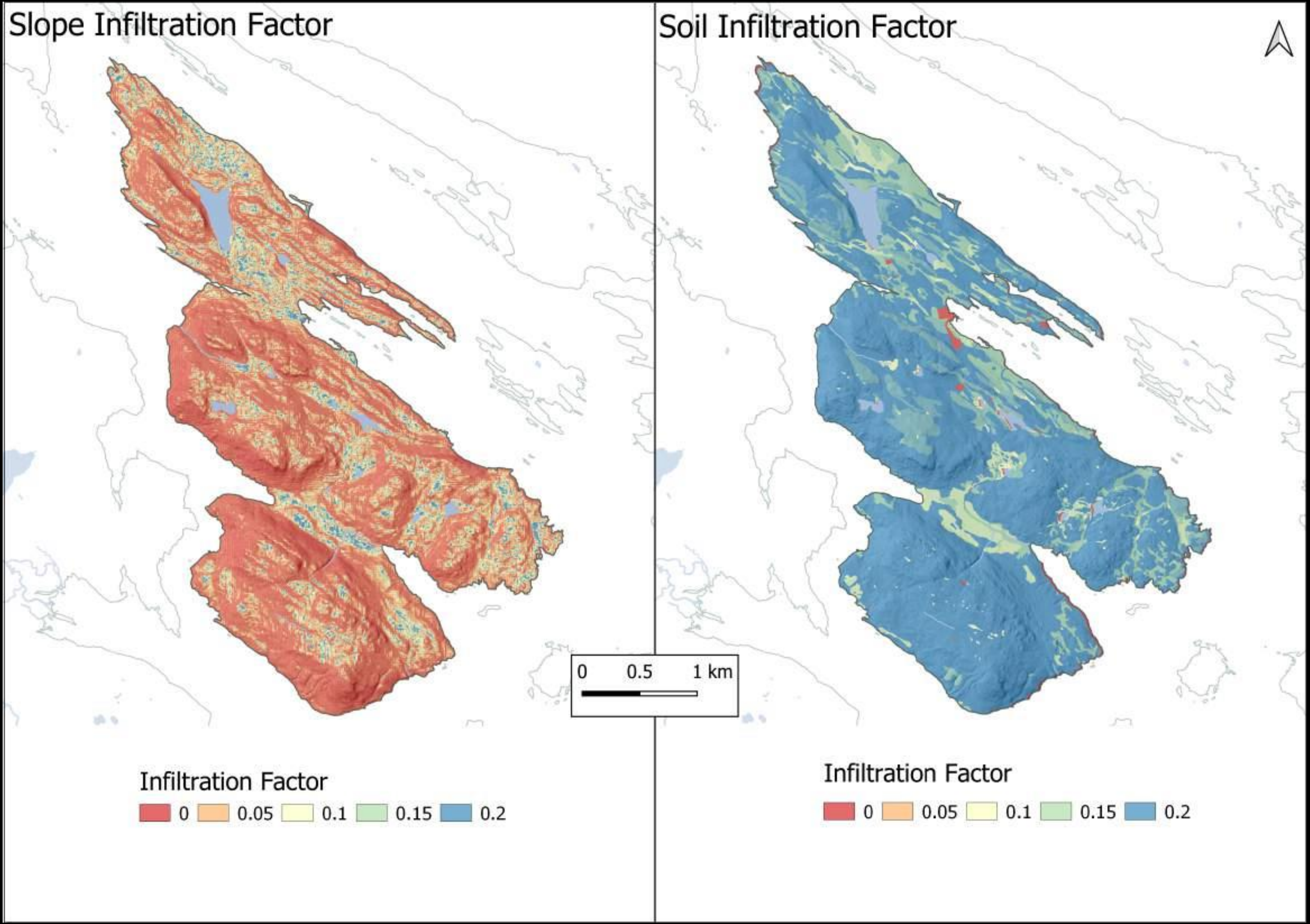



### Land Cover (circa 2000)

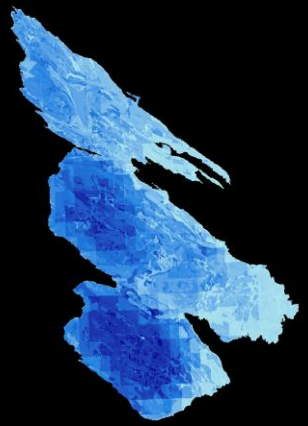
| | | |
|---|---|---|
| Water | Wetland Treed | Coniferous - Dense |
| Snow/Ice | Wetland Shrub | Coniferous - Open |
| Rock/Rubble | Wetland Herb | Coniferous - Sparse |
| Exposed Land | Herb | BroadLeaf - Dense |
| Developped | Grassland | BroadLeaf - Open |
| Shrub - Low | Annual crops | BroadLeaf - Sparse |
| | Perennial crops/Pasture | MixedWood - Sparse |

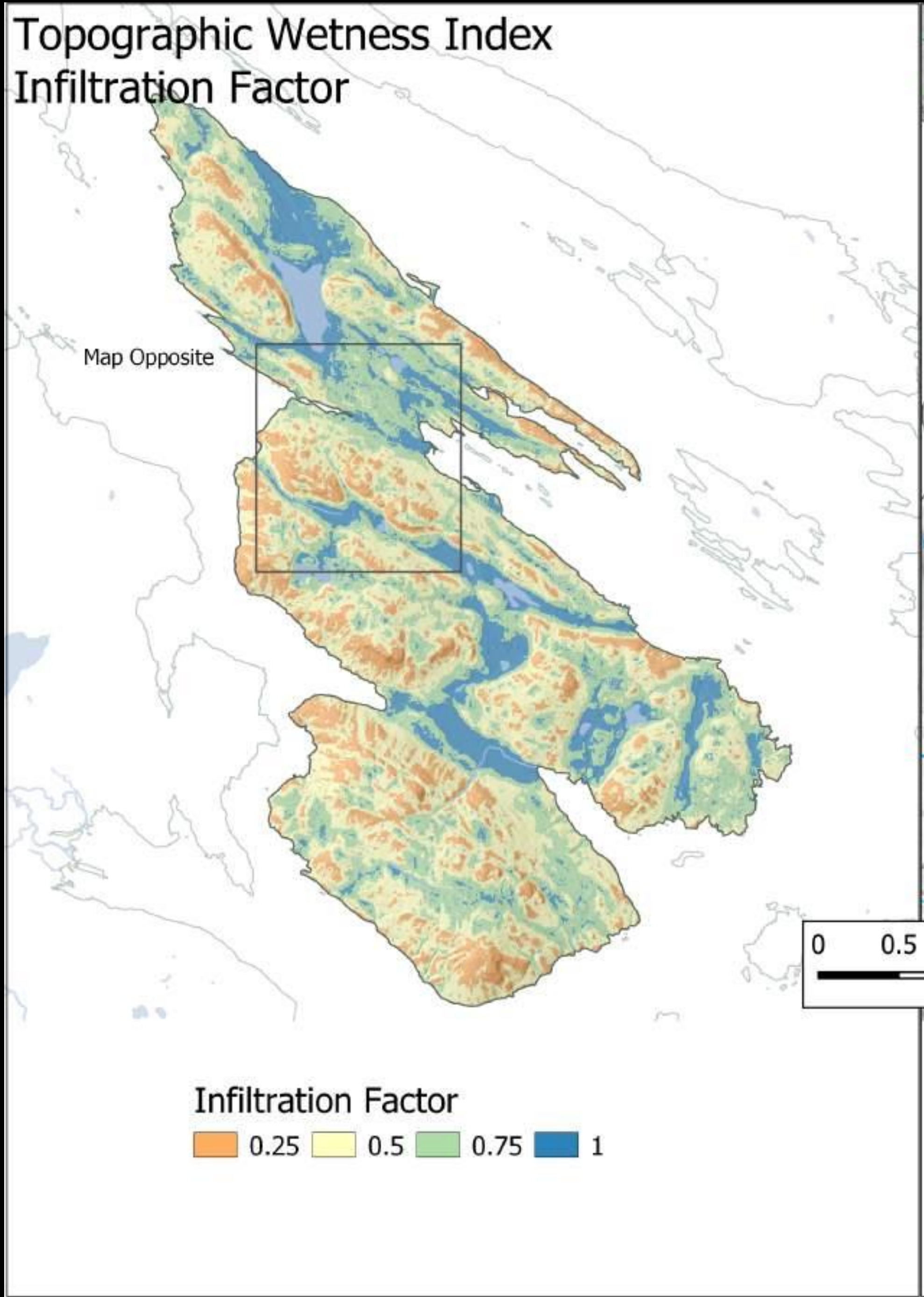
*Source: Land Cover of Canada Circa 2000. Government of Canada; Natural Resources Canada. Download available from https://open.canada.ca/data*

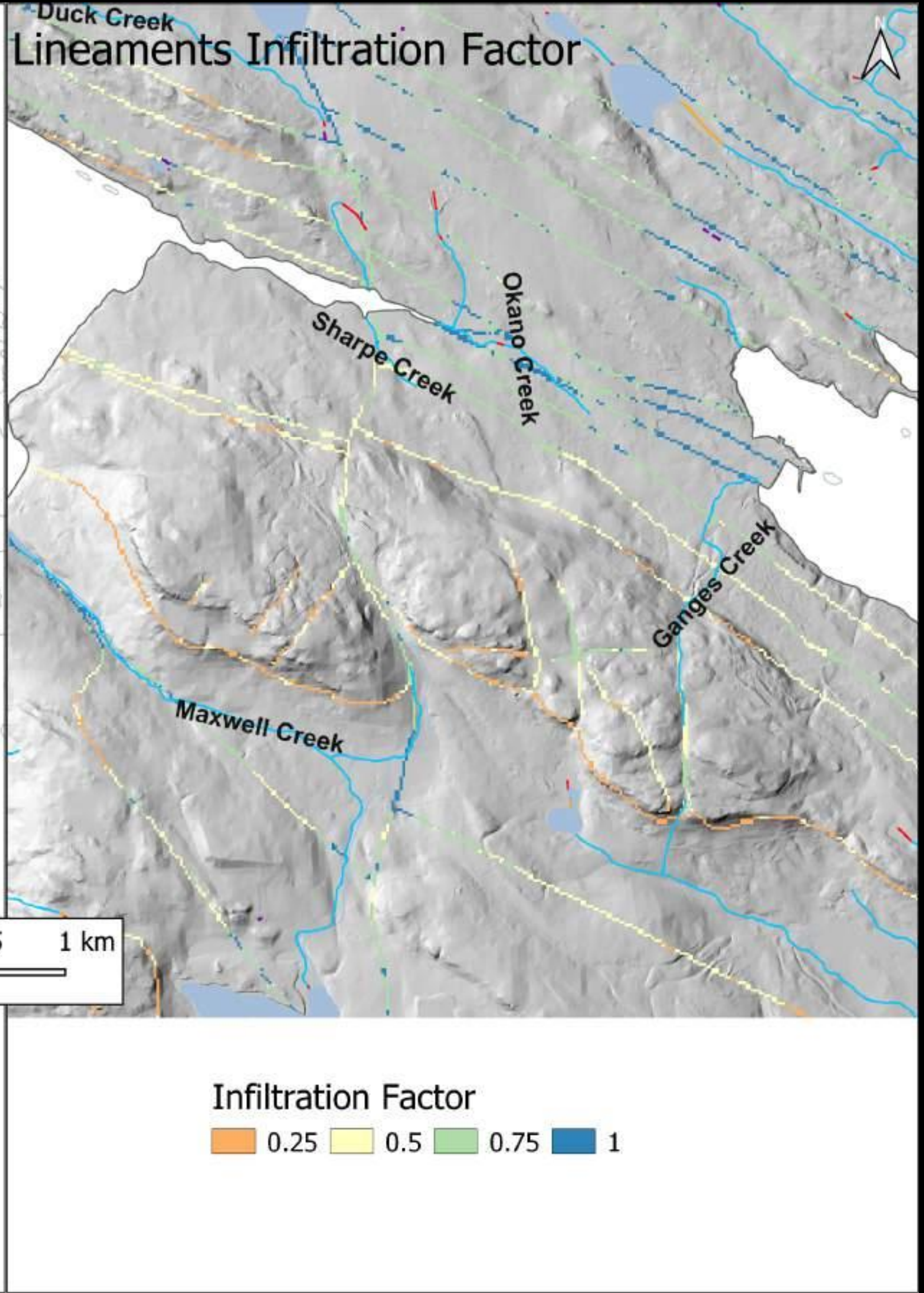


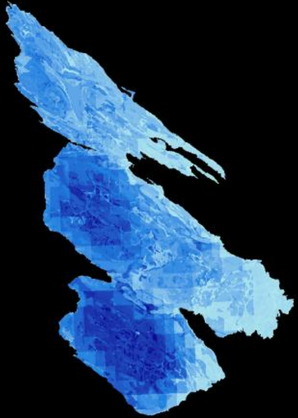


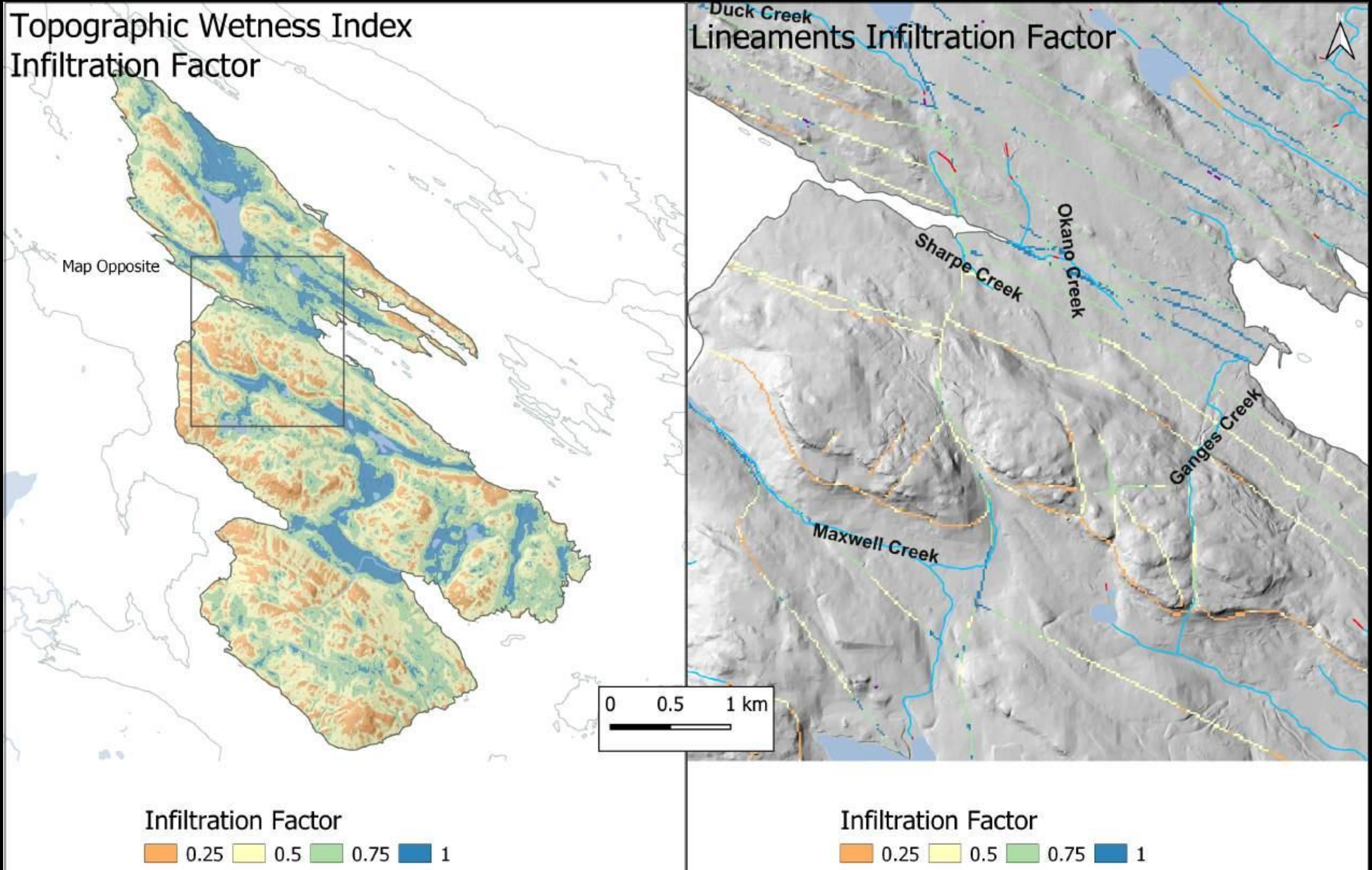
Slope Infiltration Factor
Soil Infiltration Factor
0
0.5
1 km
Infiltration Factor
0
0.05
0.1
0.15
0.2
Infiltration Factor
0
0.05
0.1
0.15
0.2

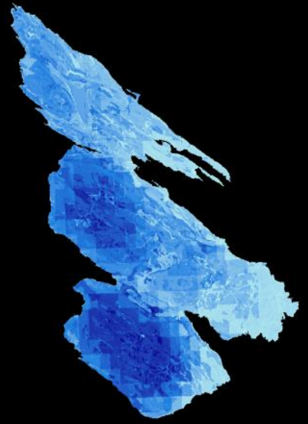


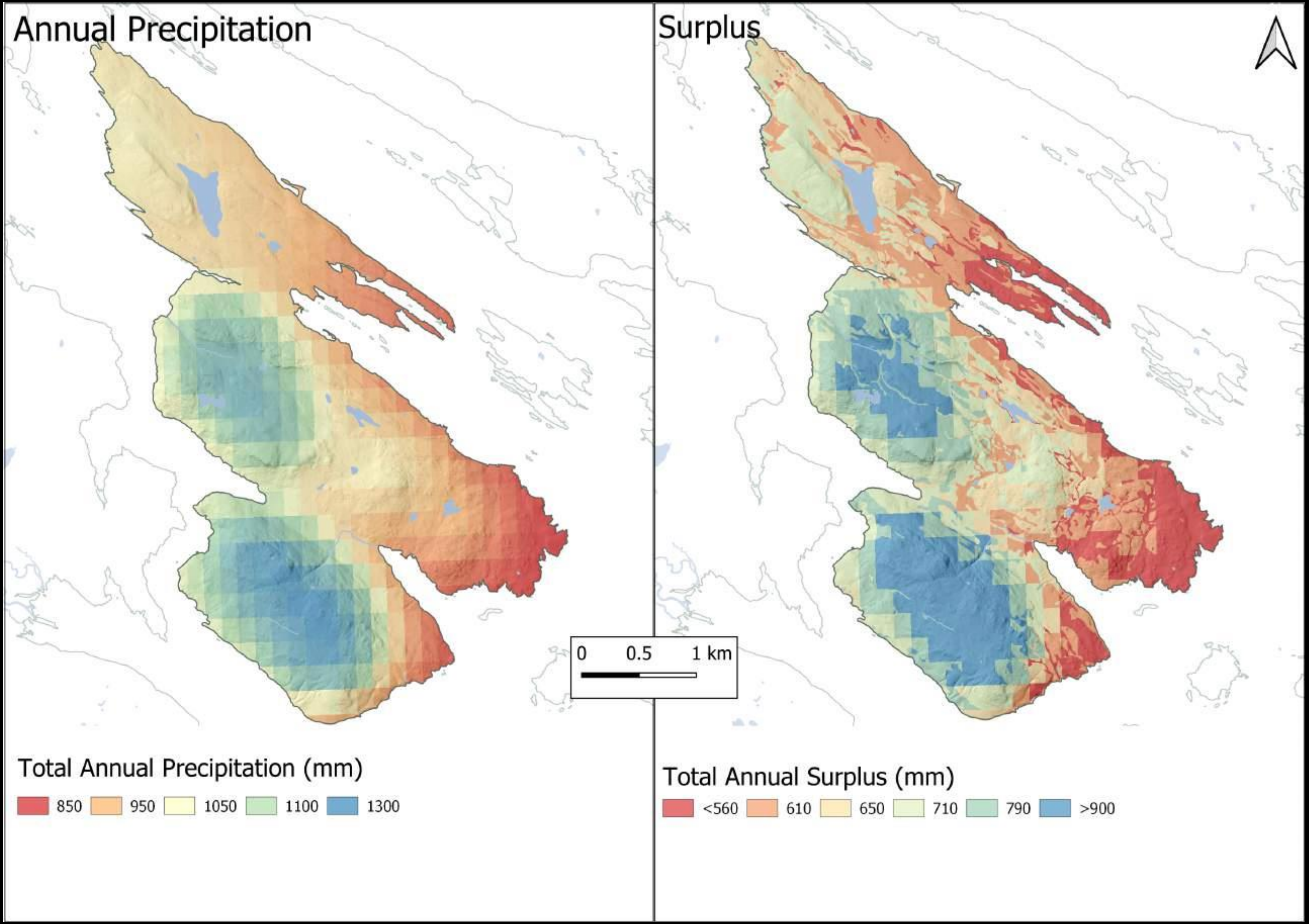

Topographic Wetness Index
Infiltration Factor
Map Opposite
Infiltration Factor
0.25
0.5
0.75
1


Lineaments Infiltration Factor
Duck Creek
Sharpe Creek
Okano Creek
Ganges Creek
Maxwell Creek
0
0.5
1 km
Infiltration Factor
0.25
0.5
0.75
1

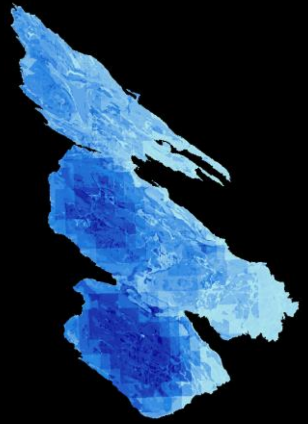


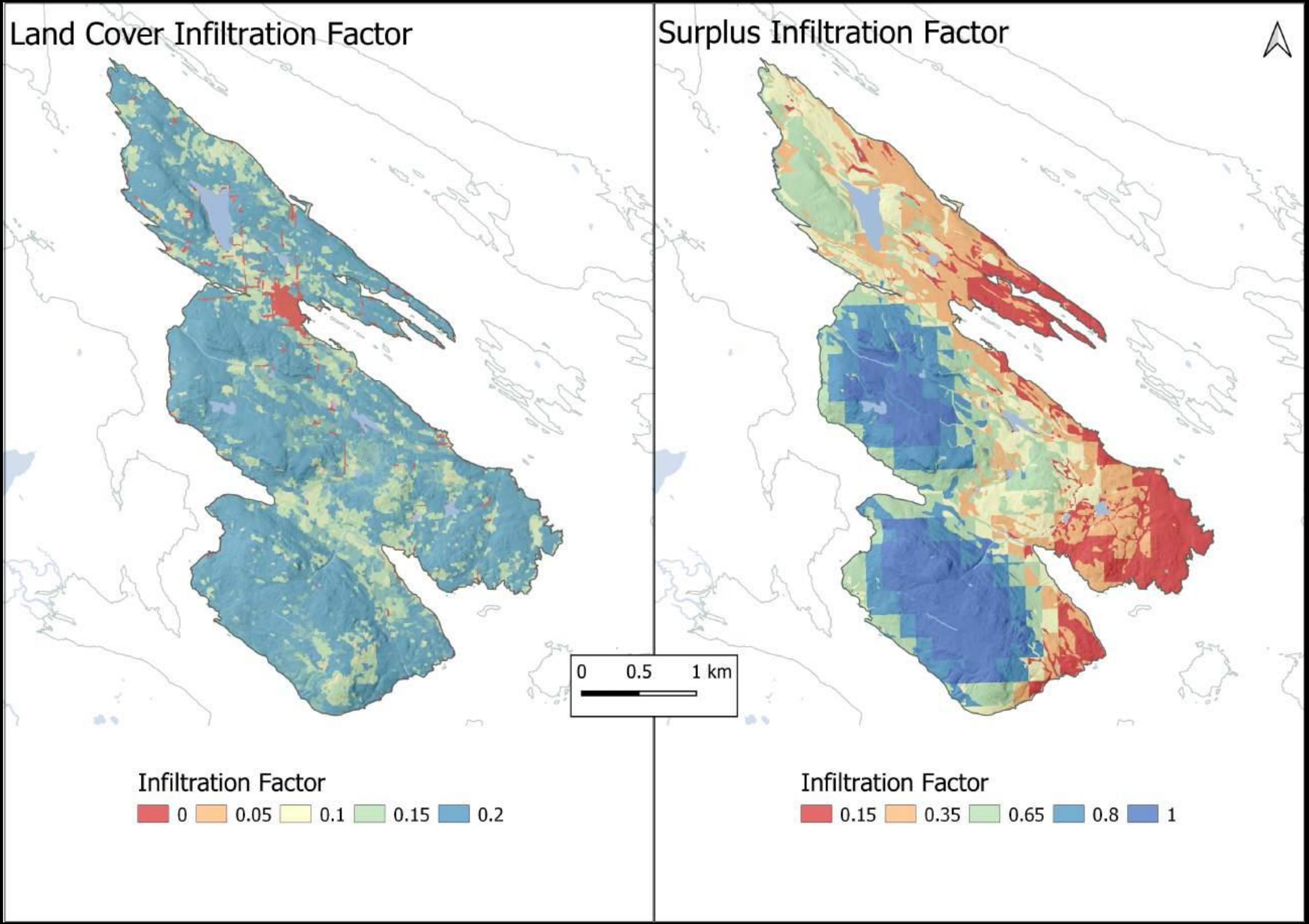

Topographic Wetness Index
Infiltration Factor
Map Opposite
Lineaments Infiltration Factor
Duck Creek
Sharpe Creek
Okano Creek
Ganges Creek
Maxwell Creek
0 0.5 1 km
Infiltration Factor
0.25 0.5 0.75 1
Infiltration Factor
0.25 0.5 0.75 1

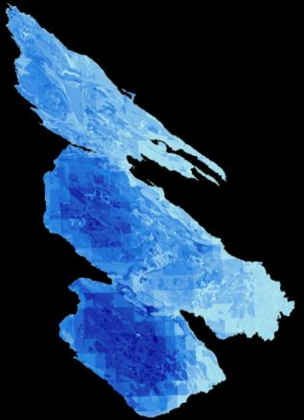




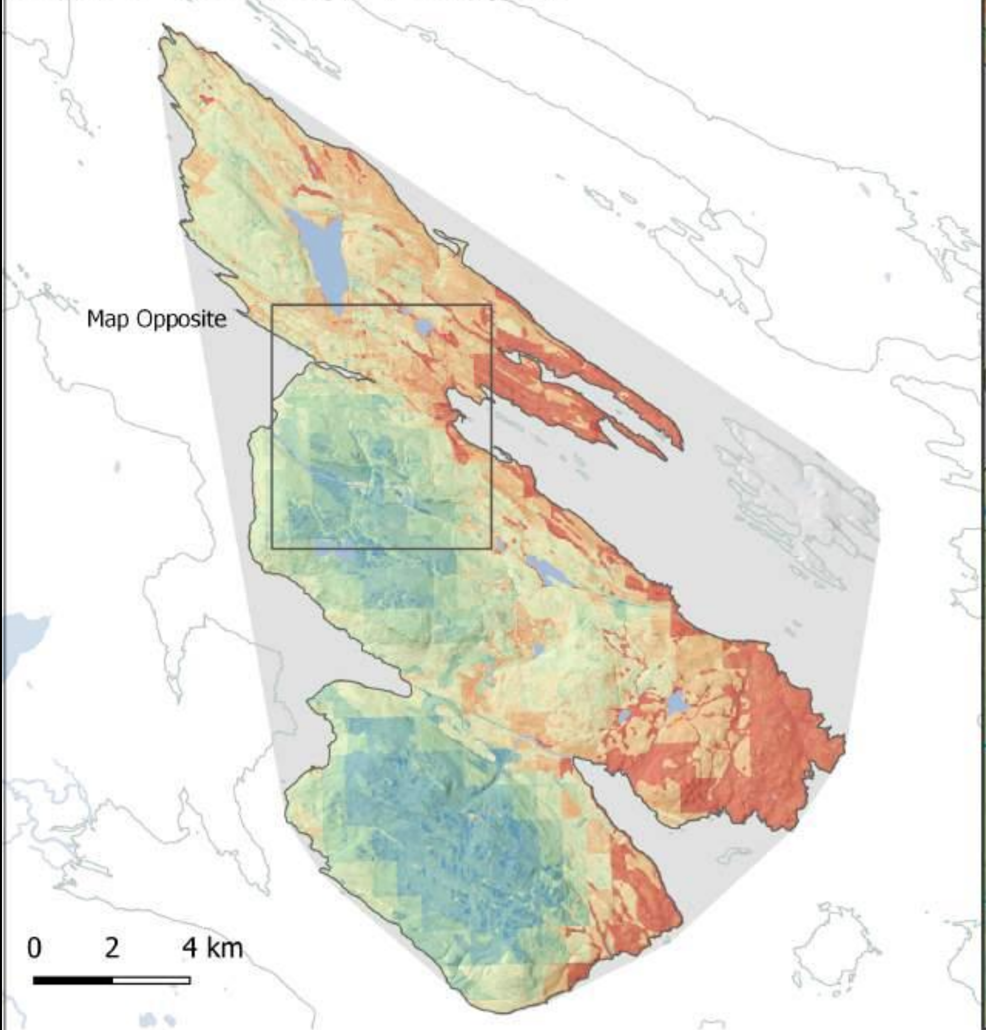
Annual Precipitation
Surplus
0 0.5 1 km
Total Annual Precipitation (mm)
850 950 1050 1100 1300
Total Annual Surplus (mm)
<560 610 650 710 790 >900

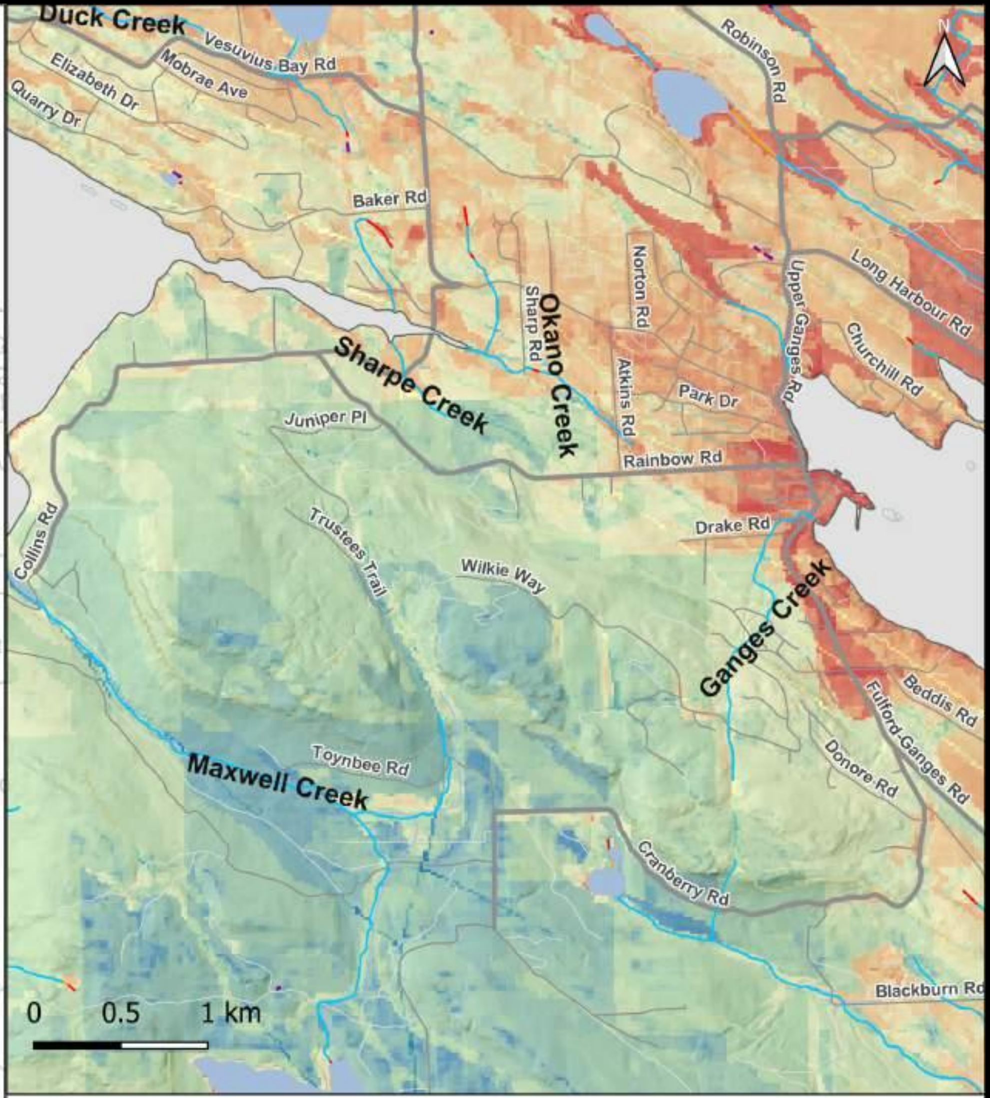



Land Cover Infiltration Factor
Surplus Infiltration Factor
0
0.5
1 km
Infiltration Factor
0
0.05
0.1
0.15
0.2
Infiltration Factor
0.15
0.35
0.65
0.8
1



# Aquifer Recharge Potential




Aquifer Recharge Potential

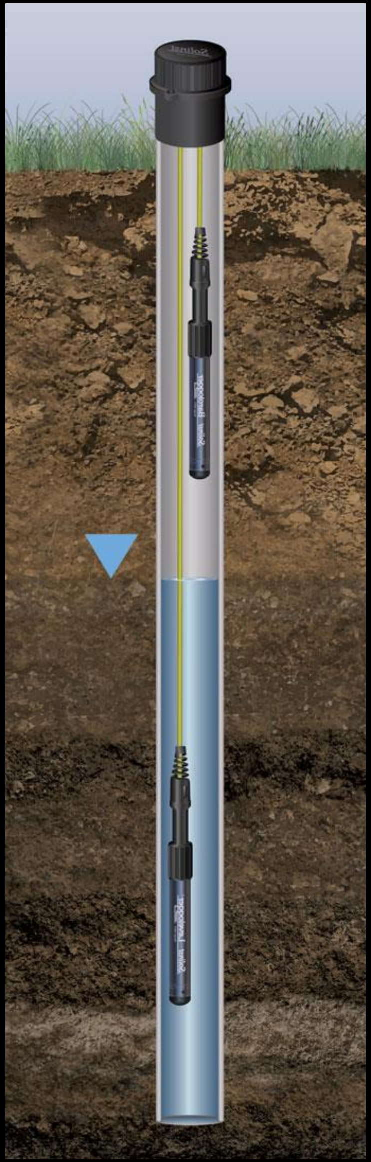
0.02 | 0.10 | 0.2 | 0.3 | 0.5

GROUNDWATER SURFACE ELEVATION (meters above mean sea level)
136
135
134
133
132
131
130
129
128
18/Jul
18/Aug
18/Sep
18/Oct
18/Nov
18/Dec
19/Jan
19/Feb
19/Mar
19/Apr
19/May
19/Jun
19/Jul
19/Aug
19/Sep
19/Oct
19/Nov
19/Dec

GROUNDWATER REGIONS OF HYDRAULIC CONTINUITY

MEASURING
HYDRAULIC CONTINUITY ….

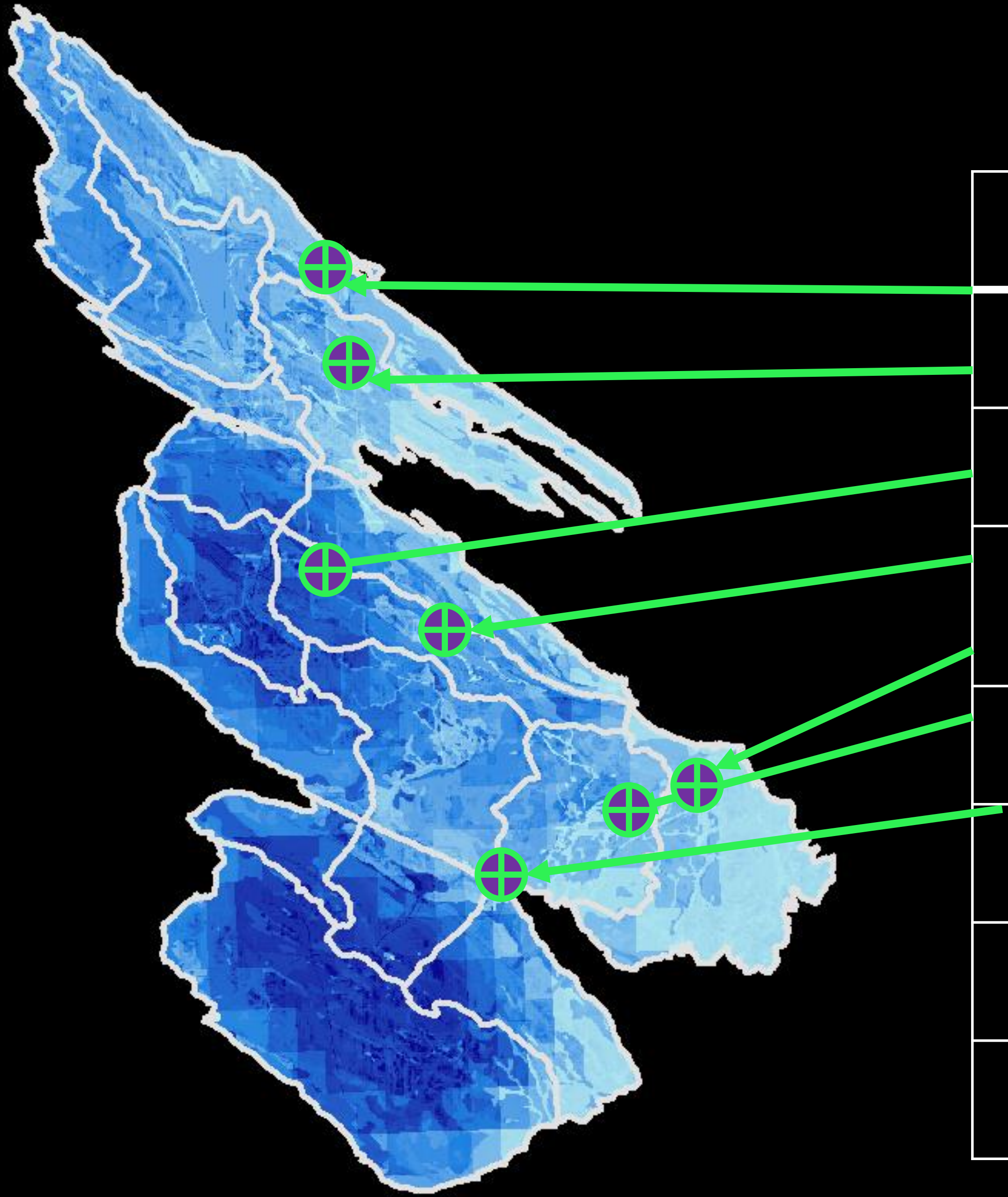
CONTINUOUSLY…




Tab
CapsLock
Shift
Ctrl
Fn

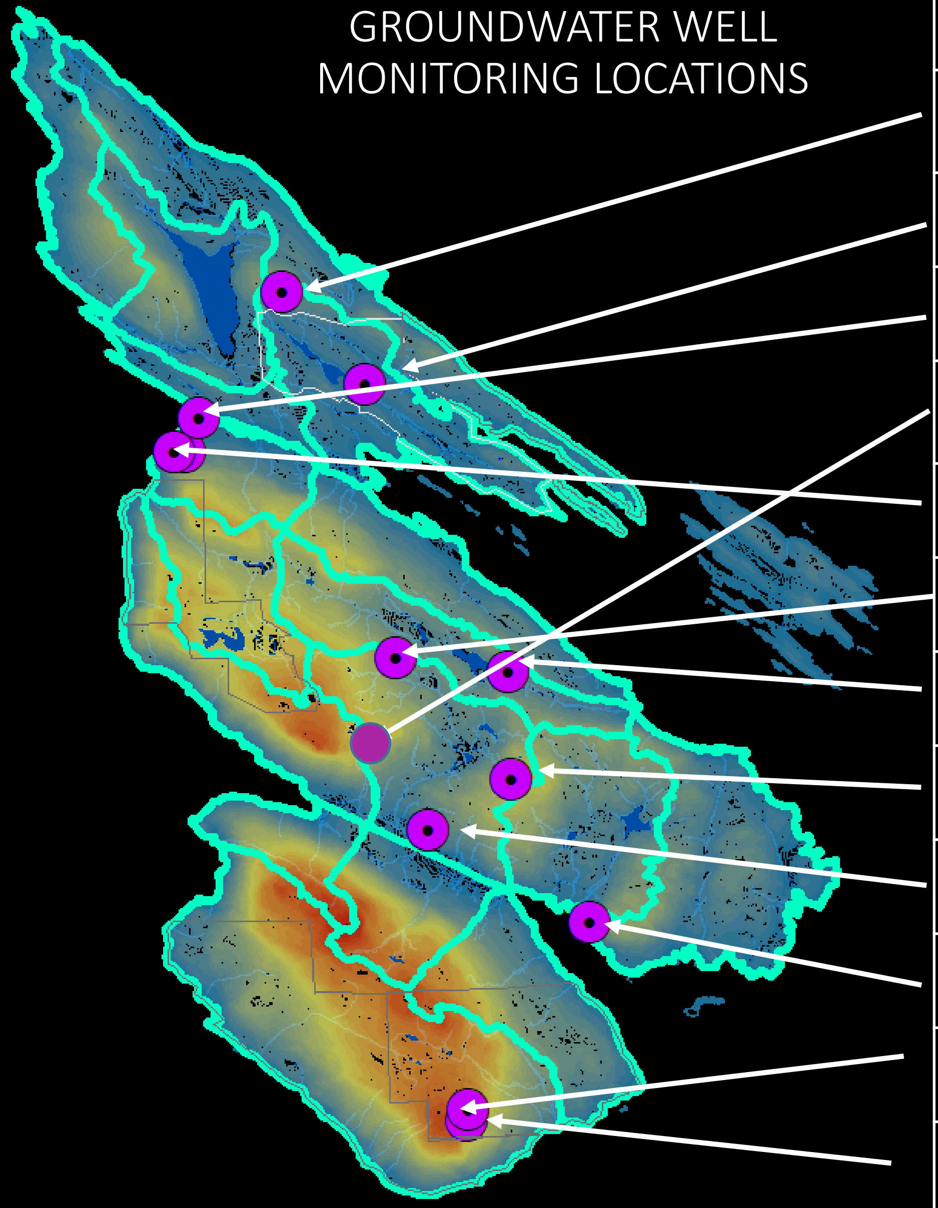

Solinst
Levelogger
App Interface
Made in Canada
SN 2019977
Identification
Location
Project
Datalogger Status
Status
Started
Stopped
Datalogger Sampling Mode
Apple Smart
(Not Included)
Bluetooth

# HYDROMETRIC MONITORING LOCATIONS



| Monitoring Location | Common Name | Solinst # | ELEV |
|---|---|---|---|
| SSIWPASWM –8002 | Ross Road Baro | 1050589 | 24 |
| SSIWPASWM – 2004 | Bollock Lake | 1076956 | 30 |
| SSIWPASWM – 3001 | Center School Weather Station | N/A | 110 |
| SSIWPASWM – 2001 | Cusheon Lake | ? | 93 |
| SSIWPASWM – 2002 | Lake Weston | 1076955 | 60 |
| SSIWPASWM – 2003 | Lake Stowell | 1077303 | 70 |
| SSIWPASWM – 8001 | Fulford Creek Baro | 2083788 | 4 |

GROUNDWATER WELL MONITORING LOCATIONS



| Common Name | ID # | Solinst # | ELEV |
|---|---|---|---|
| Trincomali Highlands | 1004 | 2087096 | 154 |
| Cedar Lane | 1012 | 1076764 | 49 |
| Swan Point | 1005 | 1075536 | 68 |
| Salt Spring Island Water Co. | 1007 | 2086677 | 47 |
| Erskine Up-gradient | 1008 | 1075538 | 68 |
| Frazier Highlands | 1006 | 2086680 | 103 |
| Cusheon Lakeside | 1001 | 2086678 | 233 |
| Jasper Highlands | 1009 | 2086681 | 300 |
| Fulford Uplands | 1003 | 2086665 | 82 |
| Reginald Hill | 1002 | 1075522 | 22 |
| Mt Tuam Highlands | 1010 | 2087093 | 446 |
| Mt Tuam Pumping | 1011 | 1075521 | 449 |