SCALING IMPLICATIONS OF VARIABLE FROZEN SOIL INFILTRATION ON RUNOFF GENERATION

JR Janowicz[1], JW Pomeroy[2] and DM Gray

[1]Water Resources Branch, Environment Yukon
Whitehorse, YT

[2] Centre for Hydrology, University of Saskatchewan
Saskatoon, Saskatchewan

Yukon

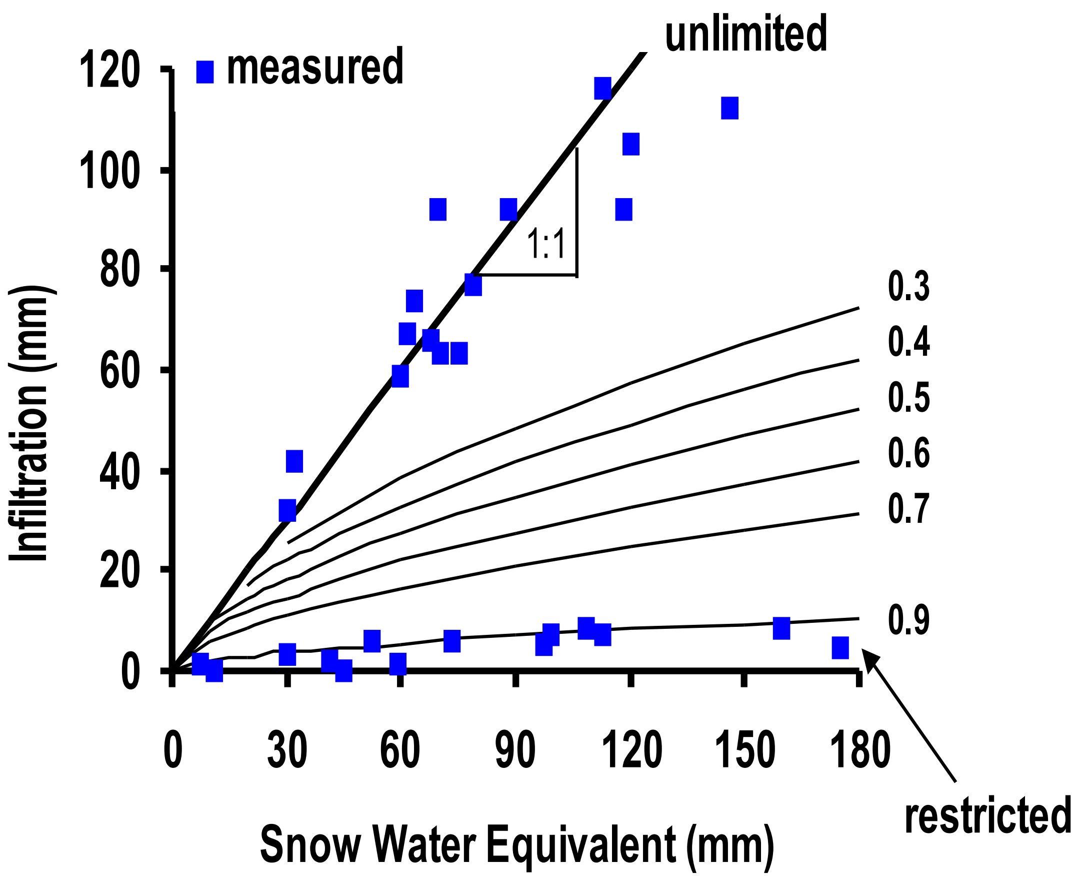
U OF S LOGO HERE

C OF HYD LOGO HERE

STUDY OBJECTIVES

- To quantify the spatial variability of parameters governing infiltration to frozen soil and infiltration excess (runoff) in cold regions
- To examine whether point scale relationships for infiltration and runoff associated with frozen soils can be upscaled using mean parameters
- To propose a method for calculating cold regions runoff generation from basins with complex physiography

INFILTRATION TO FROZEN SOILS



- Early work by U of S came up with 3 classes of infiltrability
  - Unlimited
  - Restricted
  - Limited

PARAMETRIC RELATIONSHIP

Zhao & Gray (1999)

$$INF = CS_0^{2.92}\left(1 - S_I\right)^{1.64}\left(\frac{273.15 - T_I}{273.15}\right)^{-0.45} t^{0.44}$$

- INF = Infiltration (cm)
- C = bulk coefficient
- S_0 = surface saturation (mm^3/mm^3) (vol soil moisture / porosity)
- S_I = initial soil saturation (mm^3/mm^3) (water + ice; 0-40 cm)
- T_I = initial soil temp (^{0}K)
- t = time (hrs)

SCALING PRINCIPLES

- Consider Interrelationships Between Parameters

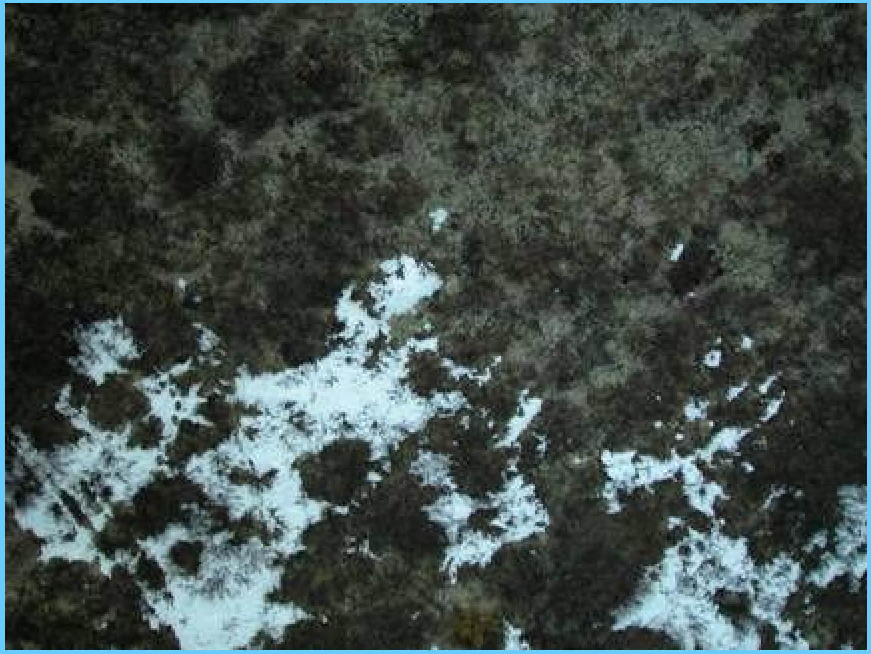
$$INF = C S_{٠}^{٢.٩٢} \left(١ - S_I \right)^{١.٦٤} \left(\frac{٢٧٣.١٥ - T_I}{٢٧٣.١٥} \right)^{-٠.٤٥} t^{٠.٤٤}$$

- INF = f (SWE, S_I)
- S_0, T_I, t = f (SWE)
- S_0, T_I = f (S_I)

DURATION OF SNOWMELT

- Controls infiltration opportunity time, runoff generation, streamflow
- Can be simply described as a function of SWE and melt rate, M.
- Approximates the infiltration opportunity time, t_0, when melt is continuous at high latitudes
- Spatially variable because SWE and M are spatially variable.

$$t_0 \approx T = \frac{SWE}{M}$$



WATER STORAGE POTENTIAL

- **Northern mineral soils often overlain by organic layer**
- **Organic layers will hold water to water storage potential**

5 – 25 cm

$$W_{sp} = 0.6\phi(1 - S_I)z_w$$

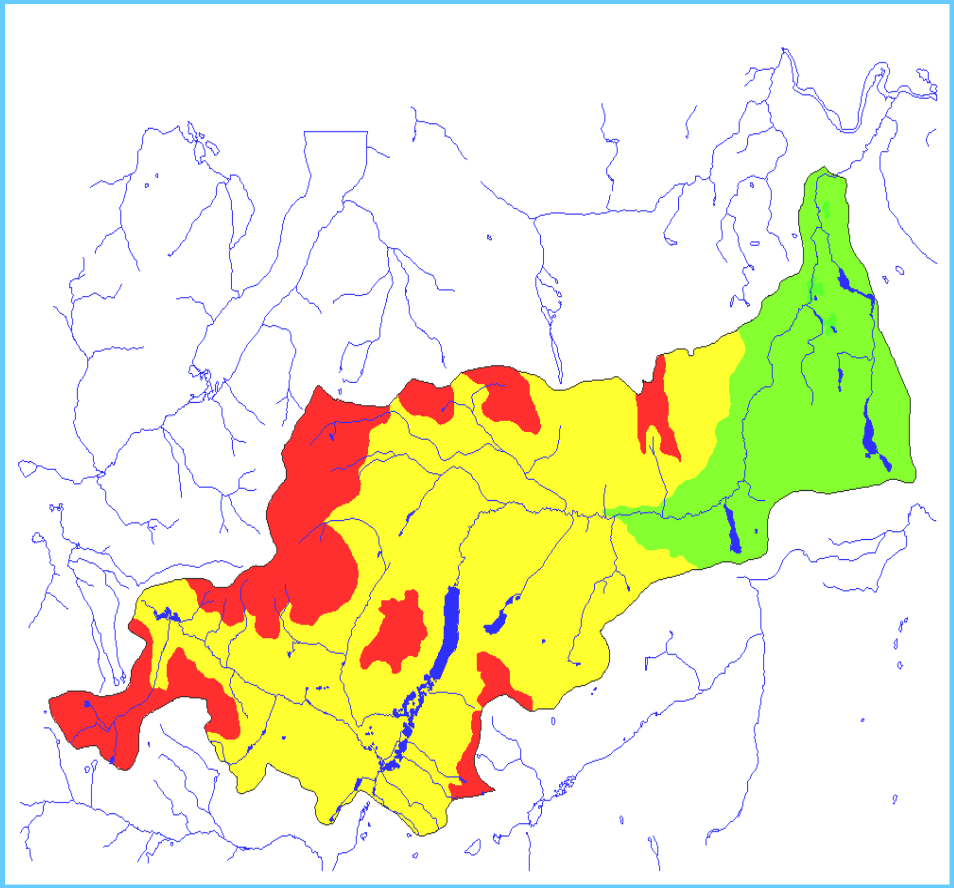
W_{sp} = water storage potential (mm)
Φ = porosity
S_I = initial soil saturation, θ/Φ
θ = average volumetric moisture content
z_w = depth of organic layer (mm)

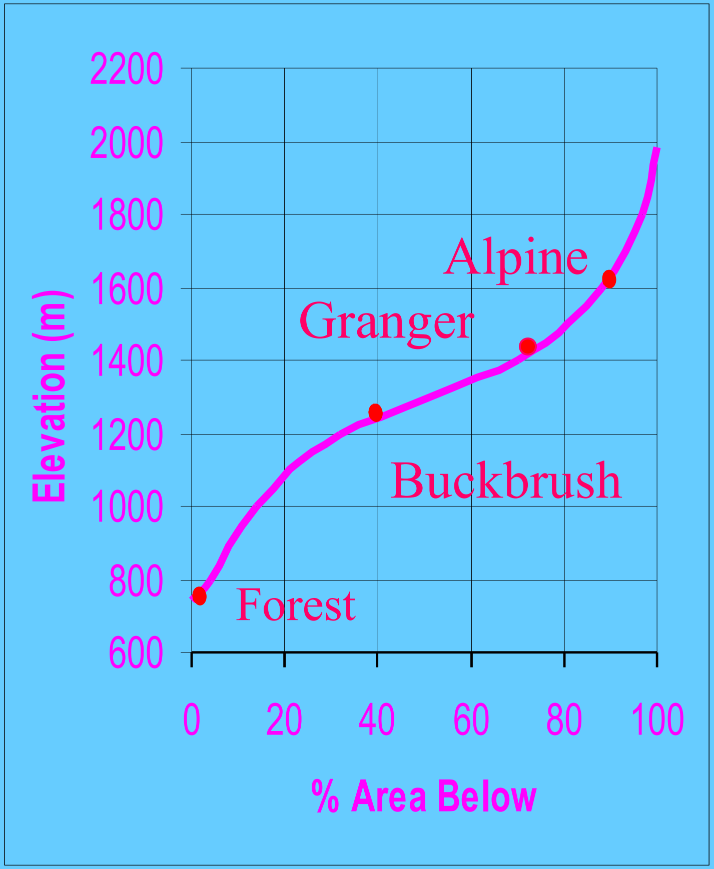
- drain rapidly down slopes
- ponds on poorly drained sites

NORTHERN RUNOFF GENERATION

- Occurs through organic matter layers and over frozen mineral soils
- Primarily snowmelt driven (mineral soils thawed during major rain events)
- Complex process Subarctic mountainous terrain has highly variable:
  - snow accumulation,
  - melt rate,
  - organic layer thickness,
  - degree of saturation,
  - ice layers
- Runoff is further complicated by
  - variable contributing area,
  - poorly defined drainages,
  - large storage terms.

WOLF CREEK ECOSYSTEMS

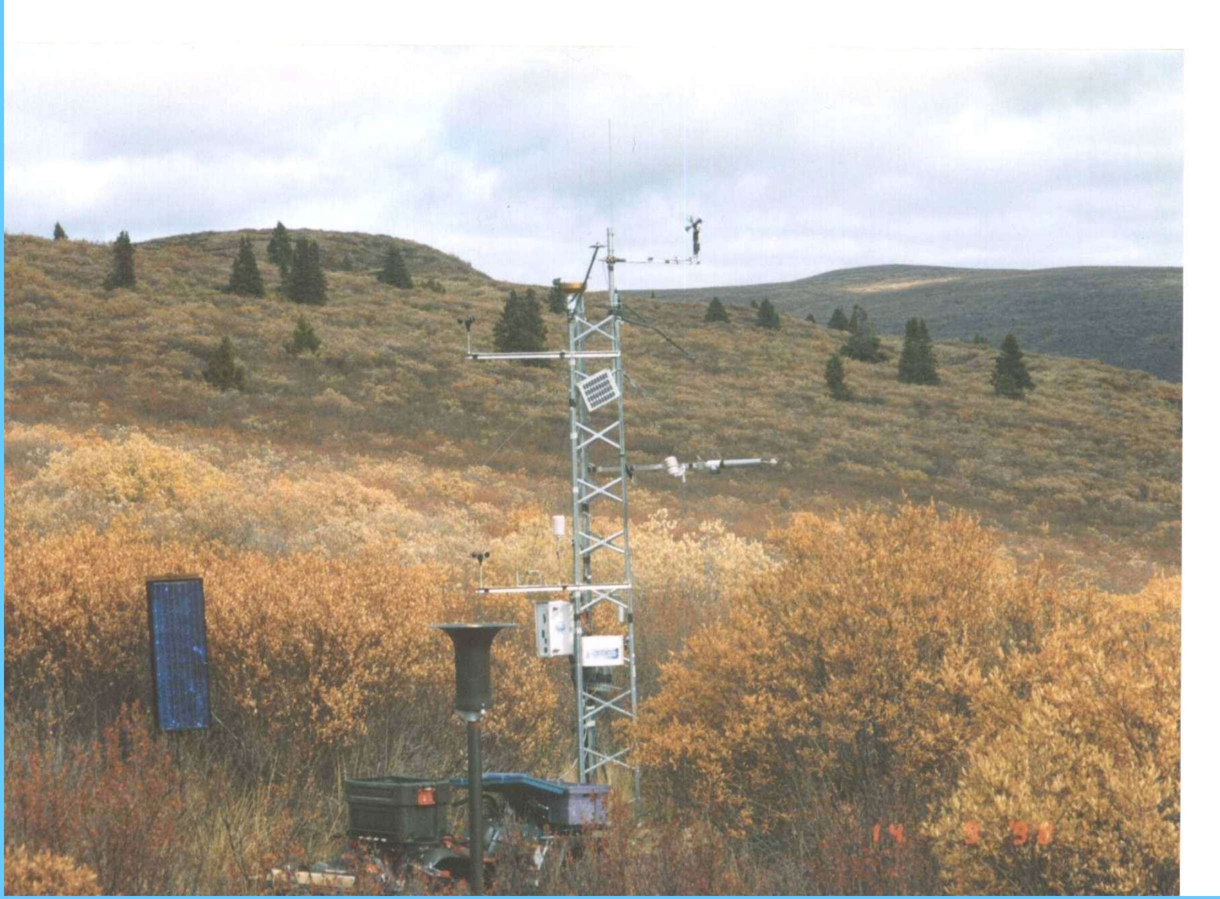




FOREST

- Thick Spruce Canopy (20 m)
- Level Undulating Terrain

SUBALPINE TAIGA



- Shrub Alder & Willow (2 m)
- Moderate (15^0) Undulating Hillslope

ALPINE TUNDRA

- Moss, Grass, Lichen
- 50 % Level; 50% Shallow Slope (10^0)

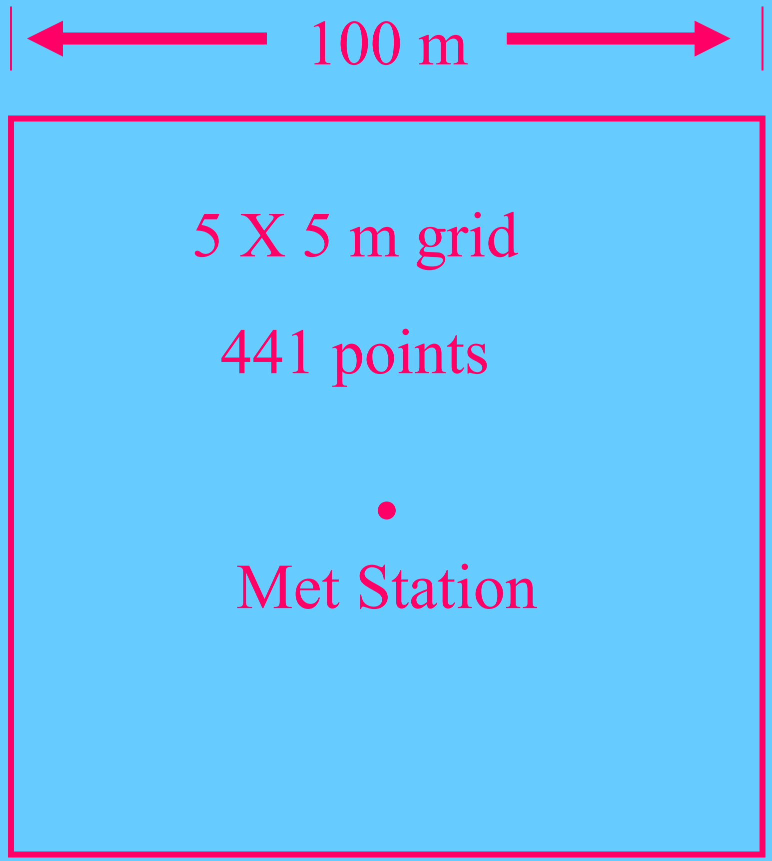
GRANGER SUB-BASIN - NORTH FACING

- Shrub Alder & Willow (2 m)
- Steep Undulating Slope (25^0)

GRANGER SUB-BASIN - SOUTH FACING

- Shrub Alder & Willow
- Steep Undulating Slope (25^0)

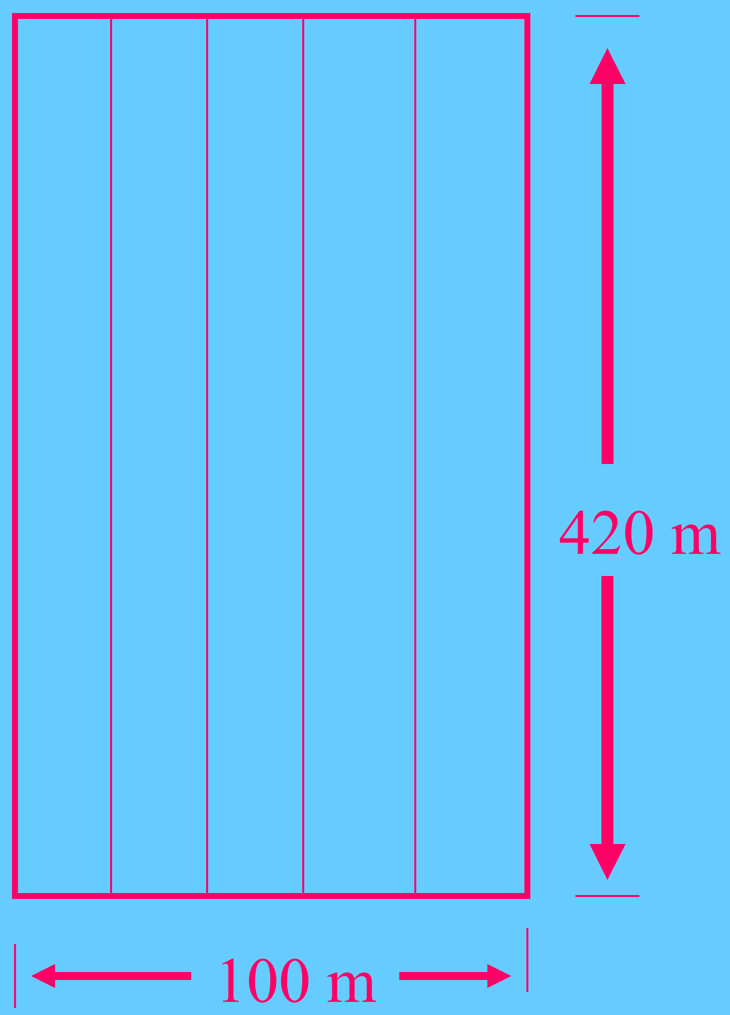
GRID SURVEY



GRID SURVEY - GRANGER SUB-BASIN

10 X 20 m grid

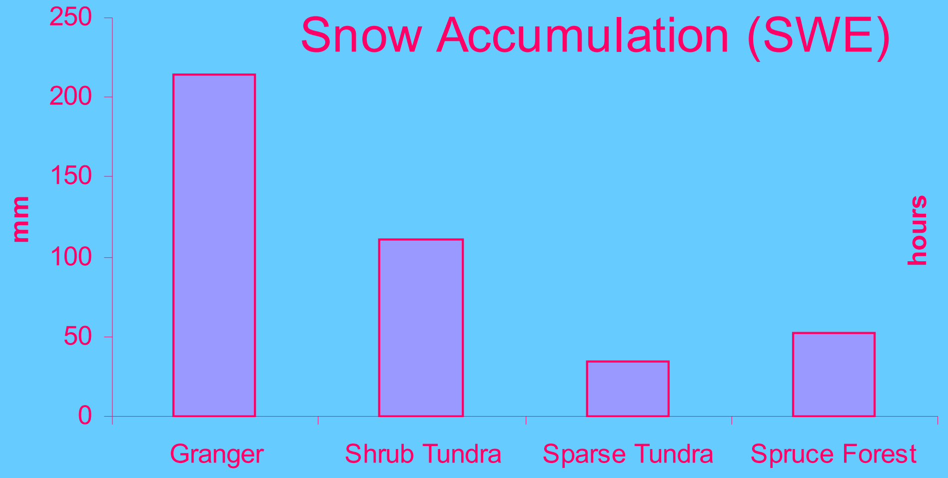
258 points

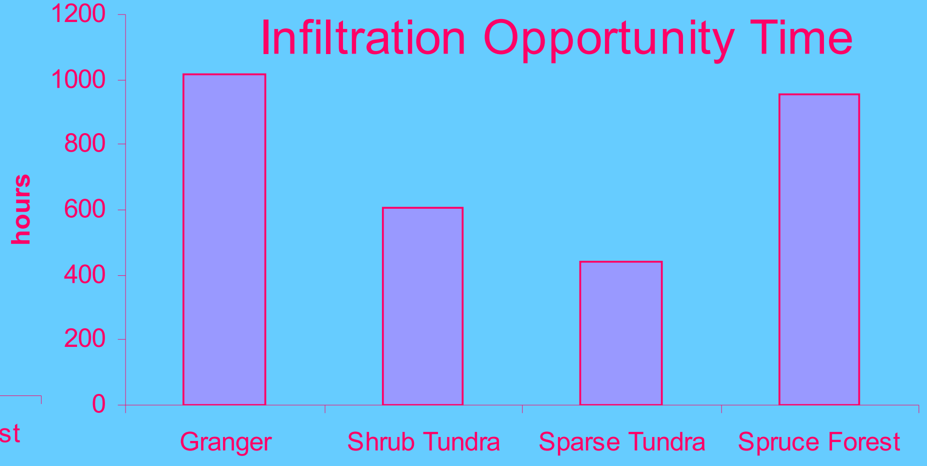


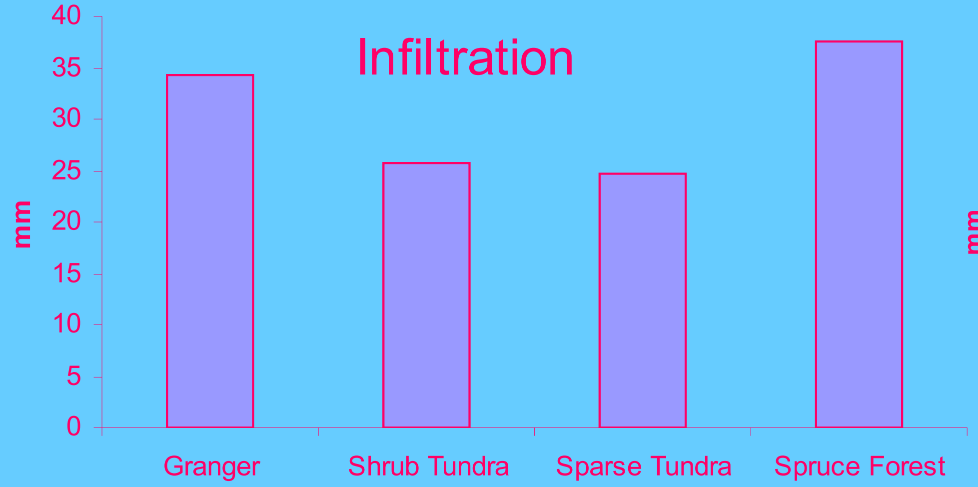
GRID DATA COLLECTION

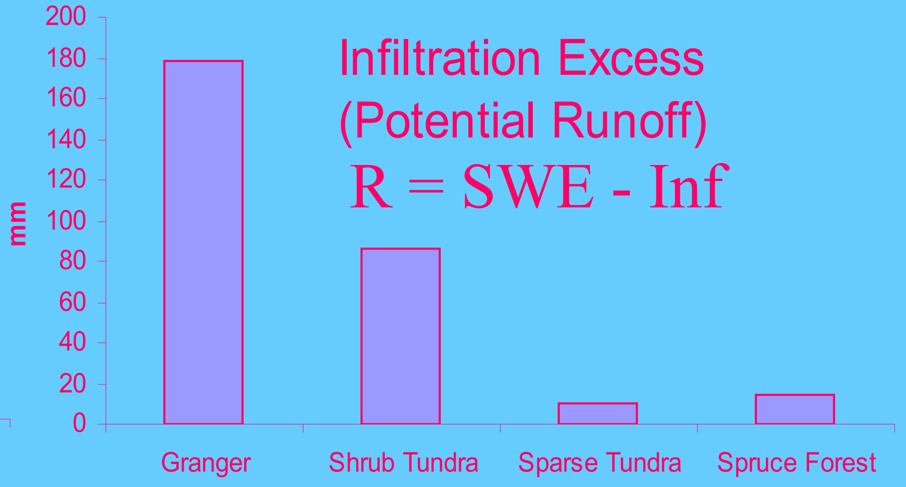
- Soil moisture - TDR – fall (prior to freeze-up)
- SWE – Mount Rose – spring (max snowpack)
- Porosity - soil particle size

VARIATION IN RUNOFF COMPONENTS

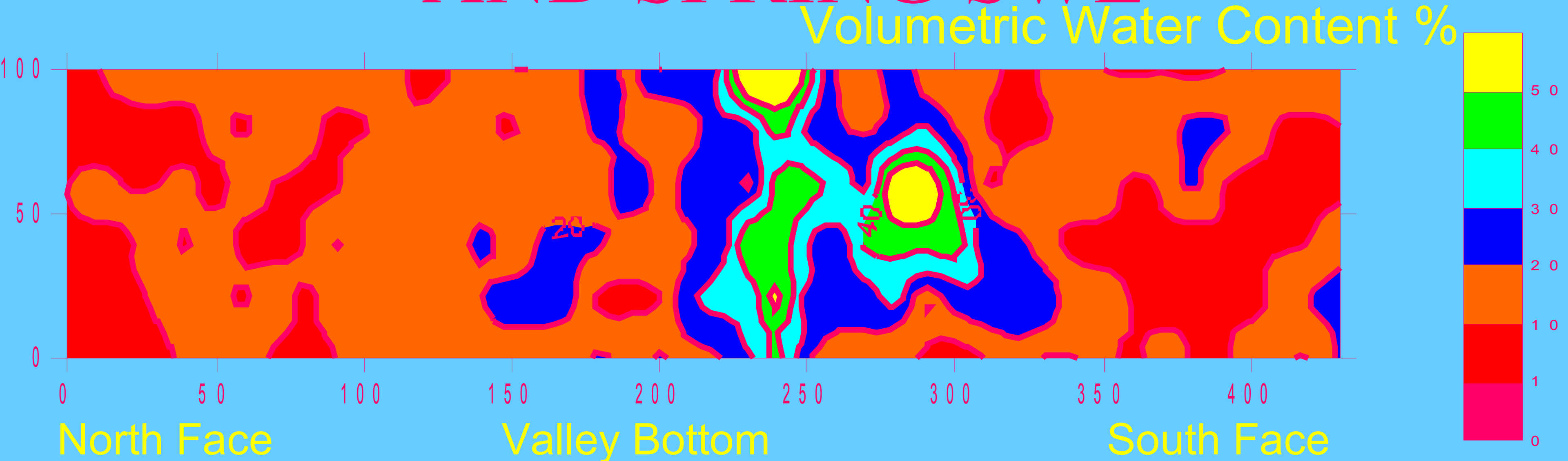


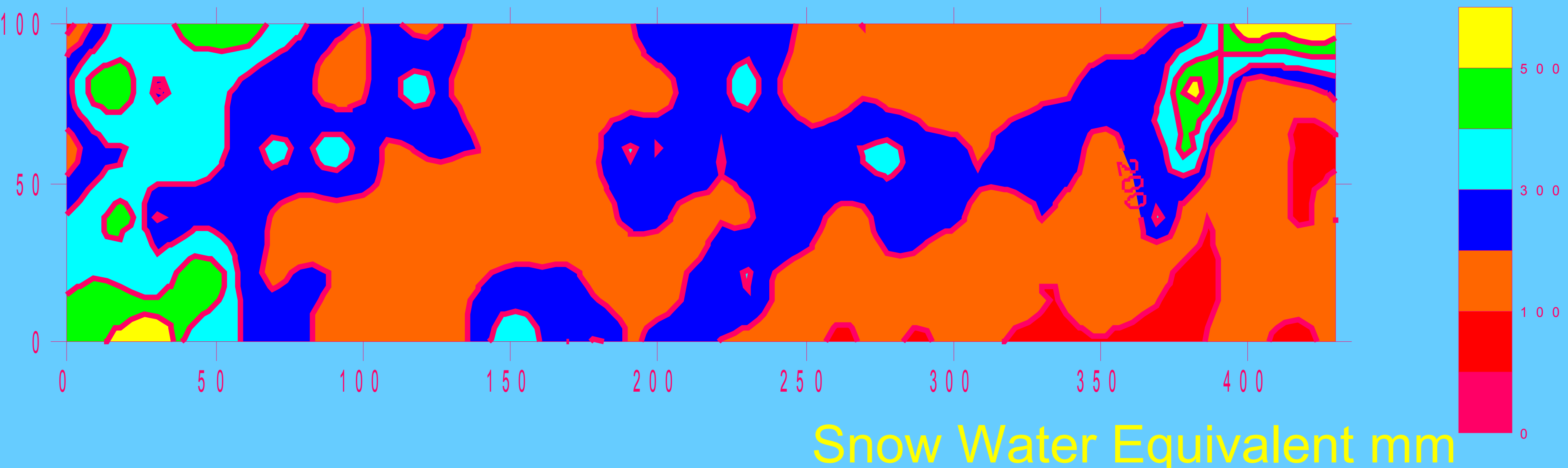




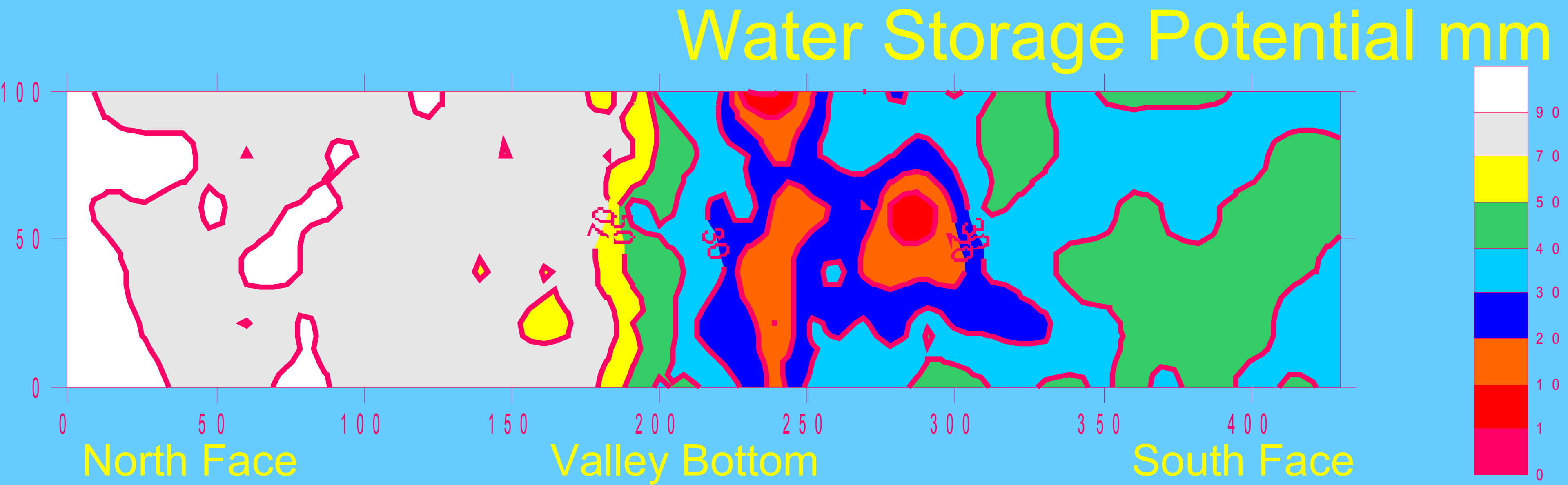


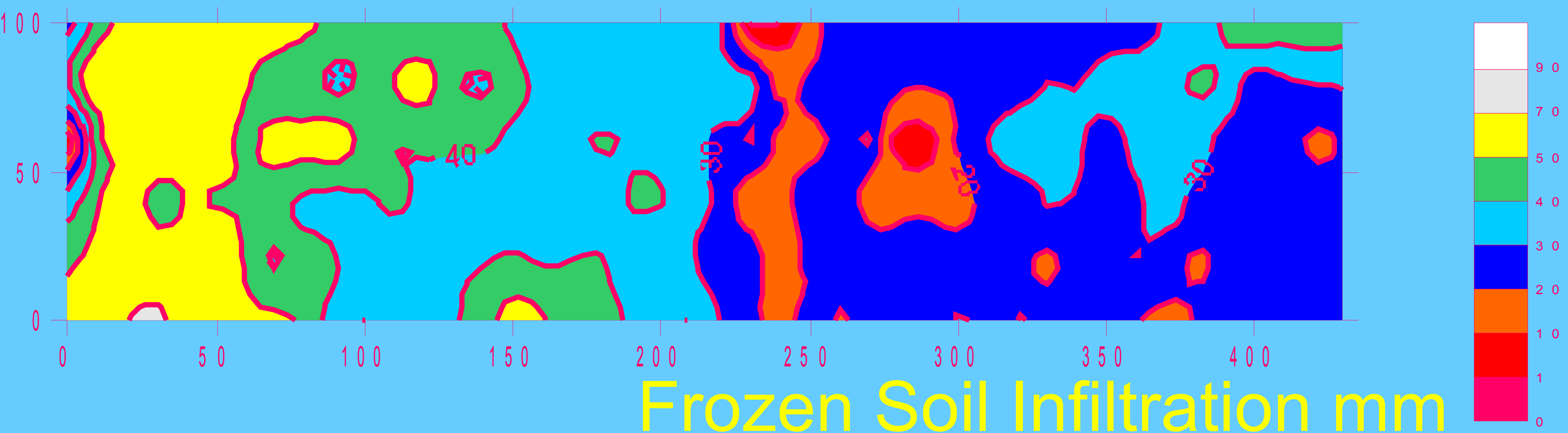
GRANGER FALL SOIL MOISTURE AND SPRING SWE



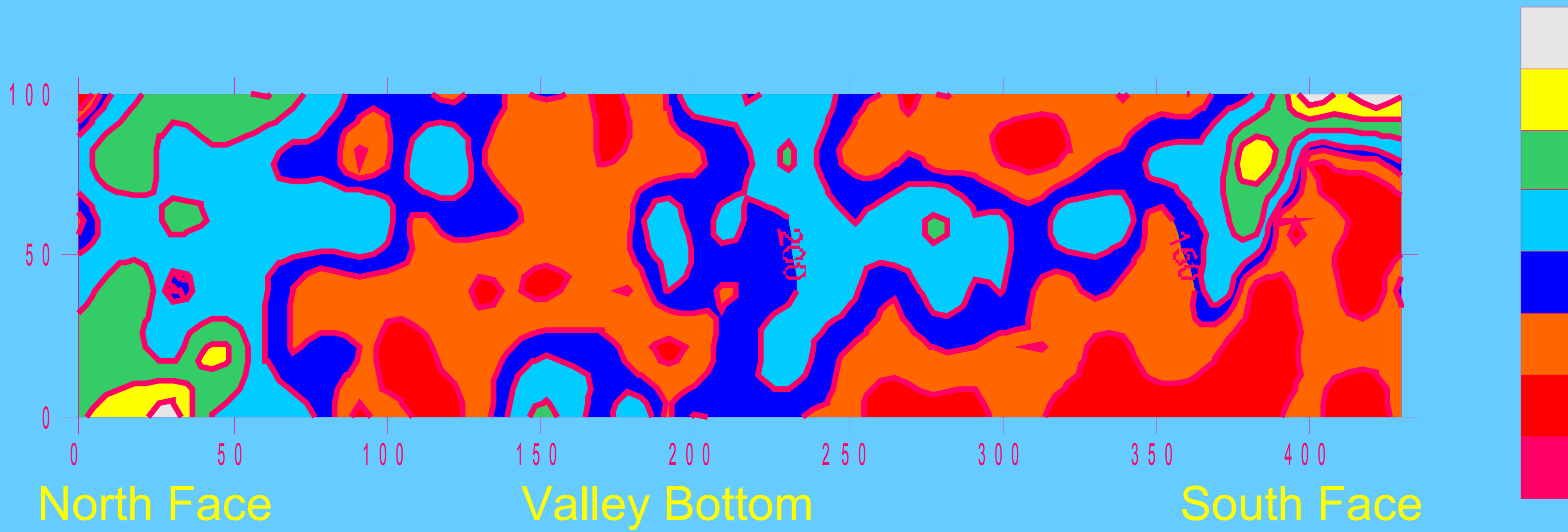


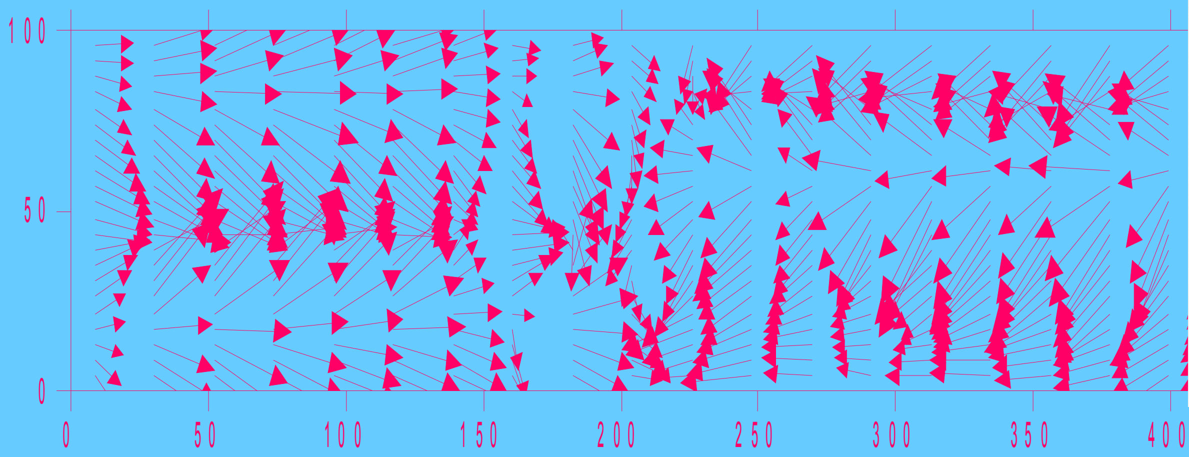
ORGANIC STORAGE & SOIL INFILTRATION





INFILRATION EXCESS (SNOWMELT RUNOFF)





CONCLUSIONS

- Infiltration and runoff can be calculated from mean parameters (SWE, θ, Φ, M) within a landscape type – no 'scaling problem' evident.
- Substantial difference in infiltration and runoff with landscape type
  - SWE determined by windflow change
  - Melt rate determined by slope and aspect
  - Soil moisture determined by drainage
  - Organic layer thickness determined by slope and aspect
- Water storage potential in organic layer and infiltration to frozen mineral soils are not primarily drainage controlled but are controlled by slope and aspect through their influence on melt energy and soil and organic layer properties
- Snowmelt runoff is not primarily topographically controlled but is controlled primarily by accumulation of wind-blown snow and melt energetics and secondarily by soil moisture.


WOLF CREEK – 15 YEARS
1993 - 2008
Thank You