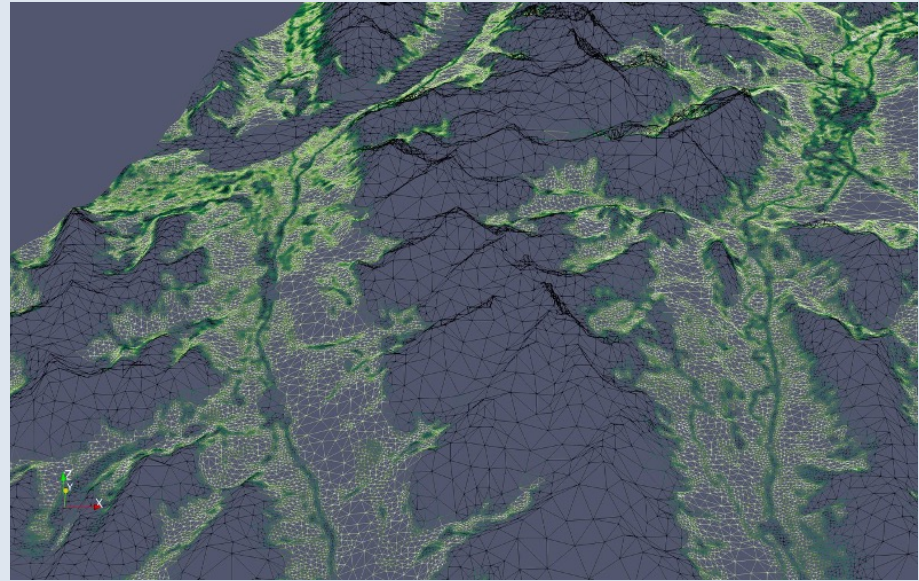
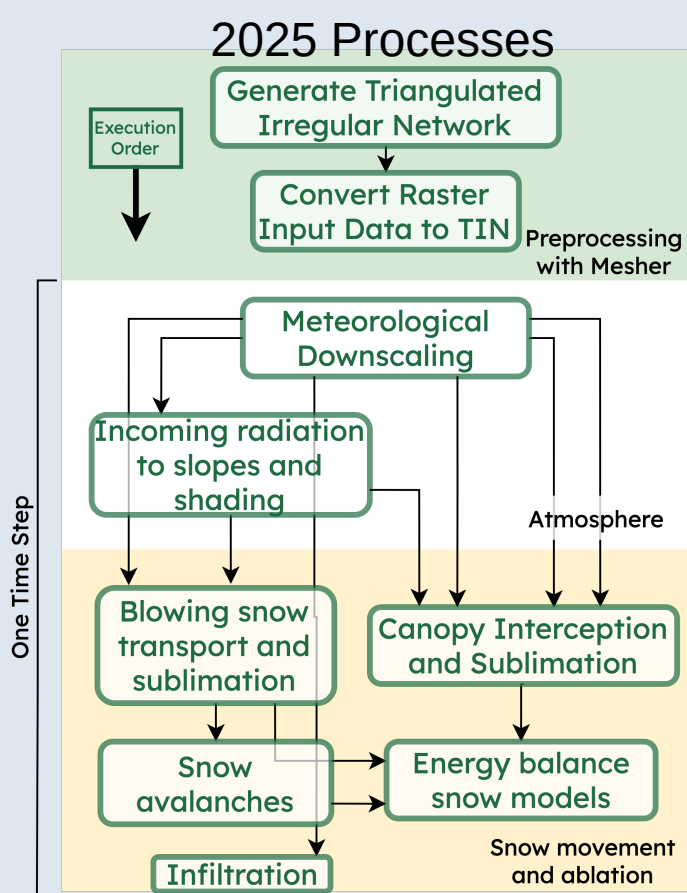


Canadian Hydrological Model Development: Route to Routing

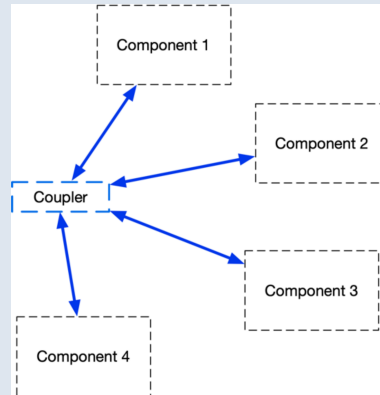
Donovan Allum¹, John Pomeroy¹, Chris Marsh²

1: Centre for Hydrology, University of Saskatchewan, 2: Environment and Climate Change Canada

Part 1: Canadian Hydrological Model



Example Output from Mesher



Route to Routing

- The goal is to include hydrology to produce streamflow outputs and projections in CHM
- First require:
 - i. Infiltration into Frozen and Unfrozen soil
 - ii. Surface and Soil moisture storage (includes evapotranspiration)
 - iii. Runoff (overland and subsurface)
- Adapt Cold-Regions Hydrological Model modules to CHM

Infiltration

1. Two options:

1) **Thawed Soil:** Ayers (1959)

- Look-up table using ground-cover and soil texture.
- Based on measurements across Canada

2) **Frozen Soil:** Gray, Landine, Granger (1985)

Physically “guided” equation for infiltration over a season

$$I = 5(1 - \theta_p)SWE^{0.584}$$

I : Infiltration

θ_p : Pore saturation in the top 30 cm of soil prior to melt

SWE : Snow water equivalent

Mapped to daily based on an expected number of major melt days (6)

Evapotranspiration

1. Two options

1) Penman-Monteith:

- Actual ET
- Combining radiative effects with mass-transfer
- uses a Jarvis style stomatal resistance (Verseghy, 1993)

2) Priestley-Taylor:

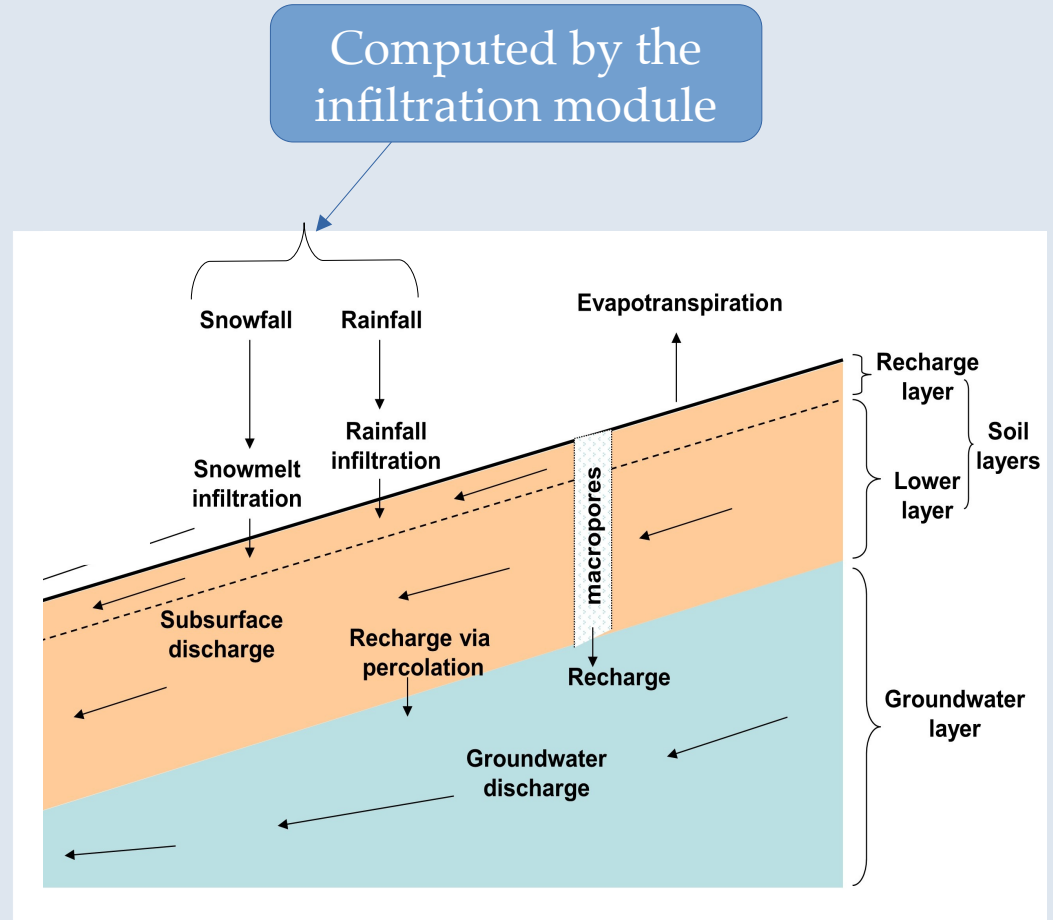
- Actual ET
- Ideal for wetlands or ponds, introduces significant uncertainty if used over large water bodies

Surface and Soil Moisture Storage and Movement

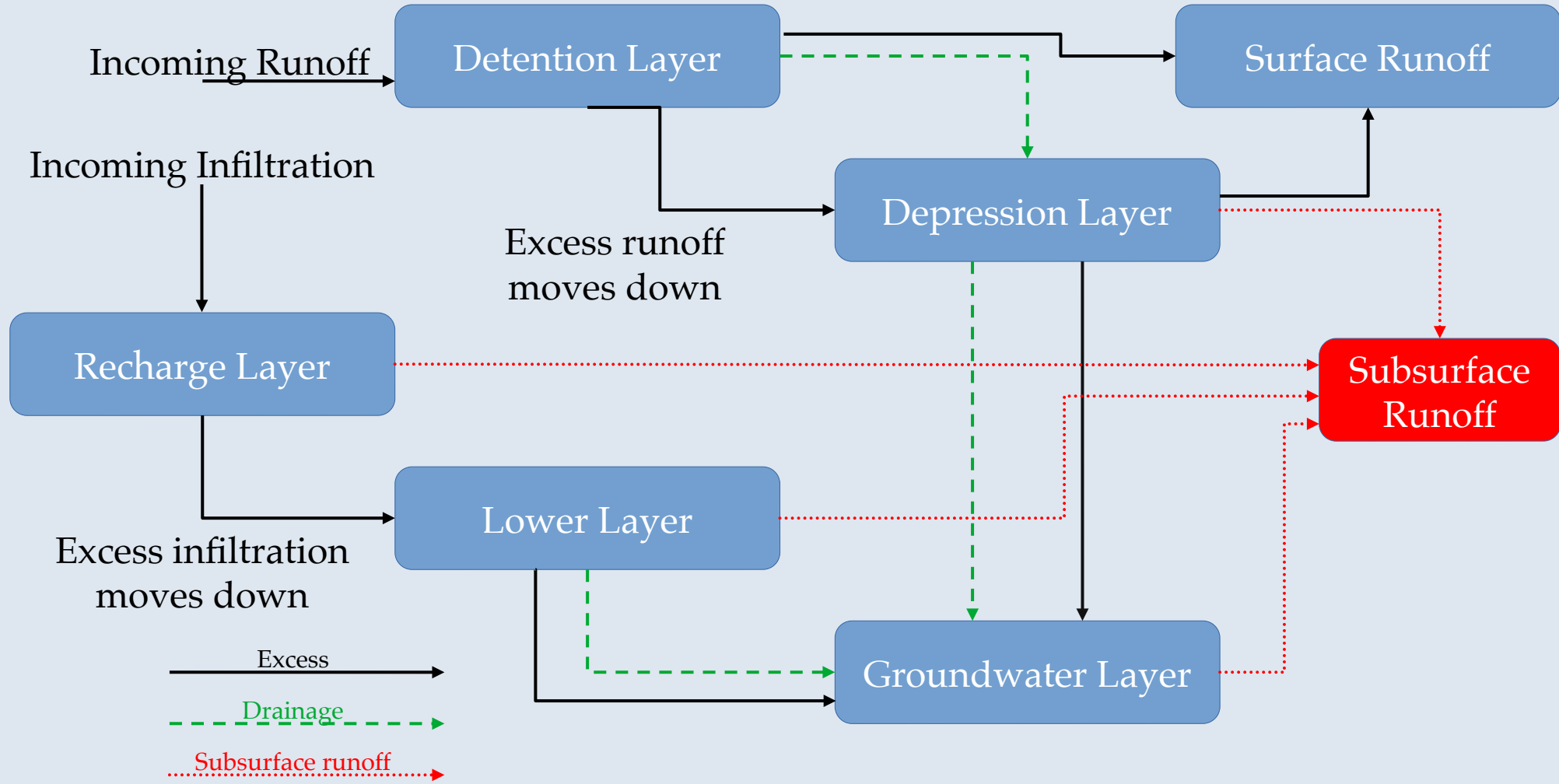
1. Conceptual Model

2. Storage:

- Detention “Storage”
- Depression Storage
- Recharge Layer
- Lower Layer
- Groundwater Layer



Surface and Soil Fluxes

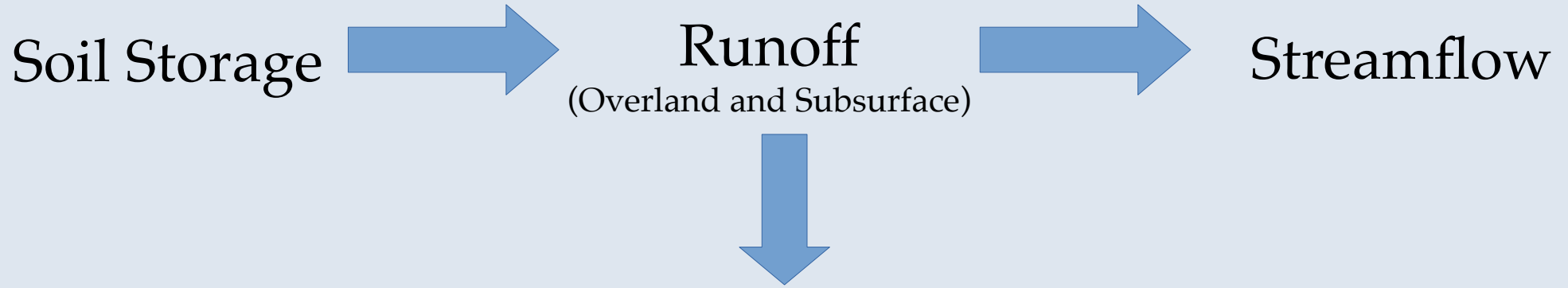


Soil Phases and Fluxes

- Freeze and Thawing of Soils
 - Freeze and thaw fronts computed with Stefan's Equation for multi-layered soils (Xie and Gough, 2013)
 - Evolved through time by surface temperature conditions
- Surface and Soil fluxes
 - *Outflow* Fluxes estimated using Richard's Equation
 - *Inflow* to other HRUs is computed by another module
 - Problem for another time.....

Runoff

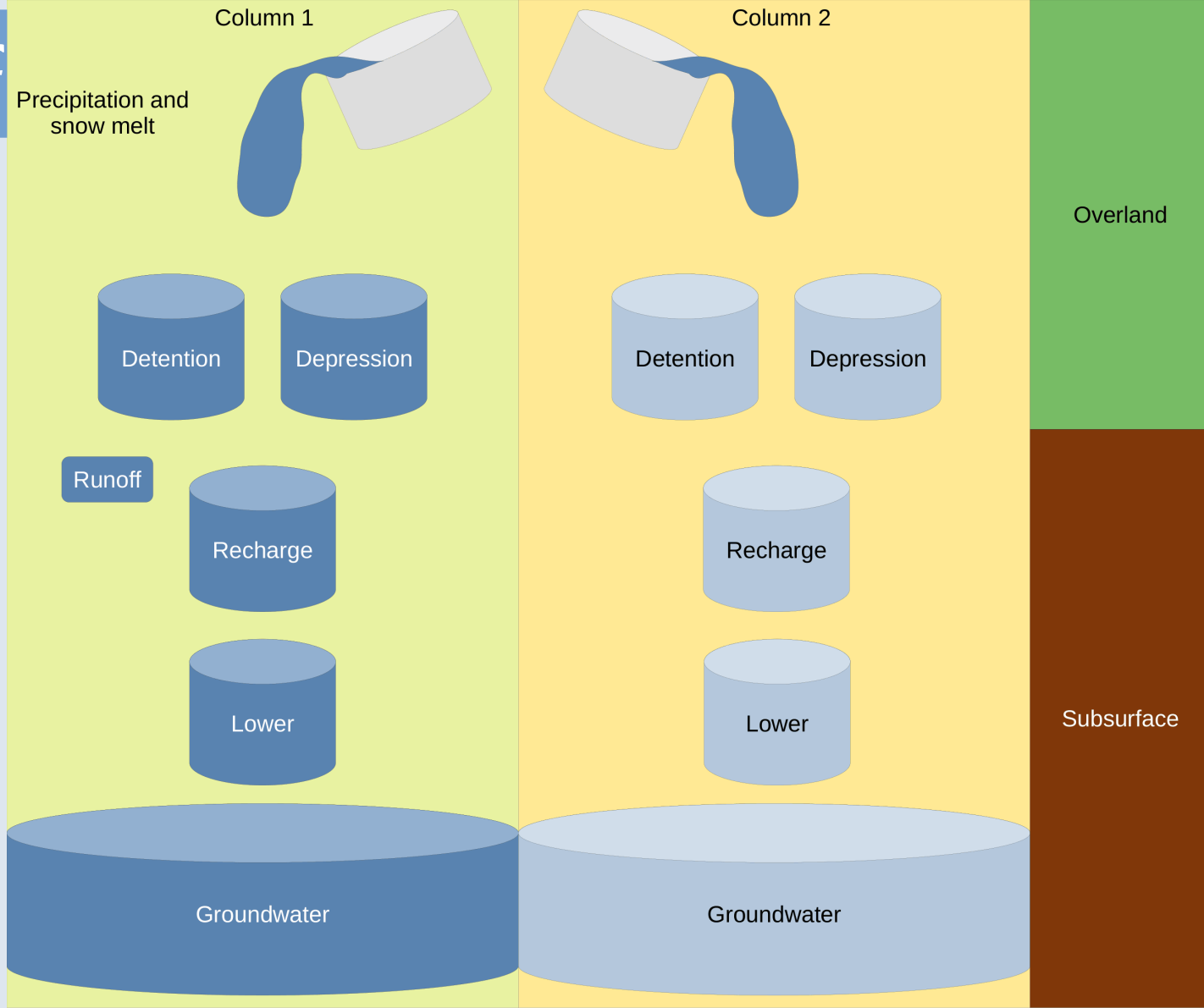
- **Purpose:** Compute Streamflow



- How to do it in CHM?
- First, How is it done in CRHM?

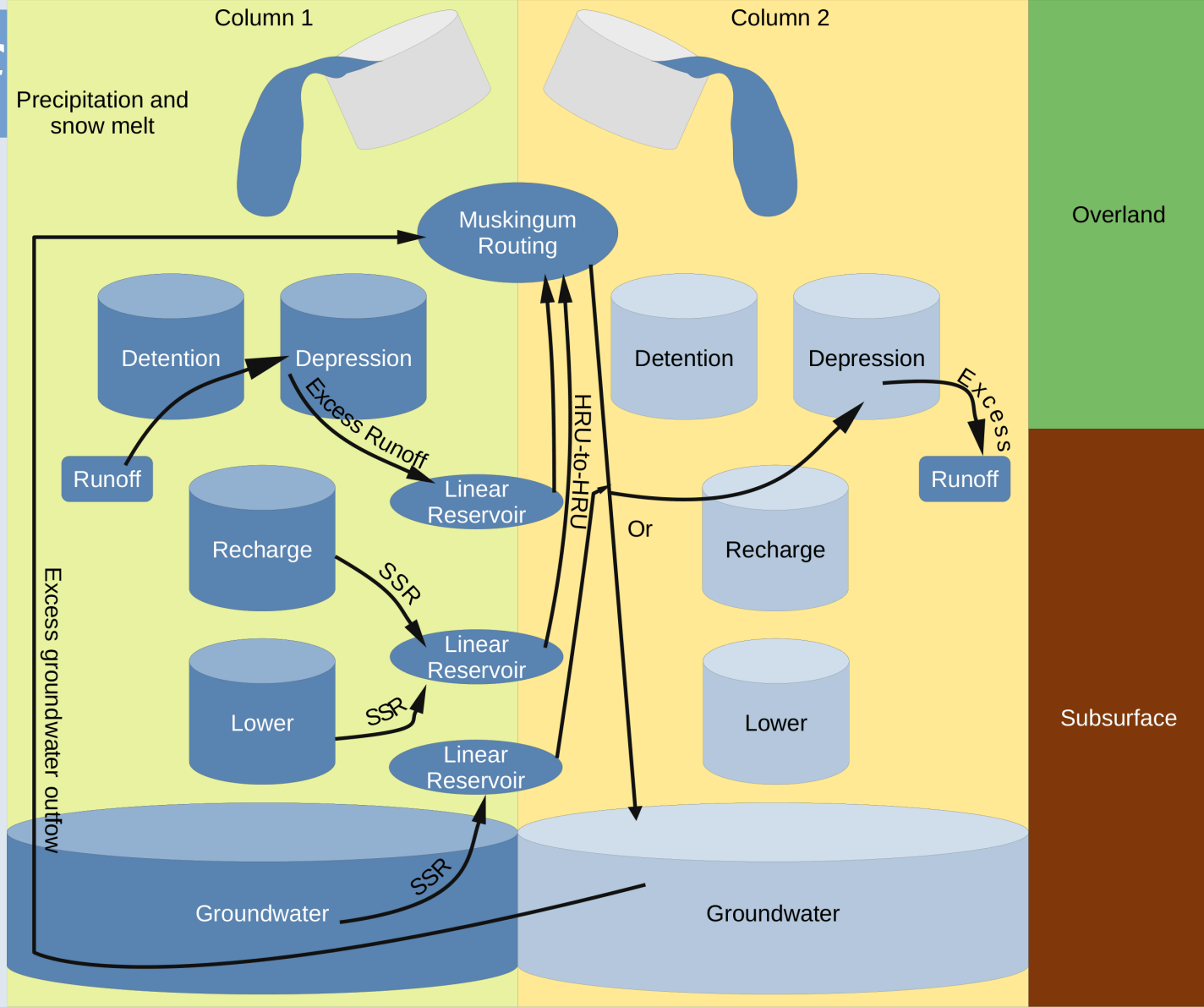
CRHM Runoff

- Imagine these are two HRUs
- HRU 2 is set to receive runoff from HRU 1
- Using the soil_module model



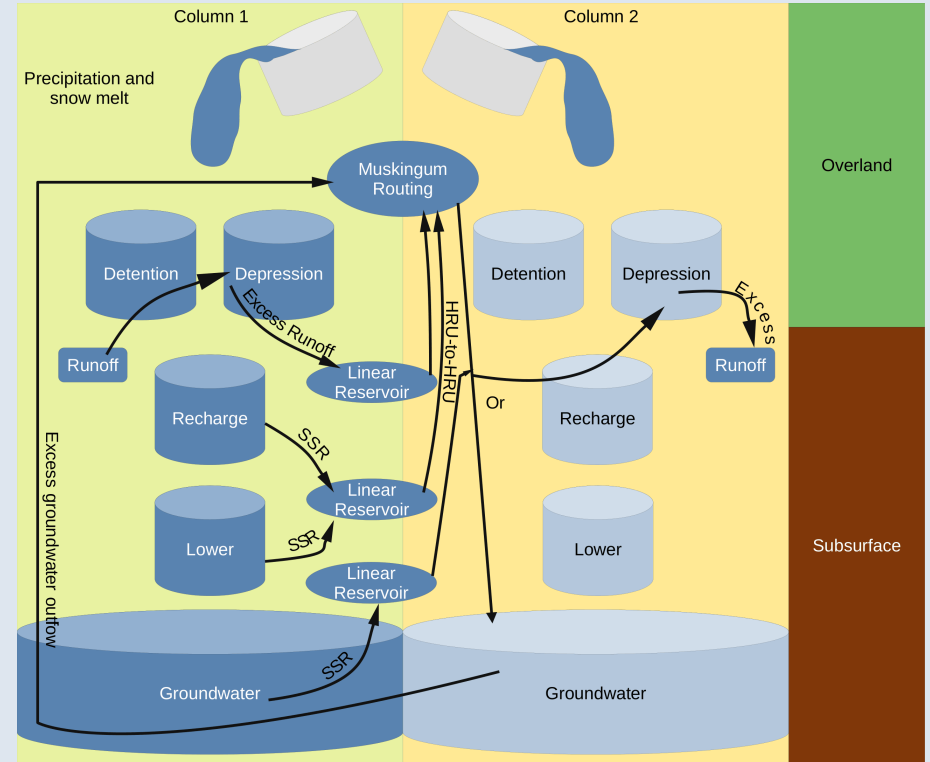
CRHM Runoff

- Made this for my own understanding
- Not really useful to show others...
- Just highlighting the complexity



Why so complex?

- CRHM model of HRUs can be arbitrarily complex
 - i. HRUs don't have to be contiguous
 - ii. Boundaries can have any geometry and aren't known to the model
- Processes are programmed in, rather than emergent
- CHM does not need to be this way
 - i. Geometry is always known and consistent



What We Learned

- CHM's triangular network easily adapts to 1D processes
 - 1D columns of triangular prisms
- Lateral processes in CRHM cannot make many assumptions about the orientation of HRUs
 - Not well suited for porting
- Soil module is largely 1D, EXCEPT when runoff is considered
 - An essential process that must be done right
- CHM has all the geometry known. **Use it!**

Surface Runoff Method

Kinematic Wave, to be determined...

Subsurface Runoff Method

Solving Richard's Equation numerically to find soil moisture movement

$$\frac{\partial \theta}{\partial t} = \vec{\nabla} \cdot (K(\theta) \vec{\nabla} H)$$

$$H = \psi + z$$

H : Hydraulic Head

ψ : Pressure Head

z : Gravitational Head

θ : Volumetric Water Content

- Using the “Finite-Volume Method”
 - i. Takes advantage of triangular mesh
 - ii. Already employed for blowing-snow module
 - iii. Map soil module layers to FVM grid
 - iv. Replaces all moisture movement between physical layers

Runoff Method: Mapping to CRHM

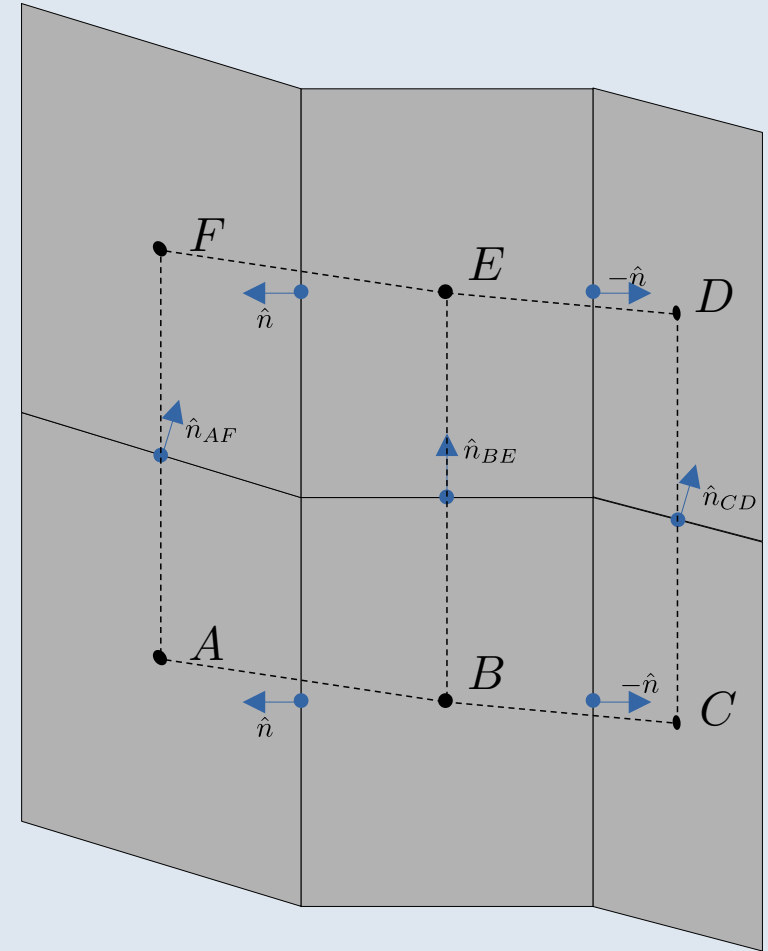
- **Right:** Side-view of three columns
- View from above would be the CHM triangular mesh
- Two layers for example, really would be three layers

i. Detention Layer

ii. Recharge layer

iii. Lower layer

- Exact geometry is known
- Fluxes are solved for simultaneously



Future Work on Runoff

- i. Testing the correctness of the implementation
- ii. Running on a real grid and evaluating against expected physicality
- iii. Coupling with additional physics
 - River Routing
 - Groundwater
 - Depressions

Conclusions

- New processes added to CHM so far:
 - i. Infiltration into frozen and unfrozen soils
 - ii. Evapotranspiration
 - iii. Surface and soil storage
 - iv. Overland and Subsurface runoff using the finite volume method
 - v. Glacier accumulation, ablation, and firn densification
- Continue to work on CHM full hydrology towards routing and multiscale hydrological simulation and analysis
- Coupling the new runoff module with the soil module for groundwater, infiltration through macropores, and evapotranspiration