Streamflow generation in Nordic till soils. What do we know and what do we guess?

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Understanding needs questions
Questions vary over time
Water power development: How large is the river discharge?

Fig. 49: Discharge measurement with current meter no 31 from cart in River Ammerån

SMHI (1914)

Forestry: Optimal wetness for growth?
Shallow groundwater flow?
Effect of clear cutting?

Tracer experiment in Kloten area
Acidification: Flow paths? Transit times?

Environmental concern: Transport processes?
Climate change: Modelling beyond calibration?
Changing flow paths – changed transport, C etc.

Arvika Nov. 2000

Where the water flows: The till soil

Process studies, isotopes
Isotopes
Thin soils, outcrops

SNA

Peat
Clay, silt
Sand
Gastrifluvial deposits
Clayey till soil
Till soil
Thin soils, outcrops
The till soil in Sweden, Norway and Finland is mostly sandy, formed by hard bedrock.
The underlying bedrock is not impermeable

Very many single household wells in fractured gneiss or granite bedrock
What we want to know:

How much water and when?
Flowpaths and velocities in unsaturated and saturated zones?
Residence time in various biogeochemical environments?
How can it be modelled?

What we know about the water flow in Nordic till soils

Shallow groundwater
Vertically and laterally continuous groundwater zone
Almost all rain and meltwater infiltrates into unsaturated soil

Groundwater levels are closely related to streamflow – near the stream

Distance from stream: 14 m
(tube J3G1)

Distance from stream: 103 m
(tube J6G1)
The hydraulic conductivity decreases rapidly with depth

Values from Nordic till soils

Notoriously heterogeneous K – soil core results less useful

“Efficient” K from observed (stream)flow and gradient may be more useful

\[ K = \frac{dT}{dz} \]

\( T = \) transmissivity

\( z = \) depth

Bishop et al., 2011

Nyberg, 1995
On a long term basis, the largest volumes of lateral flow go through superficial layers of high conductivity.

The extension of the discharge areas varies over time in response to the groundwater level.

Bishop et al. 2011
Myrabø (1997)

Depth of the water table at various runoff rates

Saeternbekken, Norway
7500 m²

Myrabø (1997)
Topography may give good information

…and I can quantify it.

High resolution DEM
New analysis techniques
Need for data on soil thickness!

K Beven  J Seibert

Temporary discharge area (no snow) at high water table, formed by small scale topography
Runoff events in streams are dominated by pre-event water

Gårdsjön F2

Rodhe, 1987
Krycklan. 15 nested catchments:

Fraction of event water in spring runoff

- independent of catchment size
- increases with wetland percentage due to soil frost
- \( \Rightarrow \) climate change – flow paths?

Laudon et al. WRR 2004 etc
Soil frost in forest land has little influence on the magnitude of the spring flood

Nyberg et al., 2001

Svartberget

Soil frost at different distances from the stream

Groundwater level (cm)

Changed groundwater – runoff relationship in frozen soil => changed flowpaths?

Laudon et al. 2004
The mean residence time for water in headwater catchments is on the order of a few months to years.
Krycklan

Mean residence time decreases with decreasing slope

Mean residence time of snowmelt water
• correlated with median catchment size
• decreases with decreasing slope

Laudon et al. JH 2007 etc.

Groundwater discharge to streams increases drastically when the shallow, highly conductive layers become saturated

"Transmissivity feed-back" (Bishop)
Artificial tracer experiment in Gårdsjön G1
(Nyberg et al. 1995)

Isotope hydrograph separation unequivocally showed the dominating role of pre-event water in runoff events

But what do they tell us about flowpaths?

Rodhe (1987) assumed all pre-event water from saturation overland flow

Spring snowmelt events
Isotopes support transmissivity feedback theory in Svartberget

Event water was traced only in superficial layers (<0.9 m) and more in upslope part

Mass budget closed: Total snowmelt = event water in soil and runoff

Laudon et al. WRR 2004

Areal pattern of new water reflects flowpaths
We must have a simplified conceptual picture of the flow paths.

But how valid is that picture in specific cases?
Our knowledge is the sum of scattered observations
Can they be synthesized in a useful theory?

North-Watch is important!

Permanent discharge area with Spagnum moss around the stream