The Krycklan Catchment Study

A unique infrastructure for field based research on hydrology, ecology and biogeochemistry

The Hitchhiker's Guide 5.0

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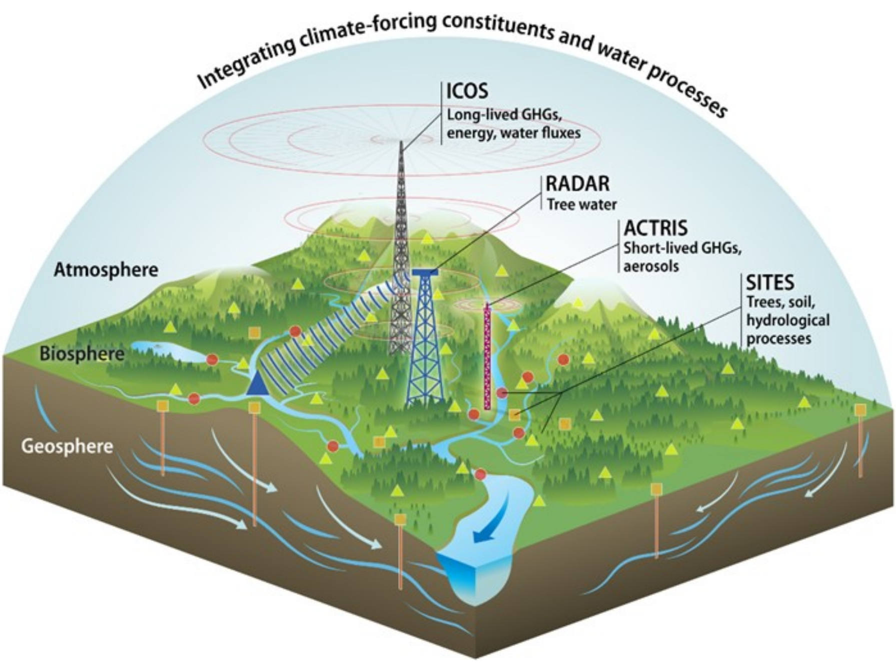
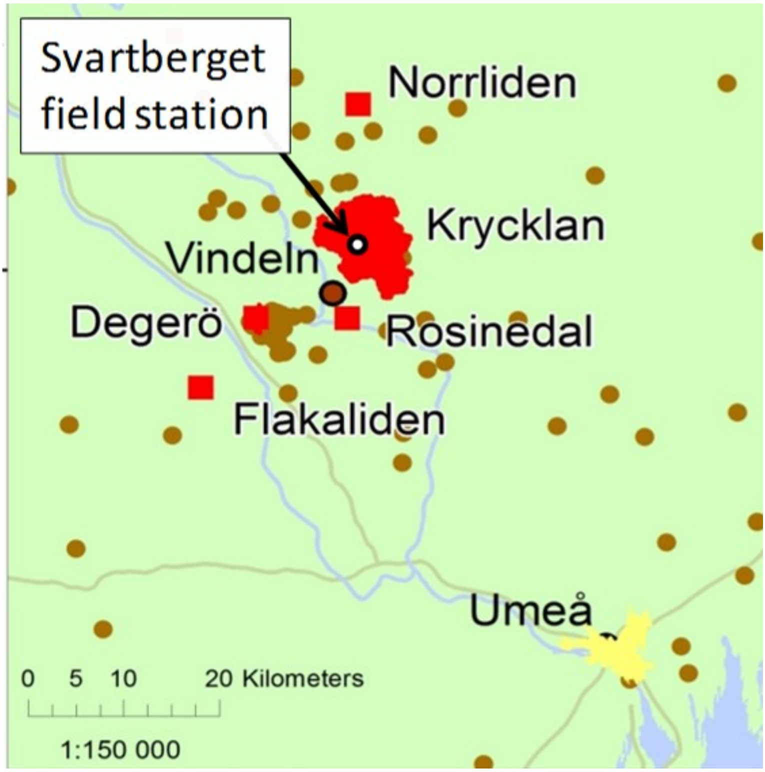
Krycklan in a nutshell...

The 68 km^2 Krycklan catchment encompasses the natural mosaic of boreal landscapes consisting of forests, mires, streams and lakes that make up 70% of the area in Sweden, and which is representative of 30% of the world's forest cover. Krycklan is an integral part of the Svartberget field research infrastructure, which belongs to the Swedish University of Agricultural Sciences (SLU). The Svartberget field station is also responsible for Degerö stormyr, Rosinedal, Flakaliden and Norrliden.

The ongoing field activities include over 50 research projects, involving several hundred scientists from all major universities in Sweden and 30 countries. In total ~ 50 PhD students conduct research at the site. Over 1000 scientific publication are based on results from Svartberget since the beginning in 1910. There is also 110 PhD-thesis (the first published in 1923) where approximately half are based directly on the Krycklan catchment.

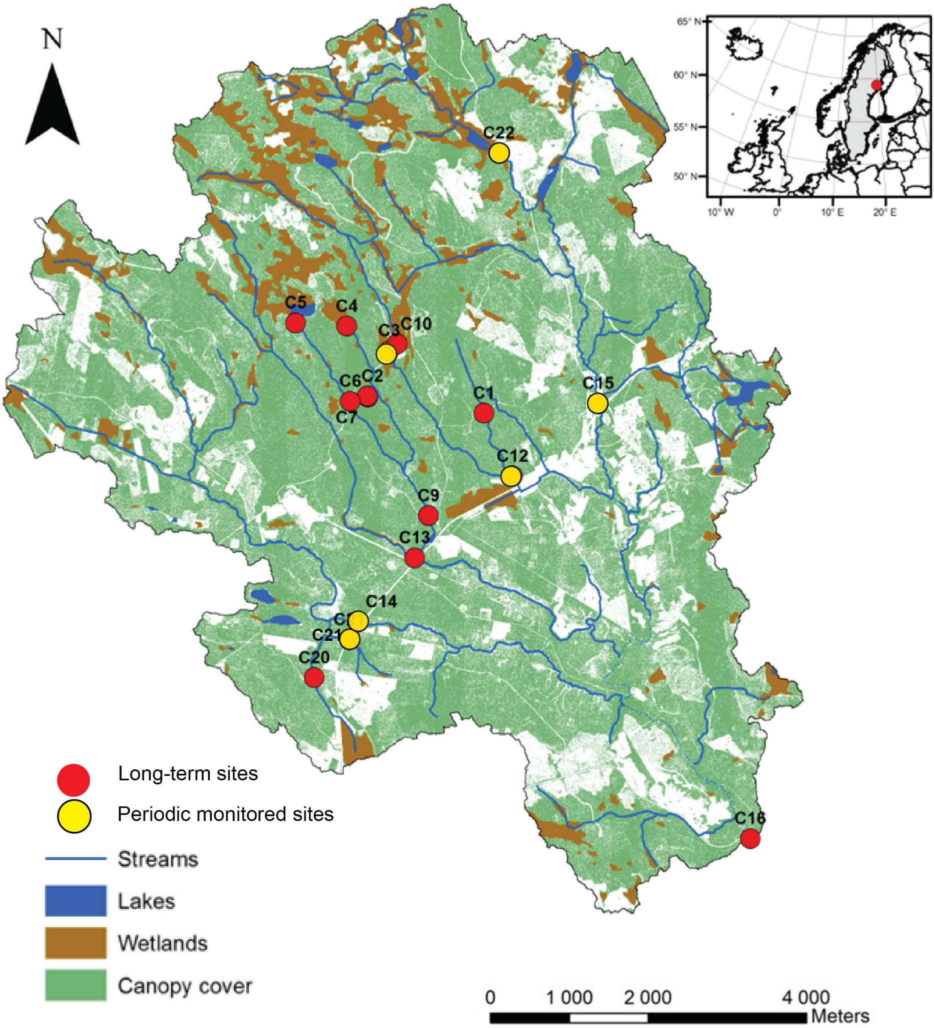


Above: An overview of the Krycklan catchment integrated with state-of-the-art infrastructures including A). **ICOS,** monitors major climate-forcing greenhouse gases, water and energy exchanges observations from a 150 m research tower. B). **ACTRIS,** monitors short-lived climate-forcing pollutants such as aerosols, clouds, reactive trace gases, and their interactions. C). **The Radar Tower,** quantify and partition forest evaporation and transpiration, based 50 m high radar tower and D). **SITES,** provides terrestrial and aquatic ecosystem field research including hydrological measurements from 11 monitored sub-catchments, 200 groundwater wells, and 120 tree-sap measurements, and 500 permanent plots for soil, water and tree interaction.



Location of the Krycklan catchment and other related study areas. The smaller dots are part of the national forest production research network consisting of 1400 sites across Sweden.

SiteNo	FullName	Area (km^2)	Wetland (%)	Forest (%)	Lake (%)
3	Lillmyrbäcken	0.04	53	47	0
2	Västrabäcken	0.12	0	100	0
4	Kallkällsmyren	0.18	51	49	0
21	Lillsed	0.26	0	100	0
7	Kallkällsbäcken	0.47	19	81	0
1	Risbäcken	0.48	0	100	0
5	Stortjärnen Outlet	0.65	48	46	6
6	Stortjärnbäcken	1.10	29	65	4
20	Mulltjärnsbäcken	1.45	12	87	0
8	Fulbäcken	2.30	17	81	0
9	Nyängesbäcken	2.88	15	80	1
10	Stormyrbäcken	3.36	29	71	0
22	Bergmyrbäcken	4.91	29	68	3
12	Nymyrbäcken	5.44	19	81	0
13	Långbäcken	7.00	12	86	1
14	Åhedbäcken	14.10	7	91	1
15	Övre Krycklan	20.13	15	82	2
16	Krycklan	67.80	9	88	1



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Swedish Infrastructure for Ecosystem Science

SITES is a national coordinated infrastructure for terrestrial and limnological field research. SITES consists of nine research stations, including Svartberget/Krycklan. The stations are distributed all over Sweden covering the different landscapes and climatic regions, including agricultural land, forests, mountains areas, wetlands, several type of inland waters, boreal catchments, tundra ecosystems etc.

SITES is available for all researchers on equal terms, regardless of affiliation. SITES offers facilities, sampling equipment and use of data generated from installations and/or observations in the field.

The SITES initiative is funded by the Swedish Research Council and the five partner organisations, i.e. the University of Gothenburg, the Swedish Polar Research Institute, Stockholm University, Uppsala University and Swedish University of Agricultural Sciences. The latter also hosts and coordinator SITES.

Much of the structures described in this guide can also be found on other SITES stations as part of the SITES Water programme. Read more at www.fieldsites.se

Left: Location of research stations within SITES

SITES AquaNet

This is a standardized infrastructure for national and international researches to run mesocosm experiments in lakes at Asa, Erken, Skogaryd, Svartberget and Bolmen field stations.

Mesocosm enclosures: Each site is equipped with a jetfloat deployed in stortjan with 20 polyethylen cylindrical enclosures for experimental manipulations.

Sensor measurements: The experimental facilities have a sensor and datalogging system to measure in each mesocosm real-time environmental parameters.

Standardized sample collection and analyses: Each station is equipped with field equipment for sample collection and access to cold storage, freezing rooms and laboratory facilities. There is connection to laboratories for further sample analyses at the SLU.

Research topics: biodiversity-functioning-stability relationships, community ecology, ecological stoichiometry, food web interactions, benthic-pelagic dynamics, biogeochemistry (e.g., nutrient cycling), land-water-air gas exchange, cyanobacterial blooms and global change research.

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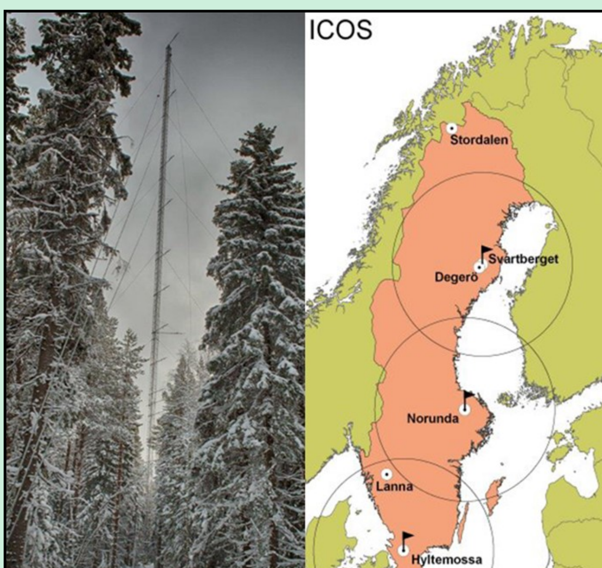
ICOS – Integrated Carbon Observatory System

ICOS is a European research infrastructure for quantifying and understanding the greenhouse gas balance of the European continent and of adjacent regions. ICOS collaborates with nationally operated measurement stations in 17 European countries. ICOS Sweden (http://www.icos-sweden.se) consist of three atmospheric, six ecosystems and one ocean station.

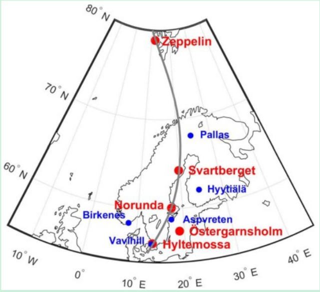
ICOS in Vindeln combines atmospheric and forest ecosystem site at Svartberget and one mire ecosystem site at Degerö stormyr.

At Svartberget, the tower is 150m high where CO_2, H_2O, air temperature, incoming and outgoing radiation, soil moisture, soil heat flux, temperature, canopy radiation and tree temperature are measured.www.icos-sweden.se



ACTRIS (Aerosols, Clouds, and Trace gases Research Infrastructure)

ACTRIS is part of the Swedish Aerosols, Clouds, and Trace gases Research Infrastructure (ACTRIS Sweden) which aims at producing long-term high-quality observations of short-lived climate forcers (SLCFs) and other relevant atmospheric pollutants.



Aerosol particles, as SLCFs in general, have a short residence time in the atmosphere, typically from hours to weeks, which differentiates them from long-lived greenhouse gases (LLGGs). The short lifetimes of aerosol particles make their concentrations highly variable in time and space, and their evolution involves atmospheric chemical and physical processes occurring on very short timescales.

ACTRIS is co-locate with the ICOS and observations are made in a coordinated and standardized way along a south-north (and hence anthropogenic pollution and climate) gradient.

RADAR

Krycklan now houses the RADAR tower where high-quality radar and forest water measurements are collected over timescales of hours to years. Forest transpiration is studied using radar tomography, which is directly sensi-tive to the water content in the entire vertical extent of the forest.

The availability of the reference ET dataset and high temporal resolution radar measurements allow us to develop the first ever methods for estimating ET from radar observations.

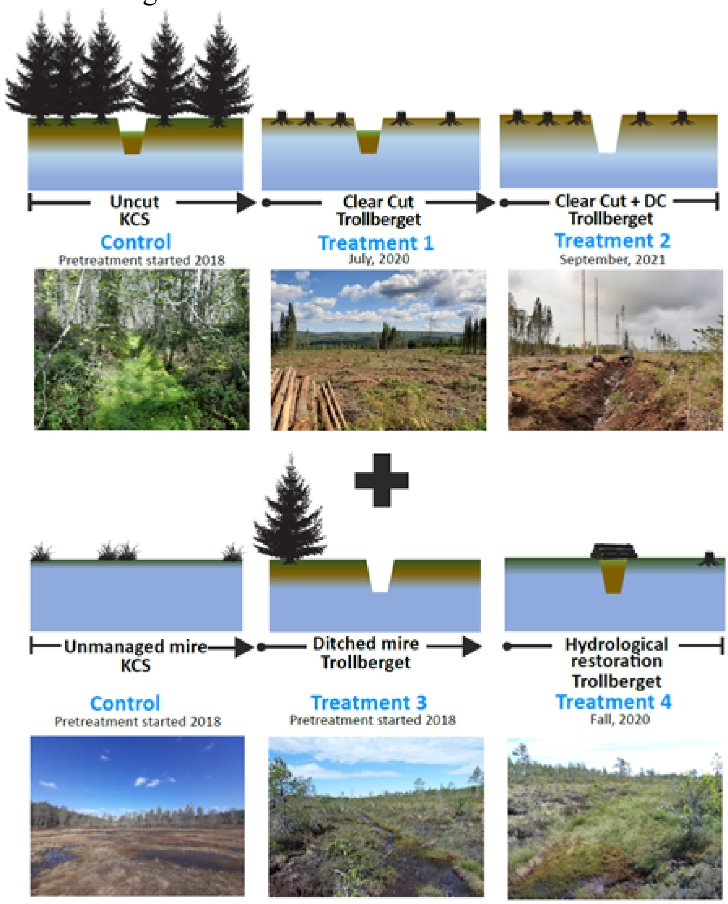
In the long-term high spatial and temporal resolution observations of forest ET and its components will help fill some of the most long-standing and important knowledge gaps in our understanding of the role of forests in the climate and hydrological systems.

Trollberget Experimental Area (TEA)

Millions of hectares of northern peatlands were drained for forestry, which has increased forest productivity in some areas, but not all. The future fate of these drainage ditches can be to:

1) clean them to ensure continued drainage,
2) hydrologically restore them to a more natural state, or
3) leave them alone.

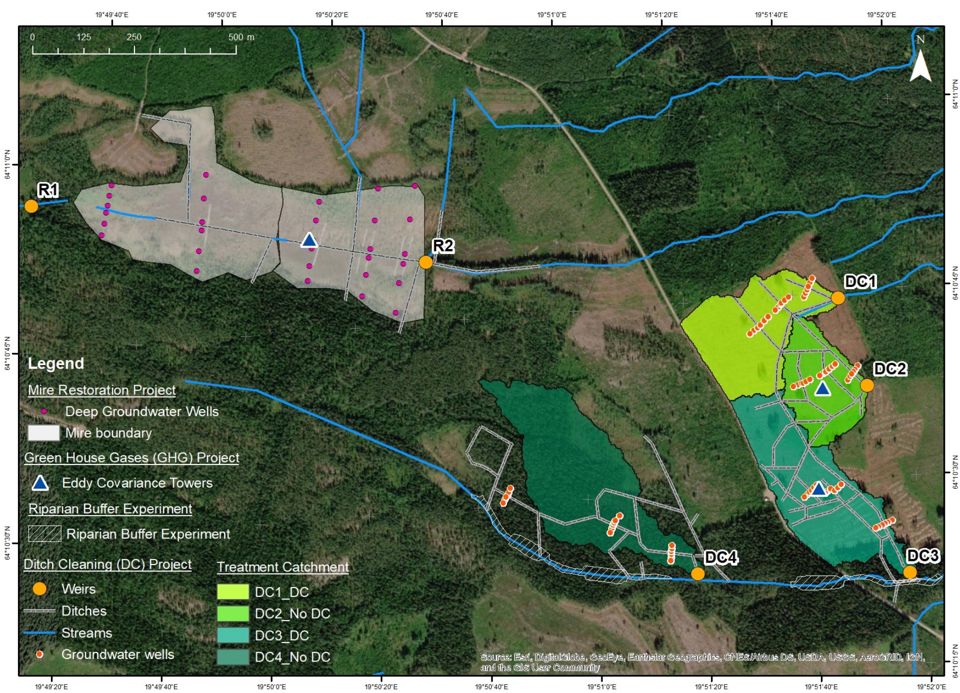
In fall of 2018, we added six stations to the Krycklan water quality mon-itoring network in a side-by-side comparison of these three different management options with the goal of determining their effects on water quality and quantity. We call this area “Trollberget” and it began with the EU LIFE program’s GRIP on LIFE Integrated Project that includes demonstration areas for the restoration of an unproductive drained peat-land and best practices for cleaning of forest ditches.



Above: Schematic showing the timing and types of treatments applied, with example photographs below. Pretreatment measurements in all catchments started in 2018. (Photos: Virginia Mosquera)

Ditch cleaning was performed with a standard excavator following the Swedish Strategic Management Objectives. Ecological restoration was performed using best practices, namely, by cutting the remaining trees on the mire, using them to create dams, as well as filling in the ditches with peat found on site. The original project has expanded to include other ongoing studies of forestry practices, in-cluding forest harvest and riparian buffer design as well as other potential environmental effects from these management actions, including green-house gas emissions, carbon and water cycling, and biodiversity, among others.

We are monitoring groundwater level and discharge in addition to meas-uring: Nitrogen, Carbon, Suspended Sediments, pH, Conductivity, CO_2, Methane, ^{18}O, Deuterium, Anions, Cations, Absorbance/fluorescence, Mercury (Hg-Tot, MeHg) in runoff water at our 6 outlet weirs. We are also measuring carbon and greenhouse gas balance of the management treatments using the Eddy Covariance technique (tower locations in lo-cation map) and chamber measurements.

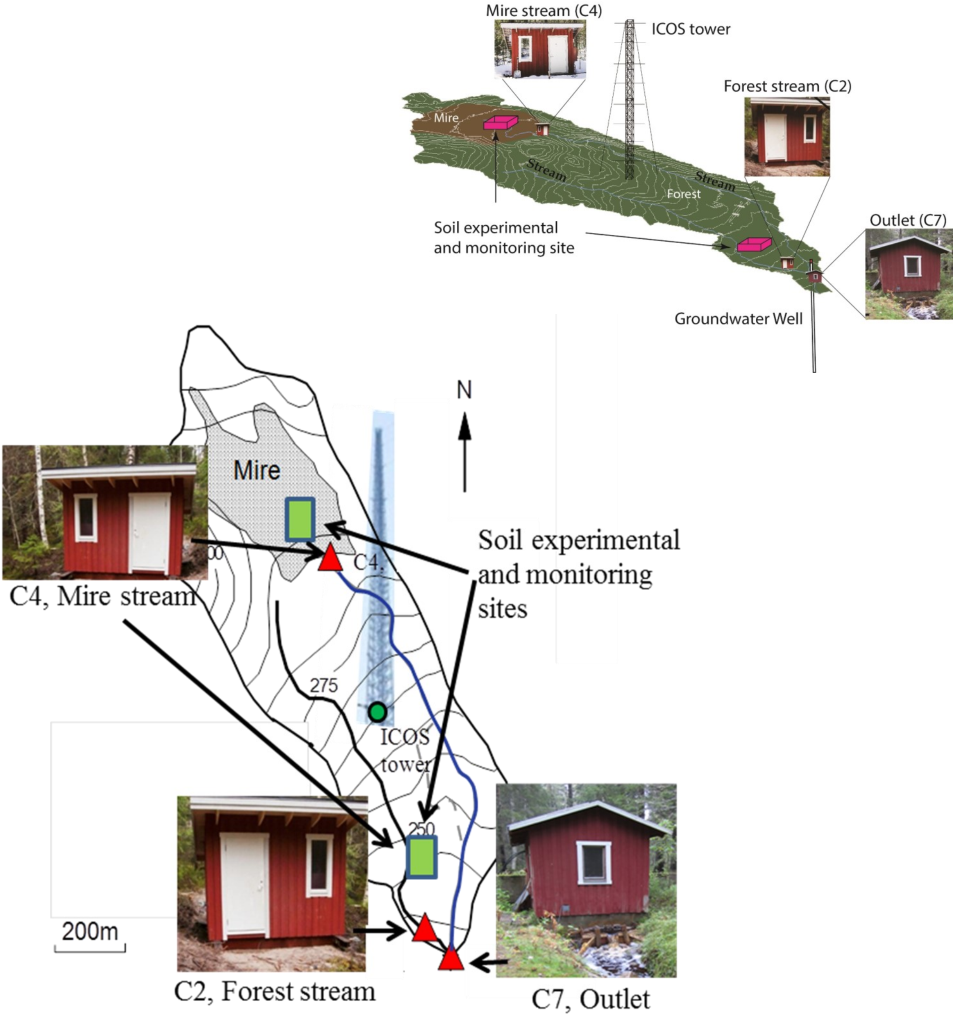


Above: Map showing infrastructure at the Trollberget Experimental Area

Skogssällskapet GRIPonLIFE Life NATURA 2000 UMEÅ UNIVERSITET Water JPI HOLMEN

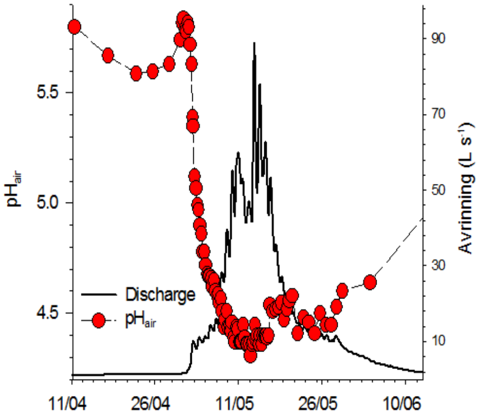
Länsstyrelsen Västerbotten FORMAS Kempestiftelserna SKOGSSTYRELSEN SLU

The Svartberget Catchment



Above: The Svartberget catchment (C7) is the centre of Krycklan

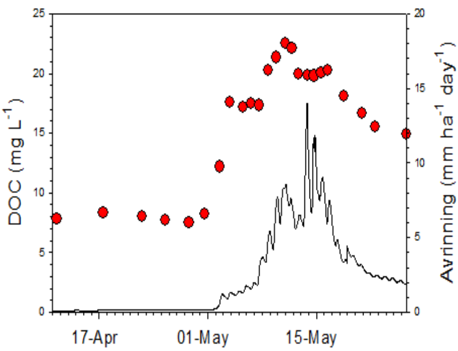
The catchment with many names (Svartberget, Nyänget, SVW, C7) is where it all began in 1979. It is also the heart of much of the current research on the contrasting hydrological and biogeochemical behavior of forested and mire catchments in Krycklan. The Svartberget catchment also hosts the first soil experimental and monitoring sites that begun in 1997, including the S-transect and the “Russian wells”.



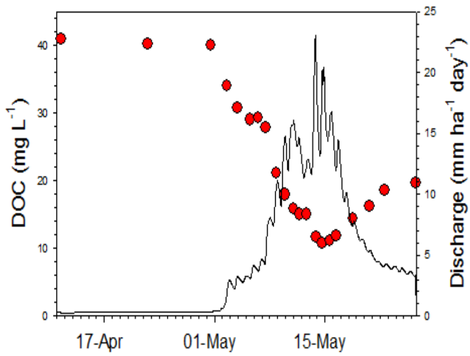
Left: Decline of pH during the spring flood at C7. This decline is mainly driven by natural processes caused by increases in the concentration of DOC (Dissolved Organic Carbon).

Below: The contrasting behavior of DOC between the forested catchments and wetland dominated catchments.

Forest Catchment (C2)



Wetland Catchment (C4)



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Experiments to evaluate multiple stressors in boreal streams

Ongoing climate change and land-use represent severe pressures on northern stream ecosystems. Both of these anthropogenic pressures trigger many physicochemical changes, and when those changes exceed the range of background undisturbed conditions they become stressors for aquatic biota.

This project will apply a unique integrative approach that combines experimental manipulations in mesocosms and natural streams with existing and new data collected in streams in connection to extreme events. We will dominantly use the fluvial mesocosms that were constructed in the Krycklan catchment in 2020.

Here a number of experiments will manipulate the most common forestry stressors (including changes in light, water temperature, turbidity and chemistry) and extreme hydrology (droughts and floods) and study how aquatic communities and ecological processes respond to and recover from those events. We will also utilize the dam infrastructure situated at the C5 lake outlet to study simulated drought in a natural stream.

An experimental facility in the KCS consist of 12 artificial stream channels, each 15 m long and 20 cm wide and deep (to the left) where water is pumped to the channels from a headwater stream. Each of the three channels (i.e., triplet to the right) have separate inlet, allowing 4-level manipulation of water chemistry. Water temperature, bottom substrate, gradient, hydrology and light can be manipulated in replicated experiments.

Key references

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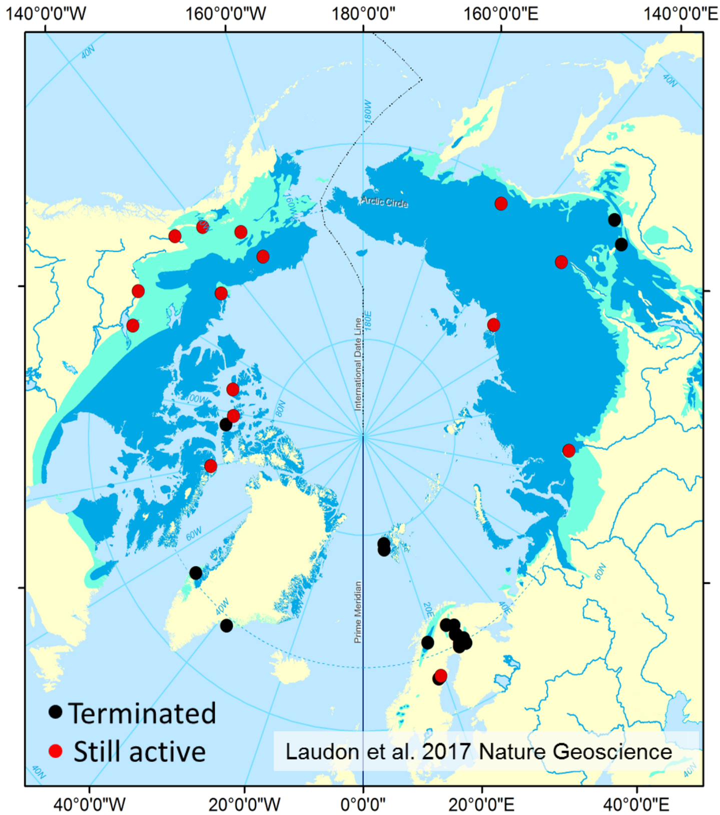
Save
northern long-term research catchments



Northern freshwaters are changing rapidly in response to global warming and human perturbation. Despite this there is an ongoing downsizing of small research catchments in the north. This is problematic as such research infrastructures are needed to understand and predict sustainable ecosystem services and social prosperity in this rapidly changing region.

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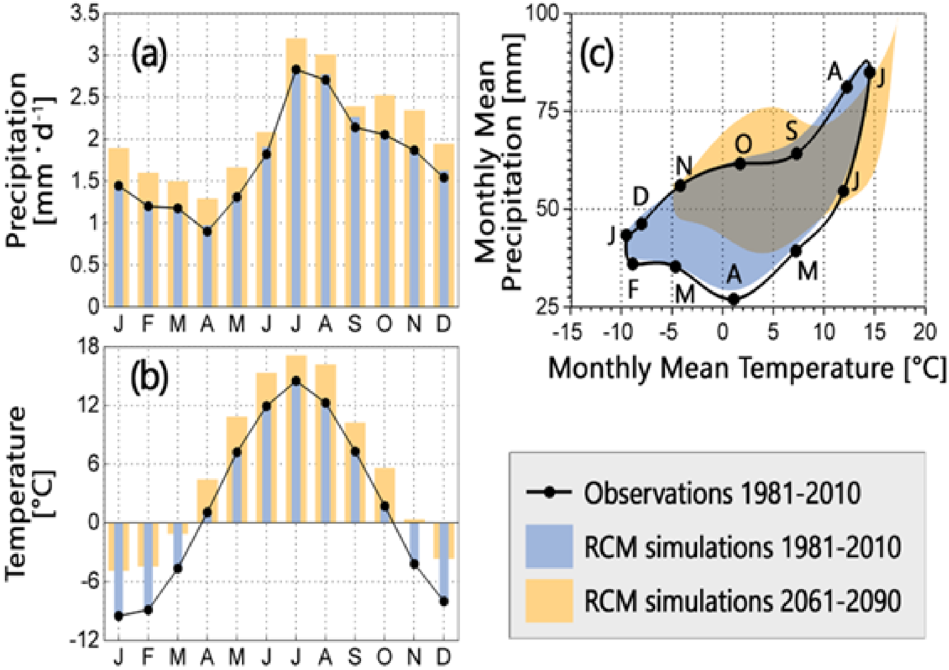
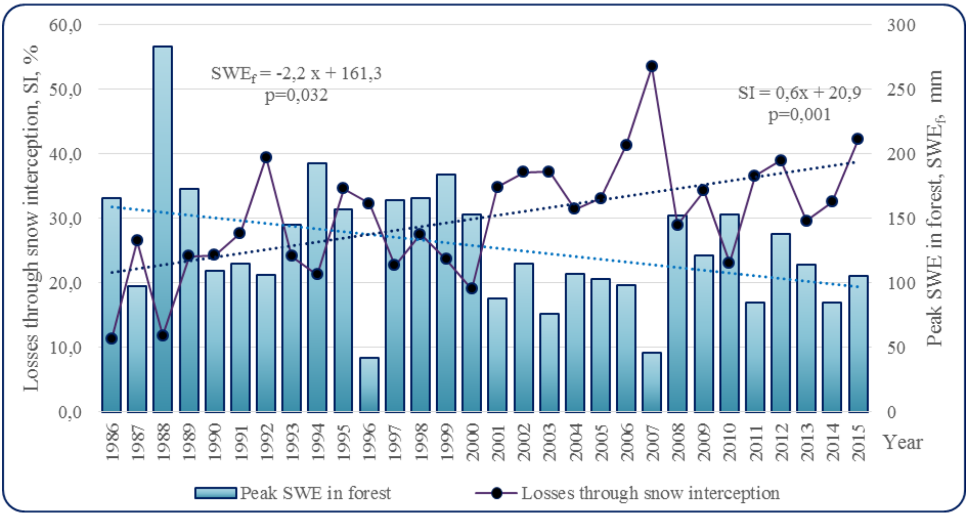
Krycklan and Climate



Above: Seasonal Regional Climate Model (RCM) simulations in Krycklan of monthly (a) P and (b) T for reference period (blue) and future climate (orange) as well as (c) monthly P-T for reference (blue) and future (orange). Black dots connected with a continuous line are observations (Teutschbein et al. 2016).

Right: One of 5 climate stations in the catchment, where the longest one has been running since 1981.



Above: Development of snow water equivalents (SWE, bars and right axis) in spruce forest and changes in losses of water through forest canopy interception (connected points, left axis). (From Kozii et al. 2017).

Key references

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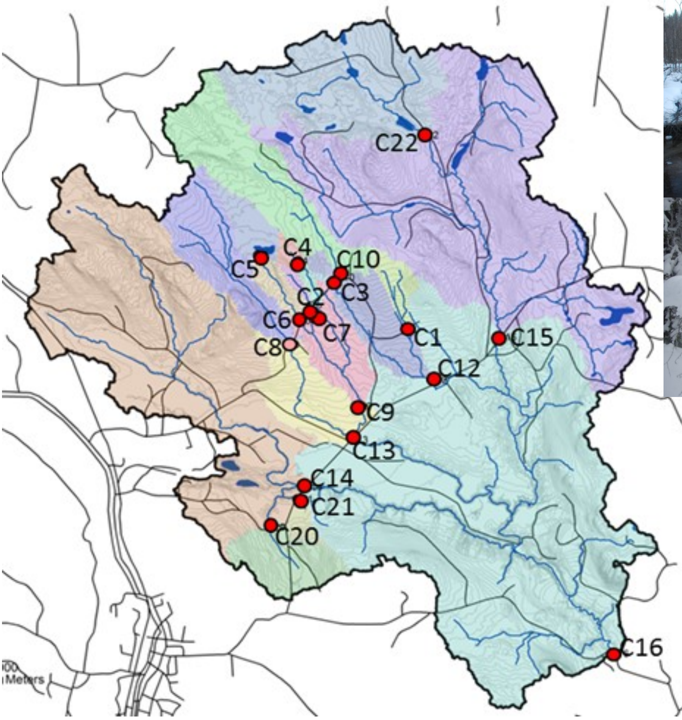
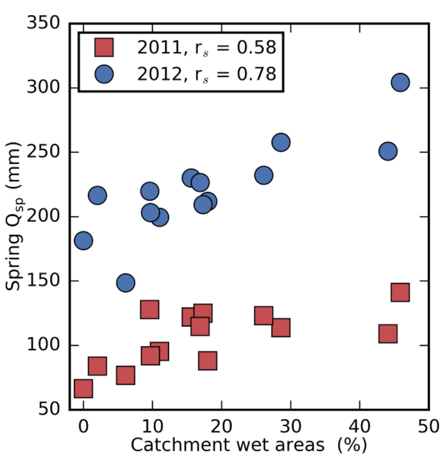
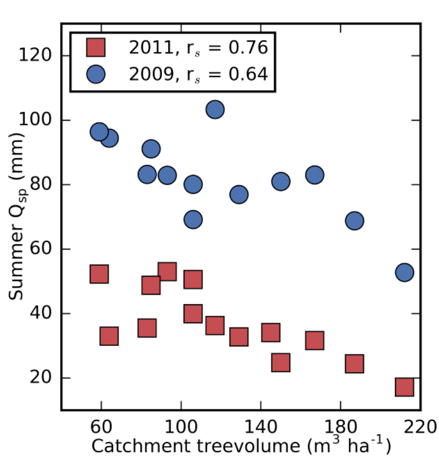
Krycklan and Hydrology

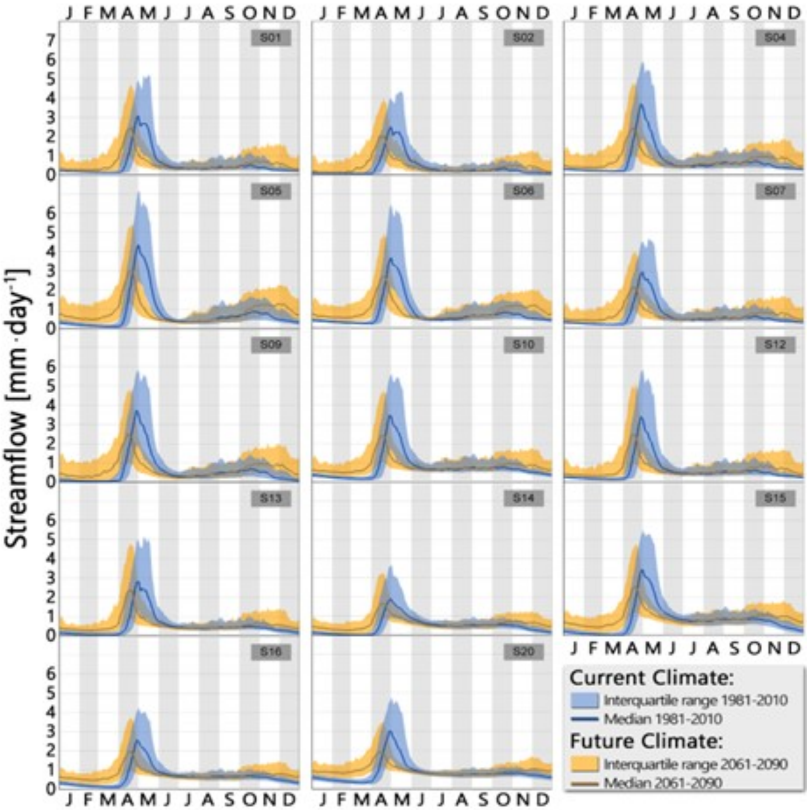


In C7 discharge has been measured since 1980 (above right), C2 and C4 from 1994 and the remaining stations from 2004. The are 18 regularly monitored water quality monitoring *stations* (above left). Six of the stations are in heated houses for year around measurements (left).

Below: Discharge in the different sub-catchments as determined by different catchment characteristics (Karlsen et al. 2016).







Above: Simulated future streamflow in 14 sub-catchments. The reference period (blue) and future (orange) climate conditions are shown. The dark curve presents the median of all simulations (Teutschbein et al. 2016).

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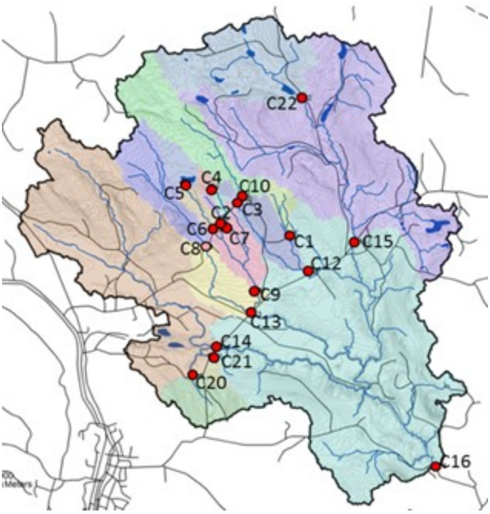
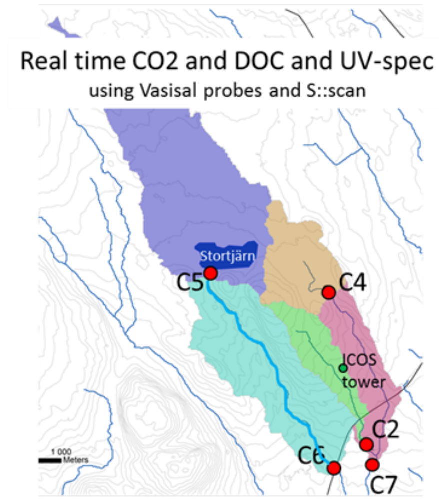
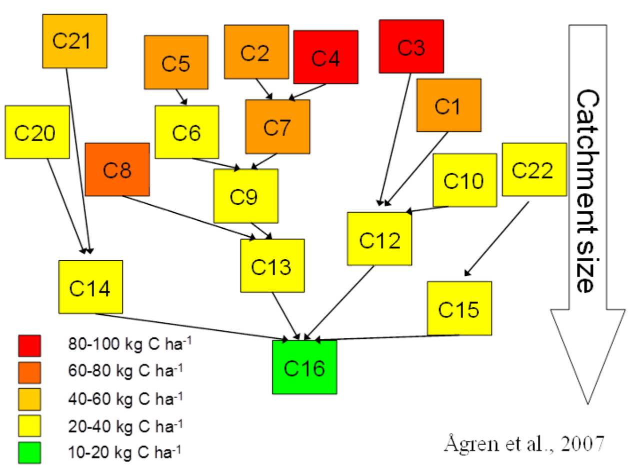
Karlsen, R. H. et al., (2016). Landscape controls on spatiotemporal discharge variability in a boreal catchment, Water Resour. Res., 52, 6541–6556, doi:10.1002/2016WR019186.

Krycklan and Stream Carbon

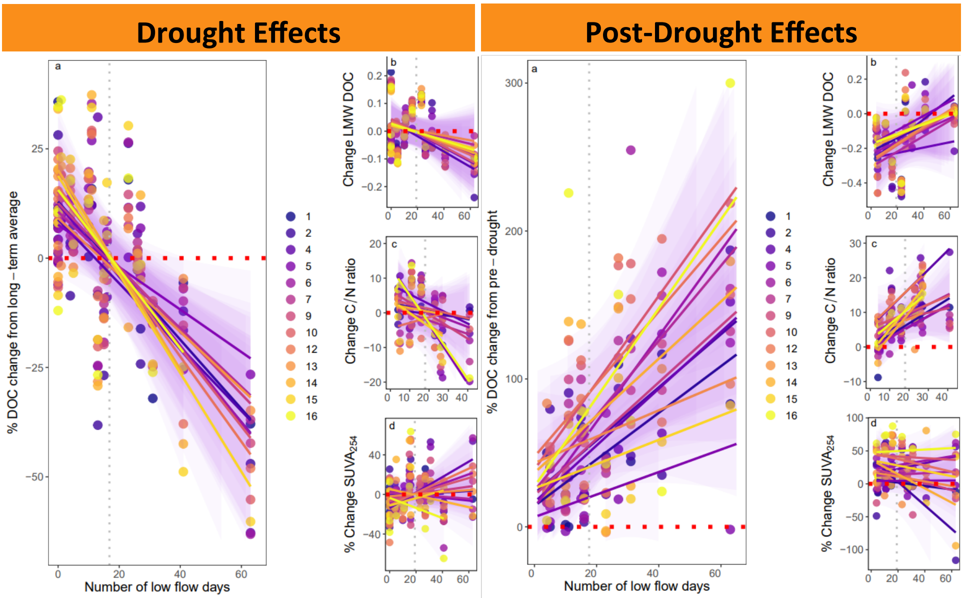




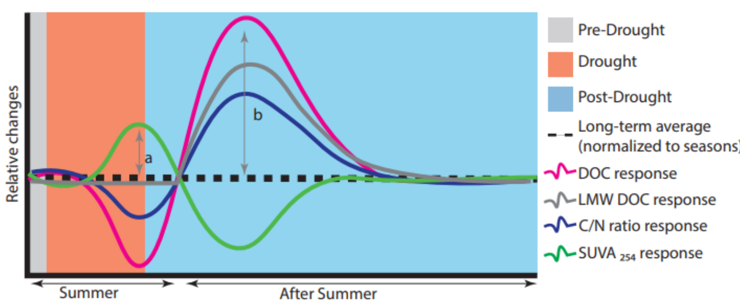
Krycklan and the stream carbon monitoring program. The grab sampling program begun 2002 and includes ~30 samples of DOC, CO_2, CH_4 and UV spec per year. The sensor network is continuously being expanded but focus on the central parts of the catchment.



Annual export of DOC from the different sub-catchments in Krycklan. Note that the export of DIC can be as large, or even larger. Here you can also see how the streams are connected.



Stream chemical responses to summer drought severity across a boreal stream network where changes in (a) DOC (b) low molecular weight DOC (LMW) (c) C/N ratio (d) SUVA $_{254}$ during drought and after drought in the Krycklan catchments (Tiwari et al 2022)



Conceptual responses of dissolved organic carbon (DOC), low molecular weight DOC (LMW DOC), carbon to nitrogen ratio (C/N ratio), and specific UV absorbance at 254 nm (SUVA254) to summer low flow conditions (Tiwari et al 2022).

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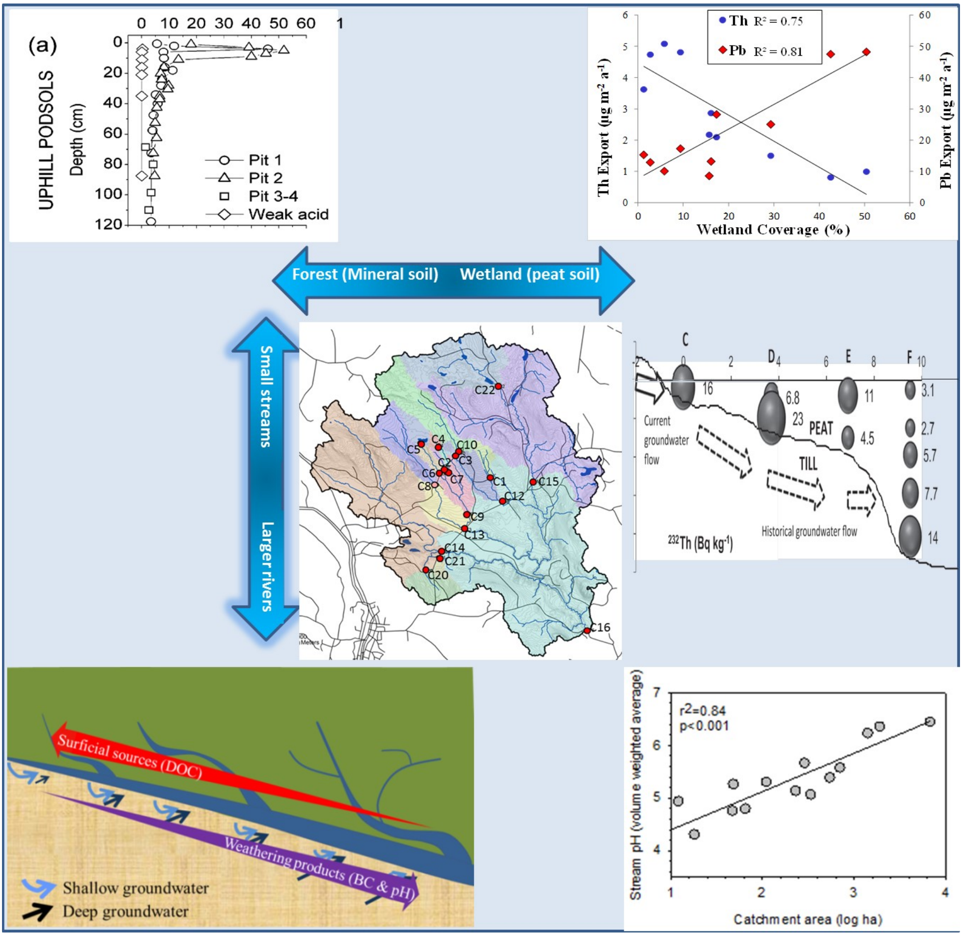
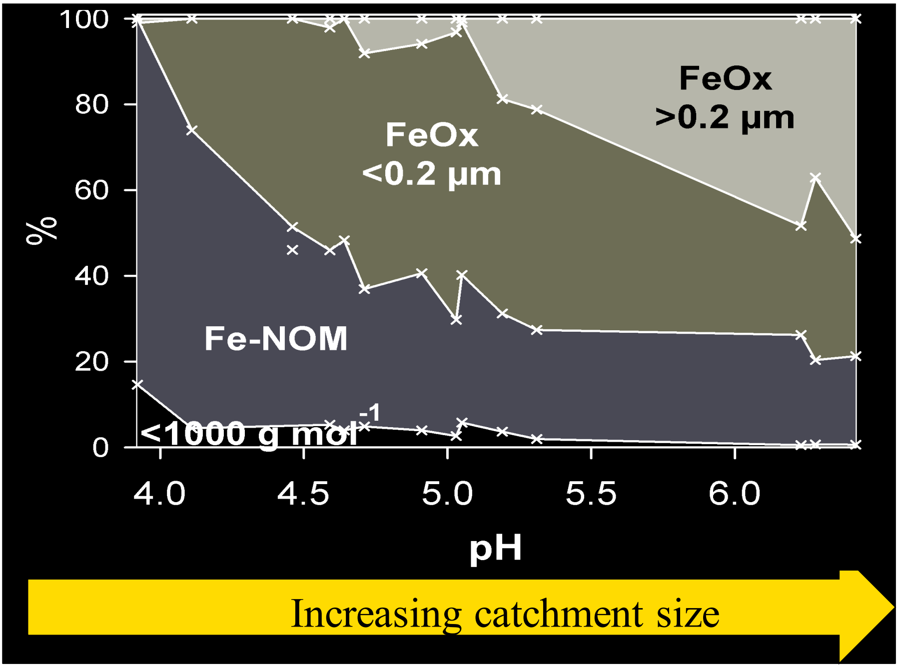
Krycklan and Biogeochemistry



The contrasting behavior of different elements in the landscape depends on 1) its affinity to organic matter and 2) the primary source of the element. For the examples above, thorium (Th) and lead (Pb) affinity to organic matter are similar but Th is a weathering product while Pb originates mainly from deposition. Similarly, another relationship can be seen with pH which increases as the catchment size increase.



Above: Iron speciation changes from the upstream low pH streams to the downstream increase in pH (Neubauer et al. 2013).

Key references

Mosquera, V., et al., (2022). Co-occurrence of browning and oligotrophication in a b oreal stream network. *Limnology & Oceanography*. https://doi.org/10.1002/l no.12205.

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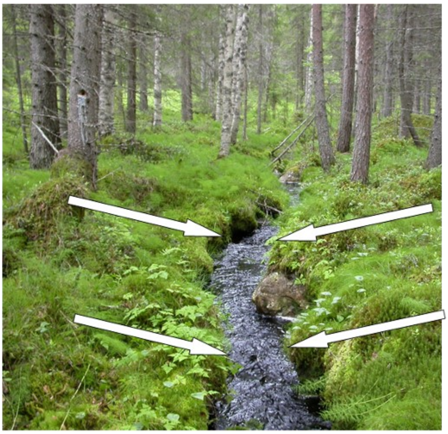
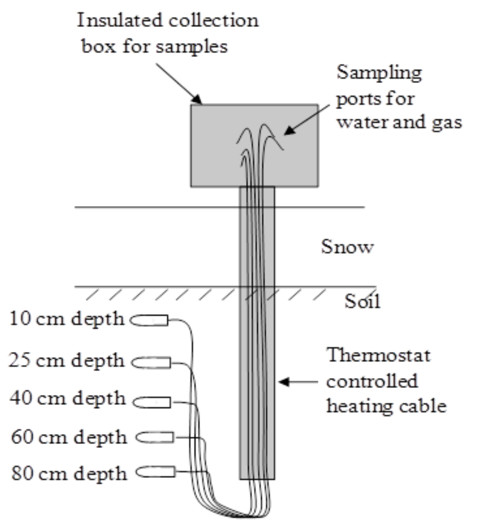
The Riparian Zone and the S-transect

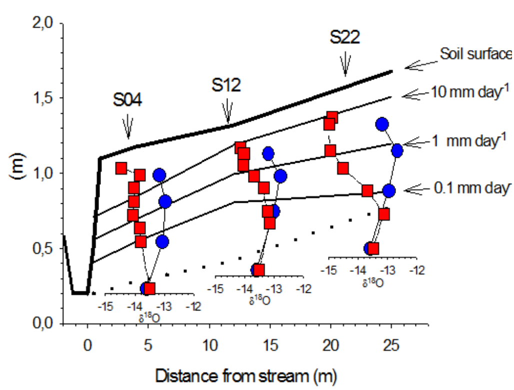


The riparian zone has a disproportional large impact on the stream biogeochemistry. Partly this is because it is the large last environment the soil water meets before becoming surface water. But this large influence also has to do with the fact that the riparian soil in the boreal region is highly organic rich, and therefore very different compared to most other soils in the catchment. The S-transect was installed 1997 and has been sampled monthly since.

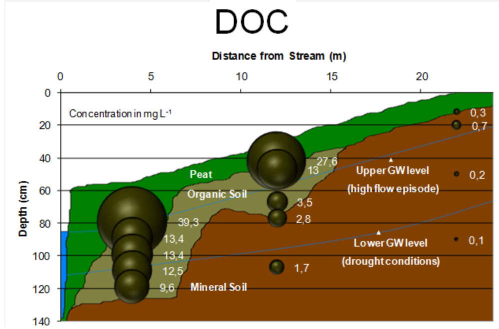
The transect consists of ceramic suction lysimeters at 5-7 depths in three plots (below): in the riparian zone 4 m from the stream (S04), 12 m from the stream (S12) and in the upslope mineral soil 22 m from the stream (S22).

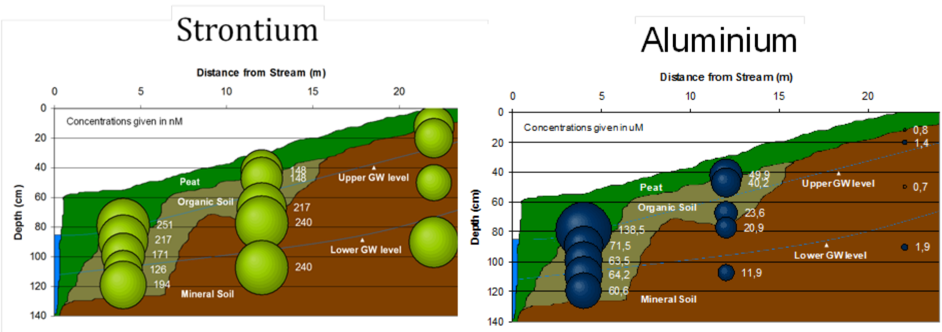
The installations are made so that samples can be collected all year by using a heating cable where the water passes through the frozen soil. The hydrology (above) is focused in the upper horizons due to the hydrological conductivity which increases exponentially towards the soil surface.





Right: Pattern of DOC in the S-transect. Note the very high concentration in the riparian zone and the much lower concentration uphill.





Above: Contrasting patterns of strontium, which has low affinity to DOC and aluminium, which has a very high affinity to DOC. Most other elements in the periodic table behave similarly depending on their DOC affinity.

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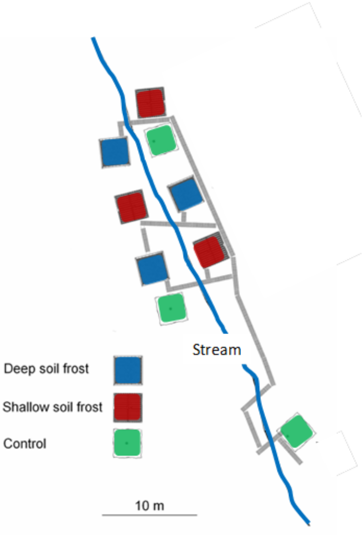
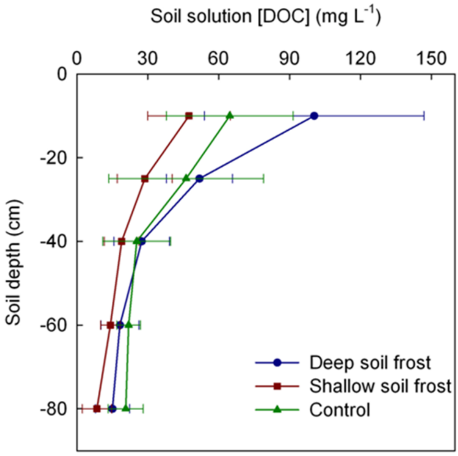
The Soil Frost Experiment

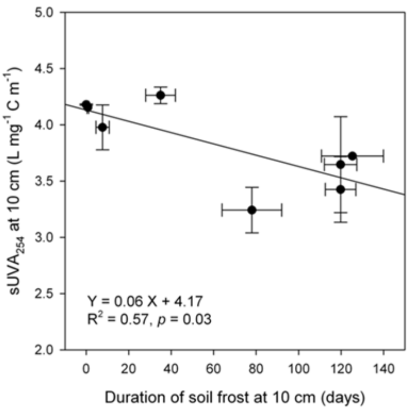


The soil frost experiment started in 2002 which makes it the longest ongoing experiment of its kind in the world. Winter conditions in the soil are strongly dependent on the timing and amount of snow. Little snow gives very cold soils, whereas early and large amounts of snow will result in "warm" soils.

Colder soils and deeper soil frost gives higher DOC concentrations in the upper soil layers

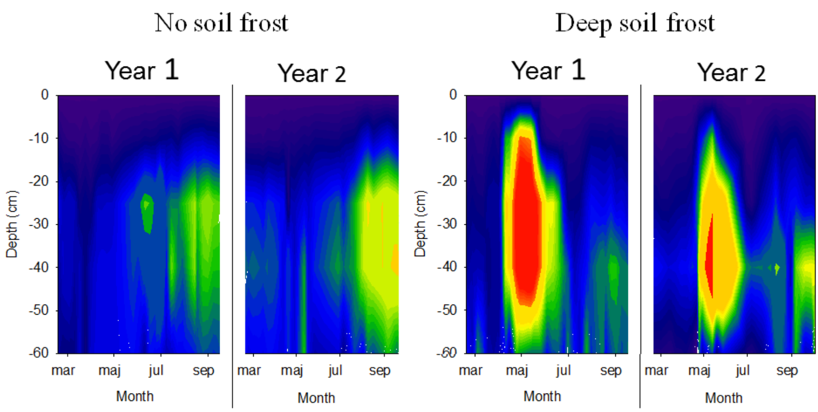
Colder soils also gives rise to higher DOC concentration in the streams during the spring flood. (From Haei et al. 2010).





Left: The DOC quality is affected negatively by the length of winter. Here it is measured as SUVA. (From Haei et al. 2011).

Below: CO_2 concentrations at different depths in the soil over two years without soil frost (left) and with extensive soil frost (right). (From Öquist and Laudon, 2008)



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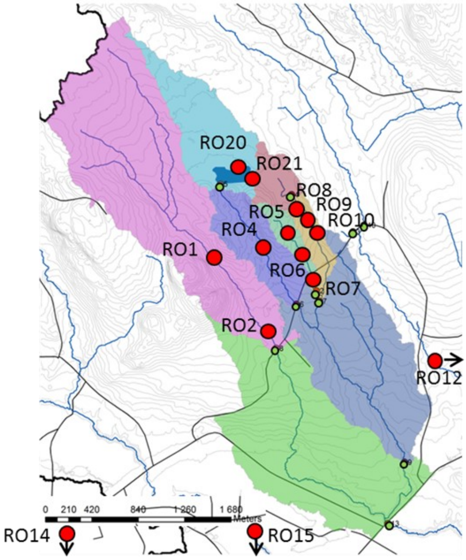
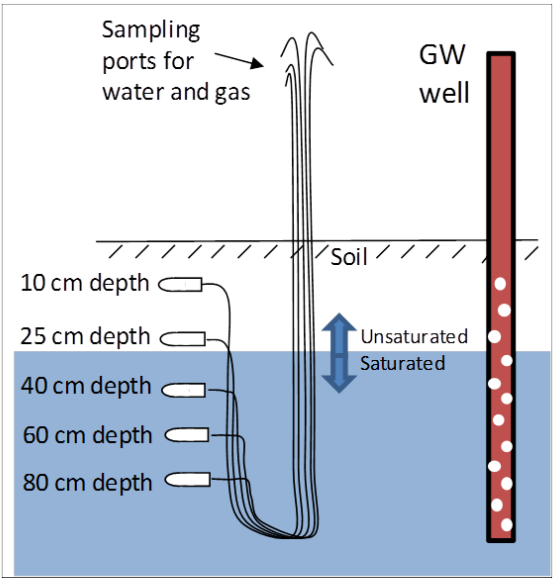
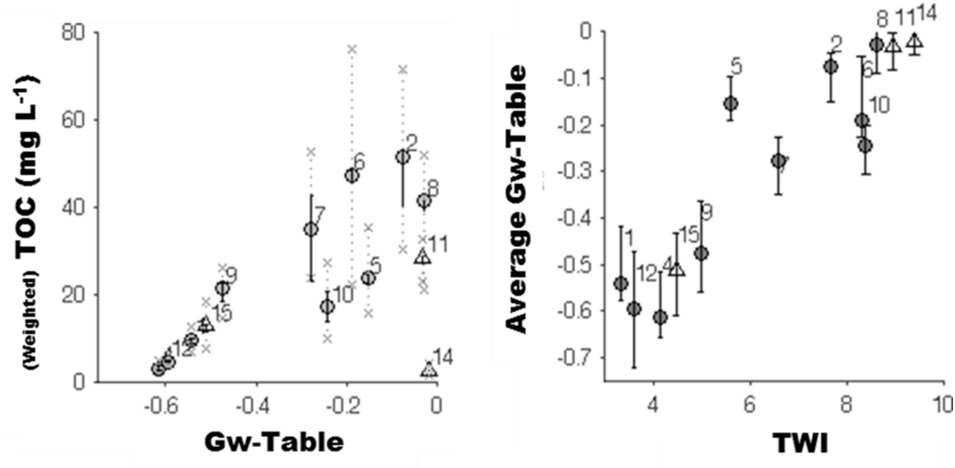
The Riparian Observatory



The riparian observatory is distributed at 20 locations in Krycklan and is designed to investigate the soil-surface water interaction in terms of hydrology and biogeochemistry. It is similar to the S-transect in design at 7 locations with transects from uphill to riparian zone.

Each of the RO sites has installations for soil water, soil gas sampling and ground-water (GW) monitoring. Seven of the sites have installations both in the riparian zone and uphill, 20-30 m away from the RO site to study the chemical evolution of water along the flow pathway.





The TOC concentration (mean weighted) is well correlated with the average groundwater table in each location (left), with the exception of RO14 which is located on sediment soils. The average groundwater table (right) is in turn strongly correlated with the TWI (topographic wetness index). As TWI can be calculated using topographic maps this is a way forward to predict TOC in the riparian soils (From Grabs et al. 2012).

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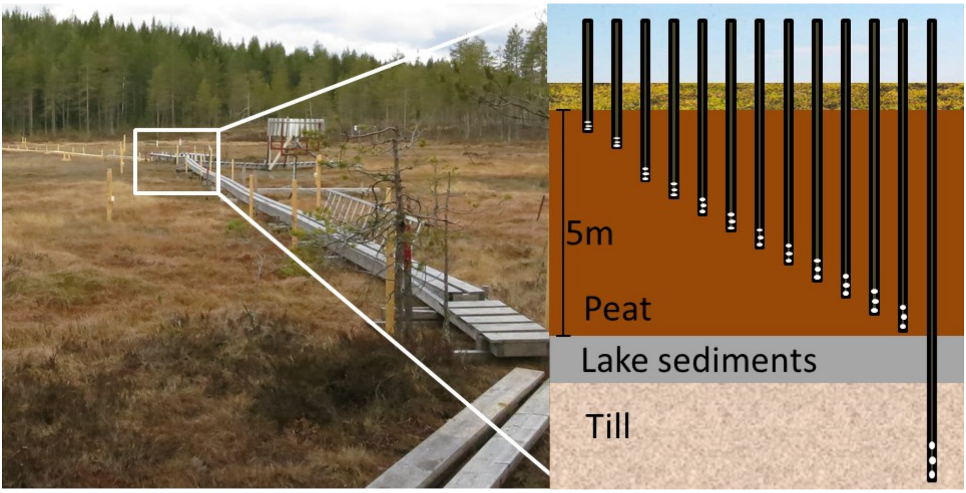
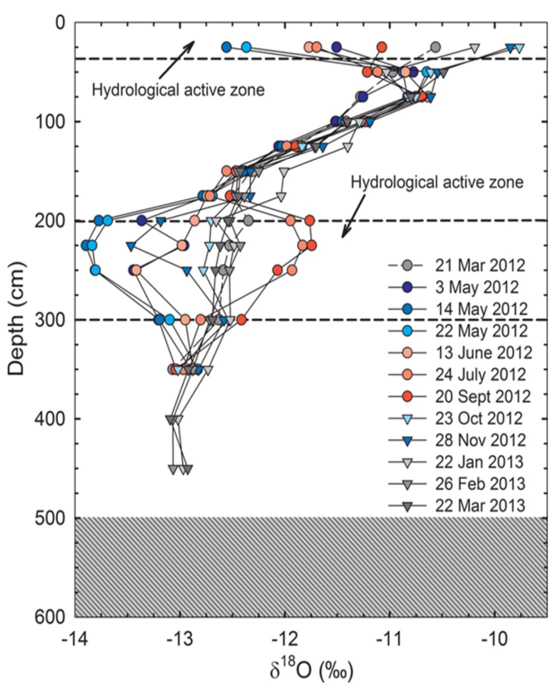
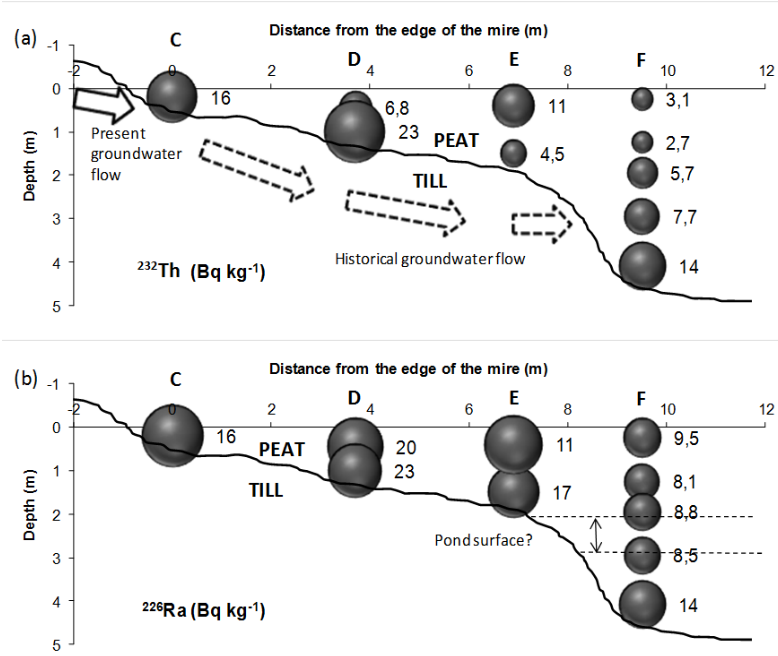
The Kallkäls Mire



The Kallkäls mire is the source area for stream C4, and the location of the "Russians wells". The "Russian wells" are a set of piezometers allowing sampling at different depth in, and below the mire.



Left: Flow pathways through the mire during spring, summer and autumn using stable isotope oxygen -18 ($\delta^{18}O$) as tracers. Note the two dominating path-ways, 1. As overland flow and 2. Through the mire at 200 to 300 cm depth at some preferential pathway (From Peralta-Tapia et al. 2015).



Profile of chemical analyses following the pathway of water as it flows from the mineral soil into the mire. Here we show the activity (concentration) of thorium (Th) (above a) which is an element with a high affinity to DOC and radium (Ra) (below b) with low affinity to DOC (From Lidman et al. 2012).

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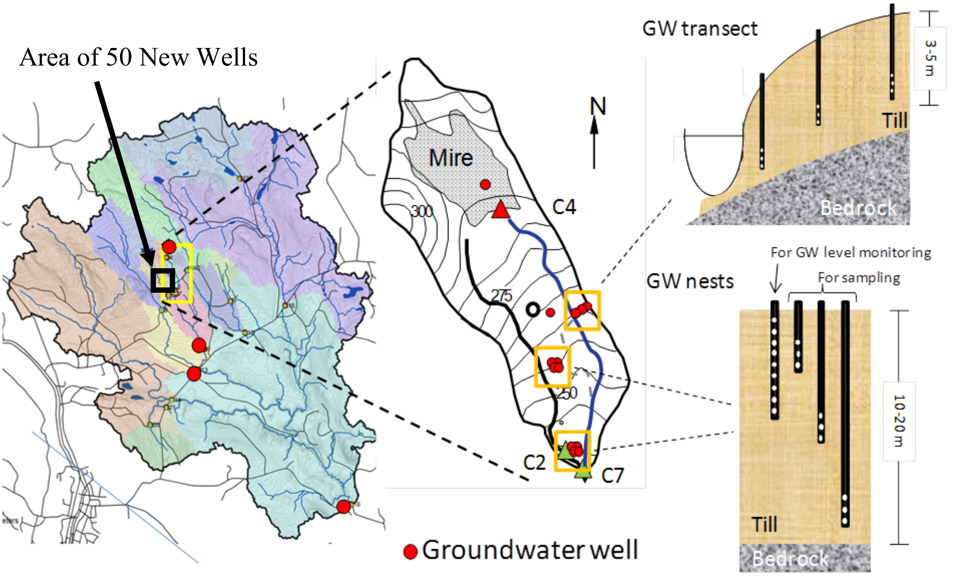
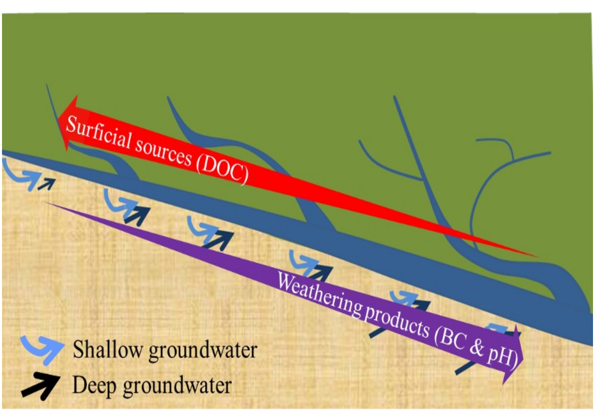
Groundwater Observatory (GO)

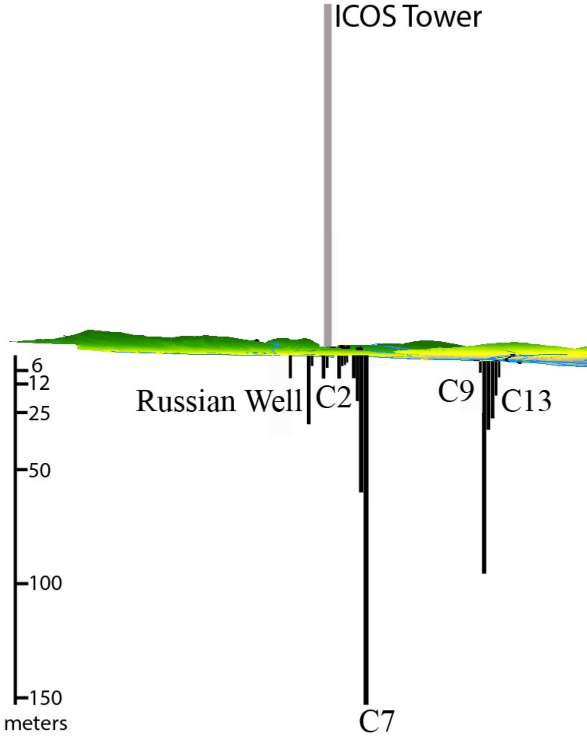


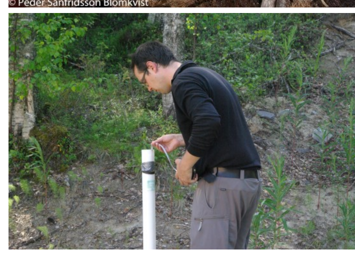
Above: Groundwater wells in Krycklan.

In total, close to 20 wells are installed spanning from 5 m to over 150 m depth. The installations were made to cover the entire catchment to investigate regional groundwater as well as allow more local studies of water pathways. The first wells were installed by the Swedish Geological Survey (SGU) in the 1980s and have been monitored since, whereas the majority was installed in 2012.



Left: Schematic figure of water flow pathway in Krycklan (Peralta-Tapia et al. 2015) showing the long travel distance for water surfacing downstream in the larger rivers.





The profile view shows the 150 m ICOS tower and major groundwater wells ranging between 5 and 153m.

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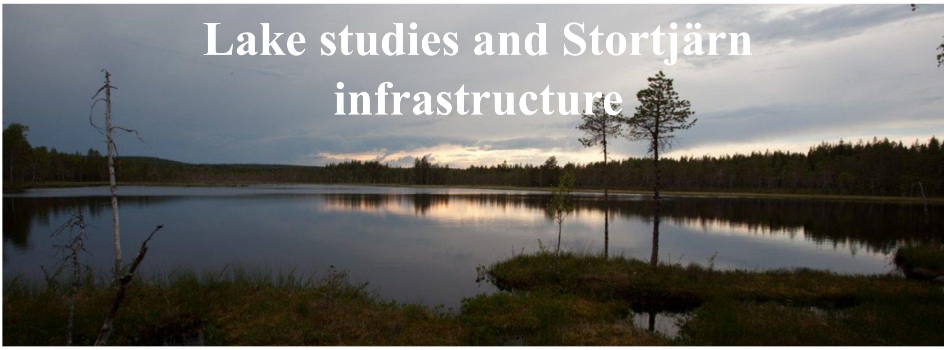
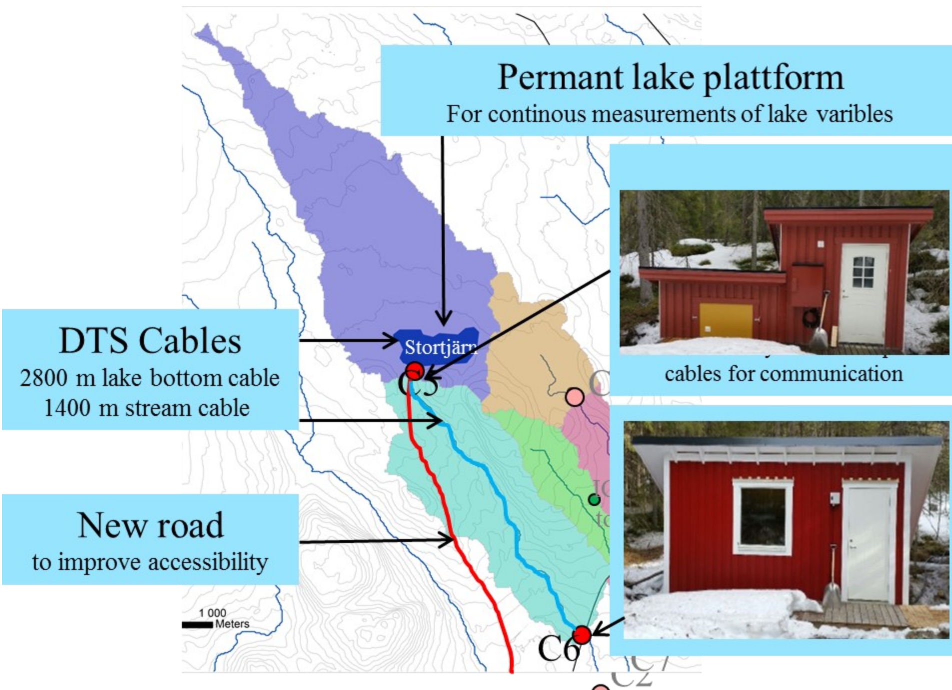
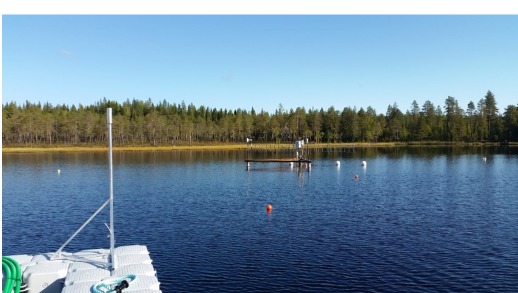
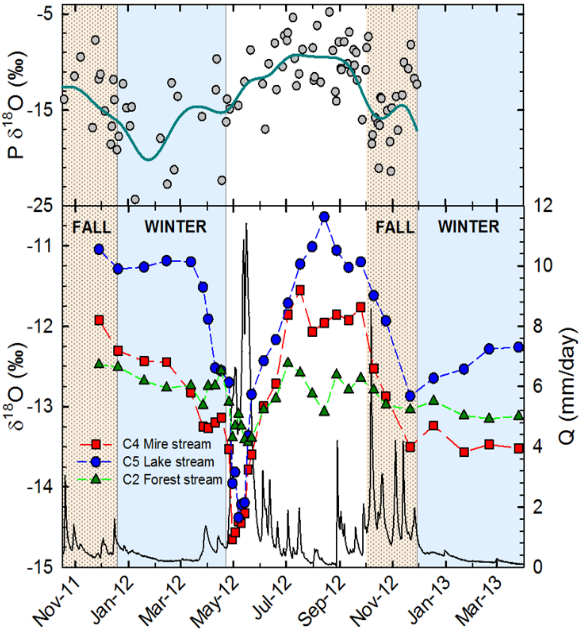
Lake studies and Stortjärn infrastructure





Lake Stortjärn is one of the most expansive research sites in Krycklan both in terms of new projects and infrastructure development.





The contrasting behavior between the lake outlet (blue C5), mire outlet (green C4) and forested stream (red C2) under a full year. Note the much larger response to snow melt and rain episodes in the lake (blue) compared to both the mire, (red) but especially the forested stream (green) (from Peralta-Tapia et al. 2015).

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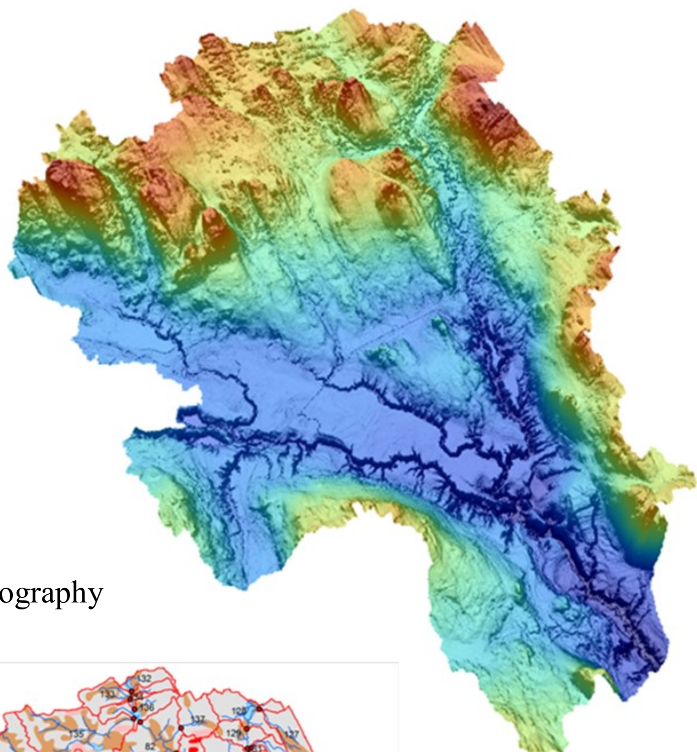
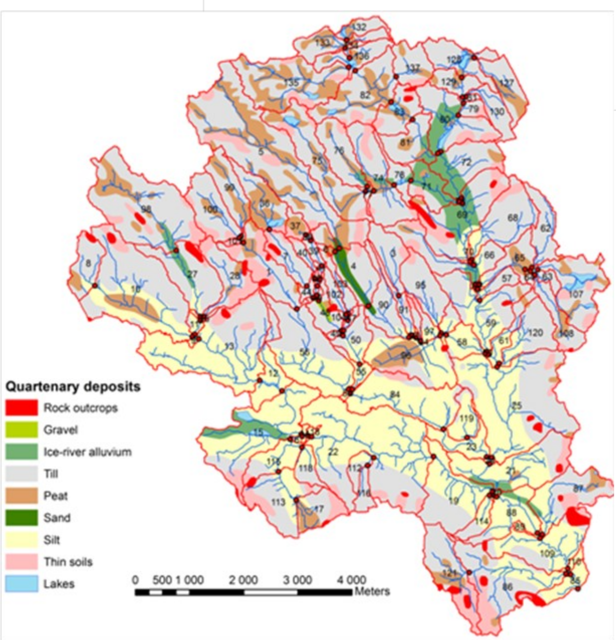
Topography, Soils and Vegetation

Based on the high resolution lidar 10, 5 and 0.5 m Digital Elevation Models (DEM) are available for the entire 68 km^2 catchcment. The survey catchments are sampled less often compared to the regular sites.

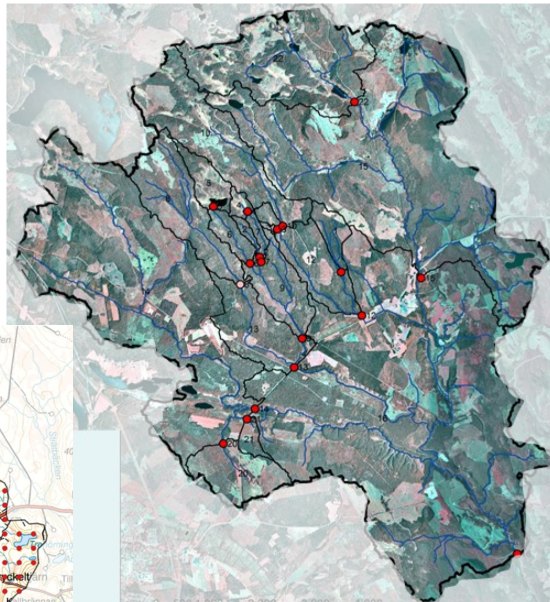


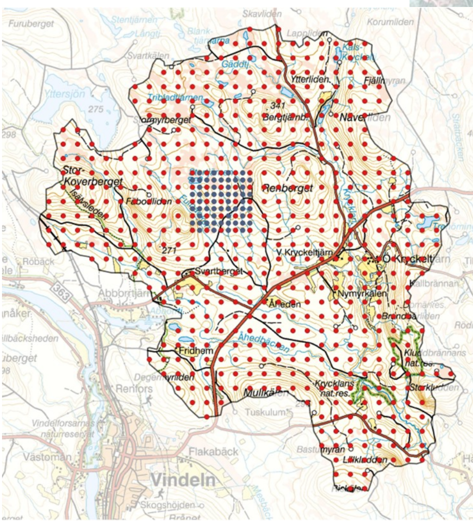
Lidar based topography



Quarternary deposits map with the 100 ”Survey locations” superimposed.

IR-ortophoto of the Krycklan catchment with the regular sites in red.





Vegetation survey (marked with black circles) carried out using the National Forest Inventory protocol with more dense survey around the ICOS tower in the center of the catchment

Key references

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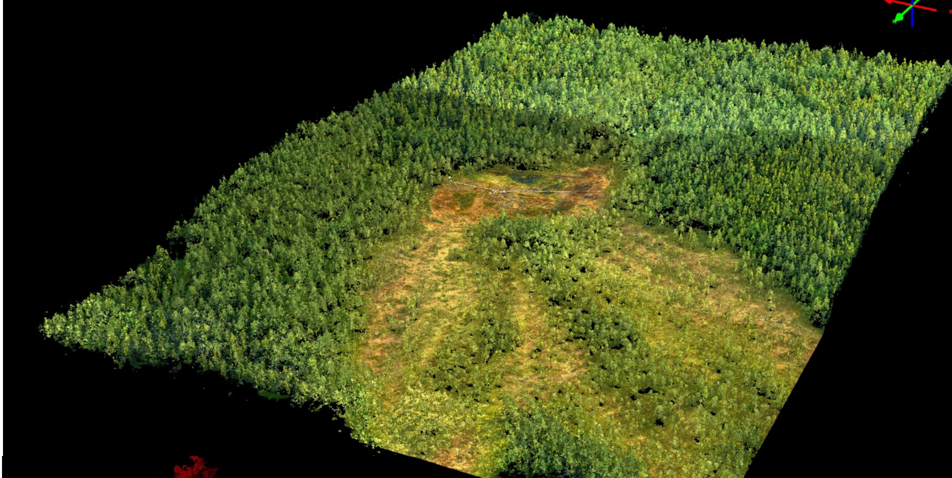
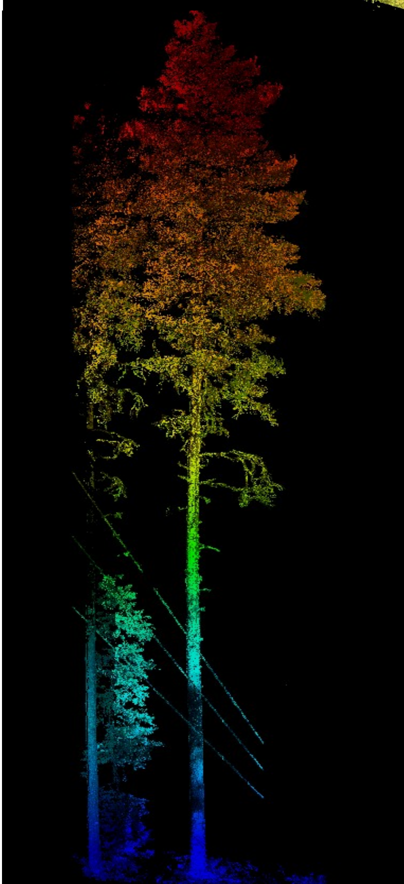
Remote Sensing in Krycklan

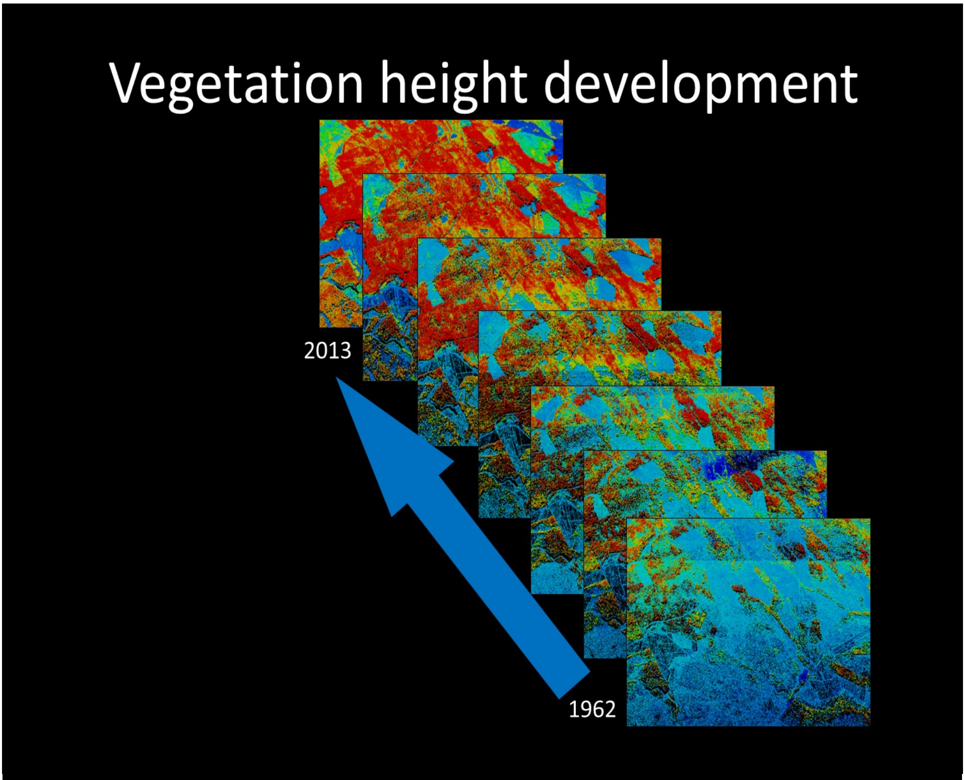
Remote sensing is currently one of the most rapidly evolving research field with the Krycklan catchment.





Above: 3D point cloud derived using stereo photogrammetry of very high resolution aerial images. This example is from the Kallkälsmyren.

Left: Example of data collected using terrestrial laser scanning using the Trimble TX8 scanner. The picture is a side-view of the three dimensional point measurements of a pine tree at the ICOS tower (note the supporting wires in the picture). Each point is color coded by the height above ground level.



Above: Aerial images of Krycklan from 1962 to 2013.

Key references

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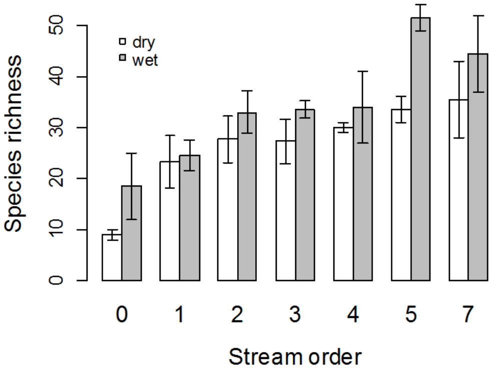
Krycklan Stream and Plant Ecology

A number of stream and riparian ecology studies have been conducted related to plants, fish and invertebrates in aquatic, terrestrial riparian ecosystems.



These results are now a basis for the new SEPA liming guidelines.Above: Riparian Zone plant species diversity in dry and wet locations along streams ranging from hollows (zero order streams) in Krycklan to the Vindeln River (7 order stream) (Kuglerová et al. 2014).

Key references

Kuglerová, L., et al., (2021). Multiple stressors in small streams in the forestry con text of Fennoscandia: The effects in time and space. Science of the Total Environment, https://doi.org/10.1016/j.scitotenv.2020.143521

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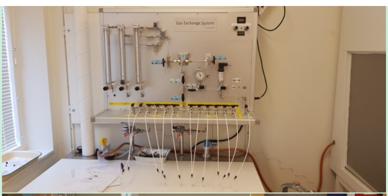
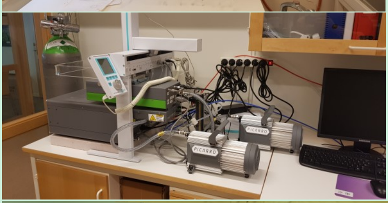
Hydrology and Biogeochemistry Lab

Krycklan is supported by a state of the art Lab that is equipped with standard instruments for analyzing approximately 2500 samples per year in soil and water chemistry following standard operating procedures.

Some of the facilities available includes:

Storage– Cool room
Dry room
Freezers for long-term storage





Analysis-

Isotopes and Gas Analyser
Titrator-pH and conductivity
Aqualog-florescence and absorbance
Shimadzu TOC-VPCH analyzer
Gas Chromatography
Fume Hoods
MQ water

Database– An active database that updates current analysis onto the **Svartberget data-portal** for easy data sharing possibilities and long-term storage possibilities.

www.slu.se/krycklan

Data includes : Stream Chemistry,
Climate,
Flux measurements,
Hydrological Loggers,
Groundwater chemistry,
Precipitation Chemistry


SLU





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Krycklan - A brief history

Research in Krycklan started over 100 years ago with the study of paludification effects on forest growth. In the 1970's, the Svartberget field station was established. Research then was focused more on forest hydrology and biogeochemical cycling. During the 1990's, a decade of more intensive work on the role of acid deposition on stream water chemistry contributed to new views of anthropogenic acidification and natural acidity in organic carbon-rich boreal waters. In recent years, the research scope expanded substantially to include more work on biogeochemistry, carbon cycling, hydrology and ecology. More intensive research also began on the connections between soils and surface waters, leading to a process-based understanding of the regulation of stream water chemistry.

Recognition of the need to work at the landscape scale when addressing climatic influences on aquatic ecology led to the expansion of the Svartberget catchment from 50 ha to the 6800 ha Krycklan catchment in 2002. This has further increased the research scope to include both fundamental research questions as well as management issues that are currently addressed.

In recent years, Krycklan has transformed into a unique experimental platform for testing pure and applied research questions in a natural environment. The platform continuously attracts new scientific projects as well as directly collaborates with the Swedish Nuclear Waste Program, Swedish EPA, Sveaskog and others.

Krycklan would not be possible without the excellent support from the field and laboratory crew.

Read more and access data at www.slu.se/Krycklan.

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