Report on national ICP IM activities in Sweden 2019

Lundin, L.[1], Löfgren, S.[1], Rönnback, P.[1], Bovin, K.[2], Eveborn, D[2]., Grandin, U.[1], Jutterström, S.[3], Pihl Karlsson, G.[3], Moldan, F.[3] and Thunholm, B[2].
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[1] Swedish University of Agricultural Sciences (SLU), Department of Aquatic Sciences and Assessment, Box 7050, SE–750 07 Uppsala, Sweden, e-mail: pernilla.ronnback@slu.se
[2] Geological Survey of Sweden (SGU), Box 670, SE–751 28 Uppsala, Sweden.
[3] Swedish Environmental Research Institute (IVL), Box 47086, SE–402 58 Gothenburg, Sweden.

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Introduction

The Swedish integrated monitoring programme is run on four sites distributed from south central Sweden (SE14 Aneboda), over the middle part (SE15 Kindla), to a northerly site (SE16 Gammtratten). The long-term monitoring site SE04 Gårdsjön F1 is complementary on the inland of the West Coast and has been influenced by long-term high deposition loads. The sites are well-defined catchments with mainly coniferous forest stands dominated by bilberry spruce forests on glacial till deposited above the highest coastline. Hence, there has been no water sorting of the soil material. Both climate and deposition gradients coincide with the distribution of the sites from south to north (Table 1).

Table 1. Geographic location and long-term climate and hydrology at the Swedish IM sites (long-term average values, 1961–1990).

	SE04	SE14	SE15	SE16
Site name	Gårdsjön F1	Aneboda	Kindla	Gammtratten
Latitude; Longitude	N 58° 03′; E 12° 01′	N 57° 05′; E 14° 32′	N 59° 45′; E 14° 54′	N 63° 51′; E 18° 06′
Altitude, m	114–140	210–240	312–415	410–545
Area, ha	3.7	18.9	20.4	45
Mean annual temperature, °C	+6.7	+5.8	+4.2	+1.2
Mean annual precipitation, mm	1000	750	900	750
Mean annual evapotransporation, mm	480	470	450	370
Mean annual runoff, mm	520	280	450	380

The forest stands are mainly over 100 years old and at least three of them have several hundred years of natural continuity. Until the 1950's, the woodlands were lightly grazed in restricted areas. In early 2005, a heavy storm struck the IM site SE14 Aneboda. Compared with other forests in the region, however, this site managed rather well and roughly 20–30% of the trees in the area were storm-felled. In 1996, the total number of large woody debris in the form of logs was 317 in the surveyed plots, which decreased to 257 in 2001. In 2006, after the storm, the number of logs increased to 433, corresponding to 2711 logs in the whole catchment. In later years, 2007–2010, bark beetle (*Ips typographus*) infestation has almost totally erased the old spruce trees. In 2011 more than 80% of the trees with a diameter at breast height over 35 cm where dead (Löfgren et al. 2014) and currently almost all spruce trees with diameter of ≥20 cm are dead. Also at SE04 Gårdsjön F1, considerable natural processes have influenced the forest stand conditions during later years, with increasing number of dead trees due to both storm felling and bark beetle infestation. Occasionally, access to the site is hampered due to fallen trees, creating a need for chain saw cleaning of foot paths. Also in SE15 Kindla, an increasing number of fallen trees and logs exert perturbation, forming gaps in the forest.

In the following, presented results mainly relate to 2019 and include climate, hydrology and water chemistry as well as some ongoing work at the four Swedish IM sites (Löfgren, 2020).

Climate and Hydrology in 2019

Based on long-term (1961-1990) mean values from the Swedish Meteorological and Hydrological Institute (SMHI), and measured data from climate monitoring in the IM sites, the 2019 annual mean temperatures were 1.1-1.3 ºC higher for all four sites. Largest deviation occurred at the southern site SE14 Aneboda. Compared with the on-site measured time series, 19 years at site SE16 Gammtratten and 23 years at the other sites, the temperatures in 2019 were somewhat higher at three sites with 0.2 and 1.3 ºC. SE15 Kindla had lowest difference. The most northern site SE16 Gammtratten showed a 0.3 ºC lower mean temperature in 2019 compared to the long-term series. The annual mean values were only slightly lower compared to the period 2014–2016 when temperatures were the highest observed for the whole measurement period with exception for SE15 Kindla where the temperature was slightly higher in the years 1999 and 2000. The variations between years have been considerable, especially for the last nine years, over 3°C at three of the sites. Smaller variations, only 1.4°C, were found at the central site SE15 Kindla. Low temperatures were observed in the years 2010 and 2012 with 1.7–2.1 ºC below the 23 years average at three sites, while SE15 Kindla only deviated with 0.9 ºC below the series mean. Higher temperatures were observed for the months January to April and December for all sites. Similar conditions were noticed the previous year 2018. However, the winter temperatures at the two northern sites were still below 0°C.

Compared to the SMHI long-term average values (1961–1990), the precipitation amounts in 2019 were higher in the two southern sites with 20% and 29% at SE04 Gårdsjön and SE14 Aneboda, respectively. In SE15 Kindla the amount was exact on the long-term mean while SE16 Gammtratten showed 20% lower precipitation compared with mean. This deviated from 2018 when all sites had lower amounts compared to the long-term mean. Distribution over months showed low values in summer apart from SE14 Aneboda with slightly more rain than usual. Apart from SE16 Gammtratten with lower values, the autumn months September to December exhibited larger precipitation compared with the long-term averages.

The characteristic annual hydrological patterns of the southern catchments are high groundwater levels during winter and lower levels in summer and early autumn. At the northern locations, the general picture is low groundwater levels in winter when precipitation is stored as snow, raising levels at spring snowmelt followed by lower levels in summer due to evapotranspiration and groundwater outflow. However, depending on rainfall events in summer and/or autumn, the groundwater levels could occasionally be elevated also during these periods. In 2019, the two sites SE14 Aneboda and SE16 Gammtratten started the year on low levels while site SE15 Kindla had fairly high groundwater levels. Spring snowmelt and rain at SE14 Aneboda, elevated the groundwater levels in Maj-June. For SE16

Gammtratten evapotranspiration together with groundwater flow lowered the levels in late summer. Autumn rains turned the groundwater levels close to ground surface at one of the two stations in SE14Aneboda and also at SE15 Kindla. The upslope station located in a well-drained slope at SE14 Aneboda had the same groundwater level pattern, but this level never reached above one meter below ground surface. At SE15 Kindla, the groundwater level generally varies in the range 0.2-0.8 m below ground surface, but the soils and piezometer location is sensitive to rain causing larger temporal variations. This deviates especially from SE16 Gammtratten piezometer site, where smooth groundwater level variations dominate at depths of 2-3 m below ground surface. The 1m depth is only reached during snowmelt, while the autumn showed small elevation dependent on few rainfall events and later also as precipitation accumulated as snow until next spring snowmelt. Compared with 2018, the groundwater levels were in general higher at all sites. Only SE15 Kindla showed almost normal levels, but the lowest groundwater level stayed at 0.8 m which was considerably higher compared with 1.5 m in 2018. The groundwater levels in 2019 were more similar to those observed in 2016-2017.

The groundwater levels were reflected in the stream water discharge patterns (Fig. 1).

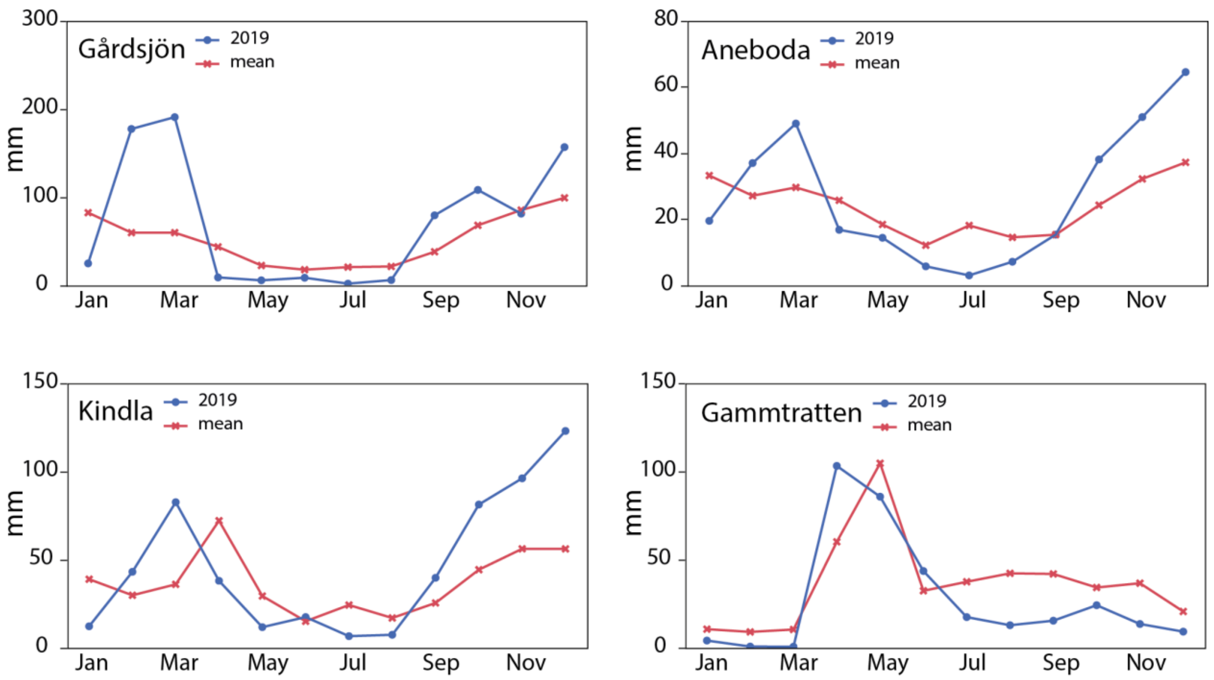

Figure 1. Monthly discharges at the four Swedish IM sites in 2019 compared with the monthly averages for the period 1996–2019 (mean). Note the different scales at the Y-axis.

Precipitation, evapotranspiration and groundwater levels affect the runoff patterns. The runoff pattern for SE16 Gammtratten 2019 was fairly typical with a snowmelt peak in April and May and lower discharges in summer and autumn but with a small peak in October before low temperatures caused snowfall and snow accumulation. Noticed was an earlier snowmelt peak compared with 2018 and the long-term pattern. At SE04 Gårdsjön, the pattern deviated from the long-term mean with high discharge in February-March not observed in 2018. In summer and autumn 2019 the discharges were similar to mean with increasing discharges from September to December. Runoff at SE15 Kindla showed an early snowmelt peak in March and comparably low summer runoff. Autumn rains increased the discharges from September to December, reaching higher levels than usual at the end of the year. In 2019, SE14 Aneboda showed similar runoff pattern as SE15 Kindla with a peak runoff in March, low discharge in summer with no runoff during a short period in July, whereafter runoff increased (Fig. 1).

At the two northern sites, generally, snow accumulates during winter, resulting in low groundwater levels and low stream water discharge. However, warm winter periods with temperatures above 0 °C have during a number of years contributed to snowmelt and excess runoff also during this season. In December 2019, only the most northern site SE16 Gammtratten had low flows while the other sites showed high runoff (Fig. 1). In January, runoff was low at the two most northern sites, but the flow started to increase already in February at SE15 Kindla. The 2018 runoff patterns deviated somewhat from this pattern with low runoff throughout the year and especially during summer and autumn. In spring, normal levels with snowmelt peaks occurred.

In 2019, the annual runoff made up 44–69% of the annual precipitation (Table 2), which is similar compared to the normal 40–60%. The highest value belongs to SE04 Gårdsjön, which had similar values in 2018 and 2017 when the proportion was 64% and 63%, respectively. The reason is high runoff in the end of the year when evapotranspiration is low. At SE04 Gårdsjön, it is quite normal that runoff constitutes almost 2/3 of the precipitation. At SE14 Aneboda, storm felling, followed by bark beetle attacks, have reduced the forest canopy cover, inducing low interception. For 2019, the total evapotranspiration was estimated to 409 mm, which is within the range of previous years with 477 mm in 2017 and 349 mm in 2016. In 2018, the evapotranspiration was much lower with 179 mm. Low precipitation and dry conditions contributed to this low evapotranspiration 2018. In 2016 and 2018, the annual runoff range was wider than usual and made up 31–83% of the annual precipitation at the four sites.

Table 2. Compilation of the 2019 water balances for the four Swedish IM sites.
P – Precipitation, TF – Throughfall, I – Interception, R – Water runoff

	Gårdsjön SE04		Aneboda SE14		Kindla SE15		Gammtratten SE16	
	mm	% of P	mm	% of P	mm	% of P	mm	% of P
Bulk precipitation, P	1240	100	731	100	1072	100	618	100
Throughfall, TF	991	80	715	98	1052	98	581	94
Interception, P–TF	248	20	16	2	20	2	37	6
Runoff, R	851	69	322	44	559	52	330	53
P–R	389	31	409	56	513	48	287	47

At SE15 Kindla, the 2019 water balance was influenced by relatively high precipitation, resulting in normal distribution between evapotranspiration and runoff, 48% and 52%, respectively. In 2018, evapotranspiration was 56% and runoff 44%. At the northern site SE16 Gammtratten, throughfall and bulk precipitation were fairly similar with 94% throughfall. Similar pattern was observed during several years. Presumably, snow deposition infers large uncertainties, resulting in erroneous estimates of especially bulk precipitation. A nearby SMHI station reports higher precipitation, generating more realistic evapotranspiration. However, both evapotranspiration and runoff were reasonable related to precipitation in 2019. In summary and based on the estimated evapotranspiration (P-R), it seems that the very dry summer 2018 furnished low evapotranspiration at all four sites. The year 2019 showed more reasonable evapotranspiration (Table 2).

Water chemistry in 2019

Low ion concentrations in bulk deposition (electrolytical conductivity 1–2 mS m^{-1}) characterise all four Swedish IM sites. The concentrations of ions in throughfall, including dry deposition, were higher at the three most southern sites. At the northern site SE16 Gammtratten, the conductivity in throughfall (0.8 mS m^{-1}) was almost the same as in bulk deposition indicating very low sea salt deposition and uptake of ions by the trees. At the two most southern sites, sea salt deposition provides tangibly higher ion concentrations, especially at the west coast SE04 Gårdsjön site (4.0 mS m^{-1} in throughfall).

The groundwater pathways are fairly short and shallow in the catchments, providing rapid soil solution flow paths from infiltration to surface water runoff. However, the conductivity in soil water was higher compared to throughfall showing influences from evapotranspiration and soil chemical processes. The deposition acidity has during the last 10 years been rather similar at all sites with somewhat higher pH values (0–0.3 units) in throughfall compared with bulk deposition. In 2019, however, SE04 Gårdsjön, SE15 Kindla and SE16 Gammtratten had similar pH (5.1-5.3) in both bulk deposition and throughfall. The site SE14 Aneboda had 0.3 pH units higher pH in throughfall compared with in bulk deposition (Table 3).

Table 3. Mean deposition chemistry values 2019 at the four Swedish IM sites. S and N in kg ha^{-1} yr^{-1}.

	SE04	SE14	SE15	SE16
pH, bulk deposition	5.0	5.1	5.3	5.1
pH, throughfall	5.2	5.4	5.3	5.2
S, bulk deposition	3.4	1.8	2.4	0.8
N, bulk deposition	8.7	5.7	5.6	2.0

During the soil solution passage through the catchment soils, organic acids were added and leached on its way to stream runoff. In the upslope recharge areas, pH in soil water in the upper soil layers (E-horizon) was mainly lower than in throughfall with about 0.6 pH-units for the three southern sites. SE16 Gammtratten had the lowest pH-value in soil water with 3.8, being 1.4 units lower compared with throughfall. However, in the organic rich discharge areas at SE15 Kindla and SE16 Gammtratten, pH was higher in soil solution compared with throughfall while the opposite occurred at SE14 Aneboda and SE04 Gårdsjön.

In the recharge areas, the buffering capacity in soil water and groundwater varied between negative and positive values, but were most frequently on the negative side, especially for SE14 Aneboda with -0.08 mEq L^{-1}. This may be an effect of nitrification. In the discharge areas, the buffering capacity in groundwater was considerable with 0,07 mEq L^{-1}. In groundwater at SE15 Kindla, ANC was high with 0.21 mEq L^{-1} while SE04 Gårdsjön and SE16 Gammtratten showed lower values with 0.03 and 0.05 mEq L^{-1}, respectively and being lower compared with SE14 Aneboda. Bicarbonate (HCO_3) occurred at SE15 Kindla and SE16 Gammtratten, but not at SE14 Aneboda and possibly not at SE04 Gårdsjön. The latter is not measured but indicated by the very low pH of 4.4.

The stream waters were acidic with pH values below 4.7 at all sites except SE16 Gammtratten having a pH of 5.6. The stream water buffer capacity was positive at all sites (ANC $\geq$ 0.035 mEq L^{-1}), however close to zero at SE15 Kindla (ANC $\approx$ 0.001 mEq L^{-1}). Anions of weak organic acids and bicarbonate alkalinity contributed to the positive ANC (0.1 mEq L^{-1}) at

SE16 Gammtratten. At SE15 Kindla and SE04 Gårdsjön, the stream waters were more acidic compared with the other two sites probably due to oxidation of organically bound sulphur related to the legacy from earlier sulphur deposition.

The share of major anions in bulk deposition was similar for sulphate, chloride and nitrate at three of the sites, while chloride dominated at SE04 Gårdsjön due to the proximity to the sea. Sea salt showed clear influences on throughfall at SE04 Gårdsjön and also at SE14 Aneboda indicating effects of dry deposition. In throughfall, organic anions contributed significantly at all four sites. The chemical composition changed along the flow paths through the catchment soils and e.g. the sulphate concentrations were higher in stream water compared with deposition, indicating desorption or mineralization of previously accumulated sulphur in the soils. For Aneboda, nitrification have contributed to relatively high nitrate values in the recharge area soil water (0.05 mEq L^{-1}), however, values turning rather low in 2019 with concentration only 0.012 mEq L^{-1}. Lower concentrations occurred in the discharge areas, probably due to nitrogen uptake and denitrification.

At site SE16 Gammtratten in the north, sulphate concentrations in soil water and stream water were considerably higher compared to throughfall, indicating release from the soil pool. Organic anions and HCO_3^- dominated the stream water anion flow (2/3 of the anions) to be compared with 1/3 at SE15 Kindla and 1/6 at SE14 Aneboda and SE04 Gårdsjön.

Base cation relations indicate soil and soil water processes. In deposition, Na^+ dominated the base cations for all sites. This was valid also in stream water except for at the northern site SE16 Gammtratten where Ca^{2+} showed the highest concentrations. At sites SE04 Gårdsjön and SE14 Aneboda, Cl^- concentrations were similar with Na^+ while Na^+ dominated at the other two sites. A higher outflow of Na^+ compared to Cl^- in stream water indicate weathering of minerals and release of base cations. Mg^{2+} was the second highest base cation in runoff water at SE04 Gårdsjön, also a result of the marine influence, while Mg^{2+} and Ca^{2+} were quite equal at the other three sites.

Besides effects on ANC and pH, the stream water chemistry was to a considerable extent influenced by organic matter. At SE14 Aneboda, the DOC concentration was high with 28 mg L^{-1} while SE04 Gårdsjön showed 17 mg DOC L^{-1} and the two northern sites had ca 10 mg DOC L^{-1}. High DOC concentrations create prerequisites for metal complexation and transport as well as high fluxes of organic nitrogen. This was the dominating nitrogen fraction in all stream waters, ranging from 0.21 to 0.67 mg N_{org} L^{-1}. The shares of N_{org}/N_{tot} were 88–97%, with SE16 Gammtratten having the highest share and the other sites on very similar values, 88-89%. Inorganic N concentrations were low ($\leq$0.04 N_{inorg} L^{-1}) at three sites with SE14 Aneboda considerably higher (0.08 N_{inorg} L^{-1}). However, the inorganic nitrogen flux was higher at the two southern sites compared to the northern ones with 0.26 and 0.46 kg N_{inorg} ha^{-1} y^{-1}, in the north 0.02-0.12 kg N_{inorg} ha^{-1} y^{-1}. The high concentrations in stream water at SE14 Aneboda, probably reflects the poor forest stand condition. Compared with 2012, however, when the mean inorganic N concentration exceeded 1100 µg L^{-1}, a considerable decrease have occurred.

Total phosphorus concentrations (P_{tot}) in bulk deposition varied between 5 and 36 µg L^{-1} with the highest value at SE14 Aneboda and lowest at SE16 Gammtratten. In stream water, SE14 Aneboda showed the highest P_{tot} (26 µg L^{-1}) as well as DOC concentrations. The other sites had average P_{tot} concentrations between 3 and 9 µg L^{-1} with the lowest value at SE15 Kindla.

Inorganic aluminum (Al_i), toxic to fish and other gill-breathing organisms, is analyzed in soil solution, groundwater and surface waters at the IM sites. Relatively high total Al concentrations occurred in the soil solution (0.5–1.6 mg L^{-1}), and fairly high concentrations (1.1 and 0.7 mg L^{-1}, respectively) occurred also in groundwater in the recharge areas at SE04 Gårdsjön and SE14 Aneboda. The stream water Al_{tot}-concentrations were between 0.5 and 0.7 mg L^{-1} at the three sites with low pH (4.5-4.7). The Al_{tot} concentrations were lower, approximately 0.24 mg L^{-1} at the northern site SE16 Gammtratten with a pH of 5.6. Inorganic Al made up 15–58% of the total Al with the highest levels at low pH at SE15 Kindla and the lowest at SE04 Gårdsjön, corresponding to 0.05–0.30 mg Al_i L^{-1}. According to the SEPA classification system, the Al_i concentrations at SE14 Aneboda and SE15 Kindla are considered *extremely high*, but *moderate* at SE04 Gårdsjön and SE16 Gammtratten.

The priority heavy metals Pb, Cd and Hg were still accumulating in the SE14 Aneboda catchment soils, while the stream concentrations were low compared with the levels causing biological effects. Only Pb had somewhat higher concentrations compared with the established limits for ecological effects. However, methyl mercury (Hg_{Me}), only measured at SE14 Aneboda and financed by SITES, was still relatively high creating prerequisites for bioaccumulation. In stream water, the mean Hg_{tot} and Hg_{Me} concentrations were 10.5 ng L^{-1} and 1.5 ng L^{-1}, respectively. Half of the Hg_{tot} deposition was accumulated in the catchment soil and higher concentrations of Hg_{Me} in stream water compared with in throughfall which indicate ongoing methylation.

In summary, the four Swedish IM sites show low ion concentrations and permanently acidic conditions in the aquatic media. In stream water, only the northern site SE16 Gammtratten had buffering capacity related to bicarbonate alkalinity. Organic matter has an impact on the water quality with respect to colour, metal complexation, and phosphorus concentrations at all sites, but less at SE15 Kindla, where rapid soil water flow paths provide relatively low DOC concentrations but acidic waters. At SE14 Aneboda, the forest dieback provides a relatively high share of runoff as well as high nitrate concentrations compared with the other three sites. At SE04 Gårdsjön, deposition is strongly influenced by the sea.

References

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