Report on National ICP IM activities in Sweden in 2018

Lundin, L. [1], Rönnback, P.[1], Löfgren, S.[1], Bovin, K.[2], Eveborn, D[2]., Grandin, U.[1], Jutterström, S.[3], Pihl Karlsson, G.[3], Moldan, F.[3]and Thunholm, B[2].

[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.

The programme is funded by the Swedish Environmental Protection Agency.

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). 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 considerably 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.

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
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, ^{o}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

In the following, climate, hydrology and water chemistry related primarily to 2018 as well as some ongoing work at the four Swedish IM sites are presented (Löfgren, 2019).

Climate and Hydrology in 2018

Based on long-term (1961-1990) mean values from the Swedish Meteorological and Hydrological Institute (SMHI) measured data for 2018 from climate monitoring in the IM sites, the annual mean temperatures were higher (1.1-1.6 ºC) compared to the long-term mean for all four sites. Largest deviation occurred at the northern site SE16 Gammtratten. Compared with the measured time series, 18 years at site SE16 Gammtratten and 22 years at the other sites, the temperatures in 2018 were somewhat higher at all four sites with 1.1 and 1.2 ºC at the two southern sites and with 1.5 and 1.6 ºC at the two northern sites. 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 22 years average at three sites, while SE15 Kindla only deviated with 0.9 ºC below this mean.

Compared to the SMHI long-term average values (1961–1990), the precipitation amounts in 2018 were considerably lower at all sites with only 64-74% of the long-term average at three sites. At SE04 Gårdsjön, the precipitation reached 86% of the long-term mean with monthly values varying between lower and higher values for seven and five months, respectively. The other sites had lower precipitation mainly from February to December with deviations at SE14 Aneboda for August (+31 mm) and SE16 Gammtratten also in February-March (+48 mm). Mainly summer and autumn showed low precipitation, especially for the two northern sites with low soil moisture content and extensive forest fires in those regions, however not hitting the IM sites.

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 groundwater levels often are low in winter when precipitation is stored as snow, with raising levels at snowmelt in spring and returning to lower levels in summer due to evapotranspiration. However, depending on rainfall amounts in summer and/or autumn, the groundwater levels could occasionally be elevated also during these periods. In 2018, the three sites SE14 Aneboda, SE 15 Kindla and SE16 Gammtratten started the year on fairly high groundwater levels, receding to ordinary lower levels in March-April followed by elevated levels at snowmelt. Especially, groundwater levels at SE16 Gammtratten in the north reached relatively high levels. During the following months groundwater levels were lowered to unusually low levels in late summer and early autumn. Low evapotranspiration in autumn resulted in slightly elevated groundwater levels. However, only site SE15 Kindla reached ordinary high levels in end of the year. At SE14 Aneboda and SE16 Gammtratten, the groundwater levels were lower than normal with c. 0.5 m. At site SE15 Kindla, a more varying pattern was observed with several peaks 0.2 m below the soil surface during snowmelt in March – April. However, the lowest levels in 2016-2017 c. 0.8 m below soil surface, were exceeded for five months in 2018 when the levels were at 1.5 m soil depth. The groundwater levels were reflected in the stream water discharge patterns (Fig. 1).

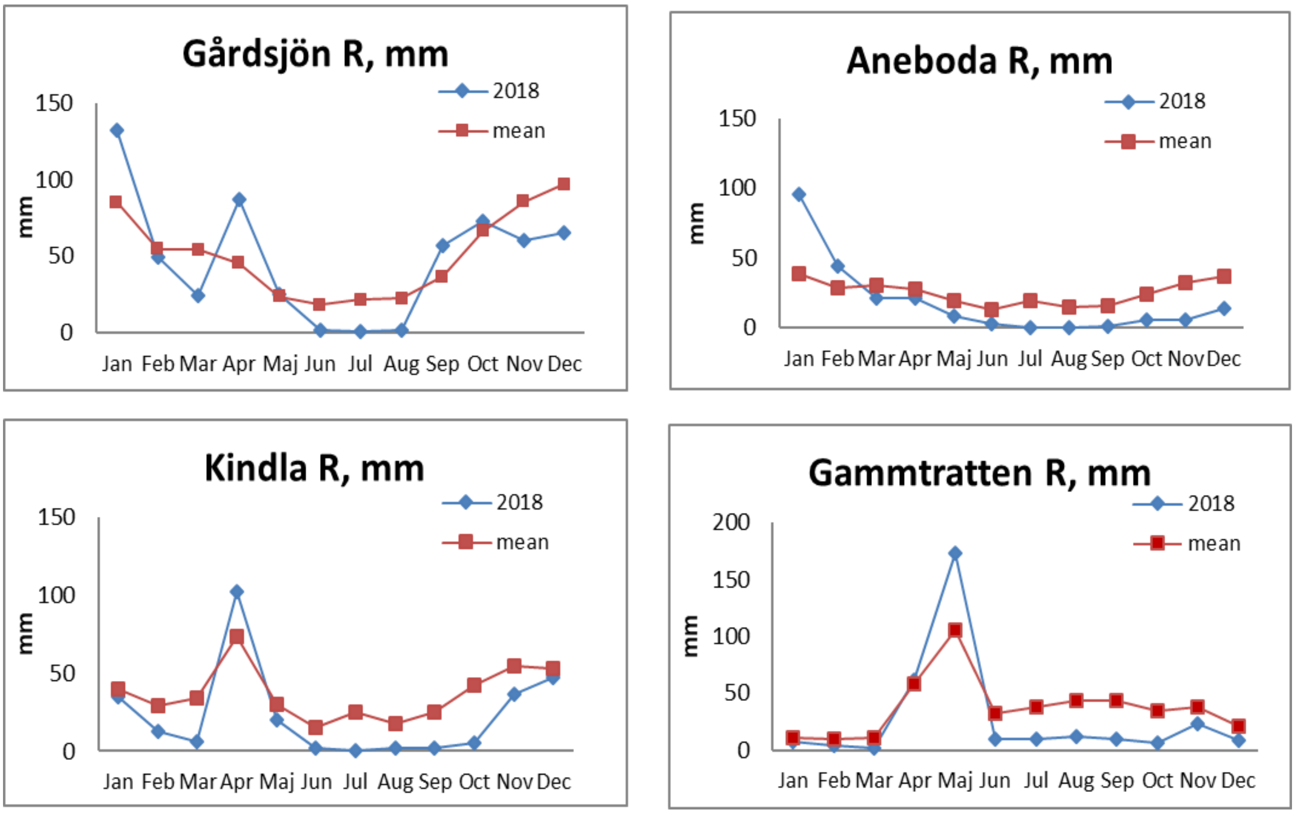

Figure 1. Discharge patterns at the four Swedish IM sites in 2018 compared to monthly averages for the period 1996–2018 (mean). Note the different scales at the Y-axis.

In addition to precipitation, evapotranspiration affects the runoff pattern. The runoff pattern for SE16 Gammtratten 2018, was fairly typical with a snowmelt peak in May and lower discharges in summer and autumn but with a small peak in November before low temperatures caused snowfall and snow accumulation. At SE04 Gårdsjön, the pattern was in accordance with the average except for high values in January and very low values in summer. Also comparably low flows occurred in November-December. Runoff at SE15 Kindla followed the ordinary pattern during 2018 but with considerably lower monthly runoff in June to November. Runoff at SE14 Aneboda showed high monthly values in the beginning of the year, turning to very low runoff until end of the year (Fig. 1). In July surface water runoff actually ceased.

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. Runoff during 2018 exhibited a normal pattern with peaks in spring during snowmelt, but runoff was low throughout the year and especially during summer and autumn (Fig. 1). This pattern was not as evident at the two southern sites, where slightly higher runoff than normal was observed in January and at SE04 Gårdsjön also in April and September.

In 2018, the annual runoff made up 44–80% of the annual precipitation (Table 2), a wide range compared to the ordinary 40–60% but with mainly SE16 Gammtratten deviating with a large share. In 2016 the range was even larger (31–83%). At SE04 Gårdsjön, 2018 and 2017 were similar with shares of 64% and 63%, respectively, due to somewhat high runoff in the end of the year when evapotranspiration was low (Table 2). Runoff at this site, constituting almost 2/3 of the precipitation, is quite normal. At SE14 Aneboda, storm felling, followed by bark beetle attacks, have reduced the forest canopy cover, inducing low interception. The total evapotranspiration was estimated to 179 mm, which is considerably lower than previous years with 477 mm in 2017 and 349 mm in 2016. Low precipitation and dry conditions seem to have contributed to this low evapotranspiration. At SE15 Kindla, the water balance was also influenced by low precipitation, resulting in low calculated evapotranspiration and runoff. However, the proportions related to precipitation were reasonably normal with 56% and 44%, respectively. At the northern site SE16 Gammtratten, throughfall and bulk precipitation were very similar (1% deviation), which indicates large uncertainties in these measurements. Similar patterns have been found for several years. Presumably, snow deposition infers the largest uncertainty, probably resulting in erroneous estimates of bulk precipitation. The precipitation observed at a nearby SMHI station showed slightly higher values, generating a higher and more realistic evapotranspiration. In summary and based on the estimated evapotranspiration (P-R), it must be concluded that the very dry summer 2018 furnished low evapotranspiration at all four sites (Table 2).

Table 2. Compilation of the 2018 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	906	100	397	100	619	100	409	100
Throughfall, TF	733	81	497	125	494	80	412	101
Interception, P–TF	173	19	-101	-25	125	20	-3	-1
Runoff, R	577	64	218	55	272	44	325	80
P–R	329	36	179	45	348	56	84	20

Water chemistry in 2018

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 (1.0 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 (5.6 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 (0–0.5 units) in throughfall compared with bulk deposition. In 2018, however, both SE04 Gårdsjön and SE16 Gammtratten had similar pH (ca 5.1) in both bulk deposition and throughfall. The two sites SE14 Aneboda and SE15 Kindla had 0.3-0.5 higher pH values in throughfall compared with in bulk deposition (Table 3).

Table 3. Mean deposition chemistry values 2018 at the four Swedish IM sites. S and N in kg ha^{-1} yr^{-1}.

	SE04	SE14	SE15	SE16
pH, bulk deposition	5.1	4.9	5.0	5.1
pH, throughfall	5.1	5.4	5.3	5.0
S, bulk deposition	2.9	1.1	1.9	0.8
N, bulk deposition	7.9	3.8	6.5	1.4

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. Especially SE14 Aneboda and SE16 Gammtratten exhibited low pH-values in soil water, pH 4.4 and pH 3.6, respectively, compared with throughfall, pH 5.4 and pH 5.0, respectively. However, in the organic rich discharge areas at SE04 Gårdsjön and SE16 Gammtratten, pH was higher in soil solution compared with throughfall while the opposite was true at SE14 Aneboda and SE15 Kindla.

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 SE04 Gårdsjön with constantly negative values. In the discharge areas, the buffering capacity in groundwater varied between positive and negative values for the sites. Especially low values were found at Aneboda with ANC -0.11 mEq L^{-1} possibly dependent on nitrification in upslope locations. In groundwater in SE15 Kindla, ANC was comparably high with 0.18 mEq L^{-1} while SE04 Gårdsjön and SE16 Gammtratten showed values close to zero. Bicarbonate ($HCO_{3)}$ occurred in 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 Gammtratten having a pH of 5.6. The stream water buffer capacity was positive at all sites (ANC $\geq$ 0.033 mEq L^{-1}), except for SE15 Kindla (ANC -0.005 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 SE14 Aneboda and SE04 Gårdsjön, the stream waters were more acidic compared with the other two sites probably due to nitrification and the legacy of historically high acid deposition, respectively.

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 contributed to fairly high nitrate values in the recharge area soil water (0.05 mEq L^{-1}), however, values being lower compared to previous year. Considerably 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 dominated anion flow in the stream with 2/3 of the content to be compared to 25% at SE15 Kindla, 15% at SE14 Aneboda and only 10% at SE04 Gårdsjön.

Soil and soil water processes could be evaluated through relationships between mainly sodium and chloride. In deposition, Na^+ dominated the base cations except for at the northern site SE16 Gammtratten where Ca^{2+} showed the highest concentrations. At sites SE04 Gårdsjön and SE14 Aneboda, Cl^- were higher compared to Na^+ while the opposite occurred at the other two sites. A higher Cl^- outflow than Na^+ in stream water indicate ion exchange in the soil and release of other base cations, H^+ and/or Al^{3+} from the catchments. Mg^{2+} was the second highest base cation in runoff water at SE04 Gårdsjön 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 18 mg L^{-1} while the other sites SE04 Gårdsjön, SE15 Kindla and SE16 Gammtratten showed lower values 16, 9, and 10 mg L^{-1}, respectively. High DOC concentrations create prerequisites for metal complexation and transport as well as high organic nitrogen fluxes. Organic nitrogen was the dominating nitrogen fraction in stream water, ranging from 0.19 to 0.44 mg N_{org} L^{-1}. The shares of N_{org}/N_{tot} were 81–97%, with SE14 Aneboda having the lowest share while SE16 Gammtratten and SE15 Kindla had the highest values. However, the nitrogen flux was higher at the two southern sites compared to the northern ones. Inorganic nitrogen (NO_3–N and NH_4–N) was low at the two sites SE15 Kindla and SE16 Gammtratten with 34 and 4 µg L^{-1}, respectively. At SE04 Gårdsjön, somewhat higher concentration (61 µg L^{-1}) was found, reflecting a somewhat higher deposition. The highest concentrations in stream water were found at SE14 Aneboda (102 µg L^{-1}), probably reflecting the poor forest stand condition. Compared to 2016, however, when the mean inorganic N concentration was 191 µg L^{-1}, a considerable decrease have occurred.

Total phosphorus (P_{tot}) in bulk deposition varied between 4 and 28 µg L^{-1} with the highest values at SE15 Kindla and lowest in site SE14 Aneboda. In stream water, SE14 Aneboda showed the highest P_{tot} (13 µg L^{-1}) as well as DOC concentrations. The other sites had average P_{tot} concentrations between 4 and 9 µg L^{-1} with the lowest value at SE15 Kindla.

Inorganic aluminum (Al_i), toxic to fish and other gill-breathing organisms, has been analyzed in soil solution, groundwater and surface waters at the IM sites. Relatively high total Al concentrations occurred in the soil solution (0.5–1.8 mg L^{-1}), however only half of the concentrations in 2017. Sites SE04 Gårdsjön and SE14 Aneboda showed fairly high concentrations in groundwater in recharge areas with 1.2 mg L-1 and 1.6 mg L^{-1}, respectively. In stream water, Al_{tot}-concentrations were between 0.4 and 0.7 mg L^{-1} at three sites with low pH (4.4-4.8). Only at the northern site SE16 Gammtratten with a pH of 5.6, the total Al concentrations were lower, approximately 0.23 mg L^{-1}. Inorganic Al made up 13–51% of the total Al with the highest levels at low pH at SE15 Kindla and the lowest at SE16 Gammtratten, corresponding to 0.04–0.27 mg Al_i L^{-1} and 0.03 mg Al_i L^{-1}, respectively. In 2018, both Al_{tot} and Al_i were somewhat higher in stream water compared with in 2017.

According to the SEPA classification system, the Al_i concentrations at SE04 Gårdsjön, SE14 Aneboda and SE15 Kindla are considered *extremely high*, but *moderate* at 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. However, methyl mercury, 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-methyl concentrations were 5.3 ng L^{-1} and 0.4 ng L^{-1}, respectively, which is lower compared to in 2017.

In summary, the four Swedish IM sites show low ion contents and permanently acidic conditions. 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 and acidic waters. At SE14 Aneboda, the forest dieback provides a relatively high share of water runoff as well as high nitrate concentrations compared with the other three sites. At SE04 Gårdsjön, deposition is strongly influenced by the sea.

References

Löfgren, S., Grandin, U. and Stendera, S. 2014. Long-term effects on nitrogen and benthic fauna of extreme weather events: Examples from two Swedish headwater streams. Ambio 43, 58-76. Doi; 10.1007/s13280-014-0562-3

Löfgren, S. (ed.) 2019. Integrerad övervakning av miljötillståndet i svensk skogsmark – IM. Årsrapport 2018. Integrated monitoring of environmental status in Swedish forest ecosystems – IM. Annual Report for 2018. Rapport 2019:7. SLU. Uppsala. 30pp and 23 appendix. (In Swedish with English summary)