Report on National ICP IM activities in Sweden in 2014–2015

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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). 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 Aneboda, SE14. 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 breast height over 35 cm where dead (Löfgren et al., 2014) and currently almost all spruce trees with diameter of ≥20 cm are gone.

Table 1. Geographic location and long-term climate at the Swedish IM sites.

	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, water chemistry and some ongoing work at the four Swedish IM sites are presented (Löfgren 2015).

Climate and Hydrology in 2014

In 2014, the annual mean temperatures were higher (1.5–2.3 ºC) compared to the long-term mean (1961–1990) for all four sites. Largest deviation occurred at the northern SE16 site. Compared with the measured time series, 15 years at site SE16 and 19 years at the other sites, the temperatures in 2014 were somewhat higher at all the IM sites. The values were the highest observed for the whole measurement period with exception for SE15 being slightly higher in years 1999 and 2000. Low temperatures were observed in 2010 and 2012. The variations between years have been considerable, especially for the last five years, over 3°C. Smaller variations were found at the central site SE 15 Kindla, only 1°C.

Precipitation amounts in 2014 compared to the long-term average values (1961–1990) were for SE14 Aneboda 46 mm lower and for SE16 Gammtratten in the north 109 mm lower. For site SE04 Gårdsjön precipitation amount was very high exceeding the long term mean with 332 mm while the central Swedish site SE15 Kindla only showed marginally higher value with 29 mm. In 2012, the precipitation amounts were 3–44% higher than the long-term average for the four sites, while in 2013 all sites had lower values.

The characteristic annual hydrological patterns of the catchments are for the southern sites high groundwater levels during winter and lower levels in summer and early autumn. However, at site SE15 Kindla three summer peaks were noticed with groundwater levels 0.2 m below ground surface, i.e. on similar level as in spring and autumn. The groundwater level has decisive influence on the discharge values (Fig. 1).

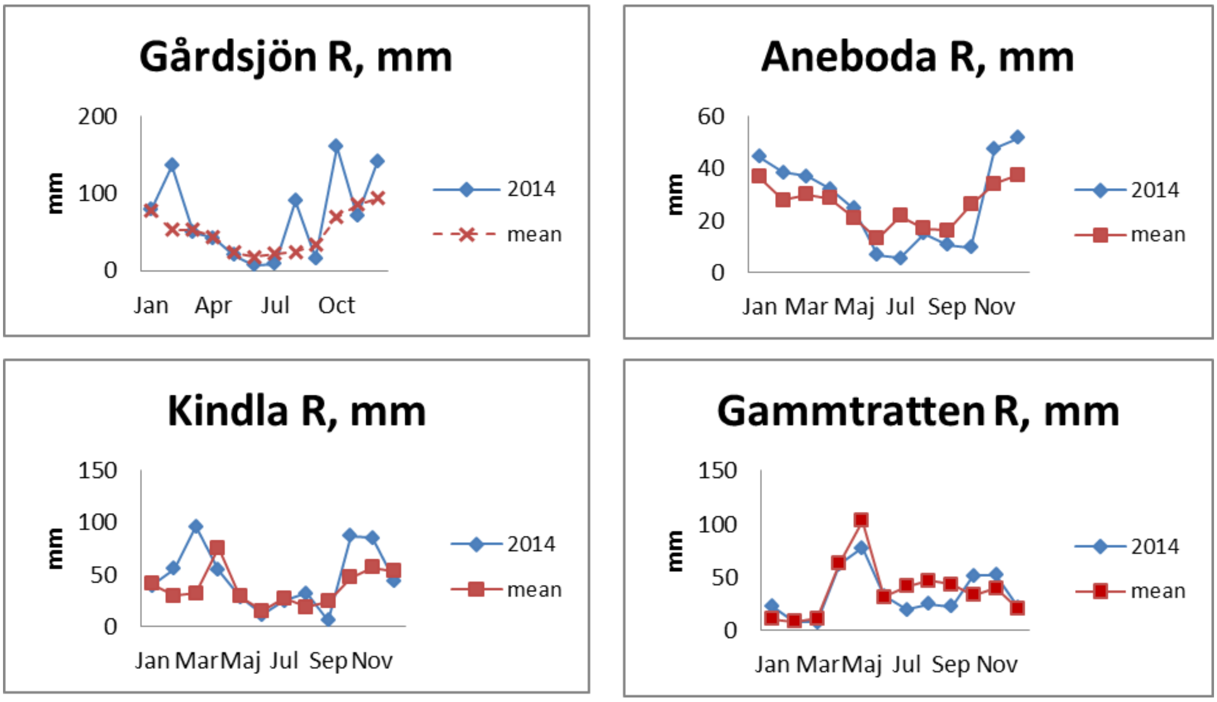

Figure 1. Discharge patterns at the Swedish IM sites in 2014 compared to monthly averages for the period 1996–2014 (mean). Note the different Y-axis scales.

In addition to precipitation, evapotranspiration affects the runoff pattern. In 2014, these patterns were fairly typical for the three sites Aneboda, Kindla and Gammtratten but high precipitation in August, October and December at SE04 Gårdsjön provided high monthly discharges and a flashy runoff pattern for late summer and autumn period. At site SE15 Kindla an early spring peak in March and high runoff in October and November pronounced the ordinary pattern for that area. For SE14 Aneboda in the south and SE16 Gammtratten in the north the patterns followed the long-term mean but with lower summer runoff than ordinary (Fig. 1).

At the two northern sites, generally snow accumulates during winter and the groundwater levels stay low furnishing low discharge. However, warm winter periods with temperatures above 0 °C have during a number of years contributed to snowmelt and runoff also during this season. As a consequence, the spring discharges have been comparably low during snowmelt, deviating from the conditions three decades ago. Apart from the early March peak at SE15 Kindla, this was not the case in 2014.

In 2014 high precipitation and runoff were observed at SE04 Gårdsjön even though interception and total evapotranspiration were high. At SE15 Kindla annual runoff 565 mm was reasonably high (Table 2), but the high precipitation (1300 mm) and throughfall (866 mm) values were out of the range compared with the national (SMHI) estimate 935 mm (sum of daily values). Hence, it is most probable that the site-specific measurements overestimated the actual conditions. A precipitation of 935 mm (national data) would result in evapotranspiration 370 mm being more in line with the long term average of ca. 450 mm. Based on the IM measurements, evapotranspiration would be 735 mm, which is out of the possible range.

In 2014, the annual runoff made up 43–82% of the annual precipitation, which is comparable to the 40–60% found during previous years. The highest share was found at the northern site SE16 Gammtratten (82%), where partly due to a rather intense snowmelt period and cold climate during the rest of the year, yielding low evapotranspiration (18%) and consequently provided high runoff (Table 2). At site Aneboda (SE14), storm felling followed by bark beetle attacks have reduced the forest canopy cover, inducing low interception. Actually, the measured throughfall was higher than bulk precipitation. The total evapotranspiration was estimated to 308 mm, a value far lower than the long-term average 470 mm. This mirrors effects of low interception and transpiration of the reduced forest stand.

Table 2. Compilation of the 2014 water balances for the four Swedish IM sites. Measured values on precipitation and throughfall at SE15 Kindla site could be biased regarding difficulties in snow collection.
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	1294	100	633	100	1300	100	493	100
Throughfall, TF	847	65	687	109	866	67	517	105
Interception, P-TF	447	35	-55	<0	434	33	24	<0
Runoff, R	825	64	324	51	565	43	404	82
P-R	469	36	308	49	735	57	89	18

Water chemistry in 2014
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 three sites. At SE16 Gammtratten, the conductivity in throughfall (1.2 mS m^{-1}) was lower than in bulk deposition (1.4 mS m^{-1}) indicating very low sea salt deposition and uptake of ions by the trees. At the two most southern sites, sea salt deposition provides higher ion concentrations especially at the west coast SE04 Gårdsjön site (4.0 mS m^{-1} in throughfall). The soil water pathways in the catchments soils are fairly short and shallow, providing rapid surface water formation from infiltration to surface water runoff. The acidity in deposition has during the last 10 years been rather similar at all sites with somewhat higher pH values (0–0.1 units) in throughfall compared with bulk deposition. However, in 2014 the two southern sites had throughfall values on 5.3 while the two northern sites only reached ca. 5.0 (Table 3).

Table 3. Mean deposition chemistry values 2014 at the four Swedish IM sites. S and N in kg ha^{-1} yr^{-1}.

	SE04	SE14	SE15	SE16
pH, bulk deposition	5.1	4.8	5.0	4.9
pH, throughfall	5.3	5.3	5.1	5.0
SO_4-S, bulk deposition	4.6	2.4	3.4	1.4
Ntot, bulk deposition	9.9	5.2	6.7	1.9

During the water passage through the catchment soils, organic acids were added and leached to the stream runoff. In the upslope recharge area, pH in the upper soil layers (E-horizon) was mainly lower than in throughfall. However, in the peat in discharge areas at SE15 Kindla and SE16 Gammtratten, pH was higher compared to throughfall while it was the opposite at SE04 Gårdsjön and SE14 Aneboda with pH 4.5 and 4.8, respectively. In the discharge areas, the buffering capacity in groundwater was fairly high with ANC over 0.04 mEq L^{-1} and with bicarbonate (HCO_3^-) present at Kindla and Gammtratten at average concentrations of 0.25 and 0.04 mEq L^{-1}, respectively. The stream waters were acidic with pH values below 4.8 at all sites except Gammtratten having a pH of 5.7. The stream water buffer capacity was positive, except for at Kindla with an ANC of -0.001 mEq L^{-}1. Anions of weak organic acids contributed to the positive ANC and bicarbonate contributed at SE16 Gammtratten.

The share of major anions in deposition was similar for sulphate, chloride and nitrate for three of the sites while chloride dominated at SE04 Gårdsjön due the proximity to the sea. In throughfall, organic anions contributed significantly at all four sites. The chemical composition changed during the passage of catchment soils and sulphate concentrations were higher in stream water compared with deposition, indicating desorption or mineralization of previously accumulated sulphur in the soils.

Besides effects on ANC and pH, the stream water chemistry is to a considerable extent influenced by organic matter. At Aneboda (SE14), the DOC concentration was high with 32 mg L^{-1} while the other sites Gårdsjön (SE04), Kindla (SE15) and Gammtratten (SE16) showed lower values 16, 10 and 10 mg L^{-1}, respectively. High DOC concentrations create prerequisites for metal complexion and transport as well as high organic nitrogen fluxes. The organic nitrogen concentrations in stream water ranged from 0.20 to 0.73 mg N L^{-1}. The shares of Norg/Ntot were 72–96% with SE14 Aneboda having the lowest share and SE16 Gammtratten the highest. At SE14 Aneboda, the average concentration of inorganic nitrogen in stream water was 0.28 mg N L^{-1}, which was high compared with 0.06 mg N L^{-1} at the other sites. The high inorganic nitrogen concentrations at Aneboda are related to the forest dieback.

Total phosphorus (Ptot) in bulk deposition varied between 3 µg L^{-1} and 14 µg L^{-1} with the highest values at SE04 Gårdsjön with influence of sea deposition. In stream water, however, Ptot was highest at SE14 Aneboda with 23 µg L^{-1} also having the highest DOC concentrations. The other sites had average Ptot concentrations between 4 µg L^{-1} and 13 µg L^{-1} with SE16 Gammtratten being highest.

Inorganic aluminum, 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 (0.6–2.8 mg L^{-1}) as well as in stream water (0.24–0.7 mg L^{-1}) at the three southern sites with low pH (4.5–4.8). At the northern site SE16 with a pH of 5.7, the total Al concentrations were low, approximately 0.2 mg L^{-1}. Inorganic Al made up 17–45% of the total Al at the four sites, corresponding to 0.11–0.25 mg Al_i L^{-1} at the three southern sites with low pH and 0.05 mg Al_i L^{-1} at the northern site Gammtratten. Those levels are considered extremely high at the three southern sites and high in the north, according to the SEPA classification system. The priority heavy metals Pb, Cd and Hg were still accumulating in the catchment soils, while the stream concentrations were low compared with the levels causing biological effects. However, methyl mercury was still relatively high creating prerequisites for bioaccumulation.

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 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 low DOC and acidic waters. For 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. SE04 Gårdsjön is strongly influenced by the sea.

References

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