Centre for Ecology & Hydrology
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Evaluation of three sub-programmes in the Swedish National Air Monitoring Programme

Acidifying and eutrophying substances

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Summary

This report conducts an in-depth review of three out of the thirteen sub-programmes in the Swedish National Air Monitoring Programme. These are the acidifying and eutrophying substances sub-programmes, namely the national air and precipitation chemistry network (EMEP and LNKN), SWETHRO-NV and MATCH modelling. Using previous reports and speaking to key stakeholders, it considers issues related to the financial sustainability and fragmentation within the connected networks. Among other recommendations, the major outcome of this report is to strategically realign the sub-programmes into one harmonised network that can be fully funded by the Swedish EPA, within the projected future budgets. A data, spatial and financial analysis was undertaken to develop recommendations for this redesigned network (here referred to as LNKN+) in a current funding scenario and with a 30% total budget reduction scenario. The redesigned network, along with the other recommendations, should enable the sub-programmes to become more resilient to future funding challenges and organisational risk it may face, while improving the overall impact for environmental objective reporting and, to the greatest extent possible, maintaining the range of scientifically valuable long-term monitoring that is currently supported by the Swedish EPA.

Sammanfattning

Denna rapport innehåller en genomgående granskning av tre av de tretton delprogrammen i Sveriges nationella luftövervakningsprogram (Programområdet Luft), delprogrammen Försurande och övergödande ämnen i luft och nederbörd (inkluderande EMEP och LNKN, Luft- och nederbördskemiska nätet), Krondroppsnätet-NV och MATCH-Sverigesystemet. Genom att använda tidigare utredningar och att prata med nyckelaktörer har frågor som rör finansiering och effektivisering av mätnäten diskuterats och utretts. Ett av de viktigaste syftena med rapporten är att omforma delprogrammen till ett strategiskt, harmoniserat nätverk som Naturvårdsverket har möjlighet att finansiera framöver. Det nya nätverket (här kallat LNKN+) har utformats utifrån en datamässig-, rumslig och finansiell analys, och redovisas i två olika scenarion, dels med nuvarande finansiering, dels med 30 % minskad budget. Nätverket ska tillsammans med ett antal andra rekommendationer göra delprogrammen mer motståndskraftiga mot framtida utmaningar kring finansiering och organisation, samtidigt som underlaget till miljömålsarbetet förbättras och utbudet av vetenskapligt värdefull, långsiktig nationell övervakning i största möjliga mån bibehålls.

1. Introduction

The aim of this report was to undertake an in-depth review and evaluation of three out of thirteen sub-programmes in the Swedish National Air Monitoring Programme. These are the acidifying and eutrophying substances sub-programmes, namely the national air and precipitation chemistry network (EMEP and LNKN), SWETHRO-NV and MATCH modelling.

The project was commissioned by the Swedish Environmental Protection Agency (Helena Sabelström and Salar Valinia) to the supplier Centre for Ecology and Hydrology (Christopher Evans, Alan Radbourne and Don Monteith).

Project objectives

The objectives of the project were to obtain:

- An analysis of the current system
- Assessment of the most valuable sites with regards to long term monitoring
- Recommendations of future monitoring with current funding and a financial cut of 30% of the current budget
- Recommendations for improved efficiency of the monitoring programme
- A proposal for a revised or new monitoring system.

In order to achieve these objectives, we conducted:

- A review of past report findings to better understand the network and lay the foundation for this report, while also avoiding repeating previous work.
- A spatial and data quality assessment of current stations and parameters, to determine the coverage of the network to rank the relative importance of different stations for understanding past change and supporting ongoing assessment and reporting.
- A financial analysis to assess the current and possible future options with either a stable funding situation a funding cut, aligning recommendations of improved efficiency to realistic financial possibilities.
- Meetings with key stakeholders Swedish EPA (NV/SEPA), Swedish Environmental Research Institute (IVL), Swedish Meteorological and Hydrological Institute (SMHI) and representative County Administrative Boards (CABs) to gather views and information pertinent to the project objectives from a range of perspectives.

1.1. Sub-programme summary

The acidifying and eutrophying substances sub-programmes (EMEP, LNKN, SWETHRO-NV and MATCH modelling), are currently divided into three separate, but related monitoring and modelling networks. Table 1 provides a short summary of each sub-programme.

Table 1. Description of the sub-programmes assessed in this report.

Sub-programme	Description	% SEPA funding	Delivered by
EMEP & LNKN	National air and precipitation chemistry network	100	IVL
SWETHRO-NV	National monitoring of atmospheric deposition to forests	14	IVL
MATCH	Modelling air concentrations and atmospheric deposition	100	SMHI

1.1.1. EMEP

The Swedish EMEP network comprises 4 sites producing high frequency data that are of major importance for national and international monitoring reporting. Primarily, the data contribute to international air pollution reporting for Europe. SEPA fund the programme and sub-contract management and reporting to IVL. The data is a key for the MATCH-Sweden modelling. Currently in the EMEP system, monitoring of air concentrations of inorganic components of (SO2, SO4, NO2, NO3+HNO3, NH4+NH3, Cl, Na, K, Ca, Mg), occurs on a daily time basis. Gas particle distribution (NH3, NH4, HCL, HNO3, NO3) occurs on a monthly time basis. Precipitation measurements of (SO4, NO3, NH4, pH, Na, K Ca, Mg, Cl, Conductivity) occurs on a daily time basis on two sites, and monthly on two.

1.1.2. LNKN

The LNKN comprises 16 sites conducting monthly sampling of open field precipitation (all sites) and air (9 sites). Data are used for national baseline assessment and provide a valuable long-term data series. SEPA fund the programme, sub-contracting management and reporting to IVL. The LNKN is a part of the same sub-programme as the EMEP, with data aligned to standards required to feed into the MATCH-Sweden modelling.

1.1.3. SWETHRO-NV

The SWETHRO-NV (NV/SEPA) comprises 19 sites that sample atmospheric deposition. Sites carry out a varying number of monthly sampling protocols including one or more of; air, precipitation (open field wet deposition), string sampling (open field dry deposition), throughfall (forest deposition) and soil water. Data are primarily used for estimating national atmospheric deposition to forests, and are linked to other monitoring of forest ecosystem condition, such as soil water chemistry. SEPA fund the SWETHRO-NV, which forms part of the wider SWETHRO network of around 59 sites, which is managed and financially supported by numerous organisations and management associations. The financial contribution from SEPA represents 14% of the running cost for the SWETHRO network as a whole. IVL manage, maintain and report on the SWETHRO-NV sites as part of their association with the wider SWETHRO network. The data are not currently used in the MATCH-Sweden model.

1.1.4. MATCH

The MATCH-Sweden system is used to estimate air concentrations, and wet and dry deposition of major inorganic compounds. In addition to acidifying and eutrophying compounds, it also incorporates modelling of ozone. The model is of valuable national interest, creating maps of exposure and deposition from both domestic and foreign sources. SMHI develop and run the model with funding from SEPA.

2. Background

2.1. Review of past reports

We conducted an initial review of recent reports, in order to build a picture of how the networks have been developed in recent times. Assessment of past recommendations and how (or if) they have been implemented, provided an understanding of the desired direction and challenges facing the networks.

Below is a summary of each report, including a brief outline of how it contributed to the current review.

2.1.1. 2015 IVL Report (focus on SWETHRO programme)

The 2015 IVL Report[1] assessed the long-term national environmental monitoring of atmospheric deposition and groundwater chemistry in forests, focussing on acidification and eutrophication. The report highlighted the importance of sustaining long-term data sets in order to capture any deviations from expected trajectories of change and to demonstrate the effectiveness of air pollution control measures. A review of the network concluded that it was fragmented and was ultimately under threat if not brought under central authority organisational control.

The report recommended a redesigned national monitoring programme, with three categories of station measurements (methodology of each provided in detail in text). These categories comprised: 11 sites with high intensity measures (air at various heights, open field, throughfall, string sampling and soil water chemistry); 19 sites with reduced intensity data (air above the canopy, open field, throughfall and soil water); and 26 low-intensity sites (soil water chemistry only), totalling 56 stations.

It was proposed that financing of the network should be moved to the relevant national authorities (SEPA, HaV, Forestry Agency) and fixed at the 2015 budget. Costings of proposed changes were provided.

Contribution to the current review…

The report highlighted the disjointed legacy of the network and suggested ways to bring it together under one central authority control. This approach would have clear benefits. However the report is now four years old and the recommendations do not appear deliverable in the current funding environment.

[1] IVL U 5149 Förslag till utformning av ett Bas- Krondroppsnät för nationell miljöövervakning (2015)

2.1.2. 2016 IVL Report (suggestion of new authority network)

The *2016 IVL Report*[2] was produced by IVL to propose changes to the funding of the national air monitoring network for SEPA. Four options were proposed, three within projected budget requirements and a fourth that would require an increase in budget.

Options 1 – 3 came with a strong warning that with the current funding, the necessary reductions to the size and/or scope of the network would adversely affect the scientific and policy benefits of the programme, weakening the capability to conduct regional assessments, relying on national assessment alone. Ultimately it is suggested a reduction would increase the financial burden to the County Administrative Boards (CABS) undertaking measurements and analysis.

Option 4 (increased funding) was proposed as the only suitable option to avoid the adverse impacts stated in options 1-3. It involved moving the funding and assessment to national level, while suggesting the local authorities take up regional monitoring themselves as additional to baseline options.

Key elements of each option can be summarised as follows:

Option 1 = Spread analysis thin and wide. Issue with lots of sparse data, thus poor depth of understanding.

Option 2 = Focus on lower numbers of higher intensity locations. Issue with reduction of regional picture and no clear in-depth understanding.

Option 3 = Restrict to a small number of very high intensity locations (i.e. EMEP stations). Issue with large areas between the monitoring sites, thus lack of spatial resolution for understanding outside of the sample site localities.

Option 4 = Development of a national baseline network with increased funding. This option would clearly be desirable from both a scientific and a national/regional reporting perspective. However, in the current funding environment there appears to be little realistic prospect of implementing.

The report recommends moving control to a national level focused on developing a baseline monitoring programme. This would alleviate the pressure on air pollution management associations (CABs) so they have more freedom to invest in the assessments of interest to them, generating 'bonus' analyses of hotspots across the country.

Contribution to the current review…

There is no doubt that an increase in budget proposed under Option 4 would benefit the network and add significant value to the long history of data collection, and such an outcome would be highly desirable for national and regional reporting. However, this is not consistent

[2] IVL U 5641 Krondroppsnätet-NV - Olika alternativ med nationell finansiering (2016)

with the current position of the funding streams, and the alternative options 1-3 (flat/reduced funding?) are all presented as similarly undesirable. Thus the report does not provide a clear strategy for how to develop a sustainable, cost-effective network within a significantly contracted budget (and indeed this was not the goal of the report). On the other hand, the report provides valuable information on the regional, national and international importance of the network and a strong case for its continuation. The importance of maintaining a spatially distributed network was recognised as being of particular importance. Here, the report has been used to guide what other stakeholders appear to value of the network through the development of the decision metrics in this project review.

2.1.3. 2016 NILU full programme review

The *2016 NILU Report*[3] reviewed the full (12 in this instance) national air monitoring sub-programmes, with particular focus on the 'acidifying and eutrophying substances' (EMEP/LNKN) and 'modelling' (MATCH) programmes. It reviewed each programme with an introduction describing the activities involved, legislative requirements, data relevance, institutional control, financial issues and organisation, strengths and final comments and recommendations.

Acidifying and Eutrophying components in air and precipitation. This includes both EMEP and LNKN measurements (previously separate). The report notes that EMEP monitoring in Sweden has been historically of high quality with a large number of high-intensity sites, yet has recently been reduced to what are seen as minimum standards for EMEP implementation. Nevertheless the long history of activity and high frequency of measurements make it an important data series, which feeds into the MATCH-Sweden modelling. Currently there are no high altitude measurements, but these would greatly benefit the monitoring system. The report suggests that the passive, lower-frequency sampling carried out at LNKN sites is questionable for quality and application, particularly for supporting MATCH modelling. Therefore, it recommends reducing low intensity monitoring (LNKN) to increase the number of the higher resolution sites (EMEP). The in-depth report suggested the sub-programme has no strong national coordination and strategy with data collection varying greatly. The report found no unnecessary site duplication, yet recognised that some sites are relatively closely located so a geospatial investigation is required to better guide site density requirements. It identified the potential to reduce the number of low-intensity sites with an increase to high-intensity sites that fit into model usage to cover spatial loss. It was suggested that EMEP, LNKN and SWETHRO-NV could be moved to one programme to cover all requirements and allow for better coordination. It also highlighted the possibility to move ground measurements to another programme, and focus only on atmospheric and deposition measurements within this programme.

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[3] NILU Evaluation of the Swedish national air monitoring programme "Programområde Luft" (2016)

SWETHRO-NV. This is a national effort to monitor atmospheric deposition to forests, feeding into the ICP-Forest data. However, due to forest ecosystems being very important for trade and biodiversity in Sweden the focus is predominantly towards the national interest. The SWETHRO-NV is the SEPA (NV) funded part of the wider SWETHRO network, with the network wide data well used by IVL scientists. Recent changes of analysis timing have made the SWETHRO data consistent with the LNKN data, however, the data is currently not used in the MATCH system. Current challenges in funding, distributed nature of site operation and limited central coordination make the programme difficult to steer and so it might be considered beneficial to bring under national organisation.

MATCH Sweden. This is a model used to estimate air concentrations, and wet and dry deposition of major inorganic compounds (plus ozone). SMHI developed and run the model with funding from SEPA. The results are used to create a high-resolution map of exposure/deposition, decoupling the domestic and foreign sources, while providing an opportunity to forecast future emission exposure in trends in the data. A similar system is available through the EMEP and would be available on request, yet does not contain the same detail and assimilation of national measurements. The MATCH system provides a valuable national merit and as such is a benefit to Sweden and international interest. The results are easy to access and presented in a way which is attractive for users. The report suggested improvements are possible with a focus on programme site consolidation to high-resolution sites (estimated as 10 required) and less low-resolution sites.

Contribution to the current review…

The outcomes of the 2016 NILU Report provide several of the starting points from which the current review has been developed. The recommendations to reduce spatial coverage in order to intensity measurements at fewer sites are contrary to the recommendations of the 2016 IVL report, and we considered this issue further in our review.

2.1.4. 2017 SEPA Report (Evaluation of EMEP condition)

The report[4] assesses the purpose and quality of the EMEP and LNKN programmes (combined as acidifying and eutrophying components in air and precipitation). The report does not provide recommendations for improvements only outlining the current system (i.e. locations and sampling procedure).

[4] SEPA Beskrivning av delprogrammet - Försurande och övergödande ämnen i luft och nederbörd (2017)

Contribution to the current review…

A useful reference document for detailed network sites and data.

2.1.5. 2018 IVL C286 data report

The report[5] assesses all acidifying and eutrophying data from 2001 to 2016. It highlights a gradient of deposition across Sweden, with values decreasing from the most populated Southwest to the Northeast. The critical load limit for nitrogen deposition to coniferous forest (5 kg ha^{-1} yr^{-1}) is exceeded annually in the southern half of Sweden, but there has been a trend of decreasing deposition since 2001.

Contribution to the current review…

The report shows the value of long-term monitoring and is a good basis for this project data analysis, being used to highlight key areas of data quality and coverage.

2.1.6. 2018 CABs survey

In February 2018, a survey was distributed to relevant authorities and county administrative boards (CABs) as a basis for this in-depth review. The purpose was to gain an understanding of what data are used and how the authorities feel the networks can improve. It found the most used data were nitrogen, sulphur and ammonia deposition data, with some use of ground-level ozone data and little use of air or soil water data. Each authority tends to only use local data to follow-up the environmental objectives, accessing a wide range of data sources (e.g. reports, emissions, SMHI Water web, IVL regional reports, etc). MATCH programme outputs are rarely used, but there is interest for increased use. Looking to the future, the main issues raised were focused on the organisation and funding, suggesting a central control is required for the sustainability of the network. Most suggest that every county needs at least one station (that would help in meeting environmental objectives), centrally maintained and funded by NV, complemented by regional stations.

[5] IVL C 286 Utveckling av en indikator för totalt nedfall av kväve till barrskog inom miljökvalitetsmålet Ingen övergödning (2018)

Contribution to the current review…

In summary, data from SWETHRO are used by local authorities and CABs to help inform progress in meeting environmental objectives, as well as data from the high resolution EMEP stations and the LNKN stations. MATCH data have been rarely been used to date, but the need for them might increase if monitoring stations are closed as a consequence of reducing budgets. There is a need for the potential application and value of modelling to be better communicated across a range of potentially interested stakeholders. Furthermore, there is a large demand for a national monitoring network that SEPA control and fund for the national interest.

2.1.7. 2018 IVL C360 National monitoring programme report

This report[6] presents the results from the activities within the National monitoring programme for air pollutants. Within the acidifying and eutrophying substances sub-programmes, the concentrations of pollutants in the air and precipitation during the last decades have decreased significantly due to international agreements to reduce emissions. Figures of change are provided. These demonstrate a declining pollutant concentration gradient from the Southwest to Northeast, with substantial reductions (often >50%) in concentrations of SO_2, NO_3 and NH_4 nationwide since the 1980s. However, sulphur deposition values at the Southwest coast remain above target levels.

Contribution to the current review…

The report shows the value in long-term monitoring and is a good basis for this project data analysis, being used to highlight key areas of data quality and coverage.

2.1.8. This project outline from the Swedish EPA 2018

Acidifying and eutrophying substances in Sweden have been monitored for several years, and the sub-programmes in the Swedish national air monitoring programme have been developed individually, although in many respects they cover the same substances. Consequently, the different station networks overlap in some cases. This is particularly clear for LNKN and SWETHRO-NV.

The air quality situation is quite different from the early days of monitoring. Deposition of sulphur has decreased to a large extent, with recent concentrations quite stable and generally below critical loads for acidity; thus a lesser number of stations could possibly

[6] IVL C 360 Nationell luftövervakning - Sakrapport med data från övervakning inom Programområde Luft t.o.m. 2017 (2018)

suffice. While nitrogen deposition has not seen the same decline as sulphur, there might be a need to refocus efforts to high deposition areas where critical loads for nitrogen as a nutrient continue to be exceeded. For today's needs, an in-depth review of the overlap between monitoring programmes, focusing on areas where problems still exist, should be identified and supported by an understanding of how modelling tools might be better used to a larger extent.

In the SWETHRO network, funding presents a further challenge in that the NV, the county administrative boards (CABs) and the air pollution management associations jointly contribute to the financing. Finances are currently allocated in a cost-effective way, but as financing possibilities decrease, several stakeholders might withdraw from the cooperation. Other co-financiers seldom manage to maintain a station on their own, and the station is therefore shut down. In recent years, a number of requests have been submitted for SEPA to take over monitoring stations when the CABs or air pollution management associations are no longer able to maintain them. In some cases, SEPA have done this temporarily or more or less permanently, especially when there are nationally important stations. However, this is not a sustainable situation in the long term. It has also been difficult to get an overview of the SWETHRO network and organisation, and as a consequence increased national governance has been requested. Yet the possibilities for national governance are small, as SEPA is only a part-financier among others.

The MATCH sub-programme is currently not used to its full potential. Discussions with the CABs indicate a low uptake of modelling results. With a higher time resolution at the monitoring stations, the possibilities for using the MATCH model might increase in general. It is important to continuously prioritize the development of MATCH in order to make it a useful tool, nationally as well as regionally.

2.1.9. Summary of previous reports and project outline

The previous reports summarised above have formed the foundation for this in-depth review of the acidifying and eutrophying networks. We find there is a clear desire for the currently disjointed legacy of historic programmes to come together under one unifying direction and purpose. The variety of data reports, current state analysis and stakeholder interest provides a broad set of information for us to use as a baseline for this report. From this baseline we have been able to delve in greater depth into the sub-programmes, their data output quality, the national and regional requirements and key stakeholders preferences, to provide recommendations that aim to draw together the fragmented legacy network to develop a more strategic and coordinated network, taking into account current and possible future financial constraints.

2.2. Communication with stakeholders

To develop a better understanding of key stakeholder engagement in the networks, we met with each stakeholder individually to discuss the current state of play and their ideas for future network design. The meetings were of significant importance to this report, highlighting the difficult position the networks are in, with each stakeholder presenting a strong case for the importance of their future priorities. From these interactions we have attempted to find recommendations that capture the views of each stakeholder, keep the integrity of the long-term data series intact, and strategically realign the networks in a way that is beneficial for national and regional Environmental Quality Objective (EQO) reporting, while being financially viable and logistically secure.

Below is a summary of discussions with the stakeholders and the key challenges facing the programmes.

2.2.1. Funding challenges

It is clear this report has been commissioned partly in response to financial pressures arising within the acidifying and eutrophying monitoring networks. Recent political changes have caused uncertainty in all publically funded environmental management and research areas, particularly environmental monitoring networks. SWETHRO-NV, LNKN, EMEP and MATCH are all funded by NV, so are subject to changes in government funding (as are the CABs). IVL and SMHI are currently contracted to manage their respective sub-programmes based on a fixed price for the entirety of the programmes. It has been suggested by SEPA that some aspects of the sub-programme data collection, analysis and handling could be conducted at a lesser financial cost within the local-authority remit. However, the true cost of this, allowing for the likely associated increase in central administrative cost, is still to be determined and on balance is suggested to be unlikely to lead to cost savings.

The SWETHRO programme has a complex funding system with many private and public stakeholders partly funding different aspects of the network. There have been concerns raised that a change in the structure or funding of SWETHRO might disrupt the current balance of the network, potentially leading to key parties withdrawing their support. However, funding to sustain SWETHRO is already under pressure, leading to the threat of site closures and requests for SEPA to take over administrative and financial responsibility. This is problematic given that SEPA already operates on a very tight budget. The current funding model therefore appears unsustainable in both the short and long-term.

2.2.2. Fragmented network legacy

As with many monitoring networks, the three sub-programmes examined here have grown and evolved over time, in response to a range of policy drivers, without clear strategic central oversight, direction and support. This has led to a number of challenges, including: multiple data hosts making data complicated to access; some monitoring sites being located near to others reducing spatial efficiency; complexity of funding streams constructing a fragile inter-dependent structure; and historical differences between monitoring protocols that make much of the data between sub-programmes difficult to compare (this has more recently begun to be resolved). The schematic of programme linkages highlights the complexity of the current sub-programmes (Fig. 1).

Some of the monitoring sites have a long history (>30 years), and provide highly valuable and effectively an irreplaceable time series of data. The national programme is now in a difficult position where some stakeholders want to prioritise continuing these valuable long term data series, whereas others strongly support altering the network structure to bring together a more coherent linked monitoring and modelling programme. A suitable middle ground taking on the concerns of both opinions must be found.

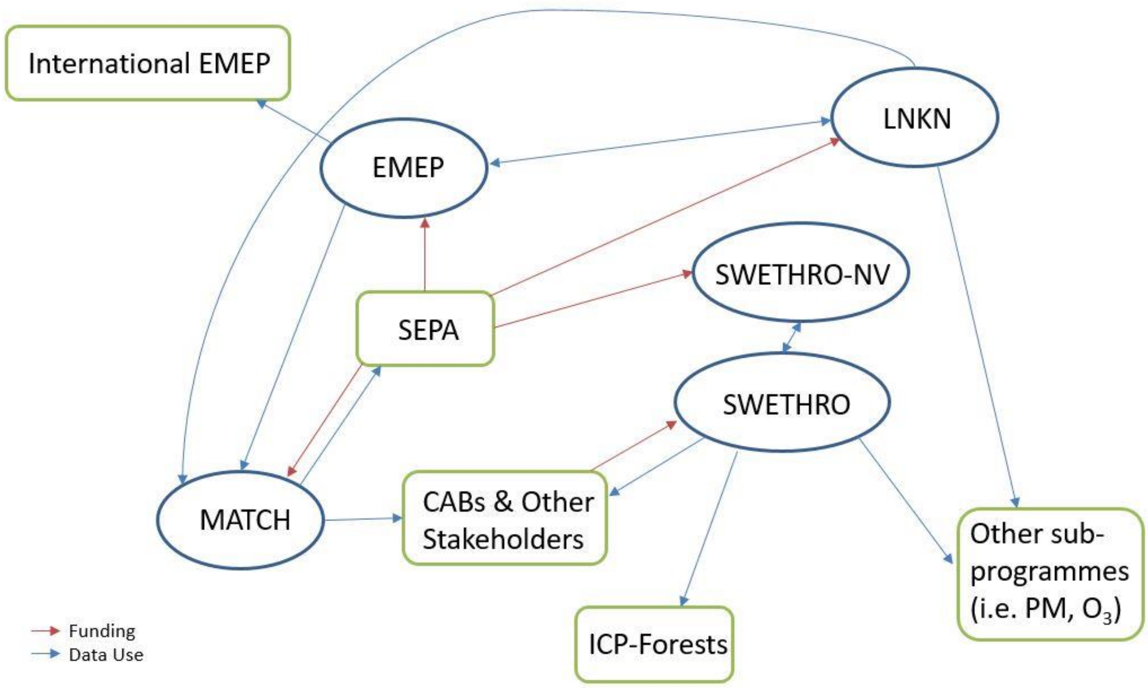

Figure 1. Schematic of data linkages and funding streams for acidifying and eutrophying substances network.

2.2.3. Sub-programme purpose and use

The data are largely used to meet international reporting requirements and regional environmental objective reporting. However, opinion on how each of the sub-programmes can meet these criteria and thus their relative importance differs between stakeholders.

Generally it was agreed that the current sub-programme structure is rather disjointed and, given a clean slate, it would be designed differently to meet current data needs and financial pressures. Yet, due to the longevity of the networks, some believed a transition to a new network would undervalue the significance of the networks, stressing the importance of protecting these valuable data series. Others suggested that with the fragmented data network, growing financial pressures and substantial inefficiencies in the current sub-programmes structure meant that there is a need to adapt the current programmes. These differences in perspective are discussed further below.

2.2.4. The Swedish EPA perspective

Following recent government budget cuts there is a concern that monitoring programmes, such as the acidifying and eutrophying deposition networks, will be under threat, especially if seen to be inefficient. It was made clear that a key purpose of the programmes is to meet international reporting requirements, specifically commitments under the EU National Emission Ceiling Directive. A second priority is to evaluate and demonstrate progress towards Sweden's 16 national environmental goals, specifically with respect to 'no eutrophication' and 'only natural acidification'. These are reported to the government on an annual basis. Annually, each county has the responsibility to provide a progress report to the NV, these feeding into the larger environmental goals national report, with an in-depth analysis produced every 4 years.

During discussion SEPA requested that the focus of the current report recommendations should be on approaches to improving efficiency, possibly through i) combining the sub-programmes into one coordinated monitoring and modelling programme; ii) redirecting funding to key high-value sites; iii) centrally controlling administration; and/or iv) promoting the increased use of MATCH model data for regional and national deposition assessment, in order to reduce reliance on primary data collection. The suggested 'super-site' expansion (i.e. more EMEP sites, as suggested in the 2016 NILU report) was not viewed favourably, because the high operating cost per EMEP site would severely limit the number of sites that could be maintained, and thus significantly degrade spatial coverage across Sweden. Better spatial coverage of lower-cost sites rather than a small number of 'high-tariff' sites was therefore preferred.

CEH have maintained ongoing contact and discussion with SEPA throughout the project. They have reviewed the recommendations proposed here prior to final report publication.

2.2.5. IVL perspective

From an IVL perspective, SWETHRO is a vitally important monitoring network that needs to be protected. It was noteworthy that IVL's interest focussed on SWETHRO as a whole network, not just SEPA funded sites or specific measurements. The primary delivery of EQOs was suggested to be through the SWETHRO network, namely total

N and S deposition to forests. On this basis, IVL staff were unclear as to why SEPA does not appear to value the programme as highly as others, especially as in their opinion financing just 14% of the network to meet EQO reporting is excellent value for money. Open field, throughfall and dry deposition (‘string’) sampling are seen as a good combination of methods to capture total atmospheric deposition loading to Swedish ecosystems. Soil solution was also felt to be a highly valuable measure, as this enabled the effects of reducing acidifying deposition to be evaluated in forest soils, and also supported associated modelling work. IVL reported that soil water ANC had briefly been included as an EQO, but that this had been discontinued after a year. They suggested that these data are greatly under-valued because it is not included as a key indicator.

The EMEP meets international reporting requirements and is therefore also of great national and international importance. Daily measures provide insight into perturbation assessment that cannot be achieved through monthly sampling alone. In response to the suggestion that daily sampling could be reduced to weekly sampling to save costs in order to release funds for other (e.g. more consistent spatially distributed) monitoring, they argued this is not suitable and the international EMEP may not support this change and thus that daily sampling should remain in place.

The LNKN has a good spatial coverage and long data record. The network began at the same time as SWETHRO running in parallel. It lacks throughfall data.

MATCH modelling in the opinion of IVL does not provide the same quality accuracy as the monitored data, and that the spatial resolution of current MATCH outputs is low compared to the interpolated maps produced from the measurement networks. They were keen to highlight that CABs use their monitored data, supplied through commissioned IVL reports. Questions were raised about SMHI’s reluctance to use the SWETHRO data within the MATCH model (see 2.2.6. SHMI perspective for response).

There was apprehension in discussing areas where possible funding adjustments could be made, with members of the IVL team remarking that there have been many reviews and funding cuts over recent years. They believe the programmes are at a point where additional cuts will undermine the spatial coverage and damage the value of the long-term data series. It was highlighted that removal of sites from certain programmes does not produce a proportional reduction in overall costs due to fixed costs and other sampling taking place at these sites. Furthermore, co-locating sites was not thought to be necessarily cost effective due to the subsequent methodological changes required at these sites, as well as the cost of moving, and in many cases sites were operated at low-cost by private individuals (such as retired scientists based locally) who could not easily be replaced, or asked to take on additional workload. Overall, they felt that the costs and risks of moving sites were likely to outweigh any financial benefit gained. There was a clear concern at the prospect of further cuts, and a view that the scientific and strategic value of the existing networks merited more rather than less investment from central government. It was suggested other agencies, such as the Swedish Agency for marine and water management (HaV) and the

Swedish Forestry Agency, use the data to meet their own objectives but do not pay towards the monitoring costs, and that these agencies should be approached to try to negotiate additional funds, rather than scaling back the networks.

Finally, data hosting was discussed. IVL provide a public data portal for the data they hold, which is not funded by NV. IVL reported that the data portal is well used by key stakeholders, such as CABs, with additional value coming from their commissioned reports.

2.2.6. SMHI perspective

SMHI believe the MATCH system is a unique and internationally significant model, which is of national benefit to Sweden. The SMHI team have strong connections across Europe, for example to EMEP and to other atmospheric modelling groups via EU projects and other international programmes. By comparison, their links to Swedish partners and stakeholders are less well developed, which appears to limit the extent to which MATCH model outputs are utilised by these groups, notably the CABs. SMHI representatives recognised this issue and expressed a desire to develop better relationships within Sweden, suggesting that a national forum for engaging with end users to tailor the outputs to their needs would be of great benefit for all.

A network of around 20 monitoring sites is considered to provide the ideal spatial coverage to run the MATCH model. Currently, LNKN and EMEP (plus 1 SWETHRO) sites are used, using monthly sample resolution data. The single SWETHRO site is used to fill a data gap for high-altitude regions. SMHI reported that additional SWETHRO sites are not required for model accuracy, partly because the computational requirements of the model calibration process increase dramatically as more sites are added. Adding more sites or changing sites would therefore be a time intensive process that would possibly require special project funding to complete. A redesigned network might be a good time to check and improve site selection.

The MATCH system does not use the SWETHRO throughfall measurements, because there are concerns over how well throughfall data represent the dry deposition component, as opposed to the effects of internal canopy cycling (particularly for nitrogen). SMHI expressed interest in string-sampling methods as an alternative source of dry deposition data.

SMHI also reported that the MATCH model does not require the daily deposition data collected at the two higher-resolution EMEP stations, and that monthly data are sufficient for the model (currently daily data is averaged to monthly as bulk sample).

The MATCH system is continually in development, and SMHI described a number of potential areas for improvement to add more value. Currently the website and data portal are undergoing an update to improve the user experience, and there is a drive towards improving the output resolution to a ~3 km grid. It is currently unknown how many (if any) additional monitoring sites would be required to confidently increase output resolution. These improvements would all be of benefit to the CABs as their main issues with the MATCH system were the lack of direct communication with SMHI, difficulties in accessing data via their portal, and the low spatial resolution of model outputs for regional-scale assessment (see 2.2.7. CABs perspective).

SMHI hold the contract from SEPA to supply the programme data portal. There were concerns about discrepancies between their data and that available through the IVL data portal, as was also noted by IVL.

2.2.7. CABs perspective

Representatives of the CABs suggested they would like more centralisation of data, with possible integration of sampling networks as they currently find them quite disjointed, making it difficult to collate data for regional reporting. Ideally they would like SEPA to control a single national network that has easily accessible data on a regional and national scale. They would then use their funding and advise the local management associations to fund more specific sites of interest in their region using their local knowledge. It was commented that the funding used by the CABs to support local SWETHRO sites comes directly from SEPA, albeit from a different source within the organisation. Therefore, SEPA indirectly funds more than the 14% of the contribution that the SWETHRO network receives directly.

Many CABs purchase IVL's county-level data reports, using these as their main tool to assess their regional metrics. These reports were considered to be well designed, informative and comprehensive. The CABs do not currently make full use of the MATCH system outputs, due to their low spatial resolution and difficulties in accessing the underlying data (as distinct from summary maps, which do not provide sufficient detail). The MATCH outputs are therefore mostly being used as secondary evidence source, to provide a cross-check on the interpolated measurement network data produced by IVL. Links were evidently strong with IVL, as the main evidence provider and as an effective 'intermediary' between the CABs and the SEPA. Links between the CABs and SMHI were not strong, as was also noted by SMHI. There was however a clear desire for more direct communication from SEPA and SMHI. The suggestion of a national forum for CABs, SEPA and SMHI (i.e. government funded authorities), as well as IVL and other interested groups (including other government agencies) was proposed, to be able to discuss needs, share advice and begin to feel part of the wider national picture. This would also support greater alignment and integration of monitoring and related activities among the different CABs.

3. Recommendations

3.1. Overview of networks

3.1.1. Redesigned network

Recommendation 1:
Redesign sub-programmes to a single SEPA funded network (see 3.2. for more details).

The primary recommendation from this report is for a redesigned acidifying and eutrophying programme that can be fully supported by SEPA. The aim of the redesigned network is to ensure that the legacy of the previous networks is maintained, while effectively rearranging site inclusions to form a new strategic, financially viable, sustainable and integrated programme of monitoring and modelling. The redesign would incorporate the EMEP, LNKN, SWETHRO-NV sites and the MATCH model into one network. Importantly, the proposed changes are intended to avoid detrimentally impacting the integrity of long site time-series, and to provide a mechanism that will continue to support the wider funding network (i.e. SWETHRO), albeit via a realigned programme structure. Specific information about how the redesigned network would function, what sites are suggested to be included and how the programme would be sustainably financed are provided below, for two funding scenarios requested by SEPA: current funding and 30% reduced funding (see sections 3.2.).

We have provisionally referred to the redesigned network as 'LNKN+'. This is intended to highlight a distinction in the network design (i.e. incorporation of other programme sites), while keeping the historical legacy of the network in place. Renaming the network might not be necessary, or an alternative new name to clearly distinguish the changes made may be preferred.

There are a number of other authorities and organisations that use data from the sub-programmes reviewed here. Initially it was suggested SEPA could approach these users to request co-funding the programmes. However, recognising some of the potential difficulties entailed and the desire of SEPA to control their own funding streams to meet national baseline reporting requirements, this recommendation has not been taken forward. It must be noted however that the redesigned network should not detrimentally affect the delivery of data to other agencies or to the other funders of the SWETHRO network. Rather, it is intended that the revised national monitoring programme described should form a stable baseline network and platform for additional measurements, sites and research activities. This should create a situation whereby any additional funding that is available can effectively add value to the network, without exposing the core programme to the risks that derive from having multiple funding sources. According to this approach, funding outside of SEPA's direct control, such as CAB and air quality association support for the wider SWETHRO network, can continue largely as before, providing excellent added value to the national picture.

3.1.2. Data hosting

> ***Recommendation 2:***
> *Data hosting alignment and removal of inconsistencies.*

Discrepancies between the parallel databases hosted by SMHI and IVL are of significant concern to all parties, and there is a clear need to quickly and effectively resolve the differences between the two data sets, which are related to the quality assurance and gap-filling of raw data. It should be noted SMHI hold the official data host assignments (data host for air quality: www.smhi.se/datavardluft, and data host for modelled atmospheric chemistry: http://www.smhi.se/data/miljo/atmosfarskemi) and IVL download from the national database combining this with their own data. However, having two data sets is proving to be complicated, especially considering there are inconsistencies in the data. This inconsistent data must be resolved with clear information as to what processing and quality assurance has taken place in the data.

3.1.3. Communication

> ***Recommendation 3:***
> *Regular network communications and creation of a national forum event.*

Communication to data end-users currently is an important part of network success and buy-in. Improvement of communication methods and frequency is needed to ensure the network is developing in the right way for the needs of those that use it. Introduction of regular communications from SEPA (and possibly SMHI) to end-users (e.g. CABs) to update the network of any developments, insights or future events should become a priority. Furthermore, the creation of an annual national forum for all end-users to attend would greatly increase the buy-in to the network. A forum would enable stakeholders to share information, ideas and feel part of the wider national picture, while enabling NV, SMHI and IVL to communicate developments and build a better working relationship and trust with the end-users.

3.1.4. SMHI and IVL

Recommendation 4:

Create a platform for SMHI and IVL to work closer together.

There was an evident lack of direct collaboration in this area between SMHI and IVL, in part because the institutions are having to effectively compete for limited and decreasing financial resources. These two institutions are both excellent at what they do, are a great asset to the Swedish air pollution monitoring programmes, and add a great deal of value to these programmes via their closely aligned, and independently funded, research activities. It is worth noting that many of these activities (both modelling and primary research) rely strongly on the core monitoring programmes, but that it is notoriously difficult to secure external (e.g. research council or EU) funding to support long-term monitoring. These funding sources are also inherently short-term (e.g. 3-5 years) so they cannot in any case provide a sustainable financial basis for the core measurement programme.

It seems clear that the limited interaction between SMHI and IVL is holding the programmes back from working to their full potential. Principally we believe this reflects the perception that they are having to compete for the same limited resource, rather than working jointly on a single programme. A transition towards coordinated working on an integrated measurement and modelling programme has the potential to enhance working relationships and communications, to the overall benefit both institutions and to the NV's wider project aims. Resolution of outstanding concerns, such as data hosting discrepancies and site selection for model calibration, are areas where that could be addressed in the first instance, building on existing moves by IVL to align sample collection dates for LNKN and SWETHRO to ensure comparability for use in modelling and other assessments. The move towards higher spatial resolution of MATCH model outputs should also enhance the extent to which the model outputs can be compared to site observations and interpolated maps, raising the possibility that MATCH outputs could be included in the well-regarded reports produced by IVL for the CABs.

3.1.5. MATCH model

Recommendation 5:

Integrate MATCH into redesigned network with calibration to the network site locations. Plus, improve output resolution and website usability.

The MATCH Sweden model is continually undergoing development and improvement. The MATCH model should be further integrated within the redesigned programme. Integration will improve the programme value while removing the blockages limiting others engagement in the output data. In order to integrate fully, the MATCH model should be recalibrated using the site locations in the redesigned network (see section 3.2.), while providing the monitored and modelled data in an easy to use online data platform. The data host is currently undergoing improvement, and this task should be made a high-priority to improve the accessibility and end-user experience, with easy to use national and regional data visualisation. As noted above, for the model to become more valuable to end-users such as the CABs, the output resolution should be improved to the target of ~3km grids (currently ~20km grids).

3.2. Sub-programme redesign

Merging programmes

We recommend merging key parts of the sub-programmes (EMEP, LNKN, SWETHRO-NV and MATCH) into one strategically aligned programme. This has been suggested as a possible option in previous reports and seemed to be favourably received during discussions with some stakeholders (although not all). To aid the merging of the sub-programmes we suggest the redesigned programme should be rebranded with an appropriate new name; for the purpose of this report we are referring to the redesigned programme as LNKN+.

While it has been suggested that the MATCH model sub-programme should remain as a separate sub-programme, we recommend its inclusion in the new programme design. This will facilitate more direct connections with the other areas of the programme and thus help the uptake of model use and encouraging those who access the data to make the most of the valuable insights the model can provide. It should also add value to the programme through greater alignment of measurements and modelling, and through greater collaboration between IVL and SMHI as key programme delivery partners, as described above.

Site Value Prioritisation

The rationale for the structure of the LNKN+ (redesigned programme) is based on the following sequence of steps:

Firstly, all current sites were mapped, with key information gathered for each (Fig. 2).

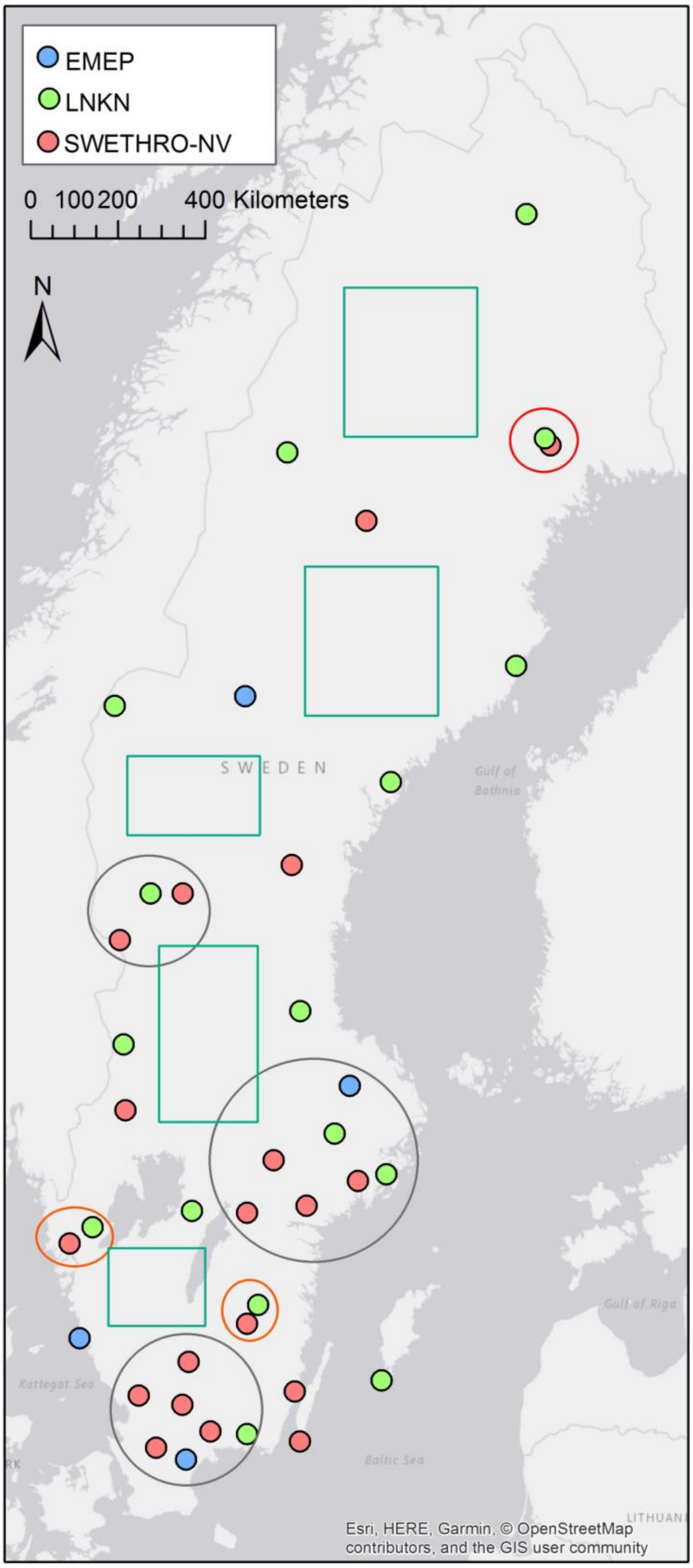

Figure 2. Map of current monitoring site locations and their related sub-programmes. Grey circles represent clusters of sites. Green rectangles represent areas of data sparsity. Red circle shows sites from different networks located in relatively close proximity.

Next, in order to determine the best structure for LNKN+, an in-depth review has focused on three categories for network assessment: data quality, site location and financial restraints (Fig. 3).

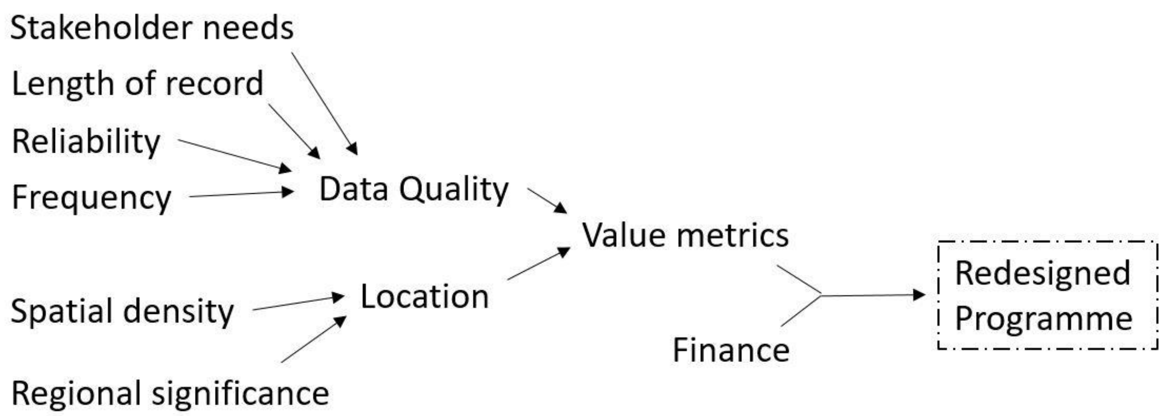

Figure 3. Value metric development tree. This method was used to determine the importance of current sites and how they fit within the various financial scenarios for the development of the new programme proposal.

Assessment of *Data quality* involved rating the stakeholder and scientific needs, length of data record, data reliability (i.e. anomalous or missing data) and frequency (i.e. number of samples at each site) of each monitoring site to score their importance in the network. *Location* refers to the spatial density (i.e. distance to nearest site), regional significance of site (i.e. site density and distance to EMEP site) and national gradient (i.e. south to north deposition gradient) for scoring. Sites were assigned to regional clusters to ensure regional representation was protected when cross-referencing site inclusion and relative location metric values. *Regional significance* took into account the importance of the southwest to northeast gradient of deposition history and population density, and placed most weight on sites in the southwest. Additionally, sites were assigned a financial cost value based on the estimated annual cost to sustain the site, and the relative cost of each site compared to the average network site cost. This score was based on budgetary information provided by IVL.

The scoring systems were combined to create a weighted site importance rank to inform decisions on which sites are of highest value to keep and which are of lesser value to the national programme and thus may be removed with less significant impact (Table 2, with detailed scoring system breakdown in Appendix 1).

Table 2. Value scoring table for current sites in Swedish air monitoring network.

Site	County	Network	Data quality	Location	Finance*	Total Score (avg.)
Norunda	Uppland	EMEP	4.8	4.3	4.0	**4.4**
Hallahus	Skåne	EMEP	4.5	4.0	4.0	**4.2**
Råö	Halland	EMEP	4.3	4.0	4.0	**4.1**
Grankölen 1	Norrbotten	LNKN	3.5	3.3	5.0	**3.9**
Sännen	Blekinge	LNKN	4.5	3.3	4.0	**3.9**
Bredkälen	Jämtland	EMEP	3.5	4.0	4.0	**3.8**
Majstre / Hoburgen	Gotland	LNKN	3.5	4.0	4.0	**3.8**
Ryda Kungsgård	Uppsala	LNKN	4.3	3.0	4.0	**3.8**
Rickleå	Västerbotten	LNKN	4.5	3.7	3.0	**3.7**
Pjungserud	Västra Götaland	LNKN	3.3	3.7	4.0	**3.6**
Sandnäset	Jämtland	LNKN	4.8	3.0	3.0	**3.6**
Jädraås	Gävleborg	LNKN	4.3	3.3	3.0	**3.5**
Blåbärs-kullen	Värmland	SW.-NV	4.3	3.3	3.0	**3.5**
Rockneby	Kalmar	SW.-NV	4.3	3.3	3.0	**3.5**
Ottenby	Kalmar	SW.-NV	3.5	4.0	3.0	**3.5**
Edeby	Södermanland	SW.-NV	4.3	3.0	3.0	**3.4**
Docksta	Västernorrland	LNKN	4.5	3.7	2.0	**3.4**
Transtrandsberget	Värmland	LNKN	3.8	3.3	3.0	**3.4**
Timrilt	Halland	SW.-NV	3.8	3.3	3.0	**3.4**
Fulufjäll	Dalarna	SW.-NV	4.0	3.0	3.0	**3.3**
Hensbacka	Västra Götaland	SW.-NV	4.0	3.0	3.0	**3.3**
Kvisterhult	Västmanland	SW.-NV	4.0	3.0	3.0	**3.3**
Höka	Östergötland	SW.-NV	3.3	3.7	3.0	**3.3**
Högbränna	Västerbotten	SW.-NV	3.8	3.0	3.0	**3.3**
Tagel	Kronoberg	SW.-NV	3.0	3.7	3.0	**3.2**
Esrange	Norrbotten	LNKN	4.3	3.3	2.0	**3.2**
Fagerhult	Jönköping	SW.-NV	3.5	3.0	3.0	**3.2**
Djursvallen, nedre	Jämtland	LNKN	4.0	2.3	3.0	**3.1**
Hissmossa	Skåne	SW.-NV	3.3	3.0	3.0	**3.1**
Ammarnäs	Västerbotten	LNKN	4.0	3.0	2.0	**3.0**
Komperskulla	Blekinge	SW.-NV	3.0	3.0	3.0	**3.0**
Stenshult	Skåne	SW.-NV	3.0	3.0	3.0	**3.0**
Storulvsjön	Västernorrland	SW.-NV	4.3	3.7	1.0	**3.0**
Farstanäs	Stockholm	SW.-NV	3.5	2.3	3.0	**2.9**
Granan	Västra Götaland	LNKN	4.3	3.3	1.0	**2.9**
Grankölen 2	Norrbotten	SW.-NV	2.8	2.7	3.0	**2.8**
Sör-Digertjärn	Jämtland	SW.-NV	3.3	2.0	3.0	**2.8**
Tyresta	Stockholm	LNKN	2.8	2.3	3.0	**2.7**
Norra Kvill	Kalmar	LNKN	4.0	3.0	1.0	**2.7**

*SWETHRO-NV finance does not include personnel sampling costs, except for Storulvsjön

Location analysis

Generally there is good spatial coverage in each network. However, with the combination of networks there is some clustering and duplication of sites that should be considered in the redesigned network. Most notably:

- Majstre and Hoburgen are currently listed as two separate LNKN sites in most documentation, yet are only 1 km apart and do not measure the same proxies, we therefore suggest they are considered as one site.
- Grankölen has both an LNKN and SWETHRO-NV site. We suggest these sites should be combined to one site in the network redesign.
- We have identified five clusters of sites (see grey circles on Fig. 2):
    - Granan and Hensbacka
    - Norra Kvill and Fagerhult
    - Djursvallen, Sör-Digertjärn and Fulufjäll
    - Tagel, Timrilt, Stenshult, Hissmossa, Komperskulla, Sännen and Hallahus
    - Höka, Edeby, Farstanäs, Tyresta, Kvisterhult, Ryda Kungsgård and Norunda
- We have also identified five areas where site coverage is sparse and additional sites may be considered (see green rectangles in Fig. 2):
    - Area north of Borås, Götaland
    - Area around Fredriksberg, Dalarna
    - Area around Svenstavik, Jämtland
    - Area around Fredrika, Västerbotten
    - Area around Skaulo, Norrbotten

Site locations were scored for value metric assessment (Table 2) and are discussed in relation to other metrics below.

Data analysis

Data were downloaded from the Datavärdskap för luftkvalitet website[7]. Wherever available, all data for base cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} and NH_4^{+}) and acid anions (SO_4^{2-}, NO_3^{-} and Cl^{-}) were retrieved for all sites. For the primary assessment of data duration, frequency of measurements and data quality we focussed on samples for which data for all nine constituent variables had been reported. Determination of data duration for EMEP and LNKN sites were considered in the context of the longer time series available, several of which begin in either 1983 or 1994. Data duration of SWETHRO sites was assessed relative to the maximum length of data runs for these sites (i.e. 2000-2017).

Time series of ion balances for most sites are presented in Appendix 2. These balances are mostly highly consistent over time. There is a general tendency for positive deviation from the zero line, possibly reflecting the influence of alkalinity which is not available and hence not included in the balance. There is some variation in deviation from the zero line, with some sites (e.g. Norunda, Granan, Sandnäset and Sännen) showing minimal deviation, while others (e.g. Råö, Bredkälen, Fagerhult, Farstanäs and Högbränna) show greater ranges.

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[7] www.smhi.se/datavardluft

Appendix 2 highlights sites with interrupted time series, relatively low frequencies of data collection and relatively short runs of data. However, with the exception of a very small number of extreme values, the concentrations of major anions and pH at individual sites are consistent over time and indicative of high quality data spatially and over time across all networks.

The data illustrate the wide range in annual volume-weighted mean concentrations of non-marine sulphate across all sites. Nearly all sites show clear long-term declines, but although concentrations have fallen most rapidly at the more polluted sites in the south of the country, a significant north-south gradient remains for the 2017 data. There is strong coherence in the non-marine sulphate signal across a wide geographical area, demonstrating the dominance of a regional-scale sulphur deposition field. These temporal patterns are particularly well correlated ($r^2 > 0.9$) in the case of certain relatively local pairs of sites (see Appendix 2).

More generally, volume weighted mean concentrations of nitrate and chloride show considerably less coherence than non-marine sulphate, and sites are less well correlated with each other (see Appendix 2). This emphasises the greater importance of more local inputs of these ions, e.g. from industry, agriculture and marine salts. Overall, therefore, there is little evidence for sites that have sufficiently similar deposition chemistry for easy decisions to be made concerning redundancy.

Site data were scored for the value metric assessment (Table 2) and discussed in relation to other metrics below.

Financial analysis

The financial analysis reviewed the current and 30% reduced budget scenarios. The current (SEPA) budget for all sub-programmes is shown in Table 3, with average site costs and contract structure.

Table 3. Current financial overview

Sub-Programme	Total cost (SEK)	Number of sites	Average cost per site
EMEP	2555000	4	**638750**
LNKN	817000	16	**51063**
SWETHRO-NV	624500	19	**32868***
MATCH	650000	n/a	**n/a**
Total	**4646500**		

LNKN sites Majstre and Hoburgen are counted as one site here due to proximity (see text for more information). * SWETHRO-NV site costs do not include personnel sampling costs, except for 1 site, implications discussed in text.

The EMEP network dominates the total budget, representing a 55% share. Of the 2,555,000 SEK budget for the EMEP network, 1,765,000 SEK (69%) is for analytical costs. This seems a disproportionally high cost for just four sites. The high costs are due to the daily measurements of precipitation taking place at the EMEP sites, yet following discussion with other members of the EMEP network we question the necessity of these daily precipitation measurements. Daily measurements do provide a high-resolution data; however, we believe that the additional benefit for deposition time series trend analysis compared to weekly (or even bi-weekly) sampling does not justify the additional cost, especially when compared to the costs of operating the lower-frequency, more spatially extensive LNKN and SWETHRO networks. Additionally, the MATCH system does not utilise the daily data, which are aggregated to a monthly time series. Therefore, a key recommendation for the redesigned network design is to change the EMEP stations from daily precipitation sampling to weekly precipitation sampling (we also suggest changing the monthly precipitation sampling at the other two sites to weekly sampling, to achieve consistency). This adjustment in sampling frequency would significantly reduce the overall analytical costs related to the network. Here, we have conservatively estimated this to be a 40% reduction in analytical costs (based on a representatively higher priced LNKN site multiplied by 4.3 to account for monthly to weekly sampling, plus an error margin). The reduction in analytical costs may vary from this figure, however we have remained cautious with the reduction based on the information made available to us.

A 40% reduction in analytical costs releases 706,000 SEK per year for the wider LNKN+ network. The implications of this are discussed below for each future funding scenario addressed in this report.

The LNKN network has a range of individual site costs, predominantly driven by personnel costs, ranging from 36,477 - 78,537 SEK per year (see Appendix 1). Seven of the sixteen sites do not currently measure air quality. It is estimated the average costs of adding air quality to each site would be 11,377 SEK per year (based on average difference in price between sites that contain air and bulk sampling and those that contain only bulk sampling). Addition of air measurements at all sites is discussed below with reference to future finance scenarios.

The SWETHRO-NV sites have a set budget allocation based on the sampling they conduct. A number of sites conduct different sampling collections with one or multiple of bulk (open field precipitation), throughfall, string sampling, soil solution and air quality measurements. The budget information provided for this report shows bulk sampling costs of 18,490 SEK and string sampling costs 13,910 SEK. Other analysis costs cannot be separated from each other. Due to the set budget price per sampling protocol, the costing analysis between sites is even amongst the SWETHRO-NV sites, except for the site Storulvsjön that has provided the additional costs for personnel sampling estimated to be 65,070 SEK (calculated as total cost of site, minus the similar sampling site cost of the Ottenby site and string sampling) as this sampling is not conducted by the local authority boards. This personnel cost seems potentially quite high and should be reviewed. Furthermore, assessment of personnel costs to the local authority boards and the potential to move costs within this programme should be considered for a true representation of programme cost, this is considered below.

We suggest simplifying the sampling taking place with direct funding from the LNKN+ network, primarily in order to fund the same core measurements (i.e. those required for EQO reporting) at all sites. Funding of bulk sampling only at each SWETHRO-NV site would cost 351,310 SEK, while string sampling would cost 264,290 SEK. Therefore the cost, required to cover both wet and dry deposition measurements would be 615,600 SEK. This is slightly lower than the 624,500 SEK total cost of the measurements currently supported by SEPA at the 19 SWETHRO-NV sites. Implications and recommendations for inclusion are provided below for each LNKN+ future funding scenario.

The LNKN and SWETHRO-NV networks financial costs were provided with additional network wide costs for management and reporting; these costs were shared evenly between sites in the network for estimated total site costs.

It was suggested that one potential way to reduce the cost of maintaining monitoring sites could be to move the data collection 'in-house'. This would involve SEPA taking on responsibility for organising, managing and reporting on all sites through a network of local data collectors, with IVL continuing to analyse samples. Moving site management in-house would release the large contractual obligation for collecting and reporting that might be completed at lower cost by local authorities and via other smaller contracts. On the other hand, IVL have long experience and expertise in performing this role, in quality checking data and in supporting the interpretation of results, all of which would potentially be lost if SEPA took over network operation. Issues such as data quality and sample handling would need to be addressed through wide spread and ongoing training and development. Furthermore the logistical and administrative costs of in-house network management are not currently fully constrained and may be higher than expected, resulting in little or no financial savings. Whilst reductions in per-site operating costs through changes in network operation might enable additional sites to be supported, which would clearly be a benefit to the LNKN+, any such change would carry a significant risk of a reduction in data quality and network reliability, and would require careful planning to ensure that anticipated cost savings are achieved. The potential loss of 'institutional knowledge' at IVL, and potential loss of co-funded research and modelling activities, could also have a severe detrimental impact on the value of the network. Therefore, we do not recommend that this option be considered further.

3.2.1. Redesign overview

We recommend that the redesigned LNKN+ network contains three types of monitoring station, each of which would have a national and regional spatial distribution. The three types are described in Table 4.

Table 4. LNKN+ site types description and intervals

Site type	Sampling	Interval	Notes
Type 1	Air and Bulk	Daily[1]/Monthly[2]/Weekly[3]	Historically EMEP, change to weekly precipitation sampling.
Type 2	Air and Bulk	Monthly	Historically LNKN, all sites upgraded to include air concentrations.
Type 3	Bulk and String	Monthly	Historically SWETHRO-NV, sampling changed at many sites.

[1] Air – inorganic components

[2] Air – Gas/particle distribution

[3] Precipitation

It is important to highlight that we are not suggesting any change to the air measurements of Type 1 sites from daily/monthly measurements. The change in Type 1 sites is from daily to weekly *precipitation* sampling, the addition of air measurements to 7 LNKN sites, and the addition of 9 string samplers to SWETHRO-NV sites. The network redesign would also require the addition of bulk deposition sampling at one SWETHRO-NV site, the cessation of SEPA funding for throughfall and soil water at 2 SWETHRO-NV sites each, and the cessation of funding for air concentration measurement from one SWETHRO-NV site. Although it is always a tough decision to remove long-standing sampling, the small number of these measurements currently funded by SEPA do not provide sufficient information of direct relevance to the SEPA objectives to support their inclusion in the redesigned LNKN+ network. This does not necessarily imply a recommendation to halt these measurements where they contribute to the broader aims of the SWETHRO network, however, and indeed we would strongly recommend the continuation of these sampling methods in the wider SWETHRO network if the (modest) alternative funding required can be obtained. These changes and estimated financial cost for the LNKN+ are provided in Table 5.

At each site we recommend adjusting the measurements taking place slightly. Air sampling measurements to be included are provided in Table 6, and bulk sampling (open field precipitation) measurements are provided in Table 7. Of note is the inclusion of total amount of precipitation, P-tot and alkalinity at pH >5.4 for all sites (previously only part of SWETHRO-NV sampling design). These analysis are important for flux estimates, quality assurance, and to identify contamination (such as bird strikes).

Additionally to the cost of the site measurements (Table 5), we recommend sustaining the MATCH system funding as is at present (650,000 SEK). This sustained funding should be based on the agreement to undertake the recommendations relevant to SMHI and the MATCH system, as well as improved integration of SMHI modelling and IVL measurements, set out earlier in this report (see section 3.1.)

Table 5. Sampling site type in redesigned LNKN+ programme. X = sampling already ongoing, O = sampling to be added to site. Estimated costs for each site with new LNKN+ sampling.

Site	County	Type	Air	Bulk	String	Est. cost (SEK)
Bredkälen	Jämtland	1	X	X		461,000
Hallahus	Skåne	1	X	X		491,000
Norunda	Uppland	1	X	X		521,000
Råö	Halland	1	X	X		481,000
Ammarnäs	Västerbotten	2	O	X		58,634
Djursvallen, nedre	Jämtland	2	X	X		58,967
Docksta	Västernorrland	2	X	X		68,057
Esrange	Norrbotten	2	O	X		57,774
Granan	Västra Götaland	2	X	X		78,537
Grankölen 1	Norrbotten	2	X	X		36,477
Jädraås	Gävleborg	2	X	X		54,887
Majstre / Hoburgen	Gotland	2	X	X		52,317
Norra Kvill	Kalmar	2	O	X		69,234
Pjungserud	Västra Götaland	2	X	X		52,747
Rickleå	Västerbotten	2	X	X		57,147
Ryda Kungsgård	Uppsala	2	O	X		50,714
Sandnäset	Jämtland	2	O	X		54,674
Sännen	Blekinge	2	X	X		53,937
Transtrandsberget	Värmland	2	O	X		54,264
Tyresta	Stockholm	2	O	X		53,644
Blåbärs-kullen	Värmland	3		X	X	32,400*
Edeby	Södermanland	3		X	X	32,400*
Fagerhult	Jönköping	3		X	X	32,400*
Farstanäs	Stockholm	3		X	O	32,400*
Fulufjäll	Dalarna	3		X	O	32,400*
Grankölen 2	Norrbotten	3		X	X	32,400*
Hensbacka	Västra Götaland	3		X	X	32,400*
Hissmossa	Skåne	3		X	X	32,400*
Högbränna	Västerbotten	3		X	O	32,400*

Höka	Östergötland	3	X	O	32,400*
Komperskulla	Blekinge	3	X	O	32,400*
Kvisterhult	Västmanland	3	X	O	32,400*
Ottenby	Kalmar	3	X	O	32,400*
Rockneby	Kalmar	3	X	X	32,400*
Sör-Digertjärn	Jämtland	3	X	O	32,400*
Stenshult	Skåne	3	O	X	32,400*
Storulvsjön	Västernorrland	3	X	X	97,470
Tagel	Kronoberg	3	X	O	32,400*
Timrilt	Halland	3	X	X	32,400*
			Total est. cost		3,546,676

*Does not include personnel sampling costs estimated to be 60,000 SEK per site

Table 6. Air measurements to be included in LNKN+ locations. X = sampling in place, O = sampling to be added to sampling design.

Inorganic components	Type 1 sites (EMEP)	Type 2 sites (All other)
SO_2	X	X
SO_4	X	
NO_2	X	X
O_3	X	X
NO_3+HNO_3	X	
NH_4+NH_3	X	
Cl	X	
Na	X	
K	X	
Ca	X	
Mg	X	
Gas / particle		
NH_3	X	
NH_4	X	
HCl	X	
HNO_3	X	
NO_3	X	

Table 7. Bulk (precipitation) measurements to be included in LNKN+ locations. X = sampling in place, O = sampling to be added to sampling design.

Inorganic components	Type 1 sites (EMEP)	Type 2 sites	Type 3 sites
Total Precipitation	O	O	X
SO_4	X	X	X
NO_3	X	X	X
NH_4	X	X	X
pH	X	X	X
Na	X	X	X
K	X	X	X
Ca	X	X	X
Mg	X	X	X
Cl	X	X	X
P-tot	O	O	X
Alkalinity	O	O	X
Conductivity	X	X	X

3.2.2. Scenario 1: Current funding

Overall spend available on the current budget is 4,646,500 SEK per year (Table 3). To fund all current sites with the redesigned sampling and MATCH will cost an estimated 4,196,676 SEK (Table 8). This leaves a remaining budget of 449,824 SEK. However, it is important to note this does not include personnel sampling costs for Type 3 sites.

Table 8. Current funding scenario LNKN+ site information and costs, keeping all sites currently active.

Site type	**Sampling**	**Interval**	**Number of sites**	**Est. cost (SEK)**
Type 1	Air and Bulk	Daily[1]/Monthly[2]/Weekly[3]	4	1,954,000
Type 2	Air and Bulk	Monthly	16	912,006
Type 3	Bulk and String	Monthly	19	680,670
Model	MATCH model	-	-	650,000
			Total est. cost	4,196,676

[1] Air – inorganic components

[2] Air – Gas/particle distribution

[3] Precipitation

Due to the changes in the EMEP site sampling frequency all currently active sites can be fully funded within the new sampling design, with budget remaining. Provided that this budget saving is realised following the network reconfiguration, it could be used to add string sampling to all type 2 sites, this providing dry and wet deposition at all sites. Based on the SWETHRO-NV budget of 13,910 SEK per string sample analysis there would be funding available to do this (222,560 SEK for 16 new string sample sites). Alternatively, the budget could be used to create a separate funding stream for additional 'added value' samples to be taken at some or all sites (e.g. it could be used to maintain measurements that have been removed from LNKN+ design, such as soil water and throughfall). We recommend making this a separate funding mechanism to avoid any confusion over what is and is not included in the LNKN+ network. Alternatively, additional LNKN+ sites could be installed with the remaining budget, possibly filling in some of the spatial gaps highlighted in Figure 2.

We also recommend the consideration of the following specific options for the final LNKN+ redesigned network:

- Removal of the Grankölen 2 (Type 3) site as it has a Type 2 site located there (note this may change the cost of the Type 2 site as is currently low priced possibly due to co-location of past network sites, needs confirmation).
- Removal of the Stenshult (Type 3) site due to clustering of type 3 sites in South.
- Conversion of Timrilt from a Type 3 to a Type 2 site to increase spatial distribution of Type 2 in that area that is dominated by Type 3.
- Renegotiation of Storulvsjön personnel sampling costs, because this is currently the most expensive site not designed as Type 1, yet is an important location for continued sampling.
- Addition of a Type 3 site to the area around Fredriksberg, Dalarna.
- Addition of a Type 3 site to the area north of Borås, Götaland.
- Addition of a Type 3 site to the area around Skaulo, Norbotten

If all of these changes are made the LNKN+ budget would be 4,253,676 SEK (without renegotiation of Storulvsjön personnel sampling costs; Table 9). The changes would improve the spatial distribution of the LNKN+ network and still come in under the current budget to be able to afford funding additional sampling or sites.

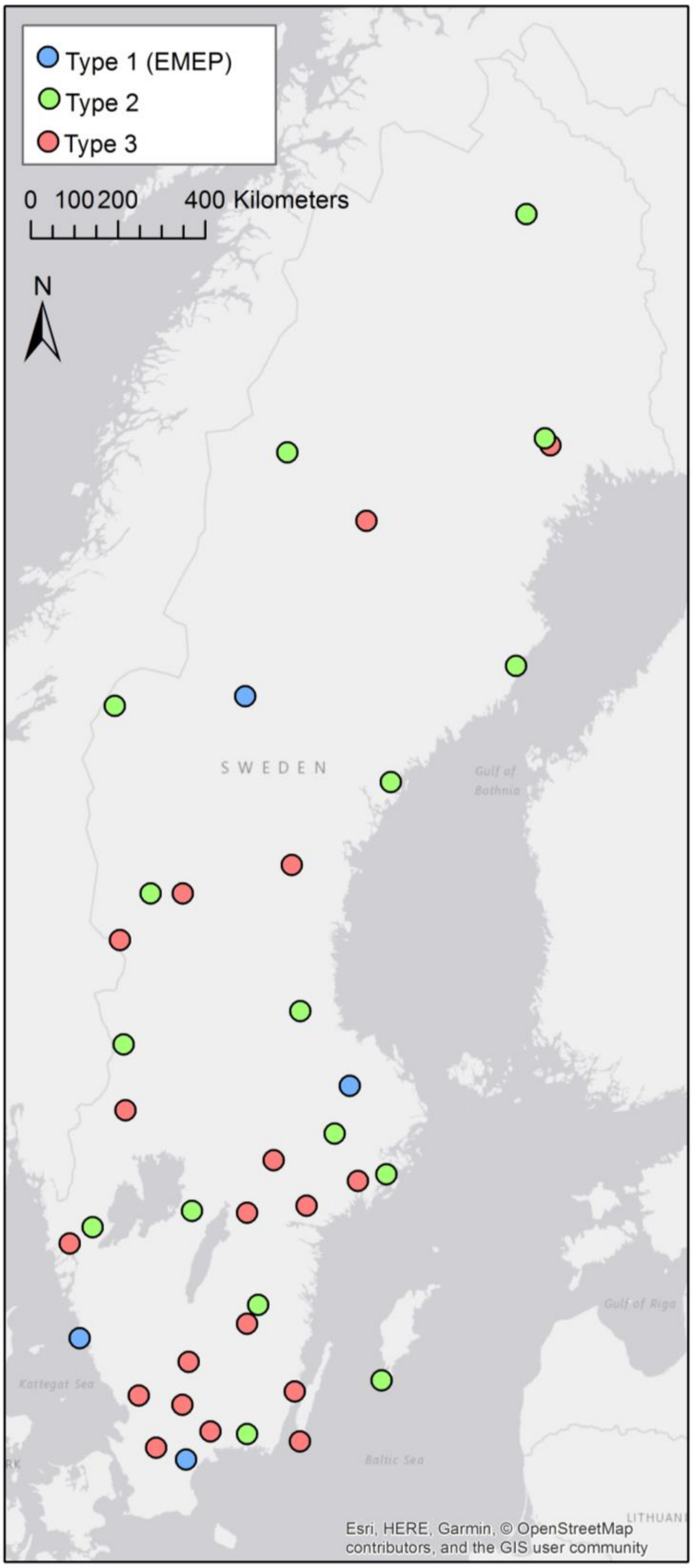


Figure 4. Map of current funding scenario LNKN+ site locations and types with continuation of all currently active sites.

Table 9. Current funding scenario LNKN+ site information and costs when changing sites as suggested above.

Site type	Sampling	Interval	Number of sites	Est. cost (SEK)
Type 1	Air and Bulk	Daily[1]/Monthly[2]/Weekly[3]	4	1,954,000
Type 2	Air and Bulk	Monthly	17	969,006
Type 3	Bulk and String	Monthly	19	680,670
Model	MATCH model	-	-	650,000
			Total est. cost	4,253,676

[1] Air – inorganic components

[2] Air – Gas/particle distribution

[3] Precipitation

Additional consideration of LNKN+ inclusion could also be given to the following sites.

- Removing the site Sör-Digertjärn (Type 3), because it is very close to the Type 2 site Djursvallen and near to the Type 3 site Fulufjäll.
- Removing the site Grankölen (Type 2), due to the relatively high cost and the close proximity of Hensbacka (Type 3).
- Removing the site Norra Kvill (Type 2), due to the relatively expensive cost and the close proximity of Fagerhult (Type 3).

These are not included in our recommendations here, yet maybe considered good options for the final LNKN+ design to release more funding for other sampling and/or sites.

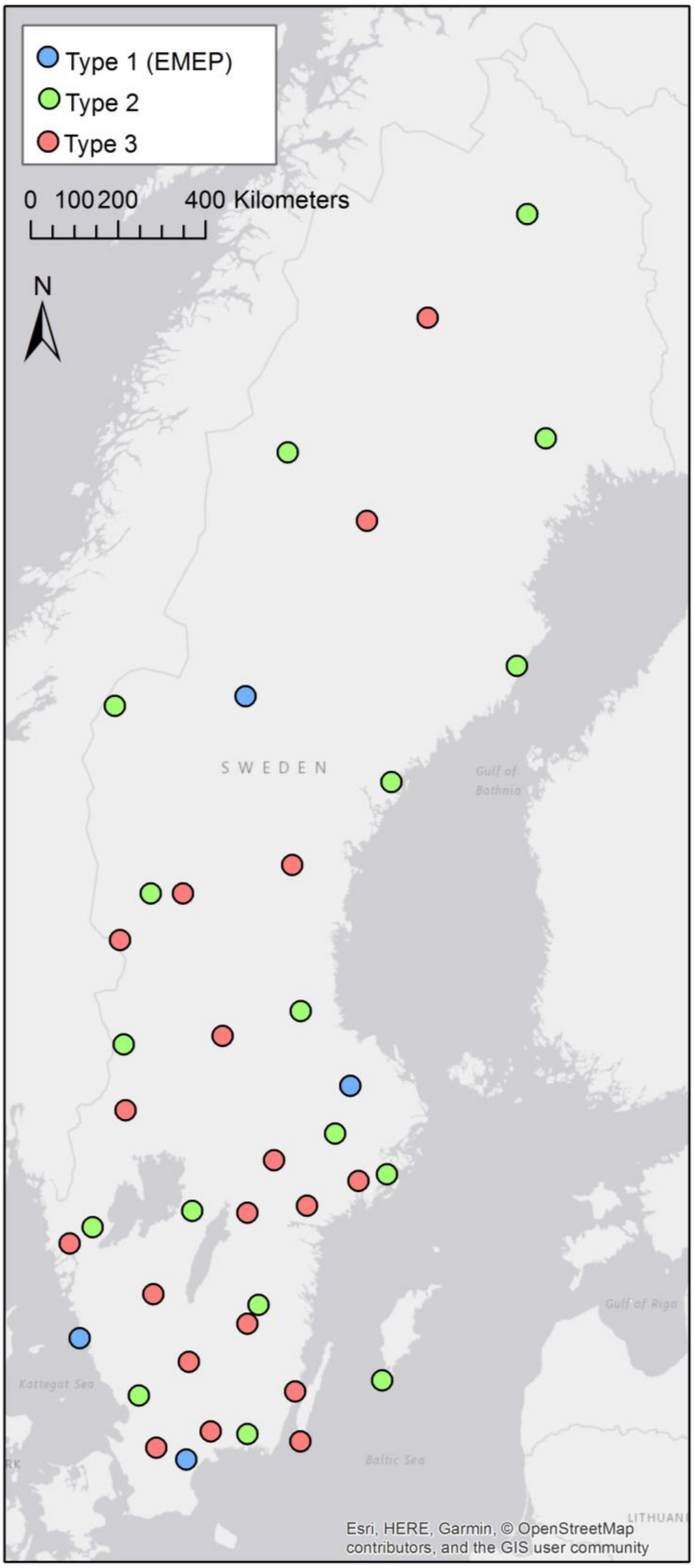


Figure 5. Map of 'current funding' scenario LNKN+ site locations and types with slight adjustments as suggested above.

3.2.3. Scenario 1: Current funding (inclusive of personnel costs)

An issue with the programme proposition above is the continued reliance on the local authority boards to fund the personnel sampling costs of the Type 3 sites (previously SWETHRO-NV). However, if the programme is to become fully self-funded so as to avoid any potential future funding challenges, then an estimated additional 60,000 SEK per site needs to be included in the figures provided in Table 5. The funding for the personnel sampling costs directly from the programme would increase programme resilience, but would also result in a financial shortfall in its current proposition. If 18 Type 3 sites (as Storulvsjön already includes personnel costs) received an additional 60,000 SEK funding for personnel sampling costs, this would create a 630,176 SEK shortfall. This is equivalent to 6 sites.

To ensure future programme resilience the option to include personnel sampling costs in the programme budget would be preferable. However this would certainly mean the optional extras discussed above with the surplus funding would not be possible, and 6 currently active sites would have to be closed. Removing funding and long-term monitoring from sites is clearly a decision not to be taken lightly, yet if this option was to be acted upon we would suggest the removal of funding from 6 Type 3 sites: Stenshult, Grankölen 2, Sör-Digertjärn, Farstanäs, Hensbacka, and Komperskulla (based upon scoring from Table 2 with additional consideration of higher financial cost resulting in a lower metric score).

If these 6 sites had funding removed the LNKN+ budget cost would be 4,717,206 SEK (Table 10), this just within the current budget limit.

Table 10. Current funding scenario LNKN+ site information and costs, keeping all sites currently active and including all personnel sampling costs.

Site type	Sampling	Interval	Number of sites	Est. cost (SEK)
Type 1	Air and Bulk	Daily[1]/Monthly[2]/Weekly[3]	4	1,954,000
Type 2	Air and Bulk	Monthly	16	912,006
Type 3	Bulk and String	Monthly	13	1,201,200
Model	MATCH model	-	-	650,000
			Total est. cost	4,717,206

[1] Air – inorganic components

[2] Air – Gas/particle distribution

[3] Precipitation

The changes would improve programme resilience, bringing funding to conduct all aspects of the programme within a central fund. It would inevitably reduce spatial coverage, but would not fundamentally threaten the integrity of the network (Figure 6).

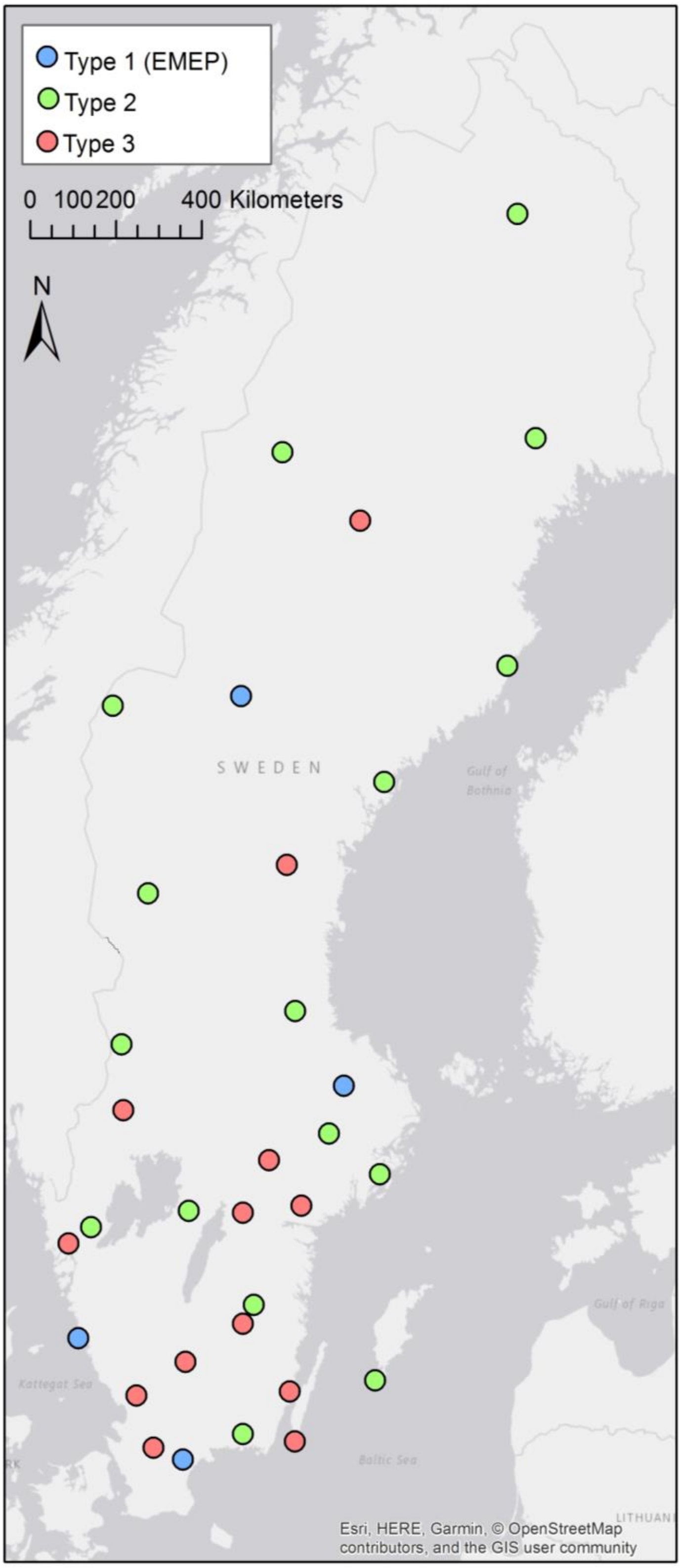


Figure 6. Map of current reduced funding scenario with 6 sites removed to fund personnel sampling for all LNKN+ sites.

3.2.4. Scenario 2: 30% reduced funding

Overall spend with a 30% budget reduction is 3,252,550 SEK per year. To fund all current sites with the redesigned sampling and MATCH will cost an estimated 4,196,676 SEK (Table 8), a shortfall of 944,126 SEK.

Despite changes not all active sites could be fully funded in this reduced budget scenario. Due to the significant funding restrictions, it would only be possible to fund 18 of the 39 sites (see Table 11), requiring closure of 21 sites (see Table 12). The number of closures would be increased if personnel sampling costs were added to the Type 3 sites as above. The closure of 21 sites would provide the required financial sustainability to the redesigned programme under the 30% cut scenario, but we consider that such a large reduction in spatial coverage would be highly undesirable, and could ultimately threaten the integrity of the programme, and of the reliability of model simulations based on the reduced dataset. In order to minimise these negative consequences, we tried to identify which sites had the lowest value to the redesigned programme, using the value metrics outlined above (Table 2), whilst also trying to maintain sufficient spatial distribution to support national assessment (note that detailed regional-level assessments would become difficult or impossible under this scenario). A 30% reduced budget LNKN+ design overview is provided in Table 13.

Table 11. Sites to be included in the 30% reduced funding LNKN+ redesign scenario. X = sampling already ongoing, O = sampling to be added to site. Estimated costs for each site with new LNKN+ sampling.

Site	County	Type	Air	Bulk	String	Est. cost (SEK)
Bredkälen	Jämtland	1	X	X		461,000
Hallahus	Skåne	1	X	X		491,000
Norunda	Uppland	1	X	X		521,000
Råö	Halland	1	X	X		481,000
Djursvallen, nedre	Jämtland	2	X	X		58,967
Esrange	Norrbotten	2	O	X		57,774
Jädraås	Gavleborg	2	X	X		54,887
Majstre / Hoburgen	Gotland	2	X	X		52,317
Pjungserud	Västra Götaland	2	X	X		52,747
Rickleå	Västerbotten	2	X	X		57,147
Blåbärs-kullen	Värmland	3		X	X	32,400
Edeby	Södermanland	3		X	X	32,400
Fagerhult	Jönköping	3		X	X	32,400
Grankölen 2	Norbotten	3		X	X	32,400
Hensbacka	Västra Götaland	3		X	X	32,400
Ottenby	Kalmar	3		X	O	32,400
Rockneby	Kalmar	3		X	X	32,400
Timrilt	Halland	3		X	X	32,400
					Total est. cost	2,547,037

Table 12. Sites that could not be supported under a 30% reduced funding LNKN+ redesign scenario

Site	County	Type
Ammarnäs	Västerbotten	2
Docksta	Västernorrland	2
Granan	Västra Götaland	2
Grankölen 1	Norrbotten	2
Norra Kvill	Kalmar	2
Ryda Kungsgård	Uppsala	2
Sandnäset	Jämtland	2
Sännen	Blekinge	2
Transtrandsberget	Värmland	2
Tyresta	Stockholm	2
Farstanäs	Stockholm	3
Fulufjäll	Dalarna	3
Hissmossa	Skåne	3
Högbränna	Västerbotten	3
Höka	Östergötland	3
Komperskulla	Blekinge	3
Kvisterhult	Västmanland	3
Sör-Digertjärn	Jämtland	3
Stenshult	Skåne	3
Storulvsjön	Västernorrland	3
Tagel	Kronoberg	3

Table 13. 30% reduced funding scenario LNKN+ site information and costs.

Site type	Sampling	Interval	Number of sites	Est. cost (SEK)
Type 1	Air and Bulk	Daily[1]/Monthly[2]/Weekly[3]	4	1,954,000
Type 2	Air and Bulk	Monthly	6	333,837
Type 3	Bulk and String	Monthly	8	259,200
Model	MATCH model	-	-	650,000
			Total est. cost	3,157,037

[1] Air – inorganic components

[2] Air – Gas/particle distribution

[3] Precipitation

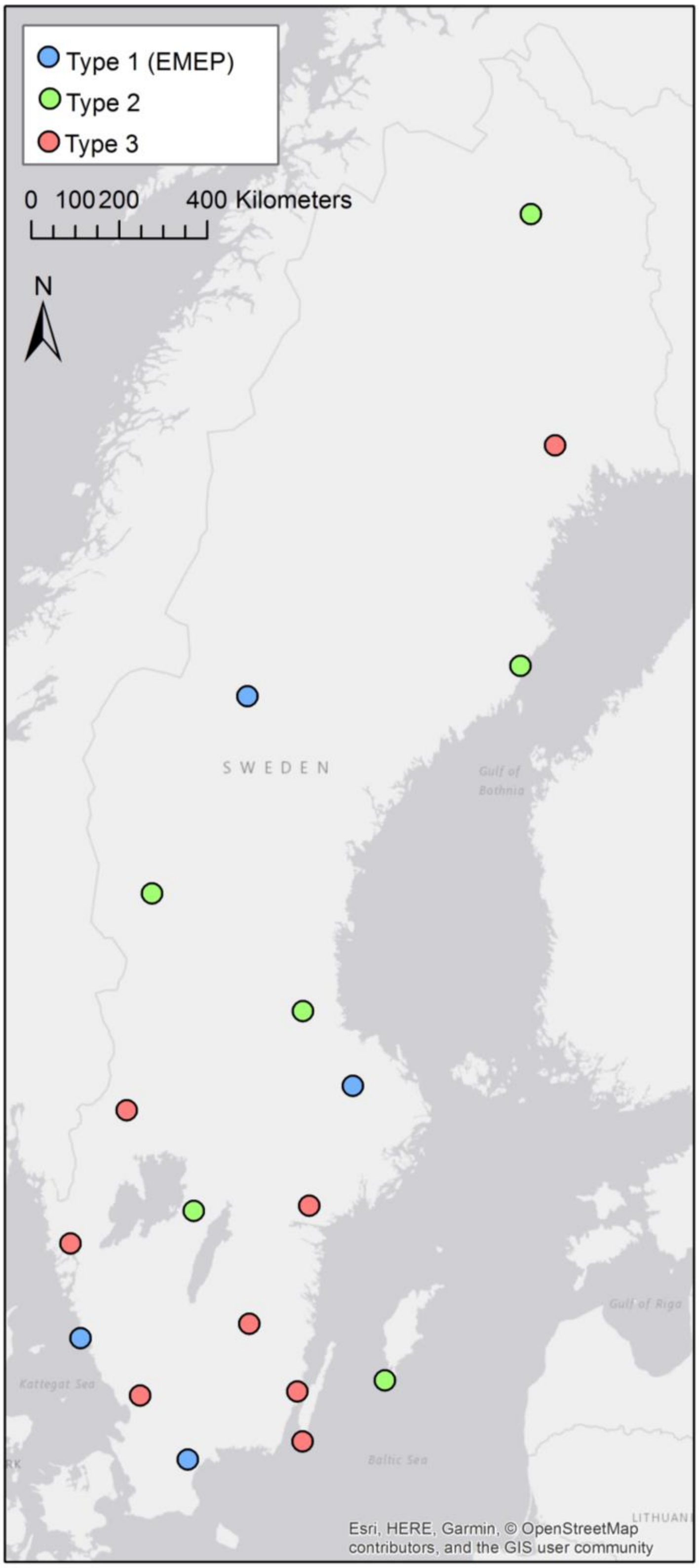


Figure 7. Map of 30% reduced funding scenario LNKN+ site locations and types.

Report summary

This report began by reviewing the past publications and speaking to key stakeholders to gather a better understanding of how the networks had developed and what challenges they now face. It was clear from this review that the three sub-programmes faced growing funding challenges to support a fragmented network legacy, with a complicated organisational structure. These challenges posed a significant risk to SEPA and their ability to sustain a national baseline monitoring network and report on their environmental quality objectives.

On this basis, we concluded that a redesigned network to strategically realign the programmes to form a baseline national monitoring network fully funded and controlled by SEPA was required. Two possible scenarios (current funding and 30% reduction in funding) were assessed for the redesigned network structure, with additional key recommendations proposed to add value to the network, such as the improvement of the data host, communications and collaborations, and MATCH model accessibility and uptake.

Metrics generated from an analysis of data, site spatial distribution and operating costs created a value metric system for individual site assessment and justification for inclusion to the redesigned network. The major recommendation was to change the EMEP sites sampling frequency from daily to weekly sampling; would reduce analytical costs circa 40%. With this large saving in analytical costs for two sites, all currently active sites can be fully funded, with the addition of sampling protocols at some sites to standardise the data being collected across the country. The new design comes in under-budget (with continued sampling by local authorities for Type 3 sites), allowing the possibly to create a new sampling fund for additional sampling measurements (e.g. string sampling in type 2 locations, or soil water sampling). The creation of a new funding source would allow for additional sampling to be better targeted across the country, while removing the risk of having to fund the sampling indefinitely with uncertain future financial support. An altered version of this redesign looked to fund all sampling through the programme to add further financial resilience would necessitate the removal of funding from 4 sites, representing a trade-off between network resilience and spatial coverage. Some further alterations to site location and design were provided to maximise the spatial coverage and remove redundant sampling costs.

The 30% reduced funding scenario presents a significant challenge to the programmes as a whole. The redesigned LNKN+ network under this funding scenario would provide spatial and data coverage for a ‘bare minimum’ national baseline network, but would have major detrimental impacts for regional assessment, added value research and the reliability of temporal and spatial modelling.

All the recommendations provided in this report have been developed with the information provided to us, using the best estimates of financial costs for different sites and activities that could be extracted from this information. Whilst we consider that the broad conclusions regarding overall network costs in each of the scenarios considered should be reasonable, it is likely that the true costs of adding or reducing sites or measurements will deviate to some extent from our estimates. Therefore, we recommend that a full budget assessment be undertaken by the NV, in collaboration with IVL and individual site operators, prior to the final implementation of any of the options proposed here.

Appendix 1

Appendix 1 Table 1. Detailed Value scoring table for current sites in Swedish air monitoring network.

Site	County	Network	Stake-holder needs i.e. is it used often?	Length of record Score (Years)	Relia-bility i.e. gaps	Frequ-ency i.e. proxies, timing	Data Quality Score Average	Spatial density Score (...km)	Regional significance Score (South, Central, North)	National gradient i.e. S to N gradient	Location Score Average	Site cost Est. annual cost	Financial Score[1] see footnote[1]
Bredkälen	Jämtland	EMEP	5	2	2	5	**3.5**	5 (130)	5 (N)	2	**4.0**	655000	**4**
Hallahus	Skåne	EMEP	5	3	5	5	**4.5**	2 (40)	5 (S)	5	**4.0**	610000	**4**
Norunda	Uppland	EMEP	5	4	5	5	**4.8**	3 (55)	5 (C)	5	**4.3**	615000	**4**
Råö	Halland	EMEP	5	4	3	5	**4.3**	4 (100)	5 (S)	3	**4.0**	675000	**4**
Ammarnäs	Väster-botten	LNKN	4	5	2	5	**4.0**	4 (96)	3 (N)	2	**3.0**	47257	**2**
Djursvallen, nedre	Jämtland	LNKN	4	5	2	5	**4.0**	1 (27)	3 (N)	3	**2.3**	58967	**3**
Docksta	Väster-norrland	LNKN	4	5	5	4	**4.5**	5 (134)	4 (N)	2	**3.7**	68057	**2**
Esrange	Norrbotten	LNKN	4	5	4	4	**4.3**	5 (201)	4 (N)	1	**3.3**	46397	**2**
Granan	Västra Götaland	LNKN	4	5	4	4	**4.3**	1 (31)	4 (S)	5	**3.3**	78537	**1**
Grankölen 1	Norrbotten	LNKN	4	4	3	3	**3.5**	5 (189)	4 (N)	1	**3.3**	36477	**5**
Jädraås	Gävleborg	LNKN	4	5	4	4	**4.3**	4 (102)	3 (N)	3	**3.3**	54887	**3**
Majstre / Hoburgen	Gotland	LNKN	4	5	3	2	**3.5**	4 (107)	4 (C)	4	**4.0**	52317	**4**
Norra Kvill	Kalmar	LNKN	4	4	5	3	**4.0**	1 (26)	4 (S)	4	**3.0**	57857	**1**

Pjungserud	Västra Götaland	LNKN	4	2	2	5	**3.3**	3 (66)	4 (S)	4	**3.7**	52747	**4**
Rickleå	Väster-botten	LNKN	4	5	5	4	**4.5**	5 (172)	4 (N)	2	**3.7**	57147	**3**
Ryda Kungsgård	Uppsala	LNKN	4	5	4	4	**4.3**	3 (57)	3 (C)	3	**3.0**	39337	**4**
Sandnäset	Jämtland	LNKN	4	5	5	5	**4.8**	4 (130)	3 (N)	2	**3.0**	43297	**3**
Sännen	Blekinge	LNKN	4	5	5	4	**4.5**	2 (45)	3 (S)	5	**3.3**	53937	**4**
Transtrands-berget	Vörmland	LNKN	4	1	5	5	**3.8**	3 (66)	4 (S)	3	**3.3**	42887	**3**
Tyresta	Stockholm	LNKN	4	5	1	1	**2.8**	1 (36)	3 (C)	3	**2.3**	42267	**3**
Blåbärs-kullen	Varmland	SW.-NV	3	4	5	5	**4.3**	3 (66)	3 (S)	4	**3.3**	32400	**3**
Edeby	Soderman-land	SW.-NV	3	4	5	5	**4.3**	2 (49)	3 (C)	4	**3.0**	32400*	**3**
Fagerhult	Jönköping	SW.-NV	2	4	3	5	**3.5**	1 (26)	3 (S)	5	**3.0**	32400*	**3**
Farstanäs	Stockholm	SW.-NV	2	4	3	5	**3.5**	1 (36)	3 (C)	3	**2.3**	18490*	**3**
Fulufjäll	Dalarna	SW.-NV	3	4	4	5	**4.0**	3 (64)	3 (C)	3	**3.0**	18490*	**3**
Grankölen 2	Norrbotten	SW.-NV	1	4	3	3	**2.8**	5 (189)	2 (N)	1	**2.7**	32400*	**3**
Hensbacka	Västra Götaland	SW.-NV	2	4	5	5	**4.0**	1 (31)	3 (S)	5	**3.0**	32400*	**3**
Hissmossa	Skåne	SW.-NV	2	3	3	5	**3.3**	2 (41)	2 (S)	5	**3.0**	32400*	**3**
Högbränna	Väster-botten	SW.-NV	3	4	3	5	**3.8**	4 (96)	3 (N)	2	**3.0**	18490*	**3**
Höka	Östergötlan d	SW.-NV	3	3	2	5	**3.3**	3 (66)	4 (C)	4	**3.7**	18490*	**3**
Komperskulla	Blekinge	SW.-NV	2	3	2	5	**3.0**	2 (46)	2 (S)	5	**3.0**	18490*	**3**
Kvisterhult	Västman-land	SW.-NV	3	4	4	5	**4.0**	3 (57)	3 (C)	3	**3.0**	18490*	**3**

Ottenby	Kalmar	SW.-NV	3	3	4	4	**3.5**	3 (61)	4 (C)	5	**4.0**	61500*	**3**
Rockneby	Kalmar	SW.-NV	3	4	5	5	**4.3**	3 (61)	2 (C)	5	**3.3**	32400*	**3**
Sör-Digertjärn	Jämtland	SW.-NV	2	3	3	5	**3.3**	1 (27)	2 (N)	3	**2.0**	18490*	**3**
Stenshult	Skåne	SW.-NV	3	3	3	3	**3.0**	2 (48)	2 (S)	5	**3.0**	15400*	**3**
Storulvsjön	Västernorrl and	SW.-NV	4	4	4	5	**4.3**	4 (120)	4 (N)	3	**3.7**	140480	**1**
Tagel	Kronoberg	SW.-NV	3	2	2	5	**3.0**	2 (53)	4 (S)	5	**3.7**	18490*	**3**
Timrilt	Halland	SW.-NV	3	3	4	5	**3.8**	2 (54)	3 (S)	5	**3.3**	32400*	**3**

[1]Compared to network average cost and weighted to number of sampling proxies at site. SWETHRO-NV costs standardised so all sites given same grading, except Storulvsjön that incurs additional costs. Average site costs per network are EMEP 638750 SEK, LNKN 51063 SEK, SWETHRO-NV 32868 SEK. Estimated financial cost per site based on individual site cost plus equal share of network overhead costs. * Site costs do not include personnel sampling costs, estimated as 60,000 SEK.

Appendix 2

Assessment of bulk deposition data from EMEP, LNKN and SWETHRO sites

Data were downloaded from the national data host (Datavärdskap för luftkvalitet) website (www.smhi.se/datavardluft). Wherever available, all data for base cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} and NH_4^{+}) and acid anions (SO_4^{2-}, NO_3^{-} and Cl^{-}) were retrieved for all sites listed in Table 1. Ion balances were determined as the difference between the sum of base cations (plus hydrogen ion concentration) and sum of acid anions as a percentage of the sum of the two variables, after converting the concentrations of all ions to units of micro-equivalents per litre.

For the primary assessment of data duration, frequency of measurements and data quality we focussed on samples for which data for all nine constituent variables had been reported. Determination of data duration for EMEP and LNKN sites were considered in the context of the longer time series available, several of which begin in either 1983 or 1994. Data duration of SWETHRO sites was assessed relative to the maximum length of data runs for these sites (i.e. 2000-2017).

Appendix 2 figures 1-5 provide time series plots of ion balance, acid anions and pH for most sites, but omits some sites for which only very short periods of data were available, i.e. Hallahus, Grankölen 1, Grankölen 2, Transtrandsberget and Pjungserud.

Time series of ion balances for the most sites are presented in Figure 1. These balances are mostly highly consistent over time. There is a general tendency for positive deviation from the zero line, possibly reflecting the influence of alkalinity which is not available and hence not included in the balance. There is some variation in deviation from the zero line, with some sites (e.g. NOR, GRA, SAD and SAN) showing minimal deviation, while others (e.g. RAO, BRE, FAG, FAR and HOG) show greater ranges. There is an indication of a systematic error in the more recent data available for BRE which needs to be investigated in more detail.

Appendix 2 figure 1 also highlights sites with interrupted time series, relatively low frequencies of data collection and relatively short runs of data. We note:

- Vavihill (VAV) is the forerunner site to Hallahus (data available for 2016-17). The chemistry data necessary to compute the ion balance are available up to 2004 only. While there is a dataset that runs from 1995 – 2015, this does not include nitrate or potassium.
- The Råö (RAO) replaced Rörvik in 2002. These sites are relatively close to each other (within 2 kms – Salar Valinia pers. comm.). Concentrations of non-marine sulphate and nitrate around the time of the changeover are very similar. However concentrations of chloride and sodium at Råö are considerably higher. Absence of evidence for marked upward trends in either ion at other sites leads us to conclude that Råö is exposed to substantially higher inputs of seasalt (Figure 6).
- The frequency of samples collected from Majstre / Hoburgen (MAJ) is low relative to other sites and the ion balance appears highly variable.
- Data from three SWETHRO-NV sites, Höka, Komperskulla and Sör-Digertjärn, are only available for the periods 2000-2002 or 2003 and 2009–2017.

- There are very few data available at all from the SWETHRO-NV site Tagel (last records in 2008).
- Data from the SWETHRO-NV sites Ottenby and Hissmossa are available for the last decade or so only.

Appendix 2 figures 2-5 demonstrate that, with the exception of a very small number of extreme values (excluded from plots), the concentrations of major anions and pH at individual sites are consistent over time and indicative of high quality data spatially and over time across all networks.

Appendix 2 figure 7 illustrates the wide range in annual volume weighted mean concentrations of non-marine sulphate across all sites. Nearly all sites show clear long-term declines, but although concentrations have fallen most rapidly at the more polluted sites in the south of the country, a significant north-south gradient remains for the 2017 data.

Appendix 2 figure 8 shows the same data for the post-2000 period only, after standardising by dividing annual means by the site long-term mean and dividing by the site standard deviation. This emphasises strong coherence in the non-marine sulphate signal across a wide geographical area and demonstrates the dominance of regional-scale sulphur deposition field. These temporal patterns are particularly well correlated (r > 0.9) in the case of certain relatively local pairs of sites, namely:

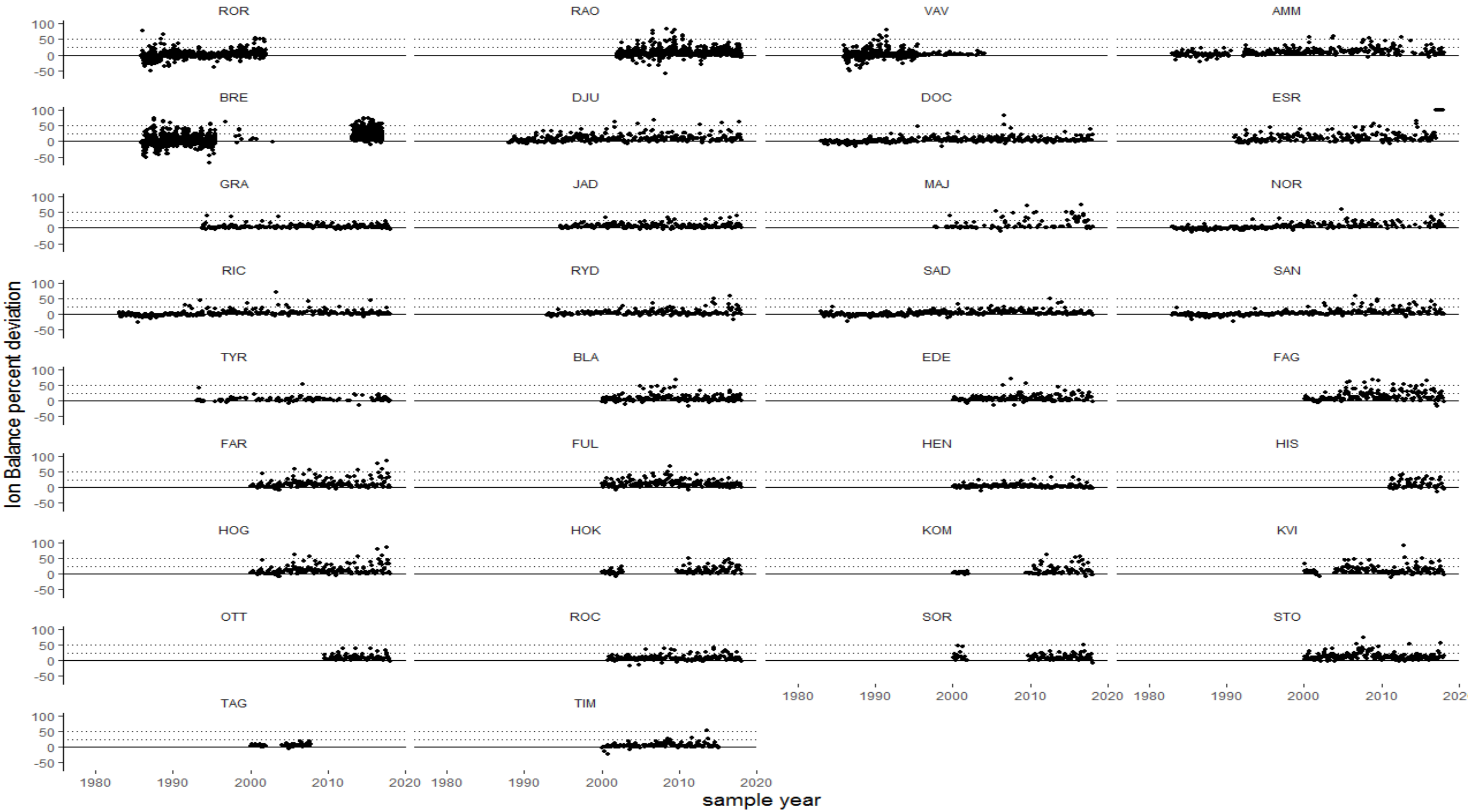
a) Granan (LNKN site) and Hensbacka (SWETHRO-NV site) both in Västra Götaland
b) Granan (LNKN site; Västra Götaland) and Timrilt (SWETHRO-NV; Halland)
c) Sännen (LNKN site) and Komperskulla ((SWETHRO-NV site) both in Blekinge
d) Jädraås (LNKN site; Gävleborg)_ and Ryda Kungsgård (LNKN site; Uppsala).

However, only pair (a) also shows a strong correlation in annual volume weighted mean nitrate (r = 0.78).

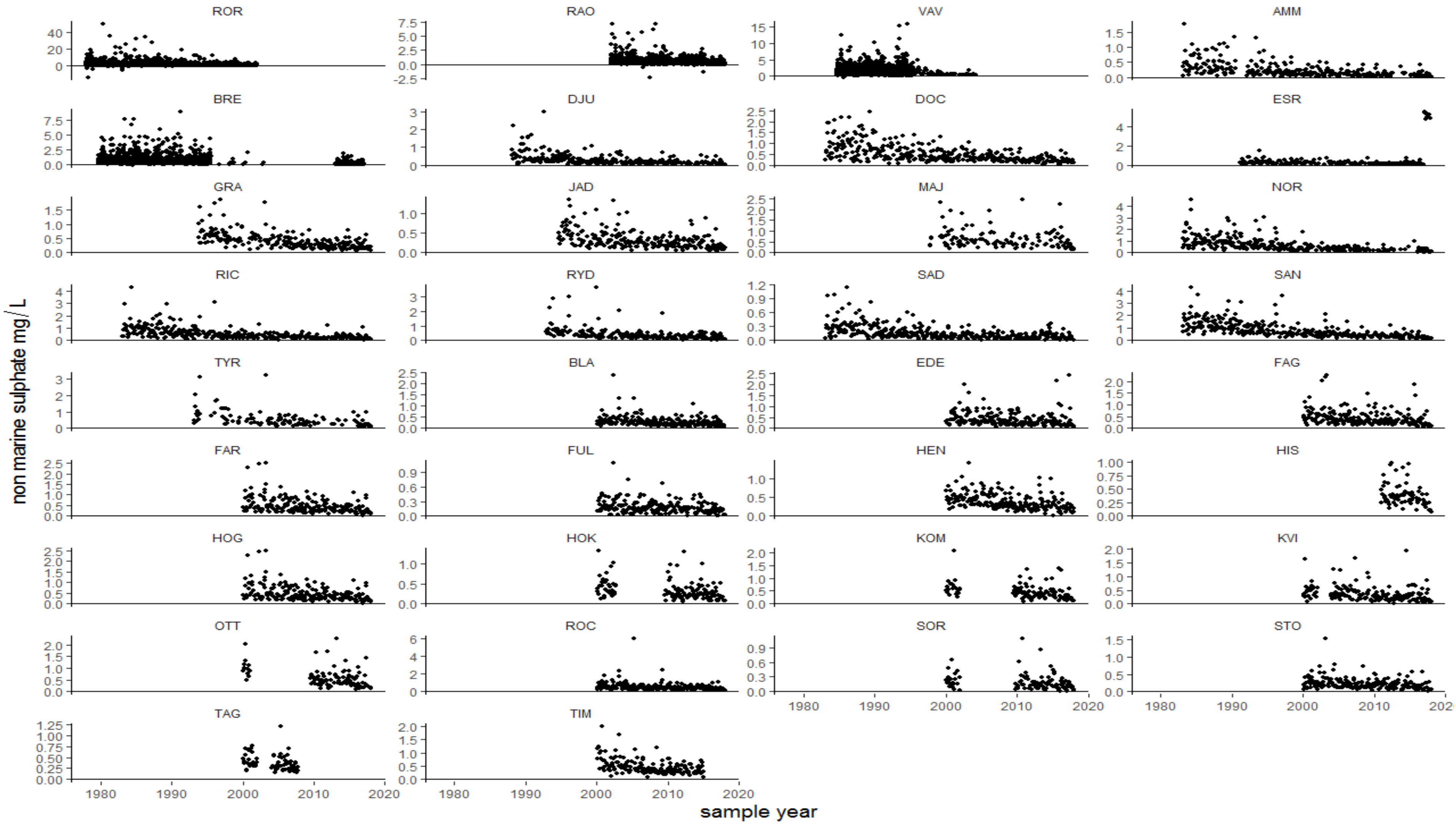
More generally, volume weighted mean concentrations of nitrate and chloride show considerably less coherence than non-marine sulphate, and sites are less well correlated with each other. This emphasises the greater importance of more local inputs of these ions, e.g. from industry, agriculture and marine salts. Overall, therefore, there is little evidence for sites that have sufficiently similar deposition chemistry for easy decisions to be made concerning redundancy.

Appendix 2 Table 1: List of air monitoring sites and abbreviations used in the data quality analyses.

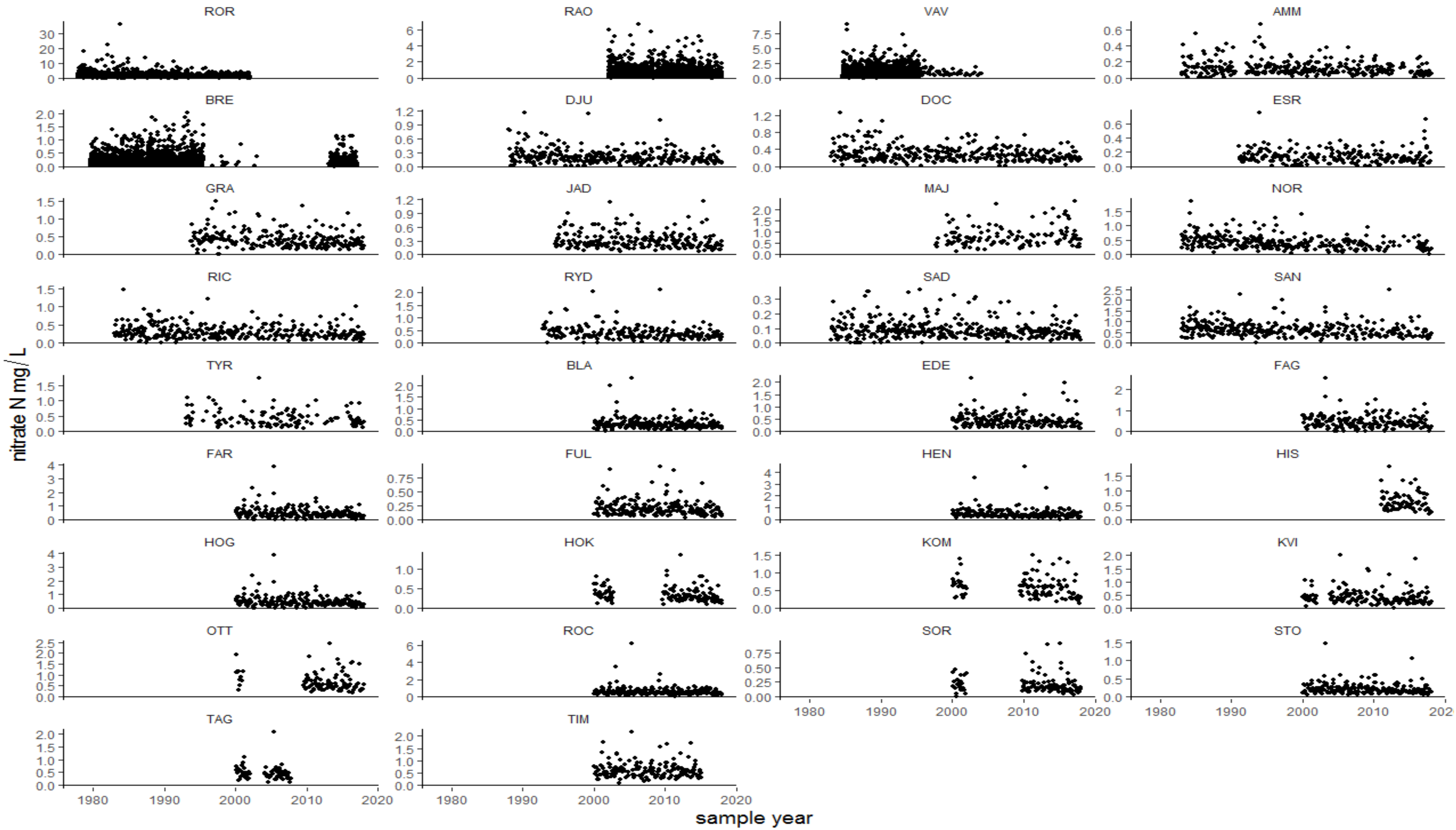
Site		County	Network
Bredkälen	BRE	Jämtland	EMEP
Hallahus	HAL	Skåne	EMEP
Norunda	NOD	Uppland	EMEP
Råö	RAO	Halland	EMEP
Ammarnäs	AMM	Västerbotten	LNKN
Djursvallen, nedre	DJU	Jämtland	LNKN
Docksta	DOC	Västernorrland	LNKN
Esrange	ESR	Norrbotten	LNKN
Granan	GRA	Västra Götaland	LNKN
Grankölen 1	GRK	Norrbotten	LNKN
Jädraås	JAD	Gävleborg	LNKN
Majstre / Hoburgen	MAJ	Gotland	LNKN
Norra Kvill	NOR	Kalmar	LNKN
Pjungserud	PJU	Västra Götaland	LNKN
Rickleå	RIC	Västerbotten	LNKN
Ryda Kungsgård	RYD	Uppsala	LNKN
Sandnäset	SAD	Jämtland	LNKN
Sännen	SAN	Blekinge	LNKN
Transtrandsberget	TRA	Värmland	LNKN
Tyresta	TYR	Stockholm	LNKN
Blåbärskullen	BLA	Värmland	SW.-NV
Edeby	EDE	Södermanland	SW.-NV
Fagerhult	FAG	Jönköping	SW.-NV
Farstanäs	FAR	Stockholm	SW.-NV
Fulufjäll	FUL	Dalarna	SW.-NV
Grankölen 2	GRA	Norrbotten	SW.-NV
Hensbacka	HEN	Västra Götaland	SW.-NV
Hissmossa	HIS	Skåne	SW.-NV
Högbränna	HOG	Västerbotten	SW.-NV
Höka	HOK	Österland	SW.-NV
Komperskulla	KOM	Blekinge	SW.-NV
Kvisterhult	KVI	Västmanland	SW.-NV
Ottenby	OTT	Kalmar	SW.-NV
Rockneby	ROC	Kalmar	SW.-NV
Sör-Digertjärn	SOR	Jämtland	SW.-NV
Stenshult	STE	Skåne	SW.-NV
Storulvsjön	STO	Västernorrland	SW.-NV
Tagel	TAG	Kronoberg	SW.-NV
Timrilt	TIM	Halland	SW.-NV



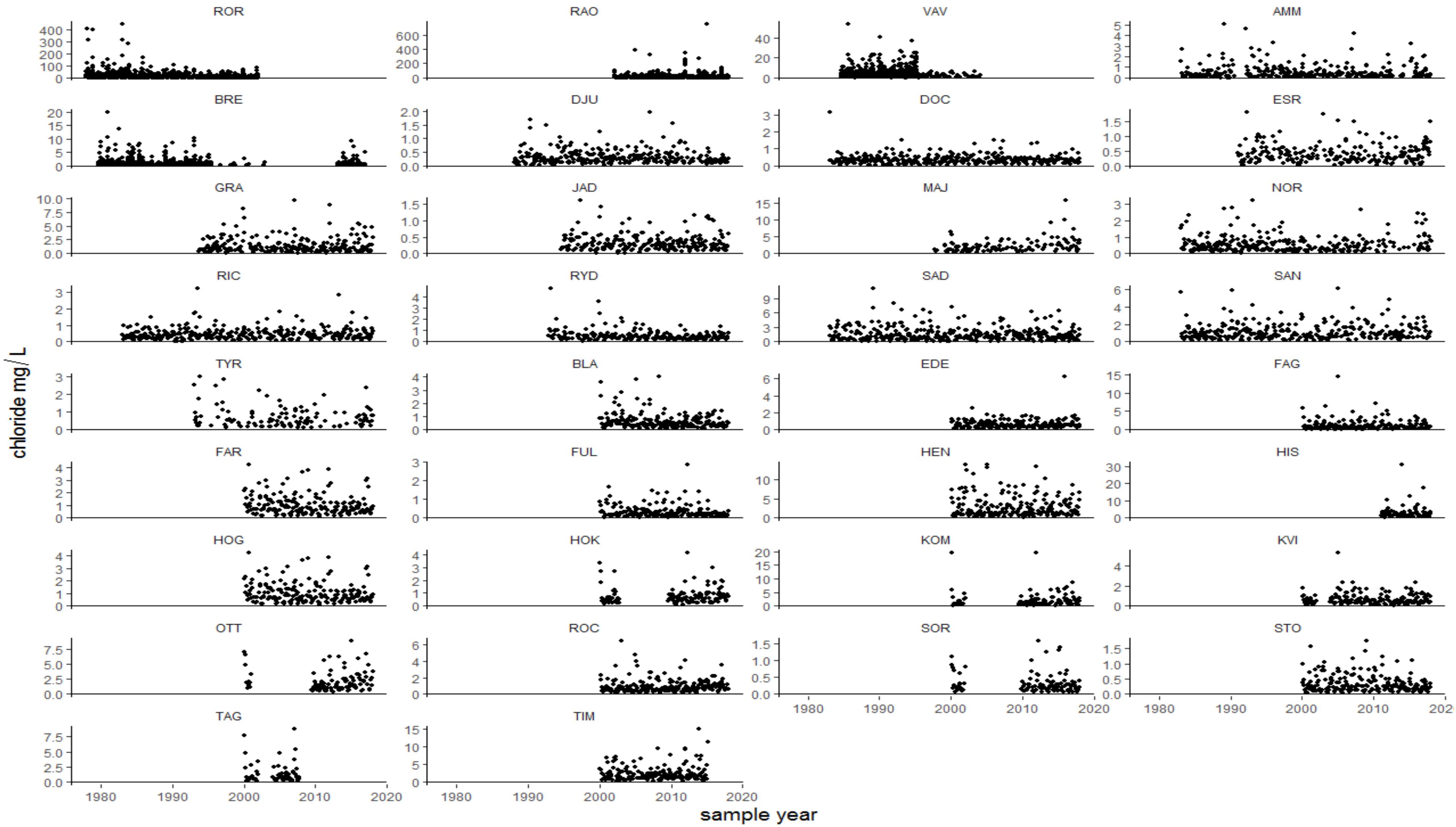
Appendix 2 Figure 1. Ion Balance. Deviation of the difference between cation and anion concentration expressed as a percentage of the sum of these concentrations.



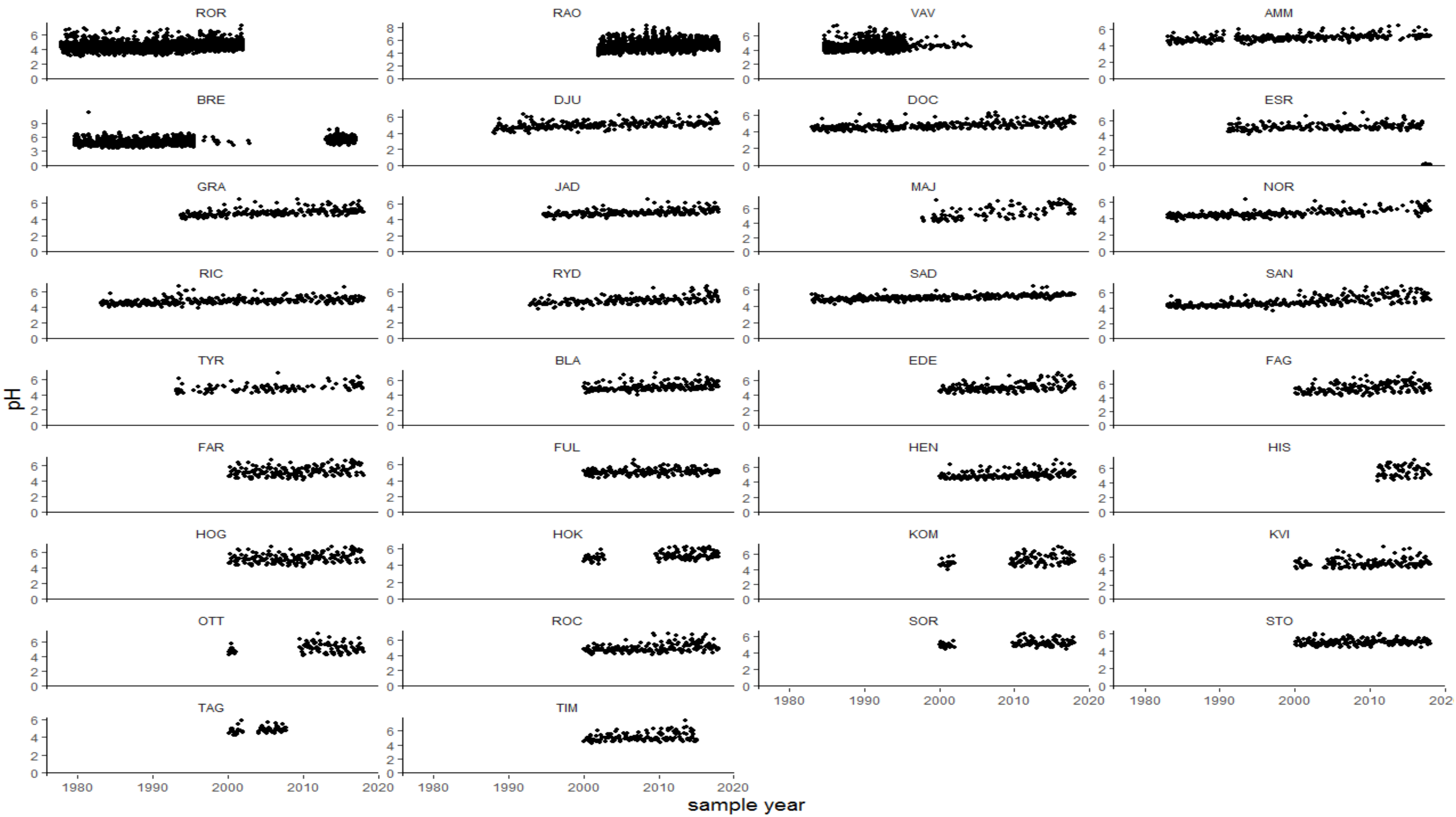
Appendix 2 Figure 2. Non-marine sulphate S concentration.



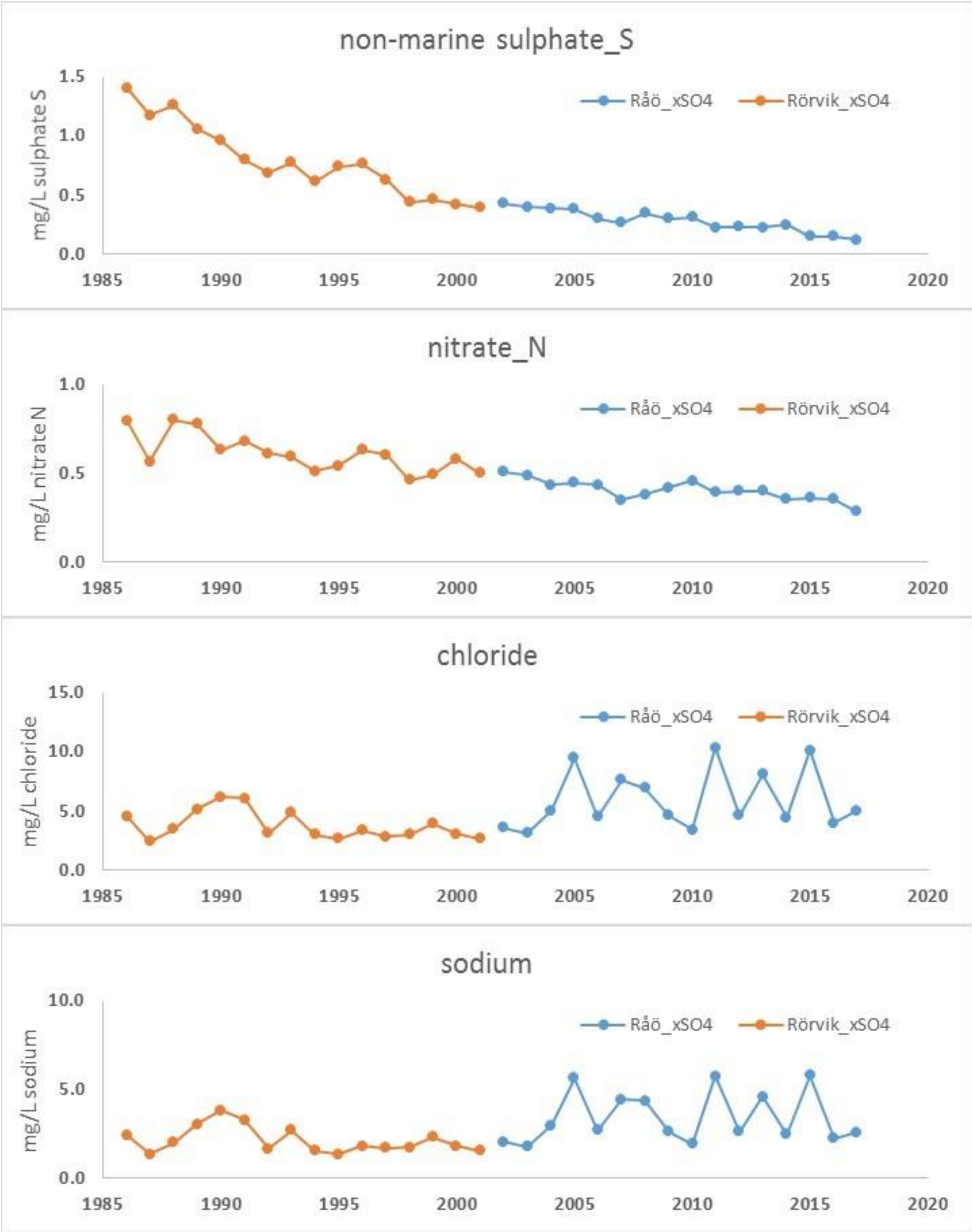
Appendix 2 Figure 3. Nitrate N concentration.



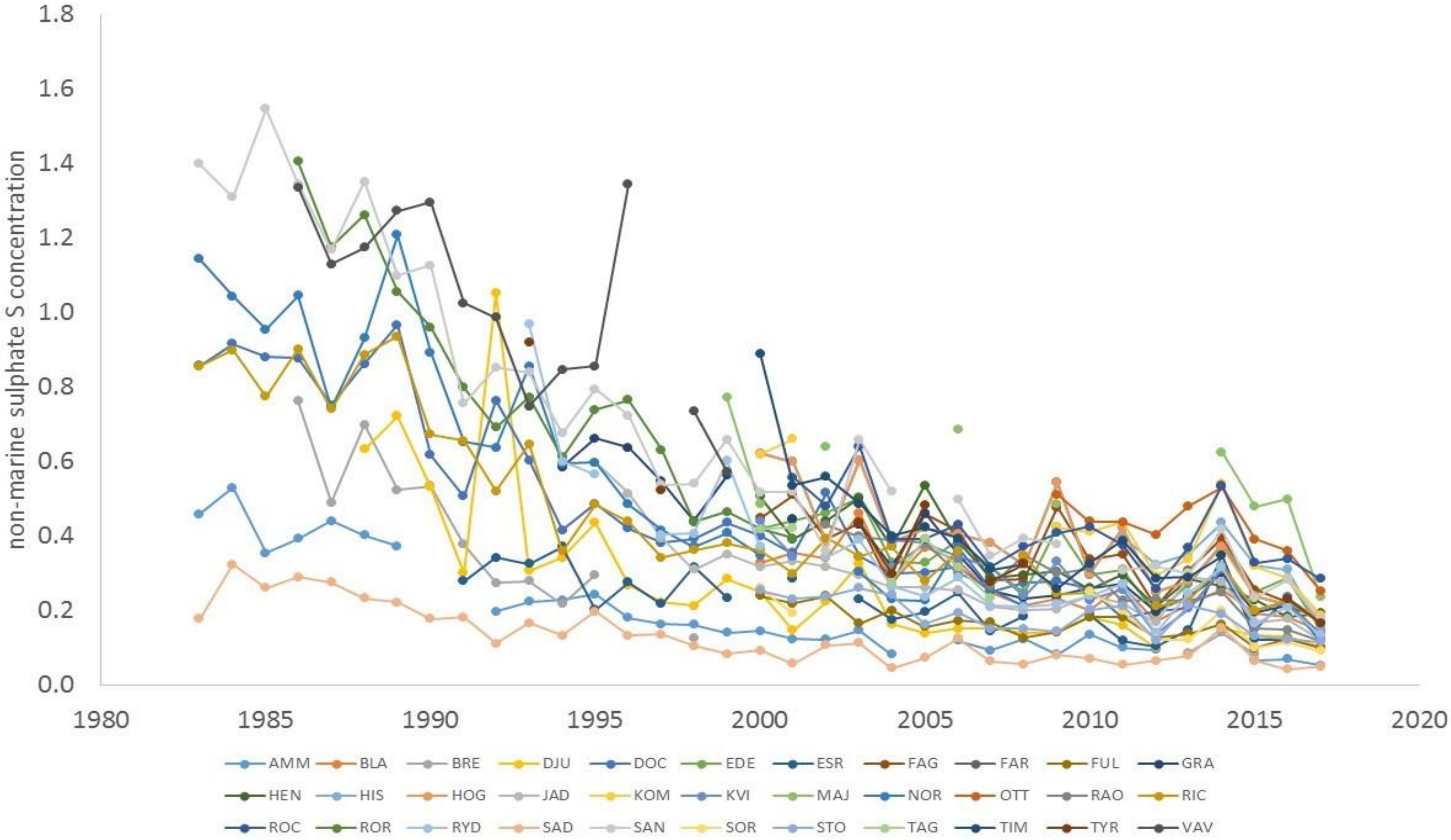
Appendix 2 Figure 4. Chloride concentration.



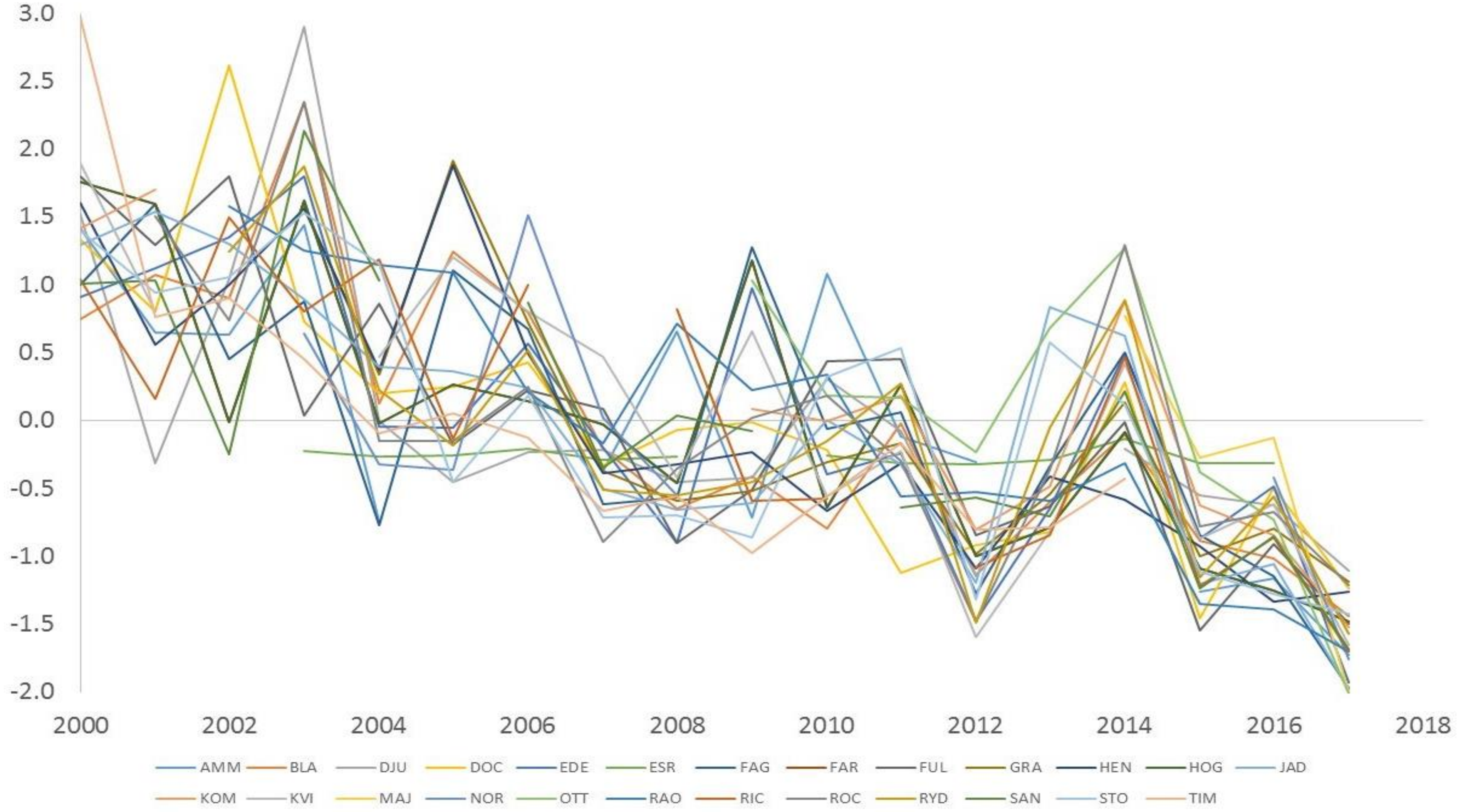
Appendix 2 Figure 5. Bulk precipitation pH.



Appendix 2 Figure 6. Comparison of annual volume-weighted mean ion chemistry at Råö and Rörvik sites.



Appendix 2 Figure 7. Volume weighted mean annual concentrations of non-marine sulphate.



Appendix 2 Figure 8. Standardised volume weighted annual mean non-marine sulphate concentration.

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