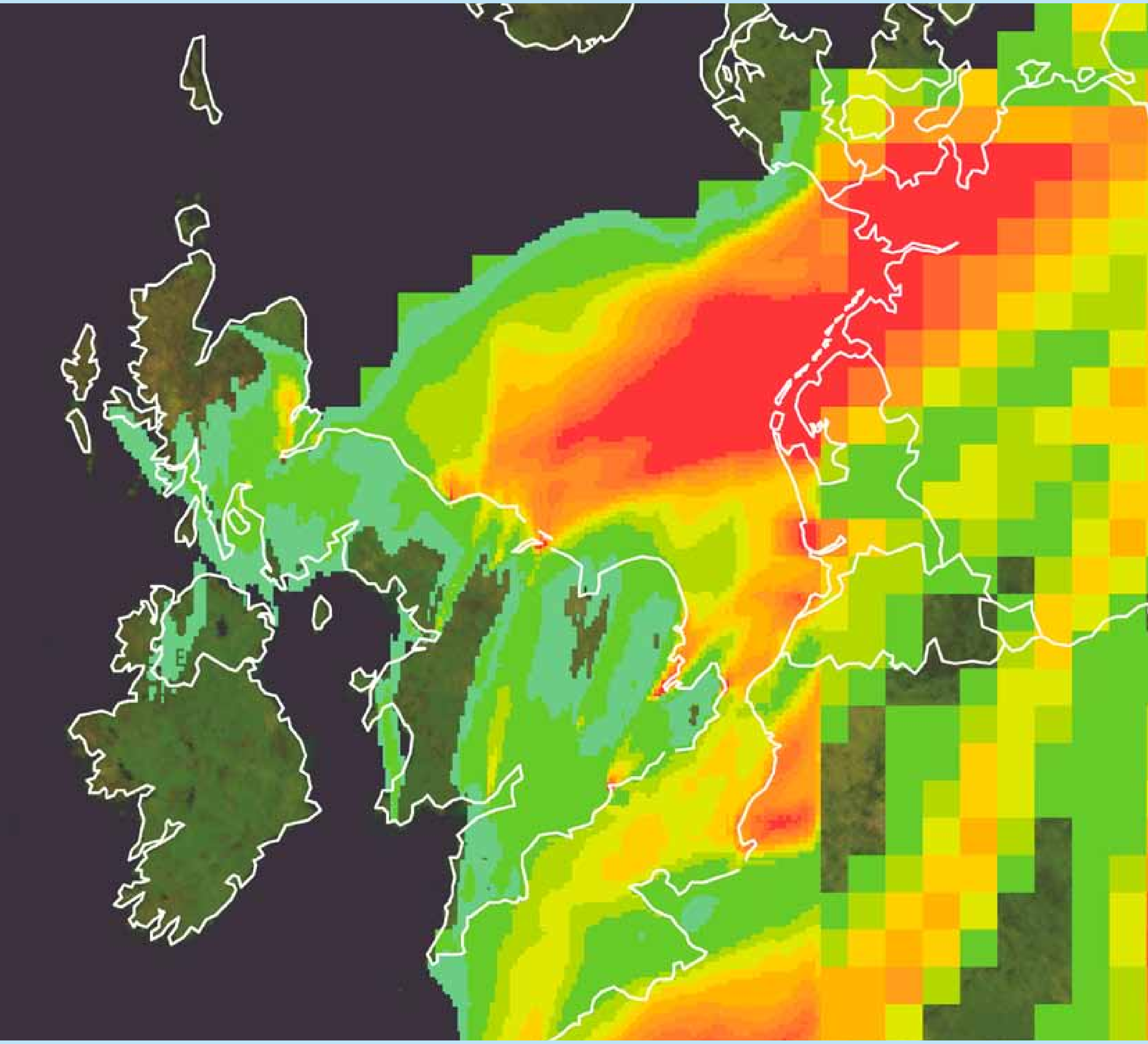
REVIEW OF TRANSBOUNDARY AIR POLLUTION (RoTAP):

Acidification, Eutrophication, Ground Level Ozone and Heavy Metals in the UK

SUMMARY FOR POLICY MAKERS



Prepared for: Department for Environment, Food and Rural Affairs; Scottish Government; Welsh Government; and Department of the Environment in Northern Ireland

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This report provides a summary of the main policy findings contained within RoTAP (2012) Review of Transboundary Air Pollution: Acidification, Eutrophication, Ground Level Ozone and Heavy Metals in the UK. This report was prepared for the Department for Environment, Food and Rural Affairs; the Scottish Government; the Welsh Government; and the Department of the Environment in Northern Ireland as part of the Defra and Devolved Administration funded contract, Review of Transboundary Air Pollution (RoTAP) (Defra Contract Number AQ0703). A list of contributors to the RoTAP report is provided at the end of this summary report.

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Cover Image represents the daily average particulate sulphate surface concentration over the UK for 16th May 2006, calculated using the EMEP4UK atmospheric chemistry transport model (v3.7). The model uses a fine grid resolution of 5 km x 5 km over the UK nested within a coarse European domain (http://www.ceh.ac.uk/sci_programmes/EMEP4UK.html). The concentrations range from ~0.3 μgS/m^3 (light green) to ~1.5 μgS/m^3 (red), with a prevailing westerly wind. Plumes from some of the main UK sources of sulphur are clearly visible.

RoTAP summary for policy makers

Summary

- Over the last 30 years the measures taken to control emissions of air pollutants have dramatically changed the chemical climate of the UK atmosphere and it is predicted to continue to change.
- Sulphur emissions and concentrations in the UK atmosphere have been greatly reduced, the rain is no longer acid and acid deposition to soils and freshwaters has declined. There has also been a large reduction in exports of airborne sulphur and nitrogen from the UK over the last 20 years.
- Chemical and biological recovery of acidified soils and freshwaters is progressing slowly throughout the UK with reductions in acidity and the reappearance of acid sensitive biota in freshwaters and reduced acidity in soils.
- The deposition of nitrogen in the UK has changed little over the last 20 years, despite substantial reductions in emissions of nitrogen oxides. Most of the benefits of emission reductions are in reduced exports of nitrogen compounds from the UK.
- Nitrogen deposition is associated with adverse effects on terrestrial biodiversity at a UK scale. There is strong evidence that nitrogen deposition has significantly reduced the number of plant species per unit area (species richness) in a range of habitats of high conservation value over large areas of the UK.
- We do not know the fate of the deposited nitrogen, which may remain in soils, and, with little change in deposition the conditions for recovery have yet to be established.
- Emissions of ammonia have changed little and effects are greater than those of the equivalent wet deposition of nitrogen and hence ammonia sources should be a priority focus for emission control.
- Peak ground level ozone concentrations have declined by about 30% as a result of controls on precursor emissions mainly in the UK and other EU member states. However, background concentrations have increased steadily over the last 20 years due to increases in emissions of ozone precursors throughout the Northern Hemisphere. With these changes in the ozone climatology, ground level ozone remains a threat to vegetation, human health, food security and climate.
- The policies to control acidification in the UK, and more widely throughout Europe, have been a considerable success. The main driver of this achievement has been the very large reduction in emissions of sulphur from combustion of fossil fuels. Recovery of ecosystems is progressing as a consequence of these controls.
- The policies to control eutrophication by nitrogen compounds have been less successful. More needs to be done to reduce the effects of eutrophication and the priority is reduction in ammonia emissions from agriculture.

- For ground level ozone, policy intervention has been useful in limiting peak ozone concentrations, with significant benefits for air quality. However the growth in the hemispheric background concentrations of ozone has erased the benefits of emission reductions in the UK. The increasing threat from rising background ozone concentrations will only be mitigated effectively through hemispheric scale measures to reduce ozone precursors, which are now an urgent priority.
- Reported emissions of metals in the UK greatly underestimate the real magnitude of UK sources as revealed by deposition measurements and this uncertainty precludes identification of the most cost effective control measures.

The purpose of the RoTAP report is to provide a scientific review of the available evidence on emissions, concentrations, deposition and effects of transboundary air pollutants in the UK. The report considers impacts on ecosystems but it does not cover direct impacts on human health.

This Summary for Policy Makers draws together the policy messages covered in the RoTAP report, reviews the success of reductions in emissions of atmospheric pollutants, explores the resulting changes in concentrations of these pollutants in the environment, and identifies any subsequent reversal of their impacts on the environment. The policy makers' summary also identifies the likely effects of current policies on future transboundary air pollution and their interactions with climate change.

Transboundary air pollution has been an issue of national and international concern over the last 40 years, especially since the identification of the problems caused by acid rain in the 1970s. More recently identified transboundary air pollution problems include eutrophication, and ground level ozone.

Acidification has been reduced substantially by a reduction in the emissions of pollutants, and a subsequent reduction in their concentrations in air, rain, freshwaters and soil, and there is now evidence that ecosystems have begun the process of recovery. However, other concerns including eutrophication, ground level ozone and heavy metal pollution have yet to be addressed as successfully, with further policy action required.

Acidification

Policy statement
Extensive policy intervention on acidification has produced considerable success, with recovery of the environment from the effects of acidification progressing.

Acidification of soils and waters can be caused by deposition of sulphur, nitrogen or hydrochloric acid (or a combination of these pollutants). Emission controls have reduced sulphur dioxide emissions by over 90% from their peak value in the 1950s, resulting in reduced concentrations of sulphur and levels of acidity in the atmosphere, soils and freshwater. Ecological recovery of these habitats is underway, but soils and freshwaters in some regions remain acidified. The legacy of previous emissions, land use and climate change may influence the extent and outcome of the recovery. Between 2006 and 2008, 54% of all habitat areas sensitive to acidification exceeded the Critical Load for acidity, predominantly due to the deposition of nitrogen. Typically, most of the deposited nitrogen is accumulating in soils and vegetation, and relatively little is currently contributing directly to acidification, but significant leaching to surface waters is occurring in higher deposition areas, and particularly in catchments with sparse soils. Current measures are predicted to decrease the Critical Load Exceedance to 40% of habitat areas by 2020. Further reductions in the emissions of sulphur and particularly nitrogen may be required to aid ecological improvement.

Eutrophication

Policy statement

Substantial policy intervention on oxidised nitrogen compounds (NO_x) and little policy intervention on reduced nitrogen compounds (ammonia; NH_3) has produced very limited success in reducing the effects of eutrophication within the UK. Most of the benefits of the policies have been in reducing exports of nitrogen compounds from the UK. Further policy intervention is required, especially on ammonia.

Eutrophication from atmospheric deposition in the UK is caused by the emissions of nitrogen oxides and ammonia. Emissions of nitrogen oxides have decreased by 58% since 1970, with a corresponding 50% reduction in air concentrations at background locations. Emissions of ammonia are only reliable from 1990 onwards, since when they have decreased by 21%, although there is large inter-annual variability, masking any overall trend. Concentrations of ammonia have changed little over the last decade. The proportion of ammonia to total nitrogen deposition has increased over the last twenty years from 45 to 50%.

Despite the large reduction in emissions, total deposition of nitrogen (oxidised and reduced forms) has changed little. This surprising result is due to changes in atmospheric chemistry leading to accelerated oxidation and deposition of nitrogen compounds over the UK compared to the rates measured in the late 1980s. Thus a larger proportion of UK nitrogen emissions is deposited in the UK than occurred twenty years ago. The main consequence of the emission reductions has been a reduction in the export of pollution. At sites in the UK where nitrogen deposition exceeds the capacity of the vegetation and soil to sequester inputs, nitrate is leaching into surface waters and has the potential to stimulate algal growth and affect species composition.

Between 2006 and 2008, 58% of all habitat areas sensitive to eutrophication from nitrogen deposition exceeded the Critical Load for nutrient nitrogen. This figure is predicted to decrease to 48% by 2020. Data from field surveys and experimental studies in the terrestrial environment provide a strong body of coherent evidence that these exceedances are associated with adverse effects on biodiversity, and in particular the loss of species adapted to the low nutrient availability that is characteristic of many habitats of high conservation importance. Controlled experiments suggest that deposition of ammonia is more toxic than other forms of nitrogen deposition and so reducing ammonia emissions is a high priority. Remedial action may also be required to allow full recovery of damaged plant communities.

Ground level ozone

Policy statement
Substantial policy intervention on ozone precursors (volatile organic compounds (VOCs) and nitrogen oxides (NO_x)) has successfully reduced peak ozone concentrations in the UK. However, greater policy intervention is required at a hemispheric scale to reduce the increasing background ozone concentrations.

Important progress has been made in reducing ozone precursor[1] emissions in the UK and more widely throughout Europe, and these have reduced peak ground level concentrations by almost 30% since the 1980s. However, increasing emissions elsewhere in the Northern Hemisphere have led to hemispheric ozone levels increasing by ~10% between 1987 and 2007. Current ozone exposures exceed critical thresholds for effects on crops, forests and semi-natural vegetation over substantial areas of the UK. It is therefore necessary to increase the geographic scale at which emissions of ozone precursors are controlled, with the hemispheric scale being the most appropriate.

Heavy metals

Policy statement
Ecosystem impacts of heavy metals have not been a priority for policy intervention and the emission inventories for metals in the UK are not adequate for the selection of effective control measures.

Emissions of heavy metals have decreased in the UK, although there are large uncertainties in the primary sources of metals in the UK atmosphere as the amount of metals deposited from the atmosphere greatly exceeds the amount of metals reported to be emitted from anthropogenic sources, by up to a factor of 10. Specific sites and some areas of the UK contain soils with large and potentially ecologically-damaging concentrations of a range of metals. However, the individual contributions from atmospheric and local industrial sources, e.g. the legacy from mining and metal processing waste, are uncertain. Concentrations of metals in these contaminated soils change very slowly; in some cases the timescale for recovery may well be centuries.

[1] Ozone is not emitted, but is produced in the atmosphere by chemical reactions in the presence of sunlight between precursors including the oxides of nitrogen (NO_x), volatile organic compounds (VOCs) including methane and other compounds, and carbon monoxide.

What changes have there been in transboundary air pollution for the UK over the last twenty years?

Current trends in emissions

Emissions of primary pollutants contributing to transboundary air pollution have declined substantially, especially during the last 20 years, mainly in response to domestic and international control measures.

Figure 1 shows the emissions of SO_2, NO_x, NH_3, NMVOCs, lead and mercury between 1970 and 2020, as reported in the National Atmospheric Emissions Inventory (NAEI). The UK fully met the 2010 targets of the National Emission Ceilings Directive 2001/81/EC (NECD). A summary of changes in emissions over the last twenty years is included in Figure 2.

Current trends in concentrations and deposition in rural areas

Ambient concentrations of sulphur dioxide and nitrogen dioxide (the main atmospheric component of nitrogen oxides) in air declined by an average of 91% and 50%, respectively between 1980 and 2007. Concentrations of ammonia remain high over the UK and have changed little over the last decade. Over the last twenty years, large decreases in the rainwater concentrations of acidity (85%), sulphate (75%), and non-marine chloride, have occurred.

Dry and wet deposition of sulphur in the UK have decreased by 93% and 57% respectively, over the last twenty years. The total deposition of nitrogen in the UK has changed little over the same period, remaining close to 400 Gg nitrogen per year, despite large reductions in the emissions of nitrogen oxides (58%) and smaller reductions in the emissions of ammonia (21%).

Peak ozone concentrations in rural areas of the UK have declined by about 30% in the last 20 years. However, hemispheric ozone levels have increased by approximately 0.2ppb per year (an increase of approximately 10% over twenty years).

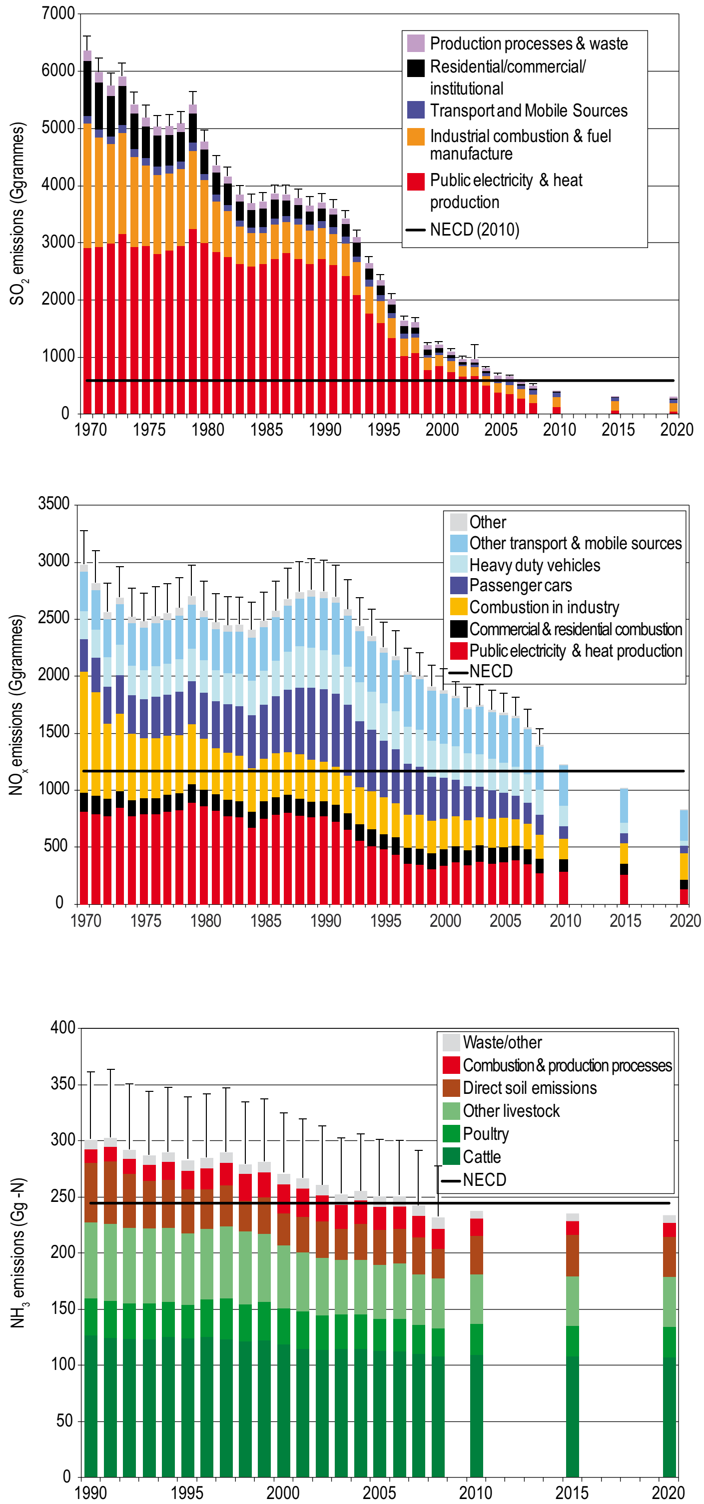


Figure 1a Emissions of pollutants from 1970 onwards.

Data taken from the National Atmospheric Emissions Inventory (NAEI). Note that summary statistics on the changes in emissions over the last twenty years are included in Figure 2.

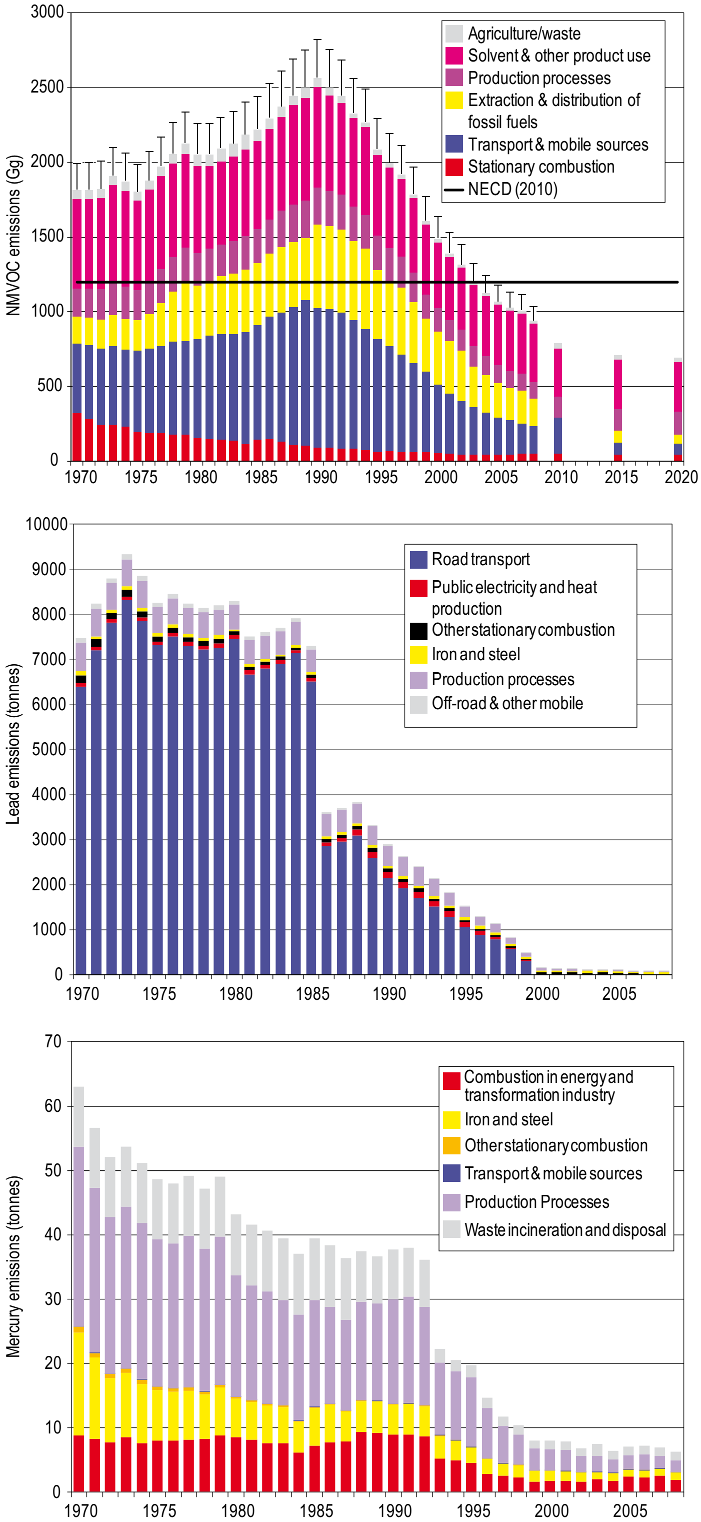


Figure 1b Emissions of pollutants from 1970 onwards.

Data taken from the National Atmospheric Emissions Inventory (NAEI). Note that summary statistics on the changes in emissions over the last twenty years are included in Figure 2.

Exceedances of critical loads and levels

Critical loads

The critical loads and levels concept is an effects-based risk assessment tool used in the development of pollutant abatement strategies. Critical loads are defined as 'a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified elements of the environment do not occur according to present knowledge'. It must be emphasised that critical loads do not describe actual changes which have taken place, they are a risk assessment tool without timescale. In some cases damage may already be in progress whilst in areas which have received less pollution to date or which have greater internal buffering, change may not occur for many years. Further information on the critical loads exceedance is provided in Sections 5.2.3 (Soil), 5.3.7 (Freshwaters) and 5.4.5 (Vegetation) of the main RoTAP report.

Assessments of ozone effects on vegetation carried out until recently have been based on cumulative exceedance over a growing season of a concentration of 40ppb (the AOT40 index). This was the basis on which critical levels of ozone were first defined. There is increasing evidence from across Europe that the definition of critical levels, and evaluation of ozone impacts, should be based on the cumulative flux of ozone through the stomata into leaves over a defined exposure period.

Large areas of the UK are in exceedance of critical loads for acid deposition; exceedances are expected to decline over the coming decade from 54% of UK habitats in 2006-08 to 40% in 2020. Critical loads for eutrophication from nitrogen deposition were exceeded across 62% of the sensitive broad habitat area using deposition data for 1986–88, and this figure remains virtually unchanged (at 58%) 20 years later using the deposition data for 2006–09. By 2020 the area exceeded is predicted to decline to 48%.

Ozone flux-based critical levels for effects on growth of sensitive forest trees are exceeded throughout the UK, and the application of flux-response relationships for wheat suggested that, in 2000, the total national yield loss was about 1.2 million tonnes, equivalent to about 7% of production.

Critical loads for ecosystem effects have been calculated for a range of metals, including cadmium (Cd), lead (Pb), copper (Cu), nickel (Ni) and zinc (Zn) for six UK habitats. Over 50% of areas of managed broad-leafed woodland and unmanaged woodland exceed the critical loads for Cu, Pb and Zn.

What are the future trends in emissions of transboundary air pollution?

Future emission projections of key atmospheric pollutants have been compiled up to 2020 (see Figure 1). The projections for 2020 included in the RoTAP report are based upon forecasts made during 2008. In addition an 85% reduction of emissions of sulphur dioxide from shipping in the vicinity of the UK is expected by 2020. Emissions of nitrogen oxides from road vehicles are likely to decrease as older vehicles are replaced with more modern ones with lower emissions. However, emissions from new road vehicles have not been as low as originally predicted from new technologies. Emissions of ammonia are expected to decline, but only by a relatively small amount and are difficult to predict accurately, as they depend on agricultural livestock numbers and fertiliser use. As large pig and poultry farms come under the Integrated Pollution Prevention and Control (IPPC) legislation, an increased uptake of mitigation methods is predicted.

Despite controls on the emissions of ozone precursor gases across Europe, emissions from shipping, aircraft, vehicles and industrial sources are increasing in other parts of the Northern Hemisphere, especially in rapidly developing countries such as India, China and South Korea. Without concerted policy action at the hemispheric scale to control precursor emissions, the background ozone concentration arriving into the UK from these larger scale emissions will continue to increase, eroding the benefits of European control measures.

Future trends in emissions of heavy metals are highly uncertain, as we are currently unable to account for most of the metals present in the air or deposited in the UK. The emissions estimates therefore need to be substantially improved to include currently unaccounted sources.

Have reductions in emissions of pollutants resulted in similar reductions in measured concentrations and deposition?

The changes in emissions, and the subsequent effects on concentration and deposition of the atmospheric pollutants covered in RoTAP are summarised in Figure 2. The reductions in emissions of sulphur dioxide and nitrogen oxides have led to major improvements in air quality, including removal of ~90% of the sulphur and over half of the nitrogen oxides from the UK atmosphere. The decline in sulphur in particular has greatly reduced the main cause of historic acidification, and evidence of a recovery from the effects of acidification is widespread. Nevertheless critical load exceedances will continue into the foreseeable future due to deposited nitrogen, which remains a potential source of terrestrial and freshwater acidification.

The reductions in emissions of nitrogen compounds, and in particular nitrogen oxides have reduced nitrogen dioxide concentrations but have not substantially reduced the deposition of nitrogen to the UK landscape. The 62% reduction in emissions of nitrogen oxides between 1990 and 2010 has resulted in a reduction of only 23% in oxidized nitrogen deposition. The cause of this non-linearity appears to be an increase in the oxidation of nitrogen oxides to nitric acid (HNO_3) and aerosol nitrate (NO_3^-) over the UK with time, but is not fully understood. The main consequence and benefit of the 62% reduction in emissions of nitrogen oxides, has been a 63% reduction in exports of nitrogen oxides from the UK to the wider European atmosphere.

Reductions in the emissions of ozone precursor gases across Europe have resulted in a decrease in peak ozone concentrations in the UK over the last twenty years. However due to increasing emissions of precursors from Northern Hemisphere sources outside Europe, the background ozone concentrations in the UK have been rising. The consequence of these trends is that the benefits of the European reductions in precursor emissions have been eroded by the growing hemispheric emissions of ozone precursors from outside Europe. It is therefore important that future policy development occurs at a much larger, preferably hemispheric scale, and includes international shipping and aviation.

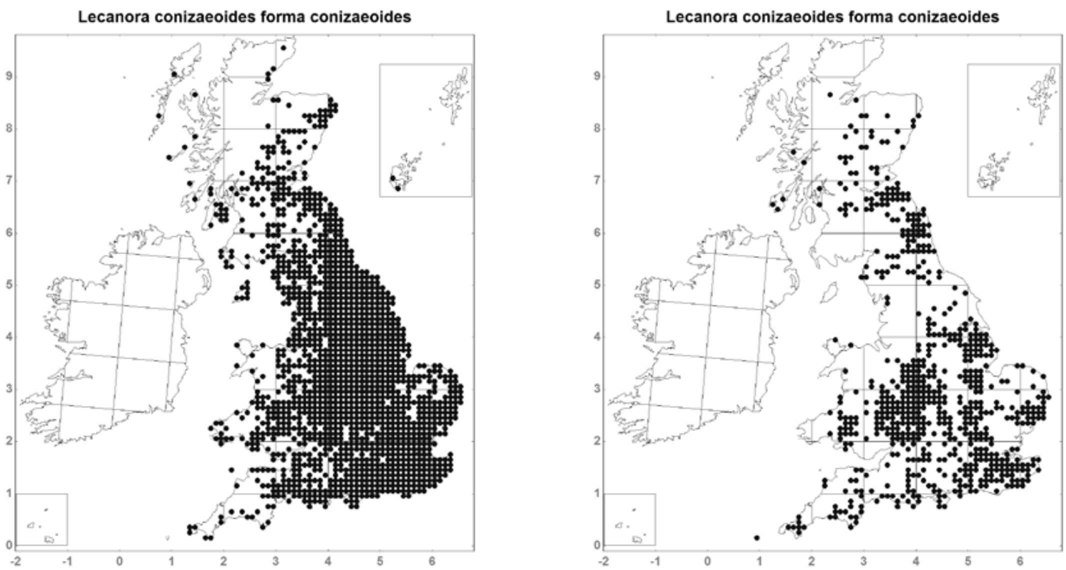
Photochemical smog visible over Snowdonia. (Photograph taken by Gina Mills, CEH).

Emissions of most heavy metals, especially lead, cadmium and mercury, have decreased significantly since 1990, and atmospheric concentrations are not considered a major threat to ecosystem health. There is concern over the accuracy of heavy metal inventories which are only able to explain 20% of the observed concentrations and deposition in the UK for many of the metals. This discrepancy is thought to be due to a variety of factors. In particular, the resuspension of material into the atmosphere from previously deposited sources is not included in the national emissions inventory. There are also uncertainties associated with the sources in the emissions inventory. It is suspected that fugitive emissions are underestimated, some source strengths are thought to be more variable than the available data indicate, and unaccounted sources may be substantial.

What are the impacts of the pollutants on the environment and is there any evidence of recovery from these impacts?

Effects of sulphur dioxide on terrestrial mosses and lichens

Historically the greatest impacts of air pollution in the UK were caused by high, toxic concentrations of sulphur dioxide, smoke and nitrogen dioxide in air. In urban areas these resulted in the widespread loss of sensitive species, especially mosses and lichens, primarily due to direct effects of sulphur dioxide. This era of the mid 20th century ended in the 1970s and 1980s as controls on emissions in urban areas began to take effect. A subsequent wide-scale re-appearance of sensitive lichen and bryophyte species has occurred in both urban and affected rural areas. Atmospheric concentrations of sulphur dioxide and nitrogen oxides have now declined to levels which do not pose a direct toxic threat to UK terrestrial vegetation except close to major roads and in urban areas.



Maps showing the distribution of the acidophilic lichen, Lecanora conizaeoides during 1980-1999 (left map) and 2000-2012 (right map). This lichen thrives in acidic conditions, and has become less prevalent as sulphur emissions have decreased. Maps provided by the British Lichen Society.

Pollutant	Emissions	Atmospheric concentrations in rural areas	Deposition
SO_2	SO_2 Emissions 1990-2010 -89%	SO_2 Average Conc. 1988-2008 -96%	SO_x Deposition 1987-2008 -88% (dry) -64% (wet) -77% (total)
NO_x	NO_x Emissions 1990-2010 -62%	NO_2 Average Conc. 1988-2008 -50%	NO_y Deposition 1986-2008 -23% (dry) -24% (wet) -24% (total)
NH_3	NH_3 Emissions 1990-2010 -21%	NH_3 No significant reduction in air concentrations	NH_x No significant reduction in UK deposition

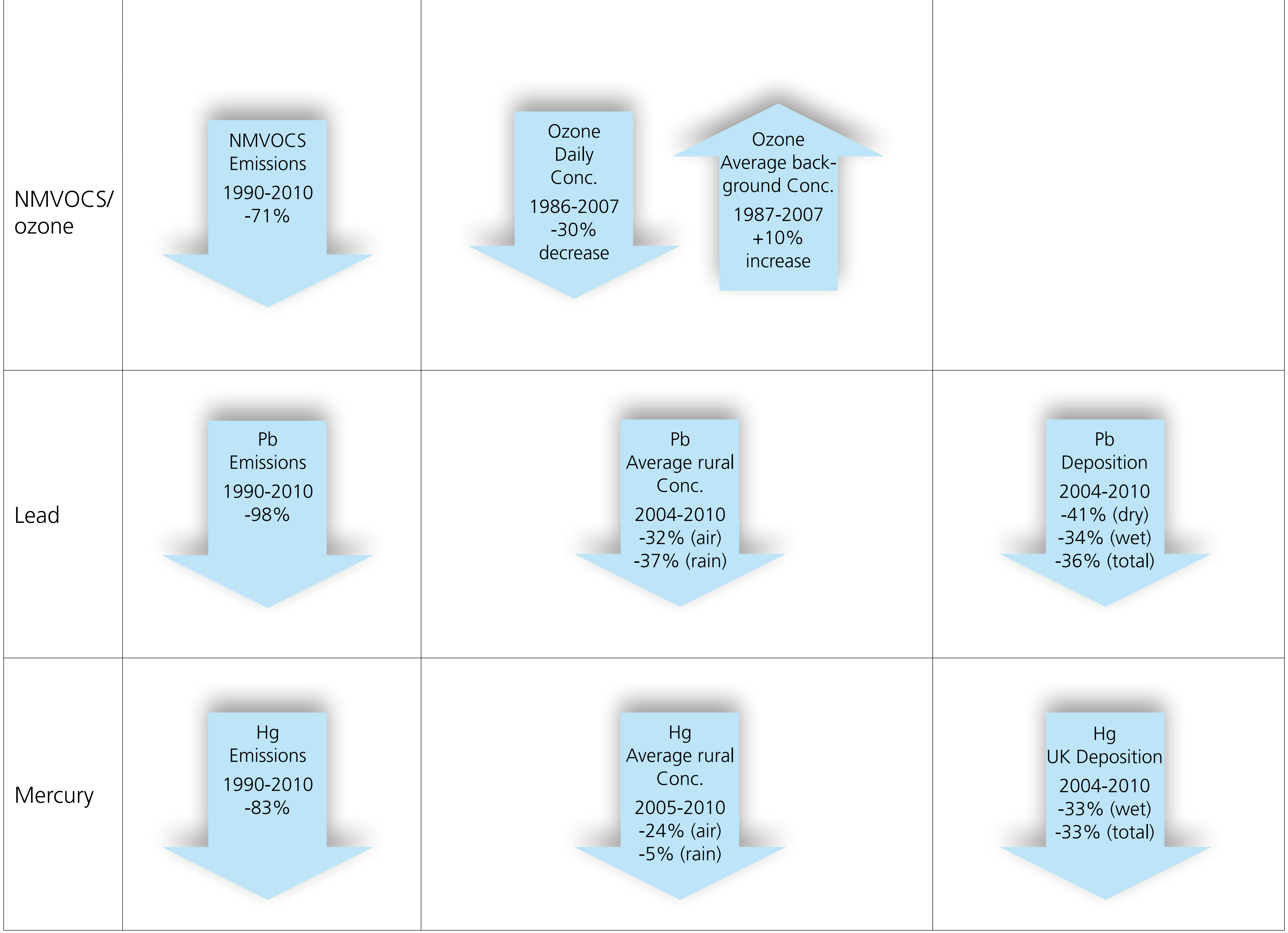


Figure 2 Schematic Diagram outlining changes in emissions and subsequent changes in concentration and deposition. Note that SO_x refers to $SO_2 + SO_4$; NO_x refers to $NO + NO_2$; NO_y refers to $NO_2 + NO_3 + HNO_3$; NH_x refers to $NH_3 + NH_4$.

Acidification of UK soils and waters and its impact on biota

Scientific and policy interest in acid rain was at a peak between 1970 and 1990. During this time widespread terrestrial effects of the deposited acidity, mainly from sulphur, (as sulphur dioxide) but also from hydrochloric acid, which are both emitted from the combustion of fossil fuels such as coal, were detected. For example, the growth of crops and semi-natural vegetation was shown to be substantially reduced during the 1970s and 1980s in the areas of the UK with the greatest pollution from sulphur dioxide. The spatial extent of freshwater acidification was also identified and quantified. Acidity linked to both sulphate and nitrate was shown to be responsible for a reduction in acid neutralising capacity (ANC) of lakes and streams, resulting in water of low pH and elevated levels of biologically toxic aluminium. This led to a reduction in health, abundance and occurrence of sensitive species and in some cases their loss, particularly affecting aquatic plants, freshwater macroinvertebrates (e.g. mayflies) and fish including Atlantic salmon and brown trout.

There is widespread evidence of recovery from acidifying air pollutants in the UK. In acidified freshwaters the reduction in inputs of sulphate has resulted in recent increases in ANC, water pH and decreases in aluminium concentrations. This chemical recovery is leading to biological recovery with the return of some acid-sensitive species and changes in species composition toward communities characteristic of less acidic waters.

This recovery is an ongoing process and further chemical and biological improvement is expected with further anticipated reductions in acid pollutant loads. However, the process is slow. Some landscapes are so depleted in base minerals as a result of past acidification that full chemical recovery to pre-acidification conditions might not be achieved in the short term.

Deposited nitrogen compounds may also contribute to acidification and are now a major contributor to the exceedances of acidity Critical Loads in the UK. Nitrate concentrations have risen in remote sensitive waters in some regions in recent decades, and as sulphate concentrations decline nitrate represents an increasing proportion of incoming acidity. The future fate of the bulk of deposited nitrogen that is thought to have been accumulating in soils remains unclear but potential acidification from this source remains a threat to freshwater ecosystems.

Effects of eutrophication on ecosystems

The deposition of nitrogen compounds also causes eutrophication. There is strong evidence that nitrogen deposition has significantly reduced the number and diversity of plant species in a range of habitats of conservation value over large areas of the UK. The link between nitrogen deposition and plant species composition in the UK landscape remains clear in the most recent Countryside Survey (2007), and is supported by a number of targeted national surveys of sensitive habitats. There is no evidence of further declines in overall plant species numbers over the last two decades in areas of high nitrogen deposition, but there is evidence of further declines in the frequency of sensitive plant species. Some lakes may be undergoing changes considered a deviation from the good ecological status required under the EU Water Framework Directive.

Despite the reductions in emissions of nitrogen oxides, there is no UK evidence of recovery from the eutrophication caused by nitrogen deposition. This is due to several contributing factors: total nitrogen deposition has not declined significantly; the deposited nitrogen is accumulating in vegetation and soils; and gaseous ammonia concentrations have not been reduced in the UK. Experimental evidence of plant effects suggests that nitrogen deposited as gaseous ammonia is more damaging to sensitive plant communities than nitrogen deposited in rain.

To address the problems of eutrophication further substantial reductions in emissions of nitrogen compounds are needed. Reductions in emissions of ammonia are therefore the priority target to reduce effects of eutrophication.

Images showing effects of eutrophication on ecosystems. The left hand image is of the heather, *Calluna vulgaris,* with loss of green photosynthetic material and bleaching of tips, caused by a combination of ammonia exposure and winter desiccation. The image on the right is of the lichen *Xanthoria*, an indicator of nitrogen enrichment, growing on twig near a poultry farm. (Photographs taken by Ian Leith, CEH, for the Air Pollution Information System (APIS), http://www.apis.ac.uk).

Effects of ozone on vegetation

Biological indicators of ground level ozone show that concentrations continue to exceed thresholds for effects on sensitive species. Background ozone levels have now increased to a level where exposure to ozone may cause adverse effects on semi-natural vegetation, especially in the spring months in upland Britain. It has been estimated that ozone may reduce the yield of wheat grown in southern Britain by 5% to 15% in a typical summer; the reduction in national production of wheat in 2000 was estimated to be approximately 1.2 million tonnes.

Ozone is a greenhouse gas in its own right (i.e. by absorbing the outgoing thermal wavelengths in the radiation budget of the earth), and is the third most important man-made greenhouse gas behind carbon dioxide and methane. Ground level ozone also reduces carbon sequestration by vegetation, thus ozone also contributes to global warming indirectly by reducing carbon sequestration.

Visible injury to clover exposed to ozone (Photograph taken by Gina Mills, CEH).

Impacts of metals on vegetation, soils and water

Emissions of heavy metals have had impacts on terrestrial and freshwater species, although there is often insufficient data to quantify the contributions of metals deposited following long range atmospheric transport relative to other local pollution sources.

Chemical recovery of soils and sediments contaminated with heavy metals through atmospheric deposition may take centuries, especially for metals which are strongly bound to the soil and sediment. Concentrations of metals such as nickel, zinc and cadmium may return to background levels in some areas during the present century, but this is not the case for copper and lead.

How do assessments of the impacts of transboundary air pollution on the environment vary between policy arenas?

Transboundary air pollution and its impacts on the environment have been considered in RoTAP largely in the context of international air quality agreements such as the Convention on Long Range Transboundary Air Pollution, the EU's Large Combustion Plant and National Emission Ceilings Directives. The environmental issues covered in the report however are also relevant to other environmental protection policy arenas including the Water Framework Directive and the EU Habitats Directive. In contrast to earlier water directives, which were based around chemical targets, the Water Framework Directive places emphasis on the ecological structure and function of aquatic ecosystems with biological elements at the centre of the status assessments, and hydromorphology and physico-chemistry as supporting elements. Critical Loads and Levels were originally developed for use as the basis for evidence-based discussion of emissions reductions at an international level through CLRTAP. Over the last decade it has been realised they are also very useful tools for assessing environmental impacts at a national and local scale, although they need to be adapted for specific applications. The RoTAP report describes how Critical Loads are used nationally and internationally under CLRTAP. The Critical Loads concept has been adopted for use in support of a range of policy areas, such as the NEC Directive, and the work underlying the Convention on Biological Diversity (CBD). Within the UK, Defra have used Critical Load exceedance data to inform the UK Air Quality Strategy, as a Sustainable Development indicator[2] and a Biodiversity indicator[3].

Although Critical Loads provide an effects-based framework they were not aimed at the Habitats Directive or Water Framework Directive; nevertheless, methods for their incorporation as an assessment tool have been developed. In collaboration with JNCC 'Site-Relevant Critical Loads' (SRCL), are being used alongside Common Standards Monitoring of SSSIs to assess risk from air pollution to protected sites, for local impact assessment and to inform reporting of nitrogen and acidification as a pressure and threat to conservation status of Annex I habitats of the Habitats Directive.

The Habitats Directive requires Member States to take measures to maintain at, or restore to, favourable conservation status Habitats and Species of Community importance. Member States are required to report on conservation status (range, area, structure and function, future prospects, pressures and threats) every six years. The Directive applies to the whole range of habitat and species and not just those within designated sites. The UK 2007 report on conservation status included an assessment that acid deposition and nutrient nitrogen are a 'current pressure' and 'threat to future viability' for a substantial proportion of sensitive habitats in the UK. A common approach for developing Europe-wide assessments is being discussed in a number of international science fora such as COST 729[4] and the International Nitrogen Initiative[5].

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[2] See http://sd.defra.gov.uk/progress/national/

[3] See http://jncc.defra.gov.uk/page-4245

[4] COST 729 - Assessing and Managing nitrogen fluxes in the atmosphere-biosphere system in Europe. See http://cost729.ceh.ac.uk/

[5] International Nitrogen Initiative; See http://initrogen.org/

Reducing emissions and deposition of nitrogen (and sulphur) will help to achieve the objectives of the Habitats Directive, by promoting improvements in chemical and biological condition and ultimately may reduce the areas of habitats at risk. This will not only help promote recovery but limit further decline at sensitive habitats.

Thus, while the direction of travel towards an improving environment is consistent in these three areas, the methodology and philosophical basis underpinning each differ substantially and preclude a quantitative comparison.

What are the international perspectives on transboundary air pollution?

Sources of pollutants outside the UK, but within Europe have declined during the last two decades. However, the contribution of external sources to measured concentrations in the UK remains significant, from both European and shipping sources of sulphur, nitrogen and metals. In the case of ground-level ozone, most of the ozone over the UK is imported through intercontinental transport with contributions from all countries in the Northern Hemisphere.

Changes in the emissions of sulphur dioxide, nitrogen oxides, and ammonia at the European scale are similar to those observed in the UK, with large decreases in emissions of sulphur dioxide and nitrogen oxides, and small reductions in emissions of ammonia. The changes in emissions across Europe have resulted in changes to the atmospheric budget for sulphur over the UK between 1987 and 2006, with imports decreasing from 60 to 20 Gg-sulphur, and exports from the UK decreasing from 1498 to 273 Gg-sulphur. Corresponding changes in the UK oxidised nitrogen budget were imports decreasing from 60 to 40 Gg-nitrogen, and exports decreasing from 809 to 299 Gg-nitrogen.

The transboundary transport of sulphur and nitrogen compounds was the main driver for the CLRTAP Convention and a substantial fraction of emitted sulphur and nitrogen is exchanged between countries. The terrestrial and freshwater effects of deposited acidity observed widely in northern Europe, especially in Nordic countries, are similar to those observed in the UK, and were detected much earlier in the 1960s, leading to the discovery of the acid rain problem. Reductions in acid deposition, especially sulphur, are leading to recovery of these damaged ecosystems. Even though emissions have been reduced substantially over the last 20 years, the UK still contributes to transboundary exchange. Approximately half of the UK emissions of sulphur and nitrogen are deposited within the UK. Ammonia is perceived to act locally as a gaseous air pollutant, however, its role in forming aerosol particles permits much longer-range transport, and may contribute to the observed non-linearity between nitrogen emissions and deposition in the UK. It is therefore an important component for future control strategies at a European scale.

Controls of emissions of nitrogen oxides and volatile organic compounds across Europe have reduced the concentrations of ozone precursors, with a subsequent decrease in peak ground-level ozone concentrations which is an important step in the process of achieving clean air. However, substantial problems due to ozone remain throughout Europe. To address the continuing ground-level ozone problems, further controls on the emissions of ozone precursors throughout Europe are required and to be fully effective in protecting human health and ecosystems, emission reductions need to be made at hemispheric scales as well.

How do transboundary air pollution issues interact with climate change?

Substantial feedbacks between climate change and transboundary air pollution are possible since many of the underlying processes are climate sensitive. For example the atmospheric processing of the pollutants is sensitive to the supply of oxidants linked to ozone and related reactive radical species found in the atmosphere, and the chemistry of these oxidants is sensitive to climate. Many of the biological responses to pollutants are also climate sensitive. Policies need to be developed in the light of these feedbacks. The research base to quantify these interactions is very limited and has only recently become a focus for primary research.

The impacts of ozone are sensitive to climate change. Ozone significantly reduces carbon sequestration in soils and plants. Ozone may also interfere with a plant's ability to respond to drought conditions. Ozone will therefore exacerbate the impacts of increased drought conditions that are predicted to occur during UK summers as a consequence of climate change. Elevated concentrations of carbon dioxide may reduce the effects of ozone, by reducing ozone uptake. The role of ozone as a contributor to the direct radiative forcing of global climate has grown in importance, and ozone is now the third most important man-made greenhouse gas after carbon dioxide and methane.

If climate change causes a reduction in soil organic matter, there is a risk that heavy metals which were previously bound to the organic matter will become remobilised and so bioavailable, increasing the risk of toxicity to organisms.

Policies for climate change present important opportunities to reduce the scale and effects of long range transport of air pollutants through reductions in fossil fuel use. It will be important in the policy context to take full advantage of these co-benefits for climate and long range transport of air pollutants in the development of control measures.

Conclusion

Policies to control acidification in the UK, and more widely throughout Europe, have been a considerable success. The main driver of this achievement has been the very large reduction in emissions of sulphur from fossil fuel burning. Recovery of ecosystems is progressing as a consequence of these controls. Policies to control eutrophication have been less successful, with no evidence, to date, of recovery. More needs to be done to reduce the effects of eutrophication and the priority is reduction in ammonia emissions from agriculture. For ground level ozone, there has been useful progress in limiting peak values, with significant benefits. However the growth in the hemispheric background will only be controlled effectively through hemispheric scale control measures on ozone precursors, which are now an urgent priority.

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This report has been prepared using input and expertise from a wide variety of contributors who are listed in Appendix A of the main RoTAP report. The main authors responsible for drafting the report are listed below.

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