I. INTRODUCTION

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To be reviewed by ICP M&M NFCs

Updated by Anne Christine Le Gall, Chairwoman of the Task Force on Modelling and Mapping and Jean Paul Hettelingh, CCE, from initial text by Till Spranger, Mapping Manual 2004

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I.1 OVERVIEW

The critical loads and levels concept is an effect-based approach by which the need for the reduction of atmospheric depositions can be quantified. As a consequence, the concept allows the quantification of atmospheric pollutants emission abatement at their source. The critical load and level concept was developed under the Convention on Long-range Transboundary Air Pollution (LRTAP-Convention) and was first applied under its effect-oriented scientific programmes (Hettelingh et al, 2004). The concept has been used for defining emission reductions aimed at protecting ecosystems and other receptors, such as materials and human health. It is based on indicators defined for specific pollutants, effects and receptors. Critical loads and levels provide a reference point for the sustainability of air pollution against which actual as well as modelled pollution levels can be compared. They have been used in a framework to address the sustainability of (combinations of) pollution drivers and effects and in particular in the effect based support of the Protocol to Abate Acidification, Eutrophication and Ground level Ozone under the LRTAP-Convention (e.g. Reiss et al, 2012) and the national Emission Ceiling Directive of the European Commission (e.g. Hettelingh, et al. 2013). This support consisted of calculating emission ceilings for individual countries with respect to acceptable air pollution levels (e.g. defined reductions of critical load/level exceedances). Critical loads and levels have been designed to support the setting of ambition levels and assess the efficiency of air pollution reduction policies. In policy frameworks such as the LRTAP-Convention, they have been developed and applied for scenario analyses or optimization of effect based emission reduction as shown in Figure I.1.

Critical loads are related to indirect, soil-mediated effects of elevated deposition and are defined as "**a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge**" (Nilsson and Grennfelt 1988). Critical levels are defined almost similarly, i.e. as ambient concentrations above which damage may occur.

Critical loads and levels correspond to a maximum allowable exposure of a receptor to deposition or ambient concentration respectively. The implications of these definitions in terms of calculations and applications within scientific and policy frameworks are presented in Chapters III, V and VI.

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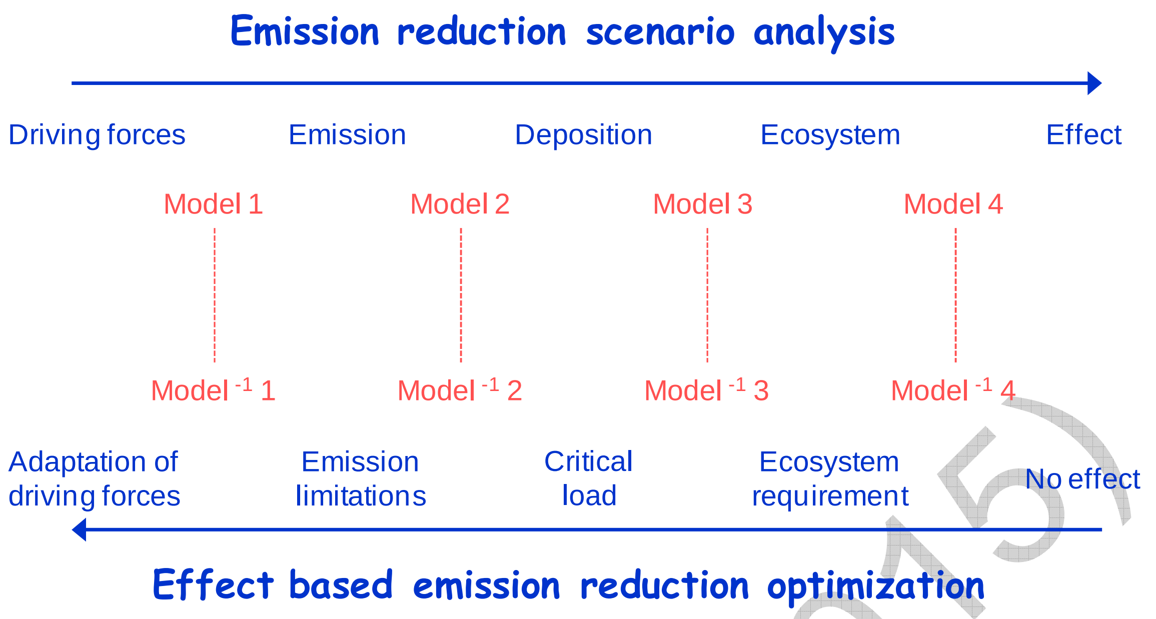

Figure I.1 Effect based emission reduction optimization and scenario analysis (adapted from Harald Sverdrup)

I.2 THE CRITICAL LOAD AND LEVEL CONCEPT IN THE UNECE CONVENTION ON LONG-RANGE TRANSBOUNDARY AIR POLLUTION

During the 1970s, it was recognised that trans-boundary air pollution has ecological and economic consequences (e.g. for the forest and fish industries) caused by acidifying air pollutants. In response to this, the countries of the UN Economic Commission for Europe (UNECE) developed a legal, organisational and scientific framework to deal with this problem. The UNECE Convention on Long-range Transboundary Air Pollution (LRTAP) was the first international legally binding instrument to deal with problems of air pollution on a broad regional basis (see http://www.unece.org/env/lrtap/). Signed in 1979, it entered into force in 1983.

The Convention requires that its Parties cooperate in research on the effects of sulphur compounds and other major air pollutants on human health and the environment, including agriculture, forestry, natural vegetation, aquatic ecosystems and materials (Article 7(d) of the Convention). The Convention also calls for the exchange of information on the physico-chemical and biological data relating to the effects of LRTAP and the extent of damage which these data indicate can be attributed to LRTAP (Article 8(f) of the Convention). To this end the Executive Body for the Convention established a Working Group on Effects (WGE) that is supported by a number of International Cooperative Programmes (ICPs, cf. Figure I.2). These ICPs provide monitoring and modelling methodologies and results on effects of air pollution to establish a sound scientific basis in support of effect oriented European emission abatement policies of the LRTAP-Convention. More recently, the Long Term Strategy of the LRTAP-Convention calls for effect-based knowledge on the interaction between changes of air pollution, climate and biodiversity.

In 1986, a work programme under the Nordic Council of Ministers agreed on scientific definitions of critical loads for sulphur and nitrogen (Nilsson, 1986). This stimulated the work under the Convention and in March 1988 two Convention workshops were held to further evaluate the critical levels and loads concept and to provide up-to-date figures. The Bad Harzburg (Germany) workshop dealt with critical levels for direct effects of air pollutants on forests, crops, materials and natural vegetation, and the Skokloster (Sweden) workshop on critical loads for sulphur and nitrogen compounds (Nilsson and Grennfelt 1988). Furthermore, at the Bad Harzburg workshop the first discussions took place on the possible use of critical level/loads maps for defining areas at risk. It was foreseen that these could play an important role in the development of air policy.

As a result of these workshops, in 1988, the Executive Body for the Convention approved the establishment of a programme for mapping critical loads and levels (Task Force on Mapping) under the Working Group for Effects (WGE) with Germany as the lead country (http://icpmapping.org/). In 1989 the Executive Body welcomed the offer of the Netherlands to host a Coordination Centre for Effects[1] (CCE) that was established in 1990 at RIVM in Bilthoven, The Netherlands (http://wge-cce.org/). From 1990 to 2015, the CCE has organised 25 so-called CCE workshops dedicated to the development of policy relevant critical thresholds and other effect based methodologies. These workshops also aimed to help reach scientific consensus on modelling and mapping methods and databases.

In 1999, the Executive Body replaced the Task Force on Mapping with the Task Force of the International Cooperative Programme on Modelling and Mapping of Critical Loads and Levels and their Air Pollution Effects, Risks and Trends (ICP M&M). In September 2009, France became the lead country of this programme.

The mandates of the ICP M&M[2], the CCE and its National Focal Centres[3] are described further below (see also Hettelingh *et al*, 2004). The Programme and the CCE positions within the Convention are shown in Figure I.2.

[1] at the Netherlands Office for Environmental Assessment (www.rivm.nl/cce)

[2] established by the Executive Body in 1999 to replace the Task Force on Mapping, see Ch. 1.3

[3] In 2013, 24 National Focal Centres are actively participating in the ICP M&M

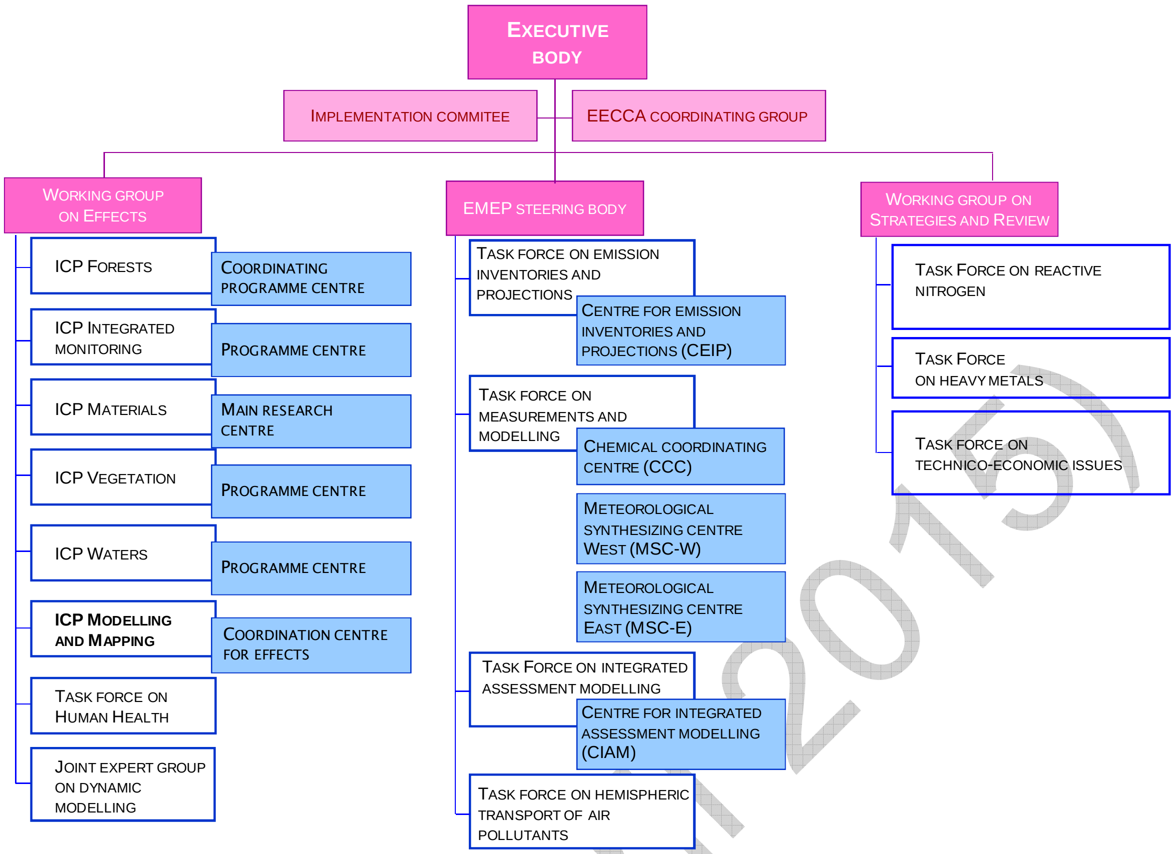

Figure I.2: LRTAP organisation chart showing the position of the ICP M&M Task Force within the WGE.

The LRTAP-Convention brings states together with a common purpose and provides a forum for solving issues that cannot be addressed by countries and sub-regions alone (UN, 2004). By 2014 the Convention was extended with eight protocols, three of which have been revised once (cf. http://www.unece.org/env/lrtap/status/lrtap_s.html). The first substance-specific protocols were negotiated on the basis of economic and technological information (e.g. best available techniques). These set the same emission reduction targets for all Parties relative to an emission level of a reference year. These technology-based protocols do not take effects to ecosystems or human health into account. A second generation of protocols came into being when, in June 1994, a second protocol for reducing sulphur emissions (the 'Oslo protocol') was signed by 30 countries. This identified effects-based, cost-effective abatement measures anchored in the analysis of impacts using critical loads. The long-term objective for negotiating national emission reductions was to eliminate the excess sulphur deposition over critical loads for sulphur, i.e. to avoid future exceedances. While cutting sulphur dioxide emissions to achieve deposition levels below critical loads was not feasible for all ecosystems in Europe, policies aimed at reducing effects. The negotiations were based on both the assessment of environmental effects and the protection of ecosystems, as well as technical and economic considerations.

Three of the eight protocols (Heavy Metals, POP and the Gothenburg Protocol to abate acidification, eutrophication and ground level ozone) have been amended between 2009 and 2012. The revised protocols will enter into force when two thirds of the parties have ratified, accepted or approved them.

The application of the critical levels and loads concept and the role of critical level/load maps for the development and implementation of air pollution control strategies are shown in Figure I.3.

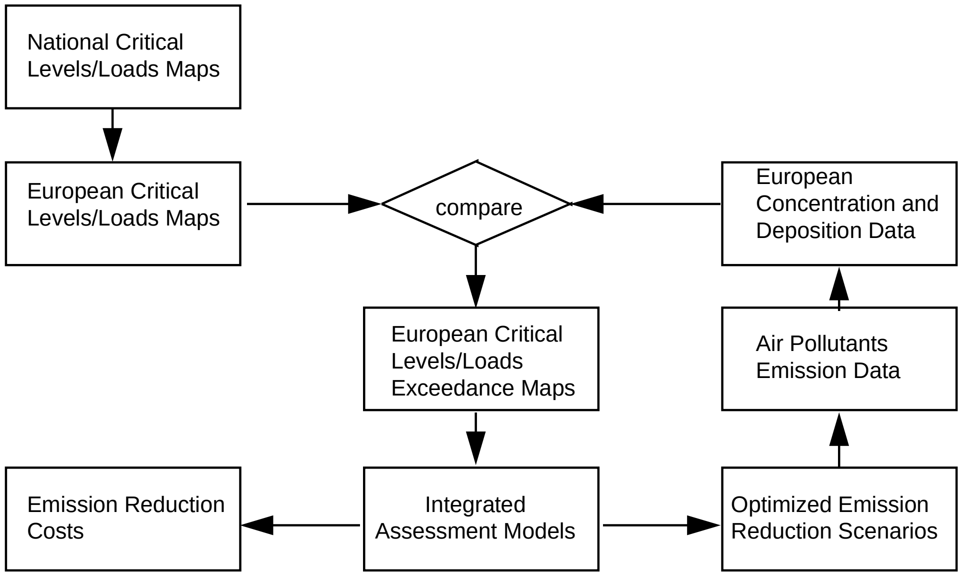

Figure I.3: Critical Loads and Abatement strategies

Summarising this figure, the following "crucial steps" are involved:

- Define methods and criteria to determine and map critical loads and levels (Convention and CCE workshops);
- Obtain international approval (Working Group on Effects and Executive Body);
- Perform a mapping exercise (based on this Manual and on the proceedings of critical levels/loads and mapping workshops; see www.icpmapping.org and www.wge-cce.org);
- Calculate excess deposition/concentration per unit area. This can be done in a scenario or optimization mode (Figure I.1) of integrated assessment models (see Hettelingh et al 2009), such as the GAINS model (Amann *et al., 2011)*
- Use the results for emission reduction strategies in support of European Air pollution policy agreements under the LRTAP Convention and in the European Union.

In practice, maps of critical loads have been used as yardsticks to assess the need for reducing depositions in each EMEP grid cell. An emission reduction scenario can be assessed by comparing a computed scenario-specific European deposition map with the European critical loads map. In support of the Oslo protocol (1994), the negotiators started to use computer models to assess national and European abatement costs of sulphur emission reduction and the effectiveness of alternative emission reduction scenarios. In particular, the RAINS model (Regional Acidification INformation and Simulation) and its successor, the GAINS model (**G**reenhouse Gas and **A**ir Pollution **In**teractions and **S**ynergies), have been applied to assist key policy negotiations on improving air quality in UNECE and in Europe (Amann et al., 2011).

A full description of the GAINS model is given in Amann et al. (2011) and on the model website (http://gains.iiasa.ac.at/models/) from which the following information is adapted. The **GAINS Model** is an integrated assessment model that simultaneously addresses health and ecosystem impacts of particulate pollution, acidification, eutrophication and tropospheric ozone. The GAINS Model considers also greenhouse gas emission rates. Thus pollutants included are:

- Carbon dioxide (CO_2)

- Methane (CH_4)
- Nitrogen oxides (NOx)
- Nitrous oxide (N_2O)
- Particulate matter (TSP, PM_{10}, $PM_{2.5}$ and PM_1)
- Sulphur dioxide (SO_2)
- Volatile organic compounds (VOC)
- Ozone (O_3)

Certain versions of the GAINS Model also address:

- Ammonia (NH_3)
- Carbon monoxide (CO)
- Fluorinated greenhouse gases (F-Gases)

GAINS has the ability to address various pollutants, emission reduction alternatives, abatement costs and impacts in a consistent systematic framework. By this GAINS provides useful information on tradeoffs between pollution sources, costs and benefits of pollutant reductions as well as impacts of different pollutants to human health and the environment. The GAINS model calculates emissions on a medium-term time horizon. Emission projections are specified in regular time (e.g. five year) intervals through a future policy-defined target year. Emission abatement alternatives and emission control costs can be simulated taking a variety of optional emission reduction technologies into account. Atmospheric dispersion processes are modelled exogenously by EMEP and integrated into the GAINS model framework in a simplified way (e.g. by means of Source-Receptor relationships between country emissions and EMEP grid cells). Critical load and critical level data are compiled exogenously under the Working Group on Effects and incorporated into the GAINS Model framework.

The CCE Environmental Impact Assessment scheme (Figure I.4) shows how the GAINS data may be used in conjunction with critical loads established under the Modelling and Mapping Programme by the CCE and its network of National Focal Centres. Critical loads are stored in the European Critical Loads database held at the CCE. The CCE tailors the European critical load database for use by GAINS and other integrated assessment models, in support of European air pollution policies. More recently the European critical load database is also considered in national programmes that address protected European natural areas.

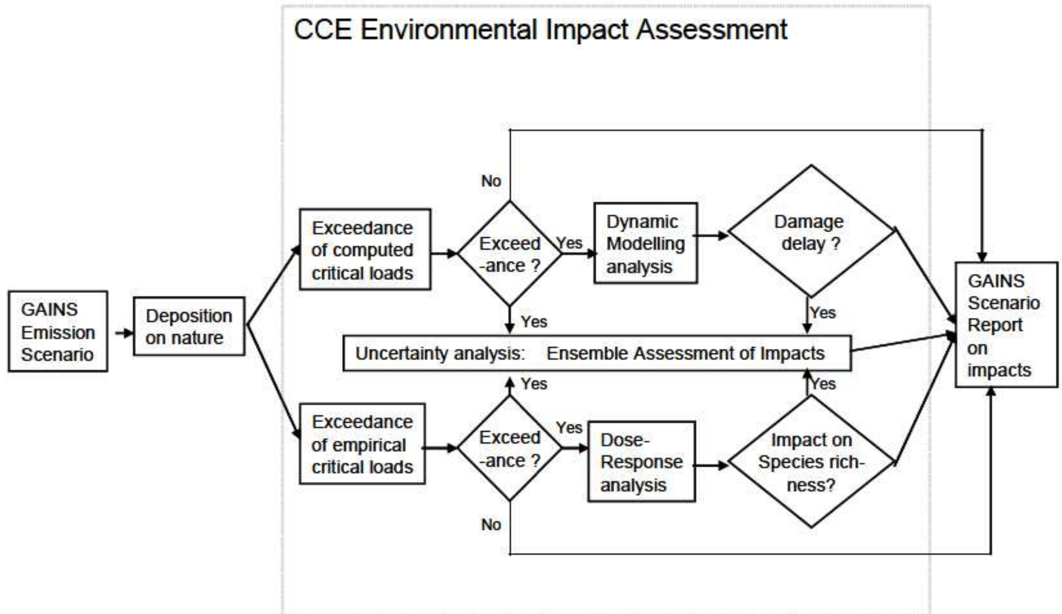

Figure I.4: The CCE Environmental impact assessment illustrates the links between the GAINS model and critical loads exceedance evaluation (Hettelingh et al., 2008).

The GAINS Model can be operated in two modes, i.e. the “scenario assessment” and “optimization mode” (see Figure I.1). The “scenario assessment” mode follows the pathways of the emissions from their sources to their impacts. In this case, the model provides estimates of regional costs and environmental benefits of several emission control strategies. The GAINS model can also operate in the “optimization mode” which identifies cost-optimal allocations of emission reductions in order to achieve specified deposition levels, concentration targets or GHG emissions ceilings. The current version of the model can be used for viewing activity levels and emission control strategies, as well as calculating emissions and control costs for those strategies.

Since 1994 and the Oslo Protocol negotiations, the complexity of the work under the ICP M&M has increased, together with the scientific knowledge mobilized to support policy.

First, the critical load approach had to be completed for use in support of the 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (the “Gothenburg Protocol”). It recognizes that:

a) sulphur as well as oxidized and reduced nitrogen contribute to acidification. Therefore, two critical loads for acidity had to be distinguished, the critical load of sulphur-based acidity and the critical load of nitrogen-based acidity (see Ch. V.1 - V.4).

b) both oxidized and reduced nitrogen contribute to eutrophication when critical loads of nutrient nitrogen are exceeded (see V.1 – V.3)

c) both oxidized nitrogen and volatile organic compounds contribute to the formation of tropospheric ozone, for which a critical level was identified for forests, crops and natural vegetation (see Ch. III.2.4).

Second, integrated assessment modelling with GAINS is commonly used to assess relationships between economic activities, pollutants emissions, their dispersion, their deposition and ambient concentration and their impacts on biological enpoints.

Third, climate change and the loss of biodiversity have become major issues in the European environmental policies in general and the long term strategy of the LRTAP-Convention (LRTAP, 2010) in particular. Relevant indicators have been (and still are being) developed (cf. chapter III to VIII). These new indicators are provided to policy makers as they complete the information issued from GAINS.

Furthermore, there have been major activities to develop effects-based approaches also for heavy metals for the preparation of the review and revision of the 1998 Århus Protocol on Heavy Metals. Critical limits, transfer functions and adapted methods to determine and apply critical loads of heavy metals are being developed and are listed in Ch. V.5.

I.3 AIMS AND ORGANIZATION OF THE MODELLING AND MAPPING PROGRAMME

The aims and objectives of the ICP on Modelling and Mapping were approved by the WGE at its nineteenth session in 2000 (Annex VII of document EB.AIR/WG.1/2000/4):

> *"To provide the Working Group on Effects and the Executive Body for the Convention and its subsidiary bodies with comprehensive information on critical loads and levels and their exceedances for selected pollutants, on the development and application of other methods for effect-based approaches, and on the modelling and mapping of the present status and trends in impacts of air pollution."*

Short-term and specific aims are defined in the convention work plan, agreed at sessions of the Working Group and approved by the Executive Body. These are in line with the Convention Long Term Strategy and respond to policy needs (LRTAP, 2010). Bi-annual work plans are available on the Convention web pages (http://www.unece.org/environmental-policy/treaties/air-pollution/meetings-and-events/air-pollution/).

I.3.1 DIVISION OF TASKS WITHIN THE PROGRAMME

A network of National Focal Centres (NFCs) under the ICP M&M is responsible for the generation of national data sets. NFCs cooperate with the Coordination Centre for Effects to develop modelling methodologies and European databases for critical loads. CCE reports on this work to the Task Force of the ICP M&M in yearly meetings held back to back with CCE workshops.

The Programme´s organization and division of tasks between its subsidiary bodies, as approved by the WGE (EB.AIR/WG.1/2000/4) are as follows:

"The International Cooperative Programme on Modelling and Mapping was established in 1999 (ECE/EB.AIR/68, para. 52 (f)) to further develop and expand activities so far carried out by the Task Force on Mapping of Critical Levels and Loads and their Exceedances (led by Germany [led now by France]) and by the Coordination Centre for Effects (at the National Institute of Public Health and the Environment[4] at Bilthoven, Netherlands), pursuant to their original mandates (EB.AIR/WG.1/18), amended to reflect the present structure of the Executive Body and the new requirements:

I.3.2 MANDATE FOR THE TASK FORCE OF THE ICP ON MODELLING AND MAPPING

(a) The Programme Task Force supports the Working Group on Effects, the Working Group on Strategies and Review and other subsidiary bodies under the Convention by modelling, mapping, reviewing and assessing the critical loads and levels and their exceedances and by making recommendations on the further development of effect-based approaches, and on future modelling and mapping requirements;

(b) The Task Force plans, coordinates and evaluates the Programme's activities, it is responsible for updating the Programme Manual, as well as for quality assurance;

(c) The Task Force prepares regular reports, presenting, and, where appropriate, interpreting Programme data.

I.3.3 MANDATE FOR THE COORDINATION CENTRE FOR EFFECTS

(a) The Coordination Centre for Effects (CCE) assists the Task Force of the ICP on Modelling and Mapping, and gives scientific and technical support, in collaboration with the Programme Centres under the Convention, to the Working Group on Effects and, as required, to the Working Group on Strategies and Review, as well as to other relevant subsidiary bodies under the Convention, in their work related to the effects of air pollution, including the practical development of methods and models for calculating critical loads and levels and the application of other effect-based approaches;

(b) In support of the critical loads/levels mapping and modelling exercise, CCE:

- *(i) Provides guidance and documentation on the methodologies and data used in developing critical loads and critical levels of relevant pollutants, and their exceedances;*
- *(ii) Collects and assesses national and European data used in the modelling and mapping of critical loads and levels of relevant pollutants. The Centre circulates draft maps and modelling methodologies for review and comment by National Focal Centres, and updates modelling methodologies and maps as appropriate;*
- *(iii) Produces reports and maps on critical loads/levels documenting mapping and modelling methodologies, with the assistance of the National Focal Centres and in cooperation with the Task Force on ICP on Modelling and Mapping;*
- *(iv) Provides, upon request, the Working Group on Effects and the Task Force on ICP on Modelling and Mapping, the Working Group on Strategies and Review and the Task Force on Integrated Assessment Modelling, with scientific advice regarding the use and interpretation of data and modelling methodologies for critical loads and levels;*
- *(v) Maintains and updates relevant databases and methodologies, and serves as a clearing house for data collection and exchange regarding critical loads and levels among Parties to the Convention, in consultation with the International Cooperative Programmes and EMEP;*
- *(vi) Conducts periodic training sessions and workshops to assist National Focal Centres in their work, and to review activities and develop and refine methodologies used in conjunction with the critical load and critical level mapping exercise;*

(c) While the Coordination Centre for Effects reports to the Working Group on Effects and the Task Force of ICP on Modelling and Mapping, and receives guidance and instruction from them concerning tasks, priorities and timetables, it also assists the Working Group on Strategies and Review, the Task Force on Integrated Assessment Modelling, and other bodies under the Convention, when appropriate."

[4] since 2003 at the Netherlands Office for Environmental Assessment

I.3.4 RESPONSIBILITIES OF THE NATIONAL FOCAL CENTRES

The tasks of the National Focal Centres have been defined in the 1996 version of the Mapping Manual. The National Focal Centres are responsible for:

a) The collection and archiving of data needed to obtain maps in accordance with the Manual guidelines and in collaboration with the Coordination Centre for Effects;
b) The communication of national mapping procedures (data, formats, models, maps) to the Coordination Centre for Effects;
c) The provision of written reports on the methods and models used to obtain national maps;
d) Organising training facilities for national experts in collaboration with the Coordination Centre for Effects;
e) Making the necessary provisions to obtain national maps in accordance with the resolution and standards (measurement units, periodicity, etc.) described in the Manual;
f) Collaborating with the Coordination Centre for Effects to permit assessment of the methods applied in order to perform multinational mapping exercises (e.g. using GIS) and model comparisons;
g) Updating the Mapping Manual as appropriate, in collaboration with the Task Force on Mapping and the Coordination Centre for Effects.

I.4 OBJECTIVES OF THE MANUAL

The principal objectives of this Manual are to describe methods that are recommended for use by the Parties to the Convention, represented by their National Focal Centres. The Modelling and Mapping Manual can help and assist NFCs to:

a) Model and map critical levels and loads in the ECE region;
b) Model and map areas with air pollution values exceeding critical levels or loads;
c) Develop, harmonize and apply methods and procedures (including dynamic modelling) to assess recovery and risk of future damage on specific targets including biodiversity in a context of climate change;
d) Determine and identify sensitive receptors and locations.

Thus it provides a scientific basis on the application of critical levels and loads, their interrelationships, and the consequences for abatement strategies, e.g. for the assessment of optimized allocation of emission reductions.

This Manual includes methodologies used by ICP Materials to assess impact of pollution on corrosion and soiling of building materials (Ch. 4) and by ICP Vegetation concerning the impact of air pollutants, and especially ozone, on crops and semi-natural vegetation (Ch. 3). In contrast to Manuals (or comparable methodological documents) of other ICPs and EMEP CCC this manual does not contain information on methods of measurements nor on detailed data generation. This reflects the aims and tasks of the ICP Modelling and Mapping within the Convention.

Specific technical information as well as detailed results and other information by National Focal Centres can be found in CCE Status Reports (and publications (http://wge-cce.org/Publications and bibliographic references therein).

I.5 STRUCTURE AND SCOPE OF THE MANUAL

Chapter I has given an overview of the Convention focuses on impact assessment and, within the Convention, of ICP M&M activities. These include the development of impact indicators, including the critical loads and levels, whose calculation methods are presented in the following chapters.

Chapter II describes methods to map pollutant concentrations and depositions. These may be used to generate exceedance maps by subtracting critical levels/loads from them. At the European scale, chemistry transport models such as EMEP model are used to construct such maps (cf. http://www.emep.int/mscw/). The modelled pollutant concentrations and depositions are derived from national emissions which provide the link to negotiations on emission controls. In addition, NFCs are encouraged to produce high resolution maps which can be used for effects assessments in specific ecosystems at the national and local level. This chapter was produced by experts including those from EMEP.

Chapter III describes the methods developed for the quantification and mapping of critical levels and fluxes of gaseous pollutants for vegetation. It is largely based on conclusions and recommendations of Convention workshops and, for ozone, on intensive work coordinated by ICP Vegetation in cooperation with EMEP. This chapter has been prepared by ICP Vegetation experts (http://icpvegetation.ceh.ac.uk/).

Chapter IV describes the derivation and application of Acceptable Levels for effects on materials. It is part of the Manual of ICP on Materials (www.corr-institute.se/ICP-Materials). It has been prepared by ICP Materials experts.

Chapter V describes how to quantify and map critical loads of nutrient nitrogen, acidity and heavy metals. The structure of the chapter takes into account three main elements: ecosystems types (aquatic and terrestrial), impacts (eutrophication, acidification, pollution by heavy metals) and methods (empirical and modelling). The chapter starts with an overview including definitions (V.1), followed by a subchapter on Empirical Critical Loads (V.2) with sections on nutrient nitrogen (results of a workshop organized by the CCE in Noordwijkerhout in 2010; Bobbink and Hettelingh, 2011) and acidity (results of a workshop in York in 2000). Chapter V.3 describes methods to model critical loads for terrestrial ecosystems (SMB model), again divided into subchapters on eutrophication and acidification. Chapter V.4 deals with Critical Loads for surface waters (developed in close cooperation with ICP Waters). Again the chapter is divided into subchapters on eutrophication and acidification. Finally, Chapter V.5 describes methods to model and map critical loads of heavy metals. Finally, new and preliminary approaches to assess the impact of nitrogen on biodiversity are described here. This chapter is at the chore of ICP M&M activity and has been mainly written by CCE.

Chapter VI describes dynamic models for acidification and eutrophication and the use of their results. The authors developed it in close cooperation with the Joint Expert Group on dynamic modelling.

The last two chapters present issues common to the use and the calculation of critical loads for all type of effects (acidification, eutrophication, heavy metals).

Chapter VII describes how to identify critical load exceedance and parameters derived from exceedance (protection isolines, [average] accumulated exceedances).

Chapter VIII describes procedures needed to produce maps, including map geometry / projections, spatial generalisation and representativity, and the estimation of uncertainty and bias.

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I.6 HISTORICAL BIBLIOGRAPHY AND WEBSITES

For historical details on the establishment of the Task Force on Mapping and the mandates of the cooperating partners in the modelling and mapping exercise see EB Air/R.18/Annex IV, Section 3.6 and EB Air/WG.1/R.18/Annex I, as well as document EB.AIR/WG.1/2004/3.

The historical development of the programme and the approaches used for calculating critical loads and levels can be followed by consulting the following background material:

(a) Nilsson J (ed) (1986) Critical Loads of Nitrogen and Sulphur. Environmental Report 1986:11, Nordic Council of Ministers, Copenhagen, 232 pp.

(b) Report of the Initial ECE Mapping Workshop, Bad Harzburg 1989

(c) Mapping Vademecum 1992, available at the Coordination Centre for Effects, Bilthoven, The Netherlands, RIVM Report No. 259101002.

(d) Manual on Methodologies and Criteria for Mapping Critical Loads/Levels (First Edition); *Texte Umweltbundesamt 25/93*, Federal Environmental Agency (UBA)(ed.), Berlin, Germany

(e) Manual on Methodologies and Criteria for Mapping Critical Loads/Levels and Geographical Areas Where They Are Exceeded (fully revised in 1995/1996); *Texte Umweltbundesamt 71/96*, Federal Environmental Agency (UBA)(ed.), Berlin, Germany

(f) CLRTAP (2004). Manual on methodologies and criteria for modelling and mapping critical loads and levels and air pollution effects, risks and trends. ICP Mapping and Modelling 251 p

(g) Numerous scientific articles referenced in the following chapters.

Status, results and agenda of the ICP Modelling and Mapping are described in various documents to be found on the Convention's web site (www.unece.org/env/wge). Various aspects concerning technical and scientific background and detailed results also of National Focal Centres can be found in CCE publications, especially the CCE Status Reports, found on the CCE web site (http://wge-cce.org/Publications).

I.6.1 GAINS MODEL

About the GAINS model as developed by the IIASA, see:

- Gains Europe: http://gains.iiasa.ac.at/gains/EUN/index.login?logout=1
- Publications: http://www.iiasa.ac.at/web/home/research/researchPrograms/MAG-Publications.en.html

I.6.2 REFERENCES

Amann, M., Bertok, I., Borken-Kleefeld, J., Cofala, J., Heyes, C., Höglund-Isaksson, L., Klimont, Z., Nguyen, B., Posch, M., Rafaj, P., Sandler, R., Schöpp, W., Wagner, F., Winiwarter, W., 2011. Cost-effective control of air quality and greenhouse gases in Europe: Modeling and policy applications. Environmental Modelling & Software 26, 1489-1501.

Gauger, T., Anshelm, F., Schuster, H., Erisman, J.W., Vermeulen, A.T., Draaijers, G.P.J., Bleeker, A., Nagel, H.-D., 2002. Mapping of ecosystem specific long-term trends in deposition loads and concentrations of air pollutants in Germany and their comparison with Critical Loads and Critical Levels Part 1: Deposition Loads 1990-1999. UBA, Umweltbundesamt.

Reiss S, Grennfelt P, Klimont Z, Amann M, ApSimon H, Hettelingh J-P, Holland M, Le Gall A-C, Maas R, Posch M, Spranger T, Sutton MA, Williams M (2012) From Acid Rain to Climate Change, Science, 338: 1153-1154

Hettelingh J-P, Bull K, Chrast R, Gregor H-D, Grennfelt P, Mill W (2004) Air Pollution effects drive abatement strategies, in: Sliggers J and Kakebeeke W (eds.), Clearing the Air: 25 years of the Convention on Long-range Transboundary Air Pollution, UN Economic Commission for Europe, United Nations Publication, ISBN 92-1-116910-0, Geneva, Switzerland, 167 pp.

Hettelingh J-P, Posch M, Velders JM, Ruyssenaars, Adam M, de Leeuw, F, Lükewille A, Maas R, Sliggers J, Slootweg J, 2013. Assessing interim objectives for acidification, eutrophication and ground-level ozone of the EU National Emissions Ceilings Directive with 2001 and 2012 knowledge, Atmospheric Environment 75: 129-140

Hettelingh J-P, De Vries B, Hordijk L, 2009. Integrated Assessment, in: Boersema J and Reijnders L (eds.), Principles of Environmental Sciences, Springer, ISBN 978-1-4020-9157-5, pp. 385-417

Bobbink R and Hettelingh J-P (eds), 2011. Review and revision of empirical critical loads and dose response relationships. Proceedings of an international expert workshop, Noordwijkerhout, 23-25 Juni 2010, RIVM-report 680359002, Coordination Centre for Effects, RIVM, Bilthoven.

Hettelingh, J.P., Posch, M., Slootweg, J., 2008. Status of the critical loads database and impact assessment. In: Hettelingh, J.P., Posch, M., Slootweg, J. (Eds.), Critical load, dynamic modelling and impact assessment in Europe. CCE Status Report 2008. PBL Netherlands Environmental Assessment Agency, Bilthoven, The Netherlands, pp. 15-28.

LRTAP, 2010. Long-term strategy for the Convention. Moving forward: a strategic vision for the Convention for 2010–2020. Convention on Long-range Transboundary Air Pollution; United Nations, European economic commission, Geneva, Switzerland, p. 9.

Nilsson, J. (Ed.), 1986. Critical loads of nitrogen and sulphur. Nordic Council of Ministers, Copenhagen, Denmark.

Nilsson, J., Grennfelt, P., 1988. Critical loads for sulphur and nitrogen. Nordic council of Ministers, Report from a workshop held at Skokloster, Sweden, 19-24 March 1988. Miljorapport 15, pp. 1 - 418