Model for multi-pollutant impact and assessment of threshold levels for cultural heritage

MULTI-ASSESS

SO_2

O_3

NO_2

Acid rain

HNO_3

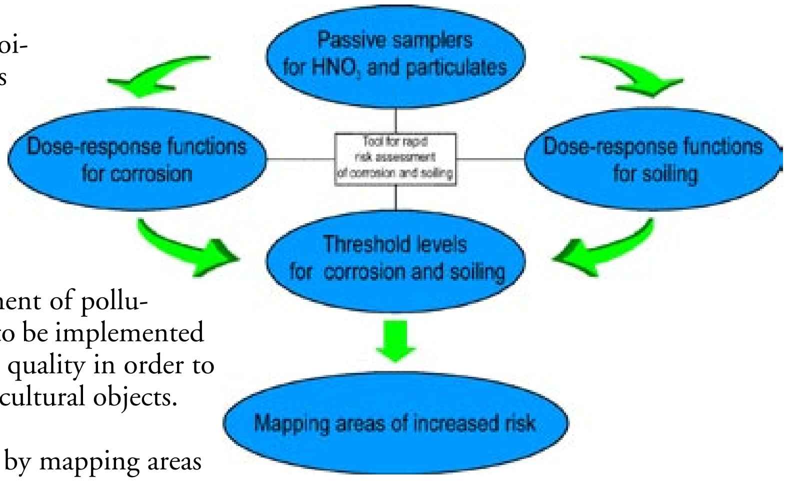
Particles

Background

The costs for deterioration and soiling of different materials due to air pollution are huge and the damage to culture targets endangers seriously the rich European cultural heritage. Interests have been focused for a long time on the effects of sulphur pollutants and especially sulphur dioxide, which was identified as the most important factor for deterioration of several materials. Existing dose-response functions reflect in principle a pollution situation dominated by sulphur dioxide emissions. The decreasing sulphur dioxide levels in most parts of Europe and the increasing car traffic causing elevated levels of nitrogen compounds, ozone and particulates has created a new multi-pollutant situation. The development of dose-response relations, which quantify the multi-pollutant effects in combination with climatic parameters on the deterioration and soiling of different materials, constitutes a necessary condition for prediction of damage and for establishment of threshold levels. The results should be fed into air quality policy and would be an efficient tool for authorities, organisations and individuals responsible for the care of cultural heritage in the efforts to preserve objects of cultural heritage and to reduce the cost for maintenance.

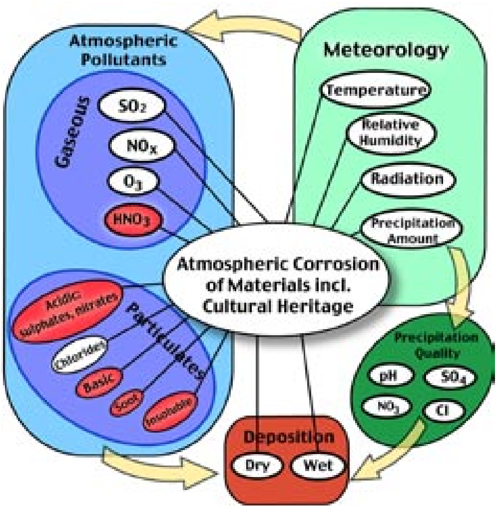
Main objectives and expected results

- To *develop* multi-pollutant deterioration and soiling models of wet and dry deposition of gases and particulates on materials used in objects of the European cultural heritage and to obtain dose-response functions quantifying the effects as function of pollution and meteorological parameters.



- To *use* the dose-response functions for assessment of pollution threshold levels and to recommend levels to be implemented in the future development of EU policy on air quality in order to minimise the pollution effects on historic and cultural objects.
- To *demonstrate* the usefulness of the approach by mapping areas exceeding threshold levels in Europe.
- To *adapt and validate* passive samplers for measuring atmospheric concentrations of nitric acid and particles.
- To *propose a kit* for rapid low cost assessment of the deterioration risk to objects of cultural heritage, consisting of a package of selected material specimens and passive samplers for pollutants.

Multipollutant effects on materials



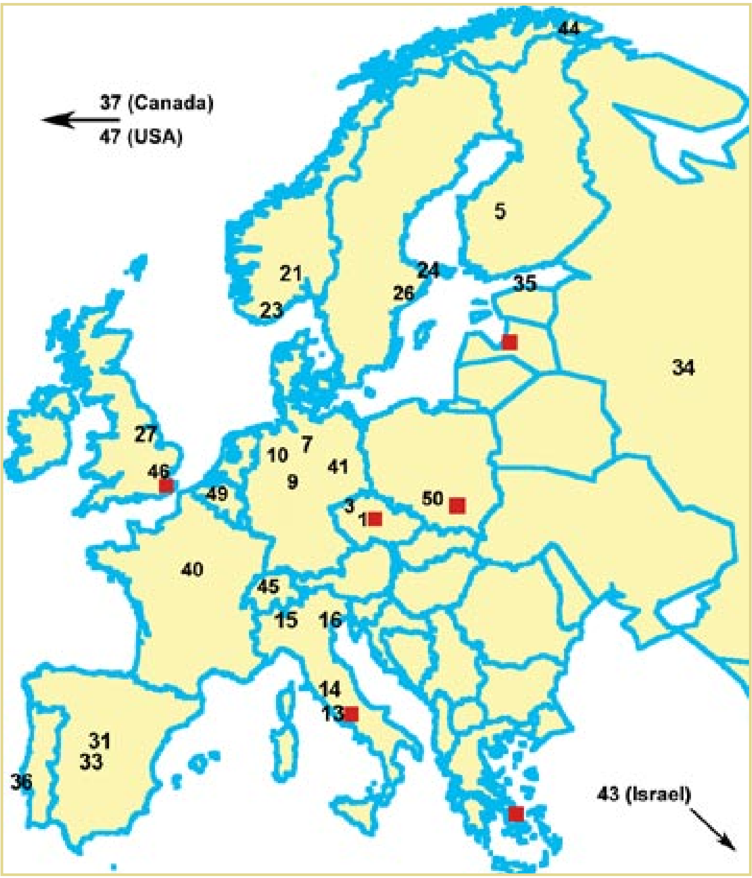
This changed pollution situation must be taken into account in the development of an improved model for the effects of pollutants on the deterioration of important material groups. The model for deterioration of materials will include both gaseous pollutants (sulphur dioxide, nitrogen dioxide, ozone and nitric acid), particulates and precipitation and will separate the effect of dry and wet deposition on the deterioration process. Also the model for soiling will reflect the new pollution situation where particulate elemental carbon is no more dominating for the soiling of surfaces.

Field exposures

Two field exposure programmes are performed within MULTI-ASSESS, the broad field exposure (WP3) and the targeted field exposure (WP4). The broad field exposure is performed in the network of ICP Materials test sites. At each site materials are exposed and, simultaneously, measurements of environmental parameters are performed. The data from the broad field exposure will be the basis for the development of the dose-response functions for corrosion.

The targeted field exposures aims at providing information on the spatial and temporal variations at a local and micro scale and for comparison of passive samplers and particulates with active sampling PM10 equipment. The ability to look at different components of particulate pollution (acidic, basic, elemental carbon and inert material) will permit the calculation of the effects of each on damage and soiling. The targeted field exposure will be performed in London, Prague, Athens, Rome and Krakow with exposure and measurements of the same materials and environmental parameters as in the broad field exposure. The soiling studies will be performed on specially designed racks with sheltering and positioned vertically on facades or roofs at about six different positions. This type of field exposure will give the possibility to make an assessment of the contribution of pollution from traffic sources (motor vehicles) and other sources to deterioration and soiling in urban environments. A special study will be performed comprising a comparison of the sensitivity to deterioration due to air pollution of the Portland limestone and some other calcareous stones frequently used in Europe. The exposure will be performed at the five targeted sites and at two Latvian sites.

Test sites



WP3 Broad field exposure sites

No	Name	Country
1	Prague-Letnany	Czech Republic
3	Kopisty	Czech Republic
5	Ähtäri	Finland
7	Waldhof-Langenbrügge	Germany
9	Langenfeld-Reusrath	Germany
10	Bottrop	Germany
13	Rome	Italy
14	Casaccia	Italy
15	Milan	Italy
16	Venice	Italy
21	Oslo	Norway
23	Birkenes	Norway
24	Stockholm South	Sweden
26	Aspvreten	Sweden
27	Lincoln Cathedral	United Kingdom
31	Madrid	Spain
33	Toledo	Spain
34	Moscow	Russian Federation
35	Lahemaa	Estonia
36	Lisbon	Portugal
37	Dorset	Canada
40	Paris	France
41	Berlin	Germany
43	Tel Aviv	Israel
44	Svanvik	Norway
45	Chaumont	Switzerland
46	London	United Kingdom
47	Los Angeles	USA
49	Antwerpen	Belgium
50	Katowice	Poland

■ = **WP4 Targeted field exposure sites**

Athens	Greece
Krakow	Poland
London	UK
Prague	Czech Republic
Riga	Latvia
Rome	Italy

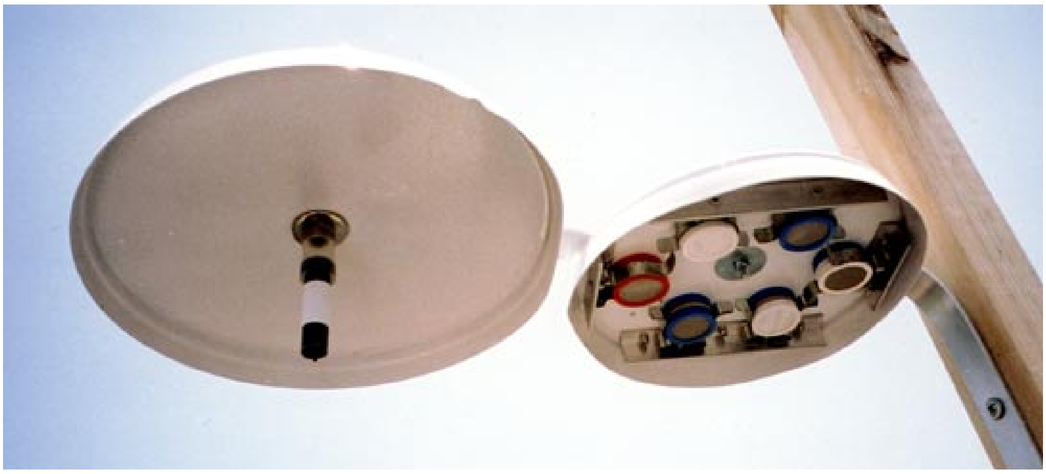
Environmental parameters

Climate	Gases	Particles	Precipitation
Temperature	SO_2	Amount	Amount
Relative humidity	NO_2	Chemical composition	Conductivity
Time of wetness	O_3		Chemical composition
Sun hours (radiation)	HNO_3		

Materials

Carbon steel
Zinc
Copper
Cast Bronze
Portland limestone
Coil coated steel
Potash-lime glass
Modern glass
Stone materials, concrete

Passive samplers for pollutants



Passive samplers for measurement of particles (left) and gaseous pollutants (right).

For field atmospheric corrosion research it is both unnecessary and too expensive to use advanced techniques for measurements of pollution parameters and many locations of interest have no access to electric power. Passive (diffusive) samplers are thus very suitable for corrosion studies and are already extensively used for this purpose in Europe. The development of diffusive samplers has so far mainly been focused on the gases measured in national and international networks (NO_2, SO_2, O_3) and VOC. In MULTI-ASSESS, passive samplers for HNO_3 (WP1) and particulates (WP2) are developed. The small size of the samplers makes it possible to sample in locations that otherwise would be impossible to reach, thereby assessing the microclimate in the true sense of the word.

Relation between MULTI-ASSESS and UN ECE ICP Materials

ICP Materials (http://www.corr-institute.se/ICP-Materials/) is one of several effect oriented International Co-operative Programmes (ICPs) within the United Nations Economic Commission for Europe (UN ECE). Exposure of materials has been performed in ICP Materials since 1987. Measured environmental data in ICP Materials includes climatic parameters, gaseous pollutants and precipitation. In addition to these parameters HNO_3 and particulates will be measured in the MULTI-ASSESS project.

In MULTI-ASSESS, the time of exposure of materials is one year in the field exposures. In the context of atmospheric corrosion this time is considered to be very short. In order to develop the model data from longer exposure times are needed. The network of UN ECE ICP Materials test sites is available for exposure of materials to the participants since several years. Besides acting as an essential resource to the MULTI-ASSESS project this means that long-term data sets on corrosion attack and environmental data exists for these test sites. These data will be used in order to permit an extrapolation of the one year data to longer time periods.

Both ICP Materials and MULTI-ASSESS are co-ordinated by the Swedish Corrosion Institute.

Test site for targeted field exposure at the National Museum in Prague.

Dose-response functions

For unsheltered exposure the materials damage is usually discussed in terms of dry and wet deposition. Wet deposition includes transport by means of precipitation and dry deposition transport by any other process. One important task for the project is to estimate the relative contribution of dry and wet deposition to the degradation of materials. Therefore, and also because it makes sense from a mechanistic point of view, all dose-response function will have the general form

$$K = f_{dry} \cdot t^{k} + f_{wet} \cdot t^{m}$$

K	*Corrosion attack*
f_{dry}	*Dry deposition term (e.g. T, Rh, SO_2, NO_2, O_3, HNO_3, particles)*
f_{wet}	*Wet deposition term (e.g. Rain, H^+, Cl^-)*
t	*Exposure time*
k, m	*Estimated constants*

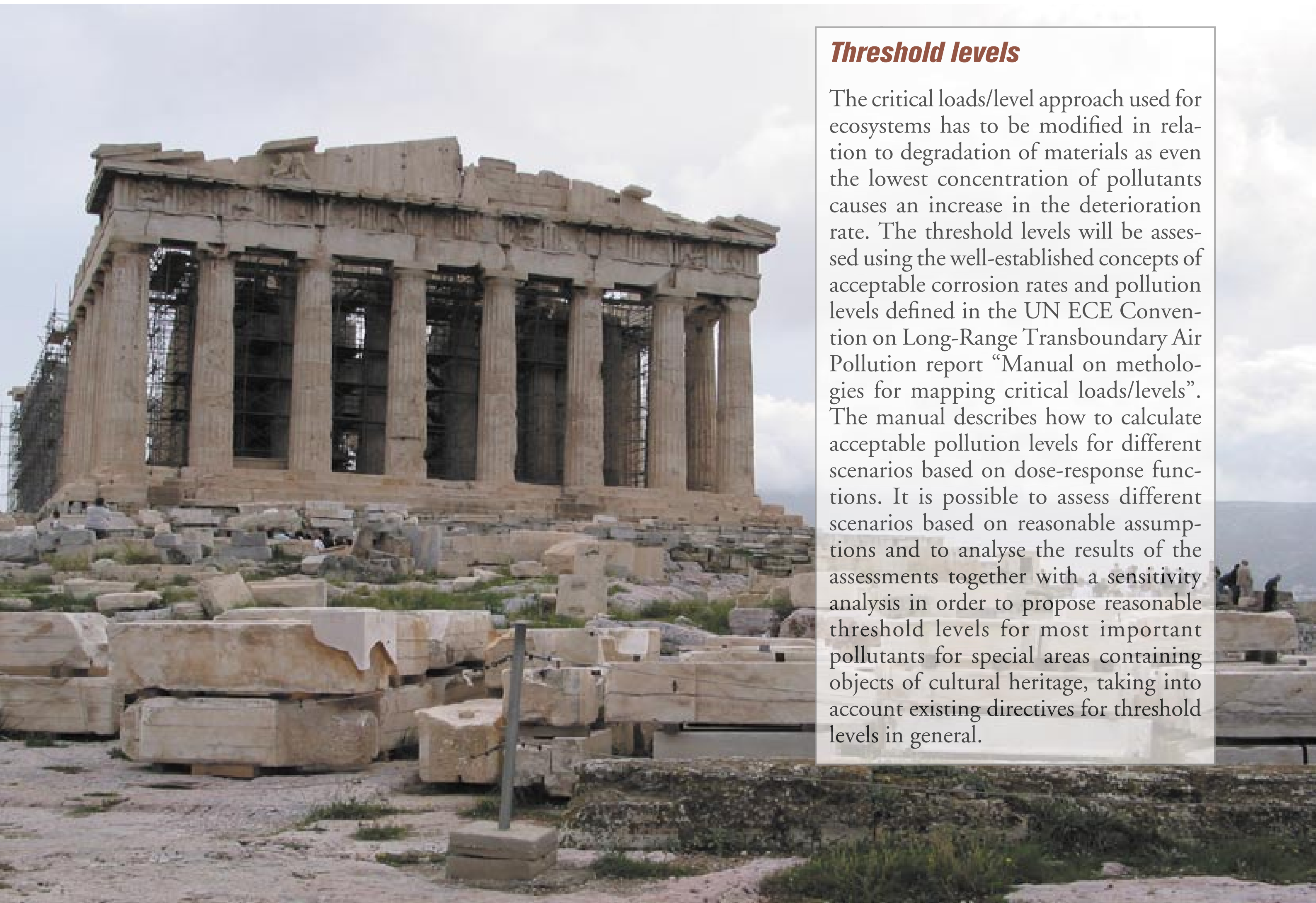
Mapping

Besides being used for the assessment of threshold levels the derived dose-response functions will also be suitable for mapping areas of increased risk of corrosion. The mapping is achieved by calculating the corrosion attack using easily obtainable environmental parameters. The produced maps are useful for communicating results of calculation and/or measurements of corrosion attack. They can be important tools for identifying areas with elevated risk of corrosion and for selecting materials to be used in a particular area.

Kit for rapid assessment

The dose-response functions can not take into account possible effects of microclimate. On the other hand, people in heritage management will be interested in the corrosivity on specific locations of their object of interest. The measurements of environment and corrosion performed by the combined efforts of MULTI-ASSESS and ICP Materials are very extensive and it would be unrealistic to ask an individual to perform all these measurements. The total analysis of the data from all these measurements will reveal that some are more important than others and also possibly that some parameters are redundant. Therefore it will be possible to propose a subset (kit) of all measurements that still captures the essential information in order to assess the corrosivity.

One-year exposures with the kit will show if acceptable pollution levels are exceeded and how the environment is affecting deterioration and soiling of the relevant materials. Regular exposures every few years will give trends of pollution and deterioration, which could be used as control of the effectiveness of strategies and measures for reduction of pollution and as an early warning of unexpected increase of corrosion due to new sources or combinations of pollutants. As an example, monuments included on the UNESCO World Heritage list have special requirements for monitoring. Organisations and individuals being responsible for these monuments can use the kit to assess if their site is properly maintained and also give indications on possible plans of action, if needed.



Threshold levels

The critical loads/level approach used for ecosystems has to be modified in relation to degradation of materials as even the lowest concentration of pollutants causes an increase in the deterioration rate. The threshold levels will be assessed using the well-established concepts of acceptable corrosion rates and pollution levels defined in the UN ECE Convention on Long-Range Transboundary Air Pollution report “Manual on methologies for mapping critical loads/levels”. The manual describes how to calculate acceptable pollution levels for different scenarios based on dose-response functions. It is possible to assess different scenarios based on reasonable assumptions and to analyse the results of the assessments together with a sensitivity analysis in order to propose reasonable threshold levels for most important pollutants for special areas containing objects of cultural heritage, taking into account existing directives for threshold levels in general.

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CO=co-ordinator; CR=principal contractor; AC=assistant contractor; SC=sub-contractor; 1) Main research centre/sub-centre of ICP Materials

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