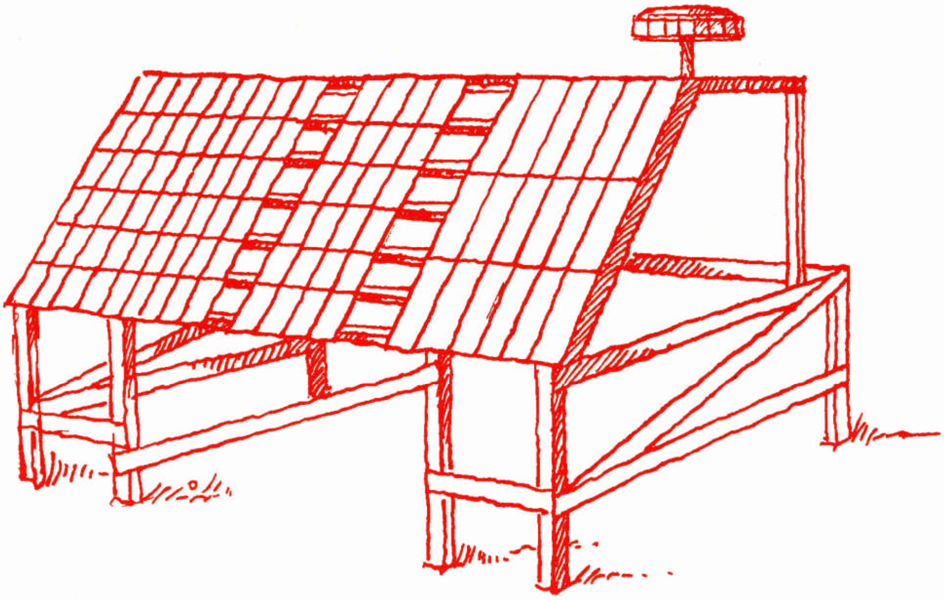
CONVENTION ON LONG-RANGE TRANSBOUNDARY AIR POLLUTION

UN/ECE INTERNATIONAL CO-OPERATIVE PROGRAMME
ON EFFECTS ON MATERIALS, INCLUDING HISTORIC
AND CULTURAL MONUMENTS



Report No 56:

Trends in pollution and corrosion of carbon steel, zinc and limestone 1987-2006

November 2008

PREPARED BY THE MAIN RESEARCH CENTRE

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Trends in pollution and corrosion of carbon steel, zinc and limestone 1987-2006

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Contents

1 Introduction

Early in the discussions on the “Convention on Long-range Transboundary Air Pollution” it was recognized that a good understanding of the harmful effects of air pollution was a prerequisite for reaching agreement on effective pollution control. To develop the necessary international cooperation in the research on and the monitoring of pollutant effects, the Working Group on Effects (WGE) was established under the Convention in 1980 and held its first meeting in 1981. The Convention involves countries in the UNECE region and has its secretariat with the UNECE [1].

The Working Group on Effects provides information on the degree and geographic extent of the impacts on human health and the environment of major air pollutants, such as sulphur and nitrogen oxides, ozone and heavy metals. Its six International Cooperative Programmes (ICPs) and the Task Force on Health identify the most endangered areas, ecosystems and other receptors by considering damage to human health, terrestrial and aquatic ecosystems and materials. An important part of this work is long-term monitoring. The work is underpinned by scientific research on dose-response, critical loads and levels and damage evaluation [1].

The International Co-operative Programme on Effects on Materials including Historic and Cultural Monuments (ICP Materials) is one of the six ICPs. During the course of the programme, which had its first exposure in 1987, the special importance of trend effects has become more and more evident. The aims of ICP Materials are now to

- perform a quantitative evaluation of the effects of multi-pollutants such as S and N compounds, ozone and particles as well as climate parameters on the atmospheric corrosion of important materials, including materials used in objects of cultural heritage;

- describe and evaluate long-term corrosion trends attributable to atmospheric pollution in order to elucidate the environmental effects of pollutant reductions achieved under the Convention and in order to identify extraordinary environmental changes that result in unpredicted materials damage;

- use the results for mapping areas with increased risk of corrosion, and for calculation of cost of damage caused by deterioration of materials.

The present report addresses the second of these aims and gives a summary of results obtained since the first exposure in 1987. During this time, exposure sites, exposed materials and measured environmental parameters have partly changed. On the other hand, some of the sites erected in 1987 are still running and provide an excellent basis for evaluation of trends.

One should note that the focus is on the most recent results, especially the 2005-2006 trend exposure. The aim of the present report is not to repeat the analysis performed in reports 52-55 (see Appendix 1), which describes the results from the 2005-2006 exposure in more detail but to extend the analysis where possible.

2 Overview

What is a “trend exposure”? Within ICP Materials, this has been defined as a one-year exposure of materials within the network of test sites accompanied by characterization of the environment. The exposure has always started in the fall, typically from October one year to September the next year. For example, the exposure performed during the period October 1987 to September 1988 is typically denoted the 1987/88 trend exposure or, even shorter, the 1987 trend exposure emphasizing the exposure start.

2.1 Test sites

The list of test sites is shown in table 1. The network of test sites originally consisted of 39 test sites, which were all part of the original 8-year exposure between 1987 and 1995. In the multi-pollutant exposure programme, a 4-year exposure programme between 1997 and 2001, only part of the original test sites were kept and in addition, eight new test sites were started. After that, five new test sites have joined and are now part of the present 2008-2009 exposure, which involves 24 test sites in the 15 countries Czech Republic, Germany, Italy, Norway, Sweden, UK, Spain, Estonia, France, Switzerland, Poland, Greece, Latvia, Austria and Bulgaria. Only data from test sites 1-50, i.e. test sites with data for more than one year is included in this report.

All data is given in Appendix 2.

2.2 Environment

Note first that, as for corrosion data, environmental data is reported with a broken year starting in the fall so that, for example, 1987/88 or simply 1987 data refers to annual averages from the period October 1987 to September 1988.

At or nearby each site environmental data were continuously measured. This includes data for gaseous pollutants, precipitation, climatic parameters and in recent exposures particulate matter. All environmental measurements were reported and compiled by the Norwegian Institute for Air Research (NILU), Norway, which also controlled the quality of the data. Environmental data have been compiled in separate reports in the official ICP Materials report series. A complete list of ICP Materials reports is given in Appendix 1.

The gaseous parameters measured include SO_2, NO_2, O_3 and in recent years also HNO_3. Because only data of HNO_3 for a few years are available only trends of SO_2, NO_2 and O_3 are discussed in this report. Precipitation data include total amount, conductivity and concentration of the ions H^+, SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, Ca^{2+}, Mg^{2+} and K^+. Only trends in total amount and H^+ / pH are discussed in this report. Measured climatic parameters include temperature, relative humidity and in the beginning of the project time of wetness, sunshine hours and sunshine radiation. Only trends in temperature and relative humidity are discussed in this report.

Only annual averages of the indicated parameters are given in this report. Monthly values are also available in the individual environmental data reports. Up until 2000, when large exposure programs were running with samples exposed for more than one year, environmental data were collected each year but after that only in connection with the 2002 and 2005 trend exposures.

Table 1. List of all ICP Materials test sites showing number, name, country site type, year with available data and participation in the 2008-2009 trend exposure.

No	Name	Country	Site type	Available data	2008-2009 exposure
1	Prague-Letnany	Czech Republic	Urban	1987 – 2006	X
2	Kasperske Hory	Czech Republic	Rural	1987 – 1995	
3	Kopisty	Czech Republic	Industrial	1987 – 2006	X
4	Espoo	Finland	Urban	1987 – 1995	
5	Ähtäri	Finland	Rural	1987 – 2003	
6	Helsinki-Vallila	Finland	Industrial	1987 – 1995	
7	Waldhof-Langenbrügge	Germany	Rural	1987 – 2003	
8	Aschaffenburg	Germany	Urban	1987 – 1995	
9	Langenfeld-Reusrath	Germany	Rural	1987 – 2003	
10	Bottrop	Germany	Industrial	1987 – 2006	X
11	Essen-Leithe	Germany	Rural	1987 – 1995	
12	Garmisch-Partenkirchen	Germany	Rural	1987 – 1995	
13	Rome	Italy	Urban	1987 – 2006	X
14	Casaccia	Italy	Rural	1987 – 2006	X
15	Milan	Italy	Urban	1987 – 2006	X
16	Venice	Italy	Urban	1987 – 2006	X
17	Vlaardingen	Netherlands	Industrial	1987 – 1995	
18	Eibergen	Netherlands	Rural	1987 – 1995	
19	Vredepeel	Netherlands	Rural	1987 – 1995	
20	Wijnandsrade	Netherlands	Rural	1987 – 1995	
21	Oslo	Norway	Urban	1987 – 2006	X
22	Borregard	Norway	Industrial	1987 – 1995	
23	Birkenes	Norway	Rural	1987 – 2006	X
24	Stockholm South	Sweden	Urban	1987 – 2006	X
25	Stockholm Centre	Sweden	Urban	1987 – 1995	
26	Aspvreten	Sweden	Rural	1987 – 2006	X
27	Lincoln Cathedral	United Kingdom	Urban	1987 – 2003	X
28	Wells Cathedral	United Kingdom	Urban	1987 – 1995	
29	Clatteringshaws Loch	United Kingdom	Rural	1987 – 1988	
30	Stoke Orchard	United Kingdom	Industrial	1987 – 1993	
31	Madrid	Spain	Urban	1987 – 2006	X
32	Bilbao	Spain	Industrial	1987 – 1995	
33	Toledo	Spain	Rural	1987 – 2006	X
34	Moscow	Russian Federation	Urban	1987 – 2003	
35	Lahemaa	Estonia	Rural	1987 – 2006	X
36	Lisbon	Portugal	Urban	1987 – 2003	
37	Dorset	Canada	Rural	1987 – 2006	
38	Research Triangle Park	USA	Rural	1987 – 1995	
39	Steubenville	USA	Industrial	1987 – 1995	
40	Paris	France	Urban	1997 – 2006	X
41	Berlin	Germany	Urban	1997 – 2006	X
43	Tel Aviv	Israel	Urban	1997 – 2001	
44	Svanvik	Norway	Rural	1997 – 2006	X
45	Chaumont	Switzerland	Rural	1997 – 2006	X
46	London	United Kingdom	Urban	1997 – 2003	
47	Los Angeles	USA	Urban	1997 – 2001	
49	Antwerpen	Belgium	Urban	1997 – 2003	
50	Katowice	Poland	Industrial	2000 – 2006	X
51	Athens	Greece	Urban	2005 – 2006	X
52	Riga	Latvia	Urban	2005 – 2006	X
53	Vienna	Austria	Urban	–	X
54	Sofia	Bulgaria	Urban	–	X

2.3 Materials

The first one-year exposure started in 1987 and many different materials were exposed including stone materials, structural metals, paint systems on wood and metal and electric contact materials. Later exposures included also patinated and waxed bronzes, glass materials of medieval and modern composition and polymer materials. The 1-year exposure of zinc was first repeated in 1989 and in 1992 for both carbon steel and zinc, which for a long time was considered the only “trend materials”. In connection with the multi-pollutant exposure programme (1997-2001), carbon steel, zinc and limestone were proposed as indicator materials and in 2002, limestone was added to the list of trend materials. This report is limited to describing corrosion attack of carbon steel, zinc and limestone as official trend materials and table 2 shows an overview of performed exposures. Note that two not directly comparable variants of zinc have been used, as will be described later in the zinc section.

Table 2 One-year (trend) exposures of carbon steel, zinc and limestone performed within ICP Materials (1987-2008).

	87	**88**	**89**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**
Carbon steel	X					X		X		X	X			X		X			X			X
Zinc[a]	X		X			X		X		X				X								X
Zinc[b]											X			X		X			X			X
Limestone	X										X					X			X			X

[a] With SVUOM Ltd., Czech Republic as responsible sub-centre
[b] With EMPA., Switzerland as responsible sub-centre

For each exposure, material and site, three identical samples were exposed and individual corrosion values for these three samples have been reported in the respective reports in the official ICP Materials report series (Appendix 1). The present report is complete in the respect that it compiles all data given in previous reports but only averages of triplicates are given. In general, the spread between triplicates are minor, especially for the metals, and typical errors are given in table 3.

Table 3 typical relative standard deviations based on corrosion values of three individual simultaneously exposed samples (s/m)

Material	**s/m**
Carbon steel	2%
Zinc	5%
Limestone	15%

3 Environmental trends

3.1 SO_2, NO_2, O_3 and pH

Table A1-A4 shows all data (1987-2005) for SO_2, NO_2, O_3 and pH, respectively. These data tables reflect the development of the exposure programmes. Between 1987 and 1994, measurements were performed each year in the original network of test sites (1-39). Between 1997 and 2004, measurements were performed each year in a modified network of test sites consisting partly of original and new test sites. After 2000, measurements are only performed in connection with trend exposures.

Figure 1 shows the average trends in SO_2, NO_2 and O_3 based on data in these tables. The average absolute pollutant levels have changed during the period 1987-2005 not only because of changing pollutant concentrations but also because of ICP Materials test site selection. Figure 1, however, has been corrected so that it only shows trends due to changing pollutant concentrations. The average trends are quite different for the gases. O_3 increased by 25% during the 1990's but was relatively constant before and after this period. NO_2 has decreased and continues to decrease over the entire period while the decrease in SO_2 has ceased after the 1990's.

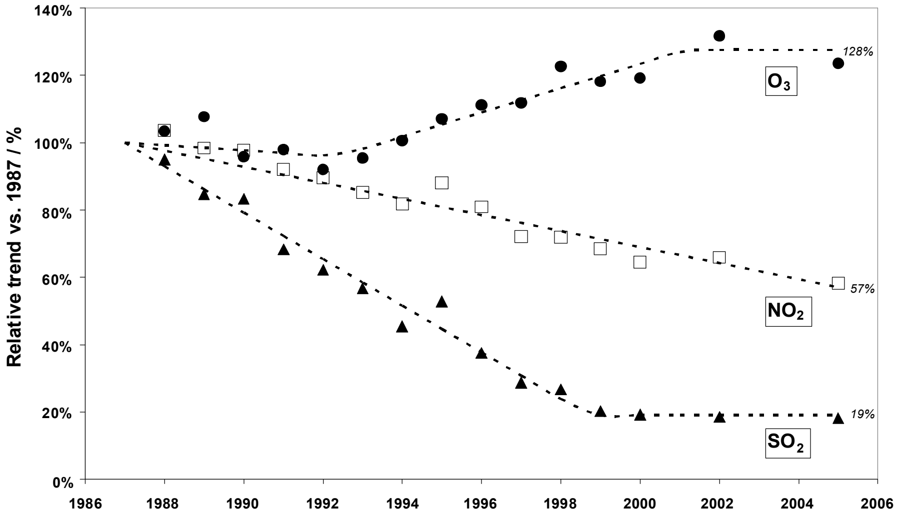

Figure 1 Average SO_2, NO_2 and O_3 trends relative to the year 1987.

Figure 1 shows only average trends while figure 2 shows three examples of individual trends for SO_2. Site 3 Kopisty and site 10 Bottrop have both reached constant SO_2 levels of about 20 µg m^{-3} but from different original levels so that the decrease for Kopisty was about 80% while the decrease for Bottrop was about 60%. Worth noting is that the decrease in SO_2 for the background site 26 Aspvreten in Sweden with very low SO_2 concentration from the beginning follows an almost identical relative pattern as for the Kopisty site.

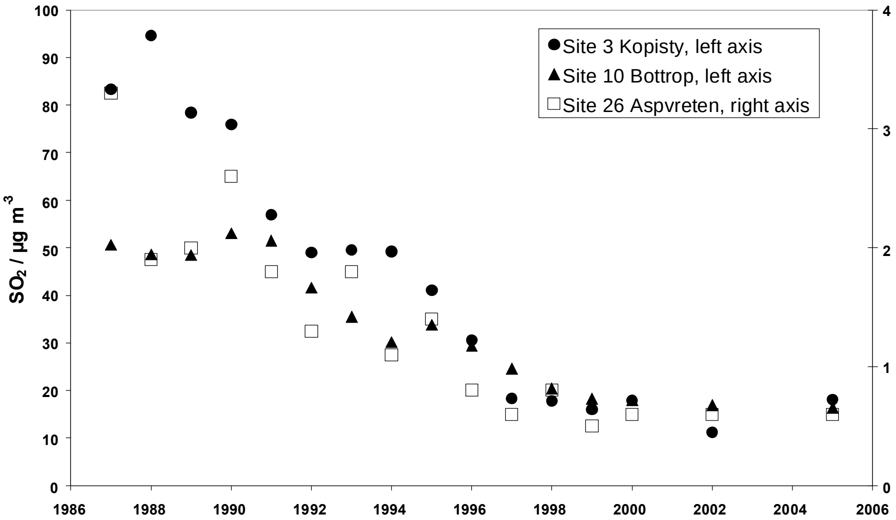

Figure 2 Annual SO_2 concentration at three selected test sites

The trend in pH is more difficult to evaluate due to the relatively high variation from year to year (Table A4). The general trend during the period is increasing and is on average about 0.5 pH units or roughly a factor of three (decrease) for the acidity, during the whole period.

3.2 Trends in T, Rh and Rain

Table A5-A7 shows all data (1987-2005) for temperature, relative humidity and precipitation, respectively.

Figure 3 shows examples of the temperature and relative humidity data for the urban site in Stockholm and the rural site Aspvreten not far from Stockholm. The “heat island” effect is clearly visible with higher temperature (+1.2 ^{o}C) and lower relative humidity (-9%) in the city. The trend in temperature is constant during the whole period but if only looking at the period 1995-2005 temperature is increasing. Relative humidity, on the other hand, shows a clear increasing trend so that the relative humidity at the site in Aspvreten now is the highest in the network. This is further discussed for zinc.

As for pH, the trend in precipitation is more difficult to evaluate due to the relatively high variation from year to year (Table A7). No general trend has been observed.

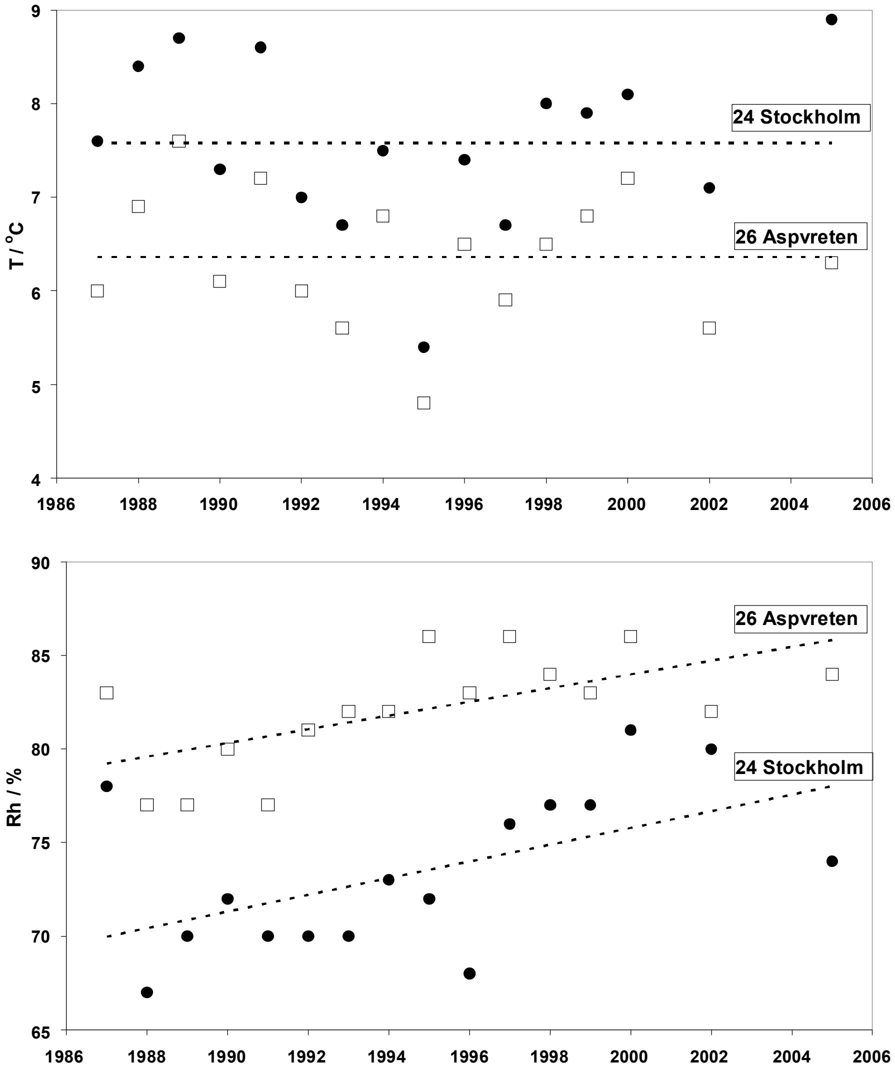

Figure 3 Temperature (top) and relative humidity (bottom) for two selected test sites

4 Corrosion trends

The previous evaluation of trends was based on data from the period 1987-2003. It concluded that during the period 1987-1997 the decreasing trend in the concentrations of acidifying air pollutants resulted in a decreasing trend in corrosion of carbon steel, zinc and limestone. During the period 1997-2003, however, the corrosion rate of carbon steel decreased while the corrosion rate of zinc and limestone increased slightly. Figure 4 shows the trend in corrosion with an updated value for carbon steel. Even for carbon steel, the average trend is no longer decreasing. In the following the materials carbon steel, zinc and limestone will be discussed individually with emphasis on the trends at different selected sites. Even though the average trend is no longer decreasing there are sites were corrosion is decreasing and, more importantly, sites were corrosion is increasing.

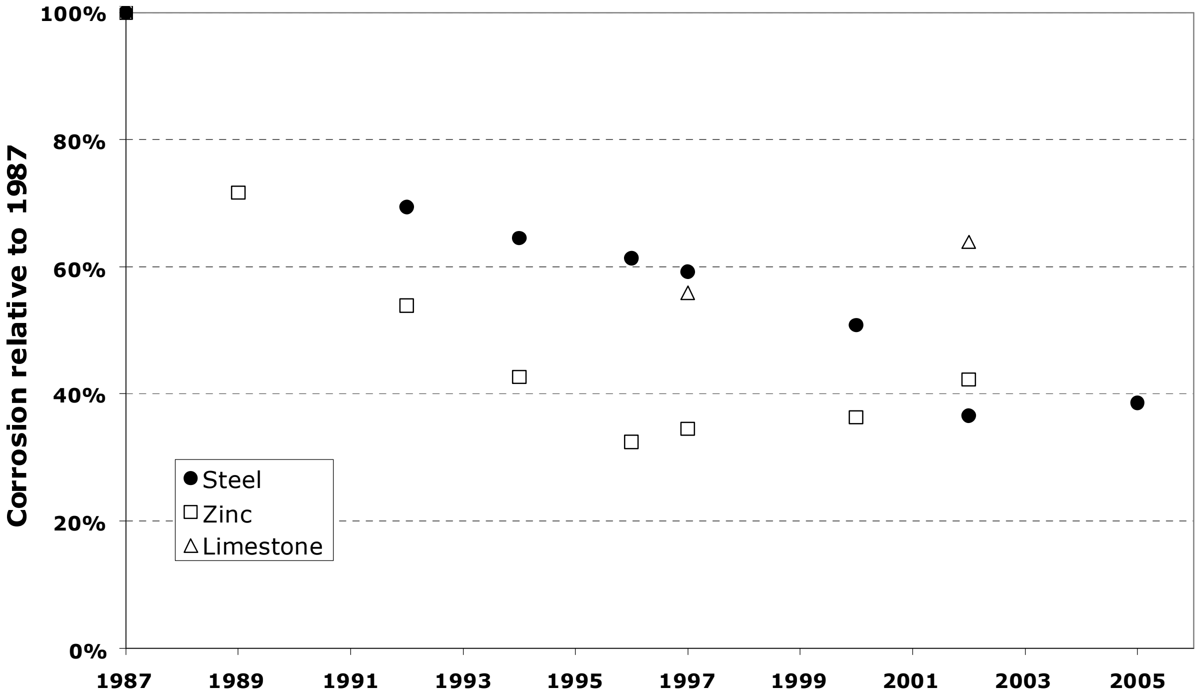

Figure 4 Average trends in corrosion relative to the first exposure in 1987.

4.1 Carbon steel

From a quantitative point of view, carbon steel is the least complicated material. The corrosion trend for an individual site can largely be explained by the SO_2 concentration (most important), followed by relative humidity and temperature. In contrast to other materials, carbon steel is less sensitive to other pollutants like O_3 and HNO_3. This makes it an ideal material for assessing in more detail the concept of tolerable SO_2 levels.

The tolerable corrosion level for carbon steel has been set to 20 µm (thickness reduction) or 156 g m^{-2} (mass loss) using a density of 7.8 g cm^{-3} [2]. One possible use of this level is illustrated in figure 5. Based on the figure it can be concluded that the corrosion situation became tolerable for carbon steel at the test site in Prague between 1997 and 2000.

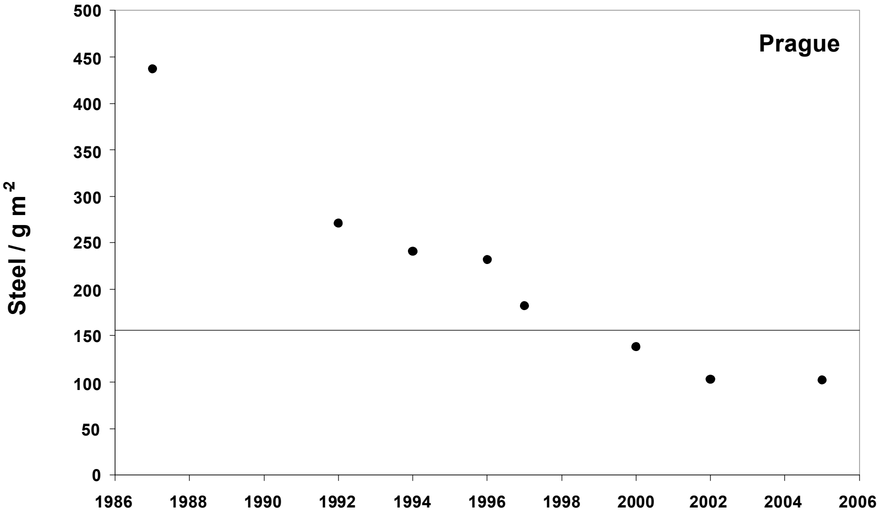

Figure 5 Carbon steel corrosion trend (1987-2005) at the site Prague in Czech Republic. The horizontal line indicates the tolerable corrosion attack.

4.1.1 Tolerable SO_2 levels for carbon steel

The acceptable/tolerable level or load of pollutants for buildings and materials is the concentration or load, which does not lead to an unacceptable increase in the rate of corrosion or deterioration. In the multi-pollutant situation the definition of a tolerable corrosion rate, K_t, implicitly defines a tolerable multi-pollution situation, which can be reached by reducing one or several of the multi-pollutants

$$K_t = f_{dry}(T, RH, [SO_2]_t, [HNO_3]_t, ...) + f_{wet}(Rain[H^+]_t)$$

In the MULTI-ASSESS final report tolerable SO_2 levels for carbon steel was estimated to be 6 µg m^{-3} or 11 µg m^{-3} for two different scenarios fixing the values of other parameters besides SO_2. In the end, an SO_2 level of 10 µg m^{-3} was proposed for materials in general protecting about 80% of the European territory at present HNO_3 levels [2].

For carbon steel, however, SO_2 is the dominating pollutant. In addition, we have reached a point were the present SO_2 levels in most cases are close to or below 10 µg m^{-3}. Reaching below 10 µg m^{-3} may anyhow in some locations result in a corrosion rate of carbon steel above the tolerable. Therefore, it would be worthwhile, and for the first time, to differentiate the tolerable SO_2 level depending on location. As it turns out, this will result in tolerable SO_2 levels for carbon steel below but also in some cases above 10 µg m^{-3} due to the local climatic situation. However, it is important to remember that at those locations with high tolerable SO_2 levels for carbon steel, a high SO_2 level not necessarily results in tolerable corrosion levels for other materials and is therefore no excuse for increasing the SO_2 level.

Figure 6 shows the corrosion of carbon steel *vs* SO_2 concentration for two different sites, resulting in different tolerable SO_2 levels by assuming the same tolerable corrosion level.

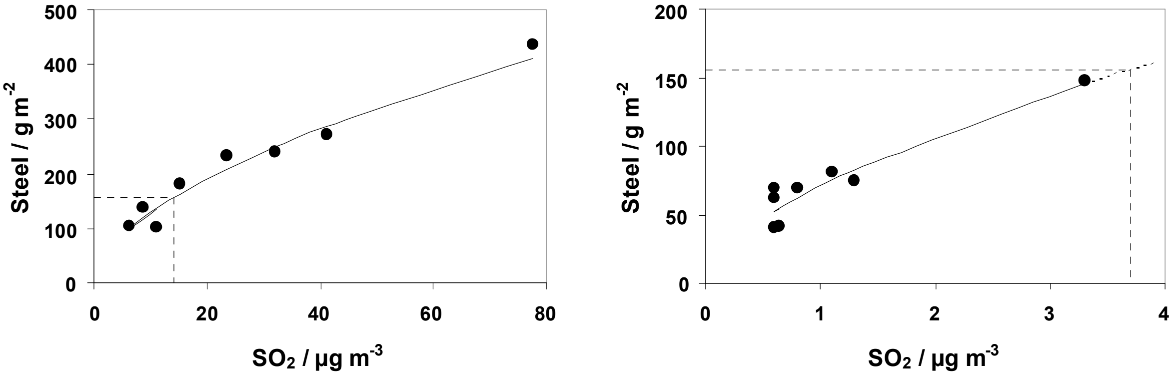

Figure 6 Estimation of tolerable SO_2 levels based on a tolerable corrosion rate for carbon steel of 156 g m^{-2} resulting in tolerable SO_2 levels of 13.9 µg m^{-3}(Prague, left) and 3.7 µg m^{-3} (Aspvreten, right).

The tolerable SO_2 level can also be shown in a trend diagram similar to figure 5 but this time for SO_2 (figure 7). Based on the figure it can be concluded that the pollution situation became tolerable in 1998. Important to note is that the pollution situation is tolerable *for carbon steel,* but not necessarily for other materials.

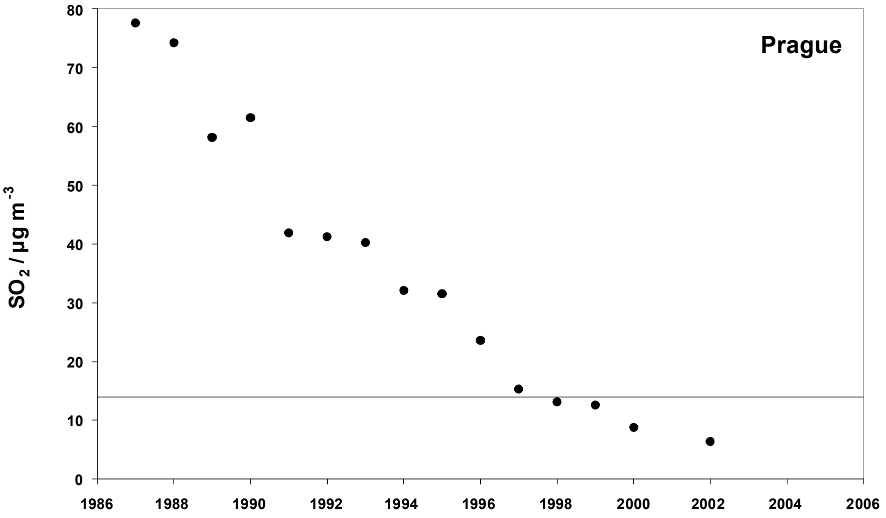

Figure 7 SO_2 trend (1987-2005) at the site Prague in Czech Republic. The horizontal line indicates the tolerable SO_2 level for carbon steel corrosion at this particular site.

Table 4 shows the result of similar estimations for other test sites where enough data are available to allow estimation. The tolerable SO_2 level varies between 1 and 16 µg m^{-3} depending on site location and three sites have not yet reached a tolerable situation: Kopisty, Bottrop and Lincoln. In Kopisty because the SO_2 level is still high, in Lincoln because the tolerable SO_2 level is low and in Bottrop because a combination of these two factors. As another example consider Madrid, where a tolerable situation was reached already in 1990, mainly due to the low relative humidity resulting in a high tolerable SO_2 level.

Table 4 Estimation of tolerable SO_2 levels for carbon steel and tolerable SO_2 period for test sites with enough data to allow estimation

No	Name	Tolerable SO_2 level µg m^{-3}	Tolerable SO_2 period
1	*Prague*	13,9	1998 –
3	*Kopisty*	9,6	not yet
7	*Waldhof-Langenbrügge*	3,6	1996 –
9	*Langenfeld-Reusrath*	7,7	1998 –
10	*Bottrop*	4,2	not yet
13	*Rome*	14,9	1994 –
15	*Milan*	16,0	1997 –
21	*Oslo*	8,1	1991 –
23	*Birkenes*	1,1	1991 –
24	*Stockholm South*	6,8	1990 –
26	*Aspvreten*	3,7	1987 –
27	*Lincoln Cathedral*	3,3	not yet
31	*Madrid*	14,1	1990 –

4.2 Zinc

Two zinc materials have been used and they differ mainly by the surface treatment before exposure. This parameter significantly affects time of wetness of the sample surfaces and subsequently their corrosion rate. The surface treatment utilized by EMPA results in a higher corrosion rate than that used by SVUOM, as can be seen in table A9 when comparing values for the year 2000, which is so far the only year with available results from simultaneous exposures of the two zinc materials. An addition, in the on-going trend exposure 2008-2009 both materials are exposed at selected sites. The average difference between EMPA and SVUOM zinc is about a factor of 1.6 but it is not possible at present to apply this factor to data for individual sites and therefore the following discussion is limited to zinc from EMPA exposed 1997, 2000, 2002 and 2005. Trends in zinc from SVUOM have been discussed in previous reports and show a decrease in corrosion related to pollution.

Figure 8 shows increasing trends in corrosion for three selected test sites. What is noteworthy is that they all are located in relatively cold areas and that the relative humidity is high and has an increasing trend. For Aspvreten the change is from 4 to 12 g m^{-2} while the corrosion of carbon steel during the same period decreased from 62 to 41 g m^{-2}.

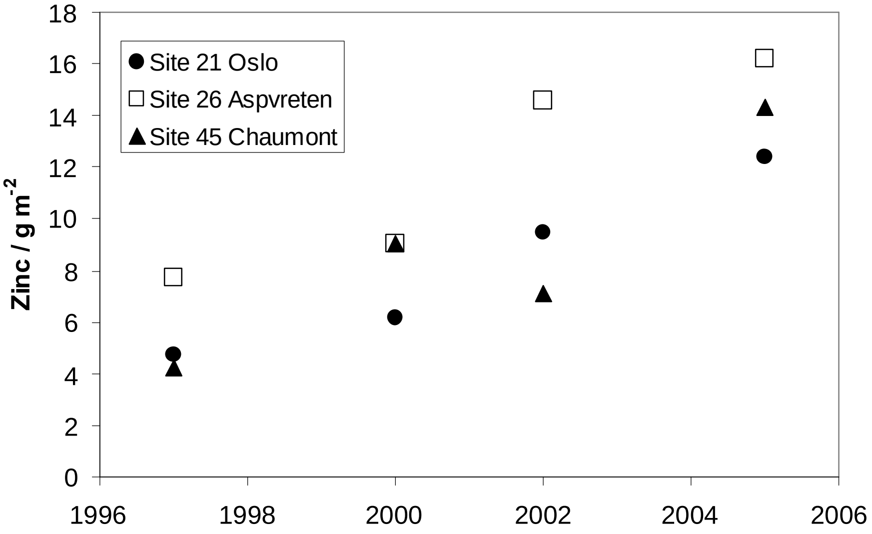

Figure 8 Corrosion of zinc for three selected sites

Are the increases in corrosion observed for some sites after one year of exposure relevant for the long-term behaviour of zinc in these environments? Zinc can be sensitive to initial exposure conditions and it is likely that the humidity dependence will be less strong after longer exposure times. A more in depth data analysis is needed, taking into account also exposures performed outside ICP Materials, in order to answer this crucial question.

4.3 Limestone

Looking at table A10 it is evident that the corrosion attack for the most recent year (2005) is much higher than the corrosion attack in recent years and in fact similar to values obtained in 1987. This was discussed in Report 55 “Results from the 2005-2006 trend exposure programme. Corrosion attack of limestone after 1 year of exposure.”. Part of the explanation could be due to change in environmental conditions but another possibility is that the stone material had a different quality. It is still Portland limestone but from another stock with higher porosity but lower saturation co-efficient. Because of this, stones of both old and new quality are exposed in parallel in the on-going 2008-2009 trend exposure and at present time, it is not worthwhile to do additional data analysis compared to what was already done in report 55 and previous reports.

5 Summary

The present report has compiled annual data of environment (pollution and climate) and corrosion of carbon steel, zinc and limestone for the period 1987-2006 based on individual ICP Materials reports. It has further discussed the trends with special emphasis on the most recent results.

For SO_2, NO_2 and O_3 the average trends are quite different. O_3 increased by 25% during the 1990’s but was relatively constant before and after this period. NO_2 has decreased and continues to decrease over the entire period while the decrease in SO_2 has ceased after the 1990’s and is now on average only about 20% of the value in 1987. Worth noting is that the percentage decrease is similar for high and low polluted sites.

The average trend in corrosion of carbon steel is no longer decreasing. Carbon steel is a material that is more or less only sensitive to SO_2 pollution and tolerable SO_2 levels in the range 1 to 16 $\mu g\ m^{-3}$ has been estimated depending on site location. For most sites the tolerable SO_2 level was reached in the end of the 1990’s but there are still today sites with an SO_2 level for carbon steel above the tolerable, either due to a high measured SO_2 level or due to a low tolerable SO_2 level.

The average trend in corrosion of zinc is no longer decreasing. However, at some sites with low pollution but with high relative humidity and low temperature levels, unexpected high values have been obtained. Further analysis should focus on the consequences of this for the long-term corrosion of zinc.

The latest corrosion exposure of limestone shows unexpected high values for all sites and this has resulted in an extension of the 2008-2009 trend exposure to include two different variants of limestone in order to quantify the importance of stone porosity and saturation coefficient.

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Table A1 Annual SO_2 averages ($\mu g\ m^{-3}$) measured at ICP Materials test sites 1-50

No	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2002	2005
1	77.5	74.2	58.1	61.4	41.9	41.2	40.2	32.1	31.5	23.6	15.3	13.1	12.6	8.8	6.4	11.1
2	19.7	14.5	25.6	18.4	12.0	17.9	16.4	12.2								
3	83.3	94.6	78.4	75.9	56.9	49.0	49.5	49.2	41.1	30.6	18.3	17.8	16.0	17.9	11.2	18.1
4	18.6	11.8	13.9		2.4	2.3	5.7	2.6								
5	6.3	5.3	1.8	1.8	0.8	0.9	1.3	0.8	1.0	0.6	0.9	0.9	0.5	0.8	0.8	
6	20.7	17.4	15.3	18.2	6.0	4.8	6.8	5.5	6.3	5.2						
7	13.7	11.4	11.0	12.9	7.3	8.2	7.8	3.9	5.9	2.9	2.1	1.5	0.9	2.3	2.2	
8	23.7	14.6	14.2	18.9	15.6	12.6	11.6	9.6								
9	24.5	25.7	20.3	23.7	19.7	16.3	13.6	11.1	12.8	10.5	8.3	6.5	5.3	5.0	6.0	
10	50.6	48.6	48.5	53.0	51.5	41.6	35.5	30.2	33.8	29.4	24.6	20.4	18.3	17.9	16.9	15.8
11	30.3	27.6	25.6	24.4	25.7	22.9	18.5	16.2								
12	9.4	13.4	6.1	5.2	4.6	3.2	2.2	2.4								
13	29.4	44.9	38.5	24.4	2.4	6.8	14.4	5.8			3.7					
14	8.3	8.3	7.4	6.4	4.7	7.5	4.7	5.2			5.2	3.0	3.4		0.7	0.2
15	72.2	82.7	65.4	50.3	58.5	39.4	32.4	22.1			15.4		15.1	12.9	12.3	7.8
16	21.1	25.7	20.2	16.4	18.6	11.0	7.1	6.3			7.4	5.5	6.4	7.8	2.5	2.2
17	35.3	31.8	32.5	30.6	27.8	25.5	21.5	20.5								
18	10.1	8.0	8.5	9.5	8.0	7.4	5.6	4.7								
19	13.0	10.2	9.9	10.4	8.1	8.3	6.7	4.5								
20	13.7	11.2	10.3	12.9	11.0	9.3	7.8	5.8								
21	14.4	12.6	7.9	8.6	6.6	6.0	5.2	2.9			4.1	5.2	3.4	3.1	1.7	1.3
22	35.8	54.0	41.5	30.7	31.1	26.4	22.8	31.3								
23	1.3	1.1	0.9	1.1	0.8	0.7	0.9	0.7	0.8	0.4	0.2	0.3	0.2	0.3	0.3	0.5
24	16.8	12.6	8.4	6.3	5.7	5.7	5.4	4.2		3.3	2.6	3.2	2.2	1.9	1.6	1.8
25	19.6	20.0	10.3	2.7	3.9	4.7	5.2	3.4								
26	3.3	1.9	2.0	2.6	1.8	1.3	1.8	1.1	1.4	0.8	0.6	0.8	0.5	0.6	0.6	0.6
27	17.7	19.6	15.5	20.2	20.4	17.8	10.9	6.8				9.8	8.0	7.5	4.9	
28	7.2	6.6	6.9	5.0	6.4	3.2	5.0	3.3								
29	4.3	3.2	3.5	5.2												
30	15.0	9.1	12.1	27.4	8.7	9.3	14.6	14.6								
31	18.4	18.1	15.3	10.3	8.6	8.2	7.6	7.8		11.4	11.8	6.5	4.2	1.2	2.6	1.6
32	35.2	49.1	41.4	23.5	7.1	9.3	8.5	6.3								
33	3.3	8.6	13.5	6.0	4.6	1.7	3.5	4.2		1.1	1.5	2.3	1.9	1.2	1.1	0.9
34	19.2	25.5	30.8	26.0	28.0	28.7	18.9	16.4				23.6			4.1	
35	0.9	0.3	0.6		0.6	0.6	0.6	0.6	1.1	0.8		1.7	1.4	1.3	1.7	3.9
36	6.8	11.9	6.6	11.3	41.1	16.1	10.0	4.7			17.7	15.2			11.0	
37	3.3	4.2	3.0	2.8	2.1	2.1	1.5	3.3	3.4		2.4				0.6	1.3
38	9.6	10.0	9.2	7.9	13.0	10.1	8.9	9.3								
39	58.1	59.4	55.2	64.3	33.9	43.1	44.3	38.3								
40											14.2	11.1	11.1	10.1	11.2	6.6
41										16.3	10.9	10.9	7.0	9.8	8.6	
43											35.0	60.3	9.8	6.6		
44									7.4	9.6	7.5	7.6	5.9	5.2	6.5	6.9
45										1.5	1.3	1.3	1.0	1.0	1.3	1.1
46												7.6	5.9	5.8	5.8	
47											0.6					
49											22.8	16.5	16.8	13.5	13.8	
50														34.4	38.6	36.1

Table A2 Annual NO_2 averages ($\mu g\ m^{-3}$) measured at ICP Materials test sites 1-50

No	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2002	2005
1	42.4	32.6	34.2	34.9	20.5	24.9	22.5	23.3	24.4	21.1	23.7	22.1	23.4	21.7	24.5	40.0
2	17.9	14.2	8.8	9.4	8.1	8.1	7.2	8.1								
3	42.2	39.1	36.0	35.1	30.6	35.6	28.1	27.4	32.8	34.9	32.6	32.1	28.0	24.8	25.3	25.2
4	20.0	17.6	20.7	24.9	24.1	20.8	30.3	23.7								
5	5.0	4.9	4.4	5.6	2.0	2.0	4.0	7.1			3.0	3.2	2.5	3.1	3.0	
6	30.5	27.4	38.9	38.3	41.2	39.4	36.8	30.4	34.8	27.4						
7	11.3	13.0	11.6	11.9	11.5	10.9	9.3	8.0	9.1	9.2	8.7	8.8	8.2	8.4	9.8	
8	33.2	44.8	39.5	38.0	41.2	38.8	40.2	38.8								
9	42.8	49.9	44.4	45.8	40.2	37.3	35.6	35.9	36.4	35.4	33.5	31.7	31.2	30.5	32.0	
10	47.9	49.5	46.4	46.8	43.8	37.9	37.6	38.0	38.4	39.5	38.2	36.4	32.7	32.6	34.6	33.0
11	46.8	44.3	41.7	41.9	40.5	37.2	33.7	32.6								
12	12.1	14.0	14.3	12.6	15.1	16.6	11.0	11.3								
13	69.2	69.5	62.5	73.3		33.1	28.5	30.4			37.8	42.8	47.1		48.8	28.7
14	13.7	13.7	8.3	18.8	16.6	14.6	11.1	8.9			21.0	31.1			8.4	4.8
15	109.2	99.1	120.9	107.8	110.0	108.3	86.6	85.3			83.9		72.7	72.8	66.6	66.3
16	40.9	40.7	51.0	47.7												35.6
17	52.1	57.2	56.7	53.8	47.3	46.6	45.4	46.5								
18	23.2	26.9	26.5	24.6	23.5	22.8	21.4	19.6								
19	28.7	33.4	33.1	33.4	32.5	29.4	27.9	25.8								
20	28.9	32.0	26.9	31.7	29.1	26.8	25.4	25.7								
21	51.7	51.9	46.8	51.9	47.1	53.4	55.2	62.9		42.3	27.5	32.5	32.0	20.8	25.9	26.9
22	19.2	18.3	16.4	18.0	16.6	17.8	20.1	19.5								
23	3.9	4.0	3.1	3.1	1.8	1.8	2.3	2.0	2.5	2.0	1.1	1.6	1.7	1.8	1.9	1.6
24	26.5	31.2	31.6	27.3	28.1	25.2	25.0	21.4	22.8	22.9	20.3	19.5	18.8	17.5	17.0	13.1
25	45.8	45.4	40.2	26.1	25.3	26.3	25.5	25.4								
26	5.1	4.5	4.8	3.8	3.6	3.2	3.6	2.9	3.2	3.0	2.9	2.6	2.4	2.7	2.3	2.1
27	68.6	54.2	33.0	28.3	29.9	21.2	7.8	8.4				22.5	22.1	22.6	16.3	
28	21.5	24.7	25.1	22.1	22.1	22.6										
29	2.3	4.1	4.2	4.6												
30	86.0	34.2	30.0	39.2	25.1	27.6	38.1	38.1								
31	24.3	31.9	22.8	20.1	21.9	32.1	29.6	20.6			22.1	24.8	16.5	11.0	28.4	21.5
32	34.7	43.0	41.8	31.6	32.8	21.4	32.0	25.9								
33	9.1	14.8	16.3	16.1	14.9	24.0	19.3	10.5		8.4	11.3	11.0	9.1	3.1	2.8	4.1
34	74.9	69.5	50.1	53.2	38.7	37.1	31.5	29.5			28.0	21.4	21.5		18.0	
35	2.9	3.8	6.5		3.8	3.8	3.8	3.8	0.8	0.6	0.7	1.7	2.3	2.2	3.1	3.7
36	36.8	21.5	32.9	30.1	45.7	35.0	33.3	35.0			42.0	31.2			24.4	
37	1.6	2.0	2.0	1.0			1.7	1.7	7.5		9.7	4.2	6.6		6.9	1.7
38	26.9	25.3	25.3	25.2	26.2	25.7	26.6	22.9								
39	41.8	44.8	40.5	50.9	25.5	43.3	40.8	39.8								
40											70.0	52.2	51.0	45.6	45.7	39.3
41										52.9	37.7	43.9	41.3	44.2	49.1	
43											38.3	44.9	20.7	17.8		
44									1.9	2.4	0.9	1.5	1.8		1.7	1.9
45										7.5	7.7	8.0	7.5	6.9	9.0	6.9
46												48.2	46.4	44.0	37.3	
47											21.7					
49											52.8	48.6	49.0	47.2	50.0	
50														22.7	21.6	43.2

Table A3 Annual O_3 averages (µg m^{-3}) measured at ICP Materials test sites 1-50

No	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2002	2005
1									55	51	48	48	50	41	49	47
2																
3										46	55	58	57	40	49	48
4																
5	52	54	52	51	66	60	58	55	58	60	60	64	60	57	60	
6										43						
7	59	69	64	45	53	57	55	54	52	51	48	55	54	51	60	
8	27	26	31	29	36	33	37	37								
9	30	27	33	32	36	34	34	32	27	32	33	36	31	36	34	
10				27	33	34	32	34	28	30	30	33	31	33	36	37
11																
12	50	49	55	57	55	49	61	52								
13	26	27	23	19	14	12	9	11			33	31	24	35	36	19
14	34	34	56	45	38	27	15	19			30	38	28		72	51
15	18	16	22	21	17	22	26	29			38		40	40	39	28
16	21	29	31	14								45	32		39	42
17	28	33	32	28	26	24	29	33								
18	40	46	47	38	39	33	38	40								
19	36	39	45	37	38	35	36	39								
20	39	42	45	39	36	34	38	39								
21											36	39	38	36	31	36
22																
23	60	53	54	55	64	58	53	56	58	56	55	59	55	53	54	61
24	44	47	52	39	45	43	49	43	48	50	44	51	48	47	55	58
25																
26	55	61	59	54	58	58	38	50	64	65	51	63	59	57	66	66
27												51	51	49	52	
28																
29	49	62	57	45												
30																
31	26										56	54	53	54	56	49
32																
33	77	77	77	77	77	76	74	82		88	89	79	88	92	93	88
34											42				36	
35										57	55	63	61	60	59	62
36		35	29	42	25	37	34	49			12	11	18		14	
37	59	60	64	52	61	56	59	46	60		62	62	59		61	53
38	54	50	57	52	48	41	49	55								
39	42	36	33	44	30	36	40	42								
40											31	35	30	35	45	38
41										21	22	25	27	29	31	
43											40	50	21	24		
44									45		54	62	57	49	57	67
45										85	86	84	82	82	91	86
46												39	33	35	46	
47											48					
49											28	29	31	30	33	
50														56	62	38

Table A4 Annual pH averages of precipitation measured at ICP Materials test sites 1-50

No	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2002	2005
1	4.03	4.71	4.66	4.21	4.41	4.15	5.42	4.47	4.53	4.53	5.56	4.75	4.44	6.59	4.36	5.69
2	3.85	4.53	4.35	4.21	3.60	3.72	4.97	4.44								
3	4.39	4.88	4.62	4.31	4.39	4.24	4.97	4.25	4.01	4.41	4.62	4.40	4.47	4.41	5.19	5.61
4	4.24	4.39	4.41	4.36	4.43	4.64	4.39	4.48								
5	4.53	4.52	4.57	4.55	4.58	4.70	4.55	4.61	4.62	4.69	4.74	4.68	4.75	4.78	4.74	
6	4.41	4.42	4.26	4.28	4.51	4.66	4.47	4.86								
7	4.26	4.35	4.45	4.47	4.55	4.47	4.50	4.58	4.70	4.79	5.04	5.23	5.00	4.85	4.84	
8	4.96	4.61	4.39	4.94	5.79	4.74	5.12									
9	4.54	4.54	4.44	4.41	4.56	4.54	4.74	4.56			4.92	5.44		4.89	5.68	
10	4.57	4.57	4.60	4.30	4.71	4.68	4.76	4.48	4.89	4.85	4.84	5.09		4.80	4.73	5.83
11	4.58	4.58	4.38	4.43	4.69	4.60	4.81	4.61								
12	4.98	4.81	4.77	4.81	5.13	5.76	5.21									
13	4.60	4.68	4.74	4.76	4.75	4.75	5.06	5.68							5.80	
14	4.94	4.80	5.38	5.05	5.47	5.30	4.82	5.08								
15	4.22	4.50	4.19	4.54	4.68	4.66	4.42	4.43								
16	5.02	4.90	5.24	6.12	6.49	6.36	6.52	6.24								
17	4.44	4.41	4.42	4.59	4.65	4.41	4.61	4.67								
18	5.45	5.50	5.34	5.51	5.34	5.40	5.38	4.44								
19	5.32	5.33	5.31	5.80	4.90	5.68	5.09	5.36								
20	4.73	4.65	4.98	4.91	5.03	4.95	5.13	5.42								
21	4.48	4.66	4.49	4.71	4.65	4.81	4.80	4.87			5.20	4.61	4.63	4.72	4.65	
22	3.93	3.96	4.07	3.96	4.18	4.32	4.33	4.32								
23	4.25	4.26	4.38	4.35	4.35	4.43	4.39	4.49	4.44	4.51	4.50	4.52	4.58	4.59	4.57	4.64
24	4.35	4.28	4.44	4.57	4.58	4.37	4.49	4.64	4.67	4.61	4.63	4.68	4.77	4.75	5.00	5.26
25	4.35	4.28	4.44	4.57	4.58	4.37	4.49	4.64								
26	4.27	4.28	4.37	4.46	4.45	4.37	4.37	4.56	4.64	4.59	4.59	4.57	4.63	4.39	4.87	4.63
27	4.86	4.11	4.20	4.30	4.47	4.77	5.60	4.46			4.61					
28	5.44	5.42	5.09	6.22	6.08	3.72	5.37	4.75								
29	4.82	4.61	4.84													
30	4.12	4.13	3.84	3.18	4.66	4.31	3.75	3.75								
31	5.26	6.42	5.14	6.14	6.46	6.56	6.40	6.79		5.46	6.05	6.17	6.57	6.33	6.42	6.29
32	4.73	5.32	4.71	5.00	5.02	5.10	5.51	5.31								
33	5.27	5.23	6.20	5.74	5.73	5.93	5.91	6.26		5.05	5.80	5.91	6.10	6.44	6.11	6.11
34	6.18	4.89	6.22	6.12	6.07	6.04	6.06	6.08			6.68	6.52	6.66		6.61	
35	4.66	4.50	4.65	4.76	4.63	4.63	4.63	4.63	5.62	4.95	5.16	4.80	4.76	4.69	4.83	4.16
36	6.06	5.46	5.57	5.37	5.54	5.83	5.59	5.75			5.98	6.56	6.03		6.02	
37	4.27	4.33	4.38	4.34	4.40	4.32	4.34	4.34	4.44		4.31		4.55	4.09	4.43	
38	4.29	4.29	4.45	4.43	4.54	4.46	4.42	4.32								
39	4.00	3.91	4.08	3.88	4.15	4.03	4.20	4.12								
40											5.71	5.87	5.18	5.17	5.35	6.21
41																
43																
44									4.72	4.70	4.77	4.87	4.69	4.89	4.97	
45										5.04	4.99	4.93	5.09	5.13	5.21	5.15
46											5.65					
47																
49													5.23	4.75	4.85	
50														4.41	4.34	

Table A5 Annual temperature averages (°C) measured at ICP Materials test sites 1-50

No	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2002	2005
1	9.5	9.8	10.3	8.5	10.0	9.1	9.9	9.8	7.7	8.6	9.9	9.6	10.1	9.5	9.3	9.3
2	7.0	7.0	7.4	5.8	7.2	6.6	7.2	7.2								
3	9.6	9.7	9.9	8.6	9.9	8.9	9.6	9.7	7.7	8.5	9.9	9.4	10.1	9.2	8.7	8.3
4	5.9	6.0	6.4	5.2	6.2	5.6	4.0	6.0								
5	3.1	4.0	3.9	2.9	4.2	3.4	1.7	3.9	1.9	3.2	3.5	4.6	5.0	4.8	4.5	
6	6.3	6.7	6.8	5.8	6.9	6.2	4.7	6.6	4.5	6.5						
7	9.3	10.0	10.2	8.9	10.2	8.9	8.9	9.5	7.6	8.9	9.5	9.4	9.8	9.4	8.8	
8	12.3	11.8	12.2	10.9	11.7	11.4	11.4	11.6								
9	10.8	11.2	11.7	9.8	11.2	10.7	10.7	11.4	9.4	10.0	10.9	11.2	11.2	11.6	11.4	
10	11.2	11.6	12.0	10.2	11.5	10.3	10.8	11.8	9.7	10.5	11.5	11.6	11.6	11.7	11.3	11.2
11	10.5	10.9	11.5	9.8	13.1	10.1	10.3	10.9								
12	8.0	7.9	7.3	6.4	7.3	7.1	8.1	7.4								
13	15.4	16.1	17.4	16.3	22.2	17.9	19.5	18.4			19.4	19.1	19.2	17.9	17.6	
14	14.6	14.0	14.3	15.1	14.9	15.2	15.2	14.9			14.5	16.4	16.7		16.3	14.5
15	15.3	14.9	15.4	14.2	14.4	14.7	14.9	14.3			14.5		14.2	15.9	15.1	14.0
16	14.9	14.7	13.5	12.9	13.2	13.2	13.8	13.2			13.5	13.9	15.2	14.9	14.7	13.9
17	10.5	11.0	11.3	9.7	10.7	10.3	10.1	11.0								
18	9.9	10.2	10.9	9.1	10.2	9.5	9.4	10.3								
19	10.3	10.8	11.0	9.4	10.4	10.0	10.0	10.9								
20	10.3	10.8	11.1	9.5	10.5	10.1	10.2	11.1								
21	7.6	7.9	8.8	7.0	8.5	7.7	6.7	7.5	5.3	6.8	6.6	7.0	7.4	7.2	6.4	7.2
22	6.0	6.9	6.8	6.7	7.8	7.0	6.5	7.4								
23	6.5	7.5	7.4	6.1	7.1	5.9	4.9	6.4	4.4	5.6	6.2	6.2	7.1	6.6	5.9	6.2
24	7.6	8.4	8.7	7.3	8.6	7.0	6.7	7.5	5.4	7.4	6.7	8.0	7.9	8.1	7.1	8.9
25	7.6	9.1	8.7	7.3	8.6	7.0	6.7	7.5								
26	6.0	6.9	7.6	6.1	7.2	6.0	5.6	6.8	4.8	6.5	5.9	6.5	6.8	7.2	5.6	6.3
27	9.2	10.7	11.1	10.0	11.0	9.6	9.4	10.5			10.2	10.1	9.8	9.7	10.4	
28	10.8	12.2	12.7	12.0	12.9	10.5	9.7	11.2								
29	9.8	10.9	10.7	6.7												
30	10.2	9.2	10.3	10.3	10.3	10.3	10.3	10.3								
31	14.1	15.0	15.2	14.4	13.8	14.3	15.0	15.7		14.8	12.9	14.0	15.8	15.0	15.3	15.3
32	15.2	15.3	16.2	13.9	14.2	14.2	13.6	14.8								
33	14.0	15.1	15.5	13.9	13.6	13.4	13.9	14.8		14.0	14.0	14.0	13.7	12.2	12.2	12.1
34	5.5	7.0	5.7	6.0	7.2	5.7	4.0	5.6			6.5	7.0	6.1	7.4	5.9	
35	5.5	6.9	6.7	5.5	6.1	6.1	6.1	6.1	4.1	6.0	5.4	6.3	6.8	6.9	5.0	5.2
36	12.1	17.8	19.3	18.2	18.2	18.0	18.3	19.1			17.9	17.1	17.1		17.4	
37	5.5	4.8	5.0	5.9	3.8	4.3	3.2	5.2	3.4	4.0	7.4	8.3	6.5	6.5	7.2	
38	14.6	15.0	16.3	15.5	15.4	15.5	15.6	15.8								
39	12.3	10.9	11.2	13.6	11.6	11.8	10.6	11.8								
40											13.4	13.7	12.7	12.7	13.3	12.6
41										8.4	10.4	10.7	11.1	11.1	11.7	
43											24.6	26.5	21.5	22.0		
44									-1.1	-0.1	0.2	1.8	2.4	1.0	0.1	0.3
45										6.2	6.9	6.3	6.8	7.2	7.3	6.2
46											12.2	12.3	12.1	12.1	12.7	
47											17.4	16.4	17.2	16.4		
49											11.4	12.0	11.9	11.7	11.9	
50														9.4	8.2	7.5

Table A6 Annual relative humidity averages (%) measured at ICP Materials test sites 1-50

No	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2002	2005
1	79	75	74	75	71	73	76	77	80	78	76	76	72	79	72	74
2	77	77	76	79	73	73	73	74								
3	73	73	72	73	71	71	73	75	78	73	76	77	76	80	73	76
4	76	77	80	82	79	79	81	80								
5	78	79	80	80	78	81	80	83	79	76	80	79	78	82	80	
6	78	78	80	81	80	78	76	76	78	74						
7	80	81	80	81	78	81	82	81	82	82	83	78	79	81	75	
8	77	72	67	65	66	64	64	65								
9	77	78	80	80	76	79	82	81	78	78	80	78	81	79	76	
10	75	76	76	77	76	78	79	80	78	79	81	80	82	81	77	76
11	79	78	77	79	78	79	80	78								
12	82	84	82	84	83	84	82	83								
13	66	62	65	67	58	60	67	68			65	65	64	66	65	
14	71	70	72	72	74	73	74	76			74	66	62		63	67
15	72	79	72	69	73	68	67	69			69		71	71	66	56
16	77	82	79	80	86	86	84	82			83	80	80	83	82	76
17	84	83	81	84	85	83	83	84								
18	83	82	79	79	79	82	83	83								
19	81	81	81	80	80	82	83	83								
20	81	80	77	83	82	81	82	82								
21	70	70	70	75	72	68	71	69	75	76	79	78	74	75	74	74
22	78	74	76	77	73	76	76	76								
23	80	76	77	80	77	75	79	76	84	75	79	82	83	83	81	79
24	78	67	70	72	70	70	70	73	72	68	76	77	77	81	80	74
25	78	67	70	72	70	70	70	73								
26	83	77	77	80	77	81	82	82	86	83	86	84	83	86	82	84
27	84	83	81	87	86	82	80	78			81	80	81	81	78	
28	86	77	83	88	88	82	80	79								
29			96													
30	78	75	76	76	76	76	76	76								
31	66	52	56	57	59	67	72	68		67	61	55	56	62	60	56
32	74	73	71	74	77	75	75	73								
33	64	59	61	56	58	61	58	57		61	59	55	60	71	78	69
34	73	75	76	75	72	74	74	71			74	70	70	69	71	
35	83	80	81	83	82	82	82	82	79	79	82	79	80	81	81	80
36	64	61	63	62	60	62	65	67			63	68	67		66	
37	75	73	79	79	75	80	81	80	75	76	75	73	76	78	76	
38	69	66	66	69	66	64	66	68								
39	67	64	61	59	61	65	68	69								
40											67	67	72	74	69	73
41										76	77	74	77	82	71	
43											83	88	70	70		
44												78	80	80	79	78
45										77	77	80	79	80	75	80
46											70	70	72	69	66	
47											61	62	64	68		
49											76	75	77	75	65	
50														81	76	76

Table A7 Annual precipitation averages (mm) measured at ICP Materials test sites 1-50

No	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2002	2005
1	639	386	381	470	409	684	563	581	550	475	522	405	525	601	513	491
2	850	752	703	832	573	921	809	941								
3	426	450	417	416	502	432	597	513	458	431	420	414	510	510	463	442
4	626	769	657	650	672	755	570	698								
5	801	666	671	544	698	610	506	675	578	618	742	614	651	845	713	
6	673	691	666	637	622	702	509	649	535	521						
7	631	448	500	529	503	624	743	596	421	615	786	503	561	620	413	
8	627	674	655	654	629	561	754	779								
9	783	686	698	662	697	619	839	841	595	781	930	796	949	997	647	
10	874	734	697	619	681	707	843	913	661	806	1044	824	967	791	780	761
11	713	664	645	578	676	684	888	889								
12	1492	1185	1183	1118	1092	1552	1169	1503								
13	591	509	463	481	602	602	969	602			1125				660	
14	650	674	626	721	973	659	717	717							600	
15	1125	1004	660	658	936	1041	1283	1092			1077		971		619	632
16	714	536	488	810	511	400	539	500			742	624	722		482	889
17	978	686	692	723	722	860	883	996								
18	904	711	706	702	687	873	969	987								
19	845	693	569	544	799	749	936	829								
20	801	642	609	647	542	680	914	790								
21	1024	577	527	433	614	440	698	680			523	888	898	1050	794	869
22	1116	535	518	286	674	628	688	819								
23	2144	1161	1762	1288	1272	1189	1542	1420	1228	1182	1744	1689	1819	2333	1390	1623
24	531	412	473	643	496	577	392	581	415	556	463	479	454	635	384	273
25	531	412	473	643	496	577	392	581								
26	543	377	342	517	413	468	490	525	319	409	479	317	567	772	562	435
27	365	289	308	206	404	530	673	515			708	729	748	831	548	
28	447	456	416	536	573	614	847	696								
29	1703	1684	2046													
30	610	629	648	499	589	549	595	595								
31	398	322	332	308	310	360	339	224			765	360	334	560	447	399
32	1355	774	831	1111	1032	1560	1012	1082								
33	785	427	610	477	540	433	468	327			872	383	287	739	411	689
34	575	613	860	802	534	881	745	667			838	611	657	812	750	
35	448	589	533	564	533	533	533	533	516	588	859	618	648	668	655	403
36	972	625	1103	955	504	545	798	443			252	188	148		196	
37	961	954	1103	1057	983	1080	1023	1023	1228		788	970	898		964	
38	847	1413	1107	1093	940	982	973	1038								
39	733	933	967	938	730	729	1043	757								
40											572	557	742	731	490	571
41											486	415	501	489	473	
43											485	321	470	254		
44									354	298	344	472	432	361	377	711
45											1053	1204	1072	1281	1011	1404
46											706	651	657	907	494	
47																
49													1008	993	674	
50														870	702	674

Table A8 Corrosion of carbon steel (g m^{-2}) measured at ICP Materials test sites 1-50

No	1987	1992	1994	1996	1997	2000	2002	2005
1	437	271	241	232	182	138	103	102
2	224	153	148					
3	557	350	352	293	239	224	184	183
4	271	131	121					
5	132	48	59	54	53	51	38	
6	270	163	196					
7	266	231	166	156	144	148	85	
8	213	116	140					
9	293	231	209	206	204	101	130	
10	376	347	294	296	311	293	222	
11	342	293	241					
12	138	90	85					
13	178		124	109	134	80	73	104
14	235		148	135	125	98	68	85
15	366		197	149	173	184	90	115
16	245		212	188	211	149		
17	344	303	256					
18	254	204	144					
19	283	239	180					
20	260	205	172					
21	229	135	101	99	93	97	56	75
22	430	346	335					
23	194	132	109	113	101	114	65	107
24	267	120	103	107	125	116	81	92
25	263	103	95					
26	147	75	81	69	62	69	40	41
27	315	309	237		270	195	180	
28	253	204	198					
29	235							
30	307	230						
31	222	162	151	159	72	77	58	44
32	322	299	245					
33	45	26	36	36	54	47	33	45
34	181	141	121	123	135	136	92	
35	185				106	95	96	88
36	224	308	204	308	214	226		
37	149	110	104	130	116	99	94	86
38	214	185	38					
39	176	290	51					
40					137	143	94	91
41				174	179	174	144	226
43					324	256		
44				160	166	148	135	139
45				93	67	58	36	41
46					177	170	150	
47					136	159		
49					171	185	110	
50						271	242	226

Table A9 Corrosion of zinc from sub-centres SVUOM and EMPA (g m^{-2}) measured at ICP Materials test sites 1-50

	SVUOM						**EMPA**			
No	**1987**	**1989**	**1992**	**1994**	**1996**	**2000**	**1997**	**2000**	**2002**	**2005**
1	14.8	7.0	7.7	5.6	5.6	3.9	6.7	7.4	11.3	6.7
2	8.9	7.9	6.7	3.4						
3	16.3	11.5	11.6	12.1	8.7	4.6	10.1	11.2	7.2	16.0
4	11.6	8.3	5.1	4.6						
5	8.8	7.6	6.6	4.6	3.1	5.8	6.8	11.1	4.7	
6	14.4	9.2	5.7	5.5						
7	20.9	7.8	9.0	4.2	3.5	4.6	6.3	10.0	6.6	
8	21.3	4.6	5.2	4.1						
9	28.7	6.6	9.0	7.6	5.7	5.8	8.9	9.0	7.3	
10	61.4	10.6	15.2	7.8	8.6	9.2	12.1	15.7	10.3	10.7
11	30.1	9.6	11.4	7.0						
12	8.3	7.2	7.2	3.7						
13	7.7	9.6		3.4	3.8	3.1	8.4	4.5	7.5	9.5
14	8.8	9.9		3.1	3.1	2.5	7.7	3.8	8.6	5.4
15	11.3	12.1		5.5	4.4	4.2	10.4	10.3	7.0	7.1
16	13.5	7.6		6.0	4.1	4.6	6.7	5.4		
17	14.4	11.3	10.6	5.8						
18	9.9	8.1	7.8	4.7						
19	16.5	9.0	11.0	6.2						
20	20.1	10.2	11.3	6.3						
21	27.5	5.6	6.6	3.5	2.3	3.4	4.7	6.2	9.5	12.4
22	43.4	16.7	15.8	12.0						
23	27.4	8.4	10.5	5.0	3.5	8.5	7.8	21.3	15.8	19.3
24	10.3	6.0	4.5	4.2	3.2	4.4	7.6	5.9	9.7	8.0
25	9.7	5.6	3.5	3.5						
26	8.2	6.7	4.8	6.0	2.6	3.5	7.7	9.0	14.6	16.2
27	10.4	12.3	10.6	7.0		5.2	11.7	8.5	11.0	
28	10.0	6.4	7.7	8.6						
29	13.0	11.6								
30	15.0	8.4	8.3							
31	7.7	4.8	3.5	2.3	2.4	2.1	4.5	4.8	11.8	3.7
32	13.1	10.6	8.7	6.4						
33	3.3	3.9	3.8	1.7	2.2	2.3	4.6	2.7	6.7	6.6
34	10.2	8.6	6.5	4.6	4.1	6.8	6.9	8.1	6.7	
35	7.1	9.4				5.1	7.3	7.7	10.5	7.3
36	9.8		10.4	5.6	4.1	8.0	8.9	5.8	12.2	
37	9.8	6.2	5.2	6.1	2.6	3.7	5.4	7.4	9.2	7.2
38	10.6	12.4	9.6	4.7						
39	13.5	10.9	7.3	5.2						
40						4.9	11.3	5.9	8.1	6.4
41					6.3	5.8	6.5	7.2	10.4	12.0
43						7.6	12.0	9.6		
44					2.8	3.9	6.3	9.3	6.1	6.7
45					3.0	5.0	4.2	9.0	7.1	14.3
46						6.1	8.9	8.3	8.5	
47						5.0	7.1	5.1		
49						8.1	9.9	12.6	7.4	
50						9.9		16.2	11.8	11.9

Table A10 Corrosion of limestone (µm) measured at ICP Materials test sites 1-50

No	1987	1997	2002	2005
1	22.6	6.1	5.3	7.7
2	9.5			
3	19.4	7.3	7.9	11.8
4	9.5			
5	15.0	4.7	5.5	
6	22.5			
7	9.1	3.3	7.0	
8	8.5			
9	14.1	6.3	7.6	
10	17.4	11.6	11.9	15.2
11	16.8			
12	9.0			
13	10.9	5.9	6.4	8.9
14	6.7	6.1	6.7	9.9
15	19.5	8.8	8.7	15.1
16	8.8	9.7	7.1	9.6
17	14.8			
18	7.9			
19	12.0			
20	6.7			
21	11.7	2.5	7.3	10.7
22	36.7			
23	17.0	6.5	7.7	14.7
24	14.0	8.1	7.3	12.8
25	14.5			
26	6.8	3.7	4.3	7.8
27	9.9	9.8	7.6	
28	9.6			
29	22.8			
30	15.7			
31	13.3	3.2	3.9	8.1
32	20.9			
33	6.2	7.6	5.8	11.5
34	9.4	9.0	7.9	
35	9.9	5.5	8.9	10.6
36	6.9	11.5	10.6	
37	8.9	6.3		14.3
38	10.2			
39	18.2			
40		8.8		10.9
41		3.4	2.0	8.6
43				
44		1.8	6.1	9.8
45		9.4	9.0	14.3
46		7.4	9.0	
47				
49		14.2	8.4	
50			14.6	15.4