

ZINC IN THE ENVIRONMENT



An Introduction



ABBREVIATIONS

g	gram
Kg	kilogram
KWh	kilowatt-hour
mg/kg	milligram per kilogram
mg/day	milligram per day
µm	micrometer
µg/m ³	microgram per cubic meter
µg/l	microgram per litre
pg/g	picogram (10 ⁻¹²) per gram
ppm	parts per million
tonne	metric tonne
>	more than
<	less than
EC50	Effect Concentration 50%
NOEC	No Observed Effect Concentration
OCEE	Optimal Concentration Range for Essential Elements
PEC	Predicted Environmental Concentration
PNEC	Predicted No Effect Concentration
SO ₂	sulphur dioxide
Zn	zinc
ZnS	zinc sulphide
EZI	European Zinc Institute (renamed IZA - Europe)
ILO	International Labour Organisation
IPCS	International Programme on Chemical Safety
IZA	International Zinc Association
OSPARCOM	Oslo and Paris Commission
UNEP	United Nations Environment Programme
WHO	World Health Organisation

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1. The value of zinc to mankind

Modern life is inconceivable without zinc.

Zinc provides the most cost-effective and environmentally efficient method of protecting steel from corrosion. In simple terms, zinc means that an average-size American home can now be built from six scrap automobiles instead of 1 acre (0.4 hectares) of forest.

By protecting steel against corrosion, zinc helps save resources such as iron ore and energy¹. By extending the life and durability of steel, zinc extends the life of capital investments, and in the case of public infrastructure - roads, bridges, ports, power and water distribution, telecommunications - helps save taxpayers' money too.

Besides protecting steel against corrosion, zinc has many other uses:

- in brass and other alloys
- in automotive equipment and household appliances, fittings, tools, toys...
- in building and construction
- in pharmaceuticals, medical equipment and cosmetics
- in tyres and all rubber goods
- in fertilisers and animal feed.

Zinc is also an essential element which is indispensable for human health and for all living organisms. This essentiality makes the interaction between zinc and the environment complex.

¹ 30-70 kg of zinc, whose production requires only 125-300 KWh, will extend the life of one tonne of steel, requiring 2500 KWh, by a factor of between 3 and 5. (Peters 1992)

zinc exists naturally in air, water and soil

2. Zinc is a natural element

Zinc is part of nature. Most rocks and many minerals contain zinc in varying amounts and zinc exists naturally in air, water and soil. The average natural level of zinc in the earth's crust is 70 mg/kg (dry weight), ranging between 10 and 300 mg/kg (Malle 1992).

At some locations, zinc has been concentrated to much higher levels by natural geological and geochemical processes. Such concentrations, found at the earth's surface and underground, are being exploited as ore bodies. The most commonly found zinc mineral is sphalerite (ZnS). Zinc metal is produced both from ores and from recycled zinc products. In fact, 30% of the world zinc supply today comes from recycled zinc (see section 6).

Due to natural erosion processes like the weathering and abrasion of rock, soils and sediments by wind and water, a small but significant fraction of natural zinc is continuously being mobilised and transported in the environment. Volcanic eruptions, forest fires and aerosol formation above seas also contribute to the natural transport of zinc. These processes cause cycling of zinc in the environment, resulting in natural background levels in the air, surface waters and soil (Table 1).

Just as the natural amount of zinc in soil varies, the zinc concentration in water depends on a multitude of factors such as the nature and age of the geological formations through which the water flows, together with biological and physicochemical conditions. Seasonal variations also influence zinc concentration in water. Nonetheless, some general categories of surface waters can be defined, which are characterised by a range of natural background zinc levels. These general categories, called habitat-types, are where communities of organisms - ecosystems - dwell, which are conditioned to the zinc levels present. The European alluvial lowland rivers, the U.S. Rocky Mountain streams, and the Great Lakes in North America are examples of freshwater habitat-types with different natural ranges of zinc concentration (Table 1).



Zinc-tolerant plants are found in zinc-enriched environments. The photo shows Viola calaminaris which thrives in the naturally zinc-rich area of La Calamine in Belgium (photo: F. Van Assche).

Table 1: Natural zinc levels (total zinc) in the environment

	Range
Air (rural) ($\mu\text{g}/\text{m}^3$)	0.01 - 0.2
Soil (general) (mg/kg dry weight)	10 - 300
Rocks (ppm)	
- basaltic igneous	48 - 240
- granitic igneous	5 - 140
- shales and clays	18 - 180
- sandstones	2 - 41
- black shales	34 - 1500
Ore bodies (%)	5 - > 15
Surface waters ($\mu\text{g}/\text{l}$)	
Habitat-type:	
- Open ocean (surface)	0.001 - 0.06
- Coastal seas/inland seas	0.5 - 1
- Freshwater:	
- Alluvial lowland rivers rich in nutrients and oligo-elements (e.g. European lowland)	5 - 40
- Mountain rivers from old, strongly leached geological formations (e.g. Rocky Mountains)	< 10
- Large lakes (e.g. Great Lakes)	0.09 - 0.3 (dissolved)
- Zinc-enriched streams flowing through mineralization areas	> 200

For references, see Van Assche et al (1996).

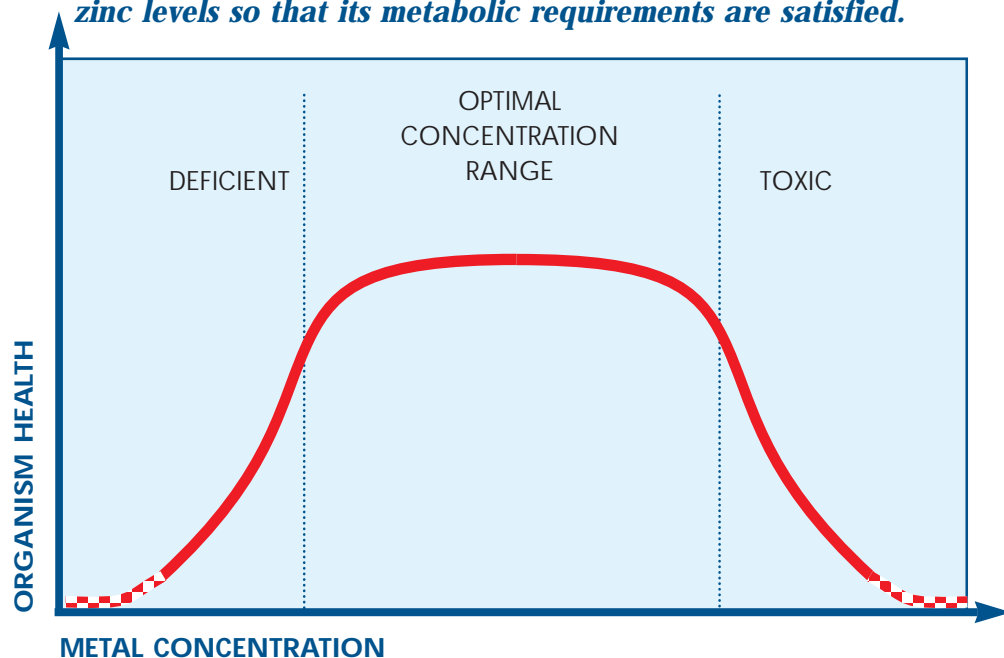
zinc is an essential element for all life, from man to the smallest micro-organism

3. Zinc is essential

All life on earth as we know it today has evolved in the presence of natural levels of zinc. Due to its general availability to organisms (bioavailability) and its characteristics, zinc has been used by nature to play a specific role in various biological reactions. As such, zinc is an essential element for all life, from man to the smallest micro-organism.

Organisms take up the essential elements they need from their environment, that means directly from air, water, soil, and from food. When their cellular requirements for these elements are satisfied, growth and development are optimal. When uptake is too low, deficiency occurs and adverse effects can be observed. On the other side, uptake of too much of an essential element can lead to toxicity. Between these two extremes, each organism has a *concentration range* for each essential element within which its requirements are satisfied. Thus, an *Optimal Concentration Range* for zinc exists for each living organism, including man. Indeed, there is an *Optimal Concentration Range for Essential Elements (OCEE)* for each essential element and each living organism (Figure 1).

Figure 1: Each organism has an Optimal Concentration Range for Essential Elements within which it can regulate its internal zinc levels so that its metabolic requirements are satisfied.



(Van Assche et al. 1996)



the zinc industry has achieved a major reduction in emissions during recent decades

4. Zinc emissions

Since the time of the Ancient Greeks, man has mined ore bodies to extract metals from the earth, refining them and converting them into various chemical forms for use in a wide variety of products. Zinc has been known as a separate metal since the Middle Ages, but the industrial extraction and refining of zinc began in Europe in the late 18th century. This industrial activity has resulted in *anthropogenic* (man-made) input of zinc to the environment and an increase in zinc levels in certain environments.

From the 1970s on, however, growing attention to the environment has led to a progressive reduction in zinc emissions to air and water and the zinc industry has achieved a major reduction in emissions during recent decades.

This trend is reflected in records of atmospheric zinc deposition in Greenland snow. The minute amounts of zinc deposited at this remote location are an indicator of both natural zinc cycling and anthropogenic zinc emissions to air in Europe and North America, and reflect the trend in zinc emissions to air observed throughout the northern hemisphere. The Greenland records show maximum zinc deposition in the 1960s, and a marked decrease since then (Boutron et al. 1995). This downward trend, resulting from emission control at *point sources*², is still continuing at present and ambient air zinc levels appear to be returning to pre-industrial levels (Figure 2).

² Point source or controlled emissions originate from stationary sources that can be easily cleaned or reduced by traditional abatement systems like electrofilters and fabric filters (OSPARCOM 1996).

Figure 2: Changes in zinc concentration in ice and snow at Summit, Greenland, from the 1770s to the present (Boutron et al. 1995)

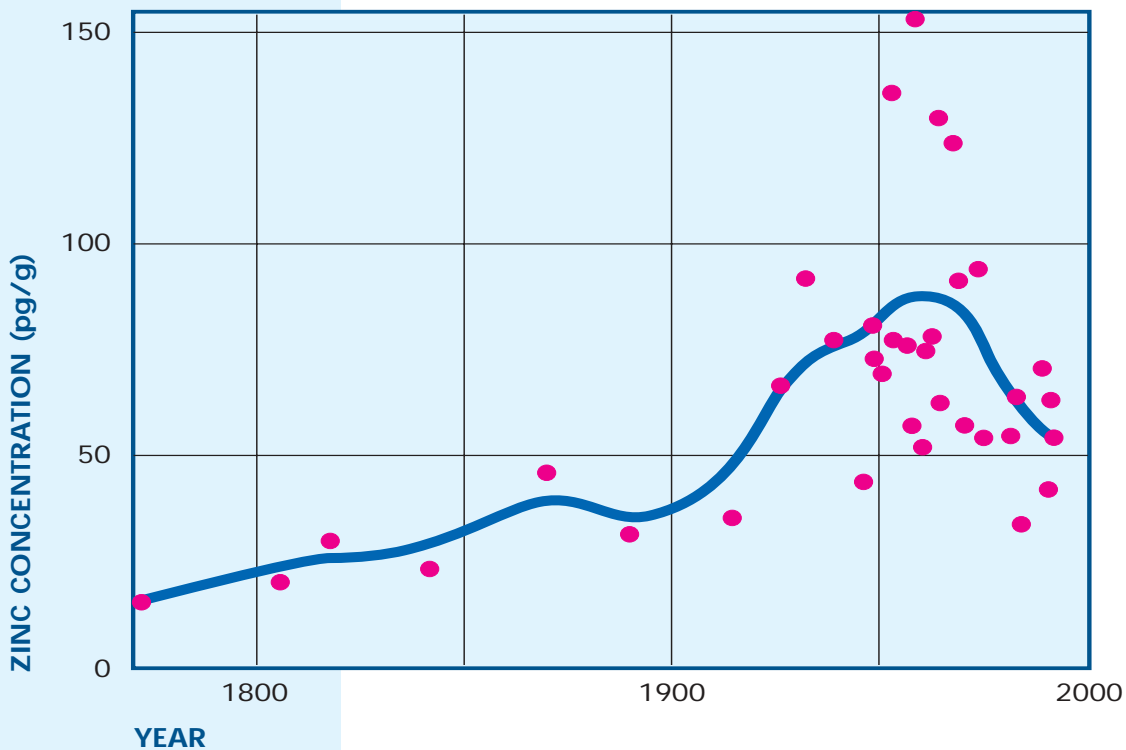
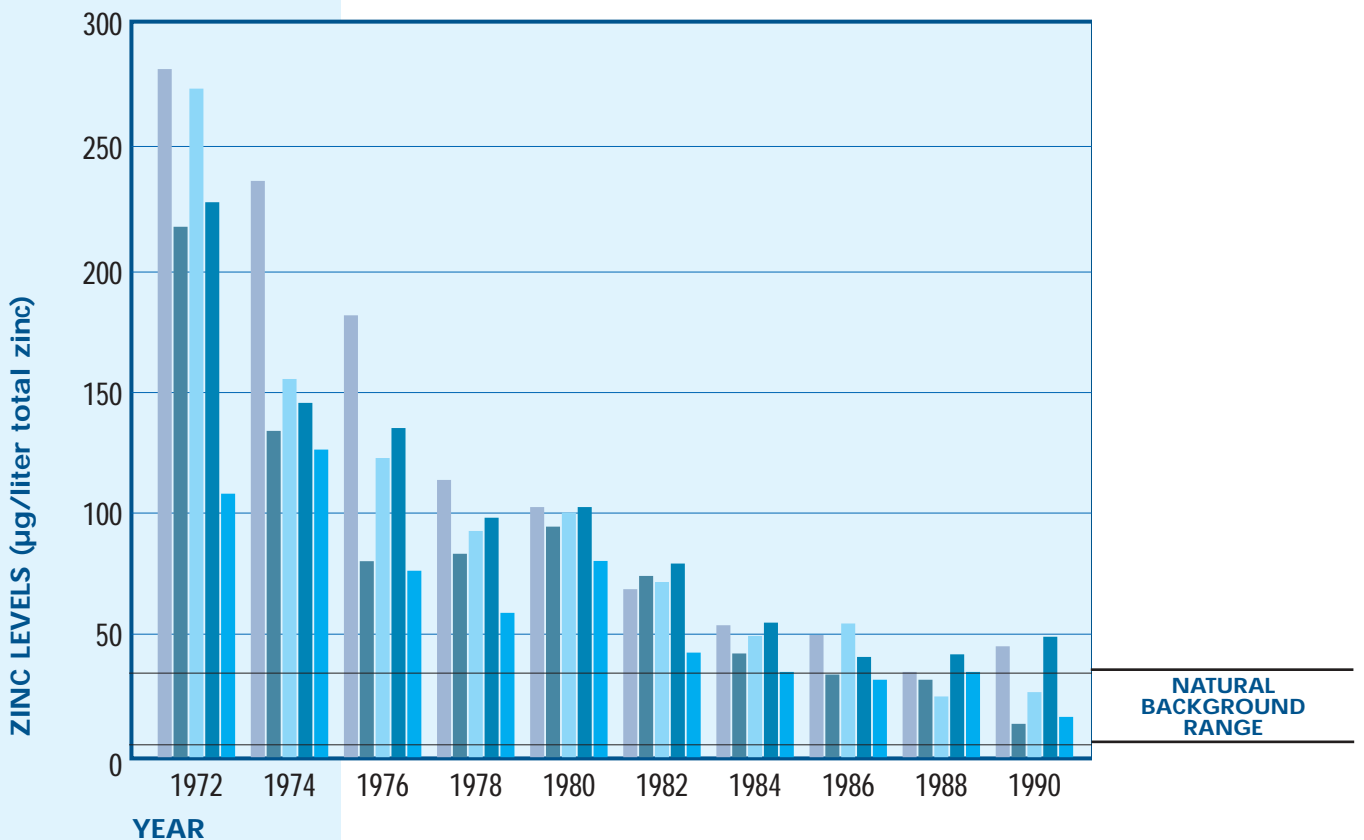


Figure 3: Trend in total zinc levels in the Rhine river at five different sampling sites in the Netherlands: 1972-1990 (after Heymen & Vanderweyden, 1991), with an indication of the natural background range (after Van Tilborg & Van Assche 1995)

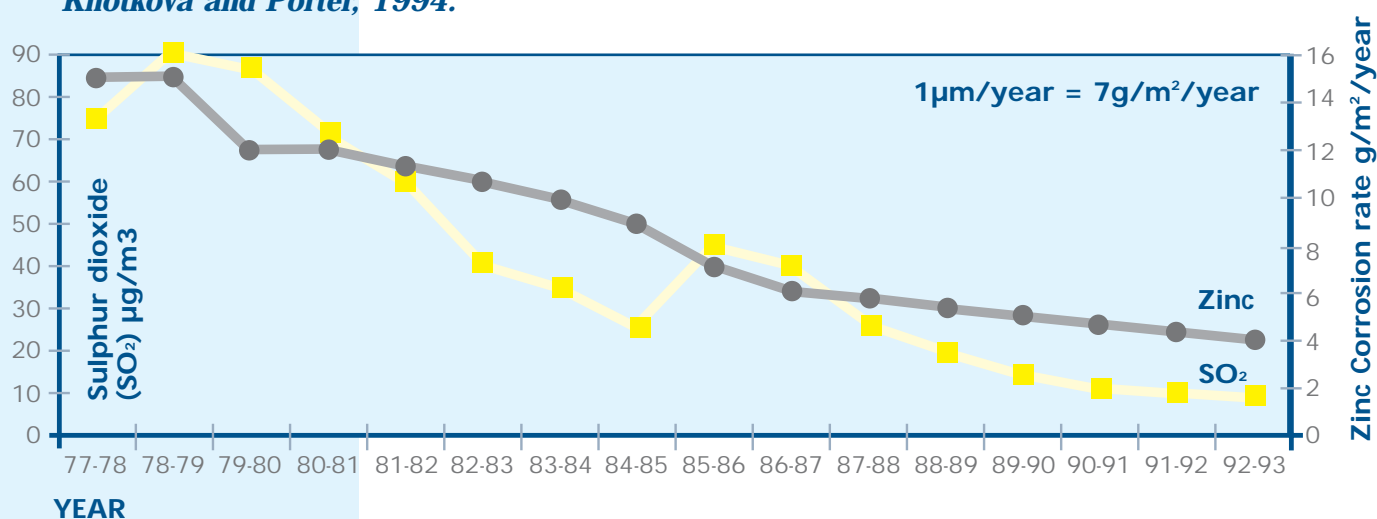


Zinc emissions from point sources to surface waters have also been reduced significantly since the 1970s due to improvements in industrial processes and more efficient emission control technology. This has resulted in a general decrease in zinc concentration in surface waters in the industrialised world, as illustrated by zinc levels in the Rhine river (Figure 3).

*Fugitive emissions*³ are nowadays minimized by the use of effective emission control technologies and best management practices at operating facilities.

A reduction in *diffuse emissions* - zinc released in the environment due to use of zinc containing products - has also been observed in recent years. Most notably, corrosion of exposed zinc surfaces has decreased markedly during the last two decades, as a direct consequence of the decreasing acidity of the air in the industrialised world, itself the result of stringent control of sulphur dioxide emissions (Figure 4).

Figure 4: Sulphur dioxide levels in Stockholm, Sweden and the corrosion rate for zinc in Stockholm. The SO₂ concentrations are mean values for the winter half year. Knotkova and Porter, 1994.



³ Fugitive emissions originate from sources such as outdoor stockpiles, handling or transfer operations, vehicle traffic as well as leakages from buildings and roofs, from maintenance operations and breakdown of plants (OSPARCOM 1996).

many other factors such as temperature, water hardness, pH, and dissolved organic carbon content, in fact determine the bio-availability of zinc in water

5. What happens to zinc in the environment?

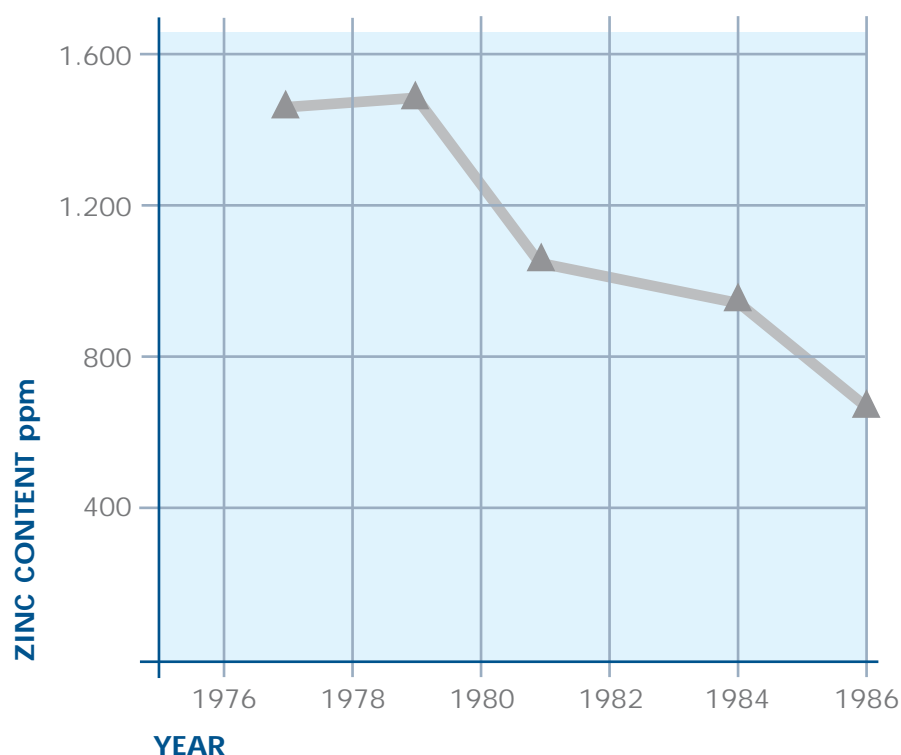
A major part of the zinc present in surface waters is ultimately deposited in the sediments of rivers, estuaries and coastal areas where it binds to inorganic and organic matter, which reduces its bioavailability.

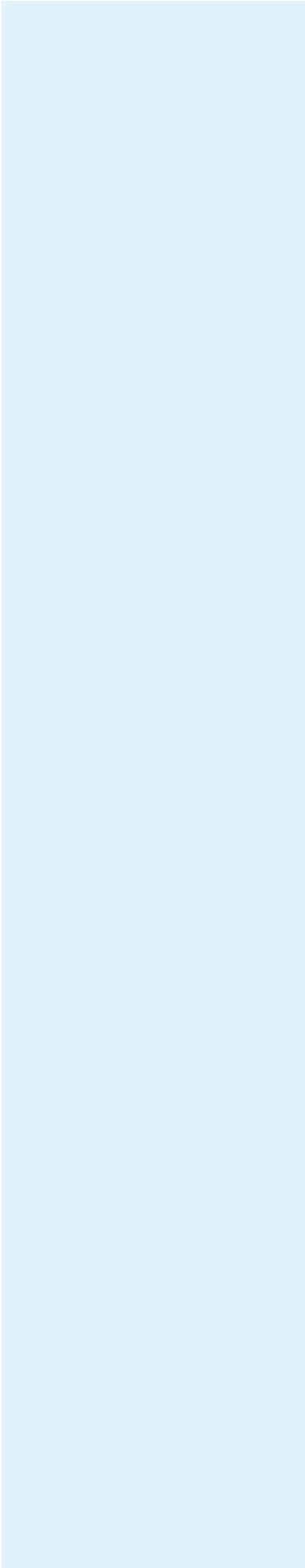
There is a difference between the *total zinc concentration* and the *dissolved zinc concentration* in water. There is no relationship between total zinc concentration and the uptake of zinc by organisms.

It is the bioavailable zinc content which has ecological significance. This bioavailable fraction is usually estimated by filtering the water sample through a 0.45 μm filter. However, many other factors such as temperature, water hardness, pH, and dissolved organic carbon content, in fact determine the bioavailability of zinc in water.

In general, zinc bound to suspended organic matter will settle and for this reason, top sediment layers usually mirror the zinc levels in the overlying water. Sediment layers, formed in rivers in recent years, show decreasing zinc levels, as illustrated in Figure 5.

Figure 5: Trend in average zinc content in sediments at Rotterdam harbour (after Malle 1992)





Airborne zinc particles are deposited on the land and surface waters. In the soil, zinc is bound to the soil complex (clays, organic matter, ...), depending on different physicochemical soil factors such as pH and organic matter content. These factors determine the solubility of the zinc contained in soil, and consequently, its bioavailability for uptake by organisms. Changes in soil pH, for example, dramatically alter the bioavailability of zinc in soil. Soils and sediments are more static compartments of the environment than air and surface waters.

In the vicinity of some old industrial sites, levels of zinc in the soil, usually in combination with other metals, can be elevated due to high emissions in the past (*historical contamination*). Such sites need specific attention and appropriate risk management to limit exposure of the local ecosystem and prevent contamination from spreading to surrounding areas. Promising results have recently been obtained with metal immobilising compounds that, when mixed with contaminated soils, fix zinc and other metals to the soil complex, rendering them less available for uptake by organisms (Van Gronsveld et al.1994).

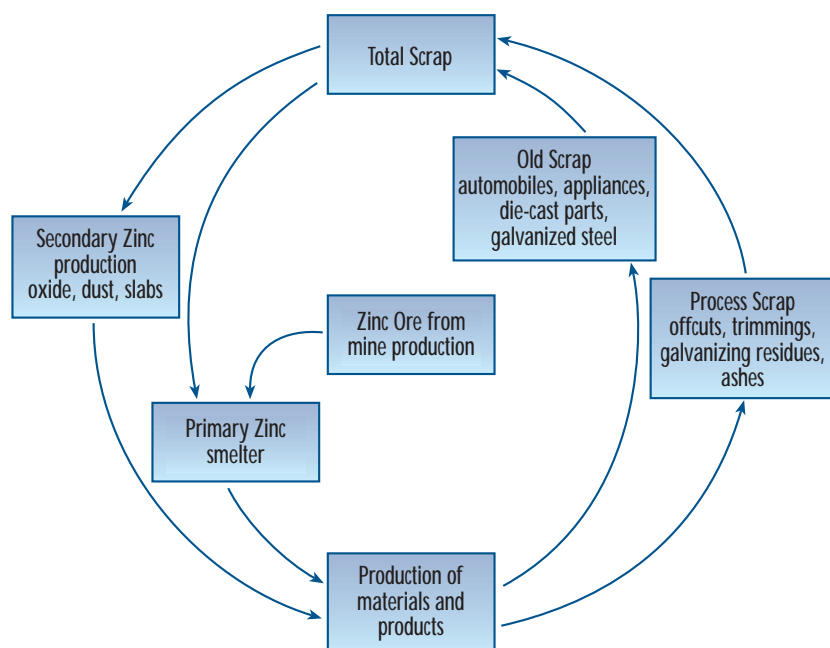
6. Zinc is recycled

Zinc is a recyclable material. At present, about 30% of the world's zinc supply comes from recycled zinc. In other words, some 2 millions tonnes of zinc are recycled every year (European Zinc Institute 1990).

Zinc is recycled from zinc-containing products which are recovered after use: post consumer waste such as brass fixtures and fittings (brass is an alloy of zinc and copper), diecast zinc parts and galvanized steel, recovered from automobiles, household appliances or electrical components. Zinc is also recovered from process scrap, such as galvanizing residues, furnace dust and ashes, offcuts, foundry returns and brass machining scrap. The brass industry alone recovers more than 600,000 tonnes of zinc each year.

It is difficult to estimate precisely the recovery rate of zinc since many zinc products have a very long life span. For example, zinc sheet used for roofing can be expected to last for over 100 years without maintenance before it becomes available for recycling. Nevertheless, estimates based on historical consumption and product life cycles suggest 80% of the zinc available for recycling is in fact recycled. Zinc can be recycled indefinitely without any loss of its physical or chemical properties.

Figure 6: Zinc Recycling Circuit





The recommended daily zinc intake is 12 mg/day for adult women and 15 mg/day for adult men

7. Zinc is essential for human health

Zinc plays an essential role in human metabolism. For example, zinc is vital for the proper functioning of more than 200 enzymes, for the stabilisation of DNA and the expression of genes, and for the transfer of nervous signals.

The human body contains 2-3 g of zinc (compared with 7 g of iron) which is found everywhere in the body, with the highest levels in muscles, liver, kidneys, bones and prostate.

The recommended daily zinc intake is 12 mg/day for adult women and 15 mg/day for adult men. Daily intake is not only dependent on food, but also on sex, age and general health status. Growing infants, children, adolescents, women in pregnancy and the elderly have a higher zinc requirement. Certain groups are known to have an increased demand for zinc and have a higher risk of not getting enough zinc (Table 2).

Food is the primary source of zinc for man, with only a small part coming from drinking water. Food products differ in their zinc content. The major sources of zinc in the diet are redmeat, poultry, fish, seafood, whole cereals and dairy products.

Table 2: Population groups with increased demand for zinc

• Children and adolescents	Higher demand due to growth
• Pregnant and lactating women	Higher resorption by the foetus and in the milk
• Elderly people	Reduced body functions, unbalanced diet
• People doing hard physical work	Increased general demand
• Diabetics and alcoholics	Higher excretion
• Smokers	Reduced absorption
• Patients with severe wounds	Extreme losses and higher demands

8. Zinc deficiency is a problem

Zinc is essential for human health but many adults and children may not be getting enough zinc in their diets. A comprehensive review (Walsh et al. 1995) of current knowledge about zinc and human health concluded that there is a potential for zinc deficiency on a worldwide scale.

In the United States, studies concluded that a substantial part of the general population is at risk from zinc deficiency. Mild chronic deficiency is even predicted in people consuming low meat diets rich in phytate and fiber. Symptoms of zinc deficiency include reduced sense of taste and smell, skin disorders, mental lethargy and reduced fertility.

Zinc nutritional supplements can successfully balance insufficient dietary zinc intake but high doses can lead to gastro-intestinal disorders and are not recommended without medical advice.

During the course of evolution, all living organisms have taken up the zinc available from their environment and used it for specific functions in their metabolism



9. Plants and animals need zinc to grow

During the course of evolution, all living organisms have taken up the zinc available from their environment and used it for specific functions in their metabolism. Consequently, all organisms are conditioned to the bioavailable zinc concentrations in their natural environment which are not constant but subject to seasonal variation.

To cope with these fluctuations, organisms have developed a mechanism (*homeostasis*) that allows them to regulate their zinc uptake within certain limits. When the limits of this regulation mechanism are exceeded, adverse effects can occur.

Deficiency is not widespread under natural conditions, due to background zinc levels in nature. Zinc deficiency commonly occurs under non-natural conditions, however, such as in modern agriculture, where zinc bioavailability is reduced and additional zinc has to be supplied in order for crops and livestock to reach optimum growth. On the other hand, zinc can be *toxic* to organisms when concentrations are too high.

10. Natural ecosystems and food chains

In nature, all organisms that live together in the same physical environment (their *habitat*) form an *ecosystem*, a complex community of numerous populations of different species that are dependent upon each other as a food source. *Food chains* or *food webs* are formed. Ecosystems are conditioned to their physical environment, such as freshwater, the sea or the soil.

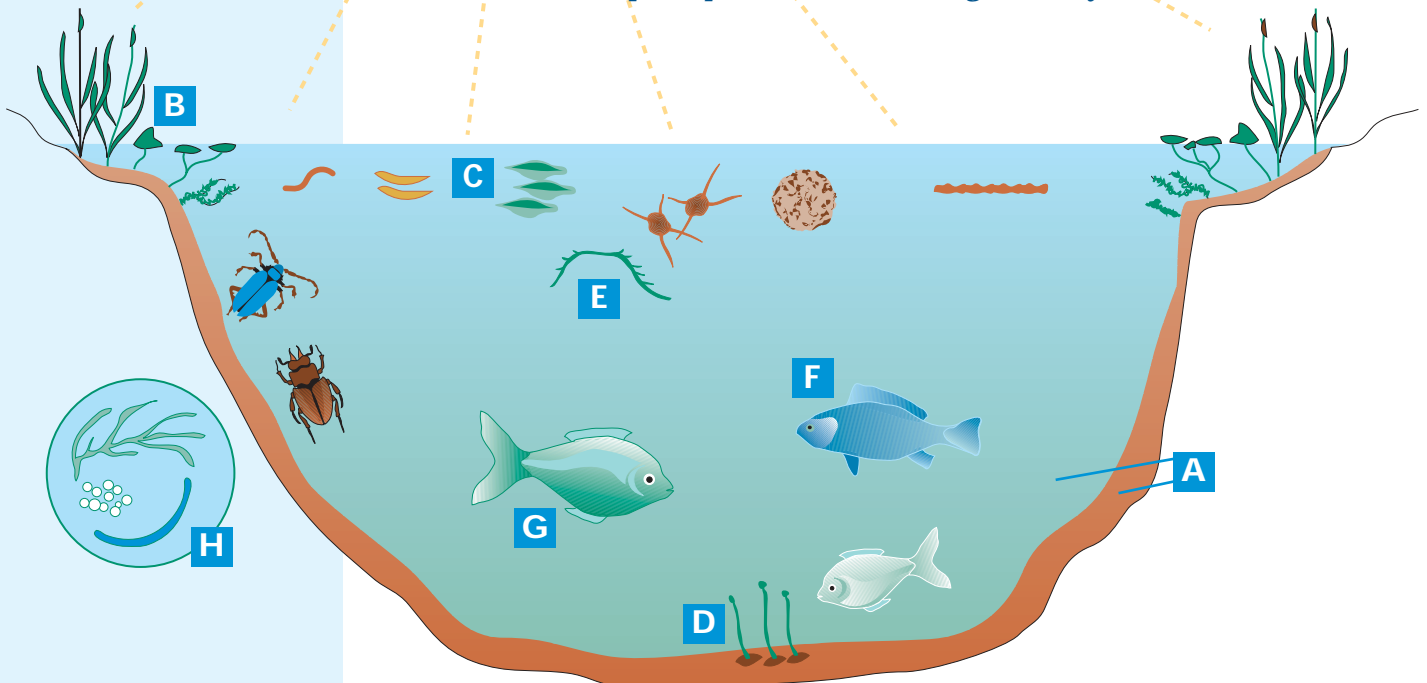
Figure 7 shows a freshwater pond ecosystem as an example. The sun is the driving force, providing the system with energy, which is transferred by the plants and algae into biomass from which the food chain starts, with different levels of "consumers" such as worms and fish, birds, animals and ... man.

Clearly, if the concentration of zinc in a given habitat rises - as a result of anthropogenic input - above levels which can be managed by some of the organisms present, then the equilibrium is disturbed and the structure (species diversity) and function of the ecosystem can be affected. This issue is addressed by environmental risk assesment.

Figure 7: Diagram of a pond ecosystem (after Odum 1971).

Basic units are as follows:

- A. Abiotic substances - basic organic and inorganic compounds**
- B. Producers - rooted vegetation**
- C. Producers - phytoplankton (algae)**
- D. Primary consumers (herbivores) - bottom forms**
- E. Primary consumers (herbivores - zooplankton)**
- F. Secondary consumers (carnivores)**
- G. Tertiary consumers (secondary carnivores)**
- H. Saprotrophs - bacteria and fungi of decay**





11. Risk assessment

In risk assessment, the possibility of a substance having adverse effects on human health or the functioning of an ecosystem is assessed by answering two questions:

- ◆ What are the critical levels of a given substance at which adverse effects can be expected?

This question is answered by analysing data from toxicology (man) and ecotoxicology (environment) to derive values for *Tolerable Daily Intake* for human health and *Predicted No Effect Concentration (PNEC)* for the environment.

- ◆ What is the true exposure to the substance in the environment?

Exposure to a substance is expressed in terms of *Daily Intake* for man and *Predicted Environmental Concentration (PEC)* for the environment. Risk is then assessed by comparing the critical effect level with the exposure level:

When Daily Intake is lower than the Tolerable Daily Intake (or PEC is lower than PNEC), there is no risk to man (or environment). If Daily Intake is equal to or higher than the Tolerable Daily Intake (PEC equal to or higher than PNEC), then a risk exists.

12. Ecotoxicology

The effect of substances on ecosystems is addressed by *ecotoxicology*. The substances may be man-made, such as organic chemicals, or natural essential elements like zinc.

In ecotoxicity tests, organisms are taken out of their natural environment and transferred to the laboratory where they are subjected to different concentrations of a given substance. By this means, the EC_{50} (Effect Concentration) value - the concentration at which 50% of the test organisms are affected with respect to *biological endpoints* such as growth or reproduction - or the NOEC (No Observed Effect Concentration) value - the highest concentration at which no effect is observed - is determined. The EC_{50} and NOEC values for the various organisms from a given ecosystem are then used to estimate the PNEC (Predicted No Effect Concentration).



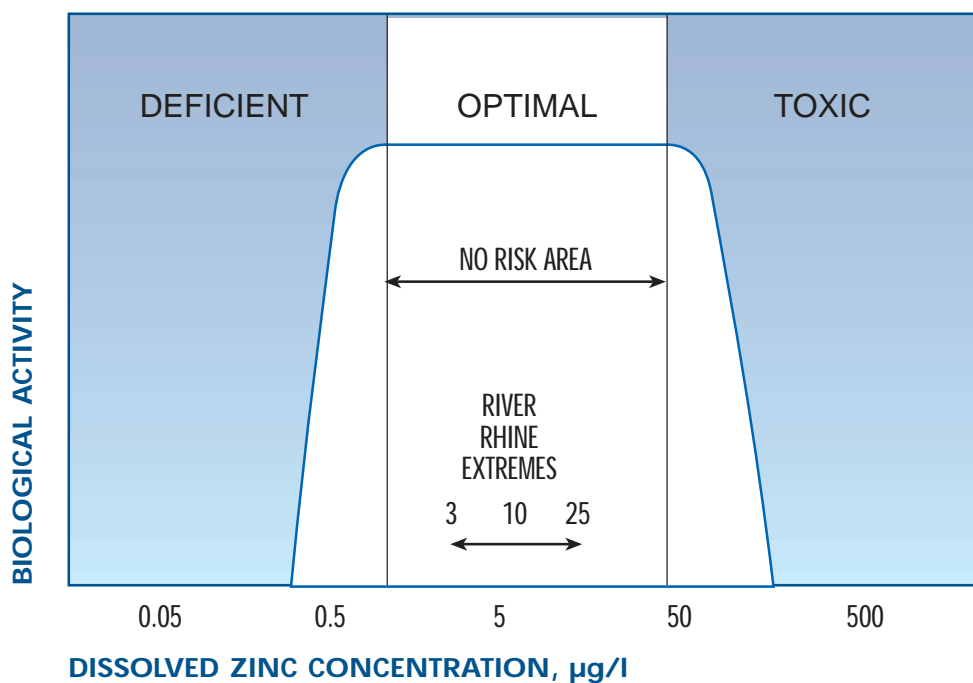
*present-day
zinc levels
do not pose
a risk to the
environment*

13. Zinc in the aquatic environment

What are the possible risks related to the presence of zinc in the aquatic environment? This question stimulates debate about risk assessment methodology for essential elements such as zinc.

Based on methodology suitable for essential elements and reliable ecotoxicity data, PNEC (Predicted No Effect Concentration) values of 50 µg/litre dissolved zinc (corresponding to about 150 - 200 µg/litre total zinc) have been determined. Risk analyses that have been conducted on aquatic and soil environments conclude that present-day zinc levels do not pose a risk to the environment (Van Assche et al. 1996). For example, present-day zinc levels in the Rhine river fall well within the *Optimal Concentration Range* described for zinc (Figure 8).

Figure 8: Risk assessment for zinc in the European alluvial lowland river habitat. Indicated are the “No Risk Area”, bordered at the toxicity side by the PNEC (Van Assche et al. 1996) and the mean, minimum and maximum concentrations of dissolved zinc in the Rhine river, observed over the years 1988, 1989, 1990 (Heymen and Vander Weijden, 1991).



14. Conclusion

Zinc is a natural element which is essential for man and most living organisms. Indeed, zinc deficiency is now recognised as a human health problem. Zinc emissions resulting from industrial activity have decreased significantly in recent decades and present-day zinc levels do not pose a risk to the environment. Localised sites where historical contamination has occurred, however, require proper management.

Recently, the International Programme on Chemical Safety (IPCS) - a world forum under the auspices of the WHO (World Health Organisation), the ILO (International Labour Organisation) and UNEP (United Nations Environment Programme) - formed a Task Force on Zinc to establish Environmental Health Criteria For Zinc. Among its conclusions, the Task Force states:

“Zinc is an essential element in the environment. The possibility exists for both a deficiency and excess of this metal. For this reason it is important that regulatory criteria for zinc, while protecting against toxicity, are not set so low as to drive zinc levels into the deficiency area.”

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