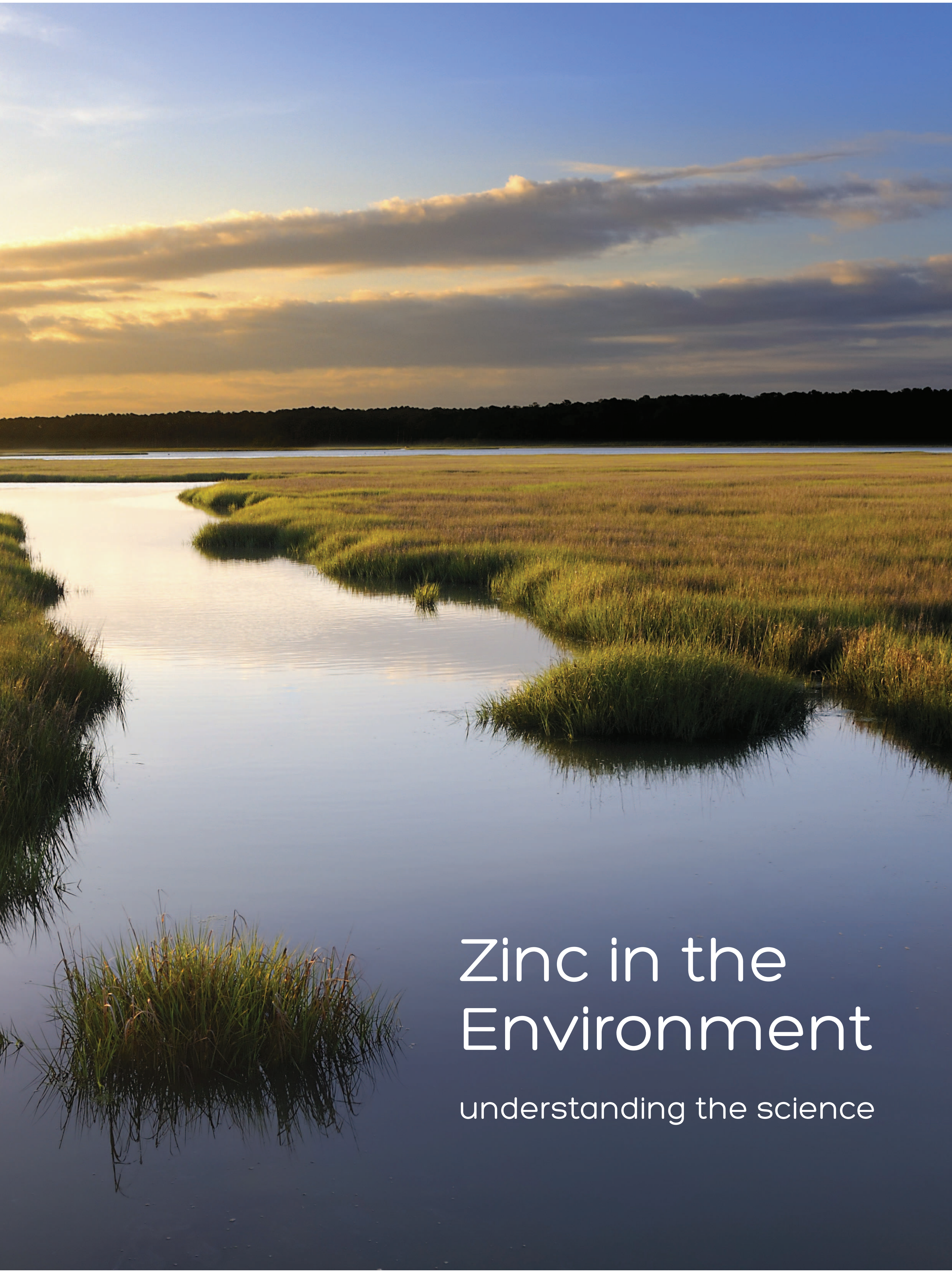


Zinc in the Environment

understanding the science

Introduction

Zinc is an essential mineral of "exceptional biologic and public health importance" and is considered a "Life Saving Commodity" by the United Nations. [1], [2]

Due to its unique properties, zinc is used in a wide range of consumer, infrastructure, agricultural, and industrial products. More importantly, zinc is essential to life, playing an important role in biological processes of all living organisms (humans, animals, and plants). Zinc is crucial for cell division, protein synthesis, the immune system and growth.

Two billion people, mainly in the developing world, are affected by zinc deficiency and related health issues. Children under five years of age are especially vulnerable. An estimated 450,000 children are at risk of dying each year as a result of too little zinc in their diet.

The environmental impact of zinc – and of all essential elements – cannot be assessed in the same way as man-made chemical compounds. Zinc's bioavailability (or presence in a form that is available for uptake by organisms) is determined by complex interactions with the environment and is strongly dependent on the characteristics of that environment.

The intent of this document is to describe the many interactions that occur between zinc and the media in which it resides that play a critical role in assessing environmental effects of zinc.

Natural Occurrence

Zinc is the 24th most abundant element in the Earth's crust and has been present ever since the planet formed its surface. All life on earth has developed in the presence of zinc.

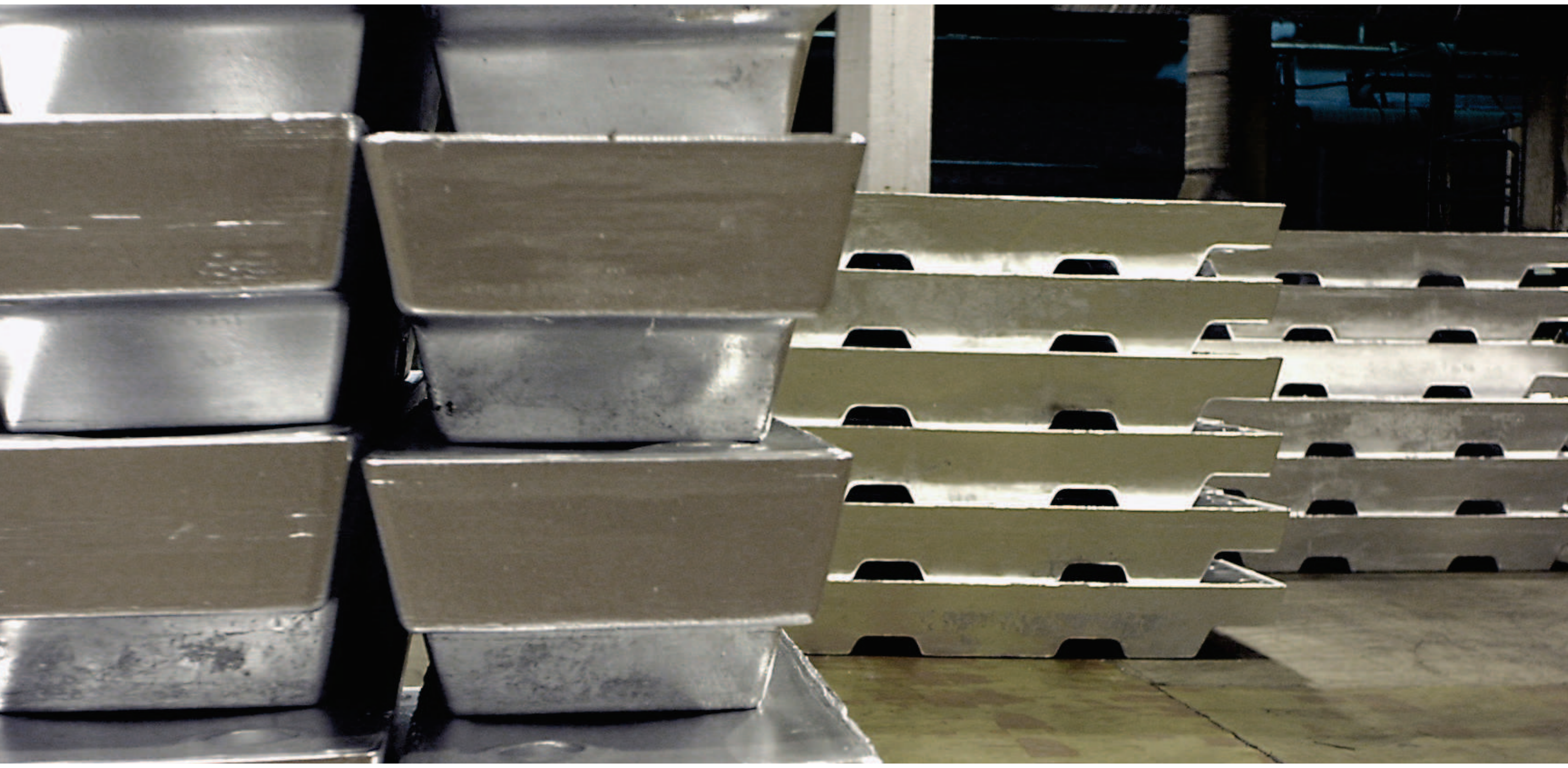
The concentration of zinc in nature without the additional influence of human activities (anthropogenic emissions) is called "natural background." The natural background levels in surface water, soil and rock vary over a wide range of concentrations. Background levels of zinc in soil and rock typically range between 10 and 300 milligrams per kilogram, and zinc in rivers varies from less than 10 micrograms per liter to over 200 micrograms.

Zinc Cycling Through Nature

By natural erosion processes, a small part of the zinc in soil, rock and sediment is constantly moved and transported through the environment. Rain, snow, ice, solar heat and wind erode zinc-containing rocks and soil. Wind and water carry minute amounts of zinc to lakes, rivers and the sea, where it collects as sediment or is transported further. Natural phenomena such as volcanic eruptions, forest fires, dust storms and sea spray also contribute to the continuous cycling of zinc through nature. It is estimated that these natural emissions of zinc amount to 5.9 million metric tonnes each year. [3]

Human activities do not add to the overall zinc amount on a global scale. But mining removes zinc from one part of the world and the production of goods and the use of zinc transports it to another, thereby changing the local zinc concentration. This is known as anthropogenic emissions, which are estimated at 57,000 metric tonnes each year. [4] Potential sources of anthropogenic zinc emissions include: the production and processing of zinc into products; emissions from power plants and other municipal and industrial sources not related to the zinc industry and; certain zinc applications where corrosion or abrasion may result in small releases of zinc to the environment, although these are generally widely dispersive in nature.

On a global scale, the influence of natural zinc cycling processes on environmental zinc levels is much more important than the influence from human activity. However, at a local scale, anthropogenic emissions can in some places outweigh natural processes.



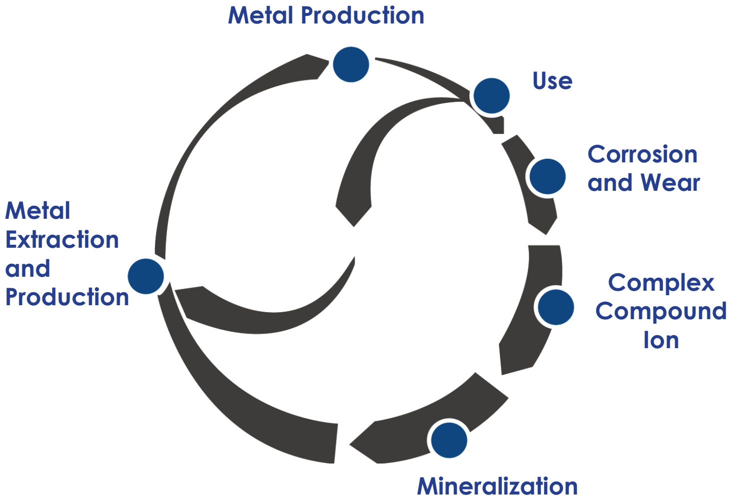
Environmental Fate of Zinc

Zinc released to the environment follows a 'natural cycle' (figure 1) in which zinc from mineral ore bodies is converted through extraction and refining processes from its mineral state (mostly sphalerite ore, zinc sulfide (ZnS)) into the metallic state. [5] Most of this metal will have a long service in stable metal applications and will be recovered and recycled at the end of life. Metallic zinc that is exposed to the atmosphere may be subject to corrosion that will result in a slow release of small amounts of zinc into the environment.

Zinc metal is also transformed into zinc compounds (e.g. zinc oxide, zinc chloride, zinc phosphate) that are used in a wide variety of applications. These uses may also result in small diffusive releases. For example, zinc oxide is a necessary ingredient in rubber manufacturing. Rubber is used to manufacture tires and as tire treads wear, small amounts of this zinc compound are released in the roadside environment.

During the production and use phase of zinc, zinc compounds with varying solubility may be formed and be released into the environment. In addition to these emissions related to human activity, a natural flow of zinc will always cycle through the environment due to the natural processes of weathering and erosion. All these processes mobilize a variety of zinc compounds into the environment.

Figure 1: The Natural Cycle of Zinc



Once mobilized, zinc interacts with the different components of water, sediments and soil and ultimately partitions between different fractions in these environmental compartments. This interaction and the dynamic processes involved ultimately define zinc's environmental fate, i.e. the form(s) in which the metal will be present in the environment and in which it will ultimately end up. In this respect, most of the zinc will return to the stable chemical form, often ZnS, from which it was originally mined. This "mineralization" back into stable chemical forms closes the "natural cycle."

The original and ultimate chemical forms of zinc (mainly ZnS) are very stable, and the contained zinc has very low solubility and very low potential for uptake by organisms ("bioavailability"). As a result, when considering the potential risks related to the presence of zinc in the environment, the attention is focused less on the 'beginning' and 'end' phases (ZnS) but instead on the complex interactions between zinc and the different environmental compartments where zinc is 'bioavailable' for uptake by organisms.

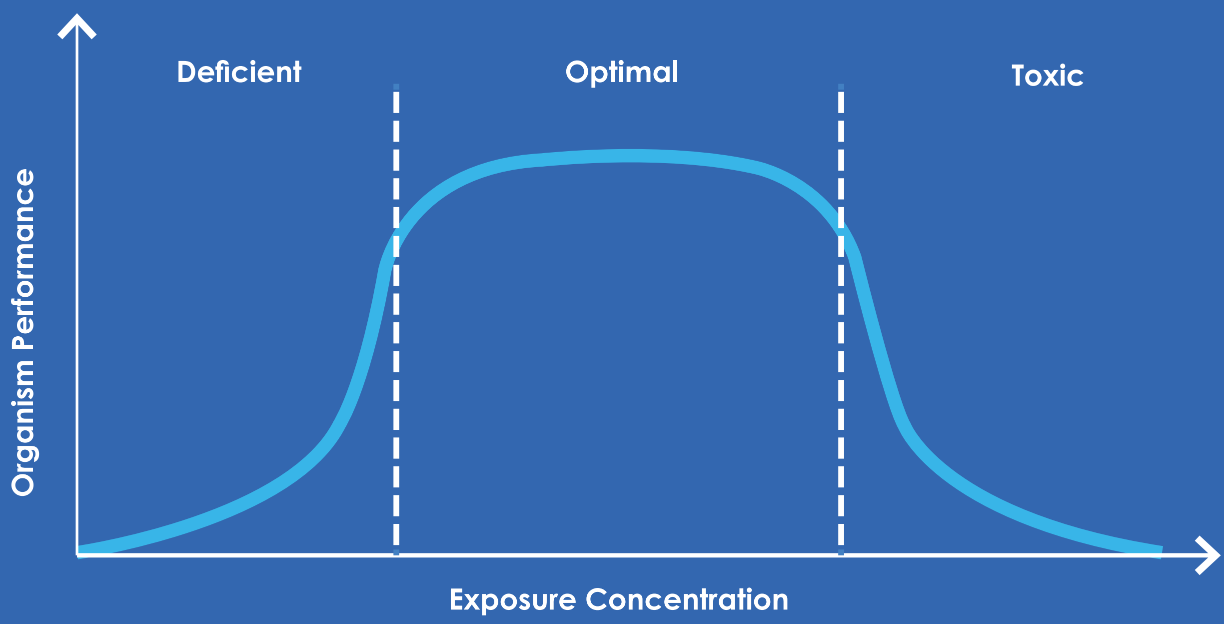
Environmental risk assessment focuses on the assessment of such bioavailable fractions in the environment.

Environmental Effects of Zinc

The environmental impact of zinc – and of all essential elements – cannot be assessed in the same way as man-made chemical compounds. Because zinc occurs naturally, eliminating it from the environment would not be possible. Moreover, because zinc is essential, achieving such a goal would ultimately lead to detrimental effects throughout an ecosystem. In other words, 'less' is not necessarily 'better'.

For essential elements such as zinc, environmental effects must be considered within the context of an organism's natural ability to regulate (uptake and excretion) and maintain a certain level of homeostasis. That is, environments containing zinc at very low, or very high, concentrations may produce undesirable effects. The range between the minimum and maximum is often called the optimal window of essentiality (Figure 2). Organisms have evolved mechanisms to supply their needs independent of the external concentration by regulating an essential element to a constant internal level. [6]

Figure 2: 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.



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Zinc Risk Characterization

The characterization of risk for metals has evolved significantly over the past several decades and currently incorporates concepts of bioavailability. The term bioavailability refers to the form (species) of a metal that is able to enter an organism and elicit an effect. For zinc, the species typically considered to be the source of toxicity (bioavailable) is the uncomplexed, free ion (Zn^{2+}). However, because zinc interacts with various constituents of water, soil and sediment, it can exist as many different complexes. (Figure 3)

In water, zinc concentrations have traditionally been considered on the basis of the total (entire zinc pool in a sample) or dissolved (complexes that can pass through a 0.45 micrometer filter) fraction. However, even following filtration at microscopic levels, the dissolved fraction contains many zinc complexes other than the free ion.

For example, increases in pH, alkalinity or natural organic matter would all tend to decrease zinc bioavailability through complexation. Similarly, zinc bioavailability may also be affected through competition with other positively charged ions (calcium, magnesium, sodium, etc.).

Although accounting for bioavailability in sediment and soils follows a conceptually similar framework as water, additional constituents must be considered. For sediments, zinc has the potential for complexation with iron and manganese oxides (minerals) or organic matter, or in the case of anaerobic sediment, with sulfides.[7] For soils, zinc is strongly adsorbed to mineral phases (oxides, silica, carbonate, clay particles) and organic matter, and the sorption tends to increase with increasing pH.[8] As a result, zinc in sediment and soil is available to complex with these additional compounds/surfaces, thereby decreasing its bioavailable form and potential toxicity to organisms.

In summary, zinc's bioavailability is determined by complex interactions with the environment and is strongly dependent on the characteristics of that environment. In order to understand the many interactions that occur between zinc and the media in which it resides, computational tools have been developed to efficiently characterize site-specific scenarios. As a result, environmental protection levels for zinc typically are no longer expressed as a single value; instead they fluctuate with the ameliorative capacity of the media of interest.

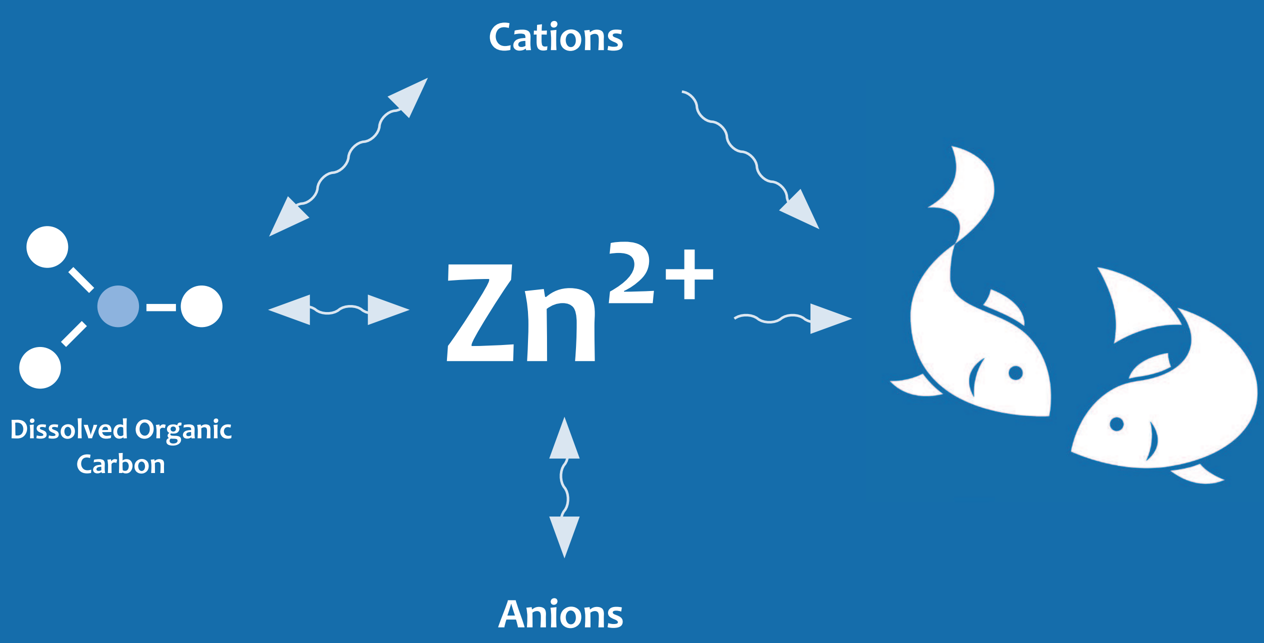
Zinc Risk Management

The objective of risk management is to ensure that bioavailable zinc concentrations in the environment stay well below predicted "no effect" levels (e.g. environmental quality standards). Zinc concentrations in the environment result not only from the production of zinc and the use of zinc in products, but also from the natural background and from other non-intentional sources, where zinc is emitted due to its presence in the raw materials, e.g. combustion of fossil fuels.

Recent risk assessments in Europe have demonstrated that the current general and widespread use of zinc in products does not result in risks for agricultural soils, road-border soils [9] and general water quality. [10] Also, it was recently demonstrated that the waste of non-recycled zinc products and other materials containing zinc, does not pose an environmental risk. [11]

Over the last few decades, zinc emissions from zinc manufacturing and processing have been reduced substantially by process improvements and the progressive implementation of more efficient emission abatement techniques. As a result, present-day emissions from industrial processes are limited.

Figure 3. Chemical and biological interactions influencing zinc bioavailability



Conclusions

The environmental assessment of metals requires a science-based approach because of the natural occurrence of metals, the great variations in metal speciation affecting the metal's bioavailability and toxicity and – for metals such as zinc – their essentiality for all living organisms.

The distribution, transport and effects (bioavailability) of zinc in water, sediment and soil depend largely on the site-specific chemical and physical characteristics of the environment and an organism's condition e.g. age, size, prior history of exposure. Thus environmental assessment of zinc must take these factors into account to be meaningful.

Studies using the state-of-the-science approach have concluded that current zinc uses contribute negligible amounts of bioavailable zinc to the environment and therefore have low potential for environmental effects.

"The total concentration of an essential element such as zinc, alone, is not a good predictor of its bioavailability or toxicity."

- International Programme on Chemical Safety (IPCS) Environmental Health Criteria for Zinc

Case Study: Understanding the Sources and Cycling of Zinc in the Rhine River Basin

Regulatory agencies often identify and implement risk reduction strategies at locations where monitoring data suggests that environmental quality standards (EQS) are not being met. Many of these jurisdictions also do not use state-of-the-science when considering the risk attributed to metal exposure, e.g. bioavailability models such as the Biotic Ligand Model. As a result, regulators often place the burden of site exceedances on the obvious in-use applications of zinc, such as galvanized structures or zinc-sheet building materials.

In an effort to develop an informed understanding of how present day zinc products and sources contribute to ambient loads in urbanized watersheds, scientists at the University of Osnabrück in Germany have extensively studied the source and cycling of zinc in the Rhine River. From 2006-2009, zinc loads from different emission sources including natural (e.g. geological) and anthropogenic (e.g. zinc operations and/or applications) in sub-catchments of the Rhine River were identified and quantified using the GREATER (Geo-referenced Regional Exposure Assessment Tool for European Rivers) model.

The study concluded that current uses of zinc in this region did not result in water quality issues and that instances of zinc concentrations above the EQS were the result of natural background and historical mining sources. By contrast, the study found that current industry and mining operations contributed negligible zinc emissions to the Rhine.

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