Hot-Dip Galvanized Steel's Contribution to Zinc Levels in the Soil Environment

Zinc, commonly referred to worldwide as a "healthy metal," is the 27th most abundant, naturally occurring element in the Earth's crust. Zinc is present in various consumer, infrastructure, agriculture, and industrial products such as:

Consumer:	Drinking water (up to 5,000 PPM)[1], chocolate (96,000 PPB), breakfast cereal (300,000 PPB)[2], fish, milk (4,200 PPB)[3], meat (70,000 PPB), and other products including ointments, pharmaceuticals, cosmetics, dietary supplements, sunscreen, and cold remedies.
Infrastructure:	Hot-dip galvanized guard rail; guiderail; sign supports; lights; telephone, and electric poles; bridges; rail stations; and power supports.
Agriculture:	Additive to fertilizer, grain storage bins, barbed wire/chain link fencing, water/grain troughs, barns, milking stations, and tillage implements.
Industrial Products:	Semi-trailers, automobile and truck body panels, boat trailers, tires, batteries, hydraulic oil, anodes, and alloys (brass & die-casting).

In contrast to man-made chemicals, zinc is a natural element that plays an essential role in the biological processes of all living organisms. For this reason, the environmental impact of zinc cannot be assessed in the same manner as man-made chemical compounds. In other words, less is not automatically better, and reduction of zinc levels in the environment can be detrimental. Because the amount of zinc present in nature varies widely, living organisms have natural processes that regulate their uptake of zinc from all environmental sources (air, water, soil, food). Deficiency occurs when the amount of zinc available is insufficient to meet the needs of a given organism and adverse effects can be observed. On the other hand, uptake of too much of an essential element such as zinc can lead to toxicity. Between these two extremes, each organism has a concentration range for zinc and other essential elements within which its requirements are satisfied.

Plants & Organisms

Plants, crops, and organisms will not achieve full potential yield if their supply of zinc is inadequate. A wide range of food crops are affected by zinc deficiency, including rice, wheat, corn, beans, fruit trees, and vegetables as well as non-food crops such as cotton and tobacco. Yield will be lower and the quality of the crop product may suffer. Losses of up to 30% in cereal grains can occur, without any obvious symptoms of stress. Zinc allows critical physiological pathways to function normally and these pathways have important roles in photosynthesis and sugar formation, protein synthesis, fertility and seed production, growth regulation, and immunity to disease.

Humans & Animals

Zinc bolsters immunity by regulating the body's production of cells and boosts brain activity and memory via its reaction with other chemicals in the hippocampus. Every cell requires zinc to multiply; thus zinc is vital during pregnancy. Sadly, one-third of the world population is at risk of zinc deficiency, primarily due to the lack of zinc in soil and water which support plant growth and other food sources. Zinc deficiency causes poor fetal development, increases the severity of diarrhea, pneumonia, and malaria. Children are especially vulnerable to zinc deficiency, with an estimated 450,000 dying each year as a direct result of too little zinc in their diet.[4]

As important as having enough zinc is to healthy plants, animals, and humans, the stewardship of our soil environment helps maintain the balance of zinc in nature. Approximately six million tons of zinc naturally circulates throughout our environment each year, transported by wind, flowing water, and precipitation.[5] Anthropogenic emissions of zinc to the atmosphere – those resulting from man's activities (industry, urban waste streams, agriculture, corrosion, tire wear, etc.) are estimated to be 62,000 tons worldwide.[6] Point sources of zinc such as the corrosion products from hot-dip galvanized steel (bridges, guiderail, light poles, sign structures, etc.) are an integral part of this anthropogenic circulation. However, it should be noted only about 10% of the naturally circulated and anthropogenic generated zinc is bioavailable to organisms.

Before delving into the impact the release of zinc corrosion products has on the soil environment, it is important to understand what galvanizing is and how it protects steel from corrosion with superior performance.

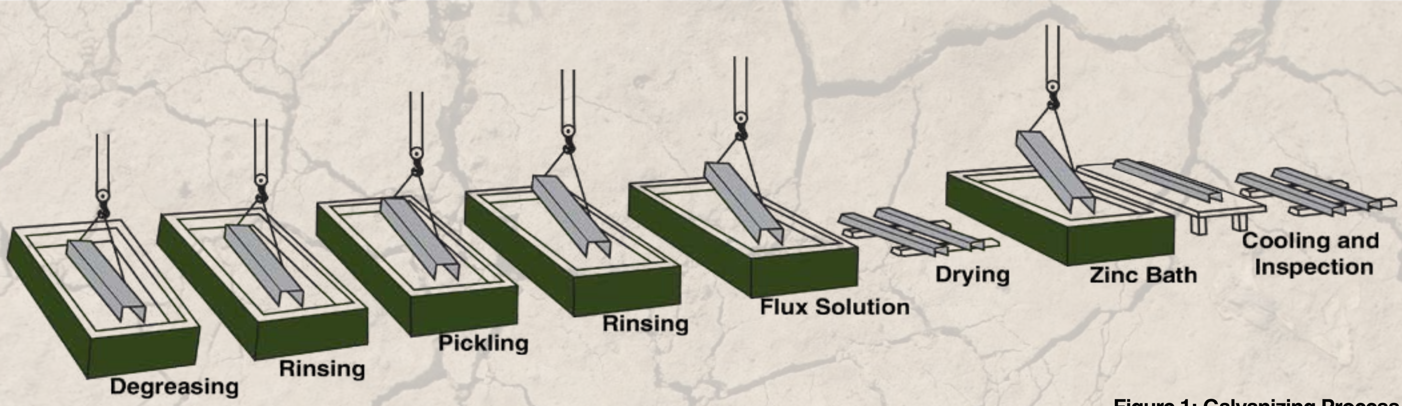

Figure 1: Galvanizing Process

Galvanizing Process

Batch, or after-fabrication, hot-dip galvanizing is the factory-controlled process of immersing fabricated steel or iron into a kettle or bath of molten zinc. While completely immersed in the bath, the zinc metallurgically reacts with the iron in the steel to form a series of zinc-iron intermetallic alloy layers. The zinc coating provides cathodic and barrier protection to the steel, resisting corrosion for many decades in most environments. The galvanizing process consists of three steps: surface preparation, galvanizing, and inspection (*Figure 1*).

During the metallurgical reaction in the zinc bath, the coating grows perpendicular to all surfaces, creating a uniform coating tightly-bonded to the steel. In fact, the three zinc-iron alloy layers are harder than the base steel and have a bond strength of approximately 3,600 psi *(Figure 2).* The tough, tightly bonded layers of the coating are abrasion resistant and difficult to damage during erection, and exposure to harsh wear and tear. Typical coatings on structural steel as specified by ASTM A123, *Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products* have between 3.6 and 4.5 mils of zinc, but can vary based on the thickness and type of steel.

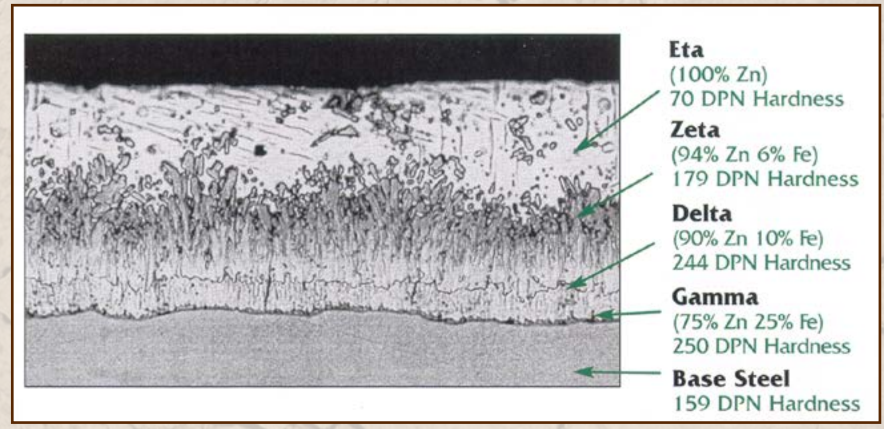

Figure 2: Galvanizing Coating

Zinc Addition to the Environment

When the zinc coating is exposed to air and goes through the natural wet and dry cycles of weather events (rain, snow, fog), it oxidizes and very slowly over time, often 75 years or more, makes its way into the soil. These compounds (zinc oxide, zinc hydroxide, zinc carbonate) of the healthy metal zinc are added to the existing background level of zinc in the soil. (It's important to note diffuse emissions, i.e. zinc released in the environment due to use of zinc containing hot-dip galvanized steel, have reduced significantly in the last two decades as a direct consequence of the decreasing acidity of the air in the industrialized world, itself the result of stringent control of sulfur dioxide emissions.)

Approximately 200,000 tons of zinc are used each year in North America in the hot-dip galvanizing process. The actual galvanized coating corrosion rate (release of zinc corrosion products of zinc oxide, zinc hydroxide, and zinc carbonate into the environment) is a function of the atmospheric conditions in which the hot-dip galvanized steel is placed.The conditions typically influencing corrosion rate of galvanized coatings include pH, chloride ion concentration, sulfur dioxide levels, and humidity.

In the soil, zinc is bound to the soil complex (clay, organic material, etc.) depending on different physicochemical soil factors such as pH and organic matter content and other factors like cation exchange capacity, redox potential, mineral composition, and moisture content.These factors determine the solubility of zinc contained in soil, and consequently, its bioavailability for uptake by organisms. Changes in pH, for example, dramatically affect the bioavailability of zinc in soils.

Background Levels of Zinc in Soil

Below is a map of the United States *(Figure 3)* showing the broad range of zinc concentration. Over 95% of all sampled soils fall within a range of 10 micrograms of zinc per gram of soil to 200 µg/g and average 70 µg/g.[7] However, more important than the measured amount of zinc in the soil is the bioavailability of zinc to organisms. Bioavailability is known to be dependent on factors such as soil pH, organic matter content, and cation exchange capacity (CEC). In a study conducted by Smolders[8], aged zinc in soils sampled along roadside guardrail and under other hot-dip galvanized structures is much less available to soil organisms than soluble compounds of zinc oxide (ZnO) and zinc sulfate ($ZnSO_4$) typically used in laboratory studies. In fact, depending on the geochemical characteristics of the soil, the interaction between the zinc and soil surfaces (organic & mineral) can make as much as 90% of the total zinc concentration biologically unavailable.

Soil quality guidelines for national/regional jurisdictions vary in their consideration of bioavailability and application to differing land uses *(Table 1)*. Australia and the European Union both comprehensively consider geochemical properties, primarily soil pH and CEC, when interpreting effects data for zinc and deriving guidelines. Currently the US Environmental Protection Agency (USEPA) does not consider such factors, and has for now set a conservative/worst case Ecological Soil Screening Level of 120–160 ug/g. However, recent efforts among scientists and regulators to incorporate the methods applied by Australia and the EU have resulted in newly published methodology for use by the USEPA.[9] The proposed approach will account for critical confounding factors in soils risk assessment – background, bioavailability, and land use.

Average natural (background) level of zinc in soil: 50 - 70 µg/g
U.S. EPA guidance level: 120 - 160 µg/g

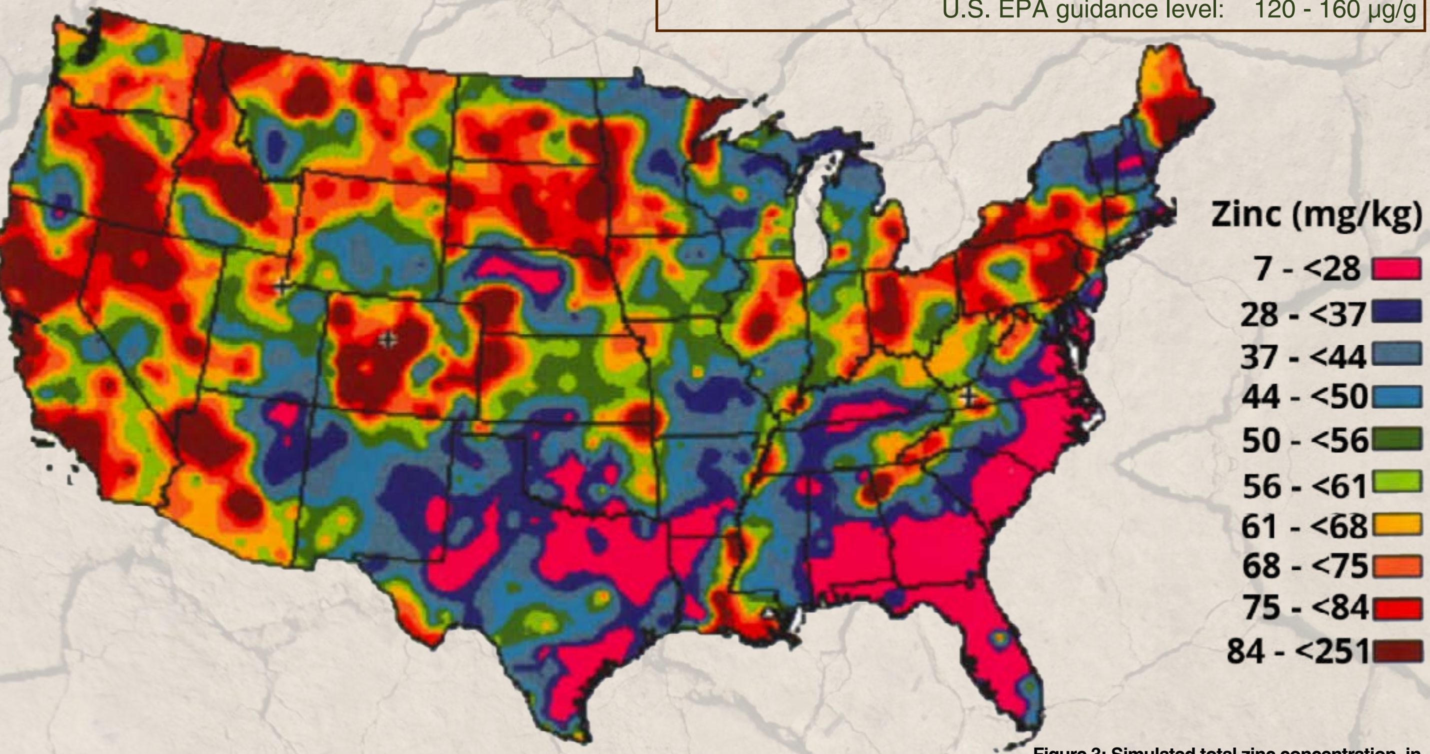

Figure 3: Simulated total zinc concentration in topsoils of the United States [10]

Table 1: Bioavailability and Application to Differing Land Uses

Jurisdiction	Guideline (mg Zn/kg dw)	Comment	Reference
Australia	350-2000	Commercial/Industrial use; added value; accounts for pH ad CEC	NEPC, 2010
Canada	360	Commercial/Industrial Use	CCME, 1999
European Union	70-150	Generic; added value; accounts for pH and CEC	IZA, 2010
United States	120-160	Generic; plants and invertebrates	USEPA, 2007

Case Study: Concentration of Zinc in Soil Near Electrical Transmission Towers

Research has been conducted to understand the impact the corrosion of zinc on the hot-dip galvanized steel products has on the overall zinc level in the environment in the immediate surrounding area. The most comprehensive was a study[11] of galvanized steel electrical transmission towers in four diverse climates throughout North America. (Note: Since the acid rain environment in the study no longer exists, data for that climate has been excluded.)

Protocol

The case study protocol included:

- Examining towers of one, five, and fifteen years of age in each climate*
- Taking samples in climate zones:
  1. Arid (<25cm annual rainfall)
  2. Moist (25-100cm rainfall)
  3. Marine splash (salt spray)
- Gathering soil samples at varying depths and radial distance from the towers
- Collecting control samples in each case to establish the background level of zinc

* Towers of slightly different age were used for some sampling due to unavailability of exact age of towers.

Data

A total of 679 soil samples were collected in the four climate areas. *Table 2* summarizes the data.

Table 2: Concentration of Zinc Near Electrical Transmission Towers

	Age of Towers (years)	Sample Depth (cm)	Location				
			Base (µg/g)	3m (µg/g)	6m (µg/g)	9m (µg/g)	Control (µg/g)
ZONE 1	1	0-5 5-30	56 52	42 37	44 36	45 38	41 42
	19	0-5 5-30	452 90	66 35	62 37	59 35	45 31
	28	0-5 5-30	115 75	107 46	81 47	72 45	46 37
ZONE 2	1	0-5 5-30	12 21	13 22	9 16	10 19	9 21
	14	0-5 5-30	559 786	71 33	53 37	62 30	51 32
	24	0-5 5-30	903 256	114 76	92 113	81 55	73 95
ZONE 3	2	0-5 5-30	135 80	104 45	69 27	63 30	68 31
	26	0-5 5-30	481 460	288 86	124 74	123 93	99 45

Conclusions of Study

- The highest zinc concentration is at the base of the tower and decreases with distance from the tower.
- Those towers in the most corrosive atmospheric conditions have the highest measured zinc concentration.
- Zinc concentrations were at background levels within six to nine meters of the towers sampled.
- There is minimal vertical movement of the zinc in the soil.

Summary

Zinc metal is as essential to sustaining life as water. It plays an important role in the biological processes of all organisms and thankfully it is abundant in the Earth's crust. Zinc is safely used for many consumer products and is a critical additive in agricultural fertilizers, especially in areas of the developing world where there is too little zinc in the soil to produce healthy crops.

Zinc is naturally cycled through the environment by Mother Nature, with approximately six million tons constantly moving in flowing water, wind, precipitation, and erosion throughout our ecosystem each year. Worldwide, man-made point sources of zinc such as hot-dip galvanized poles, sign structures, bridges, and guardrail add another 62,000 tons per year. That one percent anthropogenic contribution is statistically very small, but any imbalance to nature must be critically assessed.

Studies reveal zinc corrosion products emanating from hot-dip galvanized steel products remain in very close proximity to the products themselves, meaning a very small area of the environment has elevated levels of zinc. With the exception of one measurement at 3 meters distance from the base of one tower in the study (*Table 2*, page 4), levels of zinc were far below the USEPA Ecological Soil Screening Level even in the most corrosive atmosphere to zinc. More importantly, very little of the zinc is actually available for absorption by organisms and thus remains harmlessly in the ground, to be redistributed by Mother Nature over the next centuries.

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[1] FDA 2003a 21 CFR 165.110

[2] USDA SR-21, http://nutritiondata.self.com/facts/breakfast-cereals/1686/2

[3] http://www.healthaliciousness.com/articles/zinc.php

[4] UNICEF, September 2009, http://www.unicef.org/nutrition/index_51215.html Zinc in the Environment, International Zinc Association, pg.2

[5] M. Richardson, Critical Review of Natural Global and Regional Emissions of Six Trace Metals to the Atmosphere, Risk logic Scientific Services, Inc., 2001.

[6] J.M. Pacyna and E. G. Pacyna, An assessment of global and regional emissions of trace metals to the atmosphere from anthropogenic sources worldwide, Norwegian Institute for Air Research, 2002.

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[9] U.S. Environmental Protection Agency. 2007. Ecological Soil Screening Levels for Zinc Interim Final. OSWER Directive 9285.7-73. Office of Solid Waste and Emergency Response, Washington,DC

[10] White JG, Welch RM, Norvell WA. 1997. Soil Zinc Map of the USA using Geostatistics and Geographic Information Systems. Soil Sci. Soc. Am. J. 61:185-194

[11] ASARCO. 1993. Preliminary survey of soil contamination resulting from corrosion of galvanized structures. Final Report to the International Lead Zinc Research Organization
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Additional Resources

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- National Environment Protection Council. 2010. Guideline on Soil Quality Guidelines for Arsenic, Chromium (III), Copper, DDT, Lead, Naphthalene, Nickel & Zinc. Schedule B5c. National Environment Protection Council, Adelaide, Australia.