Hot-Dip Galvanized Steel's Contribution to Zinc Levels in the Water 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 myriad 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 guiderail, sign supports, light, telephone, and electric poles, bridges, rail stations/power supports, corrugated steel pipe

Agriculture: additive to fertilizer, grain storage bins, barbed wire/chain link fencing, water/grain troughs, barns, milking stations, tillage implements

Industrial Products: semi-trailers, automobile/truck body panels, boat trailers, tires, batteries, and alloys (brass & die-casting), hydraulic oil, anodes

More importantly, zinc is essential to life, playing an important role in biological processes of all living organisms (humans, animals, and plants). 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, and 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 water environment helps maintain the balance of zinc in nature. Approximately 6 million tons of zinc naturally circulates throughout our environment each year, transported by wind, flowing water, and precipitation.[5] Anthropogenic (man-made) 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 products (bridges, guiderail, light poles, sign structures, etc.) are an integral part of this anthropogenic circulation.

Before examining this further, it is important to understand what hot-dip galvanizing is and how it protects steel from corrosion.

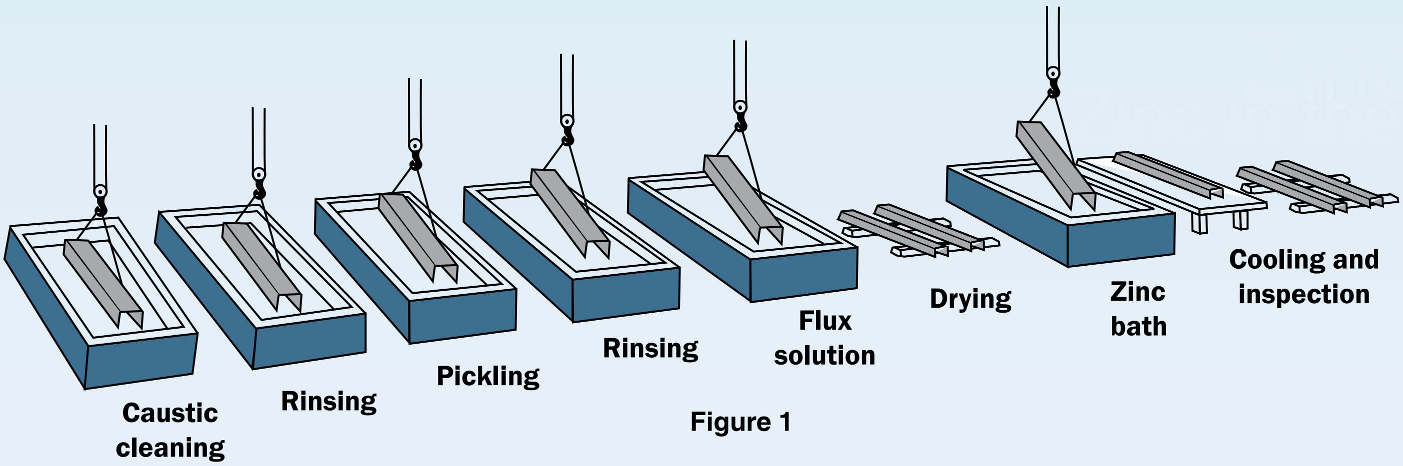


Figure 1

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 3600 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, but can vary based on the thickness and type of steel.

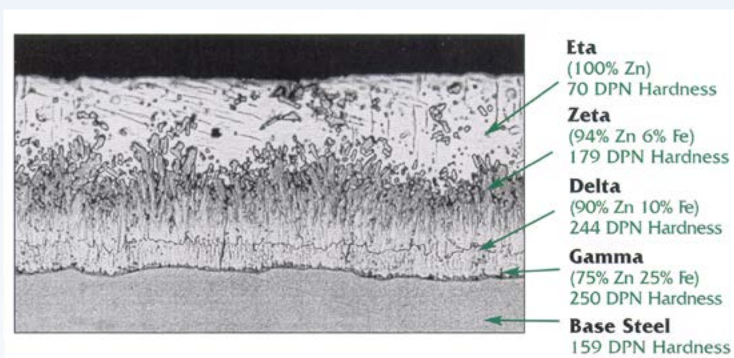


Figure 2

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 streams, rivers, and lakes. These compounds (zinc oxide, zinc hydroxide, zinc carbonate) of the healthy metal zinc are added to the existing background level of zinc in the water, but only on a very temporary basis. The zinc level does not accumulate in water due to the interactions between zinc and the various water quality constituents present in natural waters. The suspended solids in water (minerals and course organic material), decrease the total zinc due to settling and are incorporated into the sediment. Over time, the system maintains a consistent ambient zinc concentration in the water column and sediment because there is a constant supply of new sources of suspended solids in the flowing water. These new sources remove and bury the zinc in a continuous cycle. Even if there are multiple sources of zinc on a river, the dilution factor and suspended solids removal is such the natural background level of zinc is relatively unchanged approximately 2500 feet downstream from each zinc source.

Most importantly, as the case studies will show, this addition of zinc to the water environment does not cause the background level of zinc to exceed the criterion level defined by the U.S. Federal Clean Water Act as the amount of zinc in water causing toxicity to aquatic organisms.

Case Studies

Background Information and Assumptions

- Zinc accounts for 4% of the total weight of a galvanized product.
  - Approximately 25% of the zinc coating will be intact after 75 years.
  - To be conservative, the calculations assume all of the zinc has been transmitted to the water below or around the project of each case study.

- The corrosion rate of zinc is linear and some of the zinc is removed by wind, blowing particles, and vibration.
  - Case studies conservatively assume all of the zinc is transmitted to the water during an estimated 40 storm events of 4 hours duration each during a year's time.

- Background zinc levels in North America range from 1-25 PPB and the average is 7 PPB.
  - The U.S. Environmental Protection Agency Ambient Water Quality Criteria are numeric values limiting the amount of total zinc present (not all of which is bio-available) in our nation's waters.
  - Human health criteria are developed under Section 304(a) of the Clean Water Act of 1972 and are designed to protect human health via direct exposure or ingestion of contaminated diets.
    - The criteria level for waterways may be different for each locale because the ions of hardness (calcium and magnesium) influence zinc toxicity whereby the criterion increases as the hardness of the receiving water increases.

- Flow rates during storm events are often 5-10 times the average flow rate.
  - For the calculations, flow rate was conservatively estimated to be two times the average flow.

- Typically, only about 27% of all zinc corrosion products emitted into the water are bio-available to aquatic species.[7]
  - Case studies assume all zinc is bio-available to match EPA criteria.

Case Study #1:

Never Sink River, Sullivan County
Grey Road Bridge, Fallsburg, NY

Bridge - Constructed 2010

- 84 ft long by 40 ft wide
- 500,000 lbs. Hot-Dip Galvanized Steel (480,000 lbs. steel/20,000 lbs. zinc)
- Lifetime of zinc coating = 75 years

Corrosion/Erosion Rate = 267 lbs/yr (20,000 lbs. / 75 years)

River Flow Rate Average = 200 ft^3/sec (USGS Site #01437500)

Average Zinc Addition: 0.68 PPB

River Flow Rate (per storm event): 400 ft^3/sec

Per Storm Event Addition (40/year): 12 PPB

USEPA AWQ Criterion Level: 33.5 PPB

Case Study #2:

Warmington Bridge, Massillon, OH

Tuscarawas River, Stark County

Truss Bridge – Constructed 1993

- 126 ft long by 40 ft wide
- 248,000 lbs. Hot-Dip Galvanized Steel (238,080 lbs. steel/9,920 lbs. zinc)
- Lifetime of zinc coating = 75 years

Corrosion/Erosion Rate = 132 lbs/yr (9,920 lbs. / 75 years)

River Flow Rate Average = 133 ft^3/sec (USGS Site # 03117000)

Average Zinc Addition: 0.5 PPB

River Flow Rate (per storm event): 266 ft^3/sec

Per Storm Event Addition (40/year): 14 PPB

USEPA AWQ Criterion Level: 289 PPB

Case Study #3

Blough Avenue Bridge, Navarre, OH

Ohio-Erie Canal, Stark County

Truss Bridge – Constructed 1998

- 237 ft long by 40 ft wide
- 344,000 lbs. Hot-Dip Galvanized Steel (330,240 lbs. steel/13,760 lbs. zinc)
- Lifetime of zinc coating = 75 years

Corrosion/Erosion Rate = 183 lbs/yr (13,760 lbs. / 75 years)

River Flow Rate Average = 500 ft^3/sec (USGS Site # 03086500)

Average Zinc Addition: 1.5 PPB

River Flow Rate (per storm event): 1,000 ft^3/sec

Per Storm Event Addition (40/year): 5 PPB

USEPA AWQ Criterion Level: 272 PPB

Case Study #4:

SR3023 Bridge, Johnstown, PA
Little Conemaugh River, Cambria County

Truss Bridge – Constructed 2001

- 300 ft long by 40 ft wide
- 440,000 lbs. Hot-Dip Galvanized Steel (426,240 lbs. steel/17,760 lbs. zinc)
- Lifetime of zinc coating = 75 years

Corrosion/Erosion Rate = 237 lbs/yr (17,760 lbs. / 75 years)

River Flow Rate Average = 80 ft^3/sec (USGS Site #03041000)

Average Zinc Addition: 1.5 PPB

River Flow Rate (per storm event): 160 ft^3/sec

Per Storm Event Addition (40/year)**:** 41 PPB

USEPA AWQ Criterion Level: 184 PPB

Case Study #5:

Commercial Dock Facility, The Dalles, OR
Columbia River, Wasco County

Dock – Constructed 2012

- 24,542 lbs. Hot-Dip Galvanized Steel (23,560 steel/982 lbs. zinc)
  - 782 lbs. zinc above water
  - 196 lbs. below water
- Lifetime of zinc coating = 75 years above
  25 years below

Corrosion/Erosion Rate = 10.5 lbs/yr above
7.8 lbs/year below

River Flow Rate Average = 100,000 ft^3/sec (USGS Site #1410570003041000)

Average Zinc Addition: 0.0001 PPB

USEPA AWQ Criterion Level: 86 PPB

Case Study #6

Wes Smith Bridge, Index, WA

North Fork of the Skykomis River, Snohomish County

Truss Bridge – Constructed 1999

- 220 ft long by 40 ft wide
- 550,000 lbs. Hot-dip Galvanized Steel (528,000 lbs. steel/22,000 lbs. zinc)
- Lifetime of zinc coating = 75 years

Corrosion/Erosion Rate = 293 lbs/year (22,000 lbs. / 75 years)

River Flow Rate Average = 750 ft^3/sec (USGS Site #12134500)

Average Zinc Addition: 0.2 PPB

River Flow Rate (per storm event): 1,500 ft^3/sec

Per storm event Addition (40 per year): 5.4 PPB

USEPA AWQ Criterion Level: 18.7 PPB

Excellent Sustainability Performance

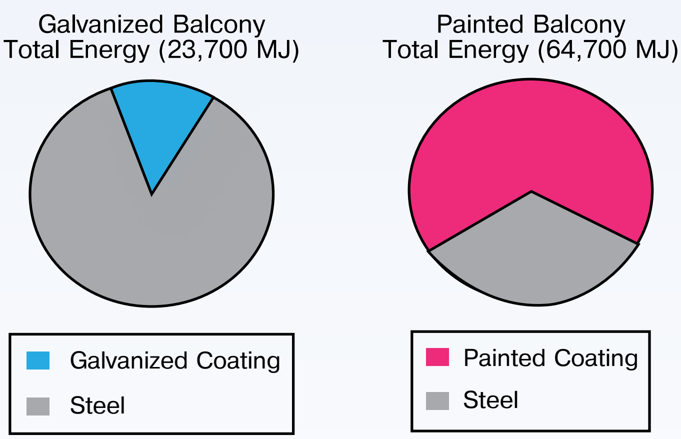
An important criterion used to evaluate products and materials suitable for the environment is inherent sustainability. Unlike paints which release toxic solvents into the air during the drying process and flake/peel solid waste material into water and soil, zinc as measured with life-cycle assessment (LCA) tools, is remarkably sustainable.

- Galvanized steel is 100% recyclable
- Zinc has a reclamation rate of 80% [8]
- Galvanized steel requires no energy, materials, labor, and money to maintain it during the typical 75-year use phase
- Galvanized steel has no associated emissions into the air during the use phase

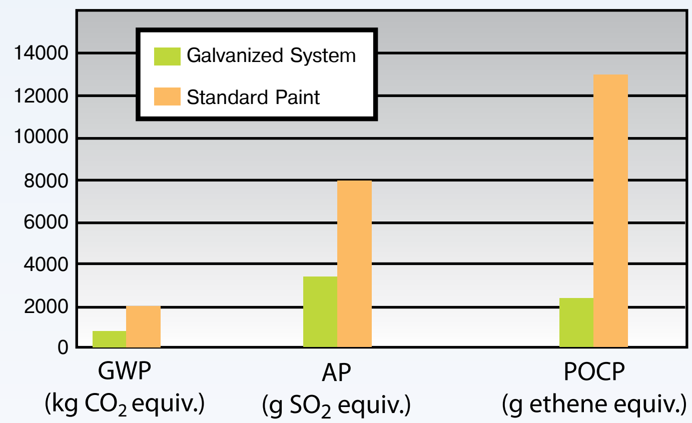
Research studies conducted provide an excellent contrast between hot-dip galvanized structures to paint.

Study #1

In a life-cycle assessment of two balconies, one hot-dip galvanized and one painted, conducted by renowned environmental product declaration expert VTT Technical Research, the galvanized balcony was found to perform far better in every measurable LCA criterion.[9] Over the 60 year expected service life of the balcony, only 23,700 mega joules (MJ) of primary energy demand (PED) is required by the galvanizing, compared to 64,700 MJ for the painting. Not only is the energy required for the painting 3 times that needed for the galvanizing, it is 69% of the total energy of the painted balcony. The galvanizing component of the balcony is just 16%.



Because the painted balcony needs regularly scheduled costly repair it also has a significantly greater impact on the environment. For the LCA criterion global warming potential (GWP), acidification potential (AP), and photochemical ozone creation potential (POCP), galvanizing's impact is just a fraction of paint's.



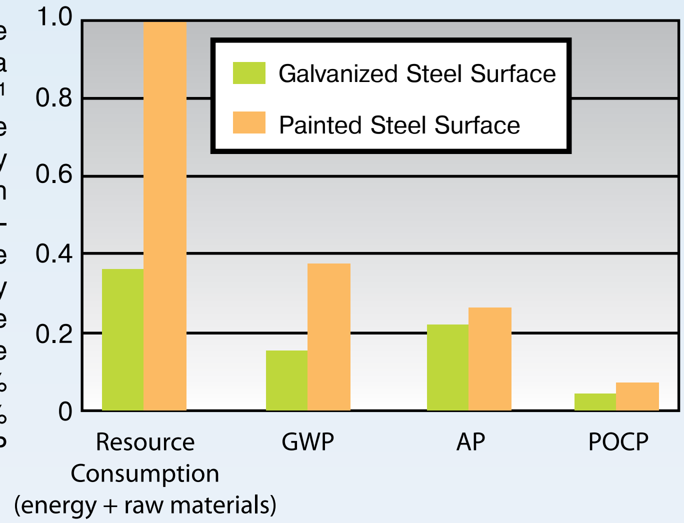
Zero maintenance required on the galvanized balcony translates into huge cost savings over the 60 year life of the balcony, another key determinant of sustainability. For this balcony, galvanizing is not only less expensive initially but 10 times more economical when the maintenance costs over the 60 years is considered. [10]

Coating System	Initial Cost		Life-Cycle Cost		AEAC[a]
	Per ft^2	Total	Per ft^2	Total	Per ft^2
Hot-Dip Galvanizing	$1.10	$ 462	$1.10	$ 462	$0.05
IOZ/Epoxy/Polyurethane	$3.10	$1,289	$9.69	$4,070	$0.43

[a]Average Equivalent Annual Cost per ft^2

Study #2

The Institute for Environmental Protection Technology at the Technical University of Berlin conducted LCAs comparing a hot-dip galvanized steel parking structure to a painted one.[11] The results of the study demonstrate the significant impact the coating plays in the overall environmental impact. The study examines the PED, GWP, AP, and POCP values for each system. The results for each impact area are much less for hot-dip galvanized parking structure. There are two maintenance cycles required for the painted garage and this significantly increases the resource consumption and emissions. Since the hot-dip galvanized parking structure requires no maintenance for the 60 year service life, it is no surprise the PED is just 32% of that for the painted garage structure and the GWP is just 38% of that produced by the painted structure. Furthermore, the AP is 15% less than the painted, and the POCP 33% less.



Galvanizing the parking structure provides a 23% savings initially and maintaining the painted parking structure in years 20 and 40 escalates the total cost to more than three times the cost of the hot-dip galvanized structure.[10]

Coating System	Initial Cost		Life-Cycle Cost		AEAC[a]
	Per ft^2	Total	Per ft^2	Total	Per ft^2
Hot-Dip Galvanizing	$1.76	$1,320,000	$1.76	$1,320,000	$0.08
IOZ/Epoxy/Polyurethane	$2.30	$1,725,000	$7.27	$5,451,272	$0.32

[a]Average Equivalent Annual Cost per ft^2

Summary

Zinc, the healthy metal, plays a key role in plant, animal, and human health but also a critical role in protecting the infrastructure and buildings that contribute to a better quality of life for everyone. The amount of zinc used to protect steel structures from corrosion is small compared to the structure itself and the addition of zinc into waterways after storm events or on an average annual basis is even smaller. The temporary addition of zinc minimally alters the naturally occurring background zinc level, keeping it far below the criterion level established by the USEPA in the Water Quality Act of 1972 and all its revisions. Hot-dip galvanized steel is ideally suited for use over even the most sensitive waterways and habitats.

The empirical, sustainability data of the galvanizing process and the use of galvanized products presents an emphatic statement the low energy requirement and zero maintenance over the life of the project make it an ideal construction material for bridges, parking structures, and most all other projects. Emissions to the atmosphere are extremely low, valuable resources are preserved, and very large savings realized.

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