How Can a Chemical in the "Parts Per Billion" Range be Dangerous?

By James R. Chastain, Jr., PhD, PE, MPH

Environmental engineering initially emerged as a design profession in order to address critical public health needs. As rural communities began to give way to more densely populated urban centers, the incidence of communicable diseases increased dramatically. In large part, this was due to poor sanitation practices. As a means to enhance living conditions and improve the population's health, engineers were tasked with developing better means of managing drinking water, wastewater and solid waste. Techniques for water and wastewater treatment, surface water management and solid waste disposal were developed, which dramatically reduced the acute disease and health risks that plagued the emerging urban environment.

As time went on, however, and the industrial revolution reshaped local and national economies, the impact that humans have on the environment began to be recognized. Humans are a part of a local, regional and global ecological balance and not independent of it. Therefore, damage that occurs as a part of anthropogenic impacts will ultimately return to affect people that are a part of that environment. The difference between this effect and the earlier communicable disease scourge is that these impacts tend to be more subdued and result in long-term health effects. Many of the state and federal environmental laws and regulations have been developed in response to such impacts.

While ecosystems can be altered or degraded in many ways, one of the most important, and yet in many cases the most difficult to quantify, is chemical pollution. Because chemistry is fundamental to much of the progress society has made, there are tens of thousands of chemicals that are discarded or excreted into the environment every day. Many of these are benign and have no measurable effect on the environment. Others, however, can have a profound effect on both the environment and, ultimately, public health. What makes these chemicals so dangerous, even when the discharge seems to be quite low ("parts per million" or "parts per billion" level)?

There are many factors involved as a chemical moves through the environment. One key question involves looking at whether the chemical **bioaccumulates** in the ecosystem. In other words, does the chemical remain in the environment and move through the food chain, or does it naturally degrade and decompose? Are the residual products harmful or benign?

Actually, there are three terms that many times are used synonymously to express this process, but which have slightly different meanings. The terms are bioconcentration, bioaccumulation, and biomagnification. Technically, **bioconcentration** refers to an organism's uptake of a contaminant from the external environment; **bioaccumulation** is the uptake of a contaminant from the external environment or food; and **biomagnification** refers to the increasing concentration of a contaminant as it moves through higher trophic levels. (A trophic level refers to an organism's position in the food chain, with humans being at the highest trophic level.) As you can see the terms are related. Most scientists classify bioaccumulation as the overall process term which is then divided into bioconcentration and biomagnification, with bioconcentration related to chemicals coming directly from the environment and biomagnification resulting from intake via the food chain.

We might find that interesting, but what does that have to do with harm to our personal health or damage to the environment? By looking at chemicals this way, we can begin to understand why certain chemicals, even when entering the environment in seemingly small amounts, can actually result in "poisoning" us.

Biologists and toxicologists have identified at least four factors which help provide clues as to which contaminants have the most potential for causing harm, especially through our food. Generally, they must have the following characteristics:

1. long-lived
2. mobile
3. soluble in fats
4. biologically active

If the chemical contaminant is short-lived, it will degrade before it can become dangerous because it won't be able to interact with a large portion of the population. If it's not mobile, unless there is just a massive amount of the material in the environment, it will be too dispersed for a population of organisms to efficiently consume it. If the contaminant is water soluble, it will tend to be routinely excreted by the organism's waste functions. However, if the chemical is soluble in fat, it will tend to be stored for long periods of time in the fatty tissue of the organism. This is one reason that environmental toxicants can show up in female milk and thus affect the very young who are often more susceptible to damage by toxins. Finally, a contaminant must be biologically active (cause changes) for it to be significant from a health perspective. With that background, all it takes is a cursory examination of where chemicals go (i.e. the fate of chemicals) and how they can enter the food chain to get a sense of the problem.

When human populations (or their activities) are concentrated, the waste products of that community tend to become concentrated at localized points rather than dispersed over large land areas as we might see in rural settings. This concept could also be extended to agriculture or other activities that significantly increase the "density" of production over normal levels. As a result, disposal of these wastes or byproducts are not uniformly distributed into the environment. When those wastes include chemicals that are persistent (don't easily breakdown or degrade), there is an opportunity for them to be consumed or otherwise absorbed by organisms at the lower levels of the food chain. Many times chemicals of concern mimic essential nutrients so the body tries to metabolize the contaminant. This is quite common so long as the concentration in the environment is not toxic to the organism. Persistent chemicals, then, will remain in the environment for long periods of time and, if the waste discharge continues, the concentration will continue to increase additively over time. This in turn gives the organisms feeding in the area an increased opportunity for uptake. If these chemicals enter the water (lake, river or groundwater), they can also be transported to other areas, increasing the range of their effect.

As organisms which are lower in the food chain metabolize the chemical, it is absorbed in the fat tissue and begins to concentrate. Thus, it is said that the body burden of the chemical increases. If they continue their intake of the chemical, it will begin to bioconcentrate because the body can eject it efficiently from the fatty tissue. Now the concentration of the chemical may not harm the organism at all because it is stable in the fatty tissue and doesn't interfere with the normal body functions, but it exists as a body burden.

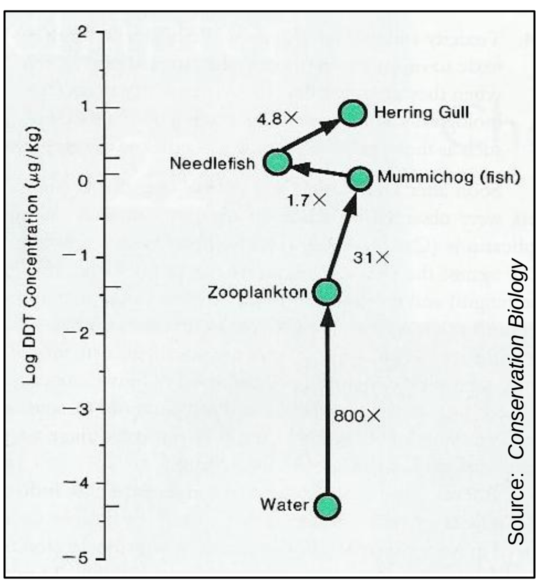

Figure 1

At this point a very significant thing happens. As one moves up the trophic levels (food chain), the new organism will be consuming organisms (food) that has the chemical bioconcentrated in the fatty tissue. This means that, in addition to any intake that may occur directly from the environment, the new organism receives a more concentrated dose from the lower trophic level.

To illustrate this point, Figure 1 is provided. The graph shows the uptake of DDT from a low level in the water itself to a level in birds that is 200,000 times as great as the water itself. Thus, DDT has concentrated in the lipid tissue of birds more than five orders of magnitude. Continued concentration will occur as one proceeds to higher trophic levels (to include humans). Different chemicals have different concentration potentials, but the class of contaminants considered here (i.e. fat soluble) typically have bioconcentration ranges in the 10^3 to 10^6 (thousands to millions). Other chemicals, however, that are not fat soluble don't have this problem.

One final point might be noted. People that have been exposed to these contaminants over time can have high body burdens of the chemicals, but not be particularly aware of this fact. As explained above, this is concentrated in the fat deposits of the body. Therefore, if these people are overweight and elect to go on a crash diet, the chemicals can be released back into active circulation in the body and damage sensitive functional organs. In these rare cases, then, a person can actually damage their health significantly if they lose weight too quickly.

There is much that is not understood in these extremely complex interactions. However, the basic concepts have been recognized and on-going research may help untangle the fate of each chemical in its path through the environment. In the interim, regulatory agencies must attempt to develop regulations that balance the beneficial use of chemicals with their adverse and potentially long-term reactions. This is a difficult task in the face of the myriad of unknown factors in each case. In the face of this uncertainty, the so-called "precautionary principle" is invoked and a conservative ruling is passed based on expert assessments.

References:

Chapra, S.C. (1997). **Surface Water-Quality Modeling**. WCB/McGraw-Hill, Dubuque, IA.
Cox, G.W. (1997). **Conservation Biology** (2nd Ed.). WCB/McGraw-Hill, Dubuque, IA.
Klaassen, C.D. (2001). **Casarett & Doull's Toxicology: The Basic Science of Poisons** (6^{th} Ed). McGraw-Hill, NY, NY.

Dr. Jim Chastain is the President of Chastain-Skillman, Inc. He has a Bachelor of Science in Civil Engineering (honors) and Master of Engineering from the University of Florida. He also has a Master of Public Health and Ph.D. from the University of South Florida. He is a registered Professional Engineer with over 30 years of experience and is a Diplomate of the American Academy of Environmental Engineers. He can be reached at (863) 646-1402 or jrchastain@chastainskillman.com.