

# Clean Earth, Clean Water... Take Your Pick!

“Ashes to ashes, dust to dust.” We are all familiar with this oft-used phrase from the *Book of Common Prayer* (based on *Genesis 3:19*). Somehow, the author of these words had a unique understanding of the *Laws of Conservation of Mass and Energy* that wouldn’t be discovered for more than a thousand years. Man cannot create matter or energy from scratch. He can only change its form. Likewise, he can never destroy matter or energy. All the molecules will remain, albeit in a different form of the exact same elements.

## It all gets recycled

Take as an example the simple tree. It takes carbon dioxide (CO<sub>2</sub>) from the air, combines it with water (H<sub>2</sub>O) and through the miracle of photosynthesis (energy from the sun), releases oxygen (O<sub>2</sub>) and creates cellulose (C<sub>12</sub>H<sub>22</sub>O<sub>11</sub>), the stuff from which plants are made. We call it a carbohydrate. Starches and sugars are also carbohydrates and they all share the exact same chemical formula as cellulose. If we eat carbohydrates as a food source or burn the wood from that tree as a source of fuel, we recombine the carbohydrate with O<sub>2</sub> from the air and send the CO<sub>2</sub> and H<sub>2</sub>O back to nature while releasing the original energy of the sun as heat. Nothing has been gained. Nothing has been lost. That’s the Law.

Water is a great cleanser. We use it to wash our clothes, our dishes and ourselves. Mother Nature uses it to scour both land and sky. During the process, however, water can become contaminated.

Atmospheric moisture will condense on tiny dust particles before falling as rain or snow, and it cleanses the atmosphere of built-up gases (primarily CO<sub>2</sub>) in addition to oxides of sulfur and nitrogen (also acid formers) and other debris. “Pure as rain” is a bit of a misrepresentation. Rain is actually a dilute acid at a pH of around 5.5 and often containing up to 50 ppm of total dissolved solids (TDS) including calcium, magnesium, sodium, sulfate, chloride and silica (which is leached from dust particles), as well as bicarbonate and CO<sub>2</sub>. You have probably noticed that when rain falls on your freshly washed and waxed car, it leaves spots when it evaporates. After a few days of rain, the TDS drops to around 5 ppm, which is mostly as carbonic acid (H<sub>2</sub>CO<sub>3</sub>)—the combination of CO<sub>2</sub> and H<sub>2</sub>O.

Most precipitation runs over the surface and collects in rivers, streams, ponds and lakes, and is known as surface water. Some soaks in and becomes well or spring water, also known as

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groundwater. Excess CO<sub>2</sub> tends to evaporate from surface containments so the water is closer to neutral in pH, generally lower in TDS, somewhat higher in dissolved oxygen, and typically iron free with low hardness. Groundwater, on the other hand, is neutralized by the soil, so is typically higher in TDS, hardness and whatever else is available from the soil. That’s the part that should have you concerned.

**Table 1. Major elements in the Earth’s crust<sup>1</sup>**

Element	Symbol	Percent by volume	Cumulative percent
oxygen	O	46.60	46.60
silicon	Si	27.72	74.32
aluminum	Al	8.13	82.45
iron	Fe	5.00	87.45
calcium	Ca	3.63	91.08
sodium	Na	2.83	93.91
potassium	K	2.59	96.50
magnesium	Mg	2.09	98.59
titanium	Ti	0.44	99.03
hydrogen	H	0.14	99.17
phosphorous	P	0.12	99.29
manganese	Mn	0.10	99.39
fluorine	F	0.08	99.47
sulfur	S	0.05	99.52
chlorine	Cl	0.05	99.57
carbon	C	0.03	99.60

Earth’s crust—the part of the planet on which we live—is 20 to 30 miles (30 to 50 km) thick but only makes up less than one percent of the Earth’s volume. It is composed primarily of metal and non-metal oxides (Table 1).

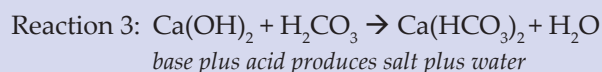
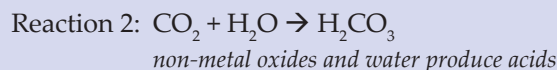
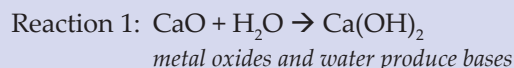
Metal oxides will form bases in water (Reaction 1), while non-metals tend to form acids (Reaction 2). These acids and bases further react to form other salts and water (Reaction 3). It is fortunate that the oxides (silica, aluminum and iron constitute nearly 85 percent) making up the surface of the Earth are sparingly soluble in water. Otherwise, we would all have fins. However, given a time span measured in hundreds of millions of years and the acidic nature of precipitation, elements are slowly leached from the crust and become part of the groundwater.

The elements listed in Table 1 make up 99.6 percent of the bulk of Earth’s surface. It is what’s in the other 0.4 percent that gives us concern. 0.4 percent is

4,000 ppm and many of the other components of the Earth’s crust make-up are toxic at only a few parts per billion!

## Just because it doesn’t show on the water analysis doesn’t mean it isn’t there

When we review the list of common ions found in water, it includes calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), iron (Fe), aluminum (Al), bicarbonate (HCO<sub>3</sub>), chloride (Cl), sulfate (SO<sub>4</sub>) and silica (SiO<sub>2</sub>). Given the composition of the Earth’s crust (Table 1), we can readily confirm the leaching of inorganic minerals into groundwater.



When we work on rating an ion exchange system, the components listed in Table 1 are often sufficient to get an accurate picture. After all, ion exchange doesn't really care who its partner is. Each ionic equivalent gets to occupy the same amount of space and an analysis that covers 99.6 percent is plenty good enough. Often, the trace elements (those making up the other 0.4 percent) *aren't even listed*. The ionic contribution of arsenic, lead, uranium and cadmium, for instance, may be less than 0.1 ppm (100 ppb). Even so, that water would be considered a toxic soup. It is the presence of those trace elements that really determines whether a given water source is potable or toxic. So, where do these contaminants come from?

### Why do you think they call it dirt?

Not only are all 90 of the naturally occurring elements found in *The Periodic Table* found in the Earth's crust (Figure 1), but all 90 can also be found in your water supply. Many are below the level of detection, but they are there. Many are considered toxic and we would call them contaminants. Much of the toxic element levels found in soil and groundwater are anthropogenic—a fancy word meaning 'caused by man'.

Of the 16 elements listed in Table 1 and making up 99.6 percent of the Earth's crust, only one (fluorine—usually present as calcium fluoride) is currently regulated on the US EPA's list of (primary) potentially harmful inorganic chemicals. The US EPA secondary regulations list includes fluorine, aluminum, iron, manganese, sulfur (sulfate) and chlorine (chloride) among the common rock-forming elements. For the most part, rocks are not very soluble in water, even acidic water. While we often experience treatable levels of *naturally* occurring arsenic, fluoride and uranium, it is unusual to find treatable levels of naturally occurring lead, cadmium, copper, zinc, selenium, molybdenum, antimony, chromium and others on the US EPA's list. That's because Mother Nature has had millions of years to clean up loose ends and most things that will dissolve are happily in equilibriums that are below the maximum contaminant levels (MCLs) for those elements (Table 2). Had things not happened that way, we might not be here. And, the way things are going, we are getting a second chance to wipe out mankind through carelessness.

### Soil contamination leads to water contamination

Contrary to common belief, there is no such thing as *pure* water or *clean* dirt. All waters are simply dilute salts of various metals and all soil contains trace elemental metallic compounds. Ever since the invention of agriculture, man has been tweaking the composition of soil to improve his lot. Some of the tweaks are rather harmless, such as the addition of ammonium salt as a nitrogen source. Some are non-issues, such as the addition of calcium sulfate (gypsum) for pH control or sodium salt (NaCl) for moisture control. Others are not so friendly, such as arsenic, lead and fluoride-based pesticides.

The two biggest contributors to excessive levels of regulated elements in soil and water are: humans. We have met the enemy and it is us! While many trace metal contaminants can occur natu-

### You are here-X

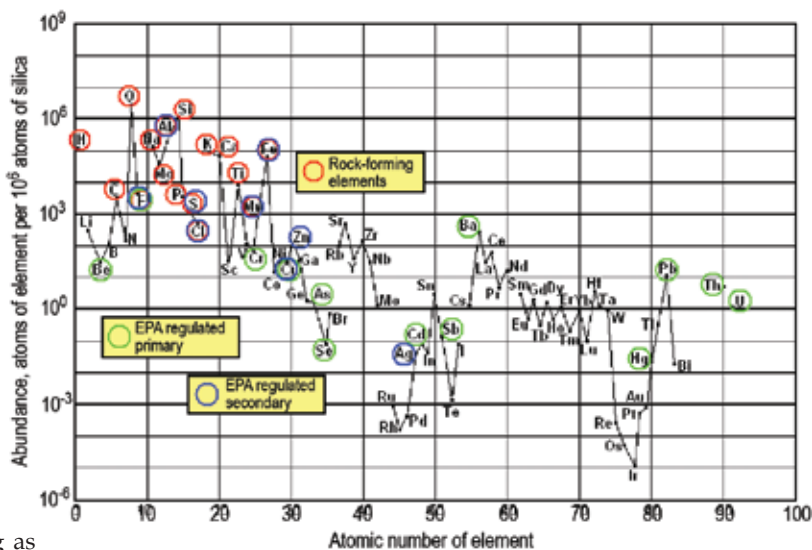
To put the enormity of the planet and the part we occupy into perspective, let's take a basketball and a can of spray paint. Our basketball is about 10 inches (25 cm) in diameter and if we give it a good coat of spray paint, we end up with about 10 mils (0.25mm) of paint (about 1/1000ths the diameter of the ball). Everything that has ever walked upon, swam through, burrowed under or flown over this planet (not counting ETs) since Day One has done so within the relative confines of that paint film. The total crust of the Earth is thinner than the rubber making up the cover of the ball. So we occupy a very small part of this rock, but at least it's the exciting part.

rally, they are generally found at levels below the MCL. Over many years, through both neglect and ignorance, industry has used the back forty as a dumping ground and applied pesticides and fertilizers with no concern as to where they might end up. Smokestacks spewed millions of tons of arsenic into the air only to have it end up in the soil, and the water. In the 1930s, California sprayed lead arsenate on orchards at a rate of 260 lbs. of active ingredient per acre (US Department of Agriculture). That works out to over 100 ppm in the top six inches of soil per season. Five decades of tetraethyl lead (TEL) as an anti-knock compound in gasoline has deposited millions of tons of lead into the atmosphere and onto the ground. In 1979 alone, auto exhausts released 208.1 million pounds of lead into the air in the US. Lead from auto emissions is carried over 50 miles and distributed widely by wind.

Arsenic is contained in *all* soils and *all* water sources. Irrigation water is, therefore, an additional source of arsenic because when that water evaporates, it leaves the arsenic behind. Irrigation can deposit about 0.1 ppm per year of additional arsenic in soil. In fact, there is more of a contribution to soil contamination from irrigation than from fertilizer.

Once in the soil and water, contaminants can be taken up by plants. The driving force behind the banning of TEL from gasoline was concerns over the continued build up of lead in soil and agricultural produce. Lead is still used in fuel for aircraft

Figure 1. Abundance of the elements in Earth's crust<sup>1</sup>



Note that the data in Figure 1 is logarithmic and that the abundance of silica is set with a value of 10<sup>6</sup>. All other elements are represented as relative to silica. For every 1,000,000 atoms of silica (10<sup>6</sup>), there is approximately 1 atom (10<sup>0</sup>) of molybdenum (Mo) or uranium (U). Gold (Au) exists at 1/1000ths or 10<sup>-3</sup> atoms for every million atoms of silica. Rule of thumb says that for every increase of 10 in atomic number there is a correspondingly relative decrease in abundance by a factor of 10.

and off-road vehicles. Arsenic is still used in pesticides and wood preservation. Add to this the use of fluoride in pesticides and other agricultural sprays (plus the questionable practice of adding fluoride to the drinking water supply) and we have a persistent problem and ongoing need for water purification for

**Table 2. US EPA primary inorganic drinking water contaminants**

Contaminant	MCL (mg/L)	Sources of contaminant
Chlorine (Cl <sub>2</sub> )	4.0	water additive for control of microbes
Antimony (Sb)	0.006	improper industrial discharge
Arsenic (As)	0.010	natural erosion and run off from farming, pesticides, wood treating
Barium (Ba)	0.004	natural erosion, burning of coal, metal refining
Beryllium (Be)	0.004	burning of coal, metal refining, industrial discharge
Cadmium (Cd)	0.005	natural erosion, runoff, corrosion of galvanized iron
Chromium (Cr)	0.1	natural erosion, steel manufacture, plating waste
Copper (Cu)	1.3 AL*	natural erosion, corrosion of copper plumbing, electronics waste
Fluoride (F)	4.0	natural erosion, water additive, discharge aluminum manufacture
Lead (Pb)	0.015 AL*	natural erosion, corrosion of household plumbing, leaded fuel
Mercury (Hg)	0.002	natural erosion, runoff from industrial, agriculture, and landfills
Nitrate (NO <sub>3</sub> as N)	10	natural erosion, fertilizer runoff, sewage and septic, animal waste
Nitrite (NO <sub>2</sub> as N)	1	leaching from agriculture, septic, sewage, feed lot animal waste
Selenium (Se)	0.05	natural erosion, oil refineries, mine drainage waste
Thallium (Th)	0.002	mining waste, electronics, glass and drug factory discharge
Radium (Ra)	5 pCi/L	natural erosion
Uranium (U)	0.03	natural erosion

\*AL = action level (also requires process to reduce occurrence)

years to come. Dental fluorosis is on the rise even in areas that do not fluoridate their water supplies because the extensive use in pesticides and its presence in irrigation water has resulted in excessive fluoride intake just from food.<sup>2</sup>

In general, the higher the level of contamination in the soil, the higher the likelihood of that contaminant showing up in groundwater. Contaminated soil leads to contaminated water. The containment of toxic substances deep underground (so called proper disposal) is but a temporary out-of-sight-out-of-mind fix. True to the parable, these substances will, one day, again join the soil and water from whence they came.

There is both a good side and a bad side to this fact. On the plus side is that should the source of contamination be halted, Mother Nature will eventually clean up the soil by having a constantly refreshed water supply pass through it. The negative side is that the movement of groundwater will move contaminants into other areas that may be more in the mainstream of urban living. This will lead to a shortage of cheap water and necessitate costly municipal and residential treatment.

### The nature of dirt

Not apparent from the general composition of the Earth's crust is what we might call the active ingredient in soil. Chemically, it is a sodium aluminosilicate or zeolite. There are more than fifty identified zeolites that occur naturally<sup>3</sup> and they vary widely in composition. They all have certain properties in common—they are all ion exchangers. Mined zeolites are typically in the sodium or potassium form (cation) and the Na<sup>+</sup> and K<sup>+</sup> ions are held rather loosely. This allows them to exchange with ions of higher charge—just like softeners. This unique chemistry of soil allows some contaminants to be far less mobile than others. One means of treating Cr<sup>+6</sup> (an anion) is to chemically (or through the use of microbes) reduce it to Cr<sup>+3</sup> (a cation), which is then immobilized by the soil. The same happens with lead, cadmium, copper, iron, manganese and zinc. Anionic metals (i.e., selenium, molybdenum, antimony, uranium, vanadium) are more mobile and show up downstream of the actual point of introduction.

### And your point is?

There's a reason your mother told you not to eat dirt! It can be pretty nasty. Soil contamination can occur through the natural erosion of rock but is primarily caused by centuries of human neglect and carelessness. Soil contamination is, in and of itself, problematic because it provides a source of heavy metals that can be taken up by plants. That puts those contaminants directly into the food chain. In addition, soil contamination leads to water contamination. This, in turn, leads to contaminated livestock, fish and fowl, all of which pass the contaminants on up the food chain and back to humans (think mercury and swordfish). Is this the origin of the expression "What goes around, comes around?" The problem is that a lot of people who are not responsible for the actions suffer the consequences.

### Conclusions

Although the oceans are the eventual repository of all things discarded, the

soil is the staging area. Atmospheric precipitation is acidic and as it passes through Earth's strata, it takes a little bit of everything it touches along with it (including those corrosion-proof burial containers). While nature provides a cleansing action, water (and the aquifer) become contaminated.

Many common contaminants such as lead, arsenic and fluoride are accumulated by the body and even though not at toxic levels now, they may become so over time. For many of these contaminants, the only safe level for drinking water is zero. In addition, water is not your only source of these contaminants. Many are also found in the food we eat. Even organically grown produce does not guarantee chemical-free because these contaminants are everywhere. Wastes that are dumped upon and buried in the ground do not stay put.

If you, as a water treatment professional, are intent on protecting the consumer with safe drinking water, you must also take the responsibility of approaching the customer with a good water analysis. Single-digit ppb levels of heavy metals can be significant. Otherwise, you'd be guessing. We all know what's out there and it does no good to bury our heads in sand (sand = soil = dirt). The water treatment industry has unlimited potential to both make a living and to help people live.

### References

1. www.wikipedia.com, en.wikipedia.org/wiki/crust\_geology
2. Michaud, C.F., Fluoride—The Good, The Bad and The Ugly, WC&P, February, 2010.
3. International Zeolite Association, Database of Zeolite Structure.

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