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What Else Should My Neighbor Know?

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A few years ago, geologist Allison R. Palmer wrote a short piece for the predecessor of *Geology Today* wherein he addressed the question: What should my neighbor know?[1] It was Palmer's clever way to get his audience to think about the challenge of spreading geological knowledge beyond the profession of geology, itself, to the greater world. His major thesis was something to this effect, "If you think education is expensive, try ignorance." He pointed out the cost of ignorance in land use planning and water planning. I would like to take up that challenge in a slightly different way and ask the question, "What else does my neighbor need to know to understand the predicaments of an environmentally precarious future?" That is, given that we are all busy living our lives, worrying about income and taxes, children and health, love won and lost, what is the most basic knowledge that we need to have to understand the complexity of modern environmental problems?

I think it mostly boils down to three things that are so unavoidably important that to not know about them is to be profoundly ignorant of the dilemmas that modern people find themselves facing. There are plenty of problems in the world, and almost all of them have centrally important aspects that can be better understood if we can grasp these fundamental issues: (1) Earth's human population, as a whole, continues to grow at a rate unprecedented in world history, or "Exponential arithmetic is not your ordinary arithmetic"; (2) The first and second laws of thermodynamics are still operating and are not likely to be revoked; (3) Everywhere in the world, we are perturbing large-scale biogeochemical cycles without anticipating exactly what effects will result from our actions.

POPULATION

One good source of information about the growth of population in the world and in the United States can be found at a Web site sponsored by the United States Census Bureau.[2] A population "clock" run by the bureau clearly shows some of our best estimates of how many people there are in the United States and the world and why these populations are growing. I downloaded the popclock for September 9, 1999, at 1:18:47 PM Eastern Standard Time and found out that the population of the United States was 273,459,155. The component parts of this estimate are based on one birth every 8 seconds, one death every 15 seconds, a gain of one person every 31 seconds when immigration and emigration are added, and a gain of one person every 4,834 seconds when returning U.S. citizens are balanced against those who leave. The net result is an increase in the population of the United States of one person every 10 seconds.

There are a number of interesting things about these component estimates. A large component of growth is from international migrants; but even if the United States were to close its borders there would still be a net increase due to the fact that there is a birth every 8 seconds but a death only every 15 seconds. A teacher I work with draws the analogy of population growth to the filling of a bathtub that is missing the stopper for the drain. If the faucet can put water into the tub at a rate faster than water can drain out, then the tub will continue to fill until it overflows onto the floor. If the input of births exceeds the output of deaths, then population will continue to grow. The rate of growth depends on the birthrate and the death rate.

All of these statistics do not mean much unless we understand how exponential arithmetic works. All of us were taught in elementary school how to do plain, old arithmetic—adding, subtracting, multiplying, and dividing. Those skills are useful in everyday life and are essential in the world of science. However, if we were taught about exponential functions, it was not until algebra classes, and then it probably did not sink in as to how important it was, that is, unless you had a knack for banking or investing. Bankers know a lot about annual percentage rates for financing loans and how the cost of interest on a loan can grow to huge amounts. Bankers sometimes try to hide the fact that for a long-term loan like a mortgage, the total interest payments can easily exceed the initial principle that was borrowed. So it is with population growth.[3] People can quickly multiply into a very large number of women, men, and children.

A nifty trick that I learned about annual percentage rates is that I can estimate the time it takes for a population to double if I divide the number 70 by the annual growth rate.[4] Thus, an annual growth rate of two percent will cause a population to double in 35 years. Twenty dollars invested at three percent per year will double and return 40 dollars in little more than 23 years. An annual growth rate of three percent will cause a human population to double in just about 23 years. What is hard to believe is this—in exponentially growing populations, every time the population doubles, it contains more people than ever existed in that population up until that time! Try it for yourself. Do the numbers: 1, 2, 4, 8, 16, 32, 64, 128, and so on. The number 16 is larger than 1 plus 2 plus 4 plus 8. This is a profoundly important idea, because we must eventually rectify the growth with the use of resources—something about which every geologist can speak.

Of course, to maintain a livable planet, we need to understand the growth of world population and the demands that come with that increase in population. The same Web site that contains the population clock for the United States has a population clock for the world.[5] It shows that the world population for September 8, 1999, at 1:52:23 PM Eastern Standard Time was 6,010,866,199 (more than six billion) people. And a graph of the estimated growth rate of world population shows the annual rate of increase to be about one and one-third percent. Some good news is that the annual percentage rate is expected to continue to decline at least through 2050. But, positive exponential growth continues, and still another graph shows world population to be an expected nine billion people or more by the year 2050.

Those of us who are interested in economic justice of the sort that assumes the rest of the world could live at the North American level of consumption assert that we need to discover and exploit resources at the same exponential population growth rate.

The way I like to think about it is this: If the people in the developing world aspire to live at the consumption level of North Americans and Western Europeans, then we will have to produce enough material things to account for both population growth and the growth in affluence. A detailed look at population growth shows that most of it is occurring in developing countries. Therefore, both population growth and growth in affluence will contribute to very large demands for material goods.

Consider the effect of consumption on the landscape. The amount of land that is dug up and profoundly disturbed by mining today would be minuscule in comparison to the land area disturbed to make and supply people over the globe with new consumer goods. Likewise, if we want the entire world to eat at the level at which most North Americans eat, we will need new agricultural land and improved efficiency so that we can produce and distribute an increasing amount of food each year. By the year 2050, world agricultural output must be 50 percent larger than it is today in order to keep pace with world population. Should people in developing countries change their diets and consume much more meat and total calories than they now do, then the world agricultural output would need to be even greater than an added 50 percent. Given present trends in agriculture, it also means more nitrate fertilizers, more pesticides, more water use, more animal wastes, and more energy consumption.

Another important trend driven by demographic change is the growth of cities. In 1970, a little more than a third of the world's people lived in cities. Now, more than half of all human beings live in cities; and by 2020, most experts think that more than 60 percent of the world's population will be urbanized.[6] When people are concentrated in cities, there is a great need for carefully conceived and developed infrastructure such as water supply, waste disposal, and building-supply resources—things like sand and gravel. When people are concentrated into small areas, the demand for water, as an example, becomes concentrated on the resources at hand. In many parts of the world, there just is not enough water to supply present populations easily, much less even larger populations.[7] Many major cities in the United States find themselves in search of water sources well beyond the city limits. New York City gets its water from vast tracts of land in the distant Catskill Mountains. Denver, Colorado, seeks to use water from adjacent river basins, but that water must be transferred from basin to basin to be used.[8] Los Angeles, California, takes water from the east side of the High Sierras and diverts streams that had once spilled into Mono Lake and the Owens Valley.[9] The development of these cities has made the countryside less habitable because water resources are directed away from rural areas.

With rapid urban growth, there is also a tendency to build on any land that is available, even if it is unsafe.[10] Thus we see people throughout the world living in flood-prone areas, on the sides of steep mountains, and near volcanic hazards. The best land seems to be taken first, and later migrants to the city must make do with marginal lands in areas prone to floods, landslides, and earthquake damage.[11] In the United States, people with financial resources often seek out dangerous mountainsides,[12] coastal zones,[13] and river floodplains[14] in an attempt to escape the city and be closer to nature.

Population has a major impact on limited resources. Two examples from my home state of Minnesota will illustrate this for you. At the northeastern end of Minnesota is the world famous Boundary Waters Canoe Area Wilderness. It is the most heavily used and popular wilderness area in the United States. It consists of hundreds of lakes that can be visited by canoe, provided you are strong enough to carry the canoe across portages from one lake to another. By portaging the canoe, it is possible to go for days on end visiting one lake after another in this remote area. In 1983, it took my college-age son more than five weeks to paddle from one end to the other by himself. He often went days at a time without seeing other canoeists. With the growth of population, primarily in the midwestern states, and the popularity of getting back to nature, this area has become very desirable for wilderness outings. Now it is so frequently used that a system of wilderness permits limiting visitors and requiring special arrangements—group size, camping spots, entry points, restricted fire building—are enforced by the forest rangers of the Superior National Forest. Inevitably, people who like to fish from motor boats have come into conflict with those who prefer the quietude of the paddle. In winter, the conflict is between snowmobile users and nonmotorized recreationists. The disagreements arise principally because wilderness and quietude are scarce resources and are in demand by more and more people. Conflicts seem inevitable.

Similar disputes occur all over my home state—hog farmers polluting the air and water conflict with people who retreat to the country for clean air and water; power boat owners who require immense water surfaces for their noisy, speeding craft conflict with anglers, sailors, and people seeking to enjoy wildlife more quietly.

The lesson seems clear. Population growth and the push for economic parity will demand the use of more natural resources and ever more intense rates of utilization. We will need to be more efficient and more clever about our exploitation of resources if we hope to mitigate some of the impact of growth. Rapid urbanization will exacerbate problems of water supply, clean air, noise, recreation, and other resource availability. Geologists will be called upon to measure those resources and suggest ways to mitigate the impact of their overuse.[15]

LAWS OF THERMODYNAMICS

Many years ago during the so-called Arab oil embargo, I was engaged in conversation with a faculty member at the college where I teach. The colleague asked me why, in the face of the embargo, we did not just synthesize all the oil we needed. I proceeded to explain some of the history of synthetic fuels research and what little I knew of the politics and economics of the situation. The faculty member became quite impatient with my explanation and reiterated the question: "Why don't we just synthesize the oil we need?"

All good teachers try hard to understand the basis of their student's questions, so I asked in reply: "What should we synthesize it from?" The faculty member, thereupon, looked very puzzled and said, "I mean, just synthesize it." At that point, I realized why we did not understand one another. Thermodynamics laws tell us unequivocally that it is impossible to synthesize something out of nothing. We cannot possibly synthesize oil out of nothing; it always takes raw materials to start the process.

Although knowledgeable and quite brilliant in some ways, this person apparently never learned the lessons of the first and second laws of thermodynamics. The first law of thermodynamics boldly states that matter—or energy—can neither be created nor destroyed. It can only be changed from one form to another. It also makes sense to think of matter as being composed of energy; according to Einstein's famous equation, the relationship is $E = mc^2$. The energy (E) available in a mass (m) is proportional to the square of the speed of light (c). The first law says that when atomic energy is used, mass is converted to energy, but nothing new is created nor is anything old destroyed. It is merely a conversion from one to another.

If it is impossible to synthesize fuel from nothing, it must be equally true that we cannot ever throw anything away. Taking trash to the nearest landfill is not a question of disposing of waste. It is simply putting the waste somewhere else. It may undergo some degradation, meaning that the original material—

paper for example—partially dissolves or breaks down to simpler molecules, but it does not disappear in the sense of going from something to nothing. That is the problem with trying to engineer sanitary landfills. Materials generated by consumers and placed in landfills by garbage haulers and dump operators have the potential to escape the confines of the landfill and go somewhere to cause problems. Where I live, there is a fairly high potential for polluting groundwater, so some people think that it is preferable to burn garbage. I hope they do not think that burning garbage makes it disappear. Garbage that is burned is converted to energy and other kinds of matter. The energy can be captured and used creatively to heat buildings in metropolitan areas, but the altered matter is a bit of a problem because it goes out the smokestack and into the air, where it causes air pollution—emissions of sulfur dioxide, hydrochloric acid, and heavy metals. Furthermore, there is still a residue of ash that must be stored somewhere, such as in a "sanitary" landfill. The first law of thermodynamics tells us that we cannot destroy the matter of which the garbage is made. If we are really clever, we might be able to convert it to some things that are not particularly obnoxious, but we cannot destroy it. We cannot throw it away.

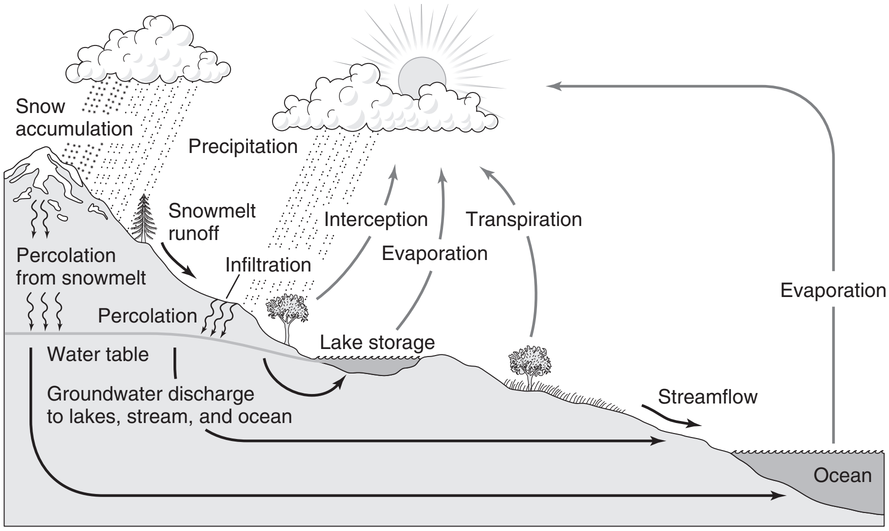
My faculty friend needs to know that we cannot create something from nothing. We cannot synthesize things in the sense that my friend understood it, nor can we make nothing out of something. We cannot get rid of garbage by giving it to the landfill. The best we can do is store it for a long, long time and hope that it does not pollute the places where we live.

Geologists have spent a large amount of time and money studying energy and matter conversions. For instance, an intriguing question arises from thinking about the energy balance of Earth and trying to write a budget that will account for all the incoming energy and all the outgoing energy. This is particularly important in the ongoing debate about global warming. The average temperature of Earth is determined by the amount of energy coming to the system versus the amount of energy leaving the system. The amount of energy available from inside the Earth is really quite small when compared with the amount of energy arriving from the sun. The amount leaving Earth is ultimately determined by the temperature of the globe and the ability of Earth to absorb and reflect radiant energy. The higher the average temperature, then the more heat will be lost to outer space. In fact, the rate of heat loss is a function of the difference between the average temperature of Earth and the temperature of outer space. So, if the sun should begin to give off more energy, then Earth's temperature will rise until the rate of heat loss just balances the new rate of heat gain. If the sun's energy level were to decline, then Earth would cool off.

What many people worry about now is what will happen if we change Earth's ability to absorb and reflect radiant energy? If we temporarily alter the way Earth absorbs and reflects radiant energy, then Earth's temperature can change. The first law of thermodynamics teaches us that we can change the rate of heat loss to outer space by changing the composition of the atmosphere and thereby raise the temperature of Earth. The consequences of having more heat energy available are not easy to determine, but an example may suffice to show the challenge. The hydrologic cycle gives a description of the movement of water from the atmosphere onto and into the land and from the land to the oceans and back to the atmosphere. The system is run by energy from the sun, which, through the action of evaporation and uneven heating of the atmosphere, turns liquid water at sea level into water vapor. It enters the atmosphere, reaches great heights, and begins its journey back to the oceans. Because it takes heat energy to evaporate water, a result of global warming is likely to be the acceleration of the evaporative part of the hydrologic cycle. But when and where the evaporation will occur is the subject of intensive research and is still poorly understood in detail. Furthermore, we do not fully understand where the subsequent condensation and precipitation will occur.

The first law of thermodynamics applies to every process and substance that has been studied, and no exceptions to the law have ever been found. In the few cases when we think we have found perpetual motion machines—machines that run forever without energy input—it turns out that our accounting system has been in error. Somewhere we missed counting all the energy and matter involved in the process.

The second law of thermodynamics is subtler and more difficult to grasp and has even been called inscrutable.[16] General statements are hard to formulate. They sound like these—living structures decay, order deteriorates, everything tends to disorder (entropy increases), and growth only occurs at the



Schematic diagram of the hydrologic cycle. Human activity changes the intensity and duration of movements through the cycle. From Thomas Dunne and Luna B. Leopold, *Water in Environmental Planning* (San Francisco: W. H. Freeman and Company, 1978), 5.

expense of destruction somewhere else. Creating a highly ordered thing like an automobile requires that the landscape of the iron mine become disordered. Coal must be converted to coke before it is used in the steel-making process. The conversion occurs only at great expense. The place where the coal comes from and the air that carries away the waste products in the coke-manufacturing process are degraded. Likewise, the plastics, rubber, copper, paint, glass, and other components of the modern automobile are created only at the expense of disordering the environment where they originated. The second law of thermodynamics says this is inevitable; we cannot be 100 percent efficient at converting matter from one form to another. There is always waste, because we cannot be 100 percent efficient at using energy, either. Entropy for the system inevitably increases.

The second law tells us that geological resources must be limited and nonrenewable. Pessimists look to the present rate of consumption and the growing population and confidently say that we are using up the resources necessary for our industrial base. Optimists almost always point to technological advances as having the potential to save us. Most often technology helps us to substitute one substance for another. So now we build more cars with more and more plastic—derived from petroleum—and aluminum and less and less steel. So we have changed from one potentially nonrenewable resource to another.

The second law also helps us to understand why it is so costly to clean up pollution. The problem arises when pollutants are dispersed into the environment—petroleum in an oil spill at sea, agricultural pesticides in ground water, or ozone-destroying chemicals in the air. An oil spill is essentially a much lower concentration of matter than oil that is still confined to a pipeline or the hold of a ship—or confined naturally in bedrock. Once the oil escapes, there are two problems: oil molecules must be identified, and we must find a cost-effective way to retrieve them. We need to get those molecules back into the pipe or into the ship's hold. The *Exxon Valdez* incident showed us that even when it was relatively easy to locate and identify the oil—for example, on the beaches of Prince Edward Sound, Alaska—it was very difficult to recapture it. In other places, we have tried paper towels, straw, shovels, and other ways to recapture the oil, but it always takes many humans—and people are a valuable resource—who have been trained to identify the oil and how to mop it up.

Likewise, but even more insidious, is the problem of DDT. It is well known by now that DDT, which was used to control insects—I remember being "fogged" with DDT sprays at Scout camp in the mosquito-infested Adirondack Mountains as a boy—has spread through the food web to the most remote parts of the globe. Even penguins in Antarctica have DDT molecules in their fatty tissues. DDT is a very persistent organic compound that seems to resist metabolism by almost all organisms. So, if we want to rid the world of DDT, and more and more that seems like a good idea, we need to find those DDT molecules, identify them properly, and put them back in the spray gun. The amount of energy spent in searching and identifying such molecules is enormous. It is so large that we will, in all likelihood, never be able to retrieve all those errant DDT molecules. The lesson is this: Be very careful about broadly dispersing new chemicals before you understand their effects in the ecosystem. In Minnesota, virtually all the shallow groundwater contains easily measured amounts of corn pesticides, and we do not know what harm they might cause or even what to do about the problem.[17]

Perhaps the most important lesson from the second law of thermodynamics is that of extinction in the biosphere. The laws of thermodynamics also govern the assembly and maintenance of unique genomes. The second law helps us understand that any particular genome is a very complex assemblage of genetic information. If that information is lost because of extinction, it is extremely unlikely that it will be reassembled. Unique genomes represent concentrations of knowledge into highly ordered systems; extinction represents the ultimate loss of that knowledge. No modern biologists I know would predict that new genomes will arise rapidly to replace those we are losing. Geological evidence from mass extinctions at the Permo-Triassic boundary (approximately 250 million years ago) and the Cretaceous-Tertiary boundary (66 million years ago) tells us that it took several millions of years for the biodiversity of Earth to climb back to pre-extinction event levels. Apparently the natural biodiversity of the world cannot be replicated in a short time.[18] My own experience with prairie restoration and that of others with wetland restoration shows how very difficult it is to recreate complex and diverse ecosystems.[19] Our descendants are going to be particularly upset with us if we do little to slow down the mass extinctions that are occurring now.

The laws of thermodynamics viewed this way seem rather depressing. But then, if your objective is to fly, the law of gravity seems depressing, too. The laws of thermodynamics keep us from believing charlatans by helping us to understand the way that the world really works.

HUMANS: A FORCE OF GEOLOGICAL PROPORTION

Earth has a number of large-scale, biogeochemical cycles, which involve the transfer of material and energy from one place to another and from places of storage to places of activity. Human beings are now so numerous and so powerful that our normal, everyday activity perturbs these cycles. Sometimes these perturbations cause huge problems because they disrupt systems that have evolved over millennia and that cannot adjust rapidly to the new set of conditions we have imposed. There are many examples, such as cycles of water, carbon, nitrogen, phosphorus, and sulfur among others, but two illustrate the overall problems. Studying the diagram of the hydrologic cycle makes it possible to see the impact that people have on the movement of water from one place to another. Every arrow in the hydrologic cycle diagram is affected by the activity of people. The impact is very significant. For example, when we build cities, we have a major influence on the places where water can percolate into soils and eventually down into the groundwater system. Roof tops—by design, lawns—because of compaction and their small size, streets, and sidewalks are all quite impervious to water. Good engineers build roadways that drain quickly and have no places for water to puddle. So, instead of percolating into the ground, rainwater flows off into storm sewers and quickly into urban streams. As a result, streams have flash floods when it rains and very low flows when it does not, because the groundwater system does not get replenished and cannot supply enough water to make the streams flow regularly. Erratic flows discourage the formation of equilibrium channels and the needed conditions for the kinds of aquatic organisms that we like. If we had, instead, decided to create a system that was biologically and geologically friendly, we would have figured out how to put the water back in the groundwater system as nature seems to have intended.

A corn field adjacent to my home acts in the same unbalanced way. Essentially no vegetation exists on that field except for part of June, July, August, and September. If all goes well, the farmer removes the crop by October and plows the field. When it rains, there is nothing to protect the soils from the impact of raindrops and little to hold back the water during all the other months of the year. The result, by our own measurements, is a huge proportion of rainfall running off the field, carrying dark-brown soil through a gully on our land and down to the nearby Cannon River. For days after a hard summer rain, the river runs dark brown and is nearly opaque. Not only has the groundwater not been replenished; the rainwater has eroded fertile soil from the field and put it into the river, where it does not belong.

Other parts of the hydrologic cycle are affected by the actions of people. We transfer groundwater to the surface by using wells. We drain wetlands. We dam rivers. We cut forests and reduce transpiration by trees. Our impact on the hydrologic cycle is immense in some areas and not always beneficial.

The carbon cycle is another large-scale biogeochemical cycle that we have perturbed—in this case, on a global basis. Under natural circumstances, carbon moves from the atmosphere to the biosphere to the hydrosphere to the lithosphere (region of soil, sediments and rocks) and back again. Plants take carbon dioxide from the atmosphere and, using photosynthetic processes, combine it with water to produce sugars and oxygen. The carbon has been taken from the atmosphere and incorporated into plant tissue. We and other animals eat the plants, metabolize the tissue by combining it with oxygen, and breathe out a residue of carbon dioxide. Shellfish and other lime-secreting organisms take carbon dioxide out of water, combine it with calcium, and produce their characteristic shells. If the shells are incorporated in the sediment on the bottom of the ocean, then the carbon is moved via the biosphere from the atmosphere to the hydrosphere to the lithosphere. Plants that become peat, lignite, and coal also move carbon from the atmosphere to the lithosphere. The rate at which things move from one place to another is determined mostly by temperature and the numbers of plants and animals on Earth.

We have learned to find coal, petroleum, and natural gas deposits, all of which are warehouses for ancient carbon. We take that carbon and burn it, thus producing more carbon dioxide that goes back into the atmosphere. The rate at which we burn coal, petroleum, and natural gas exceeds the rate at which the remains of shellfish and other animals and plants are added to the lithosphere. So, in fact, we are rapidly transferring carbon—in the form of carbon dioxide—from its position in rocks to the atmosphere. Well, so what?

For more than 100 years, we have known that carbon dioxide plays a role in the heat balance of Earth. Carbon dioxide acts as a gatekeeper for forms of radiant energy. It allows ultraviolet energy into our system but keeps infrared energy from escaping our system. The result is that, on the short term, we are changing the energy equation of the atmosphere. We are allowing more energy to come in than we allow to escape, with the result that Earth will seek a new equilibrium temperature that is higher than the present temperature.

Coming from Minnesota, where the winters can be very cold and very long, that does not seem so bad. It does not seem too bad until we try to figure out what will happen to the amount of rainfall, snowfall, and severe storms that we might get in the future. It does not seem too bad, that is, until we try to figure out what will happen to native vegetation that has evolved here under the present climate. Some people argue that part of Minnesota will become hotter and drier. That would mean the border between prairie and deciduous woods—known as Big Woods, here—would move eastward. Deciduous trees would die out but would not be replaced by prairie because there is no longer a good seed source for prairie grasses. And it does not appear too bad until we try to determine what will happen to the soils that also have evolved here under the present climate. The northern part of the state has very large areas of peat wetlands—in fact, the largest peat deposits in the lower 48 states. If they become drier and warmer, they will disappear; and the remaining soils will not be very good for growing corn and soybeans, the two most important cash crops in the state. Perhaps the winters will be milder, but there is a distinct possibility that agriculture and native vegetation will both be greatly disrupted. The point seems to be that we humans are now a geological force of global proportions, creating and running an experiment for which we have little predictive certainty.

Well, there you have it. Here is what my neighbor ought to know about how Earth works. The population is growing rapidly and becoming urbanized at an unprecedented scale. As a whole, we seem to misunderstand the lessons of the laws of thermodynamics—the set of rules governing how energy and matter behave. We cannot make things out of nothing. We cannot throw things away, and it is very hard to clean up messes. We have grown so numerous and so powerful that we are now a geological force of global proportions. We regularly disturb major biogeochemical cycles. Every human being needs to appreciate these three profound ideas. With a future that is environmentally precarious, ignorance of these ideas is just too expensive—its cost could be the livability of our planet.