ARTIFICIAL RECHARGE IN THE SOUTHWESTERN US: THE PROBLEM OF EMERGING CHEMICAL CONTAMINANTS

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Abstract

There is growing concern worldwide about aquifer pollution by large numbers of emerging, anthropogenic chemicals (ECs) that escape standard wastewater treatment. Inasmuch as the rapidly-growing, arid Southwest uses such effluent to recharge depleting aquifers, there is an acute need for a better understanding of and a more complete treatment process to protect human and environmental health. Important among these contaminants is a broad suite of endocrine-disrupting chemicals (EDCs) that include natural or synthetic hormones as well as compounds that mimic hormones and may interfere with the operation of endocrine systems even at concentrations of parts per trillion. Indeed, evidence now indicates that some aquatic organisms are adversely affected at these levels where treated wastewater is discharged into streams. The paper will elaborate on these points building a case that this issue deserves attention.

Key Words

Artificial recharge, effluent, endocrine disruptors, emerging chemicals, wastewater treatment

Introduction

The warm and sunny climate that attracts many to move to the Southwest is the very reason why it is arid. Rapidly increasing populations are creating water scarcity. For example, cities in the Colorado River watershed that use its surface water (SW) are finding it is becoming oversubscribed, and as a result communities are using groundwater (GW) to a greater extent. Indeed, many communities are totally dependent on pumped groundwater for their domestic water. To compensate the resultant GW overdrafts, reclaimed wastewater is used to recharge the rapidly depleting aquifers. Furthermore this usage is employed to increase more development through auctions of wastewater effluent credits. However, the practice has the potential to impact groundwater quality. Thus, water problems and rapid growth are on a collision course.

The Problem

Emerging chemicals (ECs): Literally thousands of anthropogenic compounds are already in our environment. The number continues to increase as we demand better, more useful, more attractive personal products. Other ECs are indirectly needed in the manufacturing process because we want better plastics, cheaper food products, better packaging, etc. In addition the chemical industry continues to make more ECs for newer drugs, improved function and use of other ECs, but also to avoid regulation.

The ECs we want and need are in various categories: *pesticides* including lindane, carbaryl, and dieldrin; *pharmaceuticals* such as analgesics, birth control pills, hormones, antibiotics, antihistamines, along with antiasthma, anti-inflammatory, antidepressant, and antiepileptic drugs; *industrial chemicals*: including plasticizers, surfactants, antioxidants, detergents, disinfectants, flame retardants; *personal care products* such as fragrances, surfactants, deodorants; *food additives* such as anti-mold agents, antioxidants, and food additives to keep components in suspension, some of which are listed in the ingredients. All this comes with a price: many of these compounds have not been adequately tested for safety nor has their use been regulated, and, although we inadvertently consume these products, we know very little about what effect they have on the environment.

Usually ECs enter our bodies through the digestive tract, skin and lungs; some are stored, others are partially metabolized; and finally, they enter the waste stream as a mixture of original compounds and metabolites. Animals that are part of the human food chain as well as pets also receive large amounts of ECs that may become part of the waste stream. However, with food animals and to some extent pets, these ECs are not subject to municipal wastewater treatment (WWT) and become part of wet-weather runoff—carried directly into streams or infiltrating to the aquifer system as natural recharge. ECs contained in agricultural pesticides may be redistributed to streams and aquifers either from runoff in wet weather—infiltrating to aquifers as natural recharge—or by in-situ infiltration of unconsumed irrigation water (incidental recharge).

Our desire for ECs and our desire for product safety have sometimes led us into ironic situations. For example, safety groups demanded that products such as carpets, bedding and clothes should not burn rapidly if exposed to fire. And that demand is now law. For example, a class of ECs, polychlorinated biphenyls (PCBs), was used as flame retardants fitting the requirements of the law. But as the evidence accumulated that PCBs were harmful, they were banned; and the chemical industry responded with compounds such as polybrominated diphenyl ethers (PBDEs) as a replacement. The chemical structure is very similar, and because halogenated hydrocarbons are usually toxic, it is likely at some point they, too, may be banned.

Although all the congeners of PCBs are no longer manufactured and their sales of existing PCBs are banned in most parts of the world, they resist destruction in the environment. As a result they continue to enter the waste stream and the environment, albeit in lower amounts. This scenario may become similar to the fate of other ECs, and as the list of ECs continues to grow. The hope that toxic ECs will disappear is problematic.

What happens to ECs after they leave our bodies? In 2002 a landmark paper, Kolpin et al. (2002) showed that a surprisingly high number of chemicals including many ECs are not decomposed by the WWT process. The researchers followed the fate of 95 compounds after they passed through 139 WWT plants throughout the US. They found a median number of seven, one or more in 80% of the sites and as many as 38 in a few water samples. Some of these compounds are in relatively high concentrations (e.g. 800 ppt of 4-nonylphenol). Most of the 95 compounds are anthropogenic including antibiotics, prescription and nonprescription drugs, pesticides, steroid hormones, detergents, and other industrial chemicals. They concluded that these compounds survive WWT and are entering our SW and GW.

Some of the more threatening ECs are the endocrine disruptor chemicals (EDCs). For some background refer to (Colborn et al. 1996; Naz, 2004). Defined by the World Health Organization EDCs are "*Any compound or mixture that alters the function of the endocrine system that causes an adverse effect on an organism or its progeny*". Thus, EDCs can act by modifying hormone production in endocrine glands or they can mimic or counteract an organism's normal hormones at the target tissue. A probable mechanism is that the EDC binds the hormone-receptor site in the target tissue by modifying the tissue's response.

Although only a small part of the EC menagerie, EDCs were among the first noticed in the 1960s with the pesticide dichloro-diphenyl-trichloroethane (DDT). The 'wonder' compound DDT was for years applied widely to control mosquitoes and agricultural pests. But then, linked to eggshell thinning in raptors such as the bald eagle, it was banned in 1972. DDT is fat soluble and resistant to metabolic destruction—attributes that caused it to become biomagnified up the food chain. When these birds of prey ate fish laced with the compound, the concentration was high enough to affect the ovary's ability to make tough eggshells.

A few other EDCs have been banned or regulated including chlordane, lead, and mercury. As a result, in some cases, newer less stable replacement ECs have been created. Most recently the USEPA established a safe level of the chemical perfluorooctanoic acid (PFOA) as a provisional health advisory of 400 ppt in drinking water as an acceptable maximum level. PFOA that is now in the GW has been linked to cancer and birth defects in animals. It has been found in virtually all Americans, as well as in marine organisms and even Arctic polar bears. Its omnipresence is understandable: it is a key processing agent to make Teflon.

The EDC bisphenol A (BPA), a widely-used plasticizer in metal can liners and plastic baby bottles, is found in the urine of virtually every American. The Kolpin group found it at a median concentration of 140 ppt in about 85% of the WWT plants studied. But this chemical is not banned, yet. The USEPA deemed it harmless, finding that only at high concentrations did it cause a decreased weight in rats, enlarged livers in mice, and very low rates of multinucleated giant hepatocytes only after very long exposures. The Federal Drug Administration (FDA) reached the same conclusions. But recently an entirely different story has emerged. Lang et al. (2008) in a major epidemiologic study showed that higher urinary concentrations in humans were associated with increased cardiovascular diagnoses and diabetes. Vom Saal and Myers (2008), briefly reviewing the animal and human studies on effects of BPA, concluded along with various expert panels in the US and the Canadian government (which has recently banned its use in baby bottles), that BPA has serious medical effects, especially if exposure occurs during fetal/neonatal life. The authors go on to question the methods of assessment of toxicity by the EPA, FDA and the European Food Safety Authority, namely that they adhere to the principle that toxicity increases with concentration. Instead, as often found when testing endocrine-related compounds, the dose-response curves are biphasic (i.e. nonlinear).

In addition to the above studies with BPA, some EDCs have been linked to testicular cancer, abnormal sexual development in men, and accelerated puberty in girls. But linking the effect of an EDC to a disease in human populations is problematic. A review by Safe (2005) summarized numerous studies that, despite conclusions reached in earlier work, found that exposure to PCBs and dichlorodiphenyldichloroethylene (DDE) could not be linked with breast cancer and lowered sperm counts.

Can highly diluted EDCs in effluent have biological effects? Studies by Jobling et al. (1998) indicate that they do. The paper described intersex characteristics (male fish exhibiting female characteristics) in a particular fish species, the roach (Rutilus rutilus), upstream and downstream from WWT plant outfalls in various rivers in Great Britain. Intersex features appear spontaneously in these fish at a range of 5-15 percent in control water. However, in effluent-impacted rivers, the percentage of affected fish is much higher, ranging from 15-100% down stream and 25-50% up stream from the outfall. Presumably, the higher-than-normal intersex percentages in the upstream fish is due to migration, or because the contamination level is simply higher than that of the control waters. Assuming that effluent from British WWT plants is no different from that studied by Kolpin et al. (2002) in the US, it would seem that EDCs are in the effluent and that they act in exceedingly low concentrations.

But in the Jobling study, there was a mixture of probably thousands of ECs and their metabolites, some of which could be the causative agents, suggesting that estrogenic EDCs may be among the culprits. The most common include natural, animal-based and plant-based (phytoestrogens) estrogens; and also anthropogenic- or xeno-estrogens, all found in WWT effluents (Kolpin, 2002). From this mixture could a single, intersex-causing EDC be involved?

To answer this question more specifically, Kidd et al. (2007) added the birth control chemical 17 α-ethynylestradiol (EE2) to a small lake in southwestern Ontario, Canada until the average concentration throughout the lake reached six parts per trillion (6 ng/L). Within two years the population of the resident fathead minnow was reduced to virtually zero. In a control lake nearby the fathead minnow population remained unchanged. These results demonstrated that even one estrogenic contaminant in wastewater may be sufficient to impact populations and even communities of exposed organisms. Importantly, wastewater contains multiple types of estrogenic compounds, and removing just one may not be sufficient to fix the problem of negative exposure outcomes. Kolpin et al. (2002) found EE2 to have a median concentration of 73 ppt in WWT outfalls throughout the US.

How are chemicals in ppt concentrations or lower measured? The answer is that concentrations at these levels are both difficult and expensive to measure. Most equipment and tests at those levels will register 'non-detect'. But in actuality as Kidd, et al. (2007) showed these low concentrations are definitely present, and do have a biological effect. Applying Avogadro's constant, one liter of water with a concentration of one part per trillion of EE2, contains a trillion molecules of EE2.

Five chemical methods of detecting and measuring ECs and EDCs are referred to in the Kolpin et al. (2002) study, and were chosen because of their sensitivity and reliability. A cheaper method, the yeast-estrogen screen (YES) technique is a molecular biologically-devised technique that measures only estrogenic activity (Conroy et al., 2007). The technique is widely used for estrogens (or YAS for androgens) but it has certain specificity drawbacks requiring appropriate controls.

Given the problems with *in vitro* assays, one technology, biomonitoring, has great promise because it has the potential to test the toxicity of effluents containing mixtures including ECs and EDCs. Here whole organisms are specially selected (or designed) to detect 'unfriendly' changes in their environment as a biological, early-warning system (BEWS). One example is the *in situ* fish-development monitor used in the Jobling and Kidd studies. In other cases the biomonitor has been especially selected based on the animal's biology or specifically designed for a particular endpoint. There are various categories and examples listed in Butterworth, et al. (2000) with nonlethal biochemical, developmental, genetic and behavioral endpoints. Some, particularly with behavioral endpoints, can be applied to automated, continuous, and remote-measuring systems. Since there are so many ECs, a whole-organism system (as the above, in situ fish monitor) will be the best way to indicate toxicity (at bioactive concentrations) before committing more costly methods.

The general principle of biomonitoring is that smaller animals and plants can be used to warn us of toxics before they enter our bodies, but the principle can be applied to us as a biometric after toxics have entered our bodies—in effect, a body-burden test for EC exposure. This would be a great aid to the medical and regulatory communities. But with the large number of ECs, finding a quick, inexpensive body-burden test may be a challenge.

Another promising approach is the lab-on-a-chip technology under development to detect specific compounds such as estrogens. Still in the prototype stage, such techniques are probably years away from application or USEPA approval. However, the benefit would be an inexpensive, automated, real-time detection in WWT plants to control the treatment processes or monitor effluent outfalls; or at source-water intakes.

Are there any pristine areas, including aquifers, in the world that are EC free? Probably not, given the fact ECs are found even in polar bears. However, a likely place to look is in areas that have relatively low populations. One such place might be the upper Verde Watershed in Central Arizona. Once populated with free-range cattle and pronghorn antelope, it is now becoming urbanized, and GW is essentially the sole source of water. Recharge with treated wastewater has begun, but only recently.

Year-round flow in the upper Verde River (see figure 1), the uppermost reach of one of Arizona's few remaining perennial rivers, issues solely from springs in the upper few miles of the river that are supplied predominantly by discharge of GW from two GW sub-basins: the Little Chino Sub-basin and the Big Chino Sub-basin (Blasch, et al., 2006). Hydrologic estimates are that the GW discharge from the Little Chino Sub-basin comprises about 14 percent of the water issuing from these springs (Wirt, 2005) and discharge from the Big Chino Sub-basin comprises 80 percent or more (Wirt, 2005; Erroll L. Montgomery and Associates, 2007).

The City of Prescott, the Town of Chino Valley, the Town of Prescott Valley (in part), several private water companies, and numerous homes supplied by individual wells obtain virtually all of their water supplies from wells in the Little Chino Sub-basin. So far, GW pumping in the Big Chino Sub-basin has supplied only extensive agricultural irrigation, one golf course, and numerous individual homes and several developments in the southern (down-valley) end of the basin. However, demand for GW from the Big Chino Sub-basin is developing both for importation to the Prescott area to support development there and for development of the extensive private lands in the Big Chino Sub-basin itself. Barring successful mitigation, the continuing GW demand in the Little Chino Sub-basin combined with the expected demand in the Big Chino Sub-basin will eventually eliminate the springs that supply the upper Verde River.

Arizona law currently limits pumping of GW for new development in the Little Chino Sub-basin. However, return of treated wastewater from municipal WWT plants to the aquifer provides credits that can be used by municipalities to pump additional GW in quantities equal to the quantities of their recharged wastewater. Indeed one municipality in the area has recently sold its wastewater credits to a developer.

Such a pumping limit does not presently exist in the Big Chino Sub-basin, but it is to be expected that the pressure to mitigate the eventual effects of GW pumpage there, whether for importa-

Figure 1. The headwaters of the perennial upper Verde River flowing through Nature Conservancy property, the Verde River Springs Preserve. Here the river, fed solely by springs most of the year, is home to a wide variety of plants and animals including beaver.

tion to the Prescott area or for extensive development in the Big Chino watershed itself, will eventually lead to massive recharge of treated wastewater there as well.

If some part of the perennial GW discharge to the upper Verde River can be preserved, a threat remains from water tainted with ECs and EDCs that enter the aquifer from the recharged wastewater. The good news is that this area is fairly well studied regarding fish, birds and other riverine animal populations. Thus these data could serve as a baseline to compare with adverse changes that may take place in the future. Few specifics exist regarding EC content, but the river and its immediate watershed is regarded by many to be so far, relatively pristine.

The Solution

Given the threat from ECs and EDCs, given the huge numbers of these compounds (and that the numbers are going to increase) and given the fact that our current waste-treatment technology cannot trap or destroy these compounds completely, an improved removal process is paramount.

Current wastewater treatment practices. The average WWT plant is allowed to discharge specified levels of pollutants just as long as simple criteria are met regarding the clarity and pathogen content of the water, the levels of standard pollutants such as nitrogen and phosphorous, and the rate at which microorganisms use up oxygen (biochemical oxygen demand or BOD) as a general measure of remaining organic content of the effluent. These amounts are spelled out in the plant's National Pollutant Discharge Elimination System permit (NPDES). The assumption is that once the clarity, pathogens, nitrogen, phosphorus, and BOD are taken care of all is OK. And even if other pollutants are discharged, they would be diluted by the receiving body of water, usually a river. But NPDES rules have not taken into account the ECs explosion. Nor did the NPDES rule makers realize that EC-contaminated effluent would be used for artificial recharge.

Currently wastewater treatment varies throughout the US including the arid Southwest. The main determining factor of the process used is the size of the municipality. For most, it usually consists of primary and secondary treatment using an activated sludge process. Occasionally tertiary treatment is required depending on the quality of effluent required in the NPDES permit. However, this may well change as we gain more knowledge of EC toxicity, about the problems of effluent recharge, and as community populations expand. In smaller communities relatively primitive methods are still employed such as sewage lagoons. And for outlying individual homes using septic tanks the WWT process is the most primitive.

Tertiary treatment may be required to meet the NPDES permit limits and can take various forms. For example, either granular, activated-carbon filtration or lime coagulation plus sand filtration might work. Other forms of tertiary treatment are nitrification-denitrification steps and aerobic-anaerobic treatment.

The final step in the WWT process is oxidation. Ordinarily it is done to kill the pathogens remaining after the digestion steps, but it also is a way to destroy remaining organics in solution. There is a variety of choices. Chlorination is traditional: it is cheap but it produces toxic trihalomethanes. Other more recent choices are ozonation, hydrogen peroxide treatment, ultraviolet radiation at a wavelength of 254 nm or a combination of all three, sometimes in different sequences.

At the end of the process the liquid is discharged into a receiving body of water and the solid fraction (sludge) is digested further, dewatered and spread on the ground, often at farms as mulch or fertilizer. However, as often happens in the arid Southwest, the effluent is discharged to a dry river bed or a recharge pond.

What is happening to all the ECs? Why is it that, as we learned from the studies by Kolpin et al. (2002) in the US and Heberer (2004) in Europe, many, if not all ECs are not completely degraded to simpler compounds? Some WWT plants in Arizona, for instance, claim a 90% removal rate of estrogens. But the remaining 10 % leave the plant unchanged either in the liquid effluent or in the sludge often spread on farm fields. Can one assume that estrogens are a bellwether, surrogate EC and that 90% of all the other ECs have been removed? Clearly, the effluents need to be monitored for a suite of ECs to answer this question. To what extent can tertiary processes, such as nitrification followed by denitrification, be improved to approach 100% removal? Or have we reached a technological limit? And if it is doable, one is still left with the EC-containing, dewatered sludge.

Successful WWT removal of ECs can depend on whether contaminants are hydrophilic or hydrophobic. Hydrophobics are traditionally removed by adsorption beginning with clarification during primary and secondary treatment. Hydrophilics will not be adsorbed and they along with the unadsorbed hydrophobics can be removed at all phases by chemical degradation. So, one is left with a conundrum. In order to produce clarified liquor, one will have removed the sludge including significant amounts of hydrophobic ECs that might leach into the GW/SW from the spreading fields. True, there may be sufficient adsorption and bioremediation in the fields to prevent this leaching, but these are unknowns and may vary considerably according to conditions.

In some cases filtration of effluent with granular, activated carbon could remove hydrophobic byproducts to reduce ECs in the effluent. Perhaps the final oxidation stage is the last chance to remove hydrophilics and unadsorbed hydrophobics. Possibly the right combinations of oxidants (chlorine, ozone, and peroxide) with UV-254 can synergistically produce powerful hydroxyl radicals that break down virtually all organic compounds. Cost for such oxidation processes is very sensitive to the concentration to be destroyed. Now given a pure effluent, the remaining challenge would be the remediation of ECs in the spread sludge, untreated animal waste, leaky sewer pipes and septic tank fields.

What is the fate of the remaining ECs once the effluent is returned to the alluvial basins of the arid Southwest? The question is being answered by various laboratories such as Traugott Scheytt's laboratory at the Technical University of Berlin and Robert Arnold's group at the University of Arizona. The latter group (Zhang, et al., 2008) studying estrogenic compounds and polybrominated diphenyl ethers (PBDEs), are finding that there are reductions up to 90% in the top two feet of the alluvium. Presumably the mechanism of removal is a combination of biodegradation and adsorption. Their work suggests that bioactivity continues to degrade the target compounds for many years, but nothing is known about the fate of thousands of other compounds that are recharging at ppt levels.

Hydrophobic chemicals would appear to be removed from the waste stream during WWT by adsorption and absorption, but Scheytt et al. (2005) found that their escape into the GW depends on pH and ionic conditions. Compounds such as two anti-inflammatory drugs, ibuprofen and diclofenac, and the antiepileptic/ ADD drug, carbamazepine, ordinarily described as hydrophobic, are found widely distributed in European GW perhaps because they become more hydrophilic in the neutral pH of waste- and groundwater. In the US carbamazepine was found at 455 ppt in the GW some distance from the outflow of one of the Tucson WWT plants suggesting that the physical conditions there facilitated its escape. The Kolpin study did not measure carbamazepine or diclofenac but found median levels of ibuprofen at 200 ppt in US rivers near WWT outfalls.

GW has a complex biology which we are just beginning to understand (Griebler et al., 2001). However, the bioremediation of ECs is entirely possible but largely unknown within the alluvium through which effluent must pass to reach the GW. Inasmuch as the biology of GW and alluvium is likely to vary with location, predicting the natural, remediative process is far into the future. Do the ECs diffuse throughout the aquifer? Are they acted upon by the microbial population in the alluvium or aquifer? Does domestic water pumped from an aquifer that contains treated sewage contain ECs? What steps are planned to monitor and remove them before human consumption?

One of the unintended consequences of effluent recharge is that the siting of recharge basins above alluvial aquifers is typically in areas of coarse sand or gravel for the fastest recharge. Such deposits are poor natural adsorbents, and with their high permeability the contact time will most likely be insufficient to achieve adequate adsorption or biodegradation. Furthermore, if ECs are adsorbed onto alluvial particulates in the first wave, they could get washed off by more hydrophobic compounds in subsequent waves, perhaps creating pulses of concentrated, sorptive fluid in transit to the aquifer.

In summary, there are substantial unresolved problems with the current system of recharging WWT effluent to the aquifer. There is no assurance that the tertiary process can be improved sufficiently to mitigate the risk of ECs. Further, the sludge containing hydrophobics may have to be treated as toxic waste.

Current state of the art: Scientists at Water Factory 21 (WF-21) considering the above problems and questions have raised the bar on effluent purification in California's Orange County. It is perhaps one of the boldest and most innovative plans in operation to date to protect the GW *(http://gwrsystem.com/about/overview.html* and plant operations engineer M. Patel, personal communication). In its most recent form, WF- 21 processes 85 million gals of sewage per day. After conventional secondary treatment, the effluent is micro-filtered, treated by reverse osmosis (RO), and finally subjected to peroxide and 254 UV. This process is now in use in other municipalities such as Scottsdale, Arizona. The WF-21-processed water, 70 million gallons per day, is pumped from its Fountain Valley location to a recharge lake, Kraemer Basin where, it is mixed with a significant buffering fraction (17%) of fresh canal water. The concentrated retentate from the RO process, approximately 15 % of WF-21influent, along with other effluent from the secondary treatment plant is pumped into the ocean. WF-21 water costs the Orange County taxpayer approximately the same as importing canal water.

California now requires that the total organic carbon (TOC), a crude surrogate for ECs, of effluent to be used as recharge cannot exceed 0.5 ppm, virtually forcing a municipality to use RO to treat its effluent for recharge. The TOC at the WF-21 plant is somewhat less at about 0.4 ppm. Achieving a TOC to near zero through a more intense oxidation step will be, according to Mr. Patel, extremely expensive. Although the WF-21 process is a vast improvement over most WWTPs, and although most ECs have likely been removed, the potentially toxic load, using TOC levels as a measure, is still one hundred thousand times higher than the 5 ppt level of EDCs that can impact aquatic life. The relationship of TOC level to the biological impact of effluent particularly that in the WF-21 effluent, is unknown.

Conclusions and Final Remarks

Society has been left with a problem and many questions. Recently the USEPA has recognized the EC issue and has identified 87 potentially dangerous organic compounds to possibly regulate, from 7500 candidates. But it may be many years before any comprehensive regulation is feasible. What should be done with newly created ECs? Should the government make the chemical industry go through a safety-test protocol for each chemical they wish to introduce (the current FDA drug- testing model)?

More advanced WWT can be expected for all communities, but the possibility for success will be challenging given the questions raised above. Certainly it would entail having tertiary treatment and all NPDES permits would require testing for a suite of ECs. At this point in time, the WF- 21-type option might be one of the better choices if cost and economies of scale can be adapted to smaller communities. In any case advanced monitoring technologies for SW/GW and WWT effluent will be needed.

Until a 'best EC removal plan' is in place, pristine areas of the environment need to be exceedingly well-catalogued, inventoried as to the biota, water quality, and EC status because eventually with the current scenario, they are likely to become polluted (if not already).

Another threat to GW is the waste from food-animals in feedlots. This waste is only partly regulated, and these animals receive their share of ECs. Routinely they are fed chemicals including steroids, pharmaceuticals, and growth factors. They are also exposed to pesticides. The waste from feedlot operations is usually collected in lagoons lined with impervious membranes. However, the liners can leak, and rain-caused overflow events do occur. Food-animal waste is not an insignificant problem. In the case of dairies alone (not to mention pig and chicken farms) a single cow produces the waste equivalent of 24 humans. In California in 1999 the dairy herd (about 1.3 million head) waste output nearly equaled that of all Californians (Hundley, 2001). Should animal waste receive the same scrutiny as that of humans?

Finally, if we continue to pollute the GW, what will be the repercussions? And since EC concentrations in GW are so low, at what level will there be an impact on the human body? A recent information publication by the National Academy of Sciences stated, perhaps prematurely, that the concentrations are too low to be a threat. And if worse comes to worst, can't we just drink water from plastic bottles made without BPA? Does it matter if aquatic populations crash? And at what concentration of EC contamination does it become unethical? In the final analysis it will depend on the cost society is willing to bear.

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