Environmental Impacts and Sustainability of Degraded Water Reuse

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Greater urban demand for finite water resources to meet domestic, agricultural, industrial, and recreational needs; increased frequency of drought resulting from erratic weather; and continued degradation of available water resources from point and nonpoint sources of pollution have focused attention on the reuse of degraded waters as a potential water source. However, short- and long-term detrimental environmental impacts and sustainability of degraded water reuse are not well known or understood. These concerns led to the organization of the 2007 ASA-CSSA-SSSA Symposium entitled *Environmental Impacts and Sustainability of Degraded Water Reuse*. Out of this symposium came a special collection of 4 review papers and 12 technical research papers focusing on various issues associated with the reuse of agricultural drainage water, well water generated in the production of natural gas from coalbeds, municipal wastewater and biosolids, wastewater from confined animal operations, urban runoff, and food-processing wastewater. Overviews of the papers, gaps in knowledge, and future research directions are presented. The future prognosis of degraded water reuse is promising, provided close attention is paid to managing constituents that pose short- and long-term threats to the environment and the health of humankind.

"If there is magic on this planet, it is contained in water."
- Loran Eisely (*The Immense Journey*, 1957)

The Merriam-Webster online dictionary defines 'degraded' as "characterized by degeneration of structure or function." From an environmental perspective 'degraded water' represents a degeneration of water quality following its original intended use, where quality refers to the condition of chemical and physical properties such as, but not limited to, turbidity, pH, salinity, pathogens, metals, nutrients, organics, and temperature. In this context, water is generally degraded in terms of its original designated use, once it has been used, whether for domestic, agricultural, industrial, or recreational purposes. However, there are instances where water that is used may not be degraded. This depends on whether or not an alteration of some physical or chemical property(ies) has occurred that detrimentally influences its intended use to the point where it is no longer suitable for that use.

There are a variety of examples of degraded water. Irrigation water applied to crops results in drainage, which is degraded from its original use through the process of evapotranspiration causing salts in the original irrigation water to be concentrated. Additional degradation of irrigation water can occur from the leaching of inorganic and organic chemicals present in the soil into ground water supplies. Agricultural runoff and irrigation tailwater contain salts, sediments, nutrients, organic compounds, and trace elements, which have been picked up as the irrigation water and runoff moves over the soil surface. Rain water falling on an urban area may serve as a source of water for landscape vegetation, but resulting urban runoff, which contains oils, greases, and a variety of other toxic organic compounds, represents a degradation of the original precipitation. Household and drinking water supplies become degraded by a variety of contaminants including biosolids, greases, oils, inorganic chemicals, soaps, detergents, etc., resulting in municipal wastewater. Ground and surface water supplies that are used on confined animal feeding operations (CAFOs) for cleaning or consumption become degraded with hormones, pathogens, salts, trace elements, nutrients, and other chemicals. The food-processing industry uses large quantities of water for cleaning and processing, which results in the degradation of water primarily with salts, nutrients, and biodegradable organic carbon compounds.

Water resources are finite and yet demand for water of varying qualities continues to increase to meet agricultural, domestic,

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Abbreviations: CAFO, confined animal feeding operations; CBNG, coalbed natural gas; EC, electrical conductivity; NMP, nutrient management plan; SAR, sodium adsorption ratio.

Table 1. Global water availability estimated for 1995 and predicted for 2025 (WRI, 2000).

		1995		2025	
Status	Water supply (m^3/person)	Population (millions)	Percentage of total	Population (millions)	Percentage of total
Scarce	< 500	1077	19	1783	25
	500–1,000	587	10	624	9
Stressful	1000–1,700	669	12	1077	15
Adequate	> 1700	3091	55	3494	48
Unallocated		241	4	296	4
Total		5665	100	7274	100

industrial, and recreation needs. The increase in demand for water occurs at the same time that erratic weather patterns have caused drought throughout the world. Global water consumption rose six-fold from 1900 to 1995, which was double the population growth rate, and continues to grow (World Meteorological Organization, 1997). Currently, humans withdraw 4000 km^3 of water a year, which is roughly 20% of the baseflow of the world's rivers (Shiklomanov, 1997). Since 2000, the USA has experienced a drought where over half the nation has had below average rainfall. The southeastern and southwestern regions of the USA have been particularly hard hit by the drought over this time period. Globally, projections for the 2090s show a net overall global drying trend with the proportion of the land surface in extreme drought predicted to increase by a factor of 10 to 30— from 1 to 3% for the present day to 30% by the 2090s. The number of extreme drought events per 100 yr and mean drought duration is predicted to increase by factors of two and six, respectively (Burke et al., 2006). From 1950 to 2000, the annual water availability per person as calculated on a global basis decreased from 16,800 m^3 to 6800 m^3 per year (Shiklomanov, 1997). Table 1 shows global water availability as estimated for 1995 and predicted for 2025 by the World Resources Institute (2000), indicating that nearly 40% of the world's population lived in conditions of water stress in 1995, which will increase to nearly 50% by 2025. The World Meteorological Organization (1997) suggests that water availability will be one of the major challenges facing human society in the 21st century and the lack of water will be one of the key factors limiting development. Water is arguably the world's most pressing resource issue.

Aside from the issue of quantity, there is the issue of water quality. Table 2 provides a list of the common water pollutants degrading the world's water supplies and their associated primary sources as compiled by United Nations Environment Program Global Environment Monitoring System (1995), Shiklomanov (1997), Taylor and Smith (1997), and Revenga and Mock (2001). In the developed countries of the world the pollution profile has changed from fecal and organic pollution associated with untreated human waste and byproducts of early industries 100 yr ago to current concerns over nonpoint source pollutants such as nutrients, sediments, and toxics, primarily from urban and agricultural runoff and leaching from agricultural fields (National Research Council, 1992; European Environment Agency, 1999; Revenga and Mock, 2001). In general, pollution law and technologies have been able to control point sources of pollution, like factories and sewage treatment plants. However, national water quality clean-up programs have not been able to effectively reduce nonpoint sources of pollution. In most developing countries, traditional pollution sources such as sewage and new pollutants such as pesticides combine to degrade surface and ground water quality. Once water is used, the resultant impairment of its quality has in the past caused it to be viewed as wastewater for disposal.

Agricultural drainage water, municipal wastewater, CAFO wastewater, agricultural and urban runoff, and food processing wastewater represent various types of degraded waters. In the past these degraded waters have been viewed as a liability due to the cost of their disposal. Today degraded waters are increasingly viewed as potential alternative water sources due to the increased demand on limited high quality water resources, the increased occurrence of drought, and the increased supply of degraded water. Therefore, the increased reuse of degraded waters is an inevitable consequence of current trends in demand for and supply of water resources, and of the need to dispose of increased volumes of degraded water.

To prepare for the expected shift to degraded water reuse an understanding and assessment of the potential detrimental environmental impacts and short- and long-term sustainability is needed. To address this issue from an environmental

Table 2. Common pollutants degrading the world's water supplies and the associated primary source of the pollutant. Sources: UNEP/GEMS (1995), Shiklomanov (1997), Taylor and Smith (1997), and Revenga and Mock (2001).

Pollutant	Primary sources
Organic matter	Industrial wastewater and domestic sewage
Nutrients (e.g., NO_3–N, P)	Runoff from agricultural lands and urban areas
Heavy metals (e.g., Hg, Cd, Zn, Pd, etc.)	Industries and mining
Microbial contamination (e.g., cholera, *Cryptosporidium*, Giardia, etc.)	Domestic sewage, CAFOs, and natural sources
Toxic organic compounds (e.g., oils, pesticides, industrial chemicals, etc.)	Wide variety of sources including industrial sites, automobiles, farmers, etc.
Dissolved salts	Leaching from agricultural soils or drawn into coastal aquifers from overdrafting of ground water
Acid precipitation and acidic runoff	Coal combustion and mining, respectively
Silt and suspended particles	Soil erosion and construction activities
Thermal pollution	Dams and power plants (e.g., cooling towers)

perspective, the S-11 division sponsored a symposium entitled "Environmental Impact and Sustainability of Degraded Water Reuse" that was organized and held at the 2007 ASA-CSSA-SSSA Meetings in New Orleans, LA, on 6 Nov. 2007.

The Degraded Water Reuse Symposium consisted of invited review and original research papers that dealt with the environmental impact and sustainability of all types of degraded water reuse. Degraded waters that were considered included: agricultural drainage water, municipal wastewater, CAFO wastewater, industrial and food-processing wastewater, and urban and agricultural runoff. Review papers provided an in-depth discussion of the source, composition, current regulatory framework and application practices, environmental issues, and reuse considerations associated with these degraded waters. Original research papers examined specific topics associated with degraded water reuse such as the transport, biogeochemical interactions, and fate of specific degraded water contaminants in the environment; the impact of degraded waters on crop production, soil quality, and/or water resources; the sustainability of existing degrade water reuse strategies; and alternative treatment approaches and best management practices for degraded water reuse.

The symposium objectives were: (i) to review what is currently known about degraded water reuse and its impacts on the environment, (ii) to evaluate the sustainability of degraded water reuse under different management practices, and (iii) to present current research that helps to fill gaps in our knowledge and understanding of the environmental impacts of degraded water reuse. The objective of this introductory paper is to provide justification for conducting research on degraded water reuse, to give an overview of the papers that were presented in the Degraded Water Reuse Symposium, and to identify critical gaps in knowledge and research that is needed on degraded water reuse.

Degraded Water Reuse Paper Summaries

A review of degraded water reuse is presented by O'Connor et al. (2008), which describes various types of degraded water (e.g., irrigation return flows, municipal wastewater, CAFO effluents, stormwater runoff [i.e., urban runoff], food-processing effluents, domestic graywater, and industrial processing waters), reuse options, and limitations and restrictions to their use. This review serves as an overarching introduction to the special collection of papers.

Agricultural Drainage Water and Water from Coalbed Natural Gas Production

Previous reviews of drainage water reuse have been published that presented the principles of drainage water reuse and disposal along with reuse criteria (Westcot, 1988); examples of reuse practices in Egypt, India, and USA (Willardson et al., 1997); and a summary of the California experience focusing on salinity, sodicity, B, Mo, and Se impacts (Grattan et al., 1999; Oster and Grattan, 2002). As a supplement rather than a reiteration of material in these previous reviews, Dudley et al. (2008) provide a review of drainage water reuse focusing on recent literature that contributes to the understanding of physical and biological constraints to drainage water reuse.

Drainage water from irrigated agricultural fields and well water from coalbed natural gas (CBNG) production are similar in that they are generally both high in salinity and sodium. The quality of drainage and CBNG waters varies with the soil and coal depositional environments, respectively. The primary concern over drainage water reuse and land application of CBNG water is how to manage the salt and sodium to minimize adverse effects on plant growth. Furthermore, high sodium levels will reduce the surface infiltration rate and lower the Darcy flux as a result of the increase in the sodium adsorption ratio (SAR). Trace elements (e.g., Fe, Mn, and B in CBNG water, and Se, Mo, and B in drainage water) can also be constituents of concern in both CBNG and drainage water.

Corwin et al. (2008) provide a short-term (i.e., 5 yr) evaluation of the sustainability of the reuse of drainage water on a marginally productive saline-sodic soil used to grow forage (i.e., bermudagrass, [*Cynodon dactylon* (L.) Pers.]). Their findings show the beneficial spatiotemporal impacts of reusing drainage water on the less desirable saline-sodic soils of the west side of the San Joaquin Valley. In particular, four soil properties were closely monitored (salinity, SAR, Mo, and Se) and found to decrease over time, thereby supporting the short-term sustainability of drainage water reuse and the viability of drainage water reuse as a means of reclaiming marginally productive saline-sodic soils. Aside from the issue of short-term sustainability, the study demonstrated the use of a set of protocols to evaluate sustainability from a spatiotemporal perspective. These protocols account for spatial heterogeneity in the evaluation of management-induced spatiotemporal changes that occur with degraded water reuse, and provide a basis from which site-specific management decisions can be made.

Whereas the drainage water reused by Corwin et al. (2008) never reached levels above 16.2 dS m^{-1}, hyper-saline drainage waters that ranged from 18 to 49 dS m^{-1} were used by Grattan et al. (2008) for irrigating pickleweed (*Salicornia bigelovii* Torr.). Salicornia that was irrigated with the hyper-saline drainage water found at locations in California's San Joaquin Valley grew well over the entire range of salinities and the drainage volumes were substantially reduced. Both studies by Corwin et al. (2008) and Grattan et al. (2008) indicate that drainage water is a viable alternative water resource when managed properly and that drainage water reuse provides a means of reducing volumes of drainage water, which are currently disposed in evaporation ponds that take land out of production.

In a novel study by Suarez et al. (2008), it was pointed out that SAR and salinity criteria for water suitability for irrigation are based on conditions where irrigation water is the only water source. These criteria may not be applicable to geographic areas where there is a combination of rain and irrigation water during the growing season. This work has particular relevance to reuse of water from CBNG production, which occurs in areas of the USA where rainfall can be a significant water source. This study suggests the need to expand our knowledge of water suitability for irrigation that goes beyond the traditional understanding.

The multi-year land application of saline-sodic waters from CBNG wells was shown by Ganjegunte et al. (2008) and Vance et al. (2008) to produce consistent trends of increased soil EC, SAR, and ESP values. Ganjegunte et al. (2008) provide an evaluation of the effects of land application with CBNG water on soil chemical properties, showing that applications of CBNG water significantly increased soil EC, SAR, and exchangeable sodium percentage (ESP) values up to 21, 74, and 24 times, respectively. The study suggests that current management strategies and practices designed to mitigate soil Na^+ and soluble salt concentrations by leaching have not prevented significant negative impacts on soil properties. Vance et al. (2008) show that increases in EC, SAR, and ESP from the application of CBNG waters reduce surface infiltration rates and lower Darcy flux rates to a depth of 120 cm. However, applications of saline-sodic CBNG water significantly increased native perennial grass biomass production and cover on irrigated as compared to non-irrigated sites. Overall species evenness decreased. Biological effects were variable and complex, reflecting site-specific conditions, and water and soil management strategies.

Municipal Wastewater and Biosolids

Municipal water is collected in sanitary sewer systems and is treated in sewage treatments plants. The treatment process generates reclaimed municipal wastewater and biosolids. Class B biosolids are usually generated from mesophilic anaerobic digestion and commonly contain 5 to 20% solids. This special collection contains papers dealing with the reuse of reclaimed municipal wastewater and Class B biosolids.

Chen et al. (2008) examine the influence of long-term irrigation with reclaimed municipal wastewater at five sites in southern California on soil enzymes that are responsible for the biogeochemical cycling of nutrients (C, N, P, and S). The overall activities of enzymes involved in nutrient cycling were enhanced by an average of 2.2- to 3.1-fold at the reclaimed water application sites compared to their controls, indicating a beneficial effect on the soil microbial community.

Pepper et al. (2008) review the sustainability of land application of Class B biosolids with regard to microbial and chemical properties of soil, and the transport and fate of biological and chemical hazards. These authors reported that pathogens in biosolids possess a low transport potential in ground water and aerosols, and therefore a low risk to human health. Long-term land application of Class B biosolids was found to increase soil macronutrients, but did not adversely influence soil metal concentrations, soil salinity, or the soil microbial community. Based on these findings, the authors concluded that long-term land application of Class B biosolids was sustainable for their particular experimental conditions.

CAFO Wastewater

Wastewater from CAFOs are typically collected and stored in lagoons before land application. This lagoon water commonly receives little or no treatment before land application and may therefore pose a risk to the environment as a result of excess amounts of nutrients, organics, heavy metals, salts, pathogenic microorganisms, hormones, and antibiotics.

Bradford et al. (2008) review the current level of understanding of the environmental impact and sustainability of CAFO wastewater reuse from the perspective of the nutrient management plan (NMP) regulatory framework. The source, composition, and environmental issues associated with CAFO lagoon water were illustrated and discussed. Contaminant transport pathways and loading rates at NMP sites were summarized, and weaknesses in NMP design were identified. Potential management and treatment options for CAFO lagoon water were reviewed that may be used to achieve environmentally acceptable risks and economically viable solutions for CAFO operators.

Read et al. (2008) discuss results from field research that studied the influence of swine effluent application timing and rate on bermudagrass [*Cynodon dactylon* (L.) Pers.] nitrogen use efficiency (NUE) and residual soil nitrate. The NUE of bermudagrass was low in August and September, and therefore excess N in the soil increased the risk to surface and ground water quality. Increasing the effluent application rate increased the NUE, but also increased the soil nitrate levels (especially in dry years with decreased biomass).

Watanabi et al. (2008) report on an investigation of the potential for monensin, a commonly used ionophore antibiotic, to move from two dairy farms in California to the surrounding ground water. Monensin was detected in all of the CAFO wastewater samples and in some of the ground water samples underneath the dairy, but not in ground water samples from adjacent fields that received manure. Concentrations of monensin in wastewater and ground water rapidly decreased with transport distance, suggesting that significant attenuation occurs in wastewater and in the subsurface.

Vanotti and Szogi (2008) developed and demonstrated a new treatment system for CAFO wastewater on a full-scale swine farm in North Carolina. The treatment system combined liquid-solids separation with N and phosphorus (P) removal processes that removed greater than 95% of the total suspended solids, biochemical oxygen demand (BOD), total Kjeldahl N, ammonium, total P, zinc, and copper from the effluent. The quality of the lagoon water rapidly improved as treated, aerobic effluent replaced the originally anaerobic water.

Eigenberg et al. (2008) conducted a study to determine if methods developed for the inventorying of soil salinity can be used to track the flow of saline feedlot runoff in a vegetative treatment area. This approach involved the use of a combination of geo-referenced soil conductivity maps that were obtained from electromagnetic induction equipment, directed soil sampling and measurement of chloride concentrations, and regression modeling. Results indicated that this approach provided a cost-effective tool to observe and manage liquid flow in a vegetative treatment area.

Urban Runoff

Urban stormwaters have become a potentially viable alternative water resource due to greater demand on limited surface and ground water supplies and increased growth of urban areas, which have increased urban runoff. Fletcher et al. (2008) review the literature for harvesting of stormwater runoff by exploring its rationale, discussing advances and trends, assessing the performance of stormwater runoff harvesting systems, and identifying impediments to the adoption of stormwater runoff as an alternative water resource.

Food Processing Wastewater

California's Central Valley contains over 640 food-processing plants (e.g., tomato canning, meat packing and rendering, grape and wine production, dairy processing, etc.), which utilize over 7.9×10^7 m^3 yr^{-1} of water, resulting in wastewater that is typically high in organic carbon (OC), N, and salts (CLFP, 2007). Roughly 80% of the food-processing plants discharge their wastewater and many use land application as the method of disposal, resulting in loads of OC, N, and salts. The main concerns with land application of this wastewater are associated with increased loads of salinity and nitrate, and to a lesser degree ammonia (NH_3), Fe, Mn, SO_4, and BOD.

Miller et al. (2008) used the multi-component reactive flow and transport model MIN3P (Mayer et al., 2002) to simulate movement of various chemical constituents, particularly labile OC, salinity, and N, found in land application of food-processing wastewater for the California Central Valley. Their objective was to evaluate the transport and attenuation of these waste constituents within the vadose zone, and to provide estimates of OC, salinity, and N loads in the Central Valley. Their challenge rested in high levels of variability in both the waste stream from the various food processing industries and the disposal site characterization. This challenge was straightforwardly addressed by bracketing the range of possibilities. The simulation results showed that when site and flow conditions were optimal, natural attenuation was able to remove most of the N and a significant portion of the applied plant nutrients. As such, numerical modeling is a potentially useful management tool for establishing the optimal conditions to enhance attenuation and minimize food-processing waste impacts on ground water, providing assistance in careful site selection, strict flow-rate controls, and alterations to the character of the wastewater.

Gaps in Our Knowledge and Future Research Direction

Each paper within this special collection of papers indicates areas where gaps exist in our current knowledge and understanding of the environmental impacts and sustainability of degraded water reuse. For example, little field documentation currently exists on the long-term sustainability of degraded water reuse and the migration and fate of all relevant environmental contaminants. There have been some reuse studies for drainage water (Goyal et al., 1999; Corwin et al., 2008), CAFO wastewater (Evans et al., 1984; Burns et al., 1985; King et al., 1985), and food-processing wastewater (Kroyer, 1995; Wersin et al., 2001; Zvomuya et al., 2005; Johns and Bauder, 2007) that have looked at sustainability and fate of particular contaminants, but over limited time periods of under a decade and generally of 1 to 2 yr. The reuse of municipal wastewater is the most widely studied degraded water, with monitoring studies conducted under real-world conditions over extended time periods of a decade or longer (e.g., Schmidt et al., 1975; Chakrabarti, 1995; Kivaisi, 2001; Lubello et al., 2004; Bixio et al., 2006; Chen et al., 2008). Even so, the impacts of degraded water reuse on sites for half a century or more are not available and it is unlikely that research will fill this gap in knowledge due to the short-term funding cycle for most research. Ostensibly, the viability of long-term degraded water reuse will depend on the ability to extrapolate beyond our knowledge and to be able to utilize concepts developed for the management and sustained use of poor quality waters on agricultural lands and municipal wastewater reuse, both of which have long histories of land application. However, many of the early monitoring municipal wastewater reuse studies did not consider emerging environmental contaminants, such as endocrine disruptors and pharmaceutical chemicals, which have only recently come to the attention of the scientific community. This makes an extrapolation problematic and fraught with uncertainty.

To most efficiently manage degraded water reuse with the least detrimental environmental impact, it will be necessary to account for the spatial variability of sites where degraded waters are applied. This will make the site-specific management of degraded water reuse possible, which will optimize the reuse of degraded waters and minimize detrimental impacts. To accomplish this will likely require the use of advanced information technologies (i.e., geographic information system, global positioning system, satellite imagery, non-invasive remote sensing such as electromagnetic induction and ground penetrating radar, pedotransfer functions, classical and spatial statistics, model- and design-based sampling, hierarchical organization theory, and scaling theory) that have been developed for precision agriculture applications (Corwin and Lesch, 2003, 2005a, 2005b; Jaynes et al., 2005; Kitchen et al., 2005; Lesch et al., 2005) and for characterizing spatial variability (Corwin, 2005; Sudduth et al., 2005; Triantafilis and Lesch, 2005; Wraith et al., 2005). Corwin et al. (2006b) have successfully demonstrated the use of geospatial measurements of apparent soil electrical conductivity (EC_a) to direct soil sampling as a means of assessing spatiotemporal impacts of management-induced changes. This EC_a–directed sampling methodology is applicable to the evaluation of sustainability of degraded water reuse (Corwin et al., 2008). However, from an applied research perspective, future research is needed that will not only look at long-term environmental impacts of degraded water reuse, but will look at the impacts of site-specific management of degraded water reuse to better evaluate the true potential of degraded waters as a viable alternative water resource. The need for site-specific management of degraded water reuse is reaffirmed by the work of Vance et al. (2008) and Ganjegunte et al. (2008), which stress the need for alternative site-specific management practices and monitoring to prevent development of extremely difficult saline-sodic conditions for land applications of CBNG waters.

The results of Suarez et al. (2008) point out that caution must be taken in the use of traditional criteria for salinity and

SAR for irrigation water quality in areas where there is a combination of rain and irrigation during the growing season. Adjusted water quality criteria may need to be developed for these areas, which take into account the significance of rainfall.

Bradford et al. (2008) indicate that the current regulatory framework for CAFO wastewater application is based on NMPs, and implicitly assumes that other contaminants (e.g., salts, heavy metals, pathogens, hormones, and antibiotics) are retained, inactivated, or degraded in the root zone. Other potential problems and weaknesses associated with the implementation of NMPs were identified and include: differences in the nutrient composition of lagoon water and the nutrient uptake rates by plants, accurate estimation and delivery of water to meet plant water demands, and preferential flow and/or facilitated transport of lagoon water contaminants. Additional research is needed to validate all of these assumptions and to overcome these weaknesses.

Fletcher et al. (2008) point out that implementation of stormwater harvesting systems is currently impeded by the lack of data assessing reliability and risk, lifecycle costs, externalities, and water energy tradeoffs, as well as by the challenges of developing stormwater technologies that can retrofit into the existing infrastructure. Furthermore, limited data exist on the environmental benefits of urban runoff reuse resulting from reductions in pollutant loads and flow peaks.

Although Miller et al. (2008) showed considerable resourcefulness in their modeling effort, the complexities involved revealed the limitations of the MIN3P model. Aside from the need for further testing, validation, and calibration, the model itself needs to be modified to include microbial growth and decay, and implementation of a more sophisticated model of root water uptake that includes the effects of salinity on crop and microbial health to account for reduced nutrient uptake and biodegradation, and increased leaching. The modeling effort scratches the surface of the overall complexity of the issue of transport and attenuation, which are overshadowed by the even greater challenges presented by spatial variability of soil physical and chemical properties influencing transport and attenuation and by scale issues related to parameterization. Although the challenges of spatial variability and scale are formidable, there are advanced information technology approaches that are available to address these problems (Corwin, 2005; Corwin et al., 2006a).

Even though there is definite potential for detrimental environmental impacts from degraded water reuse due to the presence of a wide variety of organic and inorganic pollutants, the prognosis for the reuse of degraded waters tends to be favorable from the perspective of impacts on soil. Management of degraded water reuse within a defined set of guidelines and protocols is the key to its success and sustainability. However, there is a caveat related to health issues and risk assessment that must be associated with this favorable prognosis. There is conflicting evidence in the literature related to possible health problems associated with land application of biosolids. Gaskin et al. (2003) found that long-term (i.e., periods up to 12 yr) land application of biosolids from a wastewater treatment facility did not reach toxic levels for metals and that overall forage quality was similar to that of commercially fertilized fields. In contrast, Lewis et al. (2002) and Khuder et al. (2007) found a correlation of risk of various health problems with the proximity to farms where biosolids had been applied. Even though there is a distinction between biosolids and degraded water, there are sufficient similarities to justify additional research on the environmental transport, fate, and bioaccumulation of contaminants in degraded waters, and their potential health effects on animals and humans residing near fields receiving degraded water.

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