Interpreting Science in the Real World for Sustainable Land Application

Robert K. Bastian*

ABSTRACT

Today's land application practices are designed to effectively treat wastes, and have evolved from earlier practices that centered on cheap disposal with less regard for environmental protection. The major objectives of this paper are to (i) review how current land application practices, and our understanding of them, have evolved over time and (ii) explore how science is used (and sometimes misused or ignored) in the development of design, regulation, and management of sustainable land application. Land treatment technologies have been used effectively for the treatment and recycling of many types of wastewaters and organic residuals for many years. Extensive research and demonstration efforts, as well as experience with pilot- and field-scale projects, have provided the information about soil reactions with contaminants in wastewater and organic residuals needed to design and operate sustainable land application projects. Still, systematic research programs are as important today as ever to support studies aimed at producing information on how soil-based treatment and recycling systems work, to address new areas of concerns as they arise, and continue to improve the overall design, performance, and reliability of land application systems as sustainable soil treatment and recycling systems.

For more than 2000 years, a large variety of waste residuals (e.g., manure, sewage sludge, industrial residuals) in various forms have been land-applied as soil amendments to supplement and improve the soil (Moss et al., 2002). Once sewage nutrients were shown to beneficially affect crop growth, sewage farming was promoted as being profitable as well as a technology that helped alleviate the effects of gross waterborne pollution of surface waters. Pollutant and soil interactions were considered as purifying treatment processes, but with finite limitations that could be overloaded (with too much waste) and result in system failure (Jewell and Seabrook, 1979; Seabrook, 1975).

Many of the basic wastewater treatment processes in use today (e.g., chemical precipitation, activated carbon adsorption, trickling filters, biological contact beds, and intermittent filtration) were developed between 1840 and 1890 and land treatment was one of many available treatment alternatives (Fig. 1). Along with greater acceptance and understanding of the germ theory, knowledge of disease-carrying agents provided the insight necessary to judge the public health hazards of effluents. Water supply treatment by filtration became widely adopted. The introduction of chlorination in 1910 eliminated major epidemics of typhoid and cholera. By the late 1890s, discharge of partially treated wastewater effluents was considered to be safe and cost effective. Many land-farming systems installed in the mid-1800s were used for 30 to 50 yr without size adjustment for growing populations, and resulted in unsightly overloaded conditions (Jewell and Seabrook, 1979).

Land treatment was considered to be the most effective alternative in the United States from 1980 to 1905, and was used by many communities with sewage treatment. Most of the 143 sewage treatment facilities in the United States and Canada as of 1899 were land treatment systems (Rafter, 1899). In some cases (e.g., Calumet, MI; Woodland, Fresno, and Bakersfield, CA; Lubbock, TX; Vineland, NJ), municipal wastewater land treatment systems started in the late 1880s to early 1900s have been modified over time to accommodate changing conditions, and continue to operate successfully today as effective treatment systems (Crites et al., 2000). However, from the beginning, many American engineers considered sewage farming, intermittent filtration, and other means of land application of wastes to be "disposal" systems (Jewell and Seabrook, 1979). Various forms of land application have been used by industries to treat and dispose of industrial wastes, especially by food processors. Such projects often attempted to maximize the amount of waste applied per unit land area rather than to optimize waste use as a source of water for irrigation and/or nutrients. Similar practices were undertaken by some cities as a means of disposal of municipal effluents and sewage sludge. Conventional irrigation procedures and historically accepted practices for recycling animal manure back to the soil to fertilize food, fiber, and feed crops were frequently not followed. As a result, problems often developed such as elevated nitrates in the underlying shallow ground water, severe erosion and runoff from application sites into nearby water bodies, and/or poor cover crop performance. Odors and other undesirable site conditions developed from excess moisture, organic matter, and nutrient loadings. Similar problems have resulted from excessive manure applications to farmland in some areas, where the number and size of confined animal production facilities have dramatically increased. Reduced cropping acreage also limits the land base available for effectively recycling manure by land application.

Land treatment technologies have been used effectively for the treatment of many types of industrial wastewaters and residuals for many years. Residuals include a wide range of food processing wastes (e.g., brewery; canning and frozen foods, including vegetables, fruits, citrus, pineapple, coffee, and tea; dairy products, including milk and cheese; meat processing; winery and other wastes), as well as industrial residuals such as pulp and paper, tanning, pharmaceuticals, biological chemicals, and explosives (Crites et al., 2000; Reed and Crites, 1984; Overcash and Pal, 1979). In some cases (often based on

USEPA, Office of Wastewater Management (4204M), Room 7220B EPA EAST, 1200 Pennsylvania Avenue, NW, Washington, DC 20460. The views expressed in this paper are those of the author and not official USEPA policy. Received 1 Mar. 2004. *Corresponding author (bastian.robert@epa.gov).

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677 S. Segoe Rd., Madison, WI 53711 USA

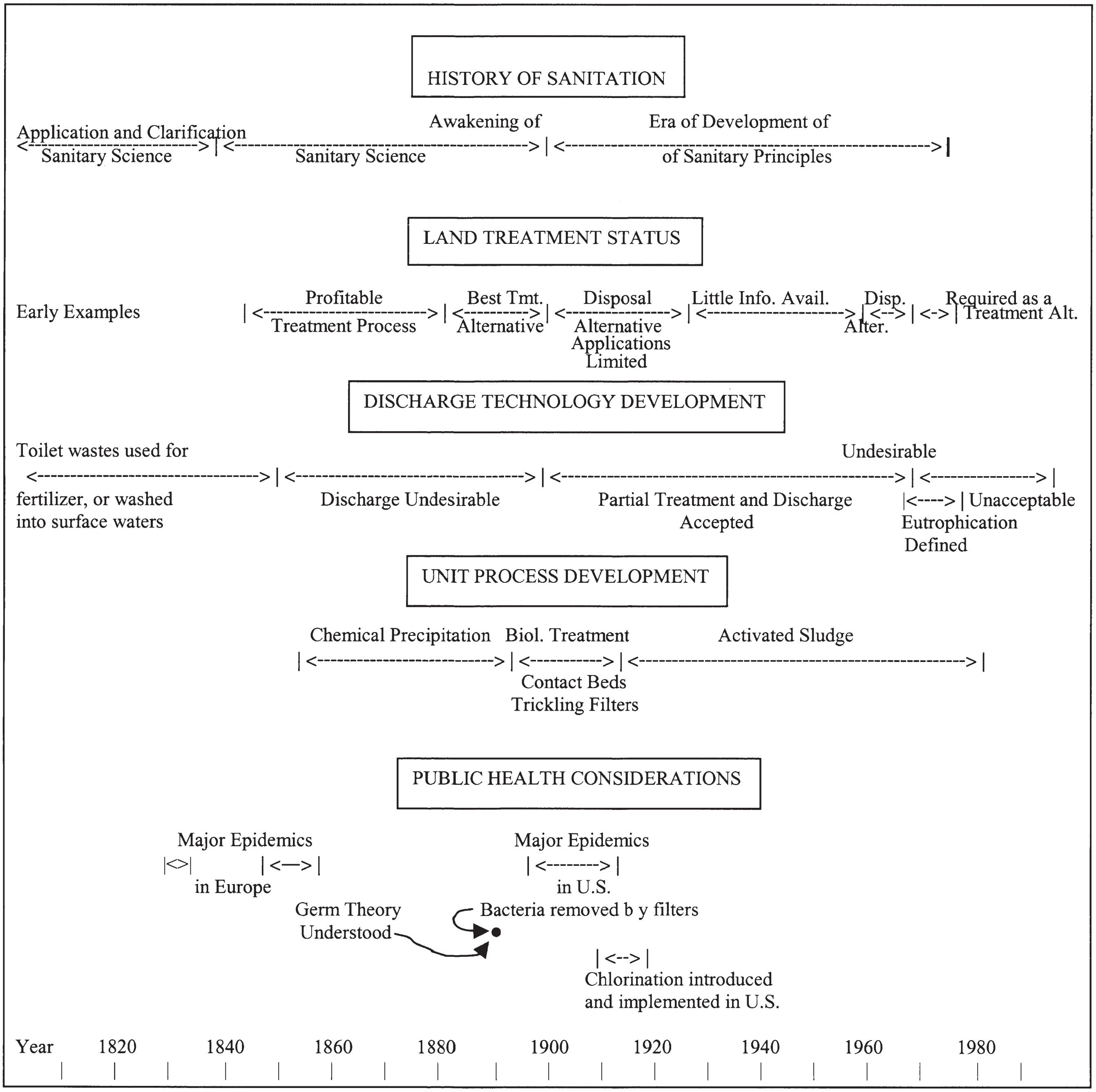

Fig. 1. Chronological development of factors partly responsible for the changing status of land treatment of wastewaters. Source: Jewell and Seabrook (1979).

trial and error experience), industrial land application projects that began as land "disposal" systems have evolved into land treatment projects. The latter limit residual application rates to avoid excessive effluent irrigation loading rates. Successful projects include Campbell Soup Co. projects in Paris, TX, and Napoleon, OH (Bendixen et al., 1969; Gilde et al., 1971; Law et al., 1970), Seabrook Farms vegetable canning and frozen foods processing operation in southern New Jersey (Pound and Crites, 1973), and the J.R. Simplot Co. potato processing operations in Idaho (Bruner et al., 1999; Crites et al., 2000).

Years of extensive research and demonstration efforts, as well as experience with both pilot- and field-scale projects, have provided the information needed to design and operate land application projects that can effectively treat and recycle wastewater effluents and organic residuals. Such systems use the soil as an integral part of the treatment system in a sustainable manner. Similarly, projects on agricultural lands, forests, and reclamation sites have focused on recycling treated sewage sludge ("biosolids"), industrial residuals, and manure. The residuals are used as organic soil conditioners and sources of macro- and micronutrients to enhance soil conditions and help establish sustainable vegetative cover and maximize crop yields (Jacobs et al., 1993). Today, application practices can be used in a sustainable manner to minimize negative effects on the environment and to restore disturbed areas with poor soil conditions (resulting from, for example, construction activities, surface mining, forest fires and clear cuts, and overgrazing) and highly contaminated sites (resulting from, for example, mining, smelting, and other industrial activity). Well-documented examples of long-term projects involving such land application practices exist in many parts of the country, for example, projects at Pennsylvania State University in University Park, PA (Kardos, 1974; Pennsylvania State University, 2001); Clayton and Dalton, GA (Reed and Bastian, 1991; Clayton County Water Authority, 2004; Dalton Utilities, 2004); Muskegon, MI (USEPA, 1976, 1980; Demirjian et al., 1980; Muskegon County, 2004); Lubbock, TX (Camann et al., 1985; Hinesly et al., 1978); Davis, CA (Smith and Schroeder, 1983; Kruzic and Schroeder, 1990); Madison, WI (USEPA, 1995a; Jacobs et al., 1993); Fort Collins, CO (Gallier et al., 1993); and Seattle, WA (USEPA, 1995a; Henry et al., 2000). These sustainable land application systems depend heavily on the soil as an integral part of the treatment and/or recycling system to effectively process and manage macro- and micronutrients, inorganic and organic contaminants, and pathogens.

The extensive operating experience with long-term pilot- and field-scale projects has often been complimented by extensive studies conducted by scientists in numerous disciplines, and an extensive body of literature exists. Efforts to compile and summarize the available information have led to identification of research needs in numerous formats. Conference proceedings (e.g., National Association of State Universities and Land-Grant Colleges, 1973; Loehr, 1977a, 1977b; Sopper and Kardos, 1973; Sopper and Kerr, 1979; Sopper et al., 1982; Page et al., 1983; Cole et al., 1986; Clapp et al., 1994; Henry et al., 2000; Rocky Mountain Water Environment Association, 2000) along with other sources (e.g., Overcash and Pal, 1979; Reed and Crites, 1984; Runge, 1986; Page et al., 1987; Sopper, 1993; National Research Council, 1996; Crites et al., 2000; Sharpley et al., 2003) have provided important information used in the development of USEPA technical guidance materials. Examples of these materials include the USEPA's process design manuals on land treatment of municipal wastewater, land application of sewage sludge, and guidelines for water reuse (USEPA, 1977, 1981, 1983, 1992, 1995a, 2004a); the USDA's *Agricultural Waste Management Handbook* and *Comprehensive Nutrient Management Planning Technical Guidance* (USDA Natural Resources Conservation Service, 1992, 2003); and the technical basis behind applicable regulations, such as 40 CFR Part 503 (USEPA, 1993) and the concentrated animal feeding operation (CAFO) rule (USEPA, 2003).

THE APPLICATION OF SCIENCE TO MAKING LAND APPLICATION SYSTEMS SUSTAINABLE

Information developed over the years suggests that sustainable land application systems can be established and maintained under a wide range of conditions. Optimal crop yields can be achieved using effluents as a water supply and source of nutrients, and effluents and organic residuals can serve as a source of nutrients and soil conditioner. Contaminants (e.g., excess trace metals, toxic organics, nitrogen and phosphorus, and pathogens) can be controlled and effectively managed by land application systems. A stream or lake responds to *specific* nutrient, trace metal, inorganic, and organic contaminant additions in a similar manner whether the input comes from point- or nonpoint-source municipal, industrial, agricultural, or atmospheric sources (Reid, 1961; National Research Council, 1969; Burns, 1985). Likewise, many biological and chemical reactions in the soil are independent of the source of the contaminants (municipal or industrial effluents, sludges, manures, or other organic residuals), unless they are derived from material with low organic matter content (e.g., metal solutions such as plating industries, grit from highway runoff).

The Role of Soil Reactions

Soil reactions with contaminants in waste represent the key to sustainable land application systems. The soil and associated microorganisms and vegetation react to the *specific* contaminants in land-applied residuals and modify the contaminants through direct oxidation–reduction reactions, adsorption–desorption, biodegradation, and plant uptake. In some cases the reactions are temporary, while in other cases they are essentially permanent, or nearly so unless the overriding factors controlling the soil properties are changed by external sources (Page et al., 1987; National Research Council, 1996; Power and Dick, 2000). Thus, scientists need not "reinvent the wheel" by studying the fate of every contaminant that may be present in every waste source to predict how the contaminant behaves in land application systems over time. The extensive body of available technical information can be effectively applied in the development of technical guidance and regulatory requirements for all sustainable land application practices (USEPA, 1992, 1993, 2004a; National Research Council, 2002). However, such technical information is only part of what goes into developing sustainable land application projects that are guided by the applicable regulatory requirements and real-world management practices.

Establishing Controls Based on Science and Risk Assessments

The controls imposed on land application practices seek to protect public health and the environment, but also consider factors such as available control technologies, cost effectiveness, public policy objectives, public acceptance, and political realities. Early land application requirements were focused on good management practices and the general consensus of the scientific community (best professional judgment), softened by the realities of best available control technologies and affordability. The "soil–plant barrier" was regarded as providing an effective means of protecting humans from exposure to excessive levels of most chemical contaminants in the food chain (Chaney and Giordano, 1977; Chaney, 1980, 1983a, 1983b). This "barrier" was viewed as limiting the transmission of heavy metals through the food chain as a result of soil chemical processes that limit solubility thereby preventing plant uptake (e.g., soil barrier), immobility in fibrous roots preventing translocation to edible plant tissue, or phytotoxicity (e.g., plant barrier) occurring when concentrations in edible plant tissues are below that injurious to animal consumers. More recently, loading limits for specific chemicals have been developed by various means, ranging from not allowing any increase in background chemical concentrations (nondegradation strategy) to establishing acceptable levels based on various risk assessments and modeling approaches. Pathogen controls have primarily been based on treatment through process technology controls and waiting periods to allow for natural die-off.

The basic paradigm used for human health risk assessment of hazard identification, dose–response assessment, exposure assessment, and risk characterization (National Research Council, 1983) has become the usual framework for development of many of the regulations in the United States, although less so in Europe. The approach was used to establish limits on annual and total chemical contaminants applied with biosolids, taking into account such factors as the bioavailability of contaminants in sewage sludge (USEPA, 1993, 1995c), to assure that land application practices are sustainable. The risk assessment–based approach is data intensive, and often leads to the use of conservative default values and sensitivity analyses or Monte Carlo simulations to address areas of uncertainty. Concerns raised over emerging pathogens and chemicals for which little or no data are available tend to be put off for future consideration when more adequate scientific data are generated. Groups following the precautionary principal advocate limitations based on rates that do not lead to increases in background chemical concentrations or banning or prohibiting land application until the documented assurance that negative effects on health and ecosystems will be avoided (Marchant, 2003; Harrison et al., 1999; Mindfully.org, 2004; Ag BioTech InfoNet, 2004). As a result, future efforts to better address pathogen concerns and potential ecological effects associated with land application practices will likely use recently developed methodologies for conducting pathogen and ecological risk assessments (Colford et al., 2003; World Health Organization, 2001; National Research Council, 2002; USEPA, 1998), for example, the USEPA's *Guidelines for Ecological Risk Assessment* and the ongoing Water Environment Research Foundation (WERF)-sponsored project, "A Dynamic Model to Assess Microbial Health Risks Associated with Beneficial Uses of Biosolids" (Project 98-REM-1A). Bioassay techniques for better evaluating the effects of multiple stressors, complex mixtures, and compound by-products resulting from degradation in the environment as well as contaminants that may be present below effective analytical detection limits may also play a role in future research efforts and may be used eventually as a part of future regulatory strategies.

The Role of Active Stakeholder Involvement and Risk Communication

The importance of public involvement and public acceptance in maintaining sustainable land application projects simply cannot be overstated. Early efforts to use land application practices were usually conducted in relatively isolated areas with few neighbors. However, most modern projects are faced with the realities of local neighbors. In many cases, individuals and/or public interest groups regard even the concept of land-applying wastewater effluents, biosolids, manures, and other residuals as unacceptable. Many states have adopted standards to accommodate effluent reuse (e.g., Florida, California, Texas, Arizona, and Washington) as well as broad goals calling for increased recycling of organic wastes in an effort to conserve landfill capacity (e.g., New Jersey Department of Environmental Protection, 2003; North Carolina Department of Environmental Regulation, 2000). In general, these standards and goals strongly support the objectives of land application practices. However, "not in my backyard" (NIMBY) reactions by local neighbors to notices of proposed land application projects and to the start-up of new projects are now the norm. Unless citizen concerns and interests are taken into account and accommodated by planned projects, such local concerns can easily grow into formal project opposition. This may result in the involvement of external groups and individuals with even broader agendas to create political and legal barriers to moving projects. Public notification requirements associated with most regulatory programs are often viewed as exacerbating these reactions. However, they also create opportunities for active public education and involvement in programs that can help lead to long-term support of well-run land application projects.

Addressing public concerns through active stakeholder involvement and effective risk communication is an important aspect in developing sustainable land application projects. The basic human health risk assessment model developed by the National Research Council (1983) emphasizes the role of "risk management" in assimilating nonscientific factors into making policy decisions and the need for effective "risk communication" to communicate such policy decisions. While scientists generally view risk as the nature of harm that may occur, the probability that it will occur, and the numbers of people that will be affected (Groth, 1991), most citizens are concerned with broader, qualitative attributes: whether risk is imposed or voluntarily assumed, the equitable distribution of risk over a population, alternatives, and the power of individuals to control the risk (Sandman, 1987). Research has identified numerous factors that influence the "perception of risk" including the origin of the risk (natural vs. technological), benefits realized from accepting risk, and trust. Such factors are important aspects of effective risk communication and underlie the two basic considerations that typically drive effective risk communication (National Research Council, 1989): (i) perception can change even if the actual risk does not and (ii) perception is the reality you have to deal with.

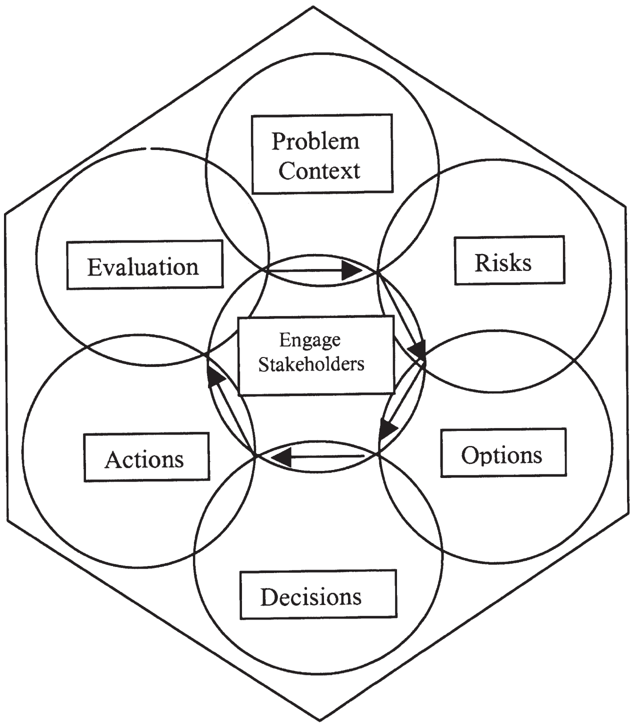

Fig. 2. The risk management cycle. Source: Soby et al. (1993) as revised by World Health Organization (2003b).

As a result, models for effective risk management and the risk communication cycle (Soby et al., 1993) generally call for the concerns of the public and other stakeholders to be actively sought at each stage of the risk management process, including risk assessment (Fig. 2).

The Effect of Odors

The initial basis for local concerns is often linked to the production of odors and/or other nuisance conditions (e.g., noise, dust, flies, truck traffic) associated with land application projects. Where such concerns have been effectively addressed through changes in treatment processes, on-site storage practices and/or field operations, local acceptance problems have often been overcome or avoided (e.g., Hamel et al., 2004). When such concerns are ineffectively addressed, complaints about nuisance conditions often escalate to complaints about potential health effects that may result from the odors, potential bioaerosols, dust, and/or runoff from the land application site. The question, When does exposure to odors or dust and the compounds and/or potential bioaerosols affect health?, probably varies widely with individual sensitivities (Schiffman et al., 2000). Highly sensitized individuals can react to exposures to smoke, perfume, cleaning agents, and certain foods (e.g., sources containing lactose, gluten, citric acid, shellfish, nuts, and even chocolate). Regulating land application of wastewater effluents, biosolids, industrial residuals, and manures based on the potentially most sensitive individuals to odors may lead to very restrictive practices.

Going Beyond Meeting Minimum Regulatory Requirements

Efforts to actively involve potentially affected and interested stakeholders in the development and implementation of sustainable land application practices has lead to the establishment of various types of voluntary partnerships. Environmental Management Systems, ISO 14,001 Standards, and various other coalitions that follow Dr. W. Edward Demming's basic "Plan/Do/Check/Act" total quality management model principles (Demming, 1986) have been established (Fig. 3). These approaches encourage achieving continuous system improvement and exceeding minimum regulatory requirements, along with the use of third-party verification. The pur-

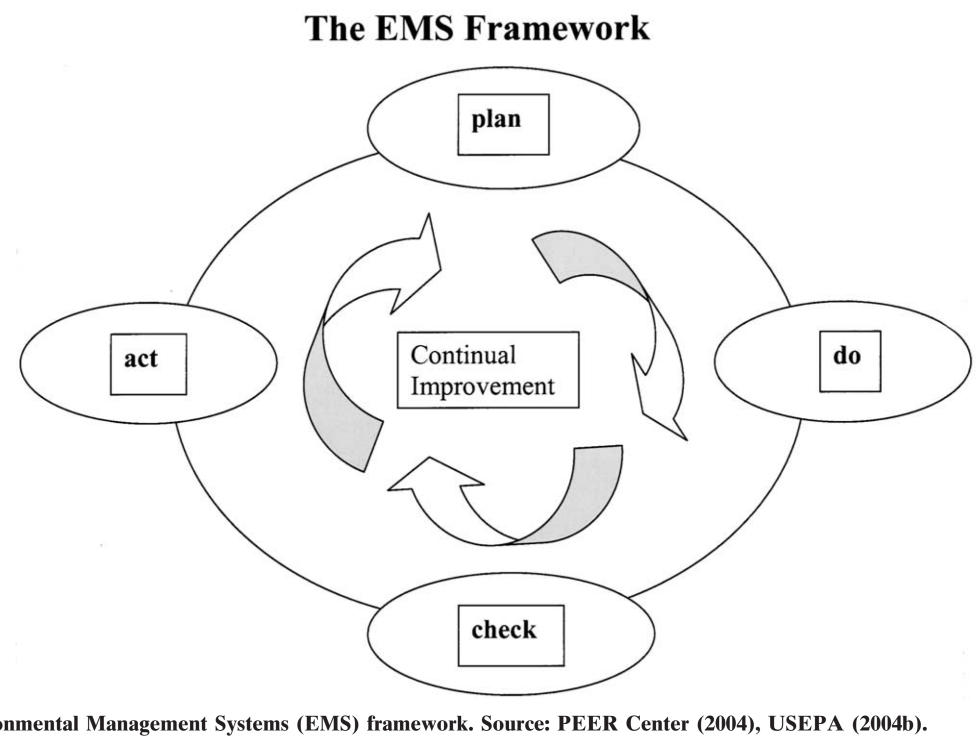

Fig. 3. The Environmental Management Systems (EMS) framework. Source: PEER Center (2004), USEPA (2004b).

pose is to resolve and solve issues and concerns associated with land application practices to attain less controversy and greater sustainability.

Meeting Multiple Legislative Mandates

Legislative mandates in the Clean Water Act (CWA), Resources Conservation and Recovery Act (RCRA), National Environmental Policy Act (NEPA), and various other federal and state statutes contain numerous provisions encouraging the safe and beneficial recycling of wastewater effluents, biosolids, and other organic residuals. The legislation also requires establishing guidance and regulatory requirements for various land application practices as well as other use and disposal practices. All of the mandates, as well as well-established formal rule-making process requirements, must be considered during the development of regulations that affect land application practices.

In addition to formal regulations, both federal and state agencies often develop and issue policy and guidance documents to help explain regulations and voluntary programs, as well as to provide technical assistance. While the agencies are generally committed to using sound science in their decision-making, many other factors affect development of policy, regulations, and guidance documents. These factors include implementation costs, technical feasibility, economic effects on small businesses, legal requirements, and social and political considerations. The agency staff and contractors involved with conducting risk assessments and the development

Table 1. Notable examples of systematic research programs on soil-based treatment systems.

Example	Type of project
Western Regional Land Application Project (W-170) (Brown et al., 2003a, 2003b, 2004; Gilmour et al., 2003; O'Connor et al., 2004; Ryan et al., 2004)	One of a series of regional land application projects supported by the USDA Cooperative State Research, Education, and Extension Service and State Experiment Station directors (e.g., 5-yr study comparing the fate of metals in land-applied biosolids when applied annually vs. once in 5 yr at the same total application rate; evaluation of plateau effect).
University of Minnesota-Rosemount Experiment Station land application of biosolids studies (Clapp et al., 1994)	Studies supported by the USDA Agricultural Research Service and Soil Conservation Service, Metro Waste Commission of the Twin Cities, and the USEPA (e.g., long-term studies of surface applied biosolids on erodible farmland; small watershed catchment studies).
Pennsylvania's Mine Land Reclamation Program and studies by Pennsylvania State University (Sopper and Kerr, 1979; Sopper et al., 1982; Sopper, 1993)	Studies initially supported as a demonstration effort by the USEPA, USDA Soil Conservation Service, Appalachian Regional Commission, Pennsylvania Department of Environmental Protection, and Pennsylvania State University; later supported by the City of Philadelphia's Sludge Management Program (effectiveness of biosolids applied at 35–50 dry tons per acre in sustainable mineland reclamation).
New Mexico State University studies involving land application of irradiated biosolids (Sandia Laboratories, 1979)	Studies supported by the U.S. Department of Energy's Office of Beneficial Uses of Nuclear Byproducts Program and Department of Energy, Albuquerque Operations Office (effectiveness of land-applied biosolids on western rangeland).
Fulton County, Illinois, Mineland Reclamation/Prairie Project and studies undertaken by the Metro Water Reclamation District of Greater Chicago and the University of Illinois (Sopper and Kerr, 1979; Sopper et al., 1982; Hinesly and Hansen, 1983)	Studies undertaken by the Metro Water Reclamation District of Greater Chicago and the University of Illinois (e.g., fate of contaminants and effectiveness of biosolids applied a high application rates to surface minelands).
Albuquerque, New Mexico's Rangeland Reclamation Program and studies (Dennis and Fresquez, 1989; Fresquez et al., 1990; Aguilar et al., 1994; USEPA, 1995b)	Studies undertaken in cooperation with the U.S. Forest Service Rocky Mountain Forest and Range Experiment Station (e.g., reduction of runoff and/or erosion and reestablishment of native grasses on badly overgrazed rangeland using biosolids).
Charles Lathrop Pack Forest Field Research Site and Mountains-to-Sound Program, and studies undertaken by the College of Forest Resources at the University of Washington (Bledsoe, 1981; Cole et al., 1986; USEPA, 1995a; Henry et al., 2000)	Studies undertaken by the College of Forest Resources at the University of Washington with support from the U.S. Army Corps of Engineers, Washington State Department of Energy, USEPA, Seattle METRO, and other groups (e.g., long-term studies on forest land application of biosolids, powerline rights of way, etc.).
Merco (Sierra Blanca Ranch, TX) project and studies undertaken by Texas Tech University and the University of Texas (Texas Tech University, 1998)	Studies undertaken in cooperation with Texas Tech University and the University of Texas with support from the New York City Department of Environmental Protection (e.g., rangeland response to land-applied biosolids).
National Center for Manure and Animal Waste Management Project (North Carolina State University, 2004a, 2004b)	Studies and white papers on a wide range of animal manure management issues.
Pennsylvania State University's Wastewater Renovation and Conservation "Living Filter" Project and studies by Pennsylvania State researchers (Kardos, 1974; Sopper and Kerr, 1979; Pennsylvania State University, 2001)	Example of sustainable land treatment of municipal wastewater via spray irrigation on old fields and forestland (initiated in 1962); studies supported by the USEPA and Pennsylvania Department of Environmental Protection covering a wide range of issues (e.g., vegetation and wildlife responses, effects on ground water quality, etc.).
Muskegon Co., Michigan's Land Treatment Project and studies by Michigan State University, University of Michigan, and USGS researchers (USEPA, 1976, 1980; Demirjian et al., 1980; Muskegon County, 2004)	Example of sustainable land treatment of municipal wastewater via spray irrigation on sandy farmland (initiated in 1973); studies supported by the USEPA, Michigan Department of Natural Resources, and USGS of crop response, fate of nutrients, and downstream water quality improvement.
Lubbock, TX, Land Treatment Project and studies by Southwest Research Institute (Camann et al., 1985; Hinesly et al., 1978)	Example of sustainable land treatment of municipal wastewater via spray irrigation on farmland; studies supported by the USEPA and LCC Institute of Water Research of crop response, fate of nutrients, bioaerosols, and worker health.
Soil Aquifer Treatment (SAT) Research Project and studies by Arizona State University, University of Arizona, Sanford University, University of Colorado-Boulder, Colorado School of Mines, and 10 local wastewater authorities with SAT projects via the National Center for Sustainable Water Supply and support by the USGS and the USDA Water Conservation Laboratory (National Center for Sustainable Water Supply, 2001; Fox et al., 2001; Fox, 2002; Arizona State University, 2004)	Research project and studies supported by American Water Works Association Research Foundation funding and Congressional earmarked funds through a cooperative agreement with the USEPA, including studies of fate of nutrients, pathogens, and trace organics (including estrogenic activity) during SAT.

of background documents associated with rule-making efforts on behalf of the regulatory agency are not experts in all of the areas of science involved with a rule-making effort. Commonly, highly conservative approaches are taken when addressing technical issues where there are, or appear to be, technical references with conflicting conclusions in the published literature. For example, information used to develop the proposed Part 503 rule concerning land application of sewage sludge included data from greenhouse studies involving sludges spiked with metal salts. These data were included despite the availability of better (more scientifically desirable) data from field studies involving sludges with elevated levels of the same trace metals. In other situations, attempts have been made to use the risk assessments and other analyses conducted in developing the Part 503 requirements for land application of sewage sludge as the basis for controlling contaminants in fertilizers and other nonorganic materials without consideration of the biosolids matrix effects and default parameters. Initial efforts to develop binding guidance or regulations for controlling certain practices are sometimes based on conservative assumptions rather than the latest science. Such requirements are open to relaxation if and when adequate technical information is provided to justify such changes in future versions of guidelines or regulations. Several sections of the Part 503 requirements for land application of sewage sludge were based on the 98th percentile quality of biosolids in the National Sewage Sludge Survey (USEPA, 1990) rather than risk assessment-based values, only to be deleted from the rule after successful court challenges after the rule was promulgated in February 1993. A good example of nontechnical influences affecting the rule-making process is reflected in the changes to the initial version of the standards issued by USDA for "Organic Foods" (7 CFR Part 205) in December 2000 under the authority of the Organic Food Production Act of 1990. The final version excluded use of sewage sludge, genetically modified crops, or irradiation in response to 40 774 public comments received in response to the more flexible initially proposed standards.

Improving Disturbed and Contaminated Sites

At least some of the concerns about and resistance to land application can be overcome by projects that help address other environmental problems such as the restoration–revegetation–rehabilitation of highly disturbed and contaminated sites. Thirty years of field experience and well-documented research and demonstration projects prove that land-applied organic residuals are effective tools in reducing the bioavailability of trace metals and establishing sustainable vegetative cover on a number of highly contaminated sites, including a number of Superfund and Brownfield sites (Ryan et al., 2004; Brown et al., 2003a, 2003b, 2004; Rocky Mountain Water Environment Association, 2000; USEPA, 1995b; Sopper, 1993; Jacobs et al., 1993).

The Importance of Nutrient Management

Sustainable land application projects should strive to effectively match the nutrient needs of the crop or vegetation to be grown on the site. Thus, comprehensive nutrient management planning (CNMP) is critical for sustainability both agronomically and environmentally. Done well, CNMP avoids the buildup of nitrates, phosphorus, or other nutrients in amended land to the point where they become contaminants in the soil, storm water runoff, and/or underlying ground water (Sharpley et al., 2003; USDA Natural Resources Conservation Service, 1992, 2003).

The Role of Systematic Research Programs

Systematic research programs have advanced the understanding of how soil-based treatment systems work, addressed new areas of concern when they arose, and improved the overall design, performance, and reliability of land application systems as sustainable soil treatment and recycling systems. Notable examples are shown in Table 1.

These, and other facilities across the country, continue to collect important data associated with the performance of operating land application projects. However, few programs are collecting the type of data needed to effectively respond to the questions being raised about emerging pathogens (World Health Organization, 2001, 2003a) and new chemicals of concern (National Research Council, 2002; Stevens et al., 2003; Hale et al., 2003) associated with land-applied wastewater effluents, biosolids, industrial residuals, and manures. Research projects supported by the Water Environment Research Foundation, USEPA, USDA, and others will help fill these information gaps over time, but more effort is needed. Systematic research programs to support studies aimed at producing information that advances our understanding of how soil-based treatment systems work, to address new areas of concern as they arise, and to continue to improve the overall design, performance, and reliability of land application systems as sustainable soil treatment and recycling systems are as important today as ever.

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