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The Application of Sewage Sludge for Soil Remediation.

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One technique for repairing degraded soils of a reclamation or restoration site is to use sewage sludge. In soil degraded sites like industrial developments and mining, the addition of organic matter is necessary for the site to sustain ecosystem processes (Bradshaw, 1997). Without adequate mineral nutrients, soil organic matter, and mineral particles that keep the ecosystem working and producing new plant material, the ecosystem can not function (Bradshaw, 1997). Natural succession of ecosystem redevelopment may take a long time to restore to a functional state (Bradshaw, 1997). The fact that sewage sludge contains high amounts of organic matter, nitrogen, phosphorus, and carbon, and micronutrients, makes it beneficial to use sewage sludge in repairing the degraded soils to sustain the ecosystem (Page and Chang, 1994). Sewage sludge can increase the rate of ecosystem redevelopment, faster than natural succession (Bradshaw, 1997). In one study of sewage sludge application on infertile and degraded soils it was seen that sewage sludge increased organic nitrogen and organic carbon levels enough to sustain plant growth where it had not been possible (Palazzo, 1983).

Sewage sludge did not exist as a waste product until the 20th century (Page and Chang, 1994). Sewage sludge is a byproduct of wastewater treatment facilities and it is an agglomeration of pollutants, organic matter, and particular metals (Page and Chang, 1994). After wastewater was cleaned, the next step was to dispose of the sewage sludge. One of the first ways used to dispose of sewage sludge was land application. Other ways sewage sludge was disposed of traditionally were landfill, surface disposal, incineration, and ocean disposal (Lue-Hing et al. 1994). Land application was the most common way to dispose of the sewage sludge and the most common users of land application were people like farmers. The farmers spread raw sewage sludge (full of pollutants) onto the land, using it as a substitute for chemical fertilizers (Page and Chang, 1994).

Sewage sludge has potential to contain pollutants and particular metals. Moreover the kinds of pollutants and particular metals varies from batch to batch. Without analysis, it is difficult to tell what kind of heavy metals and other pollutants exist in sewage sludge and if the contaminants exist at levels of concern (Clapp et al. 1994). Early users of sewage sludge did not know of the pollutants that existed in the sewage sludge, and how to lower or remove the pollutants to safe levels. The early users' incomplete understanding of sewage sludge resulted in avoidance of sewage sludge as a land amendment (Lue-Hing et al. 1994).

By the 1970's, studies on sewage sludge discovered that the fate and effects of sewage sludge contaminants could be problematic. Further studies on sewage sludge showed pollutants, both metals and organic compounds, could exist in sewage sludge. Some of the possible organic pollutants contained in sewage sludge could be aldrin / dieldrin, benzene, benzo(a)pyrene, bis(2-ethylhexyl)phthalate, chlordane, DDT/DDE/DDD, heptachlor, hexachlorobenzene, hexachlorobutadiene, lindane, n-nitrosodimethylamine, polychlorinated biphenyls, toxaphene, and trichloroethylene (Ryan, 1994). The possible heavy metals contained in sewage sludge are arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc (Ryan, 1994).

Concern grew that there was not enough information about how the pollution potential of sewage sludge could effect ground water bodies and consumers through the food chain (Page and Chang, 1994). The scientific evidence to back up how easily or quickly these contaminants could effect the food chain was lacking (Page and Chang, 1994). With an attempt to satisfy the concern, the Environmental Protection Agency developed and enforced environmental guidelines for sewage sludge use, but did not establish any regulations at the time (Lue-Hing et al. 1994). Adhering to these guidelines increased the cost of sewage sludge land application (Lue-Hing et al. 1994). The increased cost and lack of research has discouraged sewage sludge land application (Lue-Hing et al. 1994). After two decades of research Page and Chang (1994) determined that sewage sludge amended soils benefited from the favorable nutrients in sewage sludge, and that some heavy metals often do not accumulate in the soils (As, Cr, Cu, Pb, Hg, Ni, and Zn) in levels that are considered to be a risk. Depending on the soil conditions, Cd, Mo, and Se could however be taken up into the food chain at harmful rates (Page and Chang, 1994). Likewise, Palazzo (1983) found that the metal concentrations resulting from the sewage sludge increased in soil, but not to excessive levels.

Improving infertile soils while minimizing contaminant risks motivated the U.S. Environmental Protection Agency to create federal regulations, entitled *Standards for the Disposal and Utilization of Sewage Sludge* (title 40, parts 257 and 503). The regulations are based on the risks to human health and the environment (Lue-Hing et al. 1994). The regulations govern two aspects: pollutant-loading boundary of sewage sludge and application on farms, gardens and lawns of private citizens, public sites like roadways, use in land reclamation, and non-food chain uses like forests (Page and Chang, 1994). First, the regulations make sure that sewage sludge has pollutants removed to undetectable levels (Froisland et al. 1982; Palazzo, 1983; Borgegard and Rydin, 1989; and Richardson and Evans, 1986). The sewage sludge is treated to remove pathogens from it and then put into a biosolid (Lue-Hing et al. 1994; and EPA, 1995). Sewage sludge must contain less than a defined level of ten different metals, if it is to be used for land application (As, Cd, Cr, Cu, Pb, Hg, Mo, Ni, Se, and Zn) (Lue-Hing et al. 1994). Second, when the sewage sludge is land applied the regulations control where the sludge goes on the land. Land is categorized by the regulations into kinds that are suitable and unsuitable for sewage sludge land application (EPA, 1995).

Some post-regulatory examples of sites where researchers have used sewage sludge are sites of low fertility. Examples of low fertility sites are a slope of uranium tailing pile, iron-mine tailings, magnesian limestone quarrying, and acidic dredge soils (Froisland et al. 1982; Borgegard and Rydin, 1989; Richardson and Evans, 1986; Palazzo, 1983). Another type of example site is the restoration of a rangeland (Aquilar et al. 1994). On the rangeland restoration the purpose of the sewage sludge was not only to increase soil fertility, but also to increase soil water retention. The sewage sludge had a positive impact on the soil chemistry increasing the water retention and nutrient levels of the rangeland soil (Aquilar et al. 1994).

How Biosolids are derived from Sewage Sludge

The first thing to consider about sludge biosolids is the pathogen classification. The pathogen classification has two parts, A and B. Class A has such low pollutant that it is considered an organic fertilizer with no restrictions (Walker, 1994). The attempt in class A is to lower the pathogen content so low it can not be detected (EPA, 1995). This includes removing all possibilities of fecal coliform or salmonella species bacteria, enteric viruses, and viable helminth ova (EPA, 1995). Class A refers to all sewage sludge that is sold or given away for the application to land and bulk sewage sludge that is applied to a lawn or home garden (EPA, 1995). Class B contains some pathogen content requiring some restrictions on it for grazing, site access, and crop harvesting (Walker, 1994). The purpose of class B is to reduce the pathogen content to a level that is unlikely to pose a threat to public health and the environment (EPA, 1995). Class B sewage sludge can not be sold or given away for land application, and is not to be handled by people (EPA, 1995). Finally any sludge that cannot be classified under these two classifications should not even be considered to be used for land use, and should be checked with Part 503 (Walker, 1994).

Sewage sludge can go through numerous processes to reduce pathogen content. The processes are aerobic digestion, air drying, anaerobic digestion, composting, and lime stabilization (EPA, 1995). In aerobic digestion the sewage sludge is treated with oxygen, in anaerobic digestion the sewage sludge is treated in the absence of air (EPA, 1995). In air drying, the sewage sludge is dried for months on beds of sand or paved basins (EPA, 1995). In composting, the sewage sludge is treated either within a static aerated vessel or windrow composting methods (EPA, 1995). And finally lime stabilization is adding lime to the sewage sludge to raise the pH (EPA, 1995).

To make the sewage sludge usable for land application, the wastewater treatment facility needs to put the sewage sludge into a biosolid form. Presently there are six different biosolids created that can be used in land application, liquid, dewatered, air-dried, alkaline-treated, composted, and heat-dried (Walker, 1994). The liquid form is keeping the sludge in liquid state (EPA, 1995). The dewatered form is created by a high-force separation (i.e. centrifuge) of the water and solids in the sewage sludge (EPA, 1995). The air-dried form is created by air drying the sewage sludge (EPA, 1995). An aerobic process that involves the biological stabilization of sewage sludge in a vessel creates the composted form (EPA, 1995). An application of heat to the sewage sludge creates the heat-dried form (EPA, 1995). How each biosolid is created has an effect on how the end product will look, its potential for malodor (smelling bad), how publicly acceptable it is, its pathogen class, its content of nitrogen, phosphorus, potassium, lime, and metals, how it is stored, and its restrictions (Walker, 1994).

The liquid form can be stabilized in three ways: aerobic digestion resulting in 3 to 9% nitrogen content; anaerobic digestion resulting in 3 to 7% nitrogen content; and lime stabilization resulting in 2 to 4% nitrogen content (Walker, 1994). This form is applied as a liquid on the surface or injected and is in the class A pathogen classification (Walker, 1994). The *end use* of this form is a fertilizer on pasture and row crops, forests, and reclamation (Walker, 1994). Some *advantages* of this form are it is cheapest to produce, it is high in nitrogen content, it can be stored in lagoons, and anaerobic processing yields energy (Walker, 1994). Some *disadvantages* are it is expensive to transport long distance, it has malodor potential, it has management practices plus site restrictions, and aerobic processing uses energy (Walker, 1994).

The dewatered form can be stabilized in three ways: aerobic digestion resulting in 2 to 5% nitrogen content; anaerobic digestion resulting in 2 to 5% nitrogen content; and lime stabilization resulting in 1 to 3% nitrogen content (Walker, 1994). *End use* is a fertilizer on pasture and row crops, forests, and reclamation (Walker, 1994). Some *advantages* are it is cheap to transport, it can be applied as cake on the surface or it can be rewetted to inject, and the anaerobic processing yields energy (Walker, 1994). Some *disadvantages* are it costs more to dewater, it has malodor potential, it has management practices plus site restrictions, and the aerobic processing uses energy (Walker, 1994). The dewatered form is in the class A pathogen classification (Walker, 1994).

The air-dried form can be stabilized in three ways: aerobic digestion resulting in 2 to 4% nitrogen content; anaerobic digestion resulting in 2 to 4% nitrogen content; and lime stabilization resulting in 1 to 3% nitrogen content (Walker, 1994). This form is easy to handle and is spread onto the site and it is in the class A pathogen classification (Walker, 1994). The *end use* of this form is a fertilizer on pasture and row crops, forests, and reclamation (Walker, 1994). Some *advantages* of this form are it is cheaper to transport, it is easy to store and get uniform application (Walker, 1994). Some *disadvantages* of this form are it requires more space and time to dewater and it is climate dependent, and it has management practices plus site restrictions (Walker, 1994).

The alkaline-treated form can be stabilized in two ways: a process with kiln dust resulting in 1 to 2% nitrogen content and a process without kiln dust resulting in 1 to 2% nitrogen content (Walker, 1994). This form has a consistency of wet ag lime. This form can be in either A or B pathogen class (Walker, 1994). The *end use* is it is used as ag lime and artificial soil for daily landfill cover (Walker, 1994). Some *advantages* of this form are it is quick to get working, it is cheap when odor is not controlled, and it provides nutrients and lime (Walker, 1994). Some *disadvantages* of this form is high lime is not desirable for some sites, and it has potential malodor when processed and stored (Walker, 1994).

The composted form can be stabilized in many variations of agitated and static aerated processes in and out of vessels, resulting in 1 to 2% nitrogen content (Walker, 1994). This form is easy to store and handle and is in the class B pathogen classification (Walker, 1994). The *end use* of this form, a peat-like substance, is valuable as a soil conditioner and has many horticultural, landscape and nursery uses (Walker, 1994). Some *advantages* of this form are it has high public acceptance, and it works as a peat substitute with slow release of nutrients (Walker, 1994). Some *disadvantages* of this form are that the process produces odor and bioaerosols, and it is expensive to produce (Walker, 1994).

The heat-dried form is stabilized by indirect, evaporative, and direct heating processes, resulting in 2 to 10% nitrogen content (Walker, 1994). This form comes in pellets and is in the class B pathogen classification (Walker, 1994). The *end use* is mostly used at low rates as nutrient source, or carrier in chemical fertilizer (Walker, 1994). Some *advantages* of this form are it is high in nitrogen and it is easy to store and use (Walker, 1994). Some *disadvantages* of this form are it must be kept dry when stored, it has a strong odor if primary product is heat-dried, and it is expensive to produce (Walker, 1994).

Consideration of a Site for application of a Sewage Sludge Biosolid

To determine whether or not the sludge biosolid can be applied, the person in charge of the restoration needs to evaluate the site. To evaluate the site there are four categories of information that need to be considered. The person in charge needs to posess existing information sources about the site (the history of the site), the site's land use, the physical characteristics of the site, and site screening (EPA, 1995). The places that usually hold existing information are historical records, past owners of the land, and present owners of the land. Gathering information on present and past land use is next. The type of land use plays a big role in determining whether the site can be used for sewage sludge application. Sewage sludge can not be used on lands that are areas of historical or archeological significance and are environmentally sensitive (EPA, 1995). Physical characteristics of the site are important to discover. These characteristics are things like soil surveys, vegetation surveys, geology and topography surveys, and hydrology surveys. Once the physical characteristics are known, the site screening happens. The physical characteristics need to be compared with the regulations of the part 503, to perform the site screening. Sewage sludge is not suitable to apply on areas near ponds, lakes, rivers, and streams without appropriate buffer areas and it is not suitable to apply near wetlands and marshes without a permit (EPA, 1995). Steep areas with sharp relief and undesirable geology and soil conditions are not suitable areas to apply sewage sludge (EPA, 1995). Once the site is approved, it is prepared. The site preparation is to grade the site back to its original contour, roughen or loosen the soil (scarification), remove all debris from the site, and control erosion and surface runoff (EPA, 1995).

How the Sludge Biosolid is applied

The physical technique of applying the sewage sludge depends on the biosolid chosen for the site. Generally land application of sewage sludge is done by vehicular surface spreading, subsurface application, or irrigation application (EPA, 1995). Vehicular surface spreading is accomplished by tank truck spreading or tank wagon spreading (EPA, 1995). Subsurface application is performed by subsurface injection, plow furrow, or disking methods (EPA, 1995). Irrigation application is done by spray irrigation or flood irrigation (EPA, 1995).

Finally, an application rate has to be determined. The 1995 EPA Design Manual has specific formulas for determining the application rate for specific sites. In general forestland application has a typical rate of about 18 tons/hectare and a reclamation site has a typical rate of 112 tons/hectare usually applied once a year (EPA, 1995). The maximum acceptable one-time application of sewage sludge to a reclamation site is based on evaluating the effect of excess nitrogen resulting from a large application on existing soil with soil-water nitrate concentrations (EPA, 1995). There are four steps in doing this calculation. The first is to determine the maximum allowable application rate, Smax (The first step is based on the Part 503 CPLR limits, chapter three) (EPA, 1995). The second part is to perform nitrogen budget calculations to determine the available nitrogen in excess of plant needs (using Smax, as above) (EPA, 1995). The third part is to estimate the soil-water nitrate concentrations that will result from excess nitrogen from a one-time application at Smax (EPA, 1995). Finally the fourth part is calculating whether soil-water nitrate concentrations from application at Smax are not acceptable (EPA, 1995). If so, a lower application rate is set that will not exceed a defined acceptable soil-water nitrate concentration (EPA, 1995).

Summary

When considering sewage sludge as a soil remediation technique, the biosolid type, the site's usage parameters, and sewage sludge application technique all need to be reviewed. It is important to review these considerations in respect to the EPA regulations. Sewage sludge has been avoided as a soil amendment because of sewage its variable potential for pollution. With new federal EPA regulations and research, sewage sludge use has overall lower environmental risks. Federal regulations require wastewater treatment facilities to treat sewage sludge so it complies with pollution standards. The pollution standards govern pathogen content, biosolid creation and use, suitable and unsuitable land for application, and application options. Due to these advances in technology and research, sewage sludge is a viable choice for soil remediation in sites of poor fertility like mining and industrial developments, as well as infertile soils with water retention problems.

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