MECHANISMS SUPPORTING A POTENTIAL USE OF MUNICIPAL SEWAGE SLUDGE IN WETLAND CREATION

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Abstract. Municipal sewage sludge (MSS) is proposed as a suitable component of wetland substrates for the purpose of wetland creation. Sludge use is currently limited to dry sites due to potential water pollution concerns. Wetland structure and function were compared to sewage and waste disposal facilities to identify strengths and weaknesses in natural pollution control mechanisms. Wetland and substrate designs were proposed to augment the natural mechanisms.

INTRODUCTION

Background. Municipal sewage sludge has been recycled successfully as a soil conditioner in mine reclamation projects, as an agricultural soil amendment and as a top dressing in forests *(Sopper, 1993).* MSS has not been permitted for use in wetlands, because the United States Environmental Protection Agency (EPA) guidelines prohibit sludge application where there is the potential for direct surface water or ground water table contact. However, the conversion of existing wastewater treatment ponds to forested and scrub-shrub wetlands has been proposed *(Alford and Ashley, 1995),* and wetlands have been used successfully for wastewater treatment.

Sewage treatment is modelled on natural physical and biological processes. Although controlled and augmented in treatment plants, these processes occur at definable, but variable rates in the natural environment. The use of natural and constructed wetlands for wastewater treatment illustrates one case for using natural waste recycling systems. Evaluating the potential for incorporating MSS in wetland substrates is potentially a similar application.

Site Considerations. A sand and gravel mine pit located in the Chattahoochee River floodplain near Columbus, GA is to be converted to a wetland. Columbus Water Works acquired permits to dispose of inert waste (yard wastes, tree limbs, stumps and broken concrete) in the pit. Once filled, the pit will be capped with soil and planted. This research proposes combining MSS with the inert waste as an integral component of the wetland substrate.

The flooded mine pit is 17.5-hectares in area, has steep barren sides and a depth that varies from 4.5 to 7.0 meters. Compared to an adjacent wetland having a maximum depth of 75 cm. and an average depth of 23.4 cm., 540,000 m^3 of fill would be required to create a similar wetland in the pit.

On the site, Columbus Water Works (CWW) has land applied MSS by subsurface injection for many years. Vegetative crops are planted to utilize sludge nutrients and to stabilize the soil surface. The land elevation ranges between 205' and 210' MSL, while the 100-year flood elevation is 224' MSL. Inundation occurs periodically with durations of one to six days. The hydrologic regime is fully described in Sawhill, *(1995).* Although these fields do not qualify as wetlands, (lands possessing hydrophytic vegetation, hydric soils, and saturated or covered by water at least some part of the year), periodically they do experience temporary wetland conditions. This research considers a similar subsurface installation of MSS, but in extended wet conditions.

Relevance. Combining inert waste disposal, MSS disposal and wetland creation may present beneficial economic and environmental opportunities. Sand and gravel mines are infrequently reclaimed and they are often located in floodplains where development is restricted. Properties in floodplains may be available at lower cost than more developable properties. Significant subsurface investigation records are often maintained by mining companies, and these may be useful for site selection and planning purposes. The conversion of exhausted mining sites to disposal facilities would be less likely to generate controversy than would the conversion of most farmlands. Once waste disposal is completed, the created wetland could serve as a replacement wetland mitigating other public projects. Notwithstanding economic potential, the conversion of waste property to beneficial habitat is environmentally desirable and a practical step toward the sustainable use of natural resources.

METHOD

A proposed MSS substrate was compared with a natural wetland substrate to identify differences in content and differences in concentrations of shared components. Differences were considered to be an indication of a probable need for mechanisms or methods of mitigation. The structures and functions of existing approved waste treatment and disposal methods were compared to natural wetland structure and function to identify strengths and weaknesses for pollution control in natural wetlands. Identified weaknesses were proposed to be solved by substrate design and construction practices. Published data regarding nutrient cycling, fate of metals and EPA regulations for sludge disposal were used. Rates and quantities of denitrification, substrate degradation, and methane production are fully documented in Sawhill, *(1995)*.

RESULTS

The proposed wetland substrate was defined by locally available daily quantities of inert waste (160 m^3 d^{-1}) and of anaerobically digested MSS (23.78 dry tons d^{-1}). Inert waste was not considered to be a major pollutant source, therefore comparison of the MSS with a natural wetland substrate was performed. A chemical analysis of a Georgia peat was not found in the literature, so a North Carolina peat *(Campbell, 1981)*, was selected as a reasonable comparator. Chemical analysis of a CWW sludge was supplemented with average U.S. MSS data to generate a complete sludge profile *(personal communication: Jordan, Jones & Goulding, Inc., 1994 and U.S.E.P.A., 1983)*. Pathogen content was not available, but the sludge was identified as Class B (containing some pathogens). Table 1 identifies the major similarities and differences between the peat and sludge. Three differences are important: sludge is higher in nitrogen, metal content and it contains pathogens. Thus mechanisms to eliminate or mitigate these three differences were pursued.

Nitrogen

The studied sludge contains 0.08% nitrate (NO_3)-N, 1.37% ammonium (NH_4)-N and 7.27% organic-N. Nitrate-N is highly mobile in water and is the primary nitrogen pollutant of concern. NH_4-N is much less mobile, but it is converted to NO_3-N by nitrification. Organic nitrogen is slowly converted into NH_4-N. Since the process of nitrification results in the conversion of NH_4-N and Organic-N to NO_3-N, control of nitrogen must be addressed throughout the cycle.

Table 1. Peat and Sludge Characteristics

Physiobiochemical Characteristics	N.C. Peat	Site Sludge
Volatile matter	62.9%	65.1%
Organic carbon	32.4%	31.2%
Total nitrogen	1.4%	8.7%
Bulk density	low (0.1 g cm^{-3})	low
Cation exchange capacity	high	high
Metal content	low (varies)	moderate
Pathogens	n/a	some
Wetting when dry	resists	resists
Water holding capacity	high	high

Nitrogen pollution can be controlled in four distinct ways: consumption (especially by plants), denitrification of nitrates into nitrogen gas, adsorption of nitrogen compounds to clay particles, and blocking dissolved nitrogen transport by means of a barrier. Approved methods of sludge treatment and disposal use these four nitrogen control strategies to varying degrees. All four of these controls also occur in wetlands.

Consumption. Plant uptake of nitrogen is the basis for the land application of sludge as a disposal option. Applied MSS quantities are based on the plant available N content, a basis similar to fertilizer rate determination. Aerobic microbes in the soil nitrify NH_4-N to NO_3-N making the nitrogen readily available to plants. Plants then consume the nitrogen for biomass production.

Wetlands are typically nitrate deficient, because the soil is anoxic. Consequently, wetland plants have adapted to consume NH_4-N directly or to provide a thin oxygenated zone along the periphery of their roots where nitrifying microbes can operate *(Etherington, 1983)*. Because a greater portion of the sludge nitrogen content is NH_4-N or will be transformed to NH_4-N, ecosystems specifically adapted to NH_4-N consumption would appear more desirable. The restricted aerobic sites limit the location of nitrification to points of consumption, eliminating wholesale nitrification and minimizing the total quantity of mobile nitrates. Wetland plant biomass production often exceeds terrestrial production levels, suggesting wetlands have a greater capacity for more rapid utilization of available nutrients.

Denitrification. Facultative and anaerobic wastewater stabilization ponds utilize an anaerobic layer that serves as a site for denitrification by anaerobic microbes. These bacteria denitrify NO_3-N to nitrogen gas (N_2). Wetlands are effective denitrifying systems because of their anaerobic substrates. Denitrification has been shown to occur biologically as previously noted and also chemically by interaction with reduced iron (Fe^{+2}). Nitrate content in groundwater has been shown to fall to zero within one or two meters below the oxidation limit and a strong correlation between Fe^{+2} presence and the absence of NO_3 in groundwater has also been shown *(Lind, 1985)*. Because Georgia piedmont soils and groundwater contain high amounts of iron, they could serve as effective barriers to nitrate leaching in wetlands.

Adsorption. Soil cation exchange capacity is evaluated for the land application of sludge, and is an important factor in controlling nitrogen leaching. Clay particles carry negative charges which attract and adsorb positively charged ions. Hence, NH_4^{++} is readily adsorbed, but NO_3^- is not *(Killham, 1994)*. The combined tendency for adsorption and low mobility of NH_4-N typically results in high concentrations of immobile NH_4-N in wetlands. Georgia piedmont soils are often rich in clay that can be located within or at the periphery of the wetland substrate to maximize NH_4-N control.

Sealing. In order for nitrogen control to occur within a wastewater treatment pond, nutrient laden water is detained long enough to be treated while limiting leaching to the soil. Pond sealing has been shown to occur by three mechanisms: soil pore clogging by sludge solids, further clogging by chemical ion exchange, and clogging due to organic growth *(Bobay, 1988 and Chang et al., 1974)*. The effectiveness of such seals varies from partial to complete depending upon the soil type, the sludge composition and the length of time the pond has been in operation. Sewage sludge applied to an acidic lake resulted in extending the water residence time from one year to several years due to sludge stimulated eutrophication and resultant organic sedimentation *(Davison, 1986)*. Similar effects have been shown to occur at the substrate-groundwater interface in created wetlands. Newly constructed wetlands built in soils too permeable to retain a stable pond level were observed to seal themselves following an initial algal bloom. Water loss to the ground became negligible; the organic material generated by the algal bloom and its subsequent death and decomposition clogged the basin soil pores *(personal communication, Garbisch, 1994)*.

Metals

Metal content in MSS is typically low, but any movement of metals into surface or groundwater is of concern. In land application of sludge, metals are retained within the top few centimeters of the soil by two mechanisms: adsorption to soil and sludge organic matter and vegetative assimilation *(Sopper, 1993)*. Sludge application quantities are limited by the available soil cation exchange capacity or plant susceptibility to metal toxicity. Three mechanisms exist in wetlands limiting metal transport: a high wetland soil cation exchange capacity, anoxic conditions and a near neutral pH.

The organic carbon in peat yields a high cation exchange capacity. Consequently, peat has been used to treat waste water *(Coupal and Lalancette, 1976)*, remove cadmium and chromium from wastewater *(Viraraghavan and Rao, 1992)*, remove aluminum from contaminated water *(Wieder et al., 1988)* and to remove metals from landfill leachate *(McLellan and Rock, 1988)*. The combined inert waste and MSS will provide a highly organic substrate comparable to natural peat.

Anoxia in inundated wetland substrates controls soil and water pH and produces reducing conditions *(Mitsch and Gosselink, 1993)*. Metals are least mobile at a pH >6.0. Excluding some southern black water swamps and ombrogenous bogs, wetlands tend to maintain a pH of >6.5. The inclusion of sludge in the wetland substrate should enhance pH conditions, because sludge applied to acidic mine spoils and to acidic lakes has been shown to raise both soil and water pH to near neutral *(Sopper, 1993 and Davison, 1986)*. Under reducing conditions, most metals become insoluble and precipitate or are adsorbed to the soil. When reducing conditions result in the biologic consumption of sulfur, H_2S odors typical of wetlands occur. Free iron, zinc, copper and other metals at near neutral pH conditions can precipitate with sulfur as insoluble metal sulfides, sequestering metals and reducing odor production.

Pathogens

EPA 503 rules require pathogen reduction and vector attraction reduction measures for Class B sludges. None of the required pathogen reduction measures were appropriate for wetlands because of natural temperature fluctuations. However, EPA has approved the anaerobic digestion of lagooned sludge for a period of fifteen years as an equivalent measure *(U.S.E.P.A., 1992)*. Since the proposed wetland application would be permanent, wetland anaerobic conditions wetland would appear to satisfy pathogen reduction criteria.

Two vector attraction reduction methods appear to have potential application for created wetlands. If the wetland substrate is constructed by installing MSS into a flooded pit, (simulating a waste stabilization pond), "Option 503.33(b)(1) Reduction in Volatile Solids Content" could apply, requiring a reduction of the sludge volatile solids mass by 38-percent. Because the residence time in the wetland is permanent, eventual degradation of the sludge should satisfy the intent of the regulation. If the wetland substrate is constructed by layered applications in a dewatered pit, "Option 503.33(b)(11) Covering Sewage Sludge" could be implemented by applying a daily soil cover layer *(U.S.E.P.A., 1992)*.

DISCUSSION

The disposal of MSS is a balance between utilizing available nutrients and sequestering potential pollutants. Of the existing options, land application of sludge is the most sustainable approach, but it utilizes existing cropland for a non-consumable crop and sequesters pollutants in the top few centimeters of the soil. Wetland substrate construction in mine pits would enable nutrient consumption throughout the substrate profile and sequester contaminants at greater depths.

Wetlands are hydrologically based structures. To maintain effective pollution control mechanisms, the hydrological system sustaining the wetland must maintain inundation and limit massive pulses. Careful site selection will be critical to identify mine pits suitable both for MSS disposal and for wetland creation. Consideration of watershed, flood periodicity, groundwater characteristics, soil and geological attributes, inert waste and MSS composition and availability, and construction requirements will be necessary. Except for wetland establishment criteria, such site evaluations are typical of current disposal and treatment methods. Detailed site analyses of the study pit and performance evaluations of three proposed designs are detailed in Sawhill, *(1995)*.

Should the wetland begin to dry out, rapid nitrification in surface sediments would begin and metals within those surface sediments could again become soluble. Such drying periods are common in wetlands and serve to cycle nutrients, but if flooding followed a dry period, pollutants could move downstream. Anoxic conditions typically recur within three days of inundation, limiting metal mobility even after a period of oxidation.

Maintaining the surface integrity of the wetland will be important. Surface integrity is affected by plant cover, hydrologic conditions and animals. Since most of the sludge will be located deep in the pit, even catastrophic flooding would probably have little impact on the stored material. However, maintaining an effective vegetative cover will be the best defense against substrate disturbance. Animal burrowing could pose some problems, but would generally be limited to the root zone of the substrate. Depending upon the method of substrate construction, homogeneity of its contents and the rapidity of its completion, degradation of the substrate by methanogenesis may result in unequal settling or some disruption of the substrate due to methane migration to the surface. Such settling could effect the vegetation at the surface of the wetland, and should be monitored periodically.

The amount of time required to seal the substrate-groundwater interface should be considered. Different methods or rates of substrate construction may enhance the rate of sealing or may limit the amount of pollutants potentially available for transport. An initial nutrient application may be desirable to initiate eutrophication and the sealing of the ground water pores prior to placement of sludge solids. Consideration may also be given to adding clay material to the substrate if adjacent soil materials are deficient in clay content. Clay could be used as a pit liner, daily cover or as a substrate additive during application.

SUMMARY AND RECOMMENDATIONS

The disposal of sludge is currently limited to sites where there is no potential for surface water or ground water table contact due to concerns for the transmission of nitrates, metals and pathogens. Numerous mechanisms indigenous to wetlands were found to be beneficial for mitigating potential MSS pollutants. Wetlands are effective denitrifying systems eliminating NO_3-N and consuming NH_4-N. High iron content in Georgia soil and water also facilitates chemodenitrification in wetland conditions and the coprecipitation of metals at the oxidation limit. Georgia clay soils can adsorb NH_4-N, and the organic content of MSS and inert waste provide abundant sites for metal adsorption. Tending to naturally seal, a created wetland may be an effective repository for MSS.

Field testing of a created wetland by codisposal of MSS and inert waste will be needed to validate the conceptual design. The many interrelated factors cannot be fully evaluated without site testing to determine critical failure modes. Measurement of actual sealing time, the partitioning of denitrification processes and the fate of metals and pathogens needs to be better defined. Using MSS as a wetland substrate could reduce disposal costs by providing an alternative to solid waste landfill disposal, utilize abandoned mine lands and enable joint-funding of MSS disposal with wetland mitigation projects.

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