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Physical Properties of Minesoils In West Virginia and Their Influence on Wastewater Treatment

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ABSTRACT

Wastewater treatment in southern West Virginia is limited by steep terrain and shallow soil. Surface mine reclamation replaces soil materials that may be suitable for wastewater treatment. Two minesoil series, Kaymine (a loamy-skeletal, mixed, nonacid, mesic Typic Udorthent) and Sewell (a loamy-skeletal, mixed, acid, mesic Typic Udorthent), were selected and soil samples were collected on six reclaimed surface mines to determine texture, bulk density, water retention, and saturated hydraulic conductivity (Ksat). Kaymine had more clay and silt and higher moisture retention than Sewell. In A horizons, Kaymine Ksat was about two orders of magnitude faster than Sewell, but Ksat values were highly variable within and among sites. On two reclaimed mine sites (one Sewell and one Kaymine), tapwater or wastewater was surface applied to 9 m^2 field plots over 32 weeks. Leachate was collected in 50 and 100 cm wells and analyzed for chemical and microbiological properties. On the Sewell minesoil, little water was collected in wells after application, therefore water failed to move adequately in this minesoil. On Kaymine, Fe, Mn, sulfate, and suspended solids were present in all wells, indicating flushing of these materials from minesoils into wells. Nitrate (NO_3)-N was about two times greater in wastewater than tapwater and this same ratio was found in corresponding wells. Biological oxygen demand was decreased by 87% from wastewater to water in wells. Fecal coliform bacteria were not removed by wastewater passing through Kaymine soils. In general, these minesoils are not suitable for wastewater renovation based on the application methods and rates employed in this study.

Many communities and individual households in the Appalachian region of the eastern USA lack wastewater treatment facilities. For example in southern West Virginia, <20% of the housing units had adequate wastewater treatment systems in 1990 (West Virginia Bureau of Census, 1990). The mountainous topography, decreasing population, and low employment rates in the area restrict the development of large municipal wastewater collection and treatment facilities. Only small amounts of flat or nearly level land are available along creeks and rivers in the area. These lands are flood prone and generally already occupied by houses or industries. Community and industrial development in southern West Virginia is primarily found along the narrow valleys near streams and rivers. Therefore these communities must find other means and/or other technologies for wastewater treatment.

As new homes or commercial and service industries are constructed, on-site wastewater treatment systems should be considered since large-scale, municipal alternatives are not economically feasible at current population densities. Historically, the most common type of on-site wastewater treatment system for individual homes is a septic tank with a subsurface soil absorption system. The system relies on gravity to transport wastes from the residence to the soil with minimal pretreatment before application to the soil (Reneau et al., 1989). Most of the renovation occurs as the wastewater percolates through the soil prior to reaching ground or surface water. However, steeply sloping land and shallow soils in the mountainous Appalachian region make septic tank drain fields hard to install. Drain fields often provide little or no wastewater treatment due to insufficient soil depth, low hydraulic conductivity, underlying rock, and shallow water tables. Groundwater contamination is frequently reported where on-site systems discharge into shallow water tables (U.S. Environmental Protection Agency, 1977).

Large, flat tracts of land are available near many towns in southern West Virginia due to surface mining of coal. After coal has been removed, these areas are reclaimed by creating nearly level land on tops of mountains and placing excess overburden materials in engineered valley fills. Most of these areas after reclamation support a variety of forage and tree species but have not been developed to any significant extent. A few sites have been developed for houses, community services, and industries (Zipper and Skousen, 1990). Because reclaimed mine lands may be used for construction sites and large wastewater treatment facilities are unlikely to be constructed in the region, these minesoils should be evaluated for their ability to accept and treat wastewater. If minesoils demonstrate sufficient treatment potential, then individual wastewater treatment facilities can be designed and installed.

Rock fragment content and size, soil texture, bulk density, porosity, water-holding capacity, and pore size distribution are some physical properties that affect water movement and treatment in soils. Minesoils in West

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Abbreviations: BOD_5, five-day biological oxygen demand; FC, fecal coliform bacteria; TSS, total suspended solids.

Virginia generally have high rock fragment content when compared with surrounding native soils (Smith et al., 1971; Thurman and Sencindiver, 1986). Bulk density of minesoils is generally higher than that of natural soils because of compaction, poor structure, and high rock fragment content (Daniels and Amos, 1981; Thurman and Sencindiver, 1986). Thurman et al. (1985) reported bulk density values of 1.11 to 2.07 Mg/m^3 in the surface horizons of minesoils, and values of 1.14 to 2.44 Mg/m^3 in the subsurface. Water-holding capacity per unit volume of minesoils is generally less than that of natural soil, because less fine earth material, more rock fragments, and less organic matter are found in minesoils (Pedersen et al., 1980; Roberts et al., 1988). Pore-size distribution of minesoils is different from that of native soils (Pedersen et al., 1980). Thurman and Sencindiver (1986) reported low values of porosity in minesoils (26 to 38%) compared to significantly higher porosities for natural soils (35 to 50%).

The most common indicators of wastewater quality include NO_3-N, phosphate, 5-d biochemical oxygen demand (BOD_5), and fecal coliform bacteria (FC). High clay content and high cation exchange capacity (CEC) are effective in N removal (Ho et al., 1992). Monnett et al. (1995) evaluated on-site sewage spray irrigation systems on two field sites in Virginia and found NO_3-N concentrations increased in well samples with greater loading rates (1.25 vs 2.5 cm/wk). In acid soils used for wastewater treatment, most P sorption is associated with Fe and Al (Reneau and Pettry, 1976). Hill (1972) found a 100% P removal in an acid soil used for wastewater treatment as opposed to an 85 to 100% P removal on an alkaline soil with high clay and organic mater content. Most field studies indicate that P contamination is limited to shallow groundwater adjacent to on-site wastewater treatment systems and P sorption continues under saturated conditions (Reneau and Pettry, 1976). The most widely used parameter of organic pollution in both ground and surface waters is BOD_5. Organic matter in wastewater can be removed by attachment to soil particles and soil microbial degradation (Gerba et al., 1975). Peterson et al. (1994) observed a 94% decrease in FC after wastewater passed through minesoils. They also concluded that FC recovery in column leachings was closely related to influent application rate; the higher the application rate, the higher the FC.

Five minesoil series were established in southern West Virginia through cooperative efforts of USDA-Natural Resources Conservation Service (NRCS), the West Virginia Agricultural and Forestry Experiment Station, and coal mine operators (Wolf, 1988). Morphological, chemical and some physical and mineralogical data for these series are available, but interpretations have been made only for agricultural, forestry, and wildlife uses. Interpretations have not been made for other important land uses such as recreation development, building site development, and sanitary facilities be-cause data are not available.

Before minesoils can be used for wastewater treatment, baseline data must be generated from research and pilot-scale wastewater demonstration projects. Physical and chemical properties of minesoils which have an influence on water infiltration, movement, and treatment potential must be evaluated to estimate the suitability of these soils for wastewater treatment.

A field demonstration was conducted to evaluate two minesoils for on-site wastewater treatment. The objectives were to: (i) to determine whether two minesoils in southern West Virginia can accept applied water in sufficient amounts to allow surface wastewater application, (ii) evaluate and compare the chemical properties of two minesoils at two depths before and after wastewater application, and (iii) assess water quality changes of applied wastewater at two minesoil depths.

MATERIALS AND METHODS

Site Descriptions and Field Measurements

In 1991 and 1992, minesoils on six reclaimed mountaintop removal sites in a three-county area of southern West Virginia were sampled to determine physical properties. The sites ranged in age from 5 to 19 yr since reclamation. Minesoils were mapped as Kaymine on three sites and as Sewell on three sites. Three pits were dug at random locations on two Kaymine and two Sewell sites. Five pits were randomly located on the remaining Kaymine and Sewell sites, which were sampled more intensely because of their use as a field wastewater application study explained later.

Each pedon was described using standard soil survey procedures (Soil Survey Division Staff, 1993) and bulk samples and clods were collected from each described minesoil horizon. Bulk samples were sieved and weighed in the field, and material with particle size diameter <7.6 cm was saved for laboratory analyses. Soil texture was determined by the pipette method (Sobek et al., 1978). Moisture retention was determined at laboratory pressures of 10 and 1500 kPa using pressure membrane extraction (Soil Survey Staff, 1984). Water retention difference was calculated by subtracting the moisture retention at 1500 kPa from the moisture retention at 10 kPa. Soil clods were collected from each horizon for bulk density determinations using the Varsol method (Sobek et al., 1978).

Soil blocks (15 cm width, depth, and length) were collected and transported to the lab for determining Ksat using procedures of Bouma et al. (1982). Blocks were collected at depths of 0 to15, 45 to 60, and 85 to 100 cm on three sides of each pit. Some blocks, particularly at the lower depths, could not be collected because of an abundance of large rock fragments. Fast-setting concrete was used to encase the blocks. Field Ksat was determined by keeping a constant head of water on the surface of a soil block (the block was encased on four sides with concrete but the bottom of the soil block was left intact with the .

Table 1. Profile description of Kaymine and Sewell minesoil series.

KAYMINE

A 0 - 13 cm; Dark brown (10YR 3/3) loam; weak very fine to medium granular structure; very friable; many medium, fine, and very fine roots; 15 percent channers (90 percent siltstone, 10 percent sandstone); neutral (pH 6.8); clear wavy boundary.

C1 13 - 35 cm; Dark brown (10YR 3/3) very channery loam; common medium yellowish brown (10YR 5/6) lithochromic mottles; massive (weak coarse granular structure around roots); friable; common medium, fine, and very fine roots; 40 percent channers and stones (75 percent siltstone and 25 percent sandstone); moderately alkaline (pH 8.0); clear wavy boundary.

C2 35 - 78 cm; Dark brown (7.5YR 3/2) very channery loam; common medium yellowish brown (10YR 5/6) and strong brown (7.5YR 5/6) lithochromic mottles; massive; friable; common fine and very fine roots; 50 percent channers, stones and boulders (75 percent siltstone and 25 percent sandstone); moderately alkaline (pH 8.3); clear wavy boundary.

C3 78 - 135+ cm; mixed yellowish brown (10YR 5/6) and black (N 2/0) very channery sandy loam; massive; friable; few very fine roots; 45 percent channers, boulders, and stones (70 percent sandstone and 30 siltstone); moderately alkaline (pH 8.2).

SEWELL

A 0 - 7 cm; Yellowish brown (10YR 5/6) sandy loam; weak coarse granular structure; very friable; many very fine to medium roots; 5 percent rock fragments (80 percent sandstone and 20 siltstone); very strongly acid (pH 4.5); clear wavy boundary.

C1 7 - 55 cm; Yellowish brown (10YR 5/8) channery sandy loam; many medium and coarse brownish yellow (10YR 5/8) and strong brown (7.5YR 5/8) lithochromic mottles; massive; firm; few very fine roots; 25 percent rock fragments (50 percent sandstone and 50 percent siltstone); very strongly acid (pH 4.8); abrupt wavy boundary.

2C2 55 - 104+ cm; Very dark gray (N 3/0) very channery sandy loam; common medium strong brown (7.5YR 5/8) lithochromic mottles; massive; firm; 50 percent rock fragments (90 percent sandstone and 10 percent siltstone); neutral (pH 6.8).

soil in the field) and measuring water infiltration into the block of soil. The blocks were saturated and allowed to equilibrate with constant head for about 2 h before two consecutive readings of water infiltration were taken. After field Ksat measurements were completed, the blocks were broken away from the minesoil at the bottom of the block and excess soil on the bottom was trimmed evenly with the concrete. These blocks were taken to the lab and Ksat was determined by saturating the block, then placing a constant head of water on the surface of the block and collecting the water than passed through the soil.

In 1991, two of the six sites already sampled for physical properties were chosen for a field wasterwater application study. The Welch site (Kaymine soil) was mined and reclaimed approximately 14 yr ago and the Norfork site (Sewell soil) was reclaimed 12 yr ago. Descriptions of pedons representing the sites selected for the field study are presented in Table 1.

The Welch site was on Tom's Mountain, 3.5 km southeast of Welch, WV. The Norfork site was on Bluestone Mountain, 4 km northwest of Norfork, WV. The geology of both sites consists of the New River Group, the middle of the Pottsville series. Sandy Huff shale and Guyandot sandstone dominate the Welch site, whereas Lower Raleight sandstone and Quinnimont sandstone dominate the Norfork site (Wolf, 1988). Pre-mining topography of both sites consisted of very steep sides-lopes with narrow ridges and valleys. As a result of mountain top removal surface mining, the topography was significantly altered to lower elevations and the landscapes were widened and flattened. The post0mining elevations were 594 m for the Welch site and 732 m for the Norfork site.

Vegetation on the Welch site consisted of sericea lespedeza [*Lespedeza cuneata* (Dumont) G. Don], black locust (*Robinia pseudoacacia* L.), autumn olive (*Elaeagnus umbellata* Thunb.), birdsfoot trefoil (*Lotus corniculatus* L.), and tall fescue (*Festuca arundinacea* Schreb.). Vegetation at Norfork consisted of sourwood [*Oxydendrum arboreum* (L.) DC.], red maple (*Acer rubrum* L.), povertygrass [*Danthonia spicata* (L.) Beauv.], British soldier lichen (*Cladonia cristalella*), broomsedge (*Andropogon virginicus* L.), blackberry (*Rubus congruus* Bailey), iron weed (*Vernonia altissima* Nutt.), velvetgrass (*Holcus lanatus* L.), clubmoss (*Lycopodium clavatum* L.), black locust, birdsfoot trefoil, and sericea lespedeza.

Five soil pits were dug to >100 cm in depth on both sites, and the minesoils were described and classified using standard soil survey procedures (Soil Survey Division Staff, 1993). Bulk soil samples and clods were extracted from each horizon and analyzed for physical properties as described above. Soil blocks and Ksat determinations were also made as described previously except field Ksat values were not determined.

Wastewater Application Study

A nearly level area about 18 m by 9 m was chosen on each site for application of wastewater to field plots. Six plots measuring 3 by 3 m were placed within each area and two water treatments were randomly assigned to each plot. The two water treatments (tapwater and primary wastewater effluent) were surface applied to three plots each. Water was applied by sprinklers on a biweekly interval at a rate of 2.5 cm/h by gravity flow (about 174 L of fluid were applied per plot during 45 min). Tapwater and wastewater were transported to the site in two 1500-L tanks mounted on a flatbed truck. The tapwater was obtained at the Princeton City Fire Department and is used by residents of Princeton for drinking and household use. The primary wastewater was obtained from a pilot treatment plant operated by the City of Princeton, WV. The pilot plant treated wastewater directly from the Princeton municipal sewer.

Two water sampling wells were installed to depths of 50 and 100 cm in September 1991 at random locations in each plot. Wells were constructed from 5-cm PVC pipe. Twenty four holes of 0.32 cm radius were drilled around the pipe about 15 cm up from the bottom end. Fiberglass screening was wrapped around the pipe covering the holes to restrict soil particles from entering the well and filling the reservoir. Pressure caps were then glued to the reservoir bottom. Installation of the two wells in each plot was conducted by digging two 20-cm diameter holes, one to a depth of 50 cm and another to 100 cm. Wells were placed in holes and minesoil was replaced and compacted in the hole up to the screening. A 10-cm layer of sand was placed and tamped around the wells, followed by continued replacement and tamping of minesoil in the hole to within 30 cm from the surface. A 5-cm layer of bentonite was placed around the well to prevent surface flow contamination. Minesoil was compacted on top of the bentonite to the soil surface, and vegetation (sod) was replaced at the surface. Installation of wells was completed about 9 mo before tap or wastewater was applied.

Water application began on 1 June 1992, but no well water was collected. Before the next and subsequent water applications, water was pumped out of wells. On 20 June 1992, both waters were applied and application continued biweekly until 18 December 1992. Ten water applications were conducted during this period. About 24 h following application, water was removed separately from each well by a hand-operated vacuum pump and placed in bottles. All water from each well was collected and the volume was recorded (usually between 300 to 500 mL).

Sample bottles containing leachate were placed on ice, transported to the laboratory, and stored at 4°C until analyzed. At each application date, tapwater and wastewater from the city of Princeton, and well water samples were analyzed for pH, iron (Fe), Mn, phosphate, sulfate, NO_3-N, BOD_5, total suspended solids (TSS), and FC. Water pH was measured by a Fisher Scientific Accumet pH meter. Iron and Mn were analyzed by a Perkin Elmer model 403 Atomic Absorption Spectrophotometer (AAS) (Eaton et al., 1995). Phosphate was determined by the colorimetric method using ammonium molybdate and a reductant (ascorbic acid) (Eaton et al., 1995). Sulfate was measured by gravimetric analysis (McCoy, 1969). Nitrate-N was measured with a field Cardy Ion Meter kit (Horiba Instruments, Inc., Irvine, CA). The NO_3-N kit was calibrated on a biweekly basis.

The BOD_5 was determined using standard 300-mL BOD bottles "seeded" with a bacterial culture and incubated at 20°C for 5 d (Eaton et al., 1995). Gravimetric analysis was used to determine TSS (Eaton et al., 1995). Fecal coliform densities were determined by the membrane filter technique. Selected colonies were verified as FC by inoculation in EC medium (Eaton et al., 1995).

Soil samples were collected at 0 to 5, 50 to 55 and 100 to 105 cm depth ranges from a pit dug adjacent to each field site before water was applied. Soil pH was measured with a Fisher Scientific Accumet pH meter on a 1:1 soil/water paste (Sobek et al., 1978). Exchangeable acidity (Al and H) was determined by 1 *M* KCl extraction followed by NaOH titration to pH 7.0 using a Fisher Scientific computer-aided titrimeter (Soil Survey Staff, 1984). Exchangeable bases (Ca, Mg, K, and Na) were extracted by 1 *M* ammonium acetate at pH 7.0 (Soil Survey Staff, 1984) followed by analysis with a Perkin Elmer Model 403 AAS. Cation exchange capacity was determined by saturating the soil with 1 *M* ammonium acetate at pH 7.0 and replacing cations with 10% sodium chloride (Soil Survey Staff, 1984). Base saturation (BS) was calculated by dividing the sum of exchangeable bases by CEC. Phosphorus was determined by the Mehlich 1 technique (Nelson et al., 1953). Iron and Mn were determined by DTPA extraction and analyzed by AAS (Lindsay and Norvell, 1978). After the study, soil pits were again dug in each plot, soil samples were taken at the same depths, and analyzed for these same chemical properties.

Means and standard deviations were determined for minesoil physical and chemical properties. Water chemical data from the wastewater study were analyzed by analysis of variance (ANOVA) to determine significant differences (p # 0.05) among treatments and depths. When significant differences were found, Duncan's multiple range test was used to separate means.

Table 2. Physical properties (means and standard deviations in parenthesis) of Kaymine and Sewell minesoils and physical properties of the two minesoils where wastewater was applied.

		Average of All Sites		Properties on Wastewater Sites	
Horizon/Property	**Unit**	**Kaymine**	**Sewell**	**Kaymine**	**Sewell**
A Horizon					
Texture Class		Loam	Sandy Loam	Loam	Sandy Loam
Clay	%	15.5 (4.0)	8.8 (2.0)	13.8 (4.4)	7.5 (1.5)
Silt	%	43.1 (7.4)	21.2 (3.7)	44.4 (7.0)	20.6 (4.3)
Sand	%	41.4 (9.9)	70.1 (5.4)	41.9 (11.3)	71.9 (5.6)
BD^t	Mg/m^3	1.63 (.06)	1.61 (.05)	1.66 (.01)	1.64 (0.03)
WRD*	%, w:w	17.0 (1.9)	16.4 (3.2)	16.2 (2.4)	17.1 (3.3)
Field Ksat*	cm/sec	1.8×10^{-4} (1.68)	5.4×10^{-6} (1.22)	Not determined	Not determined
Laboratory Ksat*	cm/sec	8.1×10^{-3} (0.55)	1.8×10^{-3} (0.83)	8.2×10^{-3} (0.48)	2.5×10^{-3} (0.48)
C Horizon					
Texture Class		Loam	Sandy Loam	Loam	Sandy Loam
Clay	%	16.1 (5.7)	9.2 (3.3)	13.6 (4.3)	8.1 (3.1)
Silt	%	43.0 (8.2)	22.8 (6.5)	44.3 (9.4)	22.6 (6.2)
Sand	%	41.0 (12.2)	68.0 (9.5)	42.1 (13.1)	69.3 (9.0)
BD^t	Mg/m^3	1.79 (.16)	1.80 (.13)	1.88 (.16)	1.84 (.11)
WRD*	%, w:w	20.6 (4.5)	18.0 (3.1)	21.6 (4.8)	19.4 (2.4)
Field Ksat*	cm/sec	Not determined	Not determined	Not determined	Not determined
Laboratory Ksat*	cm/sec	1.3×10^{-4} (1.22)	2.1×10^{-5} (1.02)	1.3×10^{-4} (1.22)	2.1×10^{-5} (1.02)

^{t}BD = Bulk density without rock fragments.

*WRD = Water retention difference = (moisture retention at 10 kPa of pressure - moisture retention at 1500 kPa of pressure).

*Ksat = Saturated hydraulic conductivity measured on soil blocks in the field or in the laboratory. Means are weighted averages of log-transformed data. Standard deviations were calculated by $\log_{10}$ (Ksat) values for each horizon.

Definitions of Ksat classes (cm/sec): Very low = $<10^{-6}$; Low = 10^{-6} - 10^{-5}; Moderately low = 10^{-5} - 10^{-4}; Moderate = 10^{-4} - 10^{-3}; High = 10^{-3} - 10^{-2}; Very high = $>10^{-2}$ (Soil Survey Division Staff, 1993).

Table 3. Chemical properties (means and standard deviations in parentheses) of Kaymine minesoil samples for three depths before and after tapwater or wastewater were applied for 32 weeks.

		Exchangeable Acidity		Exchangeable base					
Treatment	pH	Al	H	Ca	Mg	K	Na	CEC	Base Saturation
		cmol (+)/kg							%
A Horizon (0-13 cm)									
Before Application	6.1	0.0	0.0	6.2	3.0	0.3	0.1	8.5	100
After Tapwater	5.3 -6.5	0.4 (.3)	0.0 (0)	4.7 (1.5)	3.0 (.4)	0.3 (.1)	0.1 (.1)	8.8 (.5)	94 (5)
After Wastewater	**5.4 -5.5**	**0.5 (.4)**	**0.1 (.1)**	**3.8 (0.9)**	**2.6 (.2)**	**0.5 (.2)**	**0.2 (.1)**	**9.4 (.8)**	**93 (6)**
C2 Horizon (50-55 cm)									
Before Application	7.3	0.0	0.0	6.8	3.0	0.2	0.1	6.9	100
After Tapwater	7.2 -7.7	0.0 (0)	0.0 (0)	5.7 (.4)	2.7 (.1)	0.1 (.1)	0.1 (.1)	7.2 (1.0)	100 (0)
After Wastewater	**7.6 -8.1**	**0.0 (0)**	**0.0 (0)**	**6.4 (.5)**	**2.9 (.3)**	**0.1 (.1)**	**0.1 (.1)**	**7.8 (1.1)**	**100 (0)**
C3 Horizon (100-110 cm)									
Before Application	7.4	0.0	0.0	5.8	2.7	0.2	0.1	6.5	100
After Tapwater	7.1 -7.8	0.0 (0)	0.0 (0)	6.2 (1.5)	3.0 (.3)	0.1 (.1)	0.1 (.1)	8.4 (2.0)	100 (0)
After Wastewater	**7.7 -7.8**	**0.0 (0)**	**0.0 (0)**	**5.8 (0.3)**	**2.8 (.3)**	**0.2 (.1)**	**0.1 (.1)**	**7.0 (.6)**	**100 (0)**

RESULTS AND DISCUSSION

Soil Physical Properties

Kaymine textures were loams, while Sewell textures were sandy loams (Table 2). Bulk densities for Kaymine averaged 1.63 Mg/m^3 in the A horizon to 1.79 Mg/m^3 in the C horizon. Similar high bulk densities were found in Sewell ranging from 1.61 to 1.80 Mg/m^3. Water retention difference (WRD) varied between 16 to 22% (w/w) across all sites.

The average field Ksat of A horizons was about two orders of magnitude greater in Kaymine than Sewell (Table 2), while laboratory Ksat values in A horizons were about half an order of magnitude faster in Kaymine. On just the two sites where wastewater was applied, the average laboratory Ksat was about half an order of

Table 4. Chemical properties (means and standard deviations in parentheses) of Sewell minesoil samples for three depths before and after tapwater or wastewater were applied for 32 weeks.

		Exchangeable Acidity		Exchangeable Bases					
Treatment	pH	Al	H	Ca	Mg	K	Na	CEC	Base Saturation
		cmol (+)/kg							%
A Horizon (0-7 cm)									
Before Application	4.3	3.0	1.1	0.3	0.1	0.2	0.1	5.9	13
After Tapwater	4.6 -4.9	2.1 (.3)	0.7 (.2)	0.3 (.1)	0.2 (.1)	0.1 (.1)	0.1 (.1)	3.3 (.2)	18 (9)
After Wastewater	**4.5 -4.8**	**2.4 (.7)**	**0.8 (.1)**	**0.1 (.1)**	**0.1 (.1)**	**0.1 (0)**	**0.1 (.1)**	**3.3 (.4)**	**10 (6)**
C1 Horizon (50-55 cm)									
Before Application	4.7	2.3	1.0	0.2	0.1	0.1	0.1	4.6	12
After Tapwater	5.1 -6.1	0.2 (.3)	0.1 (.1)	1.5 (.4)	1.7 (.5)	0.2 (.1)	0.0 (0)	4.5 (.2)	92 (12)
After Wastewater	**5.4 -6.1**	**0.1 (.1)**	**0.0 (0)**	**1.7 (.3)**	**1.9 (.3)**	**0.2 (.2)**	**0.1 (.1)**	**4.1 (.2)**	**97 (4)**
2C2 Horizon (100-105 cm)									
Before Application	5.7	0.0	0.0	0.1	0.1	0.1	0.1	4.5	95
After Tapwater	4.8 -6.2	0.3 (.2)	0.1 (.1)	1.6 (.5)	1.9 (.4)	0.1 (0)	0.0 (0)	4.6 (.3)	93 (9)
After Wastewater	**5.4 -6.7**	**0.0 (0)**	**0.0 (0)**	**2.0 (.3)**	**2.1 (.4)**	**0.2 (0)**	**0.0 (0)**	**4.5 (.3)**	**96 (7)**

magnitude faster in Kaymine. Field Ksat values were not determined for these two sites. The laboratory Ksat values of C horizons were one to two orders of magnitude slower than A horizons. Sewell had a higher sand content (70 vs 40%) than Kaymine, which should have translated into a faster Ksat for Sewell. Hillel (1982) found Ksat values for sandy soils to be around 10^{-1} to 10^{-3} cm/s, while loam soils ranged between 10^{-3} to 10^{-5} cm/s.

Field and laboratory Ksat values for both horizons on Kaymine were found to be in the moderate and high Ksat classes (Table 2 footnote). The laboratory Ksat value for the Sewell A horizon also was classified as high. But the average field Ksat value of the Sewell A horizon was classified as low. The Sewell field Ksat measurement was verified by the field wastewater study where surface applied water infiltrated very slowly into the minesoil, resulting in no or very little water in wells. The water puddled on the surface when lawn edging was placed around the plot. The slow infiltration rate in Sewell minesoil was not anticipated considering the surface texture, the bulk density, and the average laboratory Ksat value. However, it is apparent that field Ksat values were lower than laboratory values for other Sewell sites. It is possible that low amounts of ground cover, low soil organic matter, and weak surface structure may have allowed surface crusting, thereby reducing infiltration.

After applying wastewater to Sewell minesoils four times and obtaining no water in the wells, we determined this minesoil on this site was not suitable for wastewater disposal and treatment. Kaymine minesoils at the Welch site allowed water infiltration and the water moved through the minesoil and into monitoring wells.

Soil Chemical Analyses

Kaymine minesoils at the Welch site before water application had a soil pH of 6.1 in the A horizon to 7.4 in the C3 horizon, with a base saturation of 100% in all horizons (Table 3). Soil pH values of the A horizon decreased with application of wastewater. This result is surprising because the applied wastewater had a pH of 6.3 to 7.4 (Table 5). Soil pH values were about the same or slightly increased at 50 and 100 cm after application of tapwater and wastewater (Table 3). A small amount of Al was found in the A horizon after tapwater and wastewater application. Exchangeable cations did not appear to change much in any horizon after water application.

Sewell minesoils at the Norfork site had pH values before application between 4.3 and 5.7 and 12 to 95% base saturation (Table 4). There was a trend of increasing pH in all horizons with tapwater and wastewater application, and exchangeable acidity decreased slightly. Continued leaching with an alkaline wastewater should result in higher soil pH and lower exchangeable acidity. Exchangeable Ca increased at the 50 and 100 cm depths (the C1 and 2C2 horizons) after application.

Leachate Chemical Analysis

Chemical variations in applied tapwater and wastewater were high across the 10 water applications (Table 5). For example, water pH for tapwater varied between 7.0 and 8.0, while wastewater pH varied between 6.3 and 7.4. Large differences among dates were also noted for elemental concentrations. High concentrations of Fe (>0.5 mg/L) were measured in tapwater on two application dates, but all other dates showed lower concentrations (<

0.2 mg/L). Wastewater Fe concentrations ranged from 0.5 mg/L to 2.4 mg/L. Similar variations were found for phosphate (e.g., tapwater varied between 0.1 and 0.2 mg/L, while wastewater contained between 0.6 and 4.0 mg/L) and sulfate.

Inherently high concentrations of Fe, Mn, sulfate, and TSS were expected in soil solutions of minesoils due to disturbance and it was anticipated these materials would be flushed from the minesoil into wells with water application. There were no significant differences for Fe, Mn, and sulfate concentrations between tapwater and wastewater wells even though there were significantly higher amounts of Fe and Mn in applied wastewater vs tapwater (Table 5). Therefore, the higher concentrations of Fe and Mn in applied wastewater did not translate into higher concentrations in well water. Phosphate was significantly higher in applied wastewater compared to tapwater, and the water collected from wastewater wells was also significantly higher than water from tapwater wells. Phosphate concentrations in applied wastewater were decreased by 80% after passing through Kaymine minesoils. Wastewater TSS was significantly higher than tapwater. However, little difference existed in TSS between water from tapwater and wastewater wells, so TSS in well water was probably more influenced by TSS in the original soil solution than the TSS in applied water.

In the Sewell minesoil, the tapwater and wastewater infiltrated very slowly into the soil. In all three wastewater plots on this site, no water was ever extracted from 100 cm wells, and only a few samples were extracted

Table 5. Chemical compositon of tapwater and wastewater, and water collected from wells at two depths for Kaymine and Sewell minesoils.

Water Type	pH	Fe	Mn	Phosphate	Sulfate	TSS[#]
		-------------------------	mg/L	------------------------------		
KAYMINE						
Tapwater	7.0 - 8.0	0.3 b[y]	0.1 b	0.1 c	16.3 a	11 c
50cm Well	6.9 - 7.7	0.3 b	0.1 b	0.1 c	50.1 a	22 c
100cm Well	6.7 - 7.9	0.3 b	0.1 b	0.2 c	27.2 a	40 b
Wastewater	**6.3 - 7.4**	**1.3 a**	**0.6 a**	**2.6 a**	**24.4 a**	**93 a**
50cm Well	**6.9 - 7.6**	**0.4 b**	**0.2 b**	**0.5 b**	**28.6 a**	**40 b**
100cm Well	**6.8 - 7.5**	**0.4 b**	**0.1 b**	**0.3 b**	**39.6 a**	**44 b**
SEWELL						
Tapwater	7.0 - 7.6	0.3 a[y]	0.1 b	0.1 a	14.0 a	10 b
50cm Well	6.8 - 7.4	0.5 a	0.1 b	0.1 a	NS[t]	19 b
100cm Well	6.4	0.6 a	0.3 b	0.1 a	NS	4 b
Wastewater	**7.0 - 7.1**	**0.3 a**	**0.7 b**	**0.6 a**	**26.0 a**	**64 a**
50cm Well	**7.1 - 7.6**	**0.4 a**	**4.0 a**	**0.2 a**	**36.0 a**	**54 a**
100cm Well	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

[#] TSS = Total suspended solids.

[y] Values within columns for the same site with the same letter are not significantly different at $p<0.05$.

[t] No leachate in well.

Table 6. Concentration of nitrate-N, biological oxygen demand (BOD_5), and fecal coliform bacteria (FC) of tapwater and wastewater, and water collected from two depths for Kaymine and Sewell minesoils.

Water Type	Nitrate-N	BOD_5	FC
	------- mg/L	-------	colonies/100 mL
KAYMINE			
Tapwater	13 b[y]	3 c	<1.0 c
50cm Well	16 b	6 c	2.5×10^4 b [X]
100cm Well	19 b	7 c	1.9×10^4 b [X]
Wastewater	25 a	153 a	3.8×10^6 a
50cm Well	27 a	26 b	2.9×10^6 a
100cm Well	25 a	22 b	5.6×10^6 a
SEWELL			
Tapwater	12 c	3 c	<1.0 c
50cm Well	11 c	3 c	2.6×10^2 b [X]
100cm Well	8 c	3 c	NS[t]
Wastewater	20 a	136 a	2.2×10^6 a
50cm Well	15 b	10 b	6.1×10^3 a
100cm Well	NS	NS	NS

[y] Values within columns for the same site with the same letter are not significantly different at $p<0.05$.

[t] No leachate in well.

[X] After October 18, there were no FC bacteria in water from tapwater wells.

from the 100 cm wells in tapwater plots (Table 5). After 7 wk from the start of the experiment, all the wells were dry except one 50 cm well in a tapwater plot. We discontinued water application on this site after the fourth attempt. Data are shown for this 7-wk period in Table 5.

Biological Indicators

The tapwater and wastewater were significantly different in NO_3-N, BOD_5, and FC (Table 6). Nitrate-N concentrations in wastewater were usually about double the amount in tapwater. Mean BOD_5 concentration in tapwater was 3 mg/L compared to 153 mg/L in wastewater. During the study, there were high concentrations of FC in the tapwater wells. Because tapwater had no FC and there was little chance for wastewater to flow onto tapwater plots due to the buffer area between plots, our tapwater well samples were contaminated during well pumping. The well pumping technique was changed in October and no further contamination occurred.

The NO_3-N anion is generally flushed rapidly through soil systems. Therefore, NO_3-N concentrations in well water should reflect NO_3-N concentrations in applied water if N conversions by microorganisms (denitrification and nitrification) are occurring slowly. The results of our study verified this thinking (Table 6).

The BOD_5 of well water was significantly decreased compared to applied wastewater (usually by almost 10-fold), but there was no difference in BOD_5 between 50 and 100 cm wastewater wells. An average BOD_5 reduction of 85% was found for BOD_5 between wastewater and water in wells. Clearly, the minesoils had an impact in reducing organic matter content in the water through microbial action, and filtering and adsorption (Reneau et al., 1989).

Fecal coliform in tapwater wells can only be examined after 18 October because earlier tapwater well samples were contaminated. Concentrations of FC in wastewater and wastewater wells were essentially the same (Table 6). Reneau et al. (1989) stated that a travel distance of <3 m in soils is usually adequate to reduce FC densities in wastewater when unsaturated flow is maintained. The conditions of this experiment (largely saturated flow) would be expected to enhance contaminate transport. One meter of wastewater travel distance with Kaymine minesoil was insufficient to reduce FC in this study. Peterson et al. (1994) also found spoil materials to be less efficient in removing FC than native soils. Data from the Sewell minesoil are sparse, but are presented in Table 6.

SUMMARY AND CONCLUSIONS

Minesoil physical and chemical properties were measured for two minesoil series in southern West Virginia (Kaymine and Sewell). Soil pH was above 6.0 and textures were loams for Kaymine. Soil pH was around 4.5 and textures were sandy loams for Sewell. Bulk densities in A horizons of both soils were about 1.6 Mg/m^3, while C horizons were around 1.8 Mg/m^3. Field Ksat values of A horizons were about two orders of magnitude faster in Kaymine than Sewell, while laboratory Ksat values of Kaymine A horizons were half an order of magnitude faster than those of Sewell. In the field, very little tapwater or wastewater infiltrated into the Sewell minesoil and few water samples were collected from 50 and 100 cm wells. Water infiltrated into Kaymine minesoils and water samples were obtained from wells at 50 and 100 cm depth.

Concentrations of Fe, Mn, phosphate, and TSS were significantly higher in wastewater than well water, indicating that these materials were largely removed from wastewater by passing through Kaymine minesoils. Concentrations of NO_3-N in wastewater were twice that of tapwater, and this same ratio was observed in water from wells. BOD_5 was reduced by 85% from wastewater to well water. FC were not reduced by passing wastewater through one meter of Kaymine minesoils.

In general, these minesoils would not be suitable for renovation of wastewater. Therefore, wastewater treatment systems using Sewell and Kaymine minesoils must be carefully considered. Physical, chemical and biological properties of these soils provided some treatment of wastewater (like removal of phosphate and BOD_5), but waters containing NO_3-N and FC were not treated adequately.

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