Design and Operation of an On-Site Sewage Waste Treatment and Disposal System on a Reclaimed Coal Mine

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Situation:

A media filter system was installed to treat primary effluent from a facility located in Wise County, Virginia, in November of 2002. The project seeks to demonstrate an alternative sewage treatment technology that has the potential for widespread application on surface mined areas, if proven effective. This report documents the facility's performance over its first two years of operation.

Experimental-scale investigations conducted by R.B. Reneau, Jr., at Powell River Project Education Center in Wise County over the 1991-1998 period demonstrated that mine soil fills are capable of renovating wastewaters successfully.

Purpose:

The purpose of this project is twofold:

1. To improve sewage treatment at an existing location.
2. To investigate/demonstrate effectiveness of an alternative on-site sewage treatment technology for use on surface mined areas: Application of secondary effluent to mine spoil.

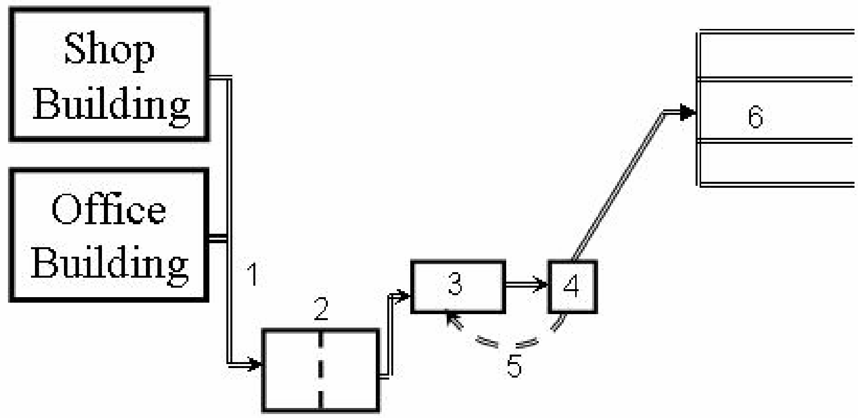
Installation:

Sewage wastes flow by gravity into a dual-compartment septic tank with an effluent filter. Primary effluent from the tank is pumped to an Advantex AX-20 secondary treatment unit.

Secondary effluent from the Advantex is pumped up slope on a timed dosage cycle to a distribution box. Effluent flows by gravity from the distribution box to four conventional gravel-trench soil-infiltration lines (see Figure 1). The drainfield consists of four seventy-foot conventional gravel lines, 3 feet in width and on 9 foot centers, with 4 inch perforated PVC piping, constructed in reclaimed mine soil located well above the level of potential floodwaters on a location formerly used for coal weighing scales.

Observation wells were installed near the end of each trench to enable monitoring of water levels in the drainfield infiltration trenches (eight total). Pits were excavated adjacent to the trenches, but separated from the trenches by 12 to 18 inches of unexcavated mine soil, close to each observation well. Suction lysimeters were installed in each pit, up against the side of the pit closest to the infiltration line, with the suction point approximately 18 inches below the trench bottom (Figure 2). The base of each suction lysimeter is comprised of a fine-pore ceramic filter, which is fixed into the bottom of each lysimeter tube with a water-tight seal (Figure 3) and embedded in a fine silica.matrix.

Figure 1. System layout (conceptual, not to scale).



1. Gravity feed from shop and office buildings to septic tank.
2. Dual compartment water-tight septic tank with outlet filter and pump, fitted with a lid, and vertical riser extending above flood stage. The tank is buried under a covering of soil and surrounded with an earthen berm constructed to a height above flood stage. A float inside the tank shuts down all electric power to tank if water in tank rises above a critical level.
3. Advantex unit located safely above flood level.
4. Pump and pump chamber.
5. Recirculation loop.
6. Four conventional gravel-trench lines for soil dispersal (see Fig. 2)

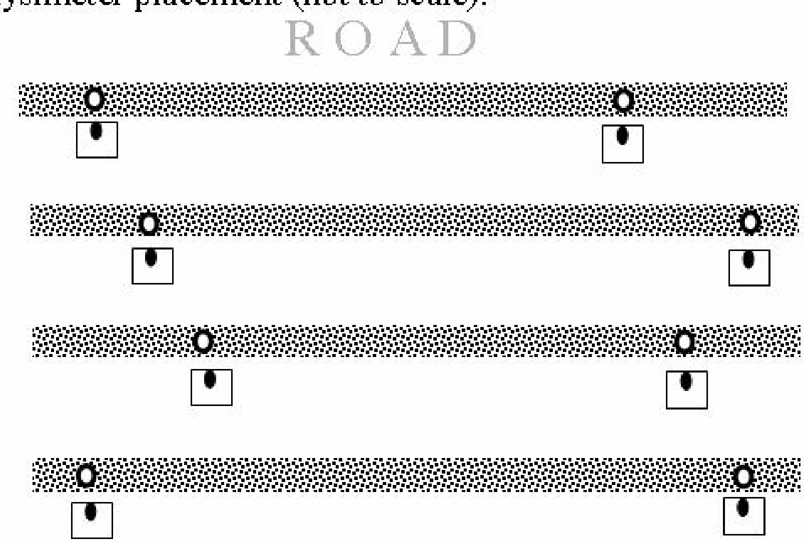
The drainfield installation did not occur without problem. The drainfield is constrained between an old gravel roadway, formerly used by coal trucks accessing the scale, and a steep excavated sideslope. Although the county sanitarian laid out and flagged a drainfield running parallel to the site contours prior to installation, the contractor installed the lines parallel to the roadway (Figure 4), making an on-site decision to implement this configuration due to his belief that it would be a superior to the initial layout. Inspection of the excavated trenches revealed evidence of compaction in the trenches nearest the roadway, presumably due to the truck traffic which can be presumed to have been heavy during years when the scale was in operation.

Maintenance and Monitoring:

Virginia Tech personnel were involved in the system's design, and took responsibility for monitoring system performance three times annually (spring, summer, and fall) over a two-year period.

Six monitoring visits were recorded during calendar years 2003 and 2004. During each visit, water levels were observed in the observation wells, a grab sample was taken from the distribution box, and solution samples were withdrawn from the suction lysimeters by applying a vacuum thus drawing groundwater (if present) into the base of the tube; the groundwater is then removed with a vacuum pump. Any residual standing water found in the suction lysimeter tube is withdrawn prior to the sampling procedure. Samples were analyzed at Virginia Tech for fecal coliform, BOD, pH, suspended solids, conductivity, nitrogen (nitrate and ammonium), and phosphorous.

Figure 2. Drainfield layout with observation well and lysimeter placement (not to scale).



Legend:

Four 70 foot long conventional drainfield trenches, with gravel and perforated pipe, on 9 foot centers. Trench bottom 18" below surface.

4-inch PVC pipes with screw-on tops, open bottoms (observation wells).

pits for suction lysimeters. Approximately 12 inches of undisturbed minesoil is left between pit and trench.

= Suction lysimeters. Approx 2.5 inch diameter PVC pipe, with porous ceramic cup at base (see Figure 3).

Figure 3. Lysimeter designs (not to scale).

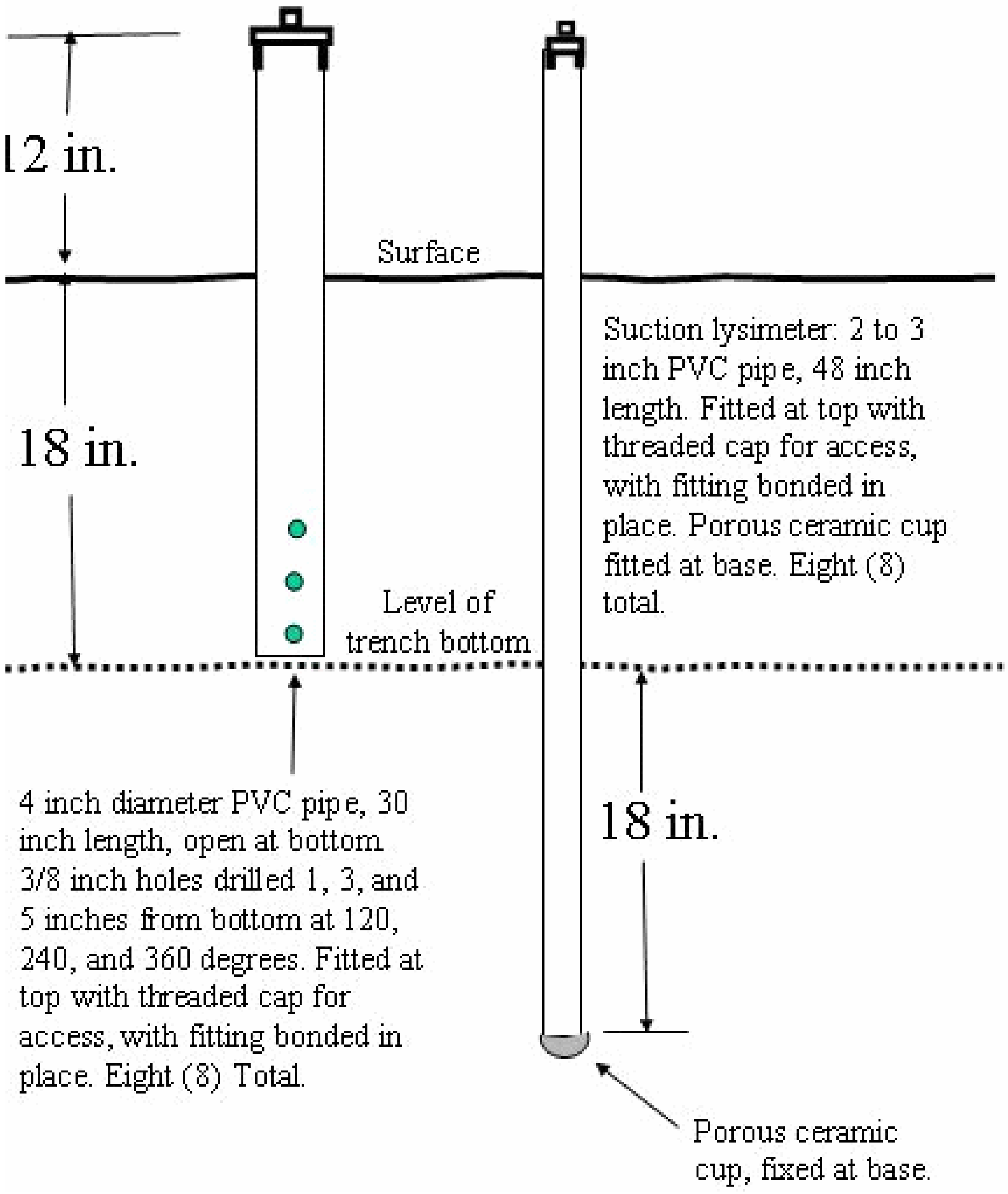
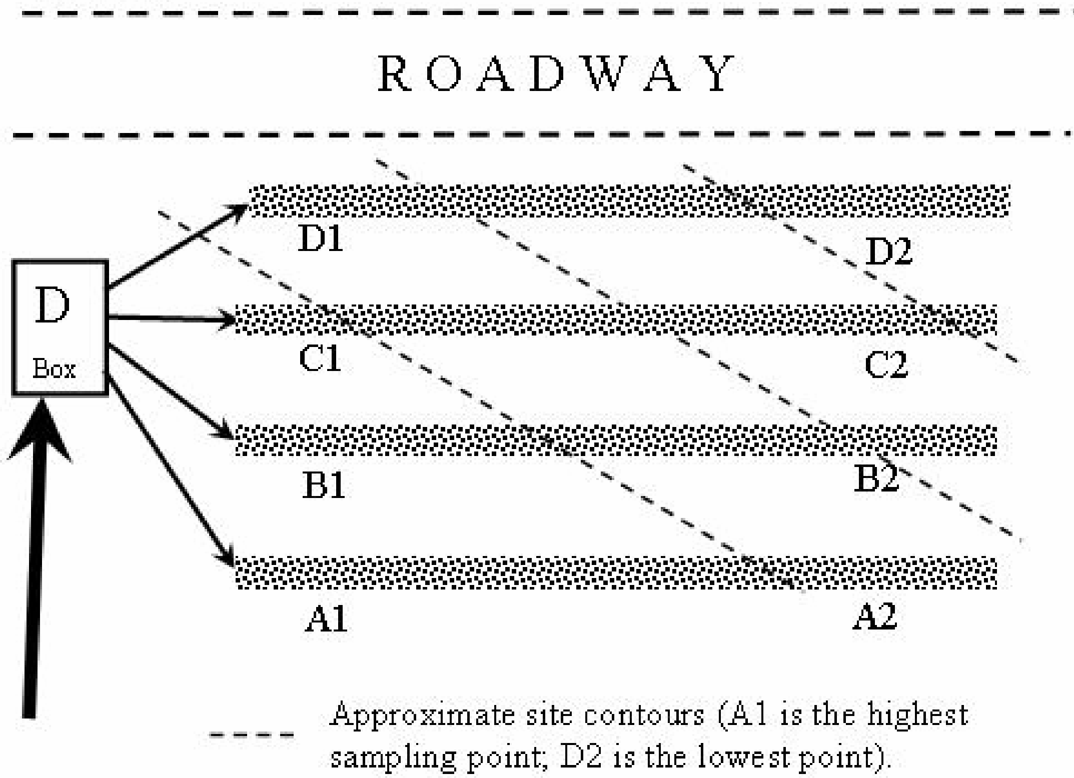


Figure 4. Location of sampling points, relative to roadway and site contours.



Monitoring Results

Hydraulic Performance:

Prior to system operation, the main building's water usage was estimated at 220 gallons per day, on a year round basis. This figure does not include volume that may be contributed to the system by the shop's toilets, but the shop is used only on an occasional basis.

During the winter and early spring of the system's first operating year, effluent was observed emerging from the surface at the lowest-lying portions of the drainfield, adjacent to the roadway (near monitoring point D2). Several factors are believed to contribute to this condition:

a) the contractor's failure to lay out the drainfield parallel to the contours, as designed (he initiated the installation prior to arrival of Virginia Tech personnel, and made an on-site adjustment to his perception of site conditions in their absence);
b) a high initial application rate (3 minutes at 17.5 gallons per minute, every 3 hours, which would be equivalent to 420 gallons per day over the 24 hour cycle);
c) an unusually wet winter and spring, combined with the fact that the drainfield surface had not been graded smooth and revegetated
d) compacted subsoil conditions near the roadway, which appeared to limit subsurface infiltration from ditch D.

After effluent surfacing was observed during the 3/18/03 monitoring visit: several actions were taken to alleviate the wastewater surfacing condition: Dialing back the hydraulic loading to 2.5 minutes on every 3.5 hours (300 gallons per day), and adjusting the D-box to restrict water movement into Ditch D. This eliminated the wastewater surfacing condition, but water levels at C2 and D2 were observed as remaining high during the 7/22/03 monitoring visit. By 10/22, the system's hydraulic performance was greatly improved despite that fact that the surface still had not been graded and revegetated (Table 1), although water levels remained high in Ditch C. Subsequent to 10/22, the distribution box was adjusted to further restrict water movement into Ditch C subsequently, creating a situation where the most of effluent was being received by Ditches A and B. As a result of these actions, most if the effluent was being directed to Ditches A and B, which seem to be handling it without problem. Despite the fact none of the 2004 monitoring visits was recorded during conditions that could be characterized as "dry," the system's hydraulic performance improved markedly. Of the three 2004 dates, water levels were highest on 10/20, when weather conditions were recorded "wet conditions, generally, due to recent rain." No recurrence of the effluent surfacing problem were observed after the actions taken in response during spring 2003.

The average hydraulic loading (calculated at 300 gallons/day) was about 15 liters / m^2 of trench bottom per day (0.6 liters / m^2 / hour, averaged over a 24-hour day). Considering that the majority of effluent was being directed to Ditches A and B, it appears that these ditches were receiving on the order of 25 liters / m^2 of trench bottom per day (1 liters / m^2 / hour, averaged over a 24-hour day).

Wastewater Renovation:

Visual observations of D-box effluent clarity, BOD concentrations, fecal coliform counts, and nitrate-ammonium ratios indicate that the media filter's performance declined between 3/18/03 and 7/22/03 (Table 2). The contractor was called in for a maintenance visit, and the recirculation cycle was increased. As a result, measured water quality had improved considerably by the 10/15/03 monitoring visit, but the high performance measured on 3/18 had not been restored. The contractor also recommended that the septic tank be pumped, but this operation was not completed until after the 10/22 monitoring visit. Monitoring data during 2004 indicated that media filter performance remained at levels comparable to 10/03 throughout the year, but did not return to the high levels that characterized early operations (3/03).

Table 1. Estimated water levels (7/22) and measured water heights above gravel (other dates) in open-bottom observation wells (inches).

Pipe	7/22/2003	10/15/2003	3/24/2004	8/11/2004	10/20/2004
	trace	3	3	1	gravel
B1	trace	3	2	3	trace
C1	20	17	16	7	15
D1	6	1	12	3	7
A2	gravel	trace	gravel	gravel	trace
B2	trace	trace	gravel	trace	trace
C2	16	19	14	9	17
D2	11	4	6	5	9

Notes: On 3/18/03, effluent was emergent from the vicinity of C2 and D2. "Gravel" indicates that gravel was visible at the well base.

Monitoring well C-1 has consistently low pH, high conductivity, and high total dissolved solids relative to the other monitoring locations. These data may indicate the presence of a pyritic material, possibly with remnant coal, in the vicinity of well C-1. Pyritic materials can oxidize and release dissolved salts, when exposed to aerated waters. This pattern persisted throughout the two-year monitoring period.

The mine soils appear to be renovating the effluent successfully. Only one lysimeter sample contained measureable FC levels on one sampling date. Despite the fact that nitrate appears to be moving from the drainfields into lysimeter A-1 during 2004 monitoring, FC levels did not follow suit.

Overall Evaluation of Performance:

One problem, experienced early in the system's operation, was created by an inappropriate dosing schedule set by the installation contractor. This problem was remedied by referencing the operator's record of daily water usage as an estimate of system loading, and resetting the dosing cycle to distribute this amount of effluent over a 24-hour period.

The primary factor limiting performance over the longer term appears to be hydraulic loading limitations created by the fact that the drainfield is not oriented parallel to site contours, and a portion of the site had been compacted by activities prior to drainfield installation. Despite the uneven loading, drainfield soils appear to be renovating effluent successfully. It is apparent that the uncompacted mine soils underlying Ditches A and B have a high capacity to accommodate wastewaters. Despite the high loadings of Ditches A and B, fecal coliform analyses of groundwater samples taken from the adjacent lysimeters indicate that the mine soils are treating the effluent successfully. With an appropriate dosing cycle, the system is performing satisfactorily despite its hydraulic loading limitations.

Table 2. Water chemistry of extracts from suction lysimeters and D-Box.

ND = Non-detect (below analytical detection limits).
- = No sample (Sample was not collected, or volume of sample collected was insufficient to allow analysis.)

pH	**03/18/03**	**07/22/03**	**10/15/03**	**03/24/04**	**08/11/04**	**10/20/04**
D Box	7.08	7.11	7.43	7.38	7.07	7.02
A-1	-	-	7.74	-	-	7.79
A-2	-	-	5.02	-	-	7.71
B-1	6.81	7.04	7.32	7.18	7.64	7.03
B-2	-	7.11	7.01	7.46	7.56	7.01
C-1	4.75	4.51	4.84	4.43	4.20	4.44
C-2	7.30	7.54	6.92	7.15	7.74	7.02
D-1	6.74	7.04	6.96	6.87	7.12	7.04
D-2	7.21	7.33	7.06	7.21	7.86	7.20

EC - Msiem.	**03/18/03**	**07/22/03**	**10/15/03**	**03/24/04**	**08/11/04**	**10/20/04**
D Box	609	561	576	520	390	468
A-1	-	-	929	-	-	752
A-2	-	-	670	-	-	437
B-1	2850	1841	2390	2500	1885	1697
B-2	-	982	1139	829	663	901
C-1	3620	3600	3260	2550	2510	2006
C-2	1990	1355	1467	1486	1340	1807
D-1	1130	1958	1101	1041	982	944
D-2	2020	961	1839	1445	1197	1092

TDS (mg/L)	**03/18/03**	**07/22/03**	**10/15/03**	**03/24/04**	**08/11/04**	**10/20/04**
D Box	308	372	384	347	200	307
A-1	-	-	628	-	-	495
A-2	-	-	448	-	-	287
B-1	1439	1228	1616	1670	974	1124
B-2	-	652	766	553	341	594
C-1	1822	2510	1984	1705	1283	1360
C-2	1005	901	995	993	690	1195
D-1	571	1958	738	695	505	623
D-2	1023	638	1239	966	616	720

Cl (mg/L)	**03/18/03**	**07/22/03**	**10/15/03**	**03/24/04**	**08/11/04**	**10/20/04**
D Box	22.5	26.0	28.3	30.9	21.6	30.8
A-1	-	-	5.6	-	5.6	29.9
A-2	0.0	-	16.4	2.5	-	9.6
B-1	1.5	9.4	33.5	6.7	3.0	5.3
B-2	16.4	15.9	18.0	8.7	20.4	21.6
C-1	0.0	3.9	13.3	1.9	2.4	7.7
C-2	6.7	13.0	22.2	6.9	7.8	10.2
D-1	9.9	14.9	16.6	6.6	4.9	17.2
D-2	2.4	5.6	5.1	4.0	1.0	6.5

NO3-N (mg/L)	03/18/03	07/22/03	10/15/03	03/24/04	08/11/04	10/20/04
D Box	10.2	0.1	2.8	1.1	9.3	10.6
A-1	-	-	0.7	4.3	0.4	5.4
A-2	4.1	-	1.2	-	-	-0.1
B-1	0.1	0.2	0.1	0.0	0.2	0.0
B-2	11.6	0.2	0.1	0.4	0.2	0.0
C-1	0.0	0.1	0.2	0.2	0.2	0.3
C-2	0.1	0.2	0.1	0.1	0.2	0.0
D-1	0.2	0.2	0.1	0.0	0.2	0.1
D-2	0.1	0.2	0.1	0.0	0.1	0.0

NH4-N (mg/L)	03/18/03	07/22/03	10/15/03	03/24/04	08/11/04	10/20/04
D Box	3.9	11.7	11.9	14.90	1.00	1.78
A-1	-	-	0.0	0.21	0.07	-0.19
A-2	0.2	-	0.0	-	-	-0.03
B-1	0.1	0.2	0.1	0.62	0.74	-0.24
B-2	3.1	3.3	3.3	1.51	1.38	1.95
C-1	0.4	1.0	0.5	0.64	0.84	0.97
C-2	0.1	0.2	1.0	0.76	0.42	1.04
D-1	0.0	0.5	1.4	1.44	1.88	3.86
D-2	0.0	0.3	0.0	0.23	0.03	0.48

TKN (mg/L)	03/18/03	07/22/03	10/15/02	3/24//4	08/11/04	10/20/04
D Box	4.6	-	11.7	11.4	0.3	-

PO4 (mg/L)	03/18/03	07/22/03	10/15/03	03/24/04	08/11/04	10/20/04
D Box	2.000	2.650	5.270	4.870	4.400	4.680
A-1	-	-	0.000	0.075	0.125	0.075
A-2	0.000	-	0.000	-	-	0.058
B-1	0.000	0.000	0.000	0.065	0.033	0.040
B-2	0.070	0.000	0.000	0.060	0.020	0.050
C-1	0.000	0.000	0.000	0.065	0.030	0.043
C-2	0.000	0.000	0.000	0.060	0.045	0.043
D-1	0.000	0.000	0.000	0.068	0.028	0.085
D-2	0.000	0.000	0.000	0.060	0.033	0.060

BOD (mg/L)	03/18/03	07/22/03	10/15/03	03/24/04	08/11/04	10/20/04
D Box	9	30	17	14.7	11.10	17.70
A-1	-	-	-	-	-	-
A-2	-	-	-	-	-	-
B-1	21	20	-	2.55	-	6.6
B-2	-	5	5	11.7	7.95	3.75
C-1	13	15	10	0.15	4.95	4.50
C-2	22	20	6	5.85	-	9.3
D-1	21	-	5	3.45	5.85	-
D-2	22	-	4	5.55	-	6.3

FC (count/100 mL)	03/18/03	07/22/03	10/15/03	03/24/04	08/11/04	10/20/04
D Box	< 100	114000	1020	1230	5680	1057
A-1	-	ND	ND	ND	-	-
A-2	-	ND	ND	ND	-	ND
B-1	ND	ND	400	ND	ND	ND
B-2	ND	ND	ND	ND	ND	ND
C-1	ND	ND	ND	ND	ND	ND
C-2	ND	ND	ND	ND	ND	ND
D-1	ND	ND	ND	ND	ND	ND
D-2	ND	-	ND	ND	ND	ND

TSS (mg/L)	10/15/03	03/24/04	08/11/04	10/20/04
D Box	0	0	0	0
A-1	ND	ND	-	-
A-2	ND	ND	-	-
B-1	ND	ND	-	-
B-2	ND	ND	-	-
C-1	ND	ND	-	-
C-2	ND	ND	-	-
D-1	ND	ND	-	-
D-2	ND	ND	-	-

Summary and Recommendations

Virginia Tech personnel participated in this project for the purpose of gaining insight regarding the potential for operation of on-site wastewater disposal systems on reclaimed mine sites. The results of the Dorchester installation, combined with experience gained in operating experimental systems (wetland, spray irrigation, and prototype media filter) at Powell River Project Education Center (1991 – 1998), lead us to conclude the following.

A primary factor that must be considered in design and installation of any reclaimed mine on-site system is spatial variability of soil properties. Because the major factor influencing variability is mining equipment operations, that variability is not predictable based on factors such as landscape position that are typically used to evaluate the spatial variability of natural soil properties. Subsurface mine soils can be highly variable within short distances, even when no expression of that variability is detectable at the surface. Mine soils can range from quite porous to heavily compacted with limited capacity to absorb wastewaters. Although not observed in the current installation and not common, it is not unheard of for mine soils to contain subsurface voids. Therefore, we believe that on-site systems constructed on mine soils should be designed to apply treated effluent only.

Our experience with this installation illustrates a basic principle of technology application: Even the "best" technology must be operated and managed properly in order to achieve the desired results. The two problems encountered with this installation – construction of the soil absorption field in an orientation that does not parallel site contours, and an initial drainfield dosing schedule that failed to distribute each day's effluent over a 24-hour period – occurred as a result of management decisions and were remedied by taking appropriate management actions. These problems occurred despite the fact that treatment technology was performing satisfactorily.

Our experience indicates that mine soils are capable of renovating septic effluent. We recommend that the following principles be applied to design and construction of on-site wastewater disposal systems on reclaimed mine sites.

Layout and Design: Apply basic principles of drainfield layout and design for natural soil areas, i.e.: avoid placement where surface water is present, where subsurface conditions indicate a high water table (i.e., gray or mottled conditions indicating that reducing conditions are present), or where soils have been compacted by high traffic or equipment operation. Expect greater lateral variability of soil conditions over the area occupied by the drainfield than would be typical in a similar sized area of natural soil. If compacted soil areas are identified during soil characterization, lay out the drainfield so as to avoid these areas. Lay out drainfield ditches parallel to site contours.

Installation: Be on site with the contractor at all times during drainfield installation, so as to assure installation conforms with layout and to assist in dealing with any unanticipated conditions found during drainfield excavation.

Install a standpipe with a removable top in each drainfield ditch so as to be able to monitor water levels. Use a distribution box that will allow the user to adjust the relative volumes being directed to each dispersal line (i.e., a "dial box" or similar system).

Grade and smooth the site after construction, so as to create a surface configuration that will aid rainwater runoff and discourage infiltration.

Operation: Use a highly treated effluent, since some mine soils can be quite porous. Time pump cycles so that average daily effluent production is applied over a 24- hour application cycle. Start out by distributing the effluent evenly over the drainfield area. If standing water levels are observed consistently in any drainfield ditch or ditches, redistribute the effluent so that larger volumes are applied in those ditches where effluent infiltrates most rapidly. Inspect system operation, including drainfield water levels, periodically as a routine maintenance activity, and be prepared to adjust dosing rates and/or effluent distribution if necessary to maintain satisfactory operation.

The recommendations above apply to use of conventional gravity-fed drainfields for effluent dispersal on reclaimed mine sites. Advanced dispersal systems have the potential to further reduce the possibility of contaminants reaching ground and surface waters.