RECLAMATION OF DISTURBED SULFIDIC COASTAL PLAIN SEDIMENTS USING BIOSOLIDS AT STAFFORD REGIONAL AIRPORT IN VIRGINIA[1]

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Abstract. Excavation through sulfidic geologic materials during construction activities has resulted in acid rock drainage (ARD) related problems across the state of Virginia. The most extensive documented disturbance at a single location resulted from construction of the Stafford Regional Airport in Stafford, Virginia. Beginning in 1998 over 150 ha of sulfidic Coastal Plain sediments were disturbed, including steeply sloping cut surfaces and spoils. This disturbed area remained barren for over two years before being recognized as sulfidic. In addition to the development of acid sulfate soils, the generation of ARD degraded metal and concrete structures and heavily damaged a receiving stream with water quality effects noted over 1000 m downstream from the site. In December 2001 the existing surface soils were composite sampled from 32 map units across the site. In February 2002 a water quality monitoring program was established with 16 locations in and around the airport. In the spring and fall of 2002, after determining liming requirements using potential peroxide acidity (PPA), the site was treated with lime-stabilized biosolids, straw-mulch, and acid- and salt-tolerant grasses. By October 2002 the site was fully revegetated ($\geq$ 90% living cover) with the exception of a few highly acidic outcrops and seep areas. Water quality quickly responded to treatment, although some N release was noted as a secondary effect. Surface soil sampling in September 2003 indicated that post-amendment pH values across the site increased from values < 3.5 to values typically > 7.0. Continued monitoring of the water and soils will be used to evaluate the multi-year efficacy of this treatment. Stafford Regional Airport illustrates the importance of accurately assessing sulfide hazards, and establishing optimal handling and treatment procedures prior to construction.

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Introduction

Sulfidic deposits are found in various settings across the state of Virginia, including unconsolidated sulfide-rich sediments in formations of the Coastal Plain, certain slate and phyllite bearing formations in the Piedmont and Blue Ridge, some black shales in the Valley and Ridge, and sulfide-rich coal seams in the coalfields of southwest Virginia (Orndorff 2001). In many of these settings, exposure of sulfidic materials during construction has resulted in localized acid rock drainage (ARD) and associated technical, environmental, and social problems. The most extensive case of acid sulfate weathering problems due to construction occurs in the Coastal Plain at the Stafford Regional Airport (SRAP) in Stafford, Virginia (Fig. 1). To our knowledge, this is the largest single exposure of acid forming materials in the eastern USA to date, other than that which occurred in the pre-1977 era of Appalachian coal mining.

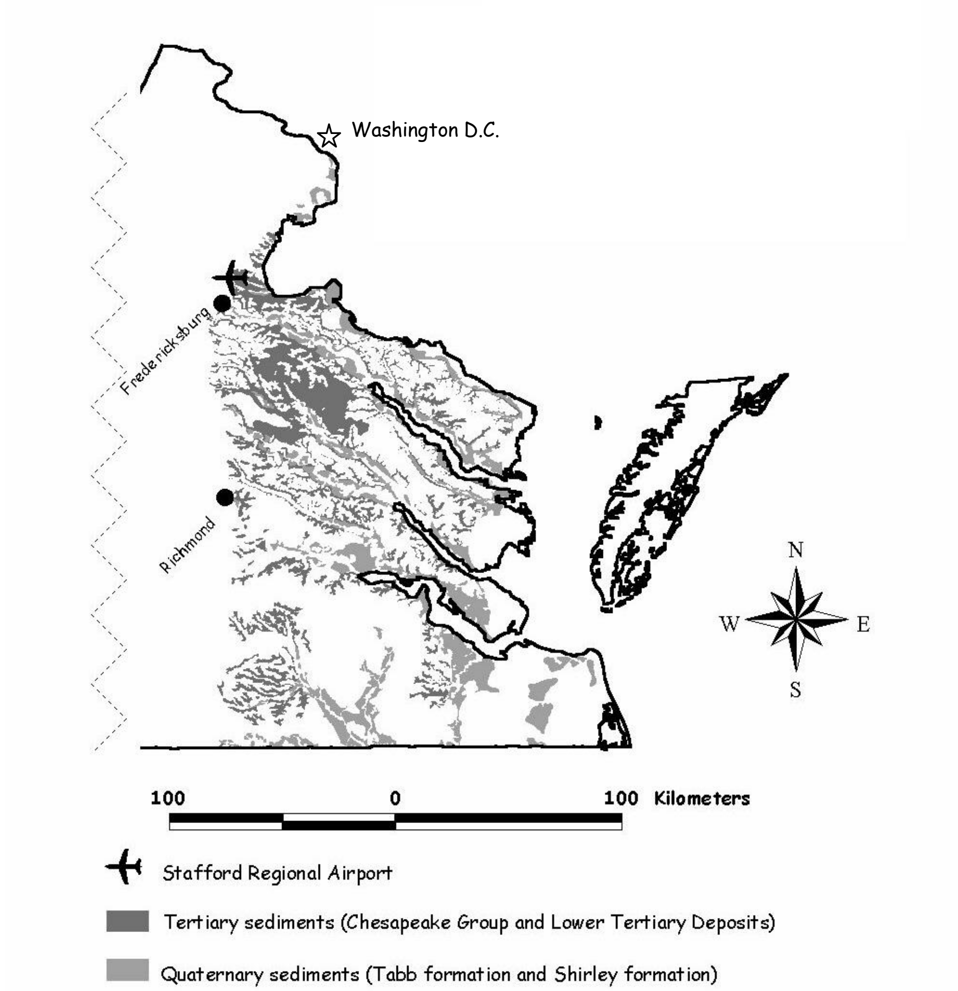


Figure 1. Location of Stafford Regional Airport, and the geographic extent of sulfide-bearing geologic materials in the Coastal Plain of Virginia.

Acid sulfate weathering problems in the Coastal Plain primarily result from exposure of unconsolidated Tertiary marine sediments, particularly those mapped as the Chesapeake Group and Lower Tertiary deposits. These sediments occur in drab shades of green, blue and gray, and consist of fine- to coarse-grained, quartzose sand, silt, and clay that is variably shelly, diatomaceous, and glauconitic (Rader and Evans, 1993). Unoxidized samples typically have pH values between 5.5 to 8.0, potential peroxide acidity (PPA) values between 30 to 50 Mg $CaCO_3$/1000 Mg material, and total-S values between 1.0 to 2.5%. Upon weathering, pH rapidly drops to values between 2.5 to 3.5, PPA values to between 10 to 20 Mg $CaCO_3$/1000 Mg material, and total-S drops to less than 1.0% (Orndorff 2001). Problem sites typically exhibit lack of vegetation due to the very low pH of surface material and sulfate salt efflorescence on cut surfaces. Most sites exhibit acid drainage, which causes Fe staining on concrete, deterioration of concrete and metal construction materials (drainage ditches, culverts, galvanized pipes and guardrails), and adversely affects local surface water.

Between 1998 and 2001, construction activities at SRAP disturbed over 150 ha of Lower Tertiary Coastal Plain materials as the airport runway was constructed through a deeply dissected landscape. As construction proceeded, long spur ridges were excavated to depths $\geq$ 25 m, exposing significant volumes of grey, reduced, sulfidic sediments which were subsequently filled into intervening valley fills to support the runway. Excavated sulfidic sediments exceeded the capacity of the valley fills and were also placed into several large steeply sloping excess spoil fills along a first-order stream draining the eastern section of the site. Since the sulfidic nature of these materials was not recognized until well after final grading was completed, the acid-forming materials were not isolated away from drainage and, in fact, were scattered randomly and thoroughly throughout the site. After multiple conventional revegetation efforts failed we were first contacted for assistance in the late fall of 2001. This paper focuses on a detailed review of the nature and extent of soil and water quality impacts and their remediation at Stafford airport. Two specific objectives include: 1) evaluation of the use of biosolids to reclaim acid sulfate soils; and 2) the resultant impact on local surface water quality.

Materials and Methods

Initial Site Inspection

This site was first visited in the late fall of 2001 at which time acid-sulfate weathering problems were readily apparent. Over 150 ha of cut and fill slopes were barren of vegetation, acid drainage was prominent, concrete lined drainage ditches and culverts were coated in iron, and significant etching and degradation of the cement components were noted (Fig. 2 – Fig.4). Galvanized steel standpipes in water control structures in storm-water basins below the site had also been completely degraded by the drainage over time, releasing large volumes of sulfidic sediments into the receiving floodplain (Fig. 5). As discussed below, acidic drainage from this site had seriously degraded surface water both on- and off-site (Fig. 6 and Fig. 7).

Inspection of the 10 to 15 m deep cut faces along the northern margin of the site in November 2001 revealed that the upper 5 to 8 m of the soil-geologic column was pre-oxidized by long term natural weathering processes (Fig. 8). Soil pH values ranged in the 3's and lower 4's and this portion of the slope was well-vegetated. Below the pre-oxidized depth, soil in the weathered 2 year old cut face ranged from pH 1.8 to 3.5, with prominent white salt-efflorescences. Fanning, et al. (2002) also confirmed the occurrence of active acid-sulfate soil conditions on site.

Figure 2. Barren fields resulting from the development of acid sulfate soils over disturbed sulfide-bearing Tertiary marine sediments at Stafford Regional Airport.

Figure 3. Erosion of acid sulfate sediments and acidic runoff and seepage from steeply sloping spoil fills (not shown in picture) have severely impacted this wetland area.

Figure 4. Throughout Stafford Regional Airport, concrete structures such as this culvert exhibit iron-staining as well as etching and degradation of cement components.

Figure 5. Galvanized steel standpipes in water control structures in storm-water basins below the site have been completely degraded by acidic drainage.

Figure 6. Acidic drainage from Stafford Regional Airport enters the Potomac River watershed.

Figure 7. Drainage from Stafford Regional Airport flows off-site to this storm-water basin.

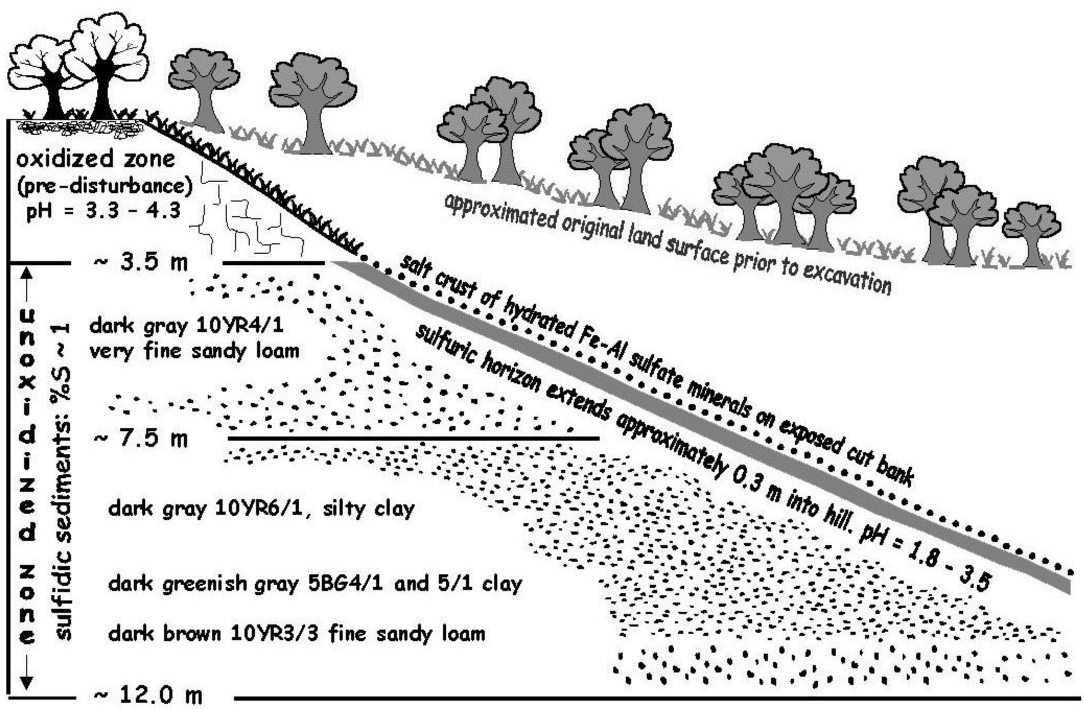


Figure 8. Profile of weathered cut slope exposing sulfidic materials at Stafford Regional Airport, Virginia (from Fanning et al., 2004).

Revegetation

In December 2001, the existing surface soils were composite sampled from 32 map units across the site in association with soil mapping requirements for remedial treatment (Fig. 9.) These samples were analyzed for pH in a 1:1 soil:water solution using a combination electrode, potential peroxide acidity (PPA) using the H_2O_2 method of Barnhisel and Harrison (1976), and for total-S using an Elementar Vario Max CNS analyzer. Based on these results, we recommended that the site be variably limed to each sampling cell's requisite calcium carbonate equivalent (CCE) requirement, fertilized appropriately, treated with an organic soil amendment, and seeded to acid- and salt-tolerant grasses and legumes based upon experience with sulfidic coal waste revegetation (Daniels and Stewart, 2000). In April 2002, class B lime-stabilized biosolids (municipal sewage sludge) from Washington D.C. were applied and incorporated across the entire site at varying rates based upon their CCE (Table 1). Rates varied from 35 to 270 dry Mg/ha. This treatment was designed to supply the full amount of lime required for complete neutralization of the potential acidity present in the soil surface along with substantial organic matter and nutrient loadings.

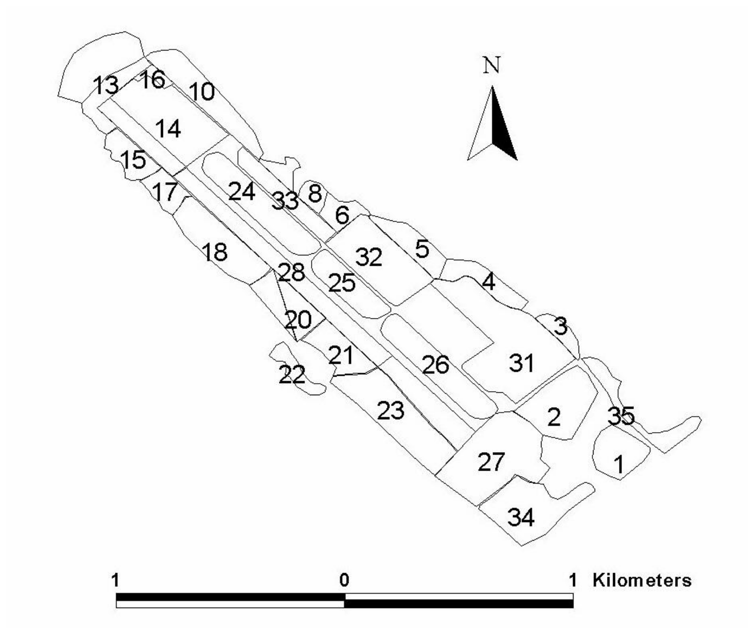


Figure 9. Soil sampling map units at Stafford Regional Airport, Stafford, Virginia.

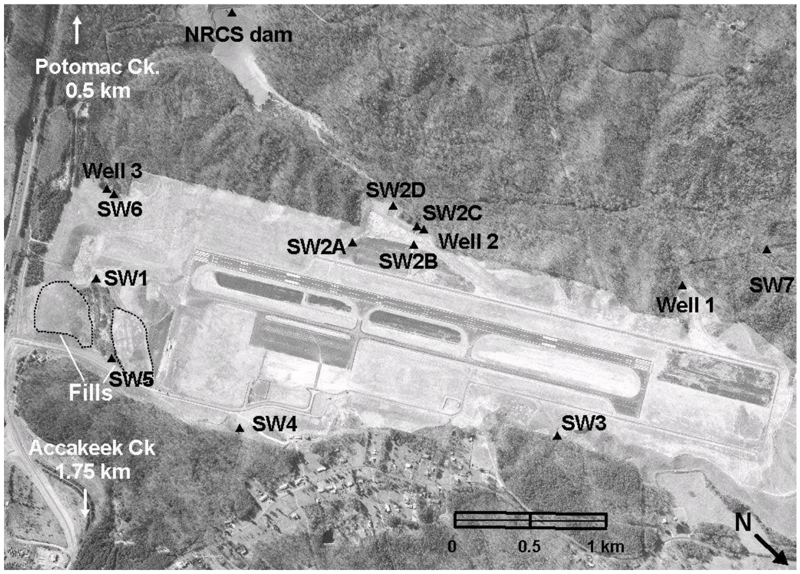
Table 1. Characterization of biosolids applied at Stafford Regional Airport.

Biosolids	C:N	Solids	TKN	CCE	Ha applied
		------------------------ % ------------------------			
Blue Plains	38.24	29.62	0.58	44.35	68
Piscataway	13.23	26.07	1.97	37.34	23
Ballenger Creek	8.26	33.18	2.62	51.99	8
Little Patuxent	9.43	28.71	3.1	38.31	4

Following the incorporation of biosolids, the soil surface was straw mulched and hydro-seeded to a mix of acid- and salt-tolerant grasses (primarily *Festuca arundinacea* Schreb. and *Fetuca ovina*). Due to severe drought conditions during the spring and summer of 2002, the site was reseeded in September 2002. Visual and photographic observations were made over the course of the following year to evaluate revegetation success. In September 2003, surface and subsoil samples were again collected from the original sampling locations. Surface samples were collected to a depth of 10 cm, and subsoil samples were collected below the incorporated zone at a depth of approximately 30 cm. These samples were analyzed for pH in a 1:1 soil:water solution.

Water Quality Monitoring

Beginning in February 2002, surface water and shallow ground water grab samples were collected in and around the Stafford airport. Additional water sampling locations subsequently were identified, and by May 2002 a complete water sampling routine was established. Water grab samples were collected monthly from 16 locations, including 13 surface water samples and 3 shallow groundwater wells. These samples are identified in Figure 10. At each location, 4 50-ml water samples were collected in 50-ml conical-bottom plastic tubes. For surface water samples, each tube was rinsed at the sample location three times prior to sample collection. Wells were purged and sampled (after a recharge period of approximately 60 to 90 minutes) with plastic bailers. For each location, two samples were acid-preserved immediately by the addition of 2 drops of 6N HNO_3, and all samples were placed on ice within 30-minutes of sampling. Dissolved oxygen (DO) and water temperature were measured in the field at the 13 surface water



SW1: On-site drainage.
SW2A-2D: Discharge to tributary to Potomac Creek.
SW3: Influent stream to Stafford Airport
SW4: Influent stream to Stafford Airport
SW5: On-site drainage.
SW6: Discharge to tributary to Potomac Creek
SW7: Tributary to Potomac Creek upstream of airport

Wells 1, 2, and 3: Shallow groundwater wells near discharge drainages
NRCS Dam: Stormwater impoundment downstream of airport
Potomac Creek: Potomac Creek at Rt. 1 (downstream from NRCS dam)
Accakeek Creek: Accakeek Creek at Rt. 1 (just North of Stafford Airport watershed).

Figure 10. Water sampling locations at Stafford Regional Airport, Stafford, Virginia.

locations using a YSI 85 DO meter. In the laboratory, one non-acidified 50-ml sample was used to determine pH, electrical conductivity (EC), and total dissolved solids (TDS). The pH was measured using a combination electrode with an Orion PerpHecT logR Benchtop meter (model 370), and EC and TDS were measured using an Orion conductivity-TDS meter (model 124). The other non-acidified 50-ml sample was used to determine nitrate-N, ammonia-N, and ortho-P. This entire sample was filtered through a 0.45 filter using a benchtop suction apparatus. Nitrate-N was determined by EPA method 353.2 using a LACHAT instruments Quikchem 8000 (QuikChem method 10-107-04-1-A). Ammonia-N was determined by EPA method 351.2 using a LACHAT instruments Quikchem 8000 (QuikChem method 10-107-06-2-A). Orthophosphate was determined by EPA method 365.1 using a Hitachi spectrophotometer model 100-20. One acidified 50-ml sample was used to determine Dissolved Organic Carbon (DOC), and dissolved metals and S. This entire sample was filtered through a 0.45 filter using a benchtop suction apparatus. Levels of Al, Fe, Mn, and Sulfur were determined on a 25 ml subsample by EPA method SW 846 6010B, revision 2, using a SpectroFlame Modula Tabletop ICP, Type FTMOA85D. Additional metals including As, Cu, Ni, Pb, and Zn were determined bi-annually. DOC was determined on a 25 ml subsample by Method 5310C found in Standard Methods for the Examination of Water and Wastewater, 20th edition, on a Sievers 800 TOC analyzer with an autosampler. The other acidified 50 ml sample was retained as an archive sample. In May 2002, following the application of biosolids, water samples were collected from 5 locations for fecal coliform analysis by Method 9221E found in Standard Methods for the Examination of Water and Wastewater, 19th edition.

Results and Discussion

Revegetation

Results from both soil sampling events are provided in Table 2. Surface soil pH values initially ranged between 1.90 to 5.28, with an average of 3.10. The PPA values ranged from 0.61 to 41.76 Mg $CaCO_3$/ 1000 Mg material with an average of 9.51, and total-S ranged from 0.02 to 1.14% with an average of 0.29. At least three conventional hydroseeding efforts were made at the site between 1999 and 2001, which would have applied a total of 6 – 10 Mg of CCE per Ha before our samples were taken. Our initial revegetation efforts during April and May, 2002, were largely unsuccessful due to an unusually hot and dry growing season (Fig. 11). However, the site was reseeded in September, 2002, and was fully revegetated (≥ 90 % perennial living cover) by late October 2002 (Fig. 12). That continued to be status of revegetation as of December, 2003. Despite our recommendations, the airport was seeded with pure grasses, as opposed to a grass/legume mix, which could result in vegetation maintenance issues due to limited N availability in future years. A few highly acidic outcrop and seep areas on steep cut and fill slopes remained barren. These sites will demand intensive spot-liming and mulch treatments over time.

Surface soil sampling a year after remediation (fall 2003) revealed pH values ranging from 6.10 to 7.77, with an average of 7.26. However, in many areas partially oxidized sulfidic material directly underlies the incorporated zone. Subsoil sampling in these cells revealed pH values ranging from 2.71 to 4.56 with an average of 3.49. While a productive topsoil zone has been established, which appears stable after 18 months, continued maintenance will be essential.

A decline in vegetation could allow erosion to expose the partially oxidized subsoil and acid sulfate weathering problems will persist. Careful monitoring over the next few years will allow for evaluation of the stability of the soils, providing lime recommendations that will ensure long-term success of the site.

Table 2. Soil pH, Potential Peroxide Acidity (PPA - Mg $CaCO_3$/ 1000 Mg material) and total-S values from airport soils before and after remediation.

	Sampled December 2001 (surface only)			Sampled September 2003	
map unit	pH	PPA	%S	pH surface	pH subsoil
1	2.82	9.1	0.27	7.03	3.53
2	1.94	31.2	0.95	6.69	2.88
3	3.61	2.3	0.13	6.98	3.53
4	2.42	11.4	0.33	6.49	3.25
5	2.47	15.7	0.49	6.10	2.84
6	2.49	5.4	0.19	7.53	3.22
8	3.45	1.8	0.06	7.29	2.97
9[†]	na	na	na	7.77	4.03
10	3.31	6.2	0.19	7.54	2.77
12	2.45	27.1	0.70	7.76	4.54
14	2.64	8.8	0.41	7.36	3.72
14a	4.01	1.6	0.15	7.40	3.57
15	2.95	2.9	0.09	7.55	3.49
16	2.34	41.8	1.14	7.51	2.92
17	2.72	6.7	0.21	7.34	3.41
18	3.41	3.8	0.10	6.84	2.79
19	2.60	11.9	0.36	6.35	3.58
20[*]	na	na	na	7.42	2.93
21	4.63	0.8	0.03	7.61	3.91
22	4.69	0.9	0.02	7.57	3.83
23	3.68	2.6	0.05	7.57	3.85
24	2.66	13.6	0.30	7.66	2.97
25	3.56	3.7	0.09	7.50	3.45
26	3.50	3.9	0.08	7.71	4.56
27	3.52	4.9	0.14	6.93	3.86
28	3.24	7.3	0.32	7.45	3.53
30	3.27	2.8	0.07	7.49	3.89
31	3.77	5.8	0.23	7.53	4.03
32	3.48	2.4	0.08	7.43	4.07
33	2.75	7.5	0.24	7.40	2.71
34	3.86	4.6	0.11	6.67	2.92

[†] After initial sampling map unit 8 was divided into units 8 and 9.
[*] After initial sampling map unit 19 was divided into units 19 and 20.

Figure 11. Overview of Stafford Regional Airport in June, 2002. The vegetated area in the foreground was incorporated and seeded by mid-April. The barren area in the background was not completed until late May.

Figure 12. (a) Field near runway in July, 2002. Late-May 2002 remediation efforts were largely unsuccessful due to an unusually hot and dry growing season. (b) The same field in August 2003 after reseeding in September 2002 and a reasonable growing season.

Water Quality Monitoring

A subset of results for water grab samples is presented in Table 3. These data portray the overall effects of the airport disturbance and subsequent reclamation efforts on water quality between February 2002 and November 2003. Due to the naturally acidic nature of the soils within this watershed, background surface water pH was acidic, with low to moderate levels of dissolved metals and S. Two streams (SW3 and SW4) draining directly into the airport, were sampled just upstream of the disturbed area. The pH values steadily fluctuated within the 4's (SW3) and lower 5's (SW4) during the entire sampling period. Dissolved Fe typically was less than 1 mg/L for SW3 and less than 10 mg/L for SW4. A headwater stream of Potomac Creek (SW7), sampled upstream of airport inputs, had pH values ranging from 4.6 to 6.6 with dissolved Fe typically less than 5 mg/L. Dissolved S at these three locations was typically less than 5 mg/L. By comparison, prior to remediation, water quality on-site (SW1), discharging from the airport (SW6), and from the downstream NRCS impoundment was highly acidified (pH 2.9 to 3.4) and high in dissolved metals and total-S. Dissolved Fe in discharge waters from the airport ranged from about 10 to 40 mg/L, and water at the NRCS dam ranged from 4 to 9 mg/L. Total-S in discharge waters from the airport ranged from about 28 to 148 mg/L, and at the NRCS dam was approximately 60 mg/L. There is no doubt that the airport construction had significant negative effects on local surface water quality, including Potomac Creek, due to the acidity and metals released over time.

Water quality was affected immediately by the application of lime-stabilized biosolids, as indicated by samples collected during the summer and early fall of 2002. The pH of water discharging from the airport and at the NRCS dam increased into the 6's and 7's; however, by mid-fall 2002 the pH somewhat declined. While the pH values at SW6 and the NRCS dam have fluctuated from the summer of 2002 to the fall of 2003, values have never dropped as low as the pre-remediation values. The pH values at SW6 were quite variable, ranging from 3.5 to 6.4. During the summer of 2003 pH values remained in the mid-3's, but increased through the fall reaching a pH of 5.7 in November. At the NRCS dam the pH values fluctuated in the 5's and 6's (with one exception) and remained in the 6's since June 2003 (Fig. 13). Following biosolids applications, dissolved Fe in water discharging from the airport decreased and past January 2003 remained below 10 mg/L, and below 2 mg/L at the NRCS dam. Sulfur levels remained elevated presumably due to the long-term release of sulfate accumulated from the pyrite weathering

Table 3. Subset of water quality data from Stafford Regional Airport.

sample	date	pH	EC	NO_3-N	NH_3-N	Fe	Al	S
			uS/cm	------------------------------- mg/L -------------------------------				
SW 1	3/6/02	2.85	2560	0.46	0.84	241.5	89.2	543.0
(upstream)	7/8/02	3.34	1407	0.30	4.88	225.2	2.2	230.0
	11/5/02	3.49	1496	8.69	3.95	34.5	17.6	252.0
	3/12/03	3.99	281	0.35	0.67	8.7	2.7	32.6
	7/8/03	3.32	565	0.03	0.73	8.3	2.1	62.4
	11/18/03	4.17	209	0.21	0.48	5.5	1.0	22.2
SW 4	3/6/02	5.02	141	0.40	0.39	3.5	0.1	2.3
(upstream)	7/8/02	dry	dry	dry	dry	dry	dry	dry
	11/5/02	4.69	636	0.30	0.41	0.6	0.3	6.1
	3/12/03	4.96	119	0.74	0.03	9.4	0.5	3.1
	7/8/03	5.26	125	0.29	0.22	2.6	0.2	2.0
	11/18/03	5.08	92	0.04	0.41	14.4	0.5	2.2
SW 6	4/5/02	3.30	1267	0.00	0.88	42.6	18.0	147.9
(site	7/8/02	6.29	470	0.30	4.01	9.8	0.3	35.4
discharge)	11/5/02	4.20	143	2.36	4.79	19.7	9.8	136.8
	3/12/03	4.43	332	1.19	0.90	8.4	3.0	37.9
	7/8/03	3.52	512	0.00	0.65	4.8	2.7	56.3
	11/18/03	5.74	253	0.54	0.71	4.4	0.5	26.3
SW 7	5/7/02	5.48	58	0.05	0.13	2.9	0.2	4.8
(upstream)	7/8/02	6.53	46	0.30	0.09	4.5	0.1	1.5
	11/5/02	5.01	96	0.08	0.09	1.7	0.1	8.1
	3/12/03	4.87	85	0.27	0.06	0.6	0.5	6.8
	7/8/03	5.37	67	0.01	0.16	3.8	0.3	4.1
	11/18/03	5.45	58	0.04	0.39	0.8	0.2	4.5
WELL 3	2/28/02	5.62	226	0.15	0.91	80.7	0.1	0.5
(downstream	7/8/02	6.26	384	0.20	1.61	118.5	0.3	0.6
in floodplain)	11/5/02	6.06	397	0.08	1.72	124.6	0.3	0.5
	3/12/03	6.09	525	0.11	1.97	131.6	0.6	21.7
	7/8/03	5.92	492	0.00	1.86	145.1	0.3	12.5
	11/18/03	6.11	523	0.40	2.40	149.9	0.8	13.0
NRCS Dam	3/4/02	3.30	590	0.36	0.14	8.7	7.7	60.7
(downstream	7/8/02	7.95	1132	2.40	27.22	0.7	0.2	124.6
of all inputs)	11/5/02	5.23	962	12.64	1.86	0.3	1.0	138.6
	3/12/03	4.91	181	0.45	0.35	1.2	1.0	19.6
	7/8/03	6.41	272	0.36	0.67	1.4	0.1	32.3
	11/18/03	6.16	128	0.45	0.11	0.7	0.2	13.4
Potomac	5/7/02	6.42	207	0.09	3.65	1.3	0.1	15.3
Creek at Rt 1	7/8/02	6.92	363	0.60	5.21	1.7	0.1	16.2
(downstream	12/10/02	6.61	272	0.70	0.54	0.8	0.1	20.8
about 1 km)	3/12/03	6.85	132	0.46	0.08	0.3	0.1	4.6
	7/8/03	6.70	108	0.00	0.03	0.5	0.0	3.1
	11/18/03	6.96	92.00	0.36	0.21	0.7	0.1	3.3
Accakeek	5/7/02	6.89	122	0.00	0.09	1.0	0.1	4.9
Creek at Rt 1	7/8/02	6.84	67	0.20	0.16	2.7	0.1	2.4
(control,	11/5/02	6.48	142	0.13	0.00	1.0	0.1	6.4
about 2 km to	3/12/03	6.72	102	0.21	0.19	0.3	0.1	5.2
the north)	7/8/03	6.58	116	0.44	0.18	1.4	0.1	3.9
	11/18/03	6.74	88	0.39	0.02	1.0	0.1	3.4

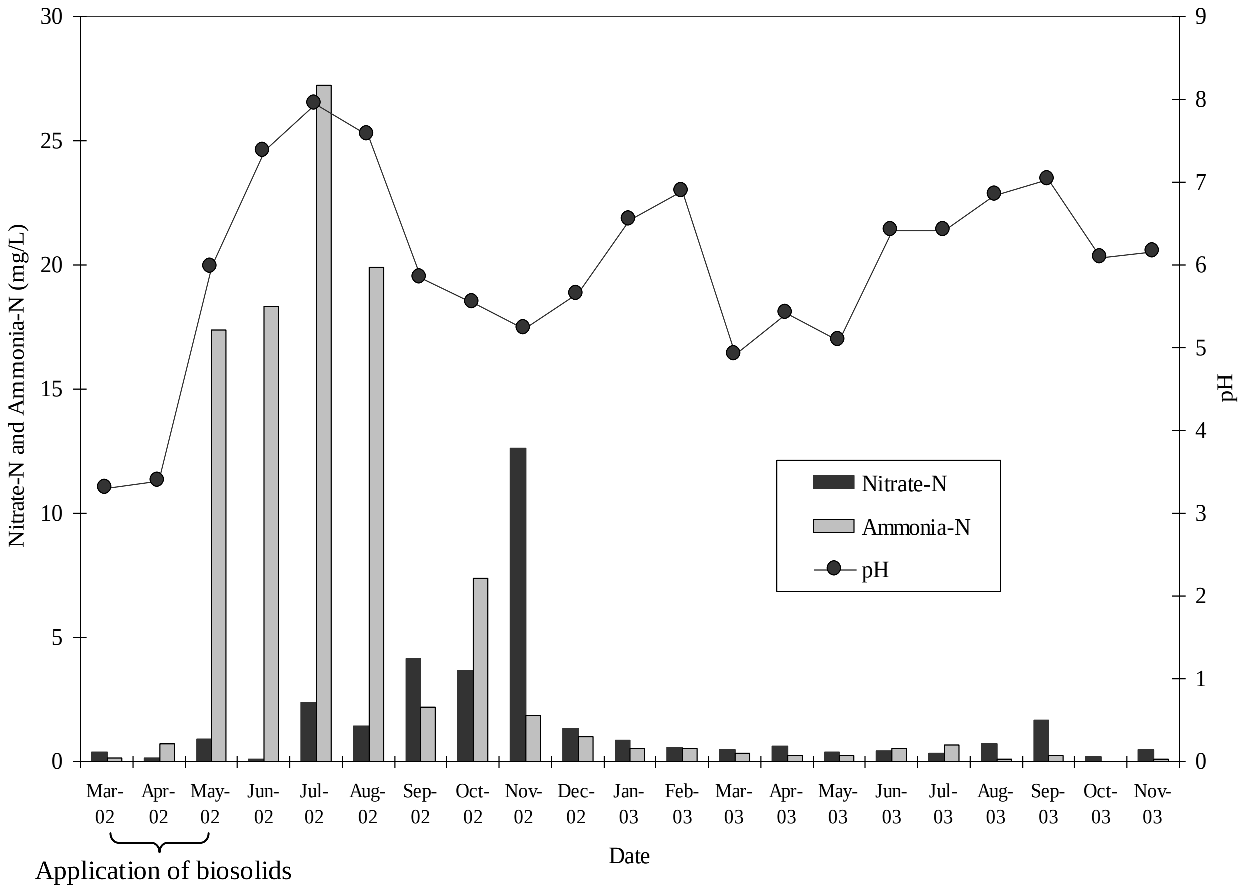


Figure 13. Nitrate-N, Ammonia-N and pH values for surface water samples from NRCS dam discharge. This location receives all runoff water from the Stafford Airport site along with runoff from a larger undisturbed portion of its watershed.

reactions associated with the site. Nonetheless, these levels are declining, particularly within the past year. Since December 2002, S levels remained below 80 mg/L at SW6, and below 50 mg/L at the NRCS dam. Past experience in coalfield acid mine drainage dynamics (Daniels, et al. 2000) has indicated that seasonal (fall/winter) flushes of acid reaction products from acid forming materials are possible. Although this may be the case at Stafford airport, further data will be necessary to reach firm conclusions regarding the long-term effects of the lime-stabilized biosolids on site run-off acidity and metal levels.

Prior to remediation, nitrate-N, ammonia-N, and ortho-P level in all influent, internal and discharge surface water samples were low. With few exceptions, nitrate-N values were typically

<0.5 mg/L (well below the drinking water standard of 10 mg/L), ammonia-N values were <1 mg/L and ortho-P values were < 0.02 mg/L. While nitrate-N values remained low through the summer, slightly elevated values occurred in September and subsequent months. This change was most noticeable at the internal sampling location SW1, the discharge area encompassing locations 2A, 2B, 2C, and 2D, and the NRCS dam during the months of September and November 2002. Since then, elevated values occurred only in the discharge area encompassing locations 2A-2D. Overall, nitrate-N values remained low with respect to the drinking water standard with only three water samples having values > 10 mg/L since biosolids were applied. However, values > 0.5 mg/L in surface waters do pose long term stream impairment risks. Ortho-P values remained low (< 0.5 mg/L) which is notable since the biosolids that were land-applied are relatively high in total and extractable P, and the steeply sloping site was essentially unvegetated for the entire spring and summer of 2002.

The only post-biosolids treatment water quality data of general concern is the fact that the May through October 2002 samples revealed significant levels of ammonia-N at the discharge points from the two on-site sediment control structures (3 to 18 mg/L) and at the discharge point from the NRCS Dam (18 to 27 mg/L). Ammonia-N levels declined during the fall and by January 2003 values were again typically below 1 mg/L. Due to the fact that pre-biosolids application values were always ≤ 1 mg/L at all locations we are certain that the elevated ammonia-N values resulted from the biosolids application on-site. Current USEPA (1999) water quality criteria for ammonia-N indicate that all of our observations at the downstream location (NRCS dam) were significantly less than acute toxicity criteria (eg 36 mg/L at pH 7.0) but were approaching or significantly above the chronic effects level of approximately 4.0 mg/L. The delayed discharge of nitrate-N over the later summer and fall of 2002 also posed a short term water quality impairment risk.

We assume that the ammonia-N levels in these waters were high due to a combination of unique factors at this site. First, and perhaps most importantly, is the very acidic initial nature of the soils and waters involved, which can lead to a net positive charge on the soil exchange complex. This charge which would repel the ammonium ion (NH_4^+) leading to enhanced initial mobility in early run-off events before the added lime was reacted. Microbial soil and water nitrifier populations were also apparently inhibited by the very low pH values and dry/hot environmental conditions through the June 2002 sampling period. However, the drastic drop in ammonia values in the October 2002 samples coupled with the increase in NO_3-N in run-off water confirms that active nitrification was occurring on-site by September 2002. Further sampling over the winter/spring of 2002/2003 confirmed that the ammonia-N levels in discharge waters continued to drop to < 1.0 mg/L.

After biosolids applications commenced (in May 2003) water was collected from 5 sites for fecal coliform analysis. These sites included Accakeek Creek, which is outside the airport watershed, one influent stream (SW3), one on-site location (SW5), the NRCS dam and Potomac Creek. These results were well below the Virginia DEQ (2003) defined standard of 235 CFU's/100 ml of *E. coli* in freshwater as a single sample maximum.

Conclusions

Stafford Airport provides an extreme example of the widespread soil and surface water acidification, and associated damage, which may result from the exposure of sulfidic materials. Disturbance of over 150 ha of sulfide-bearing Tertiary sediments in the Coastal Plain produced highly acidic soils and run-off waters. Barren slopes that could not be reclaimed by conventional methods were subject to erosion, not only causing sediment loss but also exposing fresh sulfidic materials to weathering and hence establishing a self-perpetuating degradation system. Three years of untreated acid drainage from this site had completely degraded various engineered water control structures, and lowered the pH of the main stem of a second-order stream draining a much larger watershed to pH < 3.5. Remediation efforts involving bulk-blending of alkaline materials into cut surfaces and disposal fills have proven successful. In this case, the application of relatively high rates of lime-stabilized biosolids to the acidified soils on-site successfully buffered run-off waters into an acceptable pH range and drastically reduced dissolved metal-loadings. Although N-losses to surface water are a likely secondary effect of the use of heavy loading rates, these losses declined rapidly within 8 months following application of the biosolids. Eighteen months after remediation efforts began, over 90% of the land at the airport was still successfully vegetated. Continued research at this site will be necessary to evaluate the long-term efficacy of this treatment.

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