EFFECTS OF SPOIL GROUNDWATER ON WATER-QUALITY IN A RECEIVING LAKE[1]

by

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Abstract. A groundwater and surface-water study was conducted in order to determine the source(s) which are adversely affecting a 35-acre lake in southeastern Ohio. The lake has a pH of 3 and is flanked on the north by about 100 acres of recently reclaimed spoil, and on the south and west by an area of similar size that has not been reclaimed since surface mining ceased over thirty years ago. Inflows into the lake from the north include three major seeps and the outlet of a limestone drain installed early in the recent reclamation. These inflows contribute only about 5 to 10 percent of the total inflow into the lake but have very poor water-quality, with acidities approaching 1800 mg/L as $CaCO_3$. The other major inflows originate to the south and west of the lake and include three streams and Spring U, which account for nearly 70 percent of the total inflow to the lake, but which have lower acidities ranging from -15 to 250 mg/L depending on the time of year. The remaining inflows include groundwater that seeps into the lake. Although the lake receives inflows from other sources, we believe that the groundwater contribution is a significant factor in overall lake-water quality. Coal-seam-elevation data, monitoring-well surveys and estimations from old topographic maps indicate that the dominant groundwater flow is from old underground mines and auger mining north of the site.

Additional Key Words: Spoil, Highwall, Coal Mine, Acid Mine Drainage

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Introduction

Acid mine drainage may result from a variety of mining methods performed in a watershed - underground mining, strip mining, and auger mining. The mining process exposes iron sulfide (pyrite) in the sandstone overburden and exposes faces of unremoved coal to air and water. The oxidizing conditions result in a lowering of the pH, increase in acidity, and increase in dissolved metals, leading to an overall degradation of water-quality and the inability to support aquatic life.

The degradation of Howard Williams Lake is the result of surface and underground mining of coal. The pH of the lake varies from 2.9 to 3.5 depending on the time of year and has no signs of any aquatic life. The objectives of our work include determination of the sources of acid water and engineering approaches to improve lake-water quality.

Background and Objectives

Howard Williams Lake is a 0.14 square kilometer (35 acre) reservoir located in Perry County, in southeastern Ohio. It was built before 1950 to provide water for a coal-washing plant farther down the valley. The lake, created by damming the valley, collects water from a 1554 square kilometer (6 square miles) watershed. The lake has had a low pH, around 3.0, for at least two decades, with acidity ranging from 200 to 300 mg/L as $CaCO_3$.

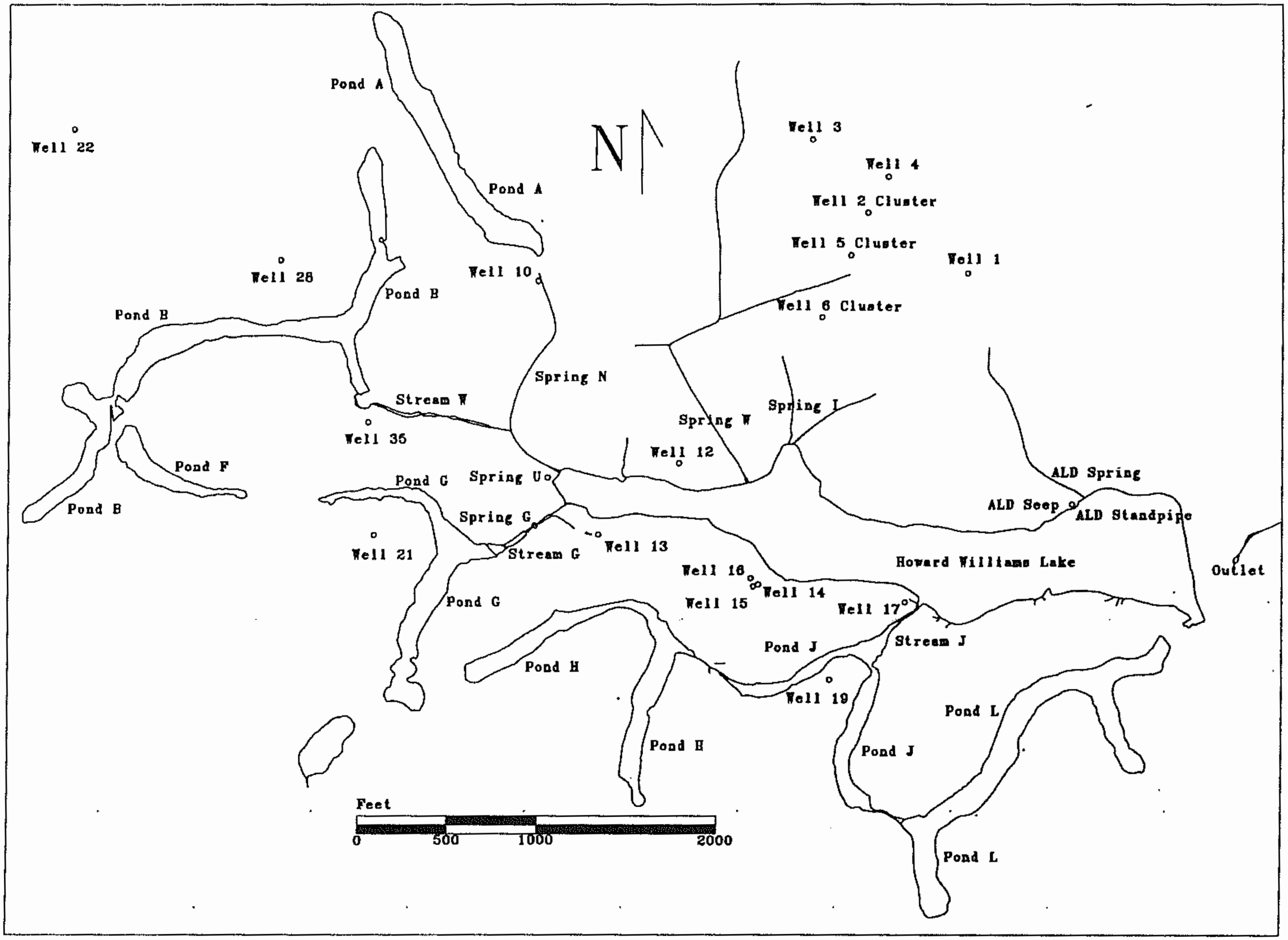
The economic coal seam in this region is the Middle Kittanning (No. 6), which averages about 1.4 meters thick (4.5 feet), with local variations. The outcrop was stripmined by dragline, and auger methods were used at some locations north and south of the lake. The auger system used the "push-button-miner", or PBM, which created rectangular borings about 12-ft in width, rather than the round boreholes common with other augering machines. Coal was also recovered by underground room-and-pillar methods until the late 1960's.

No reclamation of the surface disturbances was done until 1990. At that time the State of Ohio reclaimed about 100 acres north of the lake, primarily in areas where old township roads terminated at the tops of highwalls of about 30.5 meters (100 feet) in height. The spoil was regraded to a rolling topography from the old highwalls to the lake. Compost additions, papermill sludge additions, and revegetation seeding resulted in a current good ground cover of grasses in this reclaimed area.

Acidic waters enter this lake from (1) seeps and surface drainage from the reclaimed area north of the lake, (2) seeps from unreclaimed spoil piles and surface drainage from water ponded in old strip pits south of the lake, and (3) surface drainage from old ponded pits west of the lake. The overburden of the No. 6 seam, and the coal seam itself, contain from a few tenths percent up to several percent sulfur, as pyrite, with very little alkaline material.

The basic mechanism that produces acid mine drainage is the oxidation of pyrite. Pyrite dissolves to form ferrous iron, acidity, and sulfate in equation (1). (Donovan *et al* ., 1994; Lapakko, 1994) Both reactions take place in the presence of oxygen and water and are catalyzed by the bacteria *Thiobacillus ferrooxidans*. (White *et al* ., 1994)

Figure 1. Site Map.



$$FeS_2 + 7/2O_2 + H_2O \Rightarrow 2SO_4^{2-} + Fe^{2+} + 2H^+ \quad (1)$$

Ferrous iron is then oxidized to ferric iron in the presence of oxygen and it consumes acidity.

$$Fe^{2+} + 1/4\ O_2 + H^+ \Rightarrow Fe^{3+} + 1/2\ H_2O \quad (2)$$

Equation (3) shows that ferric iron in solution will form iron hydroxides and produce acidity, but this is a very slow reaction in waters with a pH below 3. At higher pH values this reaction is very fast, resulting in noticeable quantities of iron hydroxides precipitating out of solution.

$$Fe^{+3} + 3H_2O \Rightarrow Fe(OH)_3 + 3H^+ \quad (3)$$

Methods

Mine maps were obtained from the U. S. Bureau of Mines showing the extent of underground mining in the regions surrounding the lake. A digitized map, derived from aerial photos taken in 1994, of the area around the lake was obtained from the Ohio Department of Natural Resources. Other aerial photos taken at various stages of the surface mining operation were also examined. These, and other anecdotal information, described the deposition of a large volume of coal-washing wastes in a pit along a highwall north of the lake. This waste deposit was covered during the 1990 reclamation; estimates of the volume of this material are about 245,000 cubic meters (320,000 cubic yards).

Study of old maps, photographs, and intensive walk-through of the mined land, highwall exposures, and spoil piles provided definition of the surface waters flowing into the lake. It was expected that surface mining intercepted old deep-mine tunnels, but the bases of all current highwalls are covered with slumped material and water in abandoned strip pits. This prevented clear determination of possible hydraulic connections between underground mined areas and surface water in strip ponds.

Mine maps provided data on the extent of mine voids underneath the rolling hills of the region, underclay elevations, coal-seam thickness, and localized geologic sections. Figure 1 shows the major features of the area around the lake, with individual strip-pit ponds identified.

In early 1994, twenty-four groundwater monitoring wells were installed with the assistance of the Ohio Department of Natural Resources' equipment and staff. Figure 1 shows the locations of these wells. Well clusters were installed at No.2, No.5, and No. 14 to provide opportunities to perform medium-scale hydraulic tests of the minespoil. All wells are either 2-in or 4-in diameter and are screened either 1.5 or 3.0 meters (5 or 10-ft) above the underclay. Well Nos. 4, 19, 21, and 28, were located in attempts to intercept underground mine rooms or auger-mine voids. This was in order to determine water-quality, flow direction, and the extent to which these subsurface voids are flooded. An underground mine room was found at well 21 and an auger opening was found at well 4. Both well Nos. 22 and 28 were drilled into unmined coal.

Well Nos. 1, 2, 3, 5, 6, 10, and 12, are located in recently reclaimed spoil north of the lake. Well Nos. 13, 14, 15, 17, and 35, are located in unreclaimed spoil south of the lake. Wells 1, 2, and 3, are located in the coal-cleaning waste buried in a pit north of the lake.

Surface-water inflows to the lake have been sampled for water-quality analyses and flow rates since fall, 1994. Chemical analyses were conducted by a commercial laboratory using standard methods. Flow rates were determined by diverting flows through a 6-in polyvinyl chloride (PVC) pipe and measuring amounts captured in a bucket during a time measured by stopwatch. Flow measurements were made at least in triplicate and the results averaged. The October 2, 1995, data is shown in Table 1 and represents typical water quality data for the surface inflows.

Results

Determining whether or not the coal seam is inundated is a very important aspect of the site. The mine floor in well 21 is at an elevation of 281.16 meters (922.45 feet), the water table is at approximately 283.51 meters (930.15 feet), and with a relatively flat coal seam and a thickness of 1.22 meters, it can be assumed that the underground mine is completely flooded. The direction of flow is towards Pond G, located at the base of a highwall 15 to 23 meters (50 to 75) feet north of the well (Figure 1). Pond G has an average water elevation of 281.7 meters (924.1 feet). So, there is about 1.8 meters (6 feet) of head driving the water from the old underground mine voids towards Pond G.

Mine maps showed possible auger mining northeast of well 2 and adjacent to Pond J. Well drilling penetrated an auger opening in the highwall above well 2, and a 2-inch observation well was placed there (well 4). The well is 32.6 meters (107 feet) deep and rests on top of the underclay. The auger-mining void was completely flooded. The water level was 286.6 meters (940.4 feet) and the water level in well 2 was 284.0 meters (932.0 feet), which indicates that the auger-mining voids are a source of recharge for the coal-cleaning waste pit.

Several attempts were made to intercept auger openings in the highwall above Pond J. Every attempt resulted in hitting unmined coal. One well, well 19, was left in and surveyed to obtain water-level

Table 1. Water-Quality and Flowrates for Flows into and out of Howard Williams Lake for October 2, 1995.

Location	pH	Total Acidity (mg/L as $CaCO_3$)	Sulfate (mg/L)	Total Iron (mg/L)	Total Manganese (mg/L)	Aluminum (mg/L)	Flowrate (gpm)	Influx of Acidity (kg/day)
ALD Spring	2.93	1672	3860	600	79	60	6.5	53.9
ALD Stream	2.95	1394	3081	460	60	69	2.5	17.2
Standpipe	5.61	-22	3068	520	60	1	1.7	-0.2
Spring W	3.00	368	2140	106	44	15	4.9	8.9
Spring I	3.95	790	3002	417	64	23	1.2	4.6
Spring U	4.15	227	1288	83	25	13	83.5	94.7
Stream W	7.60	-106	230	<1	<1	<1	33.7	-17.8
Spring N	3.00	1093	2800	235	37	48	<.5	0
Stream G	6.02	-19	453	12	2	2	59.3	-5.6
Spring G	3.15	250	1255	76	19	18	18.4	22.9
Stream J	2.78	418	1473	54	31	17	21.4	44.7
Outlet	3.00	305	1236	24	23	13	234	357

elevations. The water level in well 19 is around 279.3 meters (916.2 feet) and Pond J is 278.1 meters (912.4 feet). So the strip ponds to the south of Howard Williams Lake are receiving recharge from the unmined coal seam and auger openings. This connection was verified with a qualitative tracer test using fluorescein dye. A positive result was obtained in Pond J within a week of dye injection into well 19.

Two more wells were installed in areas to the northwest of Howard Williams Lake that are thought to be affected by underground mining. Wells 22 and 28 are located above Pond A and B. Water level elevations for well 22 and 28 are 285.9 and 284.1 meters (938.0 and 932.0 feet), respectively. Both of these wells have about 16 feet of water above the underclay, thus the coal seem is also completely submerged in this area. No underground mine rooms were intercepted with these wells, but rooms do exist in the area according to the mine maps.

The remainder of the wells were placed in the strip mine areas around the lake. Wells 1, 2, 2A, 2C, and 3 are all in an old strip pit occupied by coal-cleaning waste. The mine waste has a thickness of about 18 meters (60 feet), with the bottom 5 to 6 meters (15 to 20 feet) being submerged. According to water-level elevations, the water in the pit tends to move to the southeast towards Howard Williams Lake. It may be possible that the water in this pit is seeping out at the seeps near the anoxic limestone drain (ALD).

Wells 13, 14, 15, 16, 17, and 35, are all in the unreclaimed spoil areas to the south and west of Howard Williams Lake. All of these wells are very shallow and are located near the base of the spoil piles. Wells 10 and 12 are also shallow wells, but have been placed in the reclaimed spoil areas. Well 10 is near Pond A and well 12 is within 100 feet of the north shore of Howard Williams Lake. Wells 5, 5A, 5B, and 6A are located to the southwest of the coal-cleaning waste pit in the reclaimed spoil.

Water Budget

There are several surface inflows into Howard Williams Lake. The quality and quantity of these inflows vary considerably. The lake discharges through a drop-inlet in the southeastern side of the lake. The drop-inlet then drains into a 122 centimeter (4 feet) diameter concrete pipe which passes through the dam and drains to the east of the lake. Flowrate measurements for the outlet of the lake have been done using Manning's equation, since normal flow exists in the pipe (Chow, 1959). By using Manning's equation, the only field measurement needed is the width of flow. The pipe has a slope of 0.026 m/m, diameter of 122 centimeters (48 inches), and the Manning's roughness coefficient has been estimated at 0.018 for this pipe.

All of the surface inflows to the lake were low enough to be measured using a bucket and a stopwatch. At least three trials were done on each inflow to get an average value. The location of the inflows are shown in Figure 1 and the average inflow rates are shown in Table 2. Stream J discharges water from Ponds L, J, and H, and enters the lake through a small culvert underneath an old haul road on the south side of the lake. Seep G is a seep that converges with Stream G and enters the lake though another culvert that runs underneath the haul road on the south side of the lake. Spring U is a seep about 0.3 meters (1 foot) in diameter that is located about 5 meters west of the west edge of the lake and is between the haul

Table 2. Average Flowrates.

Location	Flowrate (gpm)
ALD Spring	4.96
ALD Stream	1.87
Standpipe	1.50
Spring I	2.24
Spring W	5.08
Spring N	0.55
Stream W	27.66
Spring U	76.72
Spring G	19.30
Stream G	79.80
Stream J	27.79
Outlet	295.00

road and the lake. Stream NW has two forks - the west fork is runoff from Pond B, Spring N is fed by a seep coming out of the reclaimed spoil created by the reclamation to the north. Both forks flow through a limestone-lined channel installed during reclamation. Spring W, Spring I, Spring N, ALD Stream drain seeps originating in reclaimed spoil north of the lake and flow through limestone-lined channels installed during the reclamation. ALD Spring and ALD Stream, which drain seeps, are adjacent to an anoxic limestone drain that drains out a standpipe located near the shore of the lake. The streams are all located in swales created by the reclamation. The limestone channels are heavily covered with iron oxides. The channels also carry very little surface runoff and have not shown any scouring effects during storm events.

Water-Quality

Water sampling began in the fall of 1994 and has continued through 1995. Initially only the surface inflows to, and outflows from, Howard Williams Lake were sampled. This was expanded to include all of the monitoring wells as they were installed throughout the site. The goal of the water-quality analysis is to determine the areas around Howard Williams Lake that are contributing to the poor water-quality conditions found in the lake, so that an economical and effective restoration plan can be designed.

All inflows and outflows have been sampled several times over the last year and a half. Attempts were made to sample during wet and dry periods to see what effect rainfall had on water-quality and flow. A few sample sets were taken after rainfall events, but most of the sample sets were primarily taken during low flow periods. After rainfall events, flowrates of streams connected to ponds increased while their acidity decreased. Springs had no noticeable change in flowrate or quality.

Discussion

From Table 1 it can be seen that the major sources of acid mine drainage are ALD Spring and Spring U. These two sources of water account for only 32% percent of the surface flow entering the lake, but contribute 63% of the acidity.

ALD Spring is believed to be the result of recharge entering the spoil and flowing through zones of high pyritic content. A gob pit to the northwest of ALD Spring and underneath wells 1, 2, and 3, has been proven to be in direct connection to ALD Spring by using particle tracking in Visual Modflow (Guiguer and Franz, 1996).

The source of water for Spring U is Pond G, which is believed to be connected to an underground mine opening. Pond G is at an elevation of 281.7 meters (927.69 feet), while Howard Williams Lake is at 278.5 meters (913.8 feet). Pond G is separated from Howard Williams Lake by a spoil pile. Stream G carries water from Pond G over a series of beaver dams and into Howard Williams Lake through a culvert. The beaver G and the lake. The large difference in head between these two bodies of water is believed to be the driving force behind two seeps, Seep G and Spring U, that exit the spoil pile at or near the elevation of the lake. The seeps are believed to be the result of pseudokarstic conditions typical of mine spoil (Aljoe, 1994). Table 3 shows how the water-quality changes as it goes from the underground mine rooms through the highwall into Pond G and eventually into the lake via Stream G and Spring U.

As can be seen from Table 3, the water that seeps through the spoil pile deteriorates substantially before it exits the spoil pile. Acid-base accounting data for the spoil adjacent to Pond G is not known, but core samples from well 21 give a good indication as to the quality of the overburden (Table 4). Well 21 is located about 30 meters from the edge of the highwall that is adjacent to Pond G. Based on stratigraphy from drilling records and tables, well 21 has a height-averaged pyritic sulfur content of 0.24 percent, with a potential acidity of 7.55 g/kg, and a neutralization potential of 0.43 g/kg ($CaCO_3$). These values are representative of the spoil adjacent to Pond G. Sobek *et al* . (1978), defined geologic material as being potentially toxic if the pH is less than 4.0 or the material has a net $CaCO_3$ deficiency of 5 grams or more dams have created a head difference of 5 meters (13.9 feet) between Pond per kilogram of material. For well 21, the only material that is considered potentially toxic is the Freeport Coal, but this seam is very shallow and often non-existent in the highwalls. The gray sandstone, which makes up a good portion of the overburden, can be considered potentially toxic due to its $CaCO_3$ deficiency, but not its pH. Pyrite contents are not particularly high, but result in toxicity due to a general lack of alkalinity in the overburden.

Stream J is another major source of acid mine drainage. Pond H and L overflow into Pond J, which drains out Stream J to Howard Williams Lake. There are two sources of recharge to these ponds: spoil groundwater and the highwalls. A connection exists between the highwall and Pond J, as proven recently with a tracer test. However, adjacent spoil is the major cause of poor water-quality in Pond H, J, and L. By comparing water-quality data for Stream J, well 17 (in spoil) near Stream J, and well 19 (highwall), the water-quality of Pond J is related to the water-quality in the spoil. The percentage of water that each source contributes to Pond H, J, and L is not clear at this time. The quality of the overburden was obtained from acid-base accounting data for well 21. The height-averaged pyritic sulfur content is 0.24 percent with a potential acidity of 7.55 and

Table 3. Effects of Spoil on Typical Water Quality from Well 21A to Spring U

Location	Head (ft)	pH	Total Acidity (mg/L as CaCO3)	Sulfate (mg/L)	Total Iron (mg/L)	Manganese (mg/L)	Aluminum (mg/L)
Well 21A	929.7	6.18	-4.67	266	19	2.02	0.69
Pond G	927.7	6.66	-48.50	95	1	0.90	0.10
Stream G	922.1	4.94	32	492	15	4.43	3.08
Spring G	915.2	3.27	308	1401	79	25	21
Spring U	915.2	3.98	419	1438	82	28	15

Table 4. Acid Base Accounting Data

Location	Depth	pH	Material	Neutralization Potential	Total Sulfur	Pyritic Sulfur	Potential Acidity		CaCO3 Deficiency	
	(m BGS)			ton/kton as CaCO3	(%)	(%)	total sulfur*	pyritic sulfur*	total sulfur*	pyritic sulfur*
Well 3	4.6	2.87	Gob	-2.35	6.60	4.94	206.3	154.4	208.6	156.7
Well 3	9.1	3.39	Gob	-1.05	6.00	4.82	187.5	150.6	188.6	151.7
Well 3	10.7	4.27	Gob	3.67	4.81	3.90	150.3	121.9	146.6	118.2
Well 3	13.7	4.35	Gob	4.40	10.75	8.61	335.9	269.1	331.5	264.7
Well 3	18.3	4.06	Gob	-2.87	4.72	3.10	147.5	96.9	150.4	99.7
Well 3	22.3	3.41	Gob	-0.20	1.37	1.03	42.8	32.2	43.0	32.4
Well 5	3.0	4.10	Spoil	0.50	0.24	0.06	7.5	1.9	7.0	1.4
Well 5	6.1	4.23	Spoil	-0.25	0.50	0.36	15.6	11.3	15.9	11.5
Well 5	12.2	4.35	Spoil	-0.25	0.29	0.24	9.1	7.5	9.3	7.8
Well 5B	5.5	3.61	Spoil	-2.00	0.40	0.03	12.5	0.9	14.5	2.9
Well 6	9.1	5.38	Spoil	9.99	0.60	0.53	18.8	16.6	8.8	6.6
Well 6	12.2	4.82	Spoil	10.70	0.86	0.80	26.9	25.0	16.2	14.3
Well 6	18.3	2.10	Spoil	-75.70	20.00	11.50	625.0	359.4	700.7	435.1
Well 6	18.6	2.67	Spoil	-9.74	3.26	2.07	101.9	64.7	111.6	74.4
Well 6	19.5	5.10	Spoil	0.50	1.02	0.98	31.9	30.6	31.4	30.1
Well 10	6.1	4.91	Spoil	2.25	0.30	0.07	9.4	2.2	7.1	-0.1
Well 10	9.1	3.43	Spoil	-75.70	2.00	1.23	62.5	38.4	138.2	114.1
Well 19	13.1	5.99	WSS	4.40	0.01	0.01	0.3	0.3	-4.1	-4.1
Well 19	22.3	6.85	WSS	6.10	0.34	0.33	10.6	10.3	4.5	4.2
Well 19	25.3	6.59	USS	24.20	0.27	0.26	8.4	8.1	-15.8	-16.1
Well 19	28.3	5.68	USS	19.50	1.29	0.57	40.3	17.8	20.8	-1.7
Well 19	31.4	5.39	Shale	12.90	1.87	1.32	58.4	41.3	45.5	28.4
Well 19	32.9	6.50	Shale	11.00	1.48	0.80	46.3	25.0	35.3	14.0
Well 19	34.7	3.52	Coal (K)	-3.75	4.00	2.18	125.0	68.1	128.8	71.9
Well 21	7.6	5.21	Shale	22.00	0.36	0.36	11.3	11.3	-10.8	-10.8
Well 21	8.8	3.10	Coal (F)	-27.50	8.36	6.31	261.3	197.2	288.8	224.7
Well 21	11.0	5.59	USS	0.80	0.30	0.30	9.4	9.4	8.6	8.6
Well 21	22.3	6.16	WSS	0.57	0.01	0.01	0.3	0.3	-0.3	-0.3
Well 21	25.3	5.75	USS	-0.27	0.57	0.57	17.8	17.8	18.1	18.1

BGS = Below Ground Surface
WSS = Weathered Sandstone
USS = Unweathered Sandstone
F = Upper Freeport No. 7 Coal
K = Middle Kittanning No. 6 Coal
* units = ton / 1000 tons as CaCO3

neutralization potential of 0.43 g/kg ($CaCO_3$). That well 19 (thus the highwalls) has good water while spoil groundwater is bad indicates oxidizing conditions in the spoil.

Using the MODFLOW computer program (McDonald *et al* ., 1988), the recharge for the spoil surrounding Pond J, H, and L that is required to match the seasonal flowrate recorded at Stream J (1.6 L/s), is 0.60 cm per year, which is relatively low. This may result, in part, from the steep slopes of the spoil piles and the lack of good vegetation. The highwall was not considered a source of water; it was modeled as a no-flow boundary. The haul road between the lake and the ponds was also considered a no-flow boundary because it is less than 3 meters above the elevation of the underclay and greatly compacted.

One of the most interesting aspects of this site is the water-quality in strip ponds to the west of Pond G (Table 5). All of the water to the west and northwest of Pond G is of good quality water. The strip mining done in these areas was done at the same time as the mining around Pond G, H, J, and L. As you go to the west of Spring U the water-quality improves. One possible reason is that there is a lithologie change from west to east. We have been unable to determine if limestone is present in the overburden to the west of Howard Williams Lake. Well logs from wells 22 and 28 show no evidence of any alkaline material. Another possible reason is that Pond A, B, and F are much deeper than Pond H, J, and L. On average, Pond A, B, F, and G contain 4 to 9 meters (15 to 30 feet) of water above the underclay. Pond H, J, and L are much shallower with depths of only 4 to 10 feet. The deep ponds are able to submerge the pyritic roof shale of the exposed highwall, while the water level in the shallow ponds fluctuate within the roof-shale zone, resulting in greater acid production in the shallow ponds.

The topography of the reclaimed spoil on the north side of the lake is substantially different than the undisturbed spoil to the south and west. The most noticeable difference is the lack of any significant inflows into the lake. The reclamation eliminated all of the strip ponds, thus it also eliminated the possibility that beavers would dam up a flow, creating a situation similar to Pond G, where increased head increased the amount of water flowing through potentially toxic spoil. The north side only contributes about 25 percent of the flow that enters Howard Williams Lake, but contributes a more significant amount of chemical load due to much higher concentrations of sulfate, iron, manganese, aluminum, and various other metals.

The effects that the coal-cleaning waste pit has on lake-water quality has not been clearly defined. Wells 1, 2, 2A, 2C, and 3 are all screened within the pit and are shown on the map in Figure 1. The water-quality data for these wells are

Table 5. Typical Water Quality of Ponds West of Howard Williams Lake

Location	pH	Total Acidity (mg/L as CaCO3)	Sulfate (mg/L)	Total Iron (mg/L)	Manganese (mg/L)	Aluminum (mg/L)
Pond A	6.51	5.0	240	0.47	2.12	0.38
Pond B	7.10	-34	223	0.27	0.55	0.30
Pond F	6.83	-17.5	198	0.50	0.47	0.49

Table 6. Typical Water Quality of Wells Located in Gob Pit.

Location	pH (field)	Total Acidity (mg/L as CaCO3)	Sulfate (mg/L)	Total Iron (mg/L)	Manganese (mg/L)	Aluminum (mg/L)	Total Hardness (mg/L)
Well 1	3.55	437	1317	244	16	4.1	1144
Well 2	4.91	345	1310	215	11	0.6	1025
Well 2A	4.52	856	2800	1160	22	21.6	1913
Well 2C	5.13	334	3382	299	12	4.6	1949
Well 3	3.56	197	791	112	4	7.0	493

shown in Table 6. Though the field pH is high in wells 2 and 2C, upon oxidation the pH drops to 3.0 resulting in the hot peroxide acidities shown in the table. Acid-base accounting data for well 3, shown in Table 4, show very high pyritic sulfur contents and $CaCO_3$ deficiencies. From the water-quality data, the mine waste appears to be very heterogeneous, with some areas producing more acidity than others.

Wells 5, 6, 10, and 12 are located in reclaimed spoil north of Howard Williams Lake. Water-quality data, shown in Table 7, show acidic conditions in wells 5, 6A, 10, and 12, with varying degrees of acidity. This is another example of heterogeneous conditions within a spoil pile. Acid-base accounting information for wells 5, 5B, 6A, and 10, also show very heterogeneous conditions, with some samples being marginally toxic, while other samples

Table 7. Well Water Quality Data for October 2, 1995.

Location	pH	Total Acidity (mg/L as CaCO3)	Sulfate (mg/L)	Total Iron (mg/L)	Manganese (mg/L)	Aluminum (mg/L)	Hardness (mg/L)
Well A8	3.21	1709	3800	720	83	90	2316
Well 2	5.20	-12	1129	214	9.3	0.6	872
Well 2C	5.85	-55	3671	310	10.8	0.1	1716
Well 3	3.15	176	727	120	4.5	29	120
Well 4	3.19	124	851	97	4.2	0.5	589
Well 5	3.09	523	2245	267	51	20	1768
Well 5B	4.51	237	2335	196	30	0.1	2126
Well 6A	5.10	521	1800	303	32	0.2	1410
Well 10	5.43	187	1893	262	52	0.2	1916
Well 12	3.68	227	3071	296	107	22	2516
Well 13	3.18	1783	4987	276	78	280	2947
Well 14	3.88	178	665	89	20	2	599
Well 17	3.05	970	3323	280	68	84	2253
Well 19	6.68	-127	482	0.81	2.5	0.1	453
Well 21A	6.35	-91	356	27	1.02	0.2	473
Well 22	5.30	-14	43	0.54	0.53	0.2	326
Well 28	7.02	-197	119	0.91	0.27	0.1	316
Well 35	5.92	-105	897	40	44	0.5	1168

are extremely toxic.

To this point, direct groundwater contributions to the lake have not been discussed. According to mine maps, the elevation of the underclay is above the lake surface. This make sense due to the number of seeps that exit the spoil several feet above the lake surface. Several water budget calculations have been made and are shown in Table 7. On average, surface inlfows contribute a high percentage of the lake outflow, the differences being subsurface flows and evaporation from the lake surface.

The anoxic limestone drain (ALD), located between ALD Spring and ALD Stream has been effective in treating groundwater that would eventually enter the lake. The water-quality characteristics of the water going into and exiting the anoxic limestone drain are shown in Table 9. The drain was built in 1990 and has a flowrate of about 2 gpm. There is no stabilization pond collecting the water that drains from the ALD, the water drains directly into Howard Williams Lake. It is interesting to note the amount of aluminum being taken out by the ALD, therefore at some point in the future it may show signs of clogging up.

Conclusions

The degradation of water-quality in Howard Williams Lake is caused by movement of groundwater through toxic spoil and possibly also by drainage of underground mine voids which are not fully flooded. The source water is recharge from precipitation percolating through spoil, and head differences created by ponds in old pits surrounding the lake. The water-quality in mines which are completely inundated is good, as a result of anoxic conditions. If the water table in the inundated mines is lowered, introduction of air could cause an increase in acid mine drainage

Table 8. Water Budget for Howard Williams Lake

Date:	9/22/94	10/8/94	10/15/94	10/27/94	8/28/95	10/2/95
Inflows (gpm)						
Stream J	27	30	36	28	14	21
Stream G	78	66	73	67	94	59
Spring G	25	19	20	20	19	18
Spring N	0	0	0	0	1	1
Stream W	0	0	0	0	53	34
Spring U	90	69	72	71	84	83
Iron stone seep (east)	0	0	0	0	0	0
Spring I	4	4	4	4	2	1
Spring W	0	0	0	0	7	5
Standpipe	2	0	1	2	2	2
ALD Stream	0	0	0	0	3	2
ALD Spring	3	4	4	4	7	6
Total Inflows	229	194	210	196	284	234
Outflow (gpm)						
Drop-Inlet	295	143	163	143	295	234

Table 9. Performance of Anoxic Limestone Drain.

Anoxic Limestone Drain					
date sampled:	8-Oct-94	5-Nov-94	22-May-95	28-Aug-95	2-Oct-95
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
In					
pH			3	3	3
Total Acidity			905	1414	1709
Aluminum			87	87	90
Out					
pH	5	6	6	6	6
Total Acidity	746	791	882	618	0
Aluminum	2	2	2	1	1

production. Since the No. 6 coal seam averages several percent pyritic sulfur, the coal remaining as pillars and between auger openings may provide a significant source for acid to be produced.

The effect that the coal-cleaning waste pit has on lake Water table elevations show a slight gradient toward the lake, but whether or not this water is directly affecting the water-quality of Howard Williams Lake is not known. Tracer tests and geophysical investigations may be able to define what role the coal-cleaning waste has on lake-water-quality. Likewise, the actual contribution to lake acidity from spoil piles surrounding the lake in not yet well defined. Water-quality data and acid-base accounting data show the heterogeneous conditions throughout the spoil area.

Data clearly show regional differences in water-quality surrounding the lake. Local sportsmen routinely fish in ponds west of the lake; unfortunately these high quality ponds contribute very little flow to the lake. Complete surveys of pond depths, correlated with adjacent coal-seam elevations should confirm the extent to which mined-out subsurface areas are flooded, and to what depths. Underclay elevation data suggest very localized variations in topography which could provide preferential flow paths in partially flooded underground mine rooms. Ponds as much as 25-feet deep may be creating anoxic conditions in both the mined-out subsurface as well as several feet upward into roof shales and pyritic sandstones. Other studies in Appalachian mining regions have shown that coal-seam roof rock may be more pyrite-rich than super-jacent or subjacent strata, and thus a greater source of acidity.

Our investigations ultimately will provide data upon which a sound and effective engineering design to re-route waters affecting the lake can be based. This design may well include some classical treatment options; but control of flows within the entire watershed appears also to have a high probability of effectiveness. A future use of this lake is proposed for recreation purposes, so that consideration of all related waters in the region is highly desirable.

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