LC20D Passive Mine Drainage Treatment System
Final Report

Submitted By Hedin Environmental to
Farmington Township Supervisors

September 30, 2007

Executive Summary

Little Coon Run in Farmington Township (Clarion County, PA) is polluted by acid mine drainage. Three artesian well discharges account for a majority of the AMD pollution. This project implemented a remediation plan that targeted these three discharges for treatment and sealing. The primary funding was a $396,734 Growing Greener grant from PADEP Bureau of Abandoned Mine Reclamation to Farmington Township. Secondary support of approximately $40,000 was obtained the Office of Surface Mining's Appalachian Clean Streams Program. Hedin Environmental (Pittsburgh, PA) managed the project and provided engineering and technical support to Farmington Township.

LC20D is located on in the lower portion of the watershed on Game Lands 24. A passive treatment system was installed that included: construction of a 4,500 ft access road, an 1,800 ton anoxic limestone drain, a 15,000 ft^2 settling pond, and a 10,000 ft^2 constructed wetland. The project contractor, selected through a competitive bidding process, was Nick Construction (Lucinda, PA). The work began in September 2006 and was completed in May 2007. No major construction problems were encountered. The system's effectiveness was monitored between May and September 2007. The system has treated 53 gpm of flow and decreased acidity from 191 mg/L to 36 mg/L and Fe from 113 mg/L to 3 mg/L. The system is removing on average100 lb/day of acidity and 75 lb/day of Fe. Monitoring stations in Little Coon Run downstream of the site have pH values of 5.5 – 7.0 for the first time in recorded memory and fish have been observed in lower Little Coon Run.

The system is passive and does not require regular attention, but it must be inspected periodically. An Operation and Maintenance Plan was prepared that will assist Farmington Township and the Game Commission in these inspections.

LC35D and LC40D produce more severe AMD than LC20D and were not considered good candidates for passive treatment. Hydrologic methods were used to remediate these discharges. A well was drilled to attempt to create a drain that would lower the polluted aquifer and eliminate LC35D and LC40D. The hole, drilled to a depth of 238 ft, did not intercept polluted ground water and was not able to drain the polluted aquifer. Late in 2007, the two wells were sealed (plugged). LC35D was sealed by conventional methods. LC40D was sealed with an Alternate Method that included the installation of plastic pipe at the top of the well that can be used to block or release artesian flow.

Concerns have been raised by hydrologists and landowners about the fate of polluted water whose flow is blocked by well sealing. If the flow is redirected to another site, the environmental benefits may not be as great as anticipated. All significant artesian flows within the Frills Corner Syncline were monitored for 21 months for flow and chemistry. These data, presented in the report, are the most complete baseline of pre-existing conditions ever assembled for a well sealing project. Continued monitoring should allow a determination of how the well plugging affects local hydrology and contributes to stream restoration efforts.

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Project Background

The purpose of this project was to improve the quality of Little Coon Run through the construction of a passive treatment system and the sealing of two artesian flows of acid mine drainage (AMD). Little Coon Run is a tributary to Coon Run that is located in Farmington Township, Clarion County. Figure 1 shows the project area. The previously completed restoration plan (Little Coon Run and Walley Run Mine Drainage Assessment and Restoration Plan, June 2003) identified AMD as the primary water quality problem.

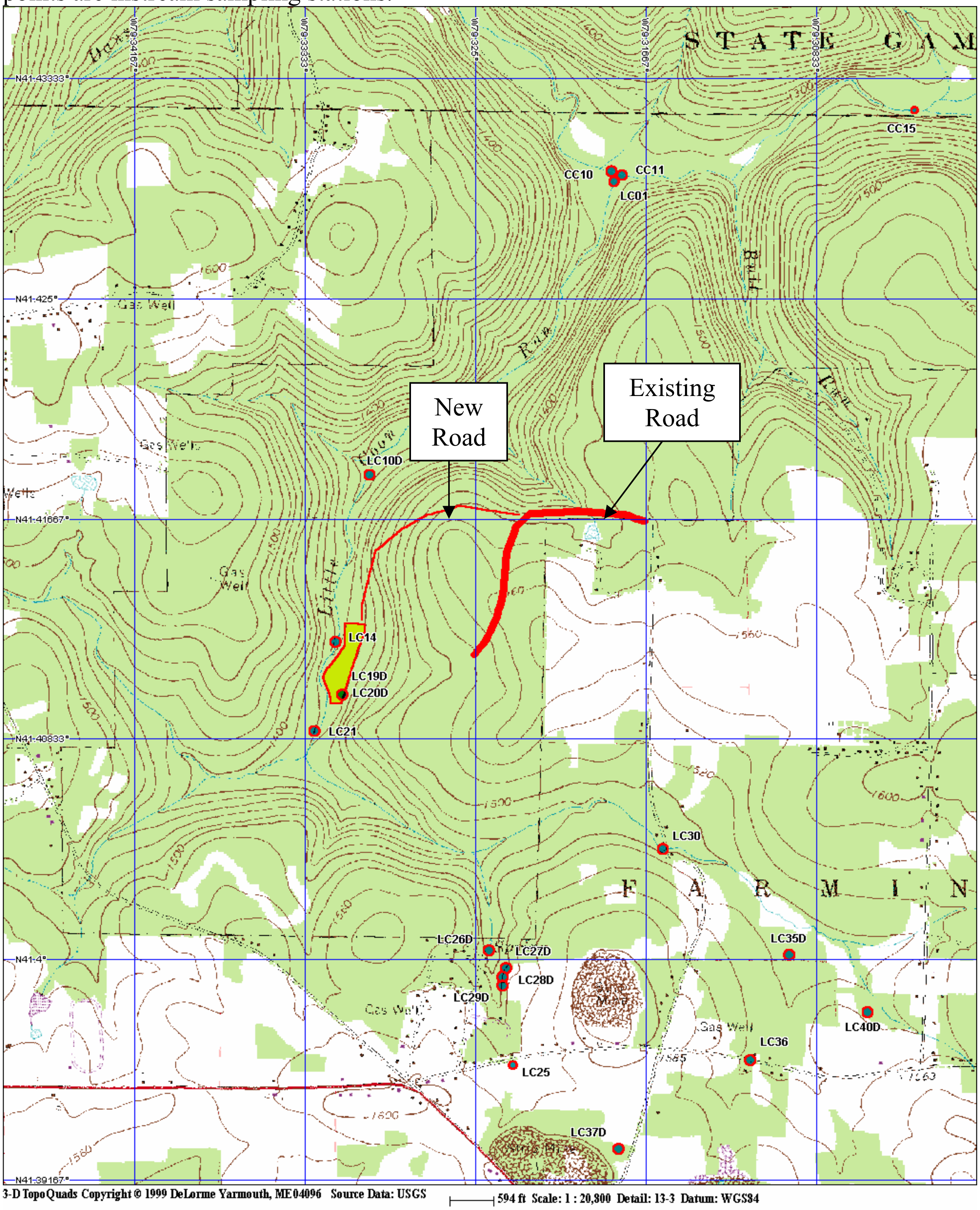
The passive system was constructed to treat LC20D, the largest point source of acidity and Fe to Little Coon Run. The system consists of an anoxic limestone drain followed by a settling pond and constructed wetland. This technology is generally reliable and significant improvements to Little Coon Run below the discharge were expected. Two artesian flows of AMD from abandoned gas wells, LC35D and LC40D, were sealed. Because these two discharges represent the 2nd and 3rd largest loads of acidity and Fe to Little Coon Run, their sealing was expected to result in immediate benefits to the stream. However, other plugging efforts in the area have caused the relocation of AMD and less stream benefits than were originally anticipated. Because of the concern that sealing might simply relocate the pollution, the project included a survey of the conditions of other artesian flows of AMD in the area. A conceptual hydrologic model was developed so that hydrologic predictions could be made regarding the consequences of sealing artesian discharges of AMD. Continued monitoring of AMD flows in the watershed (beyond this project) would allow these predictions to be evaluated, the conceptual model to be improved, and make predictions about future sealing efforts more reliable.

The project was funded by grants from the PADEP Bureau of Abandoned Mine Reclamation (BAMR) and the US Department of Interior Office of Surface Mining (OSM). The BAMR funds were provided through a “pass through” agreement with Farmington Township. The grant was administered through the DEP Growing Greener Grant Center. The DEP grant was $396,734. The OSM grant was received from the Appalachian Clean Streams Program and was provided to supplement the well sealing efforts. The well plugging efforts were higher than budgeted because the Department of Labor and Industry ruled that the work was subject to prevailing wages and because the sealing utilized innovative reversible features that made the bidding complicated. OSM grants can only be made to non-profit groups, so the grant was made to the Western Pennsylvania Coalition for Abandoned Mine Reclamation, who then contracted with Farmington Township for the required work.

The LC20D system was constructed on State Game Lands 24. The PA Game Commission was a full partner in the project, and played a key role in the design of the project access road and monitored construction activities. The well plugging occurred on private property. LC35D is located on Philip Barth’s property and LC40D is located on William Hall’s property. Both landowners provided written easement and consent for the project.

This is the final report of the BAMR project. This document reports on the construction and performance of the LC20D passive treatment system, provides an O&M plan for the system, summarizes the well sealing, and presents the background flow and chemical data collected for artesian discharges in the study area.

Figure 1: Project Location Map (Tylersburg USGS 7.5' quad). The LC20D passive system is shaded in yellow. The access road built to access the system is shown by the thin red line. LC35D and LC40D area in the lower right corner. Points with "D" suffix are discharges. Other points are instream sampling stations.



Design and Construction of a Passive Treatment System for LC20D

The "Little Coon Run and Walley Run Mine Drainage Assessment and Restoration Plan" (2003) reported the characteristics of 23 mine discharges. The largest single source of acidity and iron contamination was LC20D. The discharge is an artesian flow located adjacent to Little Coon Run 1.6 miles from the stream's inflow into Coon Creek. Table 1 shows the characteristics of the discharge. The untreated LC20D degraded Little Coon Run. Stream sampling stations established above (LC21) and below (LC14) the LC20D showed that the discharge increased the acidity and iron levels of the stream (Table 2). Little Coon Run subsequently degrades Coon Run, depressing the biological integrity of the stream (Table 3). These impacts combined to make treatment of LC20D a primary recommendation of the Restoration Plan.

Table 1. Characteristics of LC20D.

Point	Date	Flow	pH	Alk	Acid	Fe	Mn	Al	Sulfate
LC20D	12/13/01	47	5.8	48	183	105	14	0.1	680
LC20D	1/16/02	48	5.8	48	185	114	13	0.2	791
LC20D	2/19/02	75	5.9	44	206	116	14	0.1	861
LC20D	3/19/02	62	6.1	6	186	126	15	0.1	772
LC20D	4/11/02	73	6.0	55	198	118	4	0.1	626
LC20D	5/16/02		5.9	50	206	118	14	0.2	585
LC20D	6/13/02	51	7.5	5	197	120	15	0.0	632
LC20D	7/18/02	54	6.8	52	192	117	15	0.1	602
LC20D	8/14/02	54	6.2	54	194	118	15	0.0	614
LC20D	9/11/02	51	6.1	55	229	113	15	1.4	761
LC20D	10/17/02	55	6.2	53	188	127	15	0.2	860
LC20D	4/7/05	30	5.9	95	175	121	15	<0.1	1,004
LC20D	2/16/05	88							
LC20D	4/5/05	30							
LC20D	5/31/05	27							
LC20D	6/15/05	60							
LC20D	7/15/05	56							
LC20D	8/15/05	72							
LC20D	10/16/06		5.6		143	100	11	0.2	688
LC20D	average	55	6.1	47	191	116	14	0.2	713

Flow is gpm; alkalinity and acidity are mg/L $CaCO_3$; Fe, Mn, Al, and SO_4 are mg/L;

Table 2. Average instream chemistry above (LC21) and below (LC14) the LC20D discharge site in 2002.

	pH	Alk	Acid	Fe	Mn	Al	SO_4
LC21	5.0	2	12	0.3	1.3	0.8	85
LC14	4.5	0	16	2.4	1.8	0.8	110

alkalinity and acidity are mg/L $CaCO_3$; Fe, Mn, Al, and SO_4 are mg/L

Table 3. Macroinvertebrate Results and Richness, Composition and Tolerance Measures at the mouth of Little Coon (LC01) and Coon Creek above and below the inflow of Little Coon (CC16 and CC10, respectively)

Category	Metric	Metric Description	Coon Creek above LC	LC at mouth	Coon Creek below LC
			CC16	LC01	CC10
Richness Measures	Taxa Richness	Number of distinct genera of organisms.	32	7	23
	Total Numbers	Number of individual organisms counted.	615	52	232
	Taxa Diversity (H)	One measure of diversity, higher numbers indicate greater diversity.	2.039	0.346	0.887
	Evenness (E)	Measures how individuals are distributed among taxa (0.5 and above is desirable)	0.588	0.178	0.283
Composition Measures	% Ephemeroptera	Percent Mayflies	12.5	0.0	21.7
	% Plecoptera	Percent Stoneflies	12.5	28.5	13.0
	% Trichoptera	Percent Caddisflies	28.1	14.3	30.4
	% EPT	Percent total of mayflies, stoneflies and caddisflies, three pollution-sensitive groups	53.1	42.8	65.2
	% Chironomidae	Percent total of Chironomidae (a pollution-tolerate family of flies)	14.8	15.4	12.5
Tolerance / Intolerance Measures	% Intolerant Taxa (PADEP: 0, 1, 2)	Indicates the number of pollution-sensitive types of organisms	37.5	28.6	43.5
	% Intolerant Numbers (PADEP: 0, 1, 2)	High values indicate a station dominated by high numbers of pollution-sensitive organisms	19.0	7.7	15.5

Numbers reflect totals from three D-frame samples at each station
(Table is from "Little Coon Run and Walley Run Mine Drainage Assessment and Restoration Plan")

General Treatment Strategy

The discharge is an anoxic flow of circumneutral water that is contaminated with high concentrations of Fe. Aluminum concentrations are very low (<0.1 mg/L). This type of AMD is well suited for treatment with anoxic limestone drains (ALD), which add alkalinity to the water, and settling ponds and wetlands, where iron oxidizes and precipitates. This type of passive treatment has been successfully used to treat similar AMD in the nearby Toms Run and Mill Creek watersheds.

ALDs rely on the dissolution of calcite in a closed anoxic environment. Research has established that retention of 12-15 hours in and ALD is sufficient to saturate the water with alkalinity (Hedin et al. 1994). The amount of alkalinity that is generated is dependent on the water chemistry and, at this time, cannot be manipulated through design or construction. The amount of alkalinity that will be generated by a particular limestone and mine water combination can be predicted through experimental anoxic incubations (Watzlaf et al. 1993). Testing of this kind conducted for the LC20D discharge resulted in a predicted alkalinity value of 253 mg/L alkalinity. This value was sufficient to neutralize all of the acidity associated with the dissolved Fe.

Effective ALDs do *not* retain Fe. The iron contamination is removed passively by oxidative processes in settling pond(s) and wetland(s) positioned after the ALD. Iron removal in ponds occurs at a rate of 10-20 grams of Fe removed per square meter per day (90-180 lb/acre/day). (Hedin et al., 1994). Iron removal becomes slower as concentrations decrease and ponds become ineffective when the concentration reaches 10-15 mg/L. At this concentration and below wetlands are most effective at removing Fe, although the Fe removal rates are slow, generally only 3-5 g $m^{-2}d^{-1}$.

The goal of the conceptual treatment system design was to install sufficient limestone in the ALD to assure the maximum alkalinity generation and to install sufficient surface area of pond and wetland to precipitate the iron. This goal was limited by the area available for construction of the treatment system. The LC20D discharge is located in the Little Coon Run flood plain. The site is constrained by a steep hill, Little Coon Run, and pre-existing natural wetlands.

A wetland delineation was completed and the site was surveyed. Several layout alternatives were developed that avoided permanent impacts to existing wetlands and water courses. After several iterations, a layout was selected that prioritized the ALD (and alkalinity generation) over iron removal. An ALD was sized that contained 1,800 tons of limestone and would provide the 50-60 gpm flow rate with 30-35 hours of retention. This tonnage was adequate to assure alkalinity generation for several decades and would also handle larger flow rates in case local well sealing relocated AMD to the LC20D location. A settling pond was designed that had 15,400 ft^2 of surface area. If the pond achieved 20 g $m^{-2}d^{-1}$ of Fe removal, then it would lower the iron concentration of an average 55 gpm flow by about 95 mg/L. The wetland was designed with a surface area of 10,400 ft^2. If the wetland removed iron at 5 g $m^{-2}d^{-1}$, then it would lower the iron concentration of an average 55 gpm flow by 15 mg/L. The combined pond/wetland system was estimated to have the ability to treat an average flow from 116 mg/L Fe to 6 mg/L Fe.

The settling pond was constructed to facilitate the removal of iron sludge that must be removed periodically and might be sold as crude iron oxide. (Iron Oxide Recovery, Inc. has recently opened a plant in Corsica, PA that buys iron sludge and sells processed iron oxide.) The pond was lined with a geotextile fabric to prevent the iron sludge from being contaminated with underlying clay. Six inches of AASHTO #1 aggregate was placed on the bottom of the pond to facilitate the operation of heavy sludge removing equipment in the pond. This the first passive AMD treatment system constructed in northwest PA that is designed to lessen long-term maintenance requirements through iron recovery.

Construction Plans and Bidding

Construction plans were developed by DEM Survey under the guidance of Hedin Environmental. The construction plans are included on the report CD. The project was bid in June 2006. Two competitive bids were received and the low bidder, Nick Construction of Lucinda, PA was selected by Farmington Township. The bid was $204,400.

Construction

Construction commenced in August 2006. The site is located in a remote portion of Game Lands 24. Access to the site required the construction of a 4,500 ft road that met PaGC specifications. The road was completed in September 2006 and construction of the treatment system commenced immediately. The first activity was to excavate, collect, and temporarily divert the discharge. Excavation did not reveal an abandoned well, suggesting that the flow's origin is a fracture flow.

The discharge had created a large area of iron sludge deposition that was treacherous to traverse by foot or machine. The diversion of the discharge caused the sludge to dewater and after several weeks the contractor was able to maneuver into the sludge and begin excavation of the ALD. Approximately 40% of the ALD was in the iron sludge deposit while the remainder was in natural clay. The iron sludge was relocated to a disposal site located at the top of the access road on Game Lands property. The clay excavated from the ALD was saved on site and used for later filling activities. The ALD was fully excavated by November 2006, however, cold temperatures precluded the installation of the synthetic liner specified to be placed beneath and around the limestone bed to prevent leakage of water.

The settling pond was partially excavated in 2006. In December, wet weather created conditions that forced the project to shut down until spring.

Limestone aggregate was delivered to the site in March 2007 when the roads were frozen and could be traveled without damage. Construction of the system resumed in April 2007. The liner was installed in the ALD and the limestone was placed. Excavation of the settling pond and construction of the wetland occurred. Major earthwork was finished in May 2007. The wetland was seeded and planted, and the discharge was diverted into the ALD on May 29. Within 2 days the ALD produced a discharge of 55 gpm – the same flow observed before discharge was diverted. The site was seeded and mulched and equipment demobilization occurred in June 2007.

The system was installed without deviation from the original plans. The original plan view (sheet 1) is an accurate as-built drawing.

System Performance

The results of system monitoring are shown in Table 4. The individual treatment system units are discussed below.

Table 4. Average flow and chemistry for the LC20D treatment system, May – September 2007.

Point	N	Flow	pH	Alk	Acid	Fe	Mn	Al	SO_4
ALD effluent	7	53	6.6	188	34	113	12	0.4	543
Pond Effluent	3		6.1	34	12	30	12	0.2	513
Wetland effluent	4		6.1	16	15	11	12	0.2	508
Acid Seepage	2	2	3.7	0	116	10	26	1.9	360
Final at stream	6		5.6	11	36	4	12	0.5	482
Little Coon Run at Mouth	3	na	6.7	11	13	0.2	0.8	<0.5	104

Flow is gpm; alkalinity and acidity are mg/L $CaCO_3$; Fe, Mn, Al, and SO_4 are mg/L

Anoxic Limestone Drain

The ALD liner is functioning well. No seeps are apparent below the ALD. The discharge rate from the ALD has been 50-55 gpm, which is the same flow rate observed before the system was installed. The ALD has produced 160-230 mg/L alkalinity. This is lower than the 250 mg/L alkalinity obtained from limestone incubation tests in 2003. The lesser alkalinity is not due to insufficient contact as the ALD has a theoretical retention time of 35 hours and there were no features of the system that would promote preferential flow through the limestone bed.

Alkalinity generation tests performed on the ALD influent and effluent confirmed that the ALD is generating alkalinity as expected from this technology. Table 5 shows the results of anoxic limestone incubations done for the ALD's influent and effluent on September 17 and 18, 2007. The ALD discharge incubation only produced 15 mg/L more alkalinity than was measured on Sept 17 (176 mg/L). This difference is within the error of the method. The result indicates that limestone contact is not limiting the generation of alkalinity by the ALD. Adding more limestone to the system (if this was possible) would not substantially increase the alkalinity concentration of the ALD effluent.

An alkalinity generation test was done on the untreated ALD influent. The result, 194 mg/L alkalinity, was substantially lower than was measured in 2002 by the same method. Either the 2002 tests were in error or the geochemistry of the groundwater has changed so that it able to dissolve less calcite now than in 2002. Changes that would lessen the ability of the water to dissolve calcite include decreased CO_2 partial pressures or increased Ca concentrations. Data are not available to evaluate these changes. Differences between 2007 and 2002 that may have affected the groundwater chemistry include the dry conditions in the summer of 2007 and the recent activities by Modern Landfill in one of the abandoned mines in the Coon Run headwaters.

Table 5. Alkalinity values for the ALD influent and effluent (raw) and after anoxic incubation with limestone in ALKast devices. Ten incubations were done for each. Testing was done on Sept 17 and 18, 2007.

Source	**Measurement**	**Alkalinity Ave**	**Standard error**
ALD Influent	Alkalinity (raw)	32 mg/L	Not calculated
ALD Influent	Alkast Alkalinity	194 mg/L	6 mg/L
ALD Effluent	Alkalinity (raw)	176 mg/L	Not calculated
ALD Effluent	Alkast Alkalinity	190 mg/L	3 mg/L

Table 6. Measured Fe Removal Rates. Concentrations are at the effluent of the unit.

	ALD		**Settling Pond**		**Wetland**		**System**	
	Flow	mg/L	mg/L	g $m^{-2}d^{-1}$	mg/L	g $m^{-2}d^{-1}$	mg/L	g $m^{-2}d^{-1}$
May 31, 2007	56	122	--	--	8		1	13
June 21 2007	56	131	37	20	24	4	7	14
July 12, 2007	51	111					8	10
Aug 29, 2007	53	94	40	11	9	9	3	10
Sept 18 2007	55	109	12	20	5	2	2	12
Average	*54*	*113*	*30*	*17*	*11*	*5*	*4*	*11*

The ALD's alkalinity generation is approximately sufficient to neutralize the Fe content of the water. The acidity equivalent for the average iron concentration, 113 mg/L, is 202 mg/L. The ALD has averaged 188 mg/L alkalinity. The laboratory measurements for the ALD discharge have averaged 34 mg/L net acidity. The higher value is due to the acid contribution of 12 mg/L Mn (about 22 mg/L acidity).

Settling Pond

The settling pond has decreased iron concentrations from 113 mg/L to 30 mg/L. The average Fe removal rate for the pond was 17 g $m^{-2}d^{-1}$ (Table 6). As noted previously, similarly constructed systems receiving pH 6-7 water usually removed Fe at rates 15 – 25 g $m^{-2}d^{-1}$. There is variability in the rate that may be due to sampling or lab errors (see August 29). The low rate may be due to short circuiting resulting from the point source inflow to the pond. Iron removal rates of 25-30 g $m^{-2}d^{-1}$ have been recently measured for a system with similar water chemistry where the influent and effluent is distributed across the settling pond with a trough. A similar modification might increase the Fe-removal efficiency of the settling pond.

Constructed Wetland

The wetland has lowered Fe concentrations to 11 mg/L. The average Fe removal rate of the wetland has been 5 g $m^{-2}d^{-1}$. As noted above, the expected iron removal rate was 3-5 g $m^{-2}d^{-1}$. The wetland's performance is consistent with other similarly designed systems.

The wetland was planted with shade tolerate emergent plant species. The establishment was very good in during the summer of 2007. As the wetland vegetation became established, the water depth in the wetland was increased by adding stones to the discharge spillway. Deeper water should increase the retention time in the wetland and assure continued efficient removal of Fe.

Acidic Seepage

A low pH seep was recognized immediately after construction. The source is within a pre-existing wetland that was avoided during construction. This seepage likely existed before the system's construction, but it was not recognized because the flow is only 2-3 gpm and it does not create iron staining. The acid water does not appear to be from the same source as LC20D because it has much lower Fe, higher Al, and higher Mn (Table 4). Some coal refuse was encountered during excavation. This small discharge of acidic water could be result of spring water flowing through buried acidic wastes. The flow mixes with the wetland discharge, which neutralizes and dilutes it.

Final at Stream

The discharge from the constructed wetland flows into a pre-existing dry channel that carries the flow 300 feet to Little Coon Run. The final effluent from the system has been collected at the end of this channel. The channel provides additional retention for Fe precipitation and has removed an average 6 mg/L Fe. The final effluent from the system has had 11 mg/L alkalinity and 4 mg/L Fe.

System's Impact on Little Coon Run

Table 7 compares the conditions of the pre-system discharge to Little Coon Run (LC) with the current treated inflow to Little Coon Run. The "pre" samples were collected from the seepage, not at the inflow to the stream. Because the discharge was ditched to the stream and had little retention on site, the "pre" sample approximates the inflow to the stream. The current inflow to the stream is substantially improved. The stream is receiving about 100 lb/day *less* acidity and 75 lb/day *less* Fe.

Table 7. Comparison of inflow to Little Coon Run (LC) before and after the system was installed.

Point	Period	Flow	pH	Alk	Acid	Fe	Mn	Acid load	Fe load
LC20D	2001-05	55	6.1	47	191	116	14	126	77
Final at LC	2007	54	5.6	11	36	3	12	23	2

Flow is gpm; alkalinity and acidity are mg/L $CaCO_3$; Fe, Mn, Al, and SO_4 are mg/L; Acid and Fe loads are pounds per day.

The impact of the improved inflow is apparent from the instream data. Table 8 compares pre-system and post-system in-stream chemistry two downstream stations. LC14 is an instream station several hundred feet below the LC20D site. LC01 is the mouth of Little Coon Run, 1.6 miles below the LC20D site. The pH at both stations has increased almost two units. Before the system was installed, every sample at LC14 and 7 of 9 samples at LC01 had pH less than 5. All pH measurements since May 2007 have had pH at least 5.5. Before the system was installed, alkalinity was greater than 2 mg/L on only one sampling day. Since the system was installed, instream alkalinities have been 9-12 mg/L at the mouth. Because acidic discharges still exist in the headwaters, this alkalinity is a valuable pH buffer for lower Little Coon Run. These improvements occurred before the sealing of LC35D and LC40D and the potential elimination of these AMD inputs to Little Coon.

Table 8. In-stream chemistry at two stations downstream of the LC20D site before and after the system was installed. LC14 is several hundred feet downstream; LC01 if the mouth of Little Coon Run, 1.6 miles downstream.

Parameter	Period	LC14	LC01
pH	Before system	4.3	4.9
pH	After system	5.9	6.7
Alkalinity	Before system	1	2
Alkalinity	After system	7	11
Acidity	Before system	20	14
Acidity	After system	24	13
Fe	Before system	2.3	0.2
Fe	After system	1.3	0.2
Mn	Before system	1.7	1.5
Mn	After system	3.7	0.8
Al	Before system	0.8	0.7
Al	After system	<0.5	<0.5
SO_4	Before system	104	92
SO_4	After system	154	104

Operation, Maintenance, and Replacement Plan For LC20D Passive Treatment System On Little Coon Run in Farmington Township, Clarion County

Introduction

The treatment system for LC20D was completed in May 2007. LC20D is the largest mine drainage discharge to Little Coon Run and is located in Farmington Township, Clarion County on State Game Lands 024. Funds for the treatment system were obtained by the Farmington Township Supervisors from the DEP BAMR. Hedin Environmental of Pittsburgh, PA was the primary consultant, with mapping by DEM Surveying of Brookville, PA and treatment system construction by Nick Construction of Lucinda, PA.

The treatment system consists of a buried concrete collection vault, an anoxic limestone drain (ALD), a settling pond, and a polishing wetland. The major treatment system components are shown on the attached O&M Plan. Construction plans are included in the project report CD and can be obtained from Farmington Township.

Water discharges from a fracture and is collected in the buried collection vault. Water then rises up and enters the buried bed of limestone (ALD), which is encased in a plastic liner. Water flows through the limestone and discharges to the settling pond. The pond contains an internal berm that is submerged below the water level and is intended to spread out the water flow. The pond discharges to a constructed wetland that discharges to a pre-existing channel to Little Coon Run.

The purpose of this plan is to aid the Farmington Township Supervisors in inspecting, sampling, and maintaining the treatment system for decades into the future.

Regular Inspections and Sampling

<u>Inspection Schedule</u>

The treatment system should be inspected according to the following schedule:

- Monthly during its first year of service
- Quarterly after the first year of service
- After any events that cause serious flooding in the area

Monthly inspections are recommended during the first year of service, because this is the most likely time for problems to develop. These inspections also allow the inspectors to understand how the system normally operates and make it easier to spot changes in system performance.

After the first year of operation, inspections can be reduced to quarterly. The site is located next to Little Coon Run and could be damaged by an extreme flood event. The system should be inspected after rainfall or runoff events that produce flooding in the area.

<u>Inspection Checklist</u>

In addition to looking over the site in general, the following items should be specifically checked.

- Site Access Road
    - Is the gate in good condition? Was the gate locked when you arrived?
    - Is the running surface in good condition?
    - Are the road culverts free of debris?
    - If "NO" to any of the above, contact the Game Commission
    - LOCK the gate as you leave
- General Site Conditions
    - Is there any evidence of vandalism or tampering?
    - Is the site vegetation in good condition?
- ALD Area
    - Is there any water leaking to the stream? If so does it stain orange?
    - Is the ALD surface subsided or uneven?
    - Is the LC 19D water flowing clear with no staining?
- Pond
    - Is the channel from the ALD to the pond clear of debris?
    - Are the berms subsided or uneven?
    - Is the water level in the pond normal?
    - Is the exit channel from the pond to the wetland clear of debris?
    - Is there evidence of rodents living in the pond embankment?
- Wetland
    - Are the berms subsided or uneven?
    - Are there wetland plants throughout the wetland?
    - Is the water level in the wetland normal?
    - Are pests (muskrats, geese) active in the wetland?
    - Is the exit channel clear of debris?

Any problems should be noted in a field book that is dedicated to the project and reported to the PAGC.

<u>Sampling and Results</u>

During each inspection event, characteristics of the ALD effluent and system's final effluent should be measured. The flow rate can be measured at the ALD effluent pipe using a 10 quart bucket and a stopwatch. Time how long it takes to collect a known amount of water (determined from the bucket graduations) and divide the volume by the time to calculate a flow rate. Adjust this rate to gallons per minute. During the inspection, field pH and alkalinity should be measured at the ALD and at the final inflow to LCR. If the final pH is less than 6, additional measurements of pH and alkalinity should be made that wetland and pond effluents.

If water sampling is conducted to measure the effectiveness of the treatment system, the following stations should be sampled:

- ALD effluent pipe
- Pond effluent channel
- Wetland effluent channel
- Final inflow to LCR

It is possible to sample the influent to ALD at a valved pipe that is connected to the concrete collection vault. Because of the size of the pipe and limited flow possible with the installed valve, the valve must be opened and run for at least 24 hours before a representative sample can be collected. The water samples should be measured for standard AMD parameters (pH, acidity, Fe, Mn, sulfate and total suspended solids). If budget issues exist, the performance of the system can be approximated with field measurements of flow, pH and alkalinity, and laboratory measurements of Fe.

The sealing of LC35D and LC40D were hypothesized to transfer water to LC20D. If this occurs, the flow rate of the ALD discharge will increase and the treatment effectiveness of the system may decline. For the last year, the flow rate of LC20D has been 50-60 gpm. If the flow rate increases out of this range, the PADEP Bureau of Abandoned Mine Reclamation should be informed.

The Western PA Coalition for Abandoned Mine Reclamation has a program (FACTS) that finances laboratory costs for monitoring of passive treatment systems. An application to WPCAMR for this service should be considered.

Anticipated Maintenance Needs

The anticipated maintenance needs of the site have been divided into short-term needs and long-term needs below.

<u>Short-term Needs</u>

The short-term needs of the system include items that may need to be addressed from the first day of operation of the system. They are detailed below.

<u>Pest Control</u>

Animal pests such as geese and particularly muskrats have been known to damage passive treatment systems. Most of this damage occurs in wetlands. Both geese and muskrats harm wetlands by destroying vegetation and creating preferential flow paths through the wetland. Muskrats can also damage wetland or pond berms by creating burrows which weaken the berms and can cause subsidence or failure.

The berms of the pond and wetland have been protected by burying galvanized fence at the waterline, which should reduce berm damage.

Muskrat activity is apparent from the presence of uprooted wetland plants and small huts made of mud and vegetation built in the wetland. Beaver activity is apparent from dams constructed in channels. If either muskrat or beaver activity is apparent, contact the Pa Game Commission and request that the animals be removed.

Channel Cleaning

There are three channels on the site. The channel between the ALD and the pond is lined with fabric and limestone. The main concern for this channel is the accumulation of iron solids. The channel from the pond to the wetland and the channel out of the wetland are both lined with fabric and rock. These channels may accumulate iron, leaves, sticks, and other debris.

During each inspection event, the channels should be inspected and cleaned. This work may be done by hand or using hand tools such as shovels. Keeping the channels clean will ensure that proper water levels are maintained in the pond and wetland.

An additional pipe has been installed on top of the ALD to remove water from the upper side of the ALD at the LC19D location. This pipe was installed to prevent water from impounding on the upper side of the ALD and transfers water to a rock lined channel to the stream. The pipe should be inspected for the accumulation of sticks and leaves which could lead to plugging of the pipe.

Long-term Needs

The system works by removing acidity (in the ALD) and iron (in the settling pond and wetland). This leads to the two long-term maintenance needs of the system: limestone replenishment and sludge removal from the pond.

Limestone Replenishment

The system was constructed with 1,800 tons of limestone in the ALD. Assuming the long-term average flow rate of 60 gpm, an alkalinity production of 150 mg/L, and limestone purity of 85%, approximately 25 tons of limestone will be dissolved each year. Initially, the system will have a retention time of 30 hours, which will decrease by about half an hour every year. For AMD with Fe concentrations greater than 50 mg/L, the ALD should retain the flow for at least 12 hours to assure the generation of sufficient alkalinity. At current conditions, the LC20D ALD should not reach 12 hours of retention for about 35 years.

The ALD's performance may decline sooner if the flow increases or if the limestone becomes inactivated. The LC20D water was well suited for limestone treatment and the system was successfully constructed in an anoxic manner, so inactivation of the limestone is not considered likely.

At some point, (likely 20-30 years after construction), alkalinity production will decrease to the point that the effluent from the system becomes more acidic. At that point, the limestone in the ALD will need to be replenished. Assuming that the work takes place after 25 years of operation, approximately 1,000 tons of limestone will need to be added. The limestone that remains from the initial ALD construction should still be useful and should remain in place.

In order to replace the limestone, ALD should be excavated, the top liner carefully removed, and more limestone placed in the excavation. The ALD should be completely reburied after limestone replenishment. Care will have to be taken to protect the PVC liner from damages that could result in a leaky ALD.

Sludge Removal From Pond

The purpose of the settling pond is to retain iron sludge that is produced by the discharge. The pond has a capacity of approximately 460,000 gallons. Assuming that the pond retains 80 mg/L iron and the average flow rate of 53 gpm, then 50 pounds of iron per day will be retained in the pond. This sludge has a wet volume of about 40 gallons. As the sludge accumulates in the pond, the retention time in the pond will drop. This will decrease the effectiveness of the pond and allow more iron to reach the wetland.

The amount of the pond that can be filled with sludge without sacrificing the system's Fe-removal is not known with certainty. Assuming that the pond will need cleaned out when it is 30% full of solids, then sludge removal will be necessary in 10 years.

The iron sludge produced in passive systems very similar to LC20D has had value as a pigment. Iron Oxide Recovery, a company that specializes in the production of pigment-quality iron oxide from mine water, has recently opened a processing plant in Corsica, PA. It is possible that the value of the iron sludge will be sufficient to offset sludge removal and transportation costs. This opportunity to have sludge removed for free should be explored by the Township after the system has been in operation for 7-9 years.

Sludge removal from the wetlands is not anticipated to be necessary for at least 20 years. If sludge accumulation becomes an issue in the wetland (causing short circuiting), the effluent channel should be raised to increase water depths in the wetland. This can be accomplished by hand with aggregate and clay available on the site near the discharge channel.

Emergency Contact Information

In the event of any unexpected or emergency situation affecting the treatment system, contact:

PAGC Franklin Regional Office, P.O. Box 31, Franklin, PA 16323.

Installation of an Aquifer Drain

Background

The mechanism by which water flows from surface mines into underlying aquifers and out abandoned wells is not known. The artesian character of the flows indicates that head pressure is being transferred from a higher elevation. If this pressure is distributed equally throughout the aquifer, then it should be possible to create artesian flows simply by drilling a hole through the confining strata and into the pressurized zone. By drilling an "aquifer drain" it would be possible to release the aquifer at a preferred location and eliminate artesian discharges occurring a higher elevations and in poor locations.

This concept was tested by drilling a hole at a location along Salsgiver Road that was lower than LC35D and LC40D both topographically and structurally. The expectation was that a controlled discharge would be created. If this discharge was allowed to flow, the contaminated aquifer would be lowered down to the drain elevation and flow at LC35D and LC40D would cease. Because the location is further from the surface mines than LC35D and LC40D, there was a good chance that the contamination would be less severe water and be more suitable for low-cost passive treatment.

Installation of LC28

A drilling location for the aquifer drain was identified where Little Coon Run crosses Salsgiver Road just downstream of the LC30 sampling point. Easement was provided by the property owner (Larry Buehler, Ridgeway, Pa). An RFP was submitted to four drilling contractors of which three responded with proposals. Hetager Drilling of Punxsutawney, PA was selected to perform the drilling of the aquifer drain.

Drilling of the aquifer drain was started on June 30th with the installation of a 25 ft deep pilot hole. The pilot hole was outfitted with 25 ft of 4 inch PVC and grouted in place to provide for a water tight seal. Drilling proceeded from the 25 ft depth to 238 feet. Cores were collected continuously and were examined and logged by Jon Smoyer, P.G. of the Bureau of Abandoned Mine Reclamation. Smoyer's original drill logs are available from BAMR. Copies are present on the CD with this report.

Slight vertical fracturing was noted on cores to a depth of approximately 70 feet below surface. Deeper drilling showed little if any vertical or bedding plane fracturing. The cores comprised mostly of a gray medium grained to fine grained sandstone, gray fine grained siltstone alternating with layers of shale/mudstone. All of the rock units appeared to have little porosity. These fine grained units displayed little evidence of having iron contaminated ground water contained within them. The few iron stained fractures that were encountered were confined to the upper 70 feet of the core. Water was encountered within the hole but there was not sufficient head on any of the aquifers to produce artesian flow conditions. The collected cores did not show any segment to indicate major ground water flow. There were some areas of slight fracturing but most all of cores were collected in an intact manner. There was very little breakage of the individual cores.

Drilling was stopped at 238 feet due to the absence of artesian flow and to conserve project funds for other hydrologic activities.

The hole filled with water within several days of its abandonment to a static water level 7 ft below the surface. This is approximately the elevation of Little Coon Run at the drill site. Periodic monitoring of the water elevation in the well has not revealed significant changes during the last 26 months.

Conclusion

LC28 did not develop into an aquifer drain as anticipated. The failure of artesian flow to develop could be because the hole was deep enough and did not access the water-producing zones. This conclusion is not supported by observations made nearby at LC35D and LC40D. Both of these holes were cleaned and a down-hole camera was used to located inflows of water. LC35D produced water between 114 and 120 feet below the surface. LC40D produced water at 88 ft below surface. LC28 extended far below these depths. An alternative interpretation of the failure of LC28 to produce water is that the artesian flows are fracture driven and LC28 simply did not intercept a fracture. This idea is developed further in the hydrogeochemistry section of the report.

Sealing of LC35D and LC40D

Background and Summary

The project scope included the sealing of LC35D and LC40D. Both are artesian flows of AMD from abandoned gas wells that pollute the headwaters of Little Coon Run. The chemistry of the discharges is more severe than LC20D. Passive treatment similar to that used for LC20D (ALD, settling pond and wetland) was not likely to produce a net alkaline discharge because of the very high concentrations of Fe. A plan was developed to seal (plug) the discharges and monitor local artesian discharges to determine if the flow and pollution was transferred to another site or eliminated. The Hydrology Chapter provides the background information on the flows and chemistry of local artesian flows of AMD.

Plans were developed to install a reversible seal on at least one well because of concerns that transfer of the polluted water to another location may create a worse environmental problem. The "Alternate Sealing Method" included the cleaning of the well, placement of a cement plug below the water-producing zone, installation of a grouted plastic pipe above the water-producing zone, and a valve at the top of the pipe. The AMD discharges through the pipe to the surface and the valve allows controlled sealing of the hole (from a hydrologic perspective). If the sealing causes AMD problems elsewhere, the valve can be opened and the aquifer returned to the conditions that existed before the seal was installed.

The sealing of LC35D and LC40D was accomplished by a contract let by Farmington Township. Project plans and specifications were prepared by Hedin Environmental. The project was bid three times before an acceptable bid was received. The bidding problems arose from the highly uncertain nature of the project and a local oil-drilling boon that began several years ago and continues today. Companies experienced in the sealing of abandoned gas/oil wells know that the work is highly uncertain. Some holes can be cleaned and plugged in three days. Other holes contain numerous obstructions and can take weeks to clean. We were unable to obtain reasonable fixed price bids for the work because of this uncertainty. The bidding process was revised to include hourly rates and a limit on the total charges.

The project was bid in June, 2007 and a contract was developed between Cougar Energy and Farmington Township. Work began on LC35D on July 30, 2007. An obstruction was encountered at 520 feet below the surface that could not be removed. The well was subsequently plugged using standards methods that do not involve a reversible seal. Work began on LC40D on in mid-August. An obstruction was encountered 389 feet below the surface that could not be removed. On October 10, LC40D was sealed using the Alternate Sealing Method.

The following section provides reports on activities associated with the sealing of LC35D and LC40D. The reports are divided into: Pre-Sealing Planning; LC35D Sealing; and LC40D Sealing.

Pre-Sealing Planning

July 2005 Report
An onsite meeting was held during June 2005 with representatives of Farmington Township, Hedin Environmental, DEP Oil & Gas Meadville office, BAMR and the landowners of two artesian discharges LC35D and LC40D. Bill Hall owns land with the LC40D discharge and Philip Barth owns land with the LC35D discharge. Both owners expressed interest in having these wells sealed in a reversible manner. Discussions with the landowners and the DEP Oil & Gas centered on using a combination of PVC casing, shale traps, bentonite pellets and cement grout to construct a seal in a way that allows for the installation of a valve to control the flow rate of the discharge. Both landowners are concerned that plugging or sealing these wells could affect their neighbor's water wells. Sealing these wells with valves allows for the undoing of the sealing project in the event the plugged wells contaminates private water wells in the area. This method also provides for manipulating the aquifer to study effects of sealing off artesian discharges within the area.

October 2005 Report
During the month of September 2005 an area at LC40D was excavated to expose the well head. An excavator was used to dig a trench from the discharge borehole to a small drainage to allow for the free flow of water from the well. The trench was excavated through a 3 feet thick deposit of iron oxide. A wooden conductor box was found in the abandoned gas well. Water now flows through the excavated ditch to the stream. This excavation lowered the source of water by approximately 4 feet in elevation.

March 2006 Report
Water continues to flow through an excavated ditch to the stream from the LC40D borehole site. A weighted line marked in 50 ft increments was taken to the gas well locations to determine the depths of the wells. LC40D had obstructions several feet below the surface. LC35D found an obstruction at approximately 350 feet below the surface. These wells should be at least 900 feet in depth.

July/August 2006 Report
Plans have been submitted to DEP Oil & Gas division to consider an alternate plan for sealing of these wells. Along with this alternate plan for plugging a Notice of Intent to Plug was submitted on August 30 with attached maps and an oil/gas plat identifying the location of wells.

Once approval for the alternate plugging of these wells is received the project will be bid out. The project will be advertised and bids received based upon time and materials basis. Advertising should occur in September.

October 2006
The DEP Oil and Gas has approved of the alternate plan for plugging of LC35D and LC40D on October 27th. Registration numbers for the wells have been assigned by DEP Oil & Gas. LC40D number is 031-01976 and LC35D is 031-01977. A bid specification document was developed for review by the department and for the supervisors. Once the bid specifications had been finalized the project was advertised for bid. Once the bids had been reviewed and the project awarded, the plugging of the wells was to start.

<u>November/December 2006</u>
The Farmington Township Supervisors approved the advertisement for the bidding to plug LC35D and LC40D. A meeting for interested contractors was to be held on January 12, 2007 to look over the LC 35D and LC 40D sites. Bids were due on February 7, 2007.

<u>January/February 2007</u>
A mandatory pre-bid meeting for interested contractors was held on January 12, 2007 to look over the LC35D and LC40D sites. One contactor, Ray Saxton of Saxton Well Drilling, attended the meeting. Bids were due on February 7, 2007. No bids were received and the project was re-advertised for re-bid. Bids for the second round of bidding were due March 7^{th} at 4 PM.

<u>March 2007</u>
The second round of bidding for the plugging of LC35D and LC40D on March 7, 2007 resulted in one bid from Saxton Well Drilling of Tionesta, PA. The total bid amount was in excess of project available funds. The supervisors granted approval of the bid award to Saxton on condition that the plugging is performed within the available funds for this task. Negotiations with Ray Saxton were lengthy and was hoped that an agreement could be reached to plug these wells.

<u>May 2007</u>
The bid submitted by Saxton Drilling was pulled by Ray Saxton due to the inability to negotiate an agreement that allowed for the plugging of LC35D and LC45D without jeopardizing the budget.

A third round of bidding for the plugging of these wells was approved with the bids due on June 6, 2007. Each of the abandoned wells was to be a separate bid of their own and have different completion dates. The road building for access to LC40D will be an additional contract that is dependent upon the successful award of the plugging of LC40D. A new revised budget was put together that allowed for the spending of $27,050 for each of the wells for a total budget of $54,080.

Additional money ($39,803) was needed to complete this project and was sought through Western Pennsylvania Coalition of Abandoned Mine Reclamation (WPMCR) from the Office Surface Mining (OSM). WPMCR has agreed to contract with Farmington Township to use additional funds supplied by OSM to complete the well plugging project.

The project ending dates for the BAMR grant money was extended to September 30, 2007 and the project ending date for the OSM money to complete the well plugging was extended to December 30, 2007.

<u>June 2007</u>
Cougar Energy has been awarded contracts to plug LC35D, LC40D and to construct an access road to the LC40D well location. The contracts for plugging were on a per unit basis for time and materials. The access road for LC40D was awarded in the amount of $6,950. LC40D mobilization charge was for $2,000. LC35D mobilization charge was for $4,000 and an

additional $3,000 for cleanup of the access on the way out. The intent of the project is to plug both wells with a budget of $54,080.

LC35D Sealing

Access to LC35D was started on July 30, 2007 by using an abandoned log skidding trail through the Philip Barth property to the well site. Access to the Barth property was obtained from Ron and Anna Delaney off of Salsgiver Road.

At this time it was decided that LC35D will be plugged by standard conventional plugging methods while the LC40D well will be plugged by an approved alternate method that employs a reversible seal that will allow for cementing the oil and gas zones and leaving a void in the well to allow ground water to flow in a controlled manner through plastic pipe to the surface. The well will be plumbed to allow for adding screw in plugs to stop the flow of water.

A cable tool pulling rig was mobilized on August 1, and was set up over the LC35D to clean out the well. The pulling rig consists of a Cockshut farm tractor with a powered spooled cable winch mounted on the rear of the tractor. A 25 ft. boom is attached to the rear to allow for lowering tools into the well. LC35D had been cleaned to a depth of 420 ft on the first day of work. The pulling rig worked for a couple of days before it was decided that a conventional cable drilling rig was needed to clean out the well. A borehole camera lowered into the well has shown that water is entering the well at approximately 114 ft and 120 ft below the surface. The sides of the well are clean and there was no pipe down to 420 ft. It has been determined that the casing seat is near 360 ft.

After several days of work the cable rig was eventually able to get down to the original 420 ft depth and was soon drilling on a wooden plug. Over the course of several days the rig was able to deepen the well to 520' ft. The drilling tools then started to become wedged between the wooden plug and the sides of the well.

DEP Oil & Gas has given attainable bottom at 520 ft. On September 24, the well was plugged with a 50 ft plug of cement followed by several bags of aqua gel to the 140 ft elevation where the artesian flow of AMD was entering the well. A 10 bag mix of cement was placed on top of the aqua gel just below where the water was entering the well at 120 ft. The well sat vacant for one day and the crew cemented the artesian flow off on the following day stopping the flow for good.

A monument has been placed on the plugged well location. Restoration of access route has also been completed.

LC40D Sealing

LC40D access road was constructed across property owned by Bill Hall on August 17, and the drill was mobilized on August 24, to start the cleaning of this well. The well was quickly cleaned to a depth of 310' and had encountered steel.

The driller had to bring in several tools to try and remove the steel that was at the bottom of the well. Each tool has its own purpose, some to try and fish out broken pieces of steel, while others are used to try and puncture a hole into metal to help retrieve the pipe or whatever is at the bottom of the well. A magnet capable of lifting up to 300 pounds was used to bring up small pieces of steel. The retrieved material consisted mostly of steel shavings from the drill bit pounding away at the steel. A piece of broken off cable from previous works was also retrieved.

On September 28, the drill started to get inside what appeared to be steel casing. After a couple of days inside the casing a 2 feet long section of 2" pipe was brought up. The drilling continued to a depth of 389' which was confirmed by way of borehole camera. The casing seat was determined to be at 360'. The borehole camera shows water entering the well at 88 ft. At 180 ft there was a large section of the well bore broken up and fractured possibly producing water. The last water appeared to be near 240 ft.

The video did not show steel pipe to the casing seat or inside the small diameter hole below the casing seat. The steel at the bottom of the hole could be 2 inch pipe being advanced by the constant pounding of the drilling tools. When the well was bailed the contents included, bits of black shale, mud, small pieces of steel and large amounts of metal shavings.

On October 5, the DEP Oil & Gas gave permission to stop work on LC40D and to install the alternate seal as planned. The total depth of the well stands at 389 ft as verified by borehole camera.

The reversible seal was installed on October 10, by using three 20 ft long sections of 5 inch schedule 40 PVC pipe. Each section was attached by glue on couplers to produce a 60 ft length of pipe. At one foot from the bottom of the pipe (4) 5 inch by 8 inch shale traps were stacked on top of one another separated by a two inch gap in between each trap. Each trap was filled with bentonite chips as the casing was lowered into the well. The plan was for the shale traps to sandwich the bentonite chips between each trap to help seal off the upward current of the artesian flow of AMD. Since the video shows a large volume of ground water flowing into the well bore at 88 ft the placement of the shale traps at 58 ft should capture all of the artesian AMD.

As the 5 inch pipe was lowered into the well a 80 ft long piece of 1.5 inch flexible water hose was taped to the outside of the pipe for the purpose of delivering the cement to the top of the shale traps during the grouting process. One 50 pound bag of bentonite pellets was sprinkled down on the outside of the 5 inch PVC casing and allowed to settle upon the shale traps. This stopped all flow from the annulus outside the pipe and forced all water to the inside.

A 7 bag mixture of cement grout was mixed and pumped through the 1.5 inch hose to the top of the shale traps. As the cement was pumped the hose was slowly raised up the well. During the pumping of the grout a hole developed around the traps and water started to slowly flow on the outside of the 5 inch pipe. A 3 bag mix of cement grout was mixed and pumped down the annulus. The combined 10 bag grout mix brought the grout up to approximately 30 ft from the surface. It became apparent that some of the grout was flowing back into formations and possibly leaking by the traps.

More bentonite chips were added to the top of the 10 bag mix. Five more bags of cement were mixed and pumped. This brought up the grout level another 10 ft to about 20 ft from the surface. There was a small amount of leakage around the 5 inch pipe. At 3:00 another 5 bag mix of grout was mixed and pumped down the well stopping the flow of water and filling the annulus with grout. At 3:30 the pump suction hose was used to pump water from inside the well to help reduce the hydrostatic head on the water in the well. At 3:45 the cement grout settled down 10 feet below the surface and water started to flow on the outside of the casing.

This flow of water was measured at 2.5 gpm and did not turn to the color green as did the deeper artesian water. When iron contaminated water is mixed with grout the cement mixture will raise the pH of the water to precipitate ferrous iron which appears green in color before becoming oxidized and turning to the color red.

At 5 PM another 5 bag mix was pumped down the well. Over a period of several minutes the water stopped flowing on the outside and the cement grout slowly settled further down the well stopping at about 10 ft below the surface. No water was observed to be flowing on the outside of the well. The pump continued to pump water from within the well during the grouting process. At 5:15 another 5 bag mix was pumped down the outside of the well filling the annulus. This cement grout plug held and hardened overnight to form a permanent seal. The gas powered pump was filled with gas at 7:00 to continue pumping for several hours into the night to eliminate hydrostatic head on the cement grout while it cured.

Sealing Results and Discussion

<u>Final Costs</u>

The total cost of the sealing project is shown in Table 9. The total construction cost for both wells was $53,024. The costs shown were limited by the project budget ($54,080). The Bureau of Oil and Gas would have preferred that work on the cleaning both holes continued longer. Recognizing the limited budget, the Bureau allowed permanent sealing of LC35D and the temporary installation of the Alternate Seal on LC40D. It is anticipated that BAMR and the Bureau of Oil and Gas will plan the installation of a permanent seal on LC40D in the future.

Table 9. Final construction contractor costs for sealing of LC35D and LC40D.

Item	**LC35D**	**Comment**	**LC40D**	**comment**
Rig time, $200/hr	$16,100	80.5 hours	$18,300	92 hours
Cement, $30/bag	$1,050	35 bags	$990	33 bags
Mob/Demob, bid	$4,000		$2,000	
Clean up property	$3,000		0	
Access road, bid	0		$6,950	
Bentonite, $15/bag	$60	4 bags	30	2 bags
Alternate plug supplies	$0		$544	
Total	***$24,210***		***$28,814***	

<u>Flow Rates and Water Elevations</u>

The sealed wells have been inspected weekly. As of October 25, 2007, both wells are sealed without any leakage.

Only preliminary observations of the impact of the sealing on local hydrology are available at this time. Observations to date have been limited to LC35D, LC40D, and two nearly abandoned gas wells that contained water but did not discharge before the sealing. The non-discharging wells are referred to as “Gatesman” and “Hall”, after their landowners. The flow rate of LC40D was monitored after LC35D was sealed (September 28) and before LC40D was sealed (October 10). There was not a significant increase in flow from LC40D after LC35D was sealed. The water elevations in the Gatesmans and Hall wells did not change in this period.

After LC40D was sealed and the flow was stopped, water elevations increased at both the Gatesmans and Hall wells. Two weeks after flow at LC40D was stopped, the static water level at LC40D had risen 4 feet, water in the Gatesmans well was 2.3 ft higher, and water in the Hall well was 0.4 ft higher.

Hydrogeochemistry of Mining-Polluted Water in the Frills Corner Syncline

Introduction

This project includes the plugging of two abandoned gas wells that have produced artesian flows of AMD for decades. The flow and chemical characteristics of LC35D and LC40D were presented in the Little Coon Run and Walley Run Restoration Plan. The discharges produce, on average, 35 gpm of flow, 125 lb/day of acidity and 73 lb/day of Fe. The high acidity and Fe concentrations of both discharges made low-cost passive treatment infeasible, so a plan was developed to simply plug LC35D and LC40D.

The plugging of abandoned wells that produce artesian flows of AMD has become a common practice in Clarion County. The Natural Resources Conservation Service (US Department of Agriculture) has coordinated the plugging of dozens of wells in Clarion area through PADEP grants provided to the Alliance for Wetlands and Wildlife and Clarion County. The plugging has occurred without consideration of the hydrologic consequences of the activities. One goal of this project was to establish a good baseline of pre-plugging hydrologic conditions, so that follow-up monitoring could reliably determine whether the polluted water was eliminated or simply transferred to another discharge point.

Delays were encountered in the plugging of LC35D and LC40D. The wells were only plugged in the last month of the project, so post-plugging monitoring had not occurred when this report was written. This portion of the report presents all of the pre-plugging baseline information.

LC35D and LC40D occur in the Frills Corners syncline and the baseline was determined to be all substantial artesian flows of AMD that occurs in the synclinal basin. The Little Coon Run and Walley Run Mine Drainage Assessment and Restoration Plan had identified flows in the Little Coon and Walley Run watersheds. The synclinal basin extends beneath the headwaters area of the Licking Creek watershed and there are five major artesian discharges in the headwaters of Licking Creek. This project monitored flow and chemistry of LC35D, LC40D and ten artesian flows of polluted water that exist within the basin and were considered reasonable candidates for water transfer when LC35D and LC40D were plugged.

The cause of artesian flows of polluted water was somewhat of a mystery until a study of the geochemistry of the flows determined that the water was characteristic of mine water, not gas well brine (Stafford et al., 2004; Hedin et al. 2005). A hydrogeochemical model was suggested that tied together historic coal mining and gas production. The model proposed that AMD produced in the hilltop surface mines infiltrates into underlying aquifers that extend beyond the lateral extent of the mines. Contact with siderite raises the pH and precipitates Al, but also releases ferrous iron. Where these aquifers are pierced by abandoned wells that no longer contain functional casing, the polluted water uses the wells as easy conduits to discharge to the surface. The artesian force is supplied by connections with the higher elevation surface mines. The data collected by this project and previous studies in the area are used to evaluate and refine the proposed hydrogeologic model.

Methods

Flow and Chemical Analyses

Water samples were collected and flows were measured by personnel from Hedin Environmental and the PADEP Bureau of Abandoned Mine Reclamation (BAMR). Samples collected by HE were analyzed by G&C Laboratories (Summerville, PA). Samples collected by BAMR were analyzed by the PADEP Laboratory. Data obtained from the Little Coon Run Restoration Plan were all collected by HE and analyzed by G&C Laboratories using the same procedures used in this project.

Chemical measurements were made in the field and in the laboratory. For most samples, measurements were made in the field of pH, alkalinity and temperature. Two samples were collected for laboratory analyses. An acidified sample was collected for analysis of metals (Fe, Al, and Mn). A raw sample was collected for analysis of pH (laboratory), alkalinity (laboratory), hot acidity, sulfate, and total suspended solids.

Samples were not filtered. The results provided represent total concentrations. These results are considered representative of dissolved concentrations because all of the sampling locations were near the discharge and the flows were clear water free of turbidity.

Flows were measured by the timed-volume method where a known volume of water is collected in a known period of time. At each sampling site, all flow was directed through a pipe installed as close to the discharge as possible. The flow from the pipe was collected into a 2.75 gallon bucket that was read to 0.5 quart increments. At sites less than 10 gpm of flow, the volume collected in timed 15 second or 30 second periods was measured. At sites with more than 10 gpm flow, a measured volume was collected in the bucket in a measured time. Measurements were typically repeated 2 or 3 times and the average flow rate was reported.

Flow rates were calculated by dividing the volume recovered by the collection time and adjusted for units so that the result was expressed in gallons per minute.

All flow and chemical data were managed using an excel spreadsheet.

Geographic and Geologic Measurements

The latitude and longitude of each discharge was measured with a GPS unit and plotted onto USGS mapping. Elevations and acreages of surface mines and watersheds were estimated from the USGS mapping. Coal elevations were obtained from Clarion County Coal Resources maps provided by the PA Geological Survey. The Clarion Coal maps were used. The coal elevation information was used to infer geologic structure.

Precipitation data were obtained for Clarion PA from the NOAA National Data Center. Daily precipitation and temperature extremes were obtained from January 1, 2001 to August 31, 2007.

Study Area and Sampling Points

Map A and Map B show the study area. Map A is an aerial photo showing streams, surface mines and artesian flows. Map B shows surface and structural contours. The Frills Corner syncline and Leeper Anticline are plotted.

Sampling locations are shown on Map A. The first 2-3 letters identify the stream (LC = Little Coon Run; LCK = Licking Creek; WR = Walley Run). The number indicates the point's location in the watershed with "01" being the mouth and station numbers increasing upstream. The relative location of two stations in the same watershed can be assessed by comparing their numbers (LC40D is upstream of LC35D.) The letter "D" following the number indicates it is a discharge. The absence of a letter suffix indicates that the sampling point is within the stream.

Seven unreclaimed surface mines that were identified in the Restoration Plan and are considered likely sources of AMD to underlying aquifers. Map C shows the mines and sampling points. These mines are located in upper elevation areas that drain to the headwaters of the Little Coon Run, Licking Creek, Toby Creek, and Walley Run. These mines are also located upon the crest of the Leeper Anticlinal axis directing ground water towards the Frills Corner Syncline. Table 10 shows the acreage of each of the mines in each of these watersheds.

Table 10. Acreage of surface mines in the study area.

		breakdown by watershed (acres)			
Surface Mine	**Total Acres**	**Walley**	**Little Coon**	**Licking**	**Toby**
A	116	26	34		56
B	121		33	47	41
C	17	10	7		
D	29		18	11	
E	52		25	27	
F	23		12	11	
G	17		17		
sum	***375***	***36***	***146***	***96***	***97***

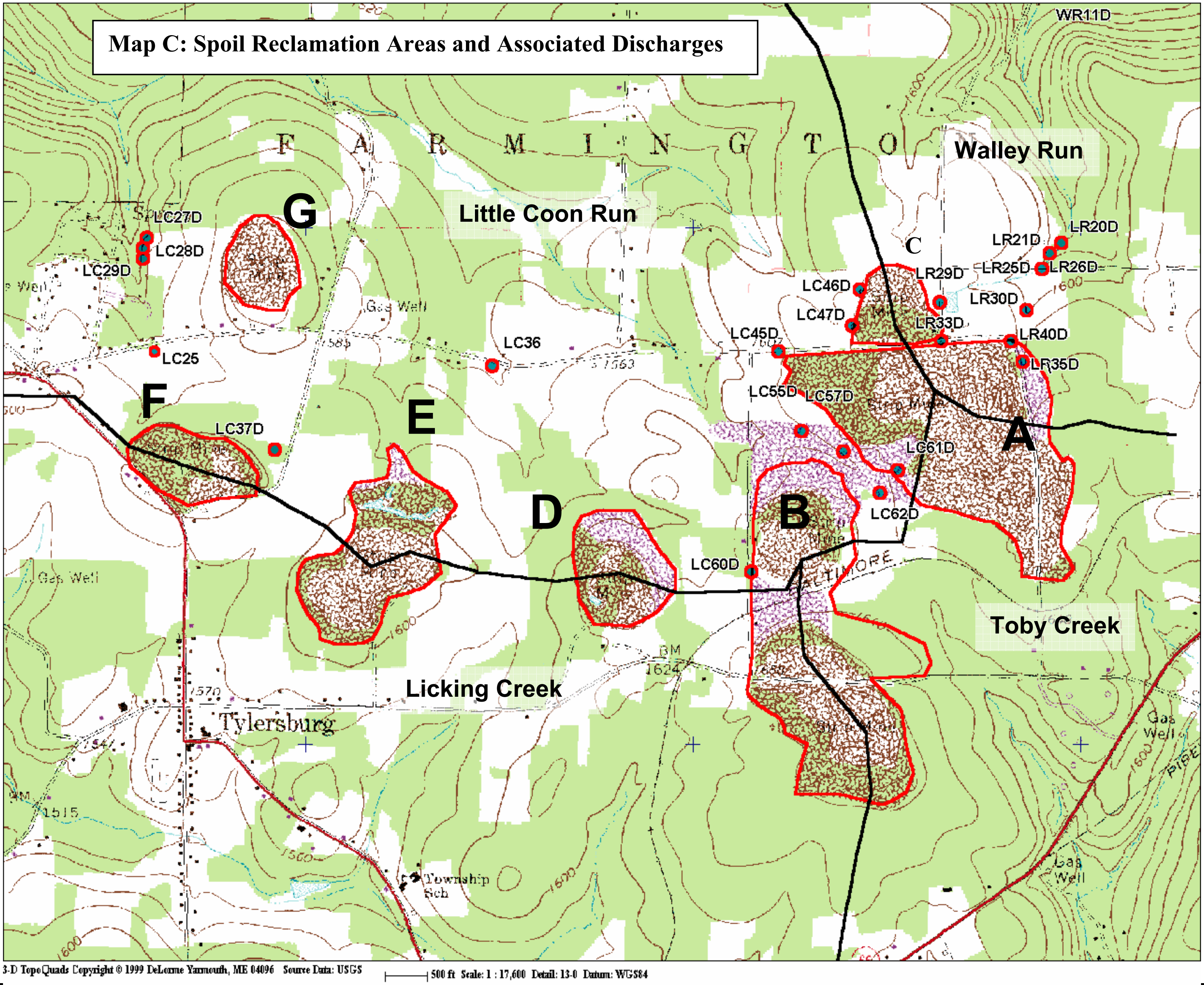

Map C: Spoil Reclamation Areas and Associated Discharges
F A R M I N G T O N
Walley Run
Little Coon Run
Toby Creek
Licking Creek
Tylersburg
A
B
C
D
E
F
G
WR11D
LR20D
LR21D
LR25D
LR26D
LR29D
LR30D
LR33D
LR35D
LR40D
LC25
LC27D
LC28D
LC29D
LC36
LC37D
LC45D
LC46D
LC47D
LC55D
LC57D
LC60D
LC61D
LC62D
Gas Well
Township Sch
3-D TopoQuads Copyright © 1999 DeLorme Yarmouth, ME 04096 Source Data: USGS
500 ft Scale: 1 : 17,600 Detail: 13-0 Datum: WGS84

Table 11 shows the frequency of flow and chemical measurements for each sampling location. Some locations were only sampled in 2001-02 during the original assessment. Others were only sampled in 2005-07 for this project.

Table 11. General information for the discharge sampling stations

Station	Type	Surface Mine	Sampling Period	Flow N	Chem N
LR40D	seep	A	2001-02	11	8
LC55D	seep	A	2001-02	12	12
LC45D	seep	A	2001-02	11	9
LC57D	seep	A	2001-02	11	6
LC60D	seep	B	2001-02	12	12
LR29D	seep	C	2001-02	11	4
LC47D	seep	C	2001-02	11	6
LC46D	seep	C	2001-02	11	6
LC37D	seep	F	2001-02	11	11
LCK40D	Well		2005-07	21	5
LCK15D	Well		2005-07	21	5
LCK37D	Well		2005-07	21	5
LCK56D	Well		2005-07	21	5
LCK186D	Well		2005-07	21	5
LC20D	Fracture		2001-07	27	14
LC35D	Well		2002-07	37	19
LC40D	Well		2002-07	37	19
WR11D	Fracture		2001-07	24	15
LR17D	Fracture		2001-07	24	14
W05D	Fracture		2005-07	4	2
LC10D	Fracture		2001-07	20	14

Results

Precipitation During Studies

Table 12 shows average and measured rainfall totals during the study period. Figure 3a and 3b show monthly precipitation totals during this study (a) and during the full period over which data have been collected in the study area (b). During the 2005-2007 period, precipitation was 9% above the long-term average. During the 2001-2007 period, precipitation was 11% above the long-term average. Autumn 2004 was very wet as two hurricanes passed through the area in September. Precipitation in 2005 and the first half of 2006 was below normal. The summer and fall of 2006 were very wet. Precipitation totals in 2007 (as of August) have been above average, due to wet months in January and August.

Table 12. Precipitation totals for Clarion PA, Jun 2001 – Aug 2007

	Precipitation Totals		
Year	**Average**	**Measured**	**Deviation**
(Jun) 2001	26.3	22.2	84%
2002	43.3	48.3	111%
2003	43.3	49.7	115%
2004	43.3	55.3	128%
2005	43.3	39.9	92%
2006	43.3	53.8	124%
2007 (Aug)	29.8	33.7	113%
Jun 01 - Aug 07	273	302.9	111%
Nov 01 – Oct 02	43	48	111%
Jan 05 - Aug 07	116	127	109%

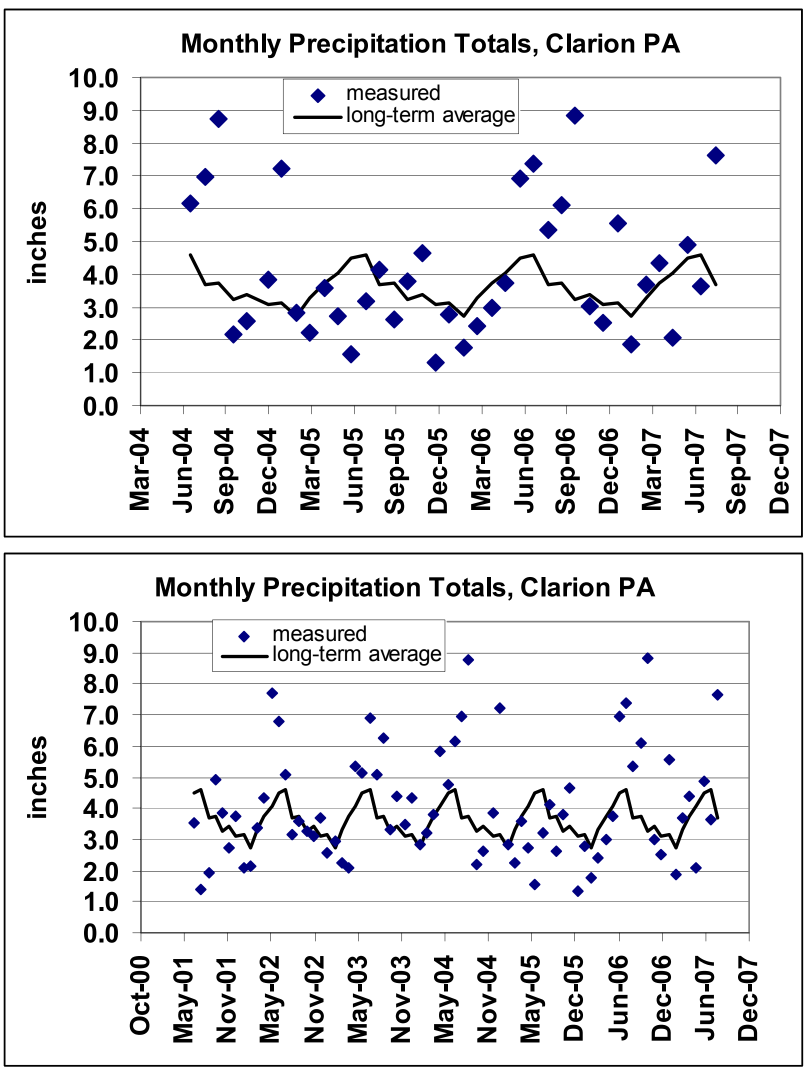


Figure 3. Precipitation in the study are in a) 2004-07; and b) 2001-07.

Comparisons are made in this report between data collected between November 2001 and October 2002 as part of the assessment used in the Little Coon Run Restoration. The precipitation during the 2001-02 period was 11% above average. Both sets of data were collected during periods with above average precipitation. There is no reason to reject comparisons due to markedly different precipitation patterns.

Local Private Wells

Five private wells located within one mile of LC35D and LC40D were sampled. The laboratory results are shown in Table 13. The Hall well is located downgradient of a surface mine and the presence of low pH and elevated concentrations of sulfate and Al indicates influence by AMD. The other four wells have water with low alkalinity and sulfate and variable amounts of the Fe. The source of Fe in these waters is likely siderite, an iron carbonate mineral that is common in the area.

Table 13. Chemistry of private wells in the vicinity of LC35D and LC40D

	Date	pH	cond	Alk	Acid	Fe	Mn	Al	SO_4	TSS
Well location			umhos	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Hall	12/4/06	4.6	177.0	<1	22	2.3	3.3	1.5	59	1
Hall	07/30/07	4.0	381.0	0	60	1.0	6.0	8.6	172	4
Hall Barn	12/4/06	5.9	74.0	7	3	0.4	0.0	0.2	12	2
Hall Barn	07/30/07	5.8	63.0	7	-2	0.1	<0.02	0.1	11	4
Stitzinger	12/4/06	6.2	63.0	11	-4	0.1	0.0	0.2	10	2
Stitzinger	07/30/07	6.2	79.0	14	-9	<0.04	0.1	0.1	10	3
Strickenberger	12/5/06	6.0	107.0	13	7	16.4	0.7	0.1	30	8
Strickenberger	07/30/07	5.9	138.0	10	8	19.7	0.9	<0.04	37	9
Delaney	12/4/06	6.0	91.0	8	3	18.8	0.7	0.1	31	17
Delaney	07/30/07	5.9	82.0	8	-2	9.9	0.7	0.2	19	5

Artesian Discharges

Eleven perennial artesian discharges are known to exist within the Frills Corner synclinal basin. This set of discharges includes LC20D, LC35D and LC40D. The flows of these discharges were measured regularly for 21 months. Samples were collected approximately quarterly during this period. The average flow and chemical characteristics of the artesian discharges are shown in Table 14. All had pH >5 and contained bicarbonate alkalinity. Concentrations of Fe and Mn were generally high, while concentrations of Al were less than 1 mg/L. The acidity associated with the Fe and Mn exceeded the buffering capacity of the bicarbonate for most discharges, resulting in a net acidic chemistry. When these discharges are aerated, iron oxidation and hydrolysis produces proton acidity that, if not neutralized, causes the pH of the flow to decrease to less than 4. One flow (LC10D) was net alkaline. This discharge contained higher alkalinity and lower Fe than the other discharges. There was enough alkalinity present to buffer the proton acidity produced by iron reactions.

Table 14. Average flow and chemistry of artesian discharges in the study area.

Name	Flow	pH	Alk	Acid	Fe	Mn	Al	SO4	Acid	Fe
	gpm		mg/L						lb/day	
LCK115D	35	5.7	35	336	192	14	<1	968	141	79
LCK112D	64	5.8	27	230	153	11	<1	760	164	109
LCK101D	11	5.8	34	170	128	11	<1	687	21	16
LCK129D	13	5.6	21	274	174	13	<1	874	41	26
LCK131D	36	5.8	27	154	118	8	<1	515	70	53
LC20D	60	6.1	46	190	116	14	<1	701	125	75
LC35D	20	5.6	37	256	153	9	<1	870	66	39
LC40D	15	5.5	34	325	187	13	<1	1,005	59	34
WR11D	2	5.3	21	98	72	5	<1	439	3	2
LR17D	5	5.0	8	133	67	11	<1	692	5	2
LC10D	7	6.7	89	-53	13	1	<1	148	-4	1
Ave/Sum	22	5.8	40	172	116	9	<1	653	57	36

Figure 4 is a panel that shows the individual flow rates for each artesian discharge. The summed flow of the five Licking Run discharges, LC35D, and LC40D are shown. These flows were measured every month. Their average total flow, 194 gpm, is 66% of the total flow measured (287 gpm). Most of the missing flow is LC20D which could not be measured while the passive treatment system was constructed. Monthly precipitation totals in Clarion are shown.

Flows for the major discharges varied similarly. Flows were low in autumn 2005, rose in winter 2007, and decreased in autumn 2007. Regional precipitation was low in the summer and autumn of 2005, and high in the summer and early autumn of 2006, and low in spring 2007. The major artesian flows appear to lag 2-3 months behind pronounced precipitation patterns.

Most of the artesian discharges showed modest month-to-month flow variation. The only discharge that stopped flowing during the study period was LR17D which was dry twice. WR11D had flows as low as 0.1 gpm twice during the study.

The artesian flows are a large source of pollution to local receiving streams. The summed discharges produced an average 688 lb/day of net acidity and 437 lb/day of Fe. Local streams are generally designated as cold water fisheries and have an instream Fe limit of 1.5 mg/L Fe. The iron loading produced by the artesian discharges is capable of polluting approximately 24,000 gpm of clean stream flow. Local unpolluted streams generally contain about 20 mg/L alkalinity (Coon Creek data in "Little Coon Run and Walley Run Mine Drainage Assessment and Restoration Plan"). The acidity loading produced by the artesian discharges can completely eliminate (neutralize) 20 mg/L alkalinity in approximately 3,000 gpm of flow. In practice, fishery degradation occurs before alkalinity levels reach zero.

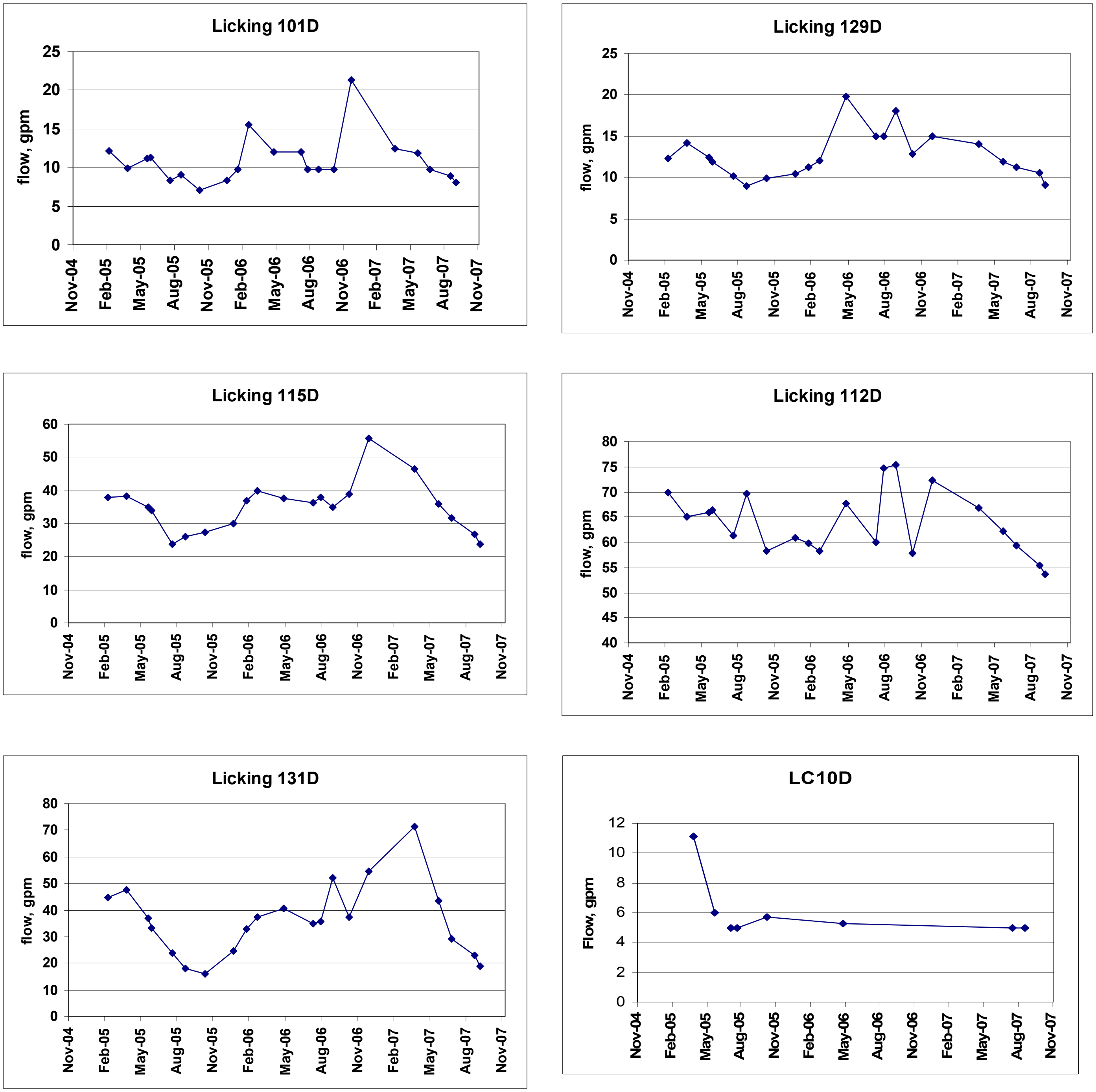


Figure 4. Flows of the artesian discharges, 2004-2007

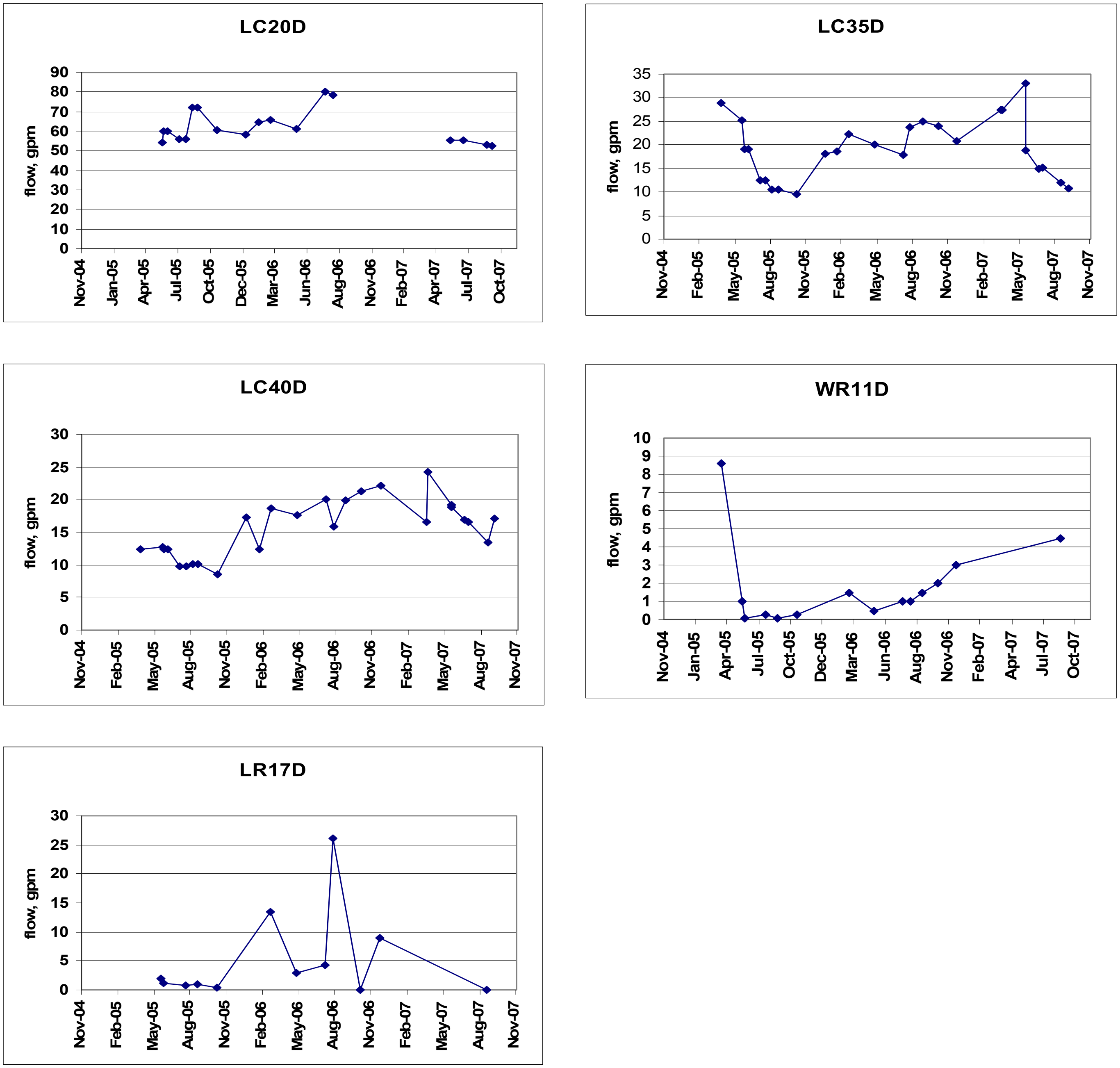
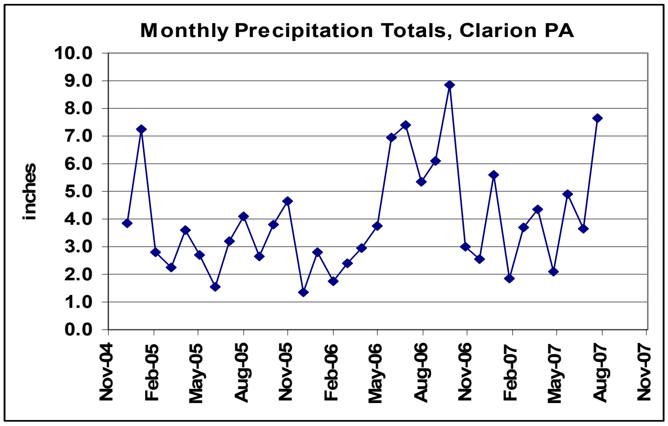


Figure 4. Flows of the artesian discharges, 2004-2007 (cont.)



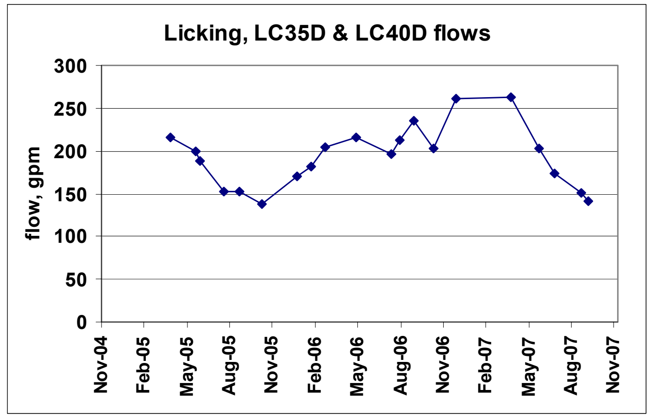


Figure 4. Flows of the artesian discharges, 2004-2007 (Cont.)

Discussion

Surface Mine Discharges in Area

The study area contains seven abandoned unreclaimed surface mines (Map C). The mines are in the Clarion Coal formation which in this region occurs at upper elevations, often in hilltops. The coal is absent (eroded) in valleys and lowlands. Discharges from these mines into the Little Coon Run and Walley Run watersheds were monitored between November 2001 and October 2002 and reported in the "Little Coon Run and Walley Run Mine Drainage Assessment and Restoration Plan." Table 15 shows the characteristics of seepage flowing directly from the mine spoils. All of the spoil discharges had low pH and were contaminated with high concentrations of Al and Mn. Iron contamination was variable.

Table 15. Flow and chemistry of spoil seepage discharges. "times dry" indicates the number of sampling occasions when the discharge was dry.

Name	Flow	Times dry	pH	Alk	Acid	Fe	Mn	Al	SO4
LR40D	1	4	3.2	0	476	19	31	45	1,776
LC55D	4	0	3.2	0	126	14	9	4	513
LC45D	6	2	3.3	0	481	3	25	70	1,415
LC57D	1	6	3.3	0	396	1	27	56	1,285
LC60D	23	0	3.4	0	211	6	20	23	1,166
LR29D	7	2	3.3	0	690	14	12	95	1,277
LC46D	2	6	3.7	0	358	2	14	51	960
LC47D	1	5	3.4	0	647	5	14	98	1124
LC37D	7	1	3.6	0	316	2	26	40	1,582
Average	5		3.4	0	411	7	20	54	1,233

Key: *Flows are gpm; acidity and acidity are mg/L $CaCO_3$; Fe, Mn, Al, and SO_4 are mg/L*

Flows of AMD from the surface mines were low and highly variable. Of the 9 discharges monitored, only two (LC55D and LC60D) flowed on all monitoring dates. The remaining seven discharges were dry in at least one autumn month. Precipitation during the monitoring period was slightly wetter than average. The variable flow is not due to droughty conditions.

Most coal seams have clay beneath the coal that acts as an aquitard and directs most spoil infiltration to toe-of-spoil discharge points. The amount of water flowing from the surface mines does not balance with the amount of flow expected if shallow infiltration was contained in the mine and directed to spoil seeps. Half of the surface mine acreage is in the Little Coon Run and Walley Run watersheds. If 25% of the precipitation on these 182 acres infiltrated and was discharged at toe-of-spoil seeps, the average summed flow of these discharges would be 410 gpm. The assessment measured a summed flow of 49 gpm. The large discrepancy suggests that the underclays in these mines are not competent and water is escaping from the mines into underlying strata.

This loss of water to underlying aquifers is supported by the presence of several surface mine impoundments on the surface mine sites that collect water from the spoil runoff but were never observed to discharge in 2001/02.

Artesian flows from the same groundwater system

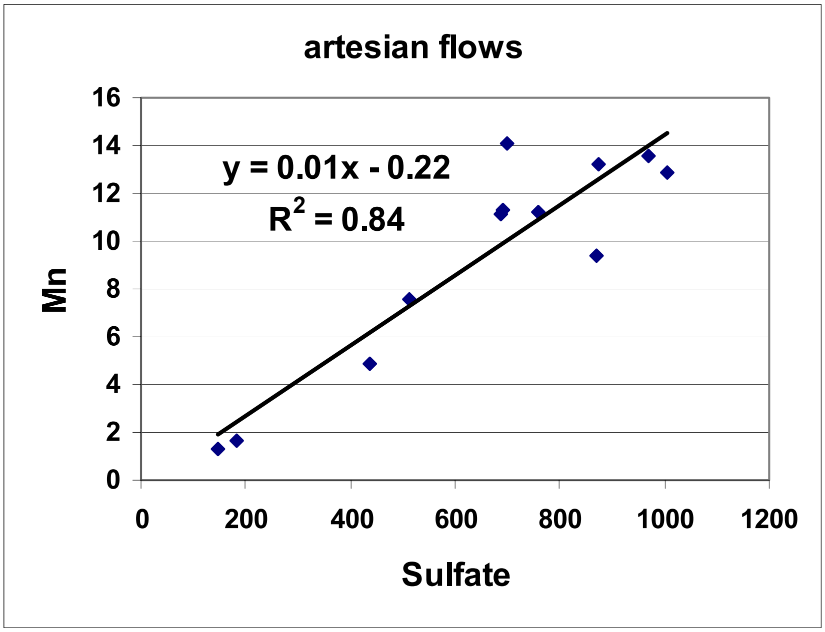
The artesian flows were selected because they all occur within the Frills Corner syncline and it was hypothesized that they drain a common groundwater system that is also connected to the higher elevation surface mines in the area. This hypothesis was evaluated by analyzing ion ratios for the spoil and artesian flows. Ion ratios are useful tools for understanding contaminated groundwater systems when the following conditions are met:

1. the ions are present in concentrations that exceed analytical detection limits and can be reliably measured;
2. the ions are present in large concentrations in the contaminated source water and low concentrations in uncontaminated inflows of clean water;
3. the ions are chemically conservative within the groundwater system.

Two ions that satisfy these conditions are sulfate and manganese. Both are present in high concentrations (>10 times their detection limit) in all water samples. Both are products of reactions associated with acid mine drainage production coal spoils. Sulfate is produced from pyrite oxidation. Manganese is produced from the dissolution of carbonates and shales by acidic spoil conditions. Neither is present in high concentrations in uncontaminated waters in the study area. The four wells that yielded "clean" water contain <1 mg/L Mn and <40 mg/L sulfate (Table 13). Lastly, both ions are chemically conservative in the anoxic moderately acidic groundwater conditions found in wells and artesian discharges. There is no evidence for significant sulfate reduction within the aquifer. Nor are calcium concentrations high enough to cause gypsum formation. Mn can form a carbonate or oxide solid, but neither is stable at pH values less than 8. All measured field pH values were less than 7.

The concentrations of ions that satisfy these conditions will be affected with flow through an aquifer *only* by dilution by inflows of clean water. If more than one ion satisfies the conditions, then the ratio of these ions will be maintained with flow through aquifers. This condition can be used to infer that water samples arise from a common aquifer that is affected to a common inflow of contaminated water and variable flow of uncontaminated water.

Analyses of Mn:sulfate ratios support the hypothesis that all of the artesian discharges located in the Frills Corner synclinal basin drain an aquifer with a common input of AMD and variable inflows of clean water. Figure 5a plots the average concentrations of sulfate vs. Mn for the artesian discharges. A significant relationship exists between the ions. This result supports the assumption that the artesian discharges all drain water from a common aquifer, whose chemistry is affected by variable amounts of diluting freshwater.



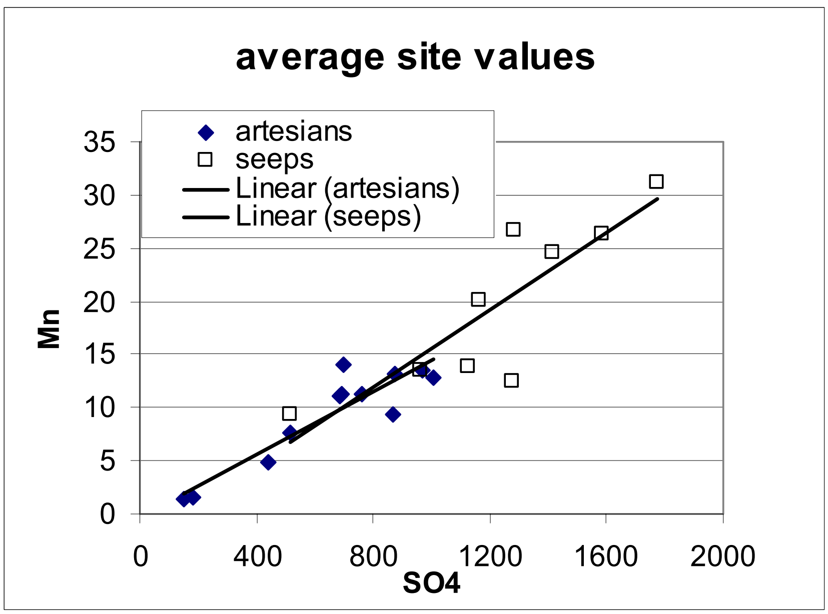


Figure 5. The relationship between Mn and Sulfate for: a) artesian flows, and b) surface mine seepages

Surface mine discharges have higher concentrations of Mn and sulfate than the artesian flows, but the Mn:sulfate ratios are similar. Figure 5b shows the Mn:sulfate relationship for spoil and artesian discharges. The regression lines calculated for each set of data have similar slopes. This result supports the hypothesis that the waters are connected.

Acidity as a Conservative Ion

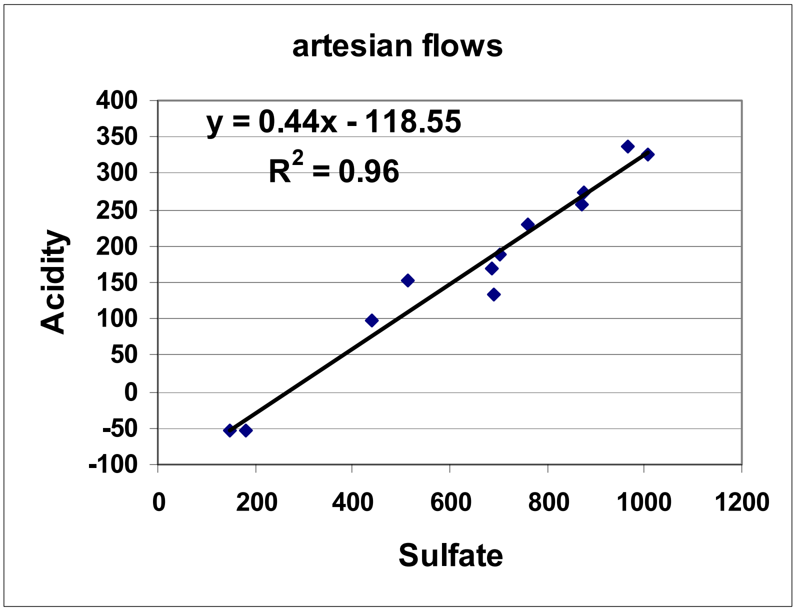
Acidity is not generally considered a good candidate as a conservative ion because of the common presence of alkaline minerals that neutralize acidity as it flows through an aquifer. When acidity is decreased by neutralization, but sulfate is not impacted, the ratio of these two ions changes with flow through the aquifer.

Groundwaters in the study area are very weakly alkaline, suggesting an absence of calcite or dolomite. The dominant local carbonate is siderite, $FeCO_3$, a mineral whose dissolution does not neutralize acidity because of the acidic aspects of ferrous iron.

Figure 6a shows a plot of acidity vs. sulfate for the artesian flows. The strong statistical relationship indicates that in situ neutralization is not occurring and that acidity is flowing conservatively through the aquifer. Acidity concentrations are affected by dilution with freshwater in the same manner that sulfate concentrations are affected.

The surface mine seepages display a more variable relationship between acidity and sulfate (Figure 6b). This result suggests that shallow highly acidic minewater is being partially and variably neutralized within the spoil environment. Part of this variation may arise from high variability in surface vegetation. Vegetation neutralizes acidity through the production of organic matter which can fuel alkalinity-producing microbial processes. Some of the spoils are forested, others are barren.

Interestingly, the average acidity and sulfate concentrations for the surface seepages, 411 mg/L acidity and 1,233 mg/L sulfate, plots almost directly on the regression line for the artesian discharges. This is the expected condition if the average spoil seepage represents the bulk inflow of AMD from the surface mines into the underlying aquifer.



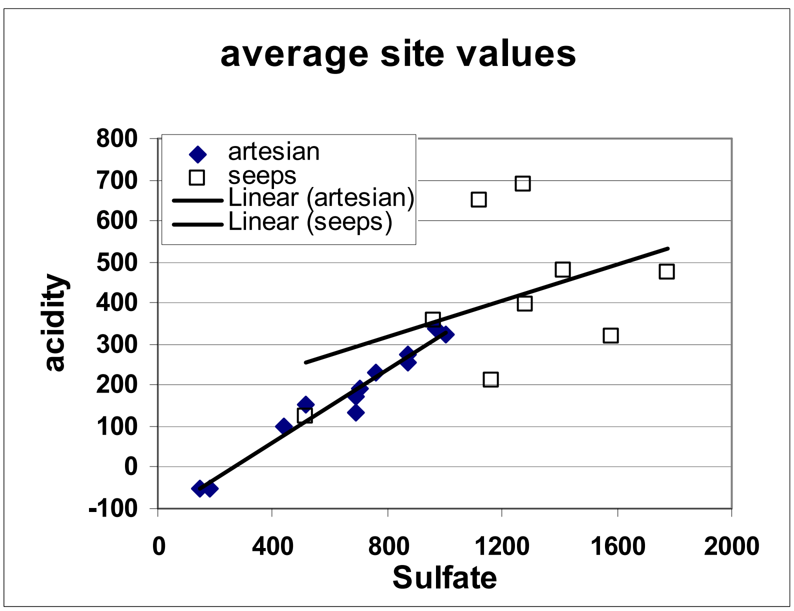


Figure 6. The relationship between Acidity and Sulfate for: a) artesian flows, and b) surface mine seepages

Evaluation of hydrogeochemical model

The occurrence of artesian flows of acidic water in the vicinity of surface mines has been observed by others and a hydrological connection between the proposed (Merritt and Emrich, (1970); Stafford et al. (2004) and Hedin et al (2005)). Hedin et al. hypothesized that:

1. The chemistry of the flows resulted from the reaction of acidic AMD generated in surface mines with native siderite present in underlying aquifers.

2. The head driving the artesian flows could be traced back to the hilltop surface mines that supply much of the flow.

In the following section, this hydrogeochemical model is assessed through data collected thus far in this study.

Evidence for a connection between the spoils and artesian flows

The model predicts a chemical connection between the surface spoils that generate AMD and the abandoned wells and springs that discharge AMD. The hypothesized reaction with siderite complicates the relationship because of significant changes in the AMD chemistry.

$$Al^{3+} + H^{+} + H_2O + 2SO_4^{2-} + 2FeCO_3 \rightarrow Al(OH)_3 + 2Fe^{2+} + 2CO_2 + 2SO_4^{-2}$$

Aluminum and protons are removed while ferrous iron is released. A relationship between the surface seeps and the artesian flows requires analysis of constituents not affected by the reaction. Sulfate and Mn satisfy this condition. The ions show a strong interrelationship that is similar within the spoils seepages and the artesian flows.

Acidity is not affected by the siderite reaction because Al and H^+ acidity is exchanged equally for Fe^{2+} acidity. Analysis of the relationship between acidity and sulfate also supports the hypothesis that the spoil and groundwater discharges are geochemically connected.

Confirmation of Siderite

The geochemical model requires reaction with siderite to trade Al for Fe and add bicarbonate to the water, without neutralizing acidity. Siderite's presence has been confirmed through historical records and through analysis of drill cuttings. Siderite deposits are knows to occur commonly in strata beneath the Clarion coals within this region. In the 1800's, siderite was mined locally and used in iron furnaces. Further confirmation was provided by X-ray diffraction analysis of drill cuttings produced when a shallow well was drilled in the adjacent Mahles Run watershed (Fidler et al., 2006). This hole produced a strong artesian flow of acidic, Fe-contaminated water.

Transfer of Pressure

Pressure is required to drive the artesian flows. No measures of the aquifer pressure have been made in the Little Coon or Licking Creek watersheds. In the adjacent Mahles Run watershed, a well that was producing 100 gpm of artesian flow was temporarily sealed with a valve that was also equipped with a pressure transducer. 10 psi was measured. Aquifer pressure will be measured in the future at LC40D where the alternate sealing method allows the installation of a pressure transducer.

While the existence of pressurized conditions is not in doubt, the source of the pressure is not clearly established. The original oil and gas deposits in this area were pressurized and at one time might have been able to force water to the surface. These waters, however, are brines, not sulfate-rich acid mine drainage. Also, the pressures that forced oil and brines to the surface 100 years ago are long exhausted.

In the absence of archaic forces, the pressure for artesian discharges must be supplied by gravity acting on the aquifer at a higher location. For pressure to be transferred to a lower elevation location, the aquifer must be confined. Classically, the confining layer is an easily identified aquitard and extends through structural features to an higher location. Drilling has revealed the presence of sandstones and shales beneath the coal-bearing strata. The structural relief necessary to produce artesian flow does indeed exist. The Leeper Anticline, where the abandoned surface mines are located, directs ground water through rock units towards the Frills Corner Syncline. Along the flow path the abandoned gas wells act as conduits allowing water to flow from shallow depths (> 150 ft) to the surface. The presence of so many outlets and conduits allows for most any rock unit to act as an aquitard or confining layer.

A permeable aquifer can still transfer pressure if water can follow highly porous fracture flows and flow faster through the fractures than through the low porosity sandstones and shales. This condition is thought to exist in the study area. Fractures, natural and created by mining activities, transfer water into underlying aquifers. If these fractures terminate within the sandstones, then the pressure is distributed throughout the aquifer and it acts to produce low-head seepage at numerous locations. If these fractures connect with an abandoned well that provides a clear conduit to the surface, the ability to pass a large volume of water is created. During the cleaning of LC35D, a downhole camera documented the inflow of much of the flow at several highly fractured sections of the well. Similar conditions were discovered in a well drilled in Mahles Run that intercepted large flows of water at several distinct elevations.

Summary

Background conditions have been established in the Frills Corner Syncline that should allow reliable evaluation of the affects of well sealing on local hydrology. Pre-sealing flow rates, chemical conditions, and contaminant loadings are well documented.

The available data allow an evaluation of the hydrogeochemical model suggested by Hedin et al. (2005) that ties the artesian flows of polluted water to local unreclaimed surface mines. Analyses of ion ratios strongly support the hypothesis that the artesian flows all originate in a common aquifer and that this aquifer is connected to high elevation surface mines. The finding that acidity flows conservatively through the aquifer supports the hypothesis that siderite, a non-neutralizing carbonate, is the principle reactant with acidic mine drainage.

The presence of numerous artesian flows of AMD suggests connection with higher elevation surface mines. Drilling has not identified an aquitard that could confine the aquifer and transfer the pressure from high elevation to lower elevation. A more plausible explanation is that fractures connecting with the abandoned wells provide highly porous flow paths for water to transfer from higher elevation surface mines to lower elevation abandoned wells. With minor head losses, these flow paths retain much of the head pressure and discharge in strongly artesian manners.

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