PASSIVE TREATMENT OF ACID MINE DRAINAGE – THE ENOS RECLAMATION PROJECT, INDIANA: PRELIMINARY RESULTS[1]

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Abstract: The Enos Gob Pile, located in Pike County, Indiana, is a 250-acre refuse disposal area emplaced prior to the August 3, 1977 enactment of the Surface Mining Control and Reclamation Act (SMCRA). Two passive treatment systems totaling approximately 64-acres were constructed in 2005 by the Indiana Department of Natural Resources, Division of Reclamation (IDOR) to treat AMD discharging from the refuse disposal area. IDOR, with the assistance of the OSM, Mid-Continent Regional Office (OSM-MCR) designed the passive treatment system at the site that includes: 1) addition of alkaline water (alkalinity = 242 mg/L) from adjacent pre-SMCRA mine impoundments, 2) construction of two vertical flow ponds (VFP) for additional alkalinity enhancement, and 3) excavation of a series of oxidation ponds and aerobic wetlands for metal precipitation. The system was designed to handle a large amount of acidic runoff during storm events (1.5 to 2.0 CFS). Underlying and surrounding the refuse pile is mine spoil with a generally favorable neutralization potential. As a result of that neutralization the water entering each VFP is relatively low in iron (19.2 mg/L) and total acidity (92 mg/L). However, the designers were required to consider the impact of a significant amount of Al (5.2 mg/L) on the life expectancy of the VFP. Post-construction evaluations are being assisted by the Indiana Geological Survey (IGS). These studies indicate nearly complete Fe removal by the system (total iron = 0.25 mg/L) and a net alkaline discharge (alkalinity exceeds acidity by about 65 mg/L). Although no specific structures were incorporated in the design for Mn removal, Mn is also being removed by the wetland system (3.7 mg/L in the VFP inlet, 0.23 mg/L at the system outlet). Improvements in metal removal occurred when aquatic vegetation developed. Additional studies will evaluate the reduction in system efficiency during winter months and a comparison of the alkalinity generated by the two parallel VFPs one with dolomitic limestone and one with high-calcium limestone, as an alkalinity source.

Additional Key Words: passive treatment, vertical flow ponds, SAPS, AMD, water sampling.

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Introduction

The Enos Gob Pile is located at Enos Corner, Indiana 3.7 kilometers (2 mi.) north of the town of Spurgeon near Coe, Indiana in Pike County, Monroe Township, T2S, R8W, Section 36 on the Oakland City and Augusta 7.5-minute quadrangles (Fig. 1). The project area is within the watershed of the South Fork of the Patoka River. The South Fork bisects an extensively mined portion of Pike County and is significantly impacted by coal mining conducted before the 1977 enactment of the Surface Mining Control and Reclamation Act (SMCRA, Fig. 2).

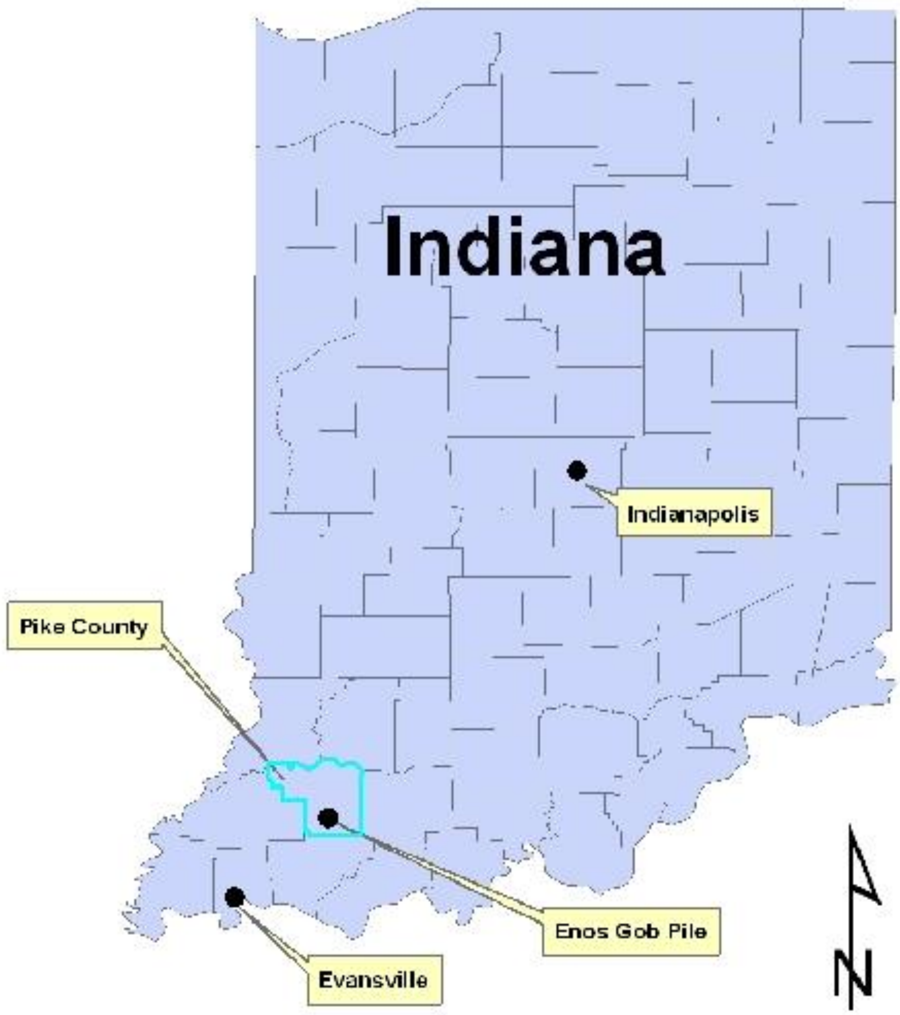


Figure 1 - Enos Project Site Location Map.

The Indiana Department of Natural Resources Division of Reclamation (IDOR) has undertaken extensive reclamation and watershed-based water quality remediation in the South

Fork Patoka River watershed. As of 2008, nine major projects with a total expenditure of $17,000,000.00 have reclaimed 1,500 acres within the watershed with a significant improvement in the water quality of the South Fork Patoka River.

Indiana has had a long mining history. Coal was extracted for riverboat use as early as 1812 (Spencer, 1953). Shipping of coal from Indiana mines began as early as 1832 with a total coal production in 1840 of 9,682 tons (Weir, 1973). Production increased rapidly during the 19th century, with 500,000 tons produced in 1870 and nearly 4,500,000 tons produced in 1897 (Spencer, 1953). Pike County is one of the oldest (local farm use began before 1838 in Pike County; Weir, 1973) and historically most important coal-producing areas in Indiana (Fig. 1). In Pike County alone, between 1890 and 1953 over 83 million tons were produced from surface mines, which were supplemented by 8.6 million tons from underground mining (Wier and Stanley, 1953). Indiana led the U.S. in strip coal production for many years during the early days of surface coal mining. Most mining in the South Fork Patoka watershed is by area-type, surface coal mining (Fig. 2). The Enos Coal Company began surface mining at Enos Corner in 1921. However, in 1963 Interlake Steel and Iron Company (Interlake) purchased Enos Coal Company, and, subsequently, sold the mining operation to Old Ben Coal Company (Old Ben) in 1965 (Endress, 1999). Interlake however, retained ownership of the gob pile surface rights. The 230-acre Enos Gob Pile was these companies between 1921 and May 3, 1978, pre-SMCRA (Fig. 3). This pre-SMCRA deposit is the principle source of water quality problems at this site.

The abandoned, Enos Mine coal refuse pile generates, stores, and transmits acid mine drainage (AMD). The pile is a combination of coarse refuse (gob) and fine coal processing waste (slurry). Infiltration through this refuse pile conveyed the acid water to a series of seeps along a north-south trending drainage channel (Fig. 3). This drainage collected in a 7.7-acre impoundment that was used by the successors of the Enos Coal Company--Old Ben and subsequently Zeigler Coal Company (1990) and then Kindill Mining, Inc. (1996) as a source of water for a large, coal preparation plant (the Old Ben No. 1/Kindill No. 1; (Endress, 1999). Between 1978 and 2006 these operations prevented this acidic drainage from discharging into the South Fork Patoka River by pumping excess water to a large, post-SMCRA slurry impoundment southeast of the pre-SMCRA Enos Gob Pile (Fig. 4). This control measure however was terminated in 2006 under agreement with the IDOR and Kindill Mining. Because of the impending discharge of runoff from the Enos Gob Pile, IDOR conducted a hydrologic investigation to support remediation (AMD passive treatment system) with the assistance of the Office of Surface Mining, Mid-Continent Regional Office (OSM).

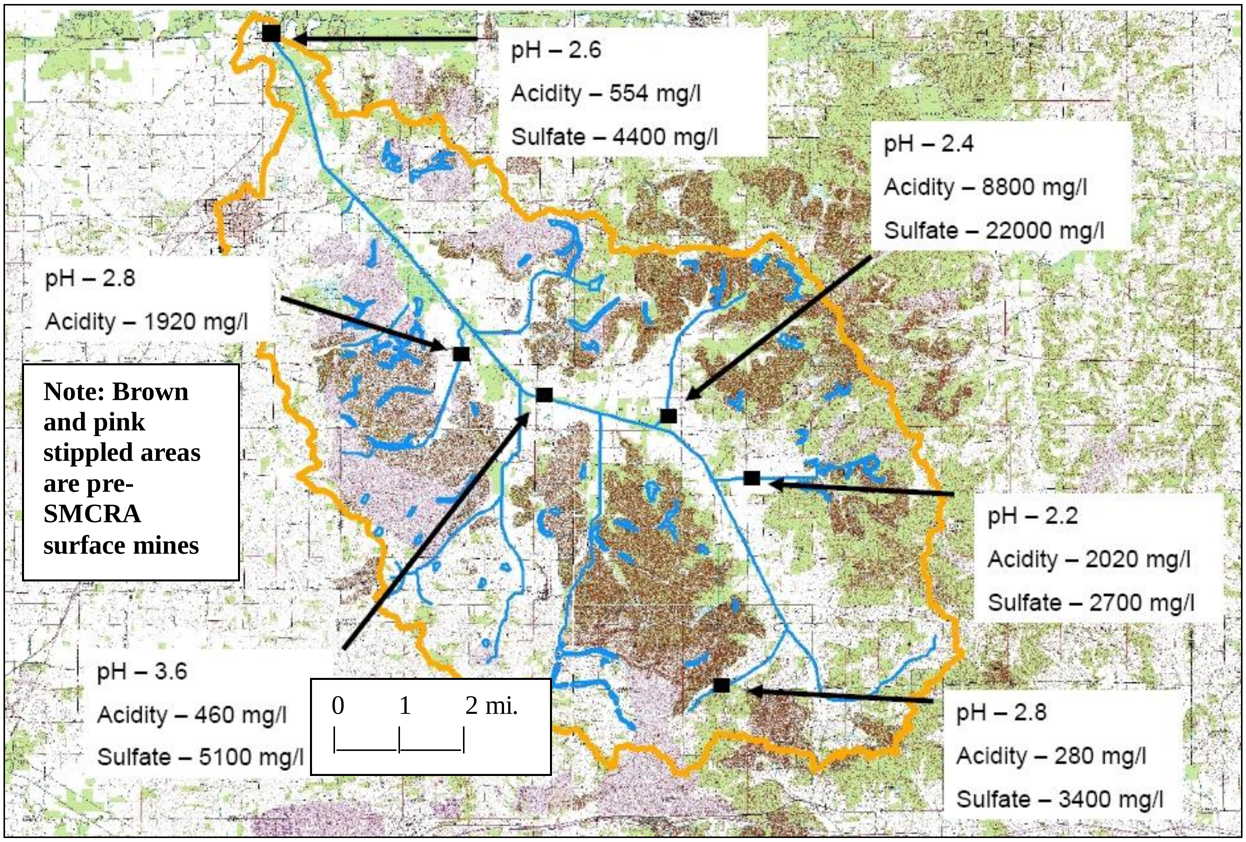
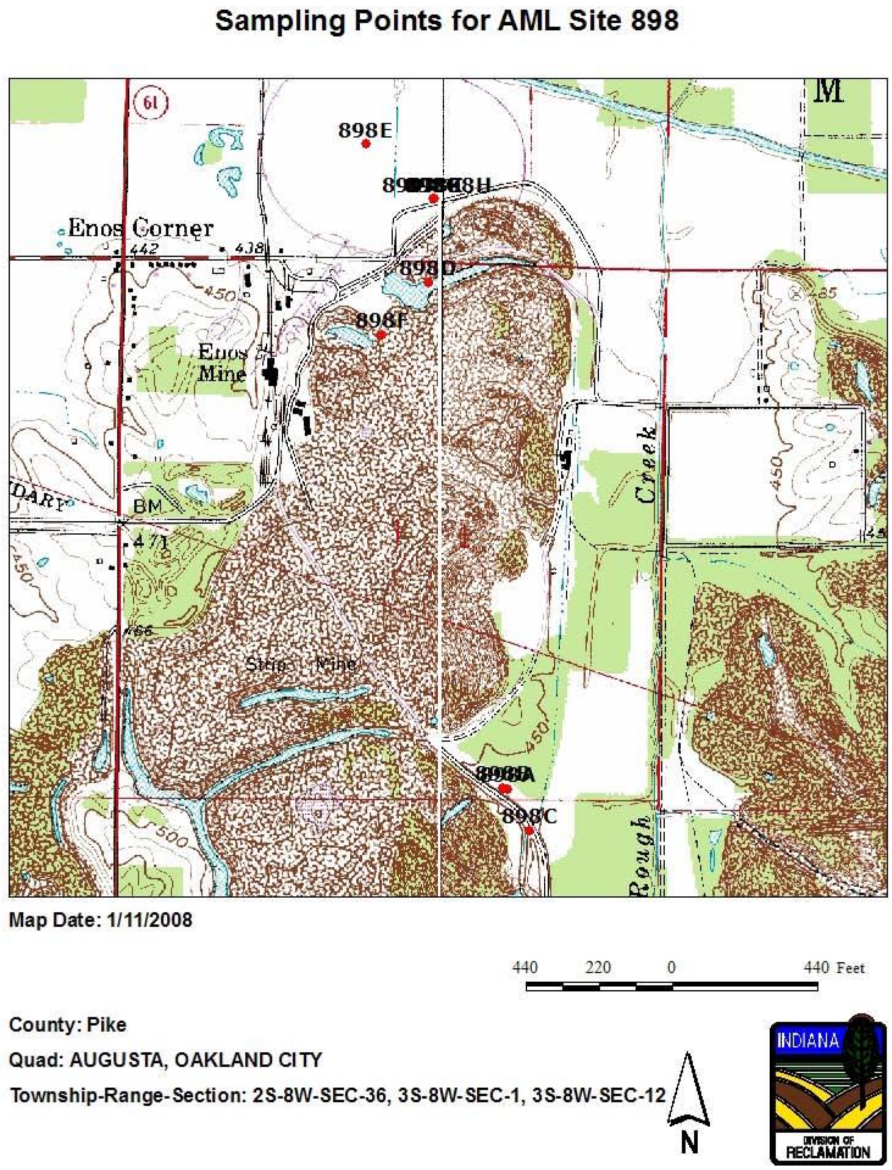


Figure 2 –Patoka South Fork Water Quality Prior to AML-funded Reclamation.

<u>Pre-Construction Hydrologic Investigation</u>

In 2001, IDOR and OSM collected baseline water quality data from acidic discharges from the Enos Gob Pile, a dilution water source, and two monitoring wells. The two wells were also used to evaluate water table depth, soil conditions in the project construction area, and the stability of an existing freshwater impoundment structure. Following a delay in the project during 2002 due to permitting requirements additional water sample data was collected in 2003 to 2004; the results of these investigations are presented in Table 1. Normally, AMD discharges from the gob pile in a series of diffuse seeps along the eastern and northern base of pile. This seepage is collected in a 2,000-foot canal built by the mine operators which drains into a large (7.7-acre) impoundment termed the "acid lake" (see Site 298D Fig. 3 and Fig. 4, Table 1).



Sample Points Include:

A – Weir: East Ditch on the southeast side of gob pile.
B – Weir: West Ditch on southwest side of gob pile.
C - Dilution or "fresh water" weir.
D - Old pump location at the “Acid Lake.”
E - Weir at final outlet of passive treatment system

F - Acidic slurry impoundment gob pile discharge.
G – Discharge from West (limestone) VFP.
H - Discharge East (dolomite) limestone VFP cell
J - West (limestone) VFP flush pipe.
K - East (dolomite) VFP flush pipe.

Figure 3 –Overview of the Enos Gob Pile with Water Sample Locations.

Figure 4 – Pumping Station at the Acid Pond with Enos Gob Pile in the Background.

During periods of higher rainfall, impoundments within the slurry cells coalesce and discharge highly metal-laden water into the acid lake. A smaller (1.9 acre) acidic impoundment, termed the "truck wash pond", also collects runoff and seepage from the Enos Gob Pile and discharges into the acid lake (Site 298F Fig. 3). A large, nearby pit impoundment was also evaluated for use as a source of alkaline dilution water. This impoundment, which had previously served as a secondary fresh water source for the preparation plant, is an excellent source of dilution water with nearly 240 mg/L of $CaCO_3$ equivalent alkalinity (Table 1) and a low metal content. Note, however, that the dilution source contains elevated Ca, Mg, and SO_4^{2-}, which is characteristic of mine drainage in which acidic drainage was generated and subsequently neutralized by calcareous strata within the mine spoil.

The design team also estimated the quantity of runoff that would be created by rainfall events in an effort to determine the total contaminant load and the size of the water treatment and conveyance structures. The best method would have been to determine the amount of water pumped by the mine operator. However, pumping was not on a fixed schedule and pumping rate or discharge measurements were not available. In the absence of pump flow and/or discharge data, the passive treatment system design flow rates were based on estimating a water balance using on historic rainfall data and assumptions for infiltration rate and water balance and evapotranspiration. Runoff estimates as the result of this water balance-based estimate indicated that peak flows of 1.0 CFS (450 GPM) could be expected from a combination of runoff and groundwater discharge to the receiving water bodies (base flow, Table 2). This discharge would be supplemented by flow from the dilution water source controlled by a gate valve.

Table 1 - Summary of Baseline Water Quality (2001-2004) Data.

Parameter	Ferruginous Seep Along Canal	Enos Gob Slurry Cell Discharge	Acid Lake @ Pump Platform (Median*)	Truck Wash Pond (Median*)	Dilution Lake (Median)	Units
pH (F)	7.2	2.32	3.0	4.5	7.6	s.u.
S.C. (F)	3,243	nm	3,033	3,139	3,301	µS/cm
D.O. (F)	nm	nm	6.0	3.32	3.4	mg/L
D. Fe (F)	NT	NT	25.90	33.70	0.32	mg/L
D. Fe^{+2} (F)	NT	NT	2.46	9.60	0.13	mg/L
D. Fe^{+3} (F)	NT	NT	22.29	1.10	0.23	mg/L
Alkalinity (F)	NT	NT	< 1	NT	217	mg/L
Sulfate	840	4,890	1,300	1,050	1,600	mg/L
Chloride	NT	NT	2.7	NT	3.5	mg/L
HCO_3^- calc***	NC	NC	0.6	3.0	304	mg/L
T. Fe	100	961	16.10	36.25	0.22	mg/L
T. Al	<0.07	54.0	5.20	1.45	0.10	mg/L
T. Mn	4.92	11.6	7.00	2.65	0.28	mg/L
D. Ca	NT	NT	357.0	NT	404	mg/L
D. Mg	NT	NT	135.3	NT	260	mg/L
D. Na	NT	NT	26.90	NT	70.9	mg/L
D. Fe	15.0	NT	18.39	34.35	0.22	mg/L
D. Al	<0.07	NT	5.20	1.33	0.04	mg/L
D. Mn	3.10	NT	7.21	2.78	0.40	mg/L
Alkalinity(lab)	NT	<10	< 1	2.5	239	mg/L
Acidity calc**	37.7	NC	126.7	90.2	1.7	mg/L
Acidity(lab)	NT	3,080	200	NT	<10	mg/L
TDS (lab)	NT	8,030	1,800	NT	3,300	mg/L
TDS calc*****	NC	NC	1,770	ND	2,516	mg/L

* Lab alkalinity and acidity are arithmetic mean values and reported as a $CaCO_3$ equivalent; symbols: NT = not tested, ND = not determined, NC=Not Calculated, F=field measurement or test.

** $Acidity_{calc} = 50[2\ Fe^{2+}/56 + 3Fe^{3+}/56 + 3Al/27 + 2Mn/55 + 1000(10^{-pH})]$.

*** Calculation Method from: Deutsch, 1997.

**** Calculated using *AquaChem* ver. 3.7 by Waterloo Hydrogeologic.

Development of Passive Treatment Options

Two options were considered for the initial design of the Enos Gob Pile passive treatment system. Both options included dilution of the AMD by a controlled addition of alkalinity-bearing water from the pit impoundment to moderate the AMD prior to wetlands-based passive treatment. This approach has been successfully employed at other AML projects in Indiana such as the Tecumseh project, AML Site 262 (Smith and others, 2003). However, the mine operator also wished to use this fresh water in the event of re-activation of the coal preparation plant and water additions were limited to 0.5 CFS (225 GPM). Based on this quantity and runoff of 1.0 CFS (450 GPM) the system was designed to handle 1.5 CFS (675 GPM) combined flow. The high flow rate demanded a large size treatment system, when applying conventional passive treatment sizing criteria developed by the U.S. Bureau of Mines (Hedin and others, 1994). In each option considered, the flow was partitioned to three parallel wetland systems and the impact of dilution on water quality is estimated in the analysis shown in Table 2. Median baseline concentration values for the acid lake and dilution water source are multiplied by the flow rate and a conversion factor to obtain contaminant loading in grams per day. These weights are then added and the concentration values back-calculated. Note that this estimate assumes all contaminants act conservatively, that is no geochemical and biologic-induced changes will occur in water chemistry due to the mixing. This estimate shows that the addition of the alkaline water at a rate of 0.5 CFS (150 GPM) nearly neutralizes the acidity contained in the AMD.

The two options considered were: Option 1, dilution with alkaline water and construction of large aerobic wetlands, and Option 2, dilution with alkaline water and construction of VFP and aerobic wetlands. These options will be discussed in detail.

Option 1: Dilution with Alkaline Water and Construction of Aerobic Wetlands: Due to the high flow rate and need for future cleanout of metal precipitates, three parallel systems was planned for the first stage (Fig. 3). This system would be constructed in a floodplain area within a railroad loop constructed for shipping coal from the Kindill No.1 Wash Plant. A 2-acre mixing pond was required to distribute the flow to the parallel wetlands. The mixing pond is an existing mine impoundment located within the railroad loop and would be fed by AMD collected in the Acid Lake. A second stage of wetland treatment and a polishing pond were also planned for Option 1.

Table 2 - Old Bevier II Project: Contaminant Load and Dilution Estimates.

Parameter	Concentration (mg/L, Median)	x Flow Rate (GPM)	x Conversion Factor	= Loading (g/day)	= Loading (3 parallel cells:g/day)
AMD Source: Acid Lake @ Pumps					
Iron	18.39	150	5.45	15,034	45,101
Manganese	5.2	150	5.45	4,251	12,753
Aluminum	7.21	150	5.45	5,894	17,683
Calcium	357.0	150	5.45	291,848	875,543
Magnesium	135.3	150	5.45	110,608	331,823
Acidity	126.7	150	5.45	103,577	310,732
Alkalinity	0	150	5.45	0	0
Sulfate	1,300	150	5.45	1,062,750	3,188,250
TDS	1,800	150	5.45	1,471,500	4,414,500
Dilution Source: Dilution Lake @ Gate Valve					
Iron	0.22	75	5.45	90	270
Manganese	0.40	75	5.45	164	491
Aluminum	0.040	75	5.45	16	49
Calcium	403.5	75	5.45	164,931	494,792
Magnesium	260.0	75	5.45	106,275	318,825
Acidity	1.7	75	5.45	695	2,085
Alkalinity	239.0	75	5.45	97,691	293,074
Sulfate	1,600	75	5.45	654,000	1,962,000
TDS	3,300	75	5.45	1,348,875	4,046,625
Resultant : AMD + Dilution Lake					
Iron	12.33	225	5.45	15,124	45,371
Manganese	3.60	225	5.45	4,415	13,244
Aluminum	4.82	225	5.45	5,911	17,732
Calcium	372.5	225	5.45	456,778	1,370,334
Magnesium	176.9	225	5.45	216,883	650,648
Acidity	**85.0**	225	5.45	104,272	312,816
Alkalinity	**79.7**	225	5.45	97,691	293,074
Sulfate	1,400	225	5.45	1,716,750	5,150,250
TDS	2,300	225	5.45	2,820,375	8,461,125

* This estimate does not consider geochemical and biologic-induced changes in water chemistry.

Option 2: Dilution with Alkaline Water and Construction of Vertical Flow Ponds and Aerobic Wetlands: Although Option 1 is the simplest design, at the time of the design there was a potential water-use conflict for co-use of the dilution water lake by the Kindill No. 1 Coal Preparation Plant (Fig. 5). Option 2 addressed this concern by adding the secondary alkalinity source of a vertical flow pond in place of one of the three parallel aerobic wetland cells shown in Fig. 5. A modified version of Option 2 was the selected option.

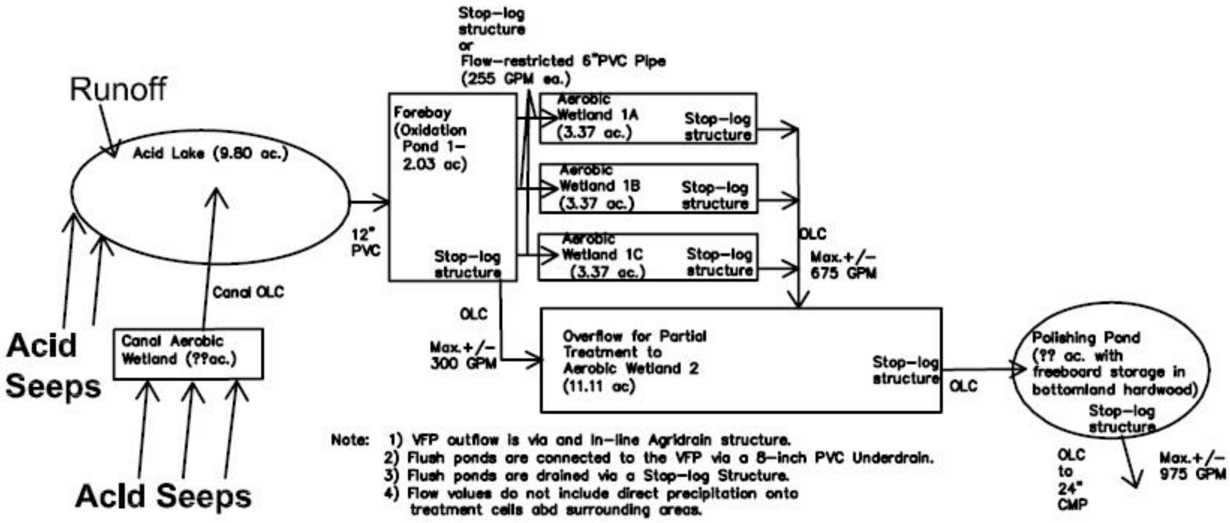


Figure 5 – Enos Loop Wetland: Option 1 Passive Treatment Plan.

<u>Design and Construction of the Treatment System</u>

Two separate contracts were necessary to construct the AMD passive treatment systems at the Enos Gob Pile: Enos Loop Wetland (Site 898), and the Enos East Wetland (Site 979).

<u>Enos Loop Wetland (Site 898)</u>: As constructed, the treatment system replaced the three parallel wetlands shown in Fig. 5 with by two parallel vertical flow ponds. These cells are followed by a large oxidation pond and final polishing wetland system. Although site is approximately 30 acres in size, only two acres have actually been impacted by mining activities. The remainder was a 15-acre soybean field and a 13-acre abandoned agricultural field. The Indiana AML Program rarely impacts “undisturbed” land in the process of reclaiming AML sites, but in this case disturbance was necessary, because the area lies directly between the 230-acre coal refuse pile and the South Fork of the Patoka River.

The two VFPs were originally designed as conventional structures consisting of a limestone-bedded, perforated PVC drainage system, and above that in sequence a limestone layer, an organic layer and finally water. Duplicate VFPs were constructed to facilitate future maintenance and to evaluate various alkaline materials. The West VFP was built in the conventional manner; the second, the East Cell, was constructed similarly, except that dolomitic limestone was substituted for the high-calcium limestone. This was done to test the theory that dolomite can reduce the problems of plugging due to gypsum formation that often plagues high-Ca limestone systems. This change was inspired by recommendations provided in Indiana SMART Grant awarded to the University of Cincinnati (Maynard and Helton, 2005). Maynard and Helton found that under certain conditions gypsum ($CaSO_4 \cdot 2H_20$) coatings form on limestone (calcite-$CaCO_3$) treatment. In an attempt to improve the overall effectiveness of these passive treatment wetlands, dolomitic limestone (containing calcite and dolomite – $CaMg(CO_3)_2$ will be directly compared to high-Ca limestone. Additional research has indicated that $CaSO_4 \cdot 2H_20$ coating are occurring on limestone surfaces within some passive treatment beds or at a bench scale (Rimstidt and Huminicki, 2006). This vertical flow pond is now part of a continuing research effort to try and improve future passive treatment installations and the relative effectiveness will be reported in future presentations by the evaluation team.

One additional change involved the selection of the compost layer material. During construction, suitable compost material was not readily available in this agricultural area. However, bailed straw and hay was in abundance and was selected as the principal organic source. Wetland substrate included transplanted substrate from the Tecumseh treatment wetland. That substrate served as the inoculants source for the establishment of sulfate-reducing bacteria (SRBs). The compost material was bulky and offered a relatively high hydraulic conductivity (Fig. 6). The compost layer thickness (estimated 3- to 4-foot thick) was thicker than designed (approximately 2-foot thick) and most of the water layer is eliminated in the completed VFP cells (Fig.7).

Enos East Wetland (Site 979): Shown in Fig. 5 as the "Canal Aerobic Wetland," a series of aerobic wetlands were planned along the eastern side of the Enos Gob Pile. The "Enos East Wetlands" is a series of wetland cells in place of the old canal that collects the AMD from the eastern and southern part the gob pile. This wetland is intended remove some of the Fe before the vertical flow ponds in the Enos Loop Wetland (Fig. 7).

This wetland is a large structure, covering approximately 16 acres (linear-shaped series of impoundments in the center of Fig. 8). Water is fed into the wetland system in the upstream (southern) end by two AMD sources. The East Ditch collects AMD from the east side of the gob pile while the West Ditch collects AMD from southern and southwestern part of the gob pile. Fresh dilution water, regulated by a rebuilt gate valve an a new weir structure enters the wetland system from the impoundment that lies to the southwest.

Figure 6 – Placement of the Compost Layer: Enos loop Wetland - West VFP.

Figure 7 – Aerial View Looking East of the Completed Enos Loop Wetland.

NORTH→

Figure 8 – Aerial Photograph of the Enos Loop (right) and East Wetlands.

Construction on the Enos Loop Wetland (Project 898) began in January 2005 and was completed in September 2005; construction on the Enos East Wetlands (Site 979) began in April 2005 and was completed in October, 2005. The Enos East Wetlands receives a mix of acid seepage and dilution water immediately upon completion, whereas the Enos Loop Wetland did not receive "acid water" until the fall 2006. This delay was necessary to allow partial composting of the straw-based organic layer and the establishment of a health microbiologic community in the VFP.

Other Reclamation Activities at the Enos Gob Pile: One of the greatest challenges encountered during this project surfaced during the permitting process. As previously mentioned, a 13-acre portion of the Enos Loop Wetland construction area was a 13-acre abandoned agricultural field. Apparently, the reason the area was no longer farmed was because the ground was so wet, which is not surprising being so proximal to a river. Following abandonment, the former cropland became overgrown with shrubs and small trees. A wetland determination was subsequently conducted and because of the existing vegetation and hydric soils present, the Army Corps of Engineers classified this 13-acre field as a shrub/scrub wetland. As a jurisdictional wetland, this area was to be protected under both Sections 401 and 404 of the Clean Water Act (CWA). And even though IDOR was actually proposing to build a wetland within a wetland (see the foreground area of Fig. 7), this construction would have changed the "form and function" of the existing wetland, requiring mitigation.

Fortunately, IDOR has good working relationships with both the local Army Corps of Engineers Field Office and the Indiana Department of Environmental Management, the agencies that administer CWA Section 404 (Dredge and Fill) and Section 401 (State Water Quality Certification), respectively. Both agencies realized that our goal was to protect water quality within the South Fork Patoka River, which is consistent with their goals. A highly cooperative effort ensued and a set of mutually agreeable plans were developed that allowed IDOR to complete the construction of this passive treatment system.

In addition to the Enos Loop Wetland (Site 898) and the Enos East Wetlands (Site 979) one additional reclamation effort is ongoing at this site. The Enos Gob Pile, Site 978, is a fine coal recovery operation that, in the process will: 1) reclaim the entire refuse pile following fine coal refuse removal, and 2) construct a 26-acre (2:1) mitigation wetland in a former slurry cell in the southeastern corner of the Enos Gob Pile (Fig. 7). This wetland was required as part of the permitting process with the Army Corps of Engineers and the Indiana Department of Environmental Management as mitigation to offset impacts to undisturbed wetlands in the Enos Loop Wetland area.

Post-Construction System Evaluation

Both the Indiana Geological Survey (IGS) and OSM-MCR are assisting in the post-construction evaluation. These studies indicate nearly complete iron removal by the system (total iron = 0.25 mg/L) and a net alkaline discharge (alkalinity exceeds acidity by about 65 mg/L). Although no specific structures were incorporated in the design for Mn removal, Mn is also being removed by the wetland system (3.7 mg/L in the VFP inlet, 0.23 mg/L at the system outlet). This is consistent with the understanding that aerobic wetlands are capable of removing Mn to low levels once iron is removed from the discharge. Improvements in metal removal occurred when aquatic vegetation developed. Aluminum is being entirely removed in the vertical flow ponds. Median Al concentration at the inlet (the Acid Lake and connected 2-acre forebay pond) is 3.34 mg/L with discharge levels between 0.25 and 0.43 mg/L (Table 3).

Table 3 – Median Post-Construction Water Quality: Enos Project Site.

Sample Location	pH	T. Fe (mg/L)	T. Mn (mg/L)	T. Al	Ca*	Mg*	SO_4	TDS	TSS	Acidity	Alkalinity
East AMD Ditch	7.00	0.43	3.520	0.121	580	300	2,030	3,590	22	33	260
West AMD Ditch	3.60	18.50	20.724	2.410	580	170	1,820	2,740	12	95	5
Dilution Water	7.32	0.28	0.30	0.101	450	280	1,960	3,180	11	27	242
Acid Pond	3.50	19.20	3.73	3.340	540	240	1,900	2,480	6	92	5
Limestone VFP Out	6.64	18.63	3.100	0.430	540	240	1,130	2,950	49	76	230
Dolomite VFP Out	6.39	21.02	3.880	0.250	530	220	2,080	2,910	59	74	180
System Out	6.92	0.25	0.226	0.127	450	230	1,239	1,630	10	5	70

* One round of samples all others have multiple sampling events.

Due to the limited number of complete samples collected and seasonal performance variations the median values presented in Table 3 are not representative of the performance of the treatment system. Data collected a detailed evaluation in July 2007 by the IGS and IDOR illustrates treatment system performance (Table 4, Fig. 9 - 11). This data shows complete Al removal as the pH increases above 4.5 (Fig. 9). It is hoped that due to the anaerobic conditions in the thick compost layer that Al is being removed within the compost as SO_4^{2-} minerals such as the hydrated aluminum – potassium sulfate mineral alunite [$(KAl(SO_4)_2(OH)_6$] and not as aluminum hydroxide mineral gibbsite [$Al(OH)_3$], which tends to precipitate in and clog the limestone layer (Gusek and Wildeman, 2002). Because K is relatively low in the mine drainage (median = 8 mg/L) the Na equivalent, natroalunite, may also form. Sodium concentration is somewhat higher in the AMD (median = 41 mg/L).

Table 4 –IGS/IDOR Post-Construction Water Quality: Enos Project Site July, 2007.

Sample Location	pH	T. Fe (mg/L)	T. Mn (mg/L)	T. Al	Ca*	Mg*	SO_4	TDS	TSS	Acidity	Alkalinity
East AMD Ditch	6.94	<1.00	0.11	<0.500	580	300	2,300	3,590	18	0	260
West AMD Ditch	3.69	84.68	34.71	3.64	580	170	2,400	2,740	13	350	0
Dilution Water	6.79	0	0.16	<0.500	450	280	2,100	3,960	8	11	220
Acid Pond	3.60	5.48	2.79	4.64	540	240	2,400	2,480	12	130	0
Limestone VFP Out	6.33	35.32	3.82	<0.500	540	240	2,100	2,510	45	76	230
Dolomite VFP Out	6.39	36.60	3.94	<0.500	530	220	2,200	3,130	35	74	180
System Out	6.98	<1.00	<0.10	<0.500	450	230	2,000	2,800	8	7	120

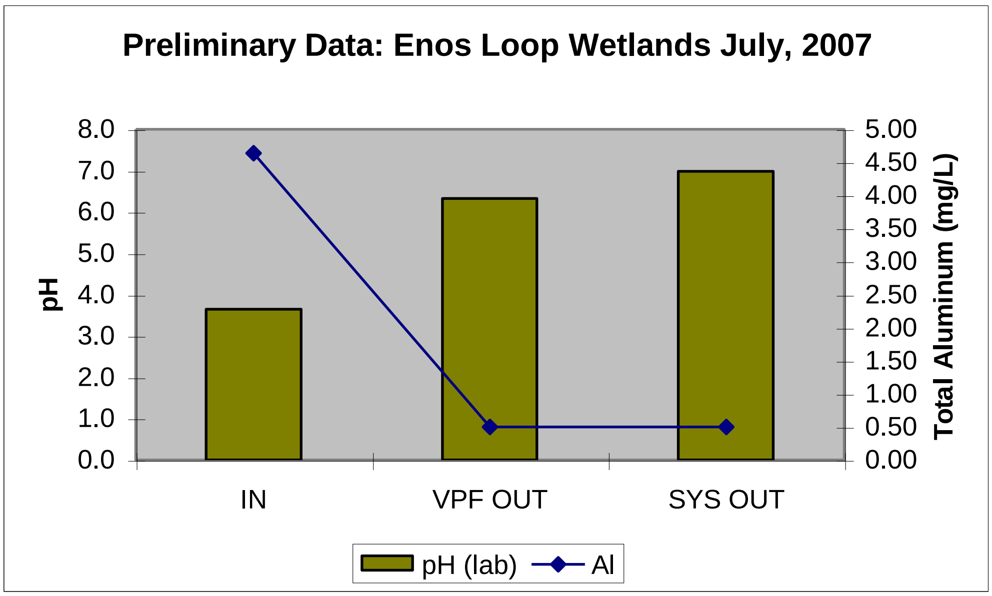


Figure 9 –The Impact on the Aluminum Content due to Changes in pH within the Enos Loop Wetland.

A high rate of metal removal has been observed by this system to date. Both Fe and Mn are removed to near or below detection limits (Tables 3 and 4, Fig. 10). The excess alkalinity and large oxidation cell and wetland areas allow complete removal of major coal mining metal contaminants (Fe, Mn, and Al).

As anticipated the limestone VFP produces considerably more alkalinity than the dolomitic limestone cell (Tables 3 and 4, Fig. 11). The comparison of a dolomitic limestone-based VFP with comparable limestone cell as suggested by Maynard and Helton (2005) and Rimstidt and Huminicki (2006) cannot be completely evaluated at this time. Additional testing and evaluation including geochemical reaction modeling and trace metal analysis is planned for 2009.

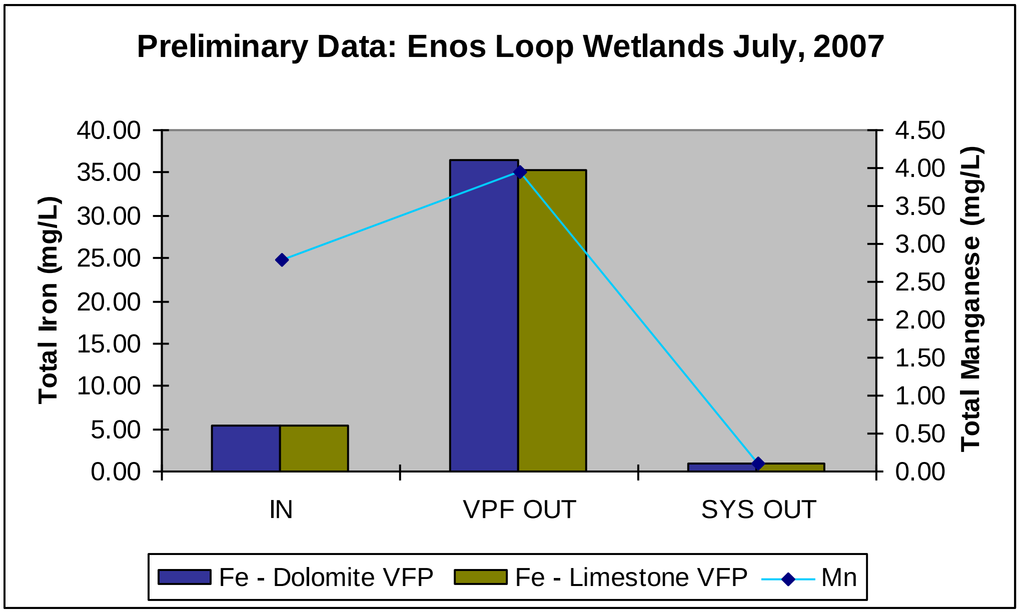


Figure 10 –Iron and Manganese levels within the Enos Loop Wetland.

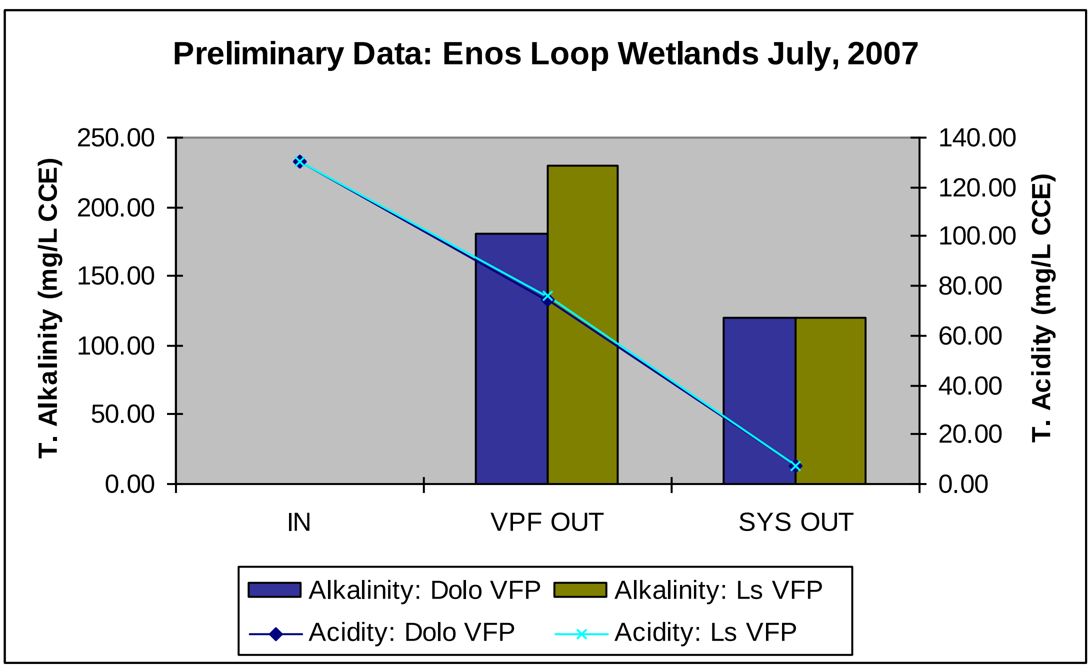


Figure 11 – Generation of Alkalinity and Corresponding Decrease in Acidity within the Enos loop Wetland.

Conclusions and Lessons Learned

Due to the extensive coal mining in the middle of the last century, the South Fork Patoka River was one of the most heavily polluted rivers in the State of Indiana. The Indiana Abandoned Mine Lands Program has spent the last twenty years reclaiming AML sites within Pike County and the South Fork Patoka River watershed. Cumulatively, these efforts have had a tremendous effect on water quality in the South Fork to the point now where it's not uncommon see fisherman on its banks. Typically, one of the goals of the AML Program is to improve water quality that has been adversely affected by past coal mining activities. The Enos Loop Wetlands AML (Site 898) and Enos East Wetlands (Site 979) are designed to "protect" water quality as apposed to "improve" water quality in the South Fork.

Lessons learned during the course of this project include the need to consider geochemistry of the mine drainage and incorporate this information in AMD remediation designs. IDOR and cooperating agencies expended considerable funds on the collection and analysis of baseline water data. This identified the availability of an alkaline dilution source, which is effectively being applied in this project. One problem encountered during construction was the lack of locally available compost. Since 2005, IDOR has negotiated agreements with local landfill authorities and municipalities to develop new sources based on yard waste and tree removal debris. These sources were successfully employed in more recent reclamation projects such as the large anaerobic bioreactor constructed at the Sunlight Mine project (Site 337) in 2007.

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