Office of Surface Mining
Mid-Continent Region Technology Transfer

Acid Mine Drainage Workshop

April 13 - 14, 2010
Evansville, Indiana

Hosted by the Indiana Department of Natural Resources
Division of Reclamation - Abandoned Mine Lands Program

OSM Mid-Continent Region Technology Transfer AMD Workshop

Tuesday, April 13, 2010

8:00 AM **Travel to Sugar Ridge Fish & Wildlife Area**

Classroom Presentations

9:00 AM **Welcome and Introductions**
Larry Lewis, Illinois AML Program

9:15 AM **Sugar Ridge F&WA and the AML Program**
Nate Levitte, Property Manager

9:30 AM **Sulfate-Reducing Bioreactors; History and Evolution**
Tracy Branam, Indiana Geological Survey

10:15 AM **Break**

10:30 AM **Bioreactor System Activity in Illinois – 2010+**
Larry Lewis, Illinois AML Program

11:15 AM **Passive Treatment of Acid Mine Drainage – The Enos Reclamation Project, Indiana: Preliminary Results1**
Paul Behum, Office of Surface Mining

12:00 PM **Lunch**

Afternoon Field Trips

12:30 PM **Leave for Enos Passive Treatment System**
Paul Behum, Office of Surface Mining, Tracy Branam, Indiana Geological Survey

2:00 PM **Leave for Log Creek Church Passive Treatment System**
Danny Hause, Craig Wolfe, Indiana AML Program

3:30 PM **Leave for Sunlight Sulfate Reducing Bioreactor**
Danny Hause, Craig Wolfe, Indiana AML Program

5:30 PM **Arrive at Hotel**

Evening Events

6:00 PM **Pizza Dinner**

7:00 PM **Guest Speaker – Establishing the Patoka River National Wildlife Refuge within the Heart of Indiana Coal Country**
Bill McCoy, Property Manager

8:00 PM **Hospitality Room**

OSM Mid-Continent Region Technology Transfer AMD Workshop

Wednesday, April 14, 2010

8:00 AM **Travel to Sugar Ridge Fish & Wildlife Area**

Classroom Presentations

9:00 AM **Evaluating the Outcomes of an Experiment Aimed at Treating an Acidic Spring by Redirecting Groundwater Flow through Alkaline Spoil**
Greg Olyphant, Indiana Geological Survey

9:45 AM **Mine No. 6 Acid Mine Drainage Treatment System**
Charles McCool, Arkansas AML Program

10:30 AM **Break**

10:45 AM **Hydrochemical Evaluation and Predictive Modeling of Sulfate Reducing Bioreactor Cells**
Tracy Branam, Indiana Geological Survey

11:30 AM **The Proposed Augusta Lake Restoration Project**
Danny Hause, Indiana AML Program

12:15 PM **Lunch**

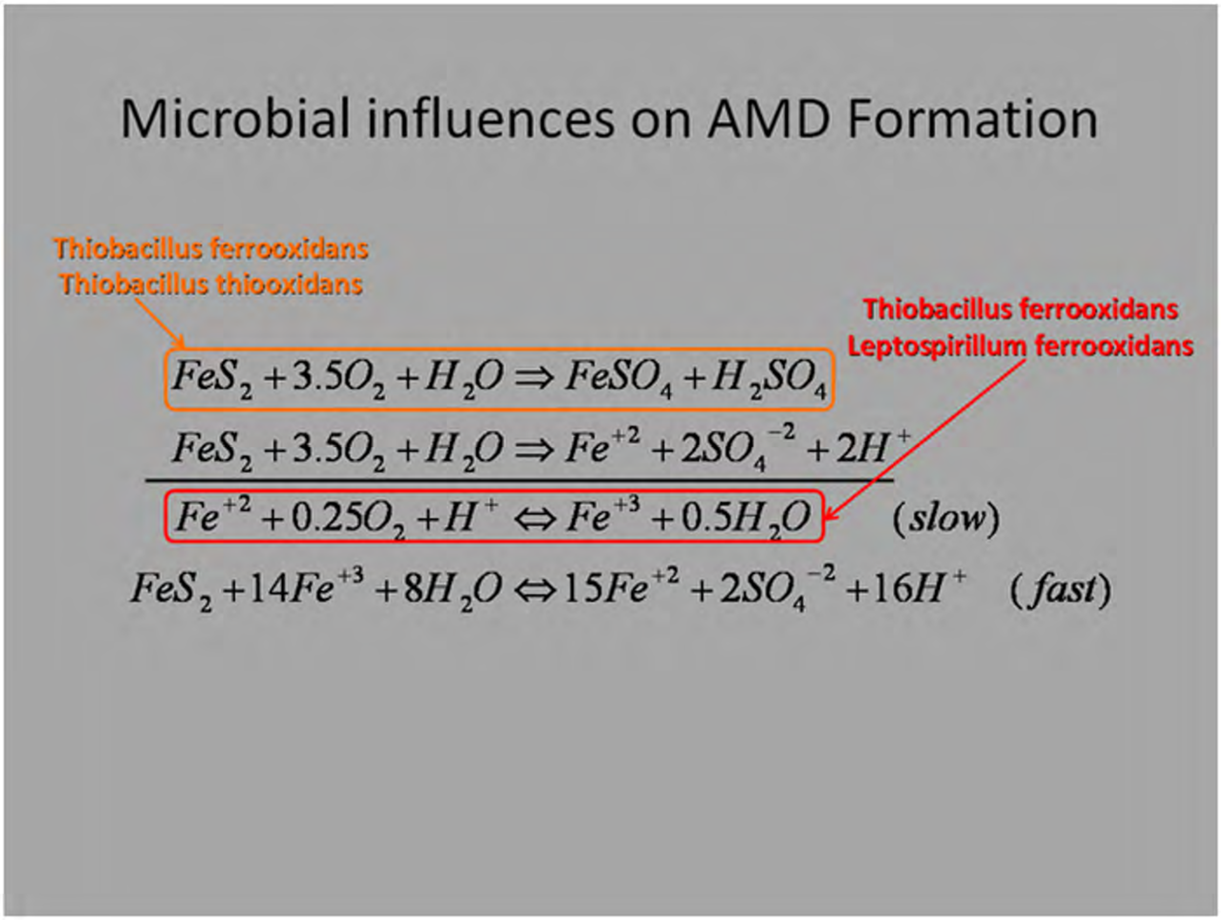
Afternoon Field Trips

12:45 PM **Leave for Proposed Fire Pit Passive Treatment System**
Danny Hause, Craig Wolfe, Indiana AML Program

2:00 PM **Leave for Proposed Augusta Lake Passive Treatment System**
Danny Hause, Craig Wolfe, Indiana AML Program

3:30 PM **Leave for Midwestern Passive Treatment System**
Tracy Branam, Indiana Geological Survey

5:30 PM **Arrive at Hotel**



Microbial influences on AMD Formation

Thiobacillus ferrooxidans
Thiobacillus thiooxidans

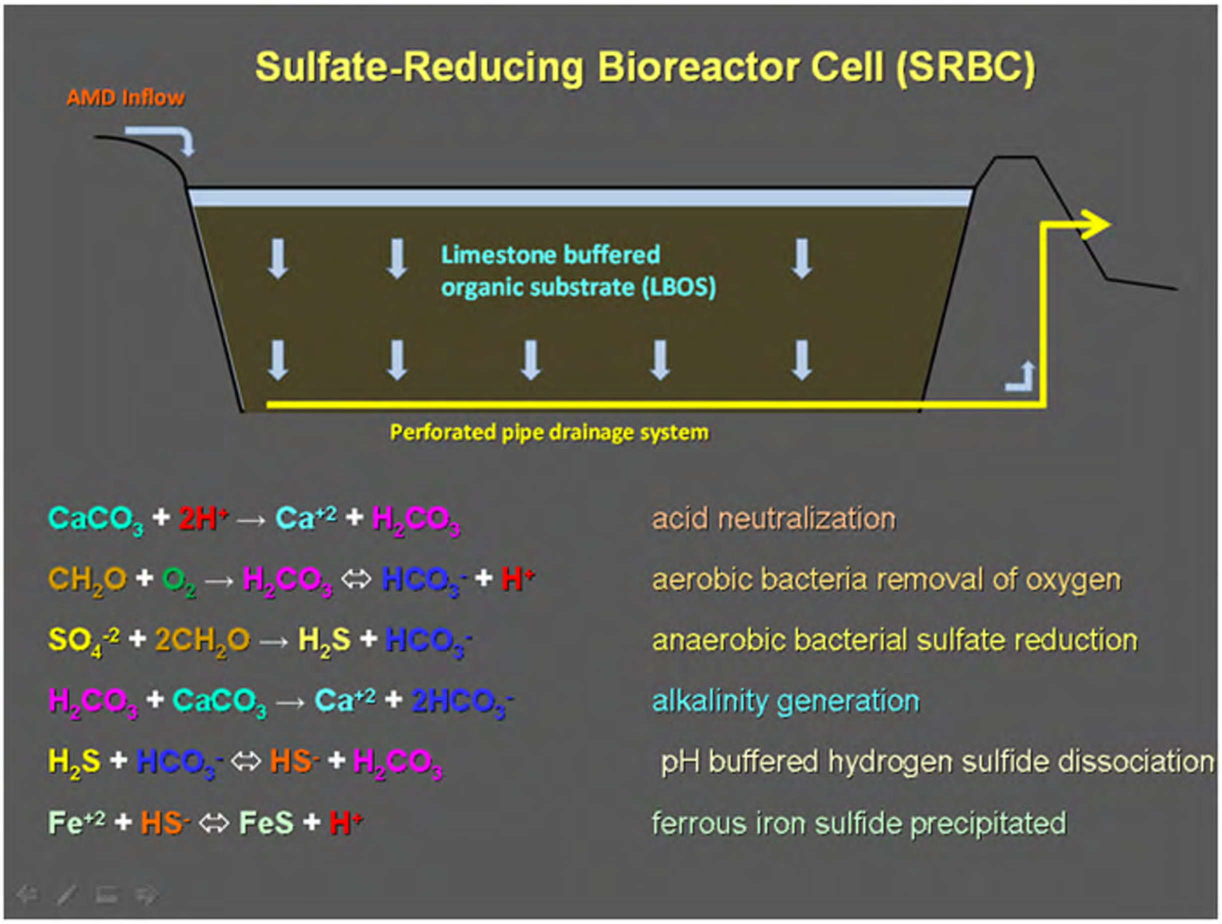
Thiobacillus ferrooxidans
Leptospirillum ferrooxidans

$$\boxed{FeS_2 + 3.5O_2 + H_2O \Rightarrow FeSO_4 + H_2SO_4}$$

$$FeS_2 + 3.5O_2 + H_2O \Rightarrow Fe^{+2} + 2SO_4^{-2} + 2H^+$$

$$\boxed{Fe^{+2} + 0.25O_2 + H^+ \Leftrightarrow Fe^{+3} + 0.5H_2O} \quad (slow)$$

$$FeS_2 + 14Fe^{+3} + 8H_2O \Leftrightarrow 15Fe^{+2} + 2SO_4^{-2} + 16H^+ \quad (fast)$$



Sulfate-Reducing Bioreactor Cell (SRBC)

$CaCO_3 + 2H^+ \rightarrow Ca^{+2} + H_2CO_3$	acid neutralization
$CH_2O + O_2 \rightarrow H_2CO_3 \Leftrightarrow HCO_3^- + H^+$	aerobic bacteria removal of oxygen
$SO_4^{-2} + 2CH_2O \rightarrow H_2S + HCO_3^-$	anaerobic bacterial sulfate reduction
$H_2CO_3 + CaCO_3 \rightarrow Ca^{+2} + 2HCO_3^-$	alkalinity generation
$H_2S + HCO_3^- \Leftrightarrow HS^- + H_2CO_3$	pH buffered hydrogen sulfide dissociation
$Fe^{+2} + HS^- \Leftrightarrow FeS + H^+$	ferrous iron sulfide precipitated

Nate Levitte

Property Manager for Sugar Ridge FWA

Nate is a Hoosier by transplant, as an original native of Michigan, he obtained a BS in Fisheries and Wildlife from Michigan State University. After spending some time with the Michigan DNR, Ducks Unlimited and the USFWA, Nate began his career with the Indiana DFW in 1994. He began with IDNR in the Indianapolis office as a wildlife planner, and later a wildlife staff specialist. In '97 he jumped the central office ship and accepted a position in the field as Assistant Manager at the Winamac FWA. A couple years later he transferred to the Jasper Pulaski FWA, and later on, in 2000, was promoted to his current position as the Property Manager at the Sugar Ridge FWA.

Tracy Branam

Research Scientist, Indiana Geological Survey

M.A. in Geology, 1991 & B.S. in Chemistry, 1979 – Indiana University. Employed as a Research Scientist in the Geochemistry Section of the Indiana Geological Survey since 1988; Research Assistant at Indiana University Department of Geological Sciences, 1984-1986; Senior Lab Technologist for Biodynamics/BMC, 1979-1981. President of Indiana Water Resource Association, 2003, and member of the Board of Directors, 2003-2006. Areas of research include acid-mine drainage formation and chemistry of treatment systems; coal combustion byproducts interaction with synthetic groundwater types; evolution of groundwater through water-rock interactions. Recent research grants were obtained from the United States Department of Interior Office of Surface Mining, Indiana Department of Natural Resources Division of Reclamation, United States Forestry Service to study the internal chemical reactions of sulfate-reducing bioreactors; and from Alcoa to study the leachate properties of coal ash interacting with different synthetic groundwater types.

Sulfate-Reducing Bioreactors: History and Evolution

Tracy Branam and Denver Harper, Indiana Geological Survey

Abstract

Bioreactors in general cover a variety of microbe-dependent methods of altering water chemistry. Sulfate-reducing bioreactors are increasingly being used to reduce sulfate and iron in surface discharges. The design of sulfate-reducing bioreactor cells (SRBCs) requires an understanding of the complex interaction of multiple microbial communities and the chemical alterations that they produce. The chemical and biogeochemical reactions involved in various passive treatment systems will be discussed, ranging from simple to more complex systems that were integral to the development of the SRBC. A conceptual model of how an SRBC works will be presented, together with a discussion of how such a model can be used in the design of SRBCs.

Hydrochemical Evaluation and Predictive Modeling of Sulfate Reducing Bioreactor Cells

Tracy Branam, Matt Reeder and Denver Harper, Indiana Geological Survey

Abstract

Sulfate-reducing bioreactor cells (SRBCs) are the latest generation of passive methods for treating acid mine drainage (AMD). As with all passive treatment systems, it is desirable but difficult to predict the size and composition of an SRBC that is needed to treat a specific AMD discharge for a targeted time interval. The difficulty of predicting performance and longevity of an SRBC is related to the complexity of its internal biogeochemical reactions. Characterizing the internal reactions that occur inside an SRBC and understanding their temporal and spatial relationships require more detailed monitoring and analyses than for most other types of passive treatment systems. At a recently installed SRBC in Pike County, Indiana, a three-dimensional array of internal sampling ports was included in the design. The presentation will provide an introduction to the site, discuss the SRBC's construction, and describe the design of the sampling ports. Problems associated with the SRBC's design and the collection of analytical data will be addressed. Preliminary data from one year of monitoring will be examined and discussed, and chemical trends will be described that may have a bearing on the development of predictive models.

Larry L. Lewis, P.E.

Supervisor of Engineering and Technical Support,
Illinois Department of Natural Resources - AMLR Division of the Office of Mines and Minerals
Received B.S. in Mining Engineering at University of Missouri at Rolla in 1973.
Became a Registered Professional Engineer in 1980.
Worked in the coal mining industry for 12 years.
Current position: Supervisor of Engineering and Technical Support for Abandoned Mined Land Reclamation Division of the Illinois Dept. of Natural Resources. Been part of the Illinois AML program since 1986.

Abstract

The Illinois Abandoned Mined Lands Reclamation Division (IAMLRD) completed its first Anerobic Bioreactor System at the Tab Simco site, located in Jackson County, Illinois, in December of 2007. The system was designed to collect and treat acid mine drainage (AMD) flowing out of underground mine works at a flow rate of approximately 30 gallons per minute before it enters Sycamore Creek. Since its completion, the system has functioned consistently overall and significantly improved the quality of water leaving the site. Since the Anerobic Bioreactor System at Tab Simco has proven so successful, an additional system is being considered not only for this site but for two other sites as well. The two other sites include the Palzo Mine, located in Williamson County, Illinois and the Florida Little Dog Mine site, in Macoupin County, Illinois. This presentation provides information and technical data to report how the existing bioreactor system at Tab Simco has performed since its completion and some preliminary information, data, and design concepts related to the development of bioreactor system applications for the other sites during 2010 and beyond.This presentation provides information and technical data to report how the existing bioreactor system at Tab Simco has performed since its completion and some preliminary information, data, and design concepts related to the development of bioreactor system applications for the other sites during 2010 and beyond.

Paul T. Behum
Sr. Hydrologist, OSM Reclamation and Enforcement, Mid Continent Region, Alton, Illinois
Previously served as a Geologist and Physical Scientist with OSM and the U.S. Bureau of Mines in Pittsburgh, Pennsylvania.
Paul also is a student in the Environmental Resources and Policy PhD Program at Southern Illinois University of where he is conducting research on acid mine drainage prevention and abatement.
Has a Bachelors and Masters Degrees in Geology from the University of Pittsburgh.

Passive Treatment of Acid Mine Drainage – The Enos Reclamation Project, Indiana: Preliminary Results

Paul T. Behum, Dan R. Hause, Mark A. Stacy and Tracy D. Branam

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 or 670 to 900 GPM). 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 mg/L) and total acidity (120 mg/L). However, the designers were required to consider the impact of a significant amount of aluminum (3.3 mg/L) on the life expectancy of the VFP. Post-construction evaluations are being assisted by the Indiana Geological Survey (IGS). Initial investigations indicated nearly complete iron removal by the system (total iron = 0.28 mg/L) and a net alkaline discharge (alkalinity exceeds acidity by about 56 mg/L). Although no specific structures were incorporated in the design for manganese removal, 60% of the manganese is also being removed by the wetland system (2.8 mg/L in the VFP inlet, 1.1 mg/L at the system outlet). Additional studies will evaluated 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. Both vertical flow ponds began to fail in 2008 following a large increase in metal loading and were reconstructed in the summer of 2009. This study presents an evaluation of the failure conditions and preliminary results of the reconstruction.

Greg Olyphant
Professor of Geological Sciences at Indiana University, Bloomington since 1984. He is also Principal Researcher in of the Center for Geospatial Data Analysis and a Research Affiliate of the Indiana Geological Survey. Dr Olyphant has been researching AML related problems since the mid-1990's and was the Founding Chair of the Hydrology Division of the American Society of Mining and Reclamation. Olyphant has published several papers related to aspects of the hydrology, geochemistry, and geomorphic stability of AML sites in southwestern Indiana.

Evaluating the Outcomes of an Experiment Aimed at Treating an Acidic Spring by Redirecting Groundwater Flow through Alkaline Spoil

Abstract

Personnel of the Indiana Department of Natural Resources, Division of Reclamation, designed and implemented an experiment to redirect the discharge of groundwater from a chronic spring towards an area of alkaline spoil in an effort to passively treat the water prior to its surface discharge at a new location. A dam was built to raise the water level at the original spring to an elevation above the new discharge location. Pressure transducers were installed in wells that intersect the ground water pool, and flumes were emplaced to facilitate measurements of discharge at the new discharge location, as well as another known area of acid water seepage. The main acid seep was already dammed when personnel of the Indiana Geological Survey commenced their investigations, and water was discharging through the flume at the new discharge location. When the dam was temporarily removed at the acid seep, the discharge at the new location ceased. When the dam was re-installed the flow at the new discharge location returned, verifying the hydrologic connection between the original spring and the new discharge location. Water quality within the groundwater pool has improved substantially since the beginning of the experiment, with sulfate concentrations declining by as much as 50 percent at some locations. Groundwater flow modeling is being conducted in an effort to better identify the flow paths of groundwater in the area of concern.

Charles McCool, PE
Arkansas Dept. of Environmental Quality

Education: Masters Degree in Agricultural Engineering, Univ. of Arkansas, 1985. Charles began his career as a field engineer for Riceland Foods, Inc. (Fortune 500 Co.) prior to beginning work for ADEQ in 1988 in the Water Division. He transferred to the Mining Division in 1991 to work in the AML program and became the Engineer Supervisor for the Division in 2006, overseeing Title IV and V engineering efforts. His AML work has included project design, contract development, construction inspection and inter-agency project coordination. A part-time farmer, whenever possible he enjoys riding his Harley, dual-sport motorcycle, or four-wheeler.

Mine No. 6 Acid Mine Drainage Treatment System

Abstract

Abandoned in the late 1920's, the Central Coal and Coke Mine No. 6's surface features included two shafts, a hoisting shaft and an artesian flowing air shaft. The air shaft was intact with only minor damage to the surface and the shaft lining, as documented by a borehole camera. The shaft originally was approximately 285 feet deep with the camera venturing to a depth of 255 feet before encountering the apex of a cone of debris. Water quality was typified by suppressed pH, net acid water with elevated iron content. Discharge of an average 125 GPM from the shaft ultimately reached the James Fork, resulting in a negative impact to the stream. The Mid-Continent office of OSM provided technical assistance to the Arkansas program in water sampling and the initial system design. Through the cooperation of the State and OSM, the design was modified to accommodate the location's limiting parameters and a contract was let for system construction in August, 2008. Using the air shaft as a vertical anoxic limestone drain, a series of three cells, one oxidation pond followed by one vertical flow pond and a final oxidation pond, were constructed to complete treatment.

During the first month of operation, heavy rains temporarily increased the flow to an estimated 2,000 GPM without system damage. As the system stabilized, it was determined that the vertical flow pond was anoxic in the lower elevations as the discharge measured near zero dissolved oxygen and hydrogen sulfide gas was significant. The sizing of the final oxidation pond was not intended to address an anoxic inflow. Therefore, the system has been modified to include a solar aeration system in the discharge from the vertical flow pond. Also, the vertical anoxic limestone drain (shaft) discharge piping was also modified to improve aeration for iron conversion in the first oxidation pond. Evaluation of the modifications is currently underway.

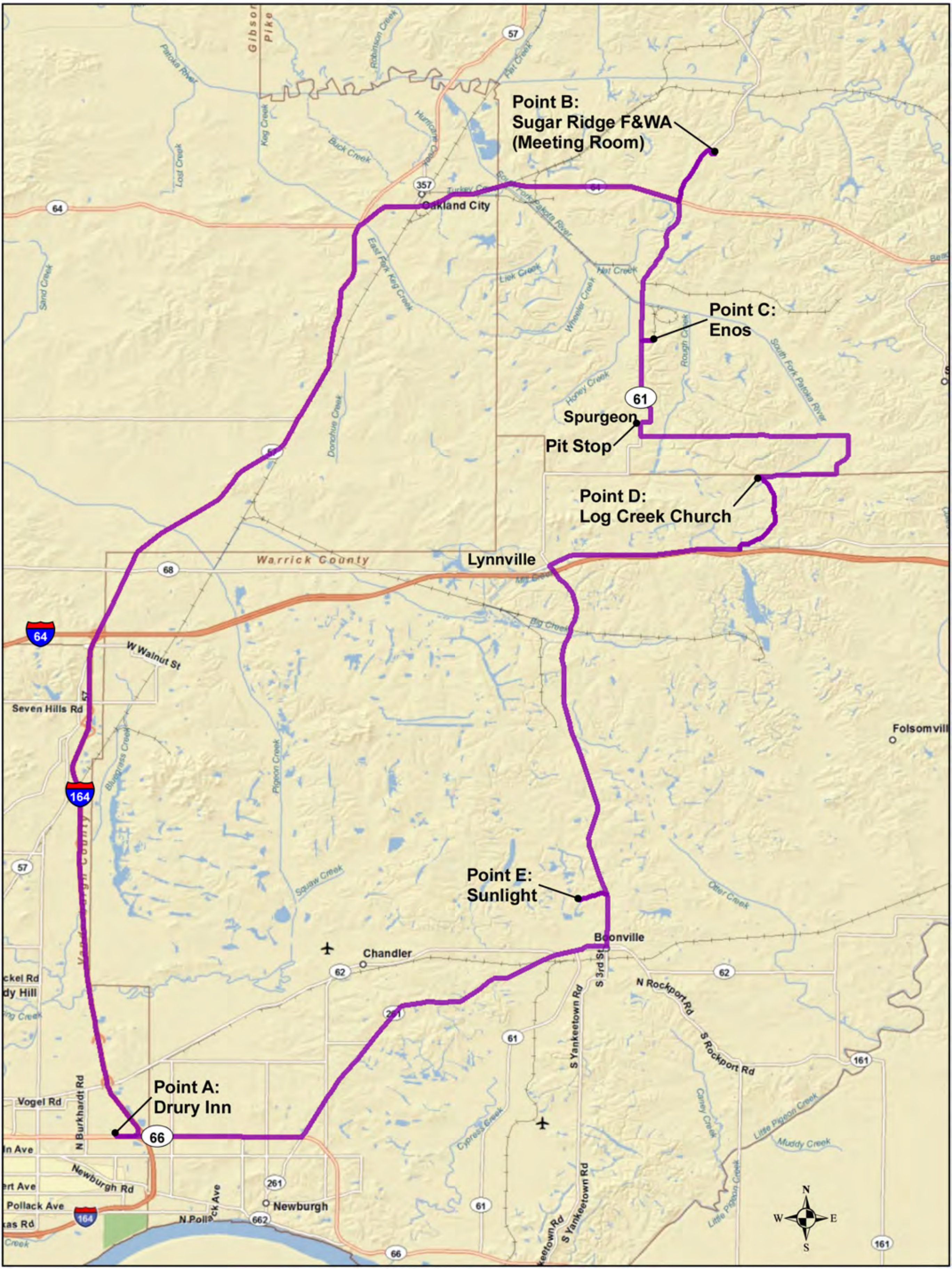
Dan Hause, PE
Chief Engineer, Division of Reclamation, IDNR

Mining Engineer with the State of Indiana for the previous 16 years doing reclamation design including Sulfate Reducing Bioreactors, geomorphic design (Squiggly Ditch) and instructing for OSM specializing in AutoCAD and Carlson. Spent 20 years as a mining engineer and Project Manager for AMAX, and Bethlehem Mines Corp holding various positions and working on mine design, ventilation, mine rescue and construction of four surface and underground coal mines in West Virginia and Kentucky.

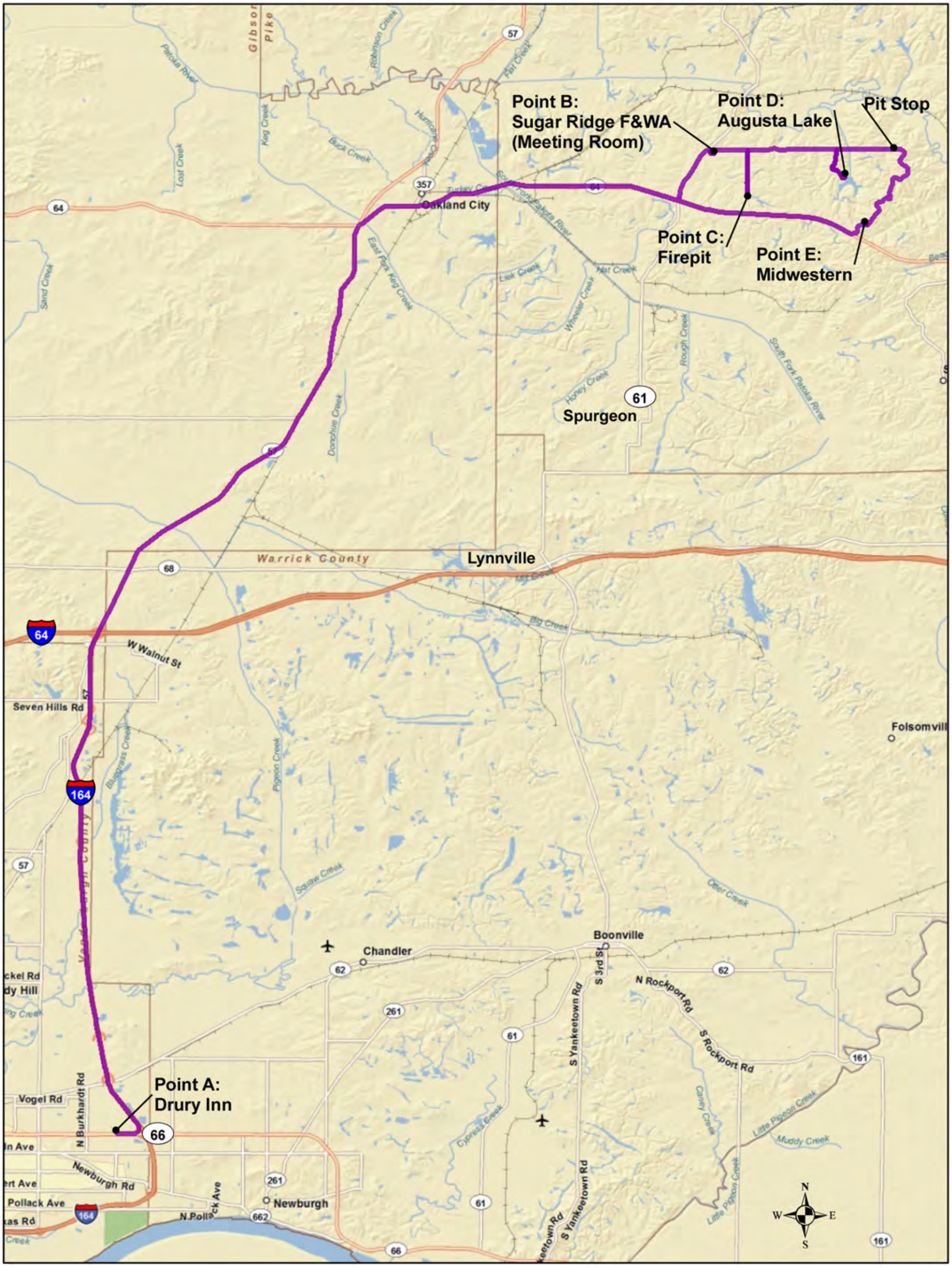
Abstract

A brief history of Augusta Lake, why it was created. An overview of the existing chemistries and our proposed bioreactor and wetland to treat approx 50% of the AMD coming into the lake.

Field Trip Route - DAY 1



Field Trip Route - DAY 2



Indiana AML Site 898 (Enos)

Mining History:

- Operated by Enos Coal Company and was surface mined from 1939-1947.
- Mining occurred approximately 45-50 feet below ground surface (Springfield Coal Member).
- Currently reprocessing coal fines from the coal refuse pile as a no-cost AML project.

AML Features Created by Historic Coal Mining:

- Approximately 200 acres of gob and coal fines.
- The exposed coal refuse generated massive amounts of AMD but was being utilized by an adjacent active tipple operation as wash water. No AMD ever left the site.
- As the active tipple operation was about to shut down, all the AMD *would have* been allowed to flow directly into the South Fork Patoka River.

Reclamation Project Costs:

- Original reclamation conducted in 2005; total reclamation cost → **$964,769**
- Maintenance of passive treatment wetland conducted in 2009 → **$595,039**

Reclamation Conducted:

- 2005 - Constructed passive treatment system including two parallel Vertical Flow Ponds.
- 2009 - Rebuilt Vertical Flow Ponds as Sulfate Reducing Bioreactors.

Reclamation Project Benefits:

- A major contributor of pollution to the South Fork Patoka River was averted with original project.
- Sulfate Reducing Bioreactors returned water quality to excellent condition after complete failure of Vertical Flow Ponds.

Water Quality Data:

	pH	Acidity	Alkalinity	AL	Fe	Mn	$S0_4$
Treatment System Inflow:	**2.79**	**660**	**BDL**	**14.17**	**189**	**4.59**	**2457**
	pH	Acidity	Alkalinity	AL	Fe	Mn	S04
Treatment System Outflow:	**7.13**	**BDL**	**105**	**0.06**	**BDL**	**1.57**	**1910**

Enos Passive Treatment System Pre-Reclamation

Enos Passive Treatment System Post-Reclamation

Indiana AML Sites 900 & 2040 (Log Creek Church)

Mining History:

- Area was extensively surface mined from 1921 – 1966.
- Mining occurred approximately 50 feet below ground surface (Springfield Coal Member).
- A small plot of ground containing the Log Creek Church and Cemetery was left undisturbed.

AML Features Created by Historic Coal Mining:

- Two linear highwalls immediately adjacent to the north and south of Log Creek Church Road (Country Road 1300). The Northern Highwall was 1,900 feet in length and the Southern Highwall was 2,100 feet in length.
- Both sections of highwall had near vertical slopes 70 feet in height.
- Approximately 70 acres of gob and 17.5 acres of highly acidic water filled impoundments.

Reclamation Project Costs:

- Site 900 - Southern Highwall (2006) Project Cost → **$1.5 million**
- Site 2040 - Northern Highwall (2007) Project Cost → **$ 579,299**

Reclamation Conducted:

- Site 900 - Northern Highwall → Backfilled highwall & installation of passive treatment wetland
- Site 2040 - Southern Highwall → Backfilled highwall using geomorphic land reclamation techniques

Reclamation Project Benefits:

- Approximately 4,000 feet of highwall backfilled and 11 million gallons of acid water treated.
- High profile project. State Fish & Wildlife Area visitors can gain a great sense of the Indiana AML program's mission.
- Improved water quality within the headwaters of the South Fork Patoka River.

Water Quality Data:

	pH	Acidity	Alkalinity	AL	Fe	Mn	$S0_4$
Pre-Reclamation Data:	**2.96**	**190**	**9**	**12**	**30.8**	**6.81**	**1050**
	pH	Acidity	Alkalinity	AL	Fe	Mn	S04
Post-Reclamation Data:	**7.18**	**0**	**88**	**0.31**	**2.61**	**1.51**	**2019**

Log Creek Church Squiggly Ditch

Log Creek Church Passive Treatment System

Indiana AML Site 337 (Sunlight)

Mining History:

- Operated by Sunlight Mining and was surface mined from 1934-1950.
- Mining occurred approximately 50 feet below ground surface (Springfield Coal Member).

AML Features Created by Historic Coal Mining:

- A large 94 acre gob pile and 102 acre coal slurry area were left uncovered and exposed to the surrounding environment.
- The exposed coal refuse began to generate massive amounts of AMD, which adversely impacted nearby Cypress Creek.
- A former coal processing plant and other abandoned structures were left behind as well.

Reclamation Project Costs:

- Original reclamation conducted in 1986 → **$3,376,306**
- Construction of Sulfate Reducing Bioreactor completed in 2007 → **$ 600,952**

Reclamation Conducted:

- 1986 – Gob pile and slurry graded and covered with 3.5 ft. of cover material; AMD was treated using sodium hydroxide.
- 1999 – Installed seep drains at the toe of gob pile to capture AMD; drains contained alkaline ash.
- 2007 –Constructed large Sulfate Reducing Bioreactor to treat remaining AMD.

Reclamation Project Benefits:

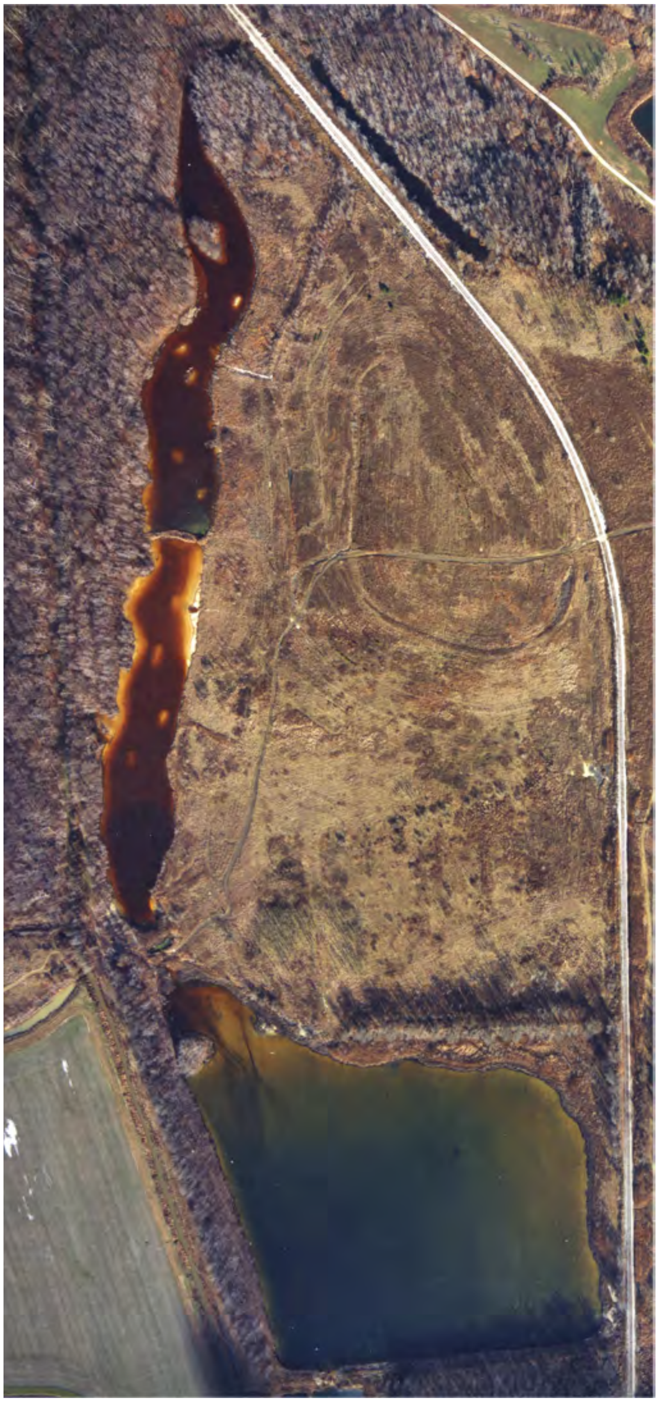
- Roughly 200 acres of gob and slurry has been buried, reducing acid generation.
- Improved water quality within Cypress Creek.
- IDoR's first successful use of large scale bioreactor technology!

Water Quality Data:

	pH	Acidity	Alkalinity	AL	Fe	Mn	$S0_4$
Pre-Reclamation Data:	**2.75**	**1209**	**20**	**17.1**	**499.4**	**9.3**	**2722**
	pH	Acidity	Alkalinity	AL	Fe	Mn	S04
Post-Reclamation Data:	**7.35**	**0**	**184**	**0.2**	**1.8**	**6.1**	**938**

Sunlight Sulfate Reducing Bioreactor

Pre-Reclamation



Post-Reclamation

Indiana AML Site 2084 (Fire Pit)

Mining History:

- Area was surface mined from 1926-1945.
- Mining occurred approximately 40 feet below ground surface (Springfield Coal Member).
- Mined by Ayrshire Collieries Corp.

AML Features Created by Historic Coal Mining:

- 8.5 acres of acidic impoundments
- 1000 linear feet of dangerous highwall
- 10 acres of spoils

Reclamation Project Costs:

- Estimated reclamation costs→ **$ 1.26 million**

Reclamation Activities Planned For Site:

- Backfill and stabilize highwalls.
- Construct Sulfate Reducing Bioreactors to treat acid mine drainage.

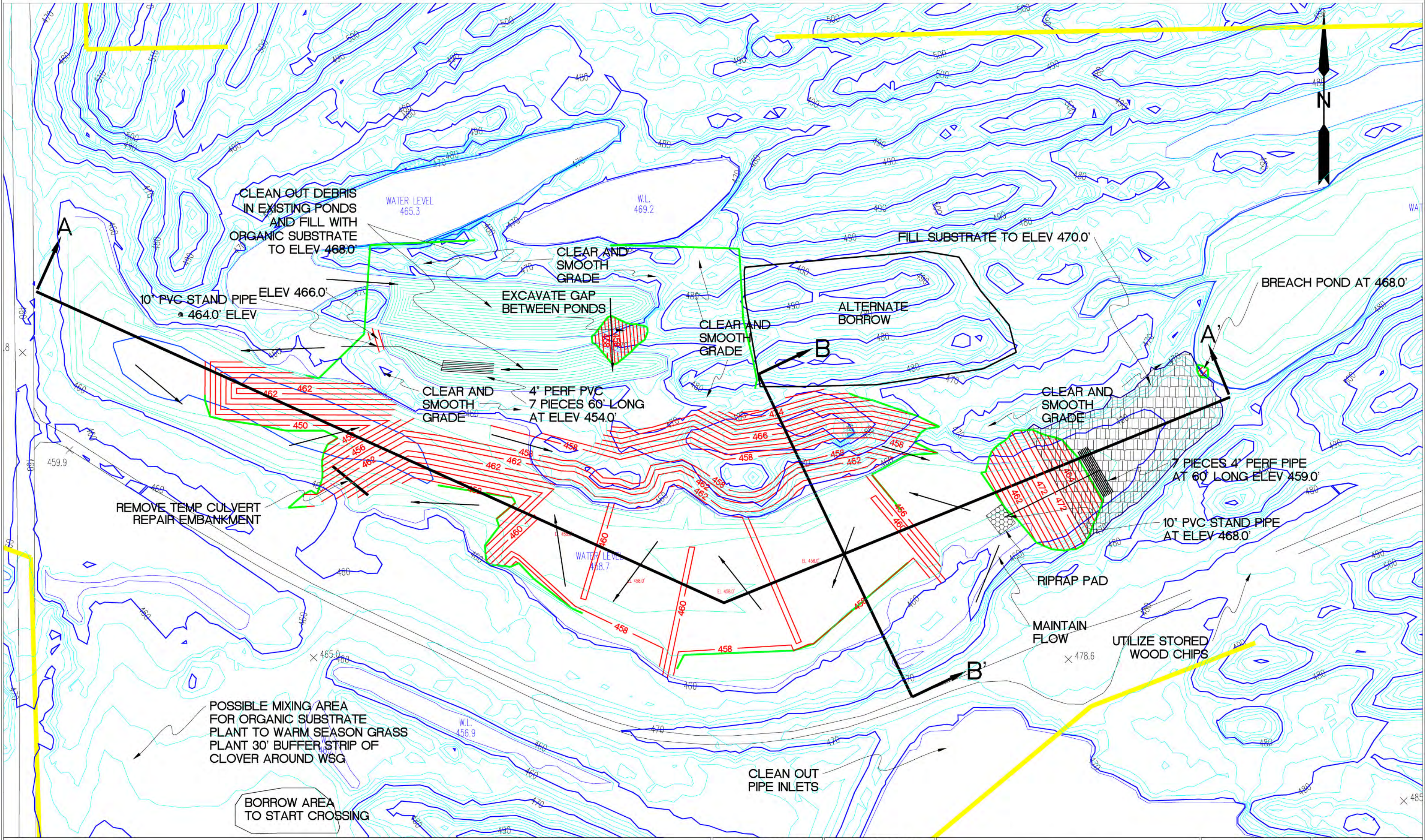
Benefits To Be Realized From The Project:

- Safety hazards associated with dangerous highwalls will be eliminated.
- Enhanced drainage within project area.
- Use of Sulfate Reducing Bioreactors to provide long term treatment of acid mine drainage.
- Overall improvement of water discharging off-site.

Water Quality Data:

	pH	Acidity	Alkalinity	AL	Fe	Mn	$S0_4$
Pre-Reclamation Data:	**3.34**	**135**	**< 1**	**13.56**	**20.91**	**21.71**	**1574**

Proposed Fire Pit Passive Treatment System



DATE MADE 07/08/2009	DESIGNED BY DRHause	FIREPIT - PLAN VIEW	SCALE 1"=50'	SHEET 3 OF 8
DATE REVISED 3/17/2010 10:37:42 AM	DRAWN BY DRHause	STATE OF INDIANA DEPARTMENT OF NATURAL RESOURCES DIVISION OF RECLAMATION	PROJECT E008-142	SITE 2084

Indiana AML Site 309 (Augusta Lake)

Mining History:

- Area was surface mined from 1939-1953.
- Mining occurred approximately 40-50 ft. below ground surface (Springfield Coal Member).
- Mined by Ayrshire Collieries Corp.

AML Features Created by Historic Coal Mining:

- A 45 acre impoundment was created to capture AMD during the active mining process.

Reclamation Project Costs:

- Estimated reclamation costs→ **$1.5 million**

Reclamation Activities Planned For Site:

- Eliminate 6.8 acres of open deep water from acidic Augusta Lake by filling 210,000 cubic yards of material in the east arm of the lake.
- Create 3 acres of Sulfate Reducing Bioreactor.
- Create 20 acres of treatment wetlands as a polishing area for the Bioreactor.
- Create 9 acres of upland habitat in the re-graded spoils.

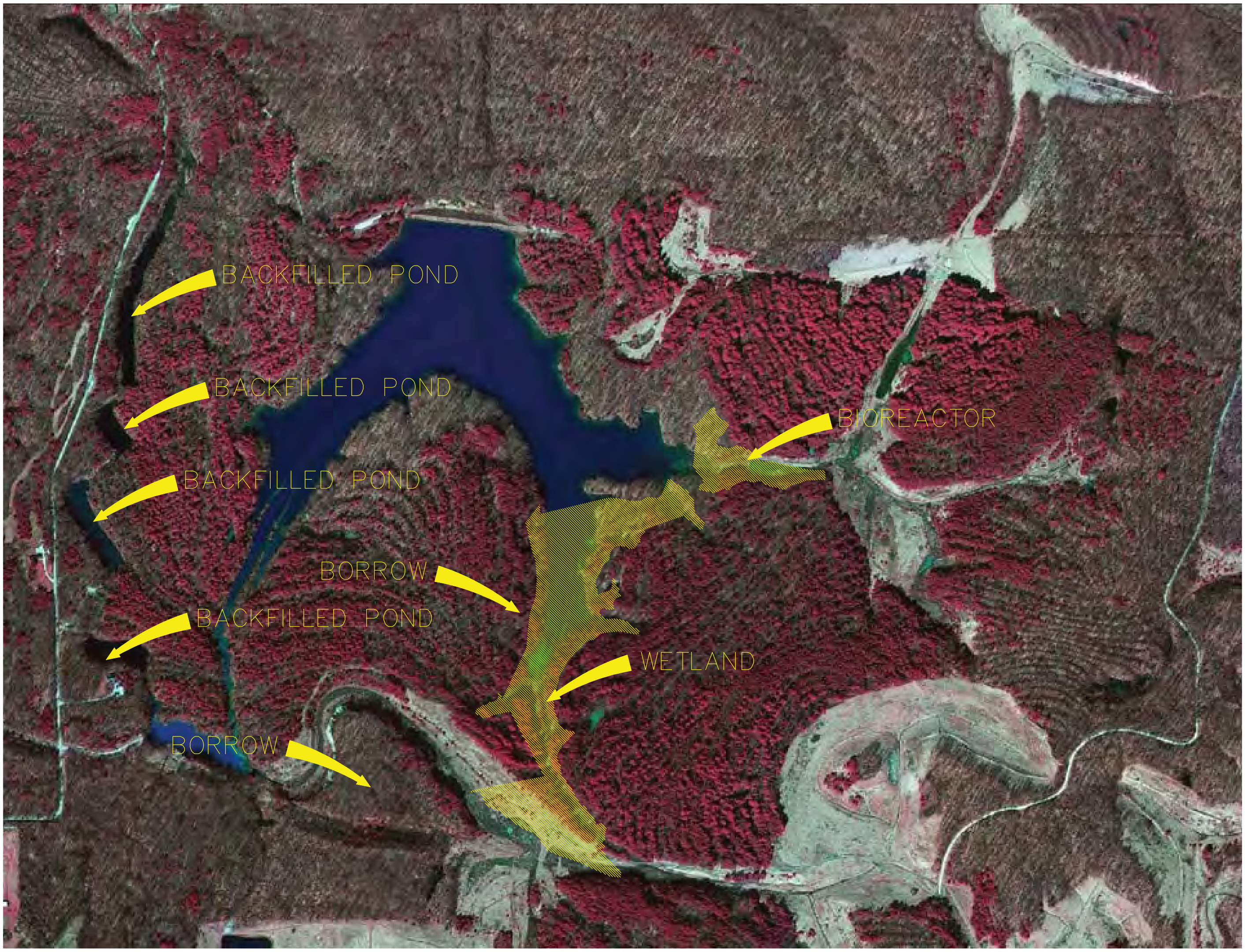
Benefits To Be Realized From The Project:

- Improved water quality of a large acidic impoundment on a State Fish & Wildlife Area will have multiple benefits for both the public and environment.

Water Quality Data:

	pH	Acidity	Alkalinity	AL	Fe	Mn	$S0_4$
Augusta Lake Inflow:	**3.33**	**223**	**<5.0**	**7.34**	**26.6**	**21.3**	**574**
Augusta Lake Outflow:	**4.1**	**55.4**	**<5.0**	**3.21**	**<0.060**	**7.32**	**959**

Augusta Lake Proposed Passive Treatment System



Indiana AML Site 1087 (Midwestern)

Mining History:

- Operated by Paul Shelton, Parke Coal, Regal Energies, Thoroughbred Energy, and Midwestern Mining from 1978-1983.
- Mining occurred approximately 40 feet below ground surface (Springfield Coal Member).
- Lost surety project site.

AML Features Created by Historic Coal Mining:

- 247 acres of acidic spoil and 13 acres coal refuse created multiple acid seeps
- 30 acres of acidic impoundments
- 4380 linear feet of highwall

Reclamation Project Costs:

- Original project completed in 1996; total construction cost→ **$ 3.9 million**
- Construction of Sulfate Reducing Bioreactor completed in 2008 → **$ 351,583**

Reclamation Conducted:

- Multiple highwalls backfilled.
- Exposed coal refuse and barren mine spoil covered, graded, and revegetated.
- Construction of Sulfate Reducing Bioreactor to treat remaining acid mine drainage.

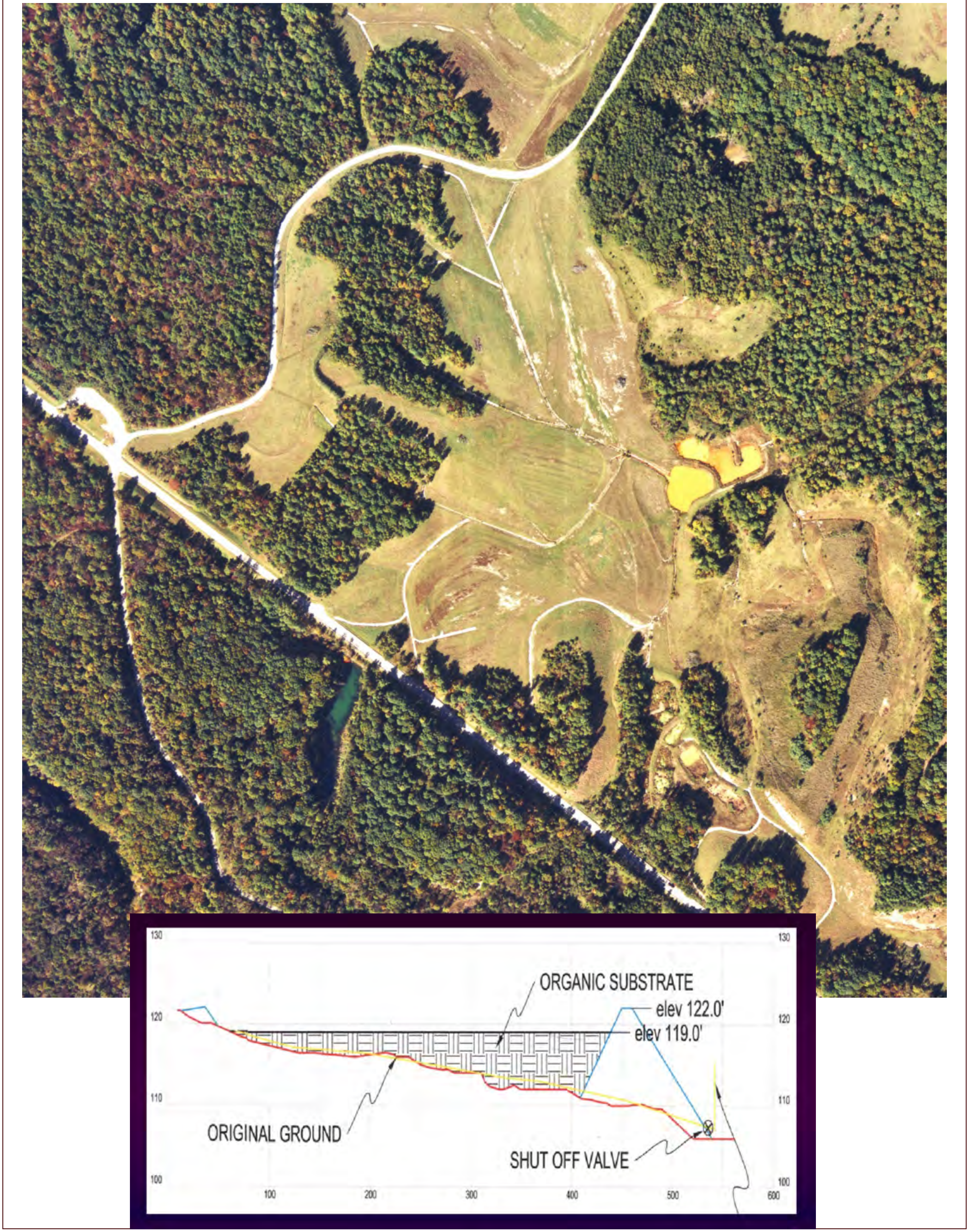
Reclamation Project Benefits:

- Health and safety issues presented by highwalls eliminated.
- Barren areas stabilized by establishing a permanent vegetative cover.
- Improved water quality and reduction of off-site acid mine drainage.

Water Quality Data:

	pH	Acidity	Alkalinity	AL	Fe	Mn	$S0_4$
Passive System Inflow:	**2.97**	**450**	**BDL**	**8.7**	**118.8**	**14**	**1843**
	pH	Acidity	Alkalinity	AL	Fe	Mn	S04
Passive System Outflow:	**6.33**	**75**	**50**	**2.11**	**3.82**	**5.6**	**776.6**

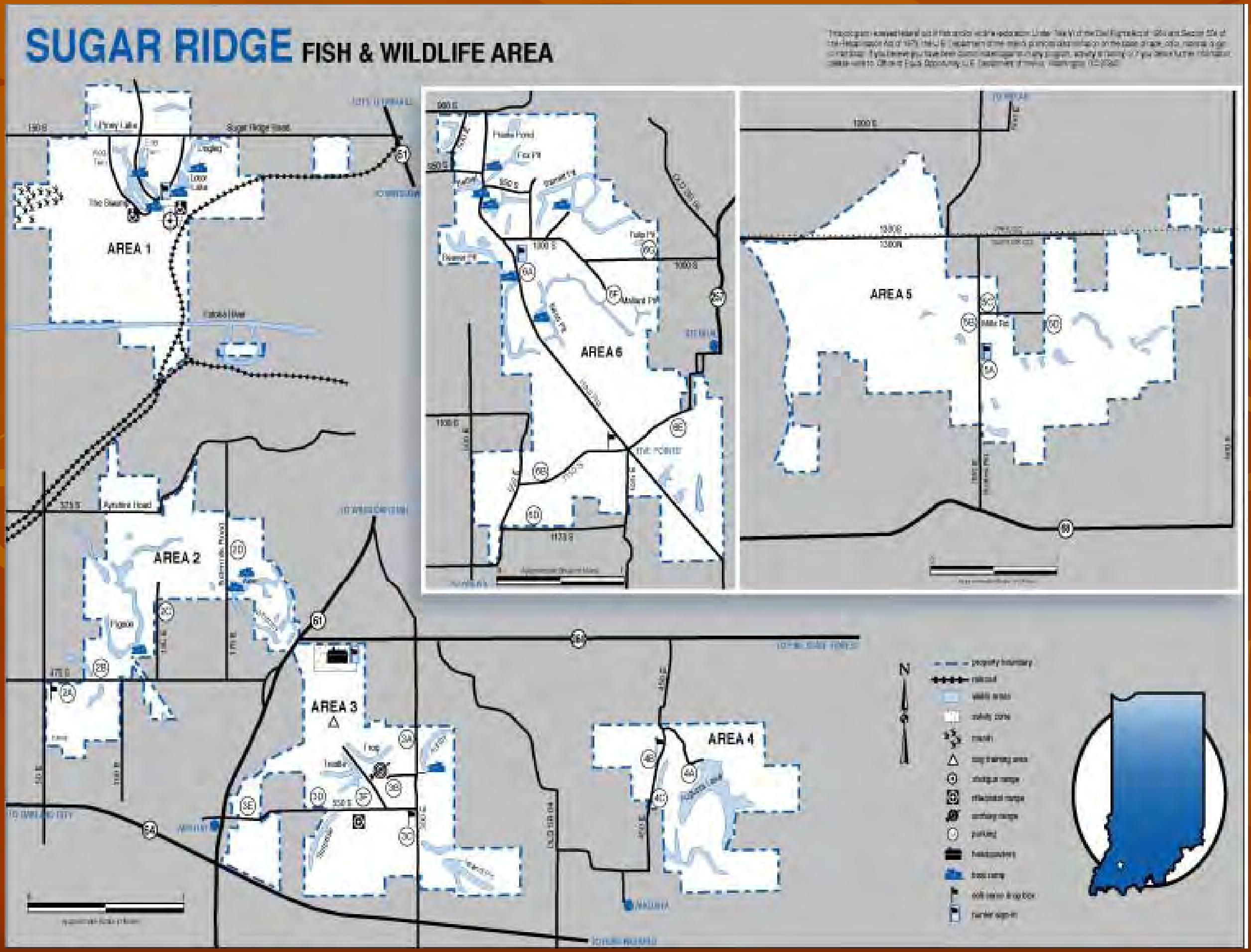
Midwestern Passive Treatment System



AML And The Sugar Ridge Fish & Wildlife Area

What we are

- 8145 acres in 6 different areas



Approximately 60% of SRFWA was previously strip-mined for coal

Approximately 100 pits/lakes

Primarily woodland habitats

What we do

DFW Mission:

"Our mission is to professionally manage Indiana's fish and wildlife for present and future generations, balancing ecological, recreational, and economic benefits."

And on FWAs…

FWAs are primarily managed to provide quality hunting, fishing, trapping, and recreational shooting opportunities.

Who we work for

Hunters, anglers, trappers and shooters

Challenges of managing AML

- Hazardous
- Soil Quality
- Water Quality
- Inaccessibility

Benefits of managing AML

- High quality refuge habitat
- Inexpensive land acquisition
- Habitat improvements can be done on a very large scale through reclamation

“You can make more high quality wildlife habitat in one reclamation project than most biologists can create in a career” – *John Wade Sugar Ridge FWA Property Manager (retired)*

Sulfate-Reducing Bioreactors: History and Evolution

Tracy Branam and Denver Harper

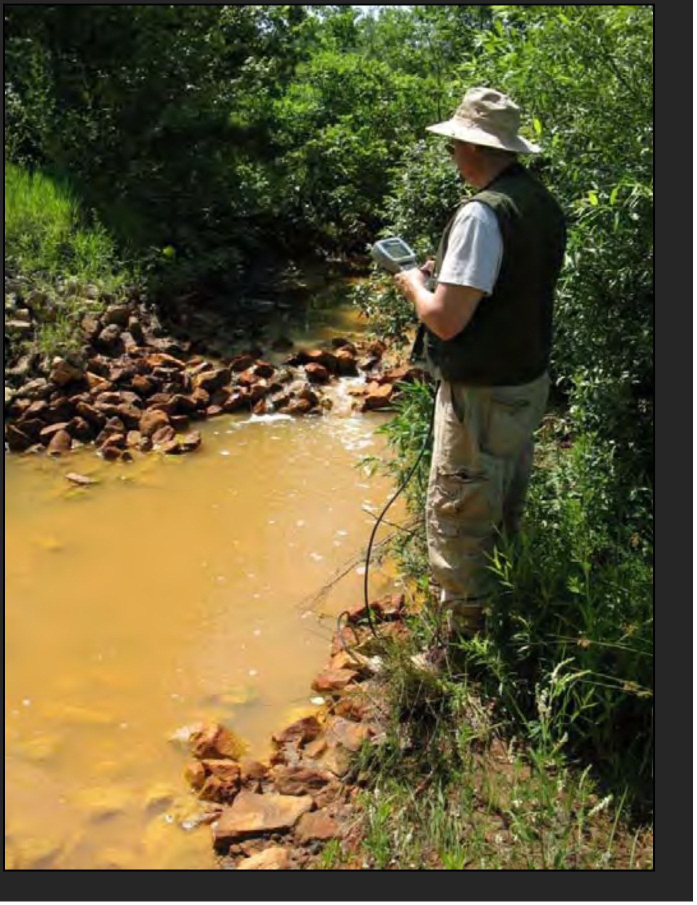
Indiana Geological Survey 1837
Indiana University

Sources of AMD

Drainage from flooded underground mines

Sources of AMD

Drainage from deposits of coal-preparation refuse



Sources of AMD

Mineral phases

- Sulfides (Pyrite/Marcasite)
- Aluminosilicates (Illite)
- Carbonates (Calcite)
- Hydroxides and Oxides (iron and aluminum)
- Sulfates (iron, aluminum and calcium)

Trace metals

Mn, Zn, Ni, Pb, Cu, Cr, Cd, Hg, As, Se, etc.

Microbial influences on AMD Formation

Thiobacillus ferrooxidans
Thiobacillus thiooxidans

$$\boxed{FeS_2 + 3.5O_2 + H_2O \Rightarrow FeSO_4 + H_2SO_4}$$

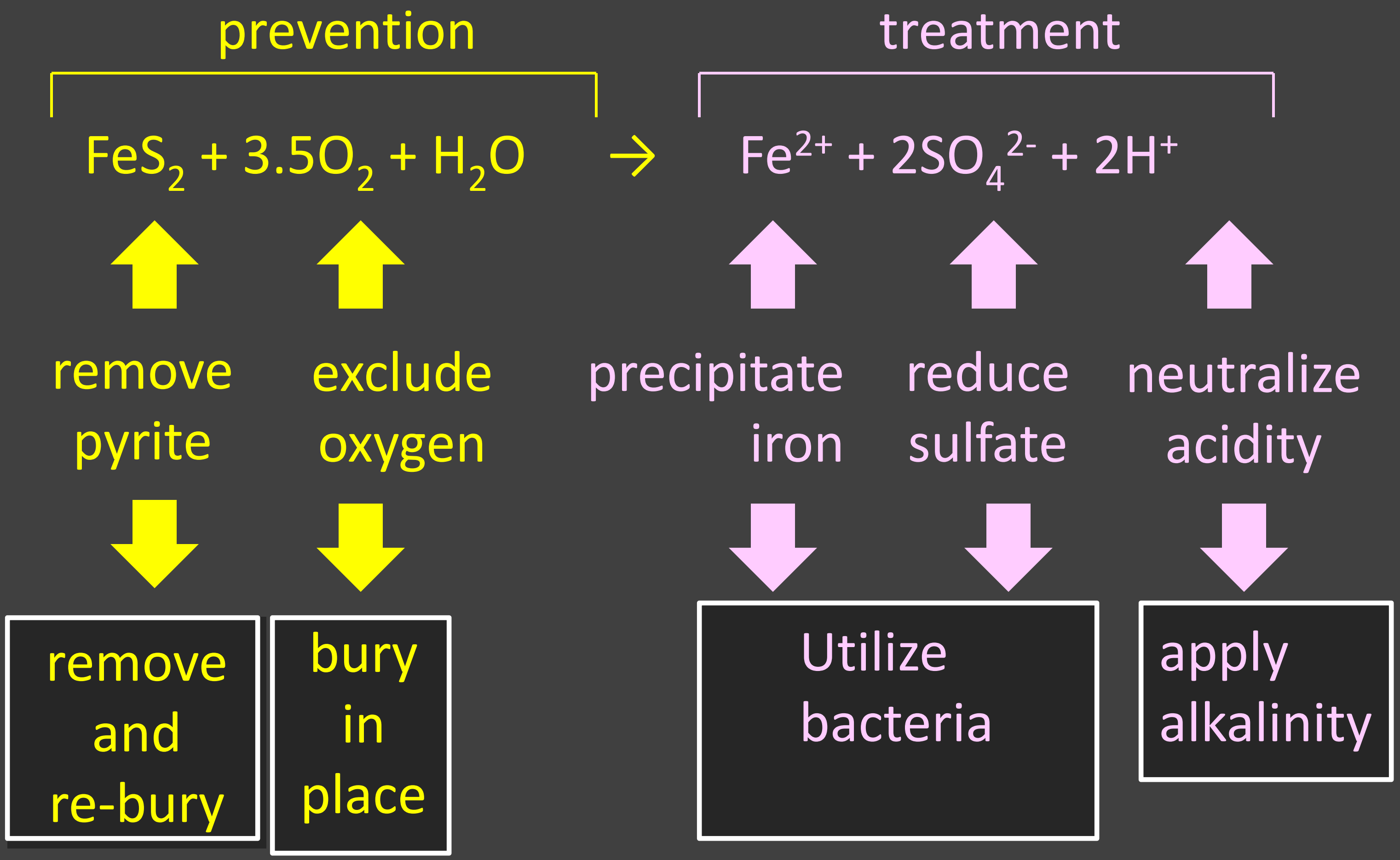
Thiobacillus ferrooxidans
Leptospirillum ferrooxidans

$$\underline{FeS_2 + 3.5O_2 + H_2O \Rightarrow Fe^{+2} + 2SO_4{}^{-2} + 2H^+}$$

$$\boxed{Fe^{+2} + 0.25O_2 + H^+ \Leftrightarrow Fe^{+3} + 0.5H_2O} \qquad (slow)$$

$$FeS_2 + 14Fe^{+3} + 8H_2O \Leftrightarrow 15Fe^{+2} + 2SO_4{}^{-2} + 16H^+ \qquad (fast)$$

Remediation Strategies



prevention

treatment

$$FeS_2 + 3.5O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$$

remove pyrite

exclude oxygen

precipitate iron

reduce sulfate

neutralize acidity

remove and re-bury

bury in place

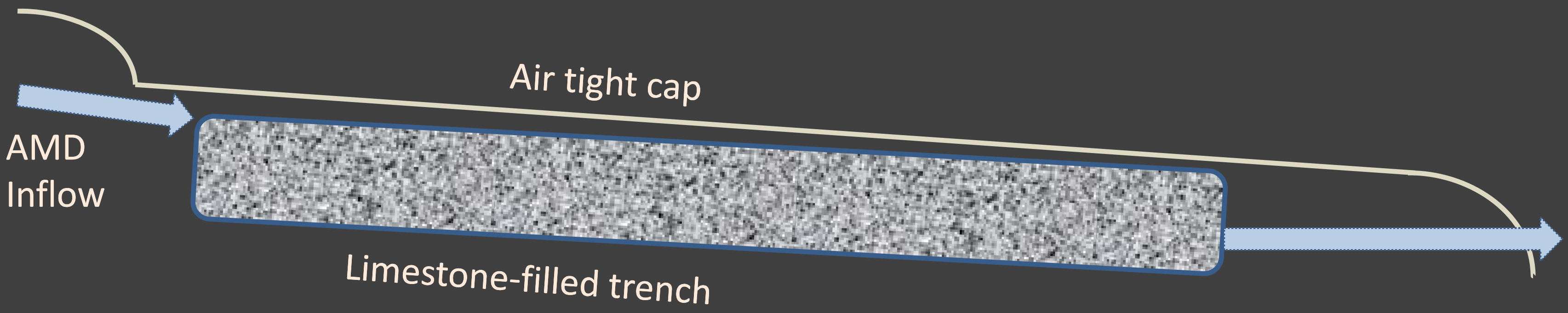
Utilize bacteria

apply alkalinity

A Progression of Passive Treatment Systems

From simple to complex biogeochemical reactions

Anoxic Limestone Drain (ALD)



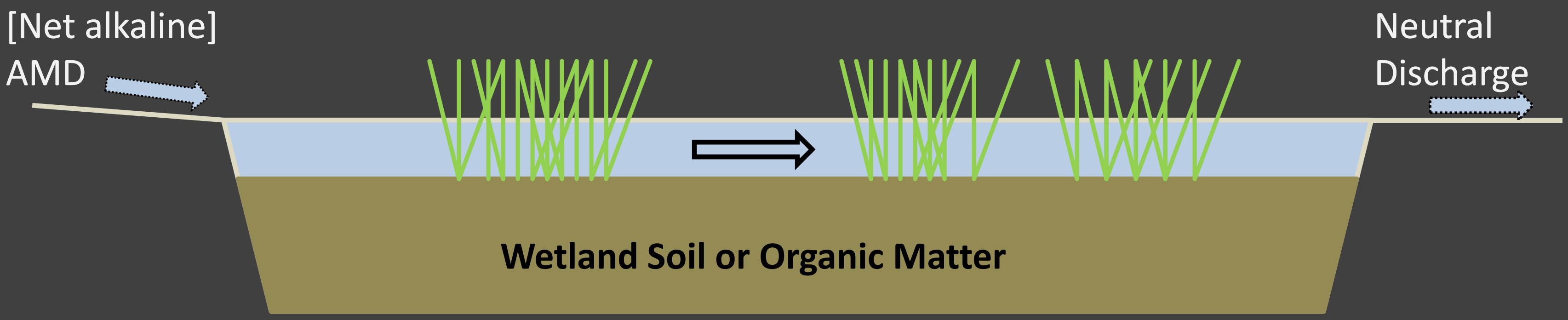
$CaCO_3 + 2H^+ \rightarrow Ca^{+2} + H_2CO_3$ acid neutralization

$H_2CO_3 + CaCO_3 \Leftrightarrow Ca^{+2} + 2HCO_3^-$ alkalinity generation

Restrictions for use on AMD:

No Fe^{+3} and low D.O.
Low (<10 mg/L) Al^{+3}
SO_4^{-2} concentrations generally < 1500 mg/L

Aerobic Wetland (AW)

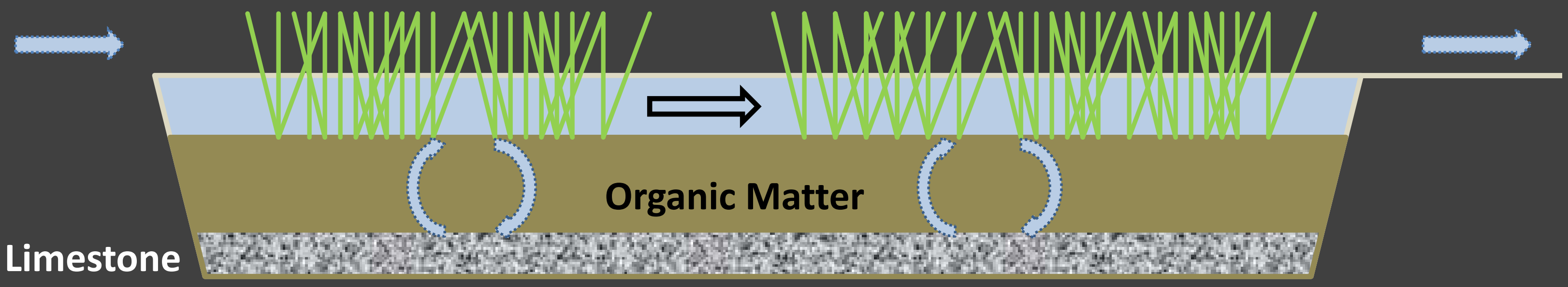


$Fe^{+2} + \frac{1}{4}O_2 + H^+ \Leftrightarrow Fe^{+3} + \frac{1}{2}H_2O$ Iron oxidation (*Thiobacillus ferrooxidans*)

$Fe^{+3} + 3H_2O \Leftrightarrow Fe(OH)_3 + 3H^+$ Oxidized Iron precipitation

$HCO_3^- + H^+ \Leftrightarrow H_2CO_3 \Leftrightarrow CO_2 + H_2O$ Acid Neutralization

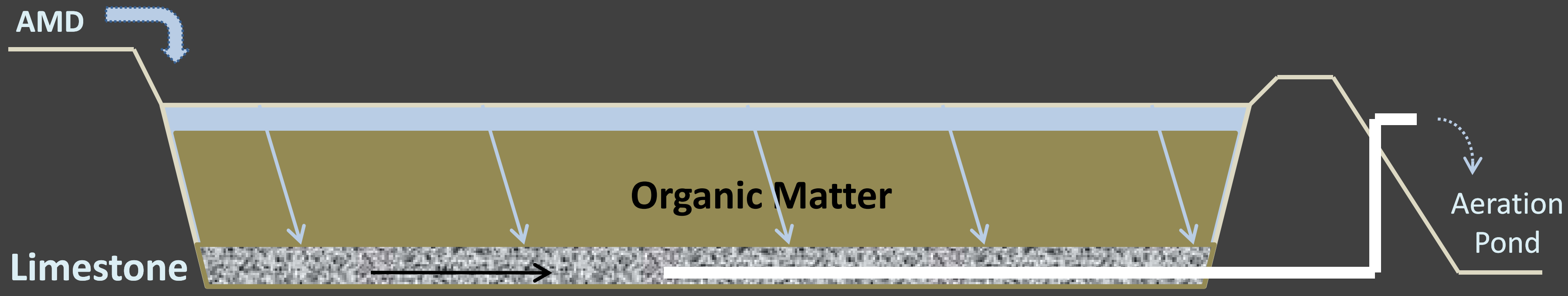
Anaerobic Wetland (AnW)



$CH_2O + O_2 \rightarrow H_2CO_3 \Leftrightarrow HCO_3^- + H^+$	aerobic bacteria removal of oxygen
$SO_4^{-2} + 2CH_2O \rightarrow H_2S + HCO_3^-$	anaerobic bacterial sulfate reduction
$H_2S + HCO_3^- \Leftrightarrow HS^- + H_2CO_3$	pH buffered hydrogen sulfide dissociation
$Fe^{+2} + HS^- \Leftrightarrow FeS + H^+$	ferrous iron sulfide precipitated
$H_2CO_3 + CaCO_3 \Leftrightarrow Ca^{+2} + 2HCO_3^-$	alkalinity generation

Size must be large enough to allow a long residence time for water diffusion to occur through substrate

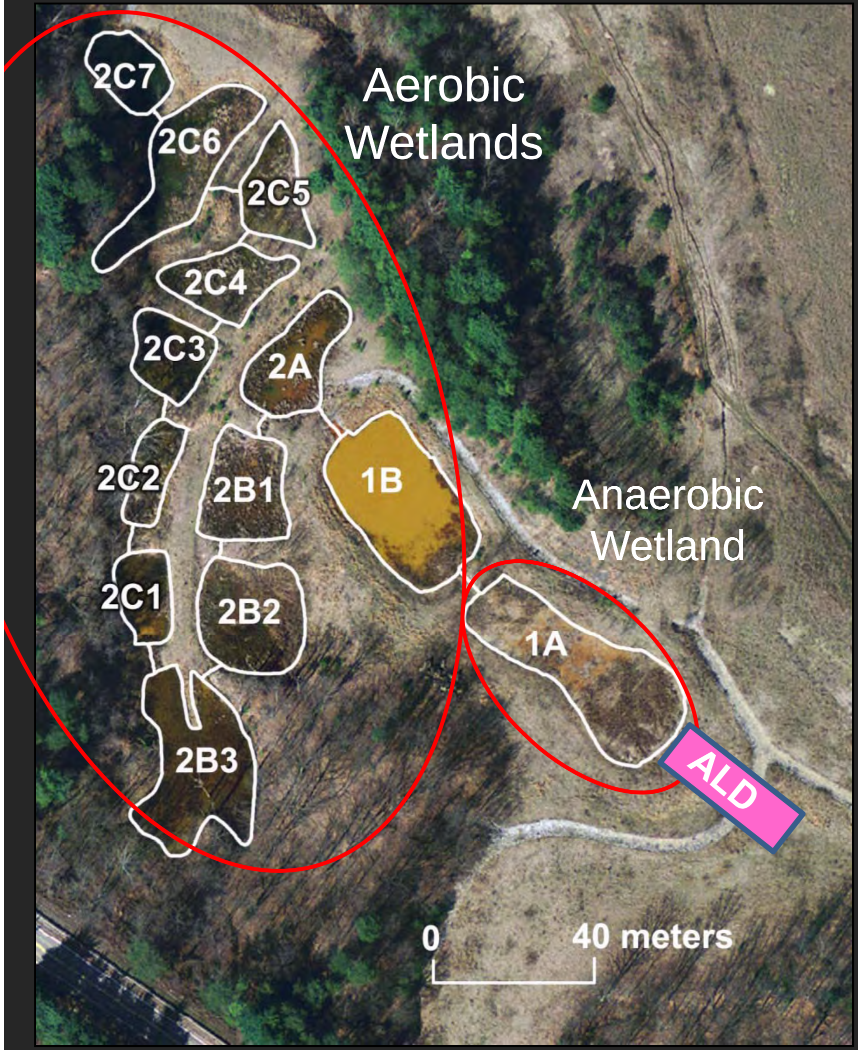
Vertical Flow Ponds (VFP) and Successive Alkaline Producing Systems (SAPS)



$CH_2O + O_2 \rightarrow H_2CO_3 \Leftrightarrow HCO_3^- + H^+$	aerobic bacteria removal of oxygen
$CaCO_3 + 2H^+ \rightarrow Ca^{+2} + H_2CO_3$	acid neutralization
$H_2CO_3 + CaCO_3 \rightarrow Ca^{+2} + 2HCO_3^-$	alkalinity generation

Minor reaction contributions

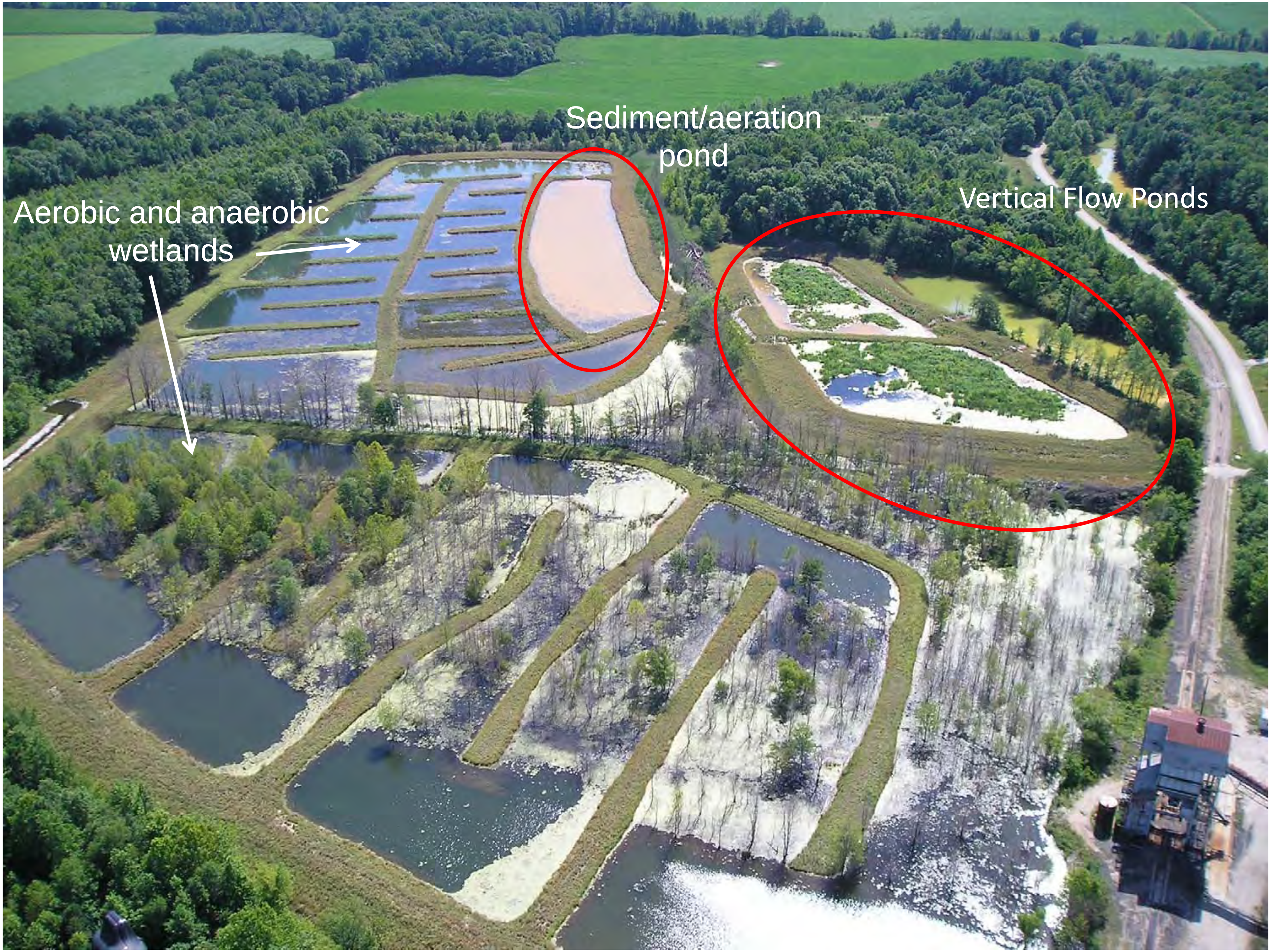
$SO_4^{-2} + 2CH_2O \rightarrow H_2S + HCO_3^-$	anaerobic bacteria sulfate reduction
$H_2S + HCO_3^- \Leftrightarrow HS^- + H_2CO_3$	pH buffered hydrogen sulfide dissociation
$Fe^{+2} + HS^- \Leftrightarrow FeS + H^+$	ferrous iron sulfide precipitated



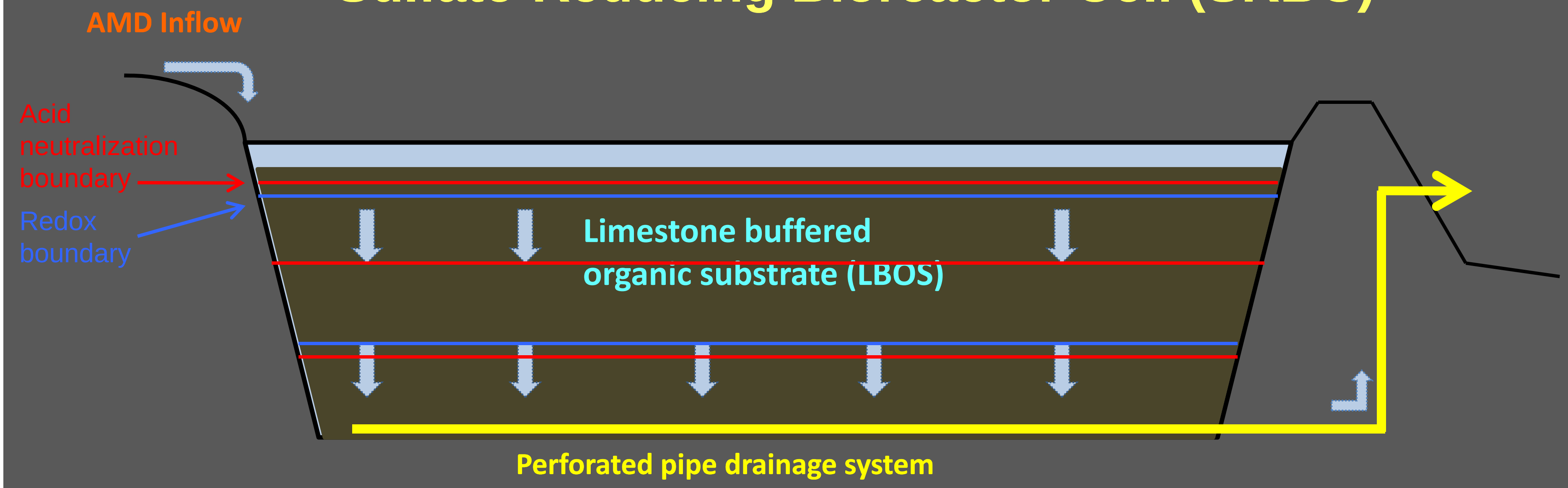
One alternative to treating complex AMD is to combine treatment systems

Considerations:

Required area
Construction costs
Maintenance costs


Sediment/aeration pond
Aerobic and anaerobic wetlands
Vertical Flow Ponds

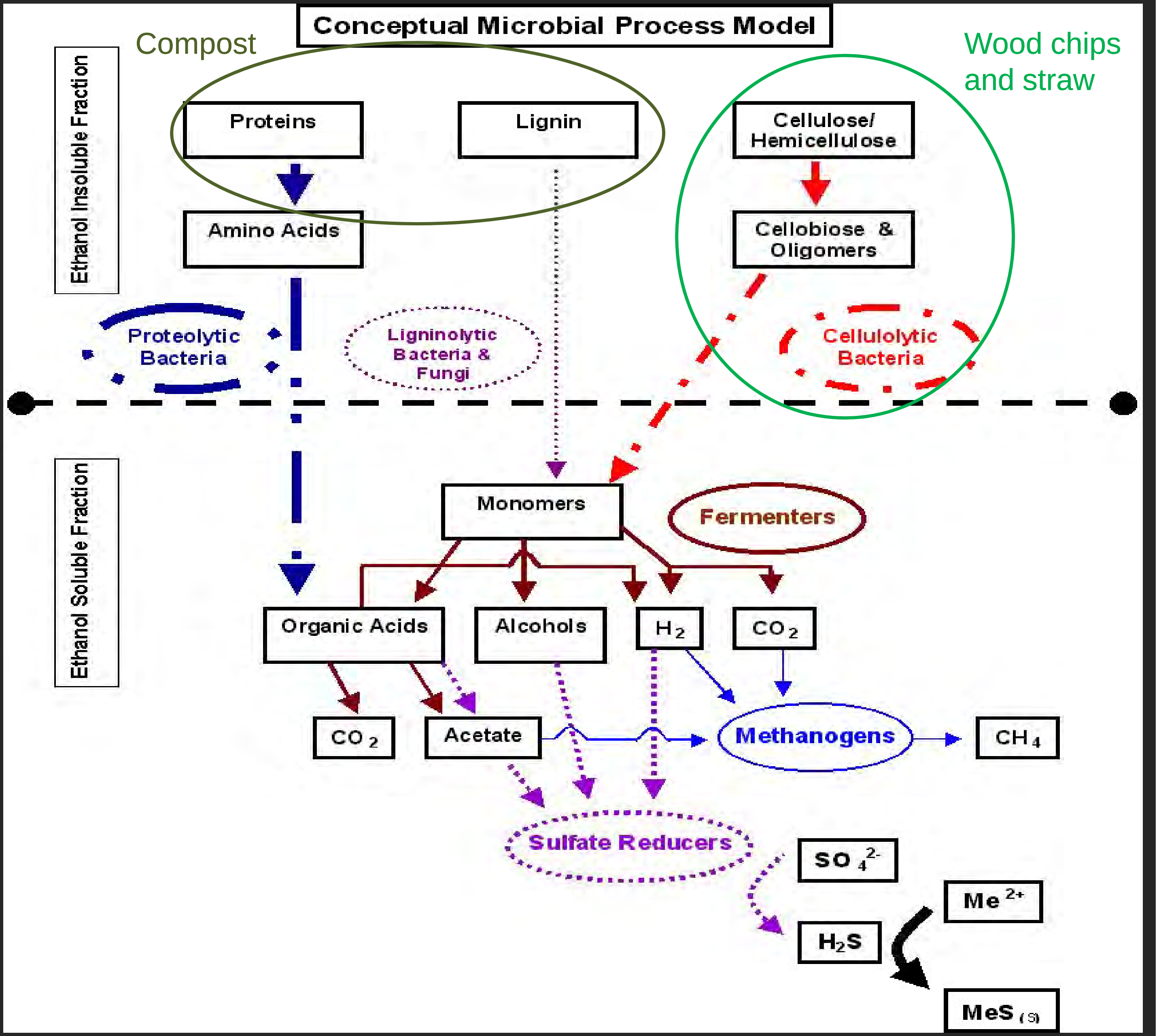
Sulfate-Reducing Bioreactor Cell (SRBC)



$CaCO_3 + 2H^+ \rightarrow Ca^{+2} + H_2CO_3$	acid neutralization
$CH_2O + O_2 \rightarrow H_2CO_3 \Leftrightarrow HCO_3^- + H^+$	aerobic bacteria removal of oxygen
$SO_4^{-2} + 2CH_2O \rightarrow H_2S + HCO_3^-$	anaerobic bacterial sulfate reduction
$H_2CO_3 + CaCO_3 \rightarrow Ca^{+2} + 2HCO_3^-$	alkalinity generation
$H_2S + HCO_3^- \Leftrightarrow HS^- + H_2CO_3$	pH buffered hydrogen sulfide dissociation
$Fe^{+2} + HS^- \Leftrightarrow FeS + H^+$	ferrous iron sulfide precipitated

Fermenters, sulfate reducers and methanogens will starve and the bioreactor cease to function if the more complex organic molecules are not broken down to simpler molecules.

Rate of complex molecule decomposition is unknown but an important component for developing predictive model



Bench scale test for substrate compositions conducted by IDNR-DOR

Substrate blend performance determined by alkalinity generation, sulfate-reduction, iron fixing, effluent composition and advance of redox front in LBOS.

Effluent discharge evaluation

Positives

- reduced sulfate
- increased alkalinity
- reduced Fe^{+2}
- decreased trace metals

Negatives

- fecal bacteria
- ammonia
- increased oxygen demand
- suspended FeS

Oxidation ponds (or aerobic wetlands) will improve effluent regarding oxygen demand and suspended FeS

SRBC Considerations

AMD composition restrictions

suitable for wide range of AMD compositions

Location requirements

can be constructed in variety of relief settings

avoid areas receiving high volumes of surface runoff

Size versatility

can be sized to fit available area

Construction costs compared to similar treatment systems

smaller size potential → lower cost

Materials

limestone, wood chips and straw locally available

labile organic material ← limiting factor – source, composition

Maintenance frequency

dependent on size and loading criteria

SRBC Optimal Performance Modeling Requirements

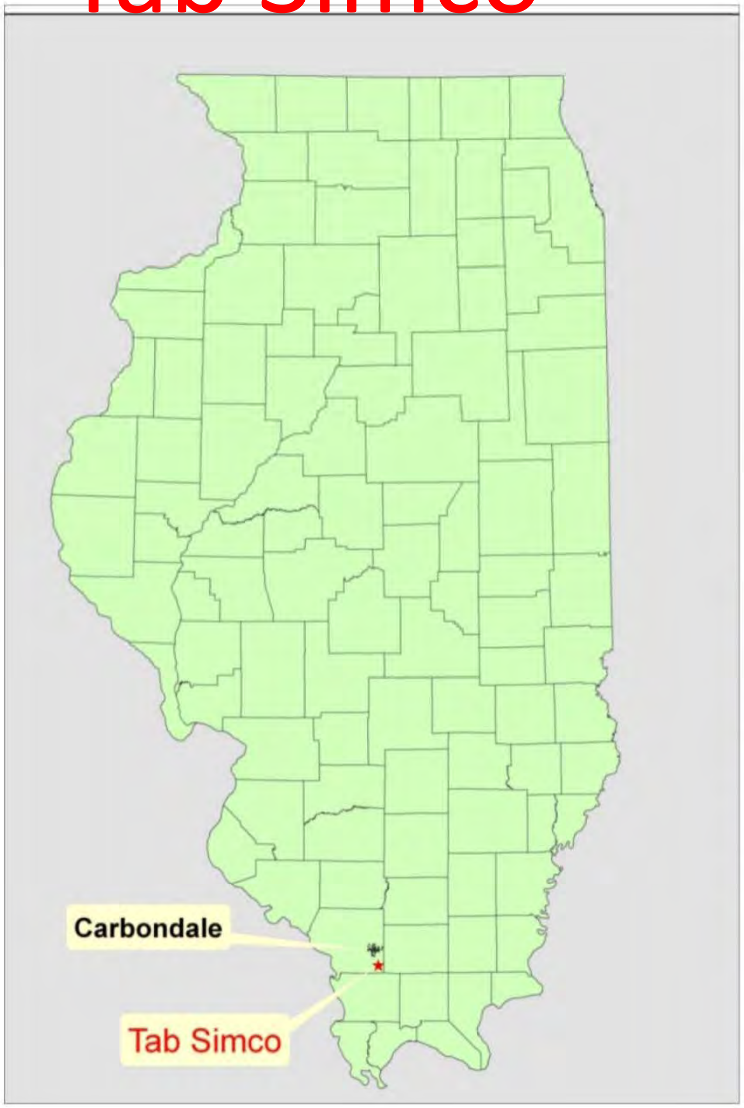
- Single inflow into cell
- Lined to prevent leaking → single outflow
- Plumbed to maximize flow through substrate
- Internal 3-D monitoring port network
- Monitoring and sampling schedule
- Monitoring duration to encompass seasonal and substrate depletion trends

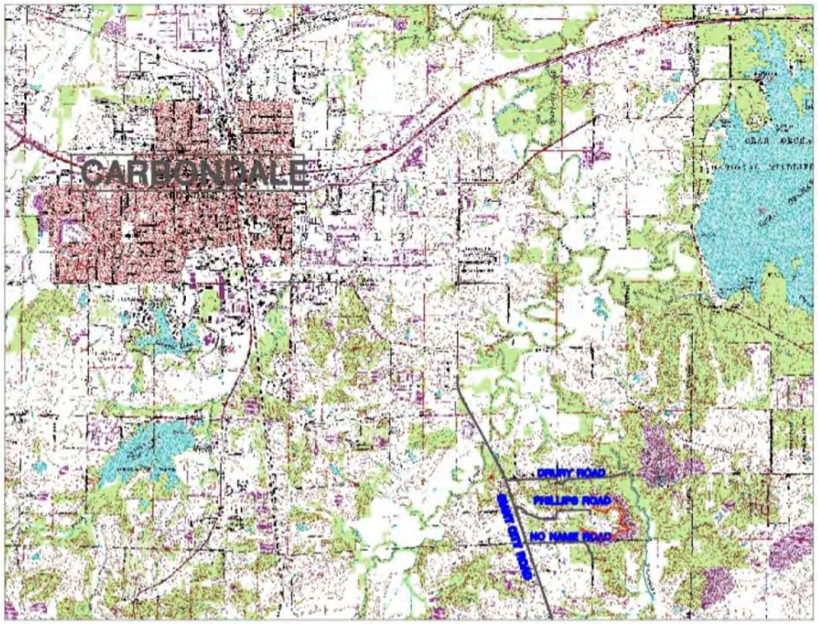
BIOREACTOR SYSTEM ACTIVITY IN ILLINOIS 2010

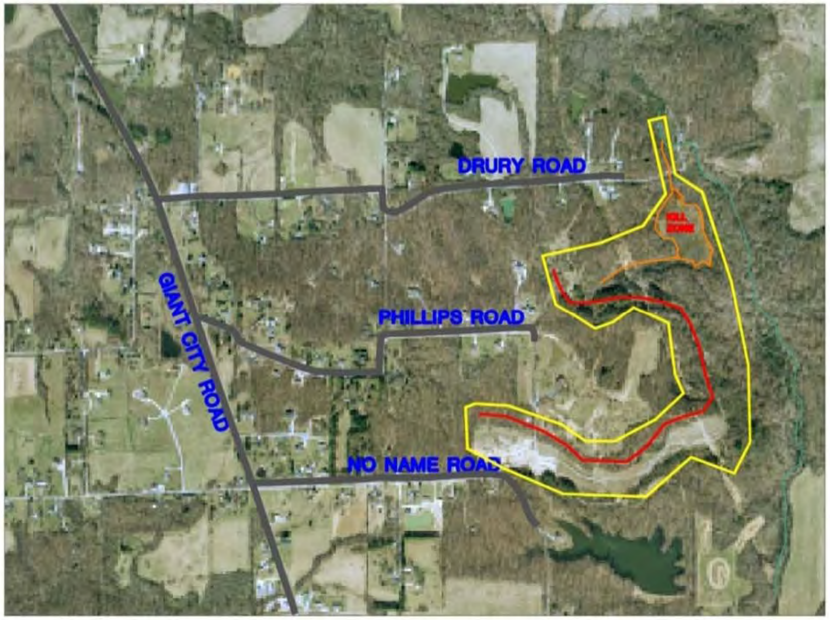
ILLINOIS DEPARTMENT OF NATURAL RESOURCES

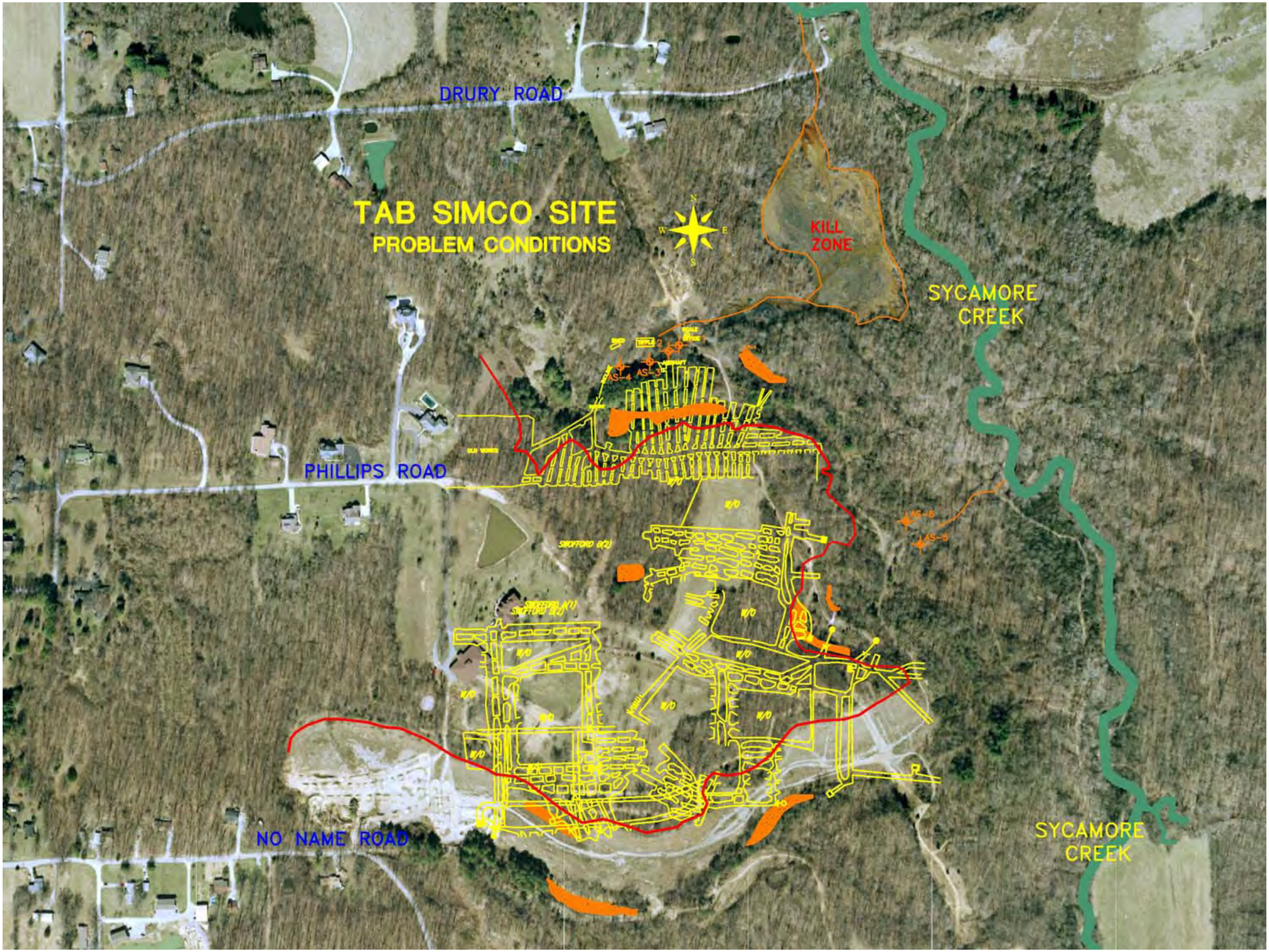
Lawrence L. Lewis, P.E.
Supervisor of Engineering Design and Tech Support
AMLR Div. of Office of Mines & Minerals
Illinois Department of Natural Resources

Tab Simco


Carbondale
Tab Simco

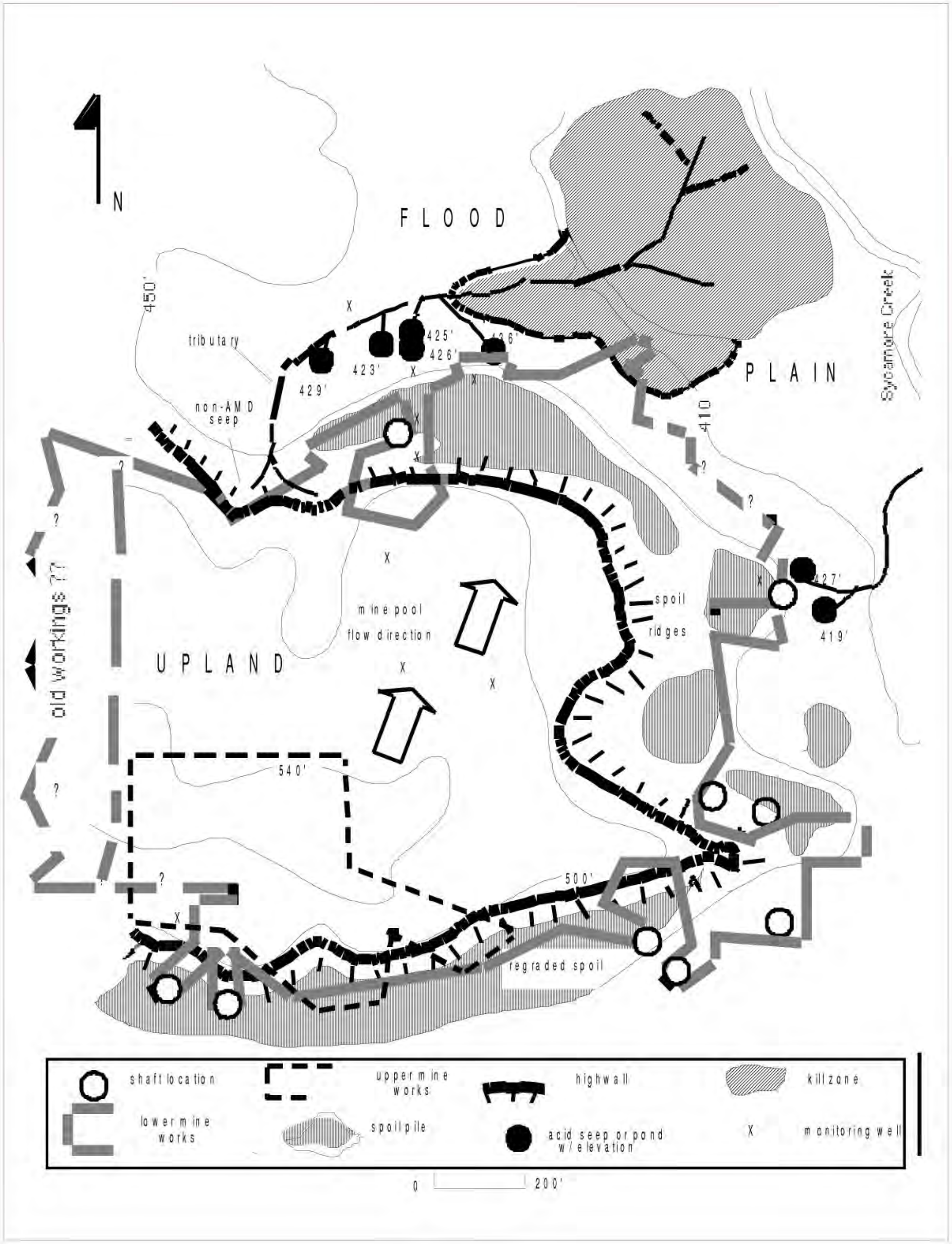

CARBONDALE
DRURY ROAD
PHILLIPS ROAD
NO NAME ROAD
GIANT CITY ROAD

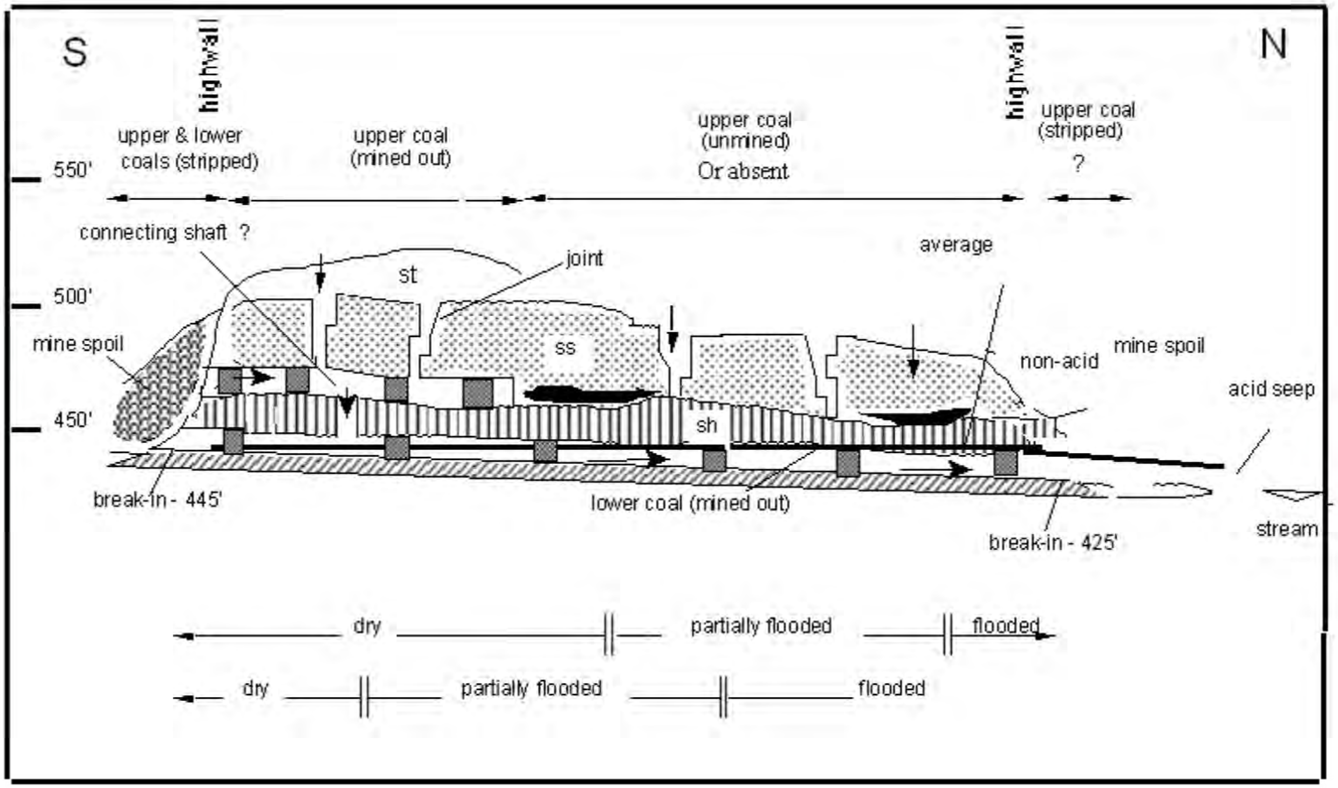

DRURY ROAD
GIANT CITY ROAD
PHILLIPS ROAD
NO NAME ROAD



TAB SIMCO SITE
PROBLEM CONDITIONS
DRURY ROAD
N
W
E
S
KILL ZONE
SYCAMORE CREEK
TIPPLE
SCALE OFFICE
AIRSHAFT
AS-4
AS-3
OLD WORKS
PHILLIPS ROAD
W/O
AS-6
AS-5
SWOFFORD 6(2)
SWOFFORD 6(1)
NO NAME ROAD
SYCAMORE CREEK

From
“Characterization of an Acid Mine Drainage Site in Southern Illinois”
by Philip. A. Smith

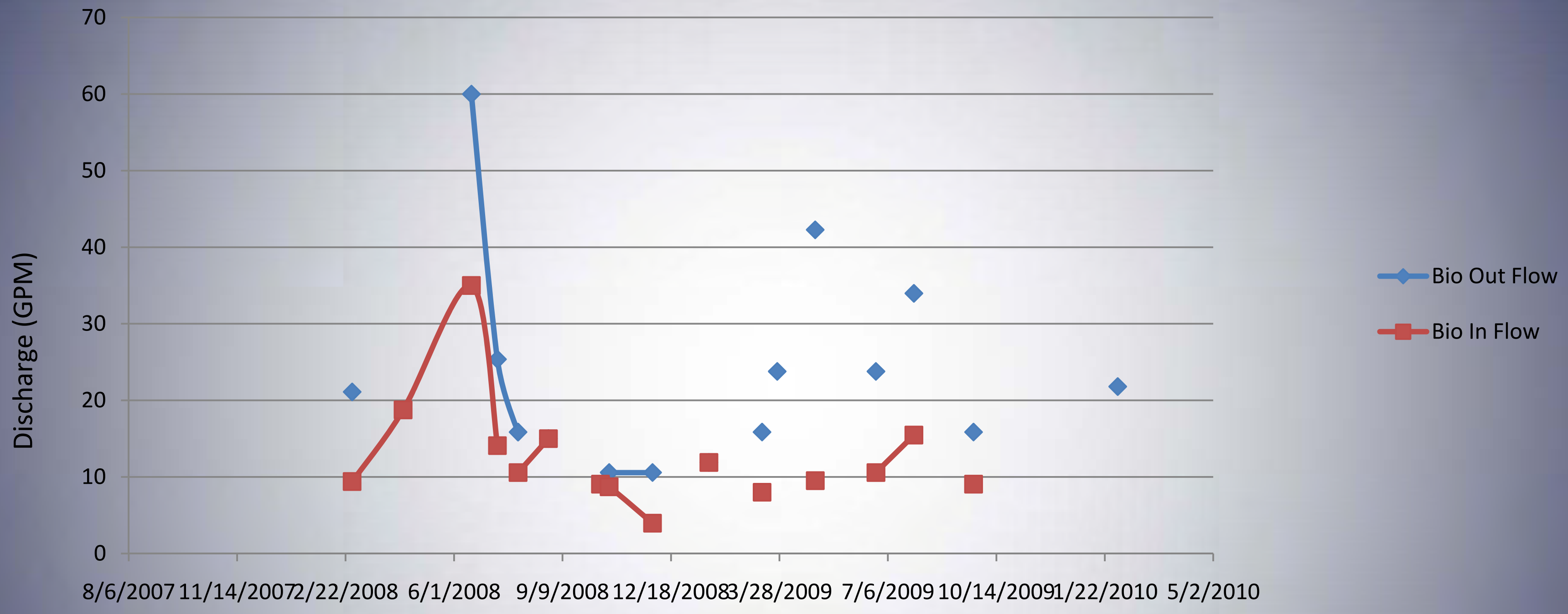




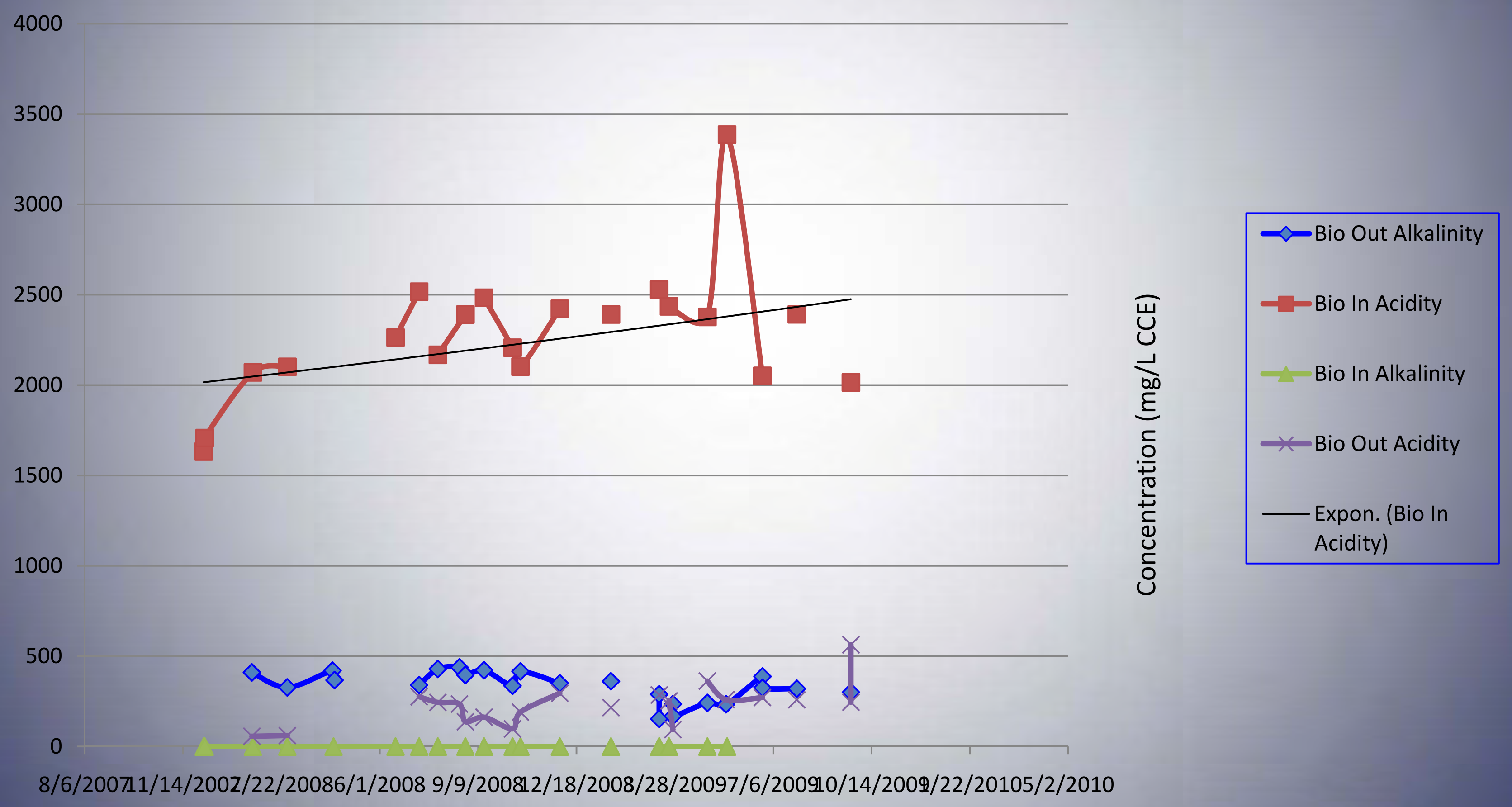
From "Characterization of an Acid Mine Drainage Site in Southern Illinois" by Philip. A. Smith


Tab Simco 2010
DRURY ROAD
SEDIMENT BASIN/ WETLANDS
SYCAMORE CREEK
BIOREACTOR CELL
PHILLIPS ROAD
NO NAME ROAD

Flow –Tab Simco Bioreactor System



Water Quality Tab Simco Bioreactor System



Tab Simco
Existing Conditions

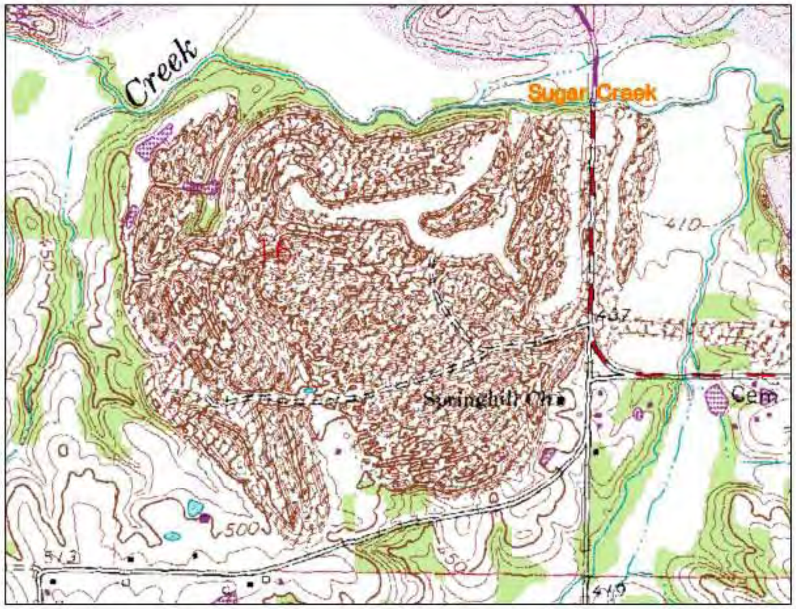
Tab Simco Proposed

AMD WORKSHOP QUESTIONS ABOUT TAB SIMCO

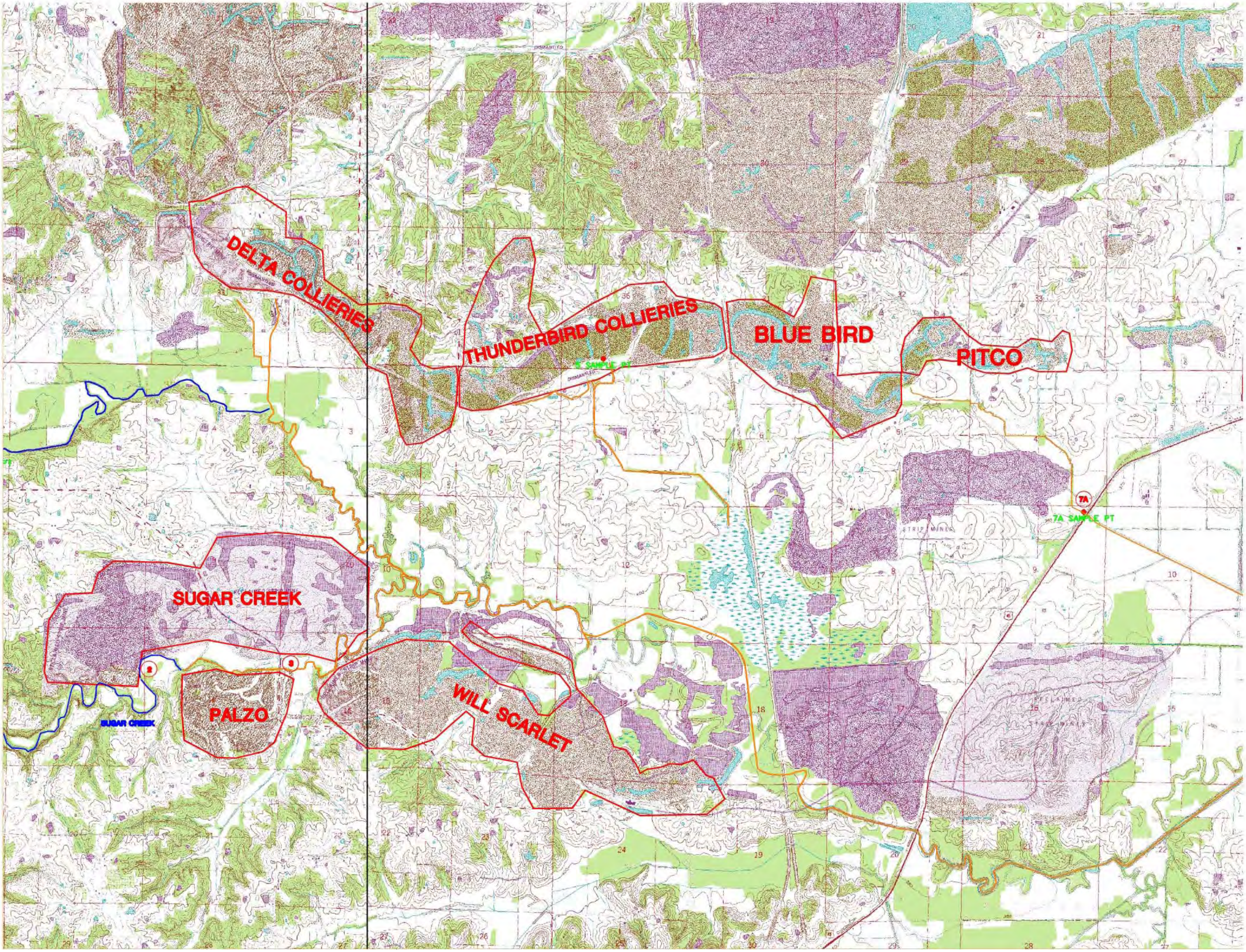
1. Considering the performance of the Bioreactor Cell, would you leave it as is to see how long it continues to function or plan to replace the Bio material before it completely fails?
2. Do you see any other alternatives to the above? If so please provide them.
3. How would you modify the concept proposed in the presentation to improve the quality of water entering Sycamore Creek from the site?
4. Provide a detail to show how you would direct the AMD seep flowing in the Main Drainage-way to the Bio Reactor Cell?

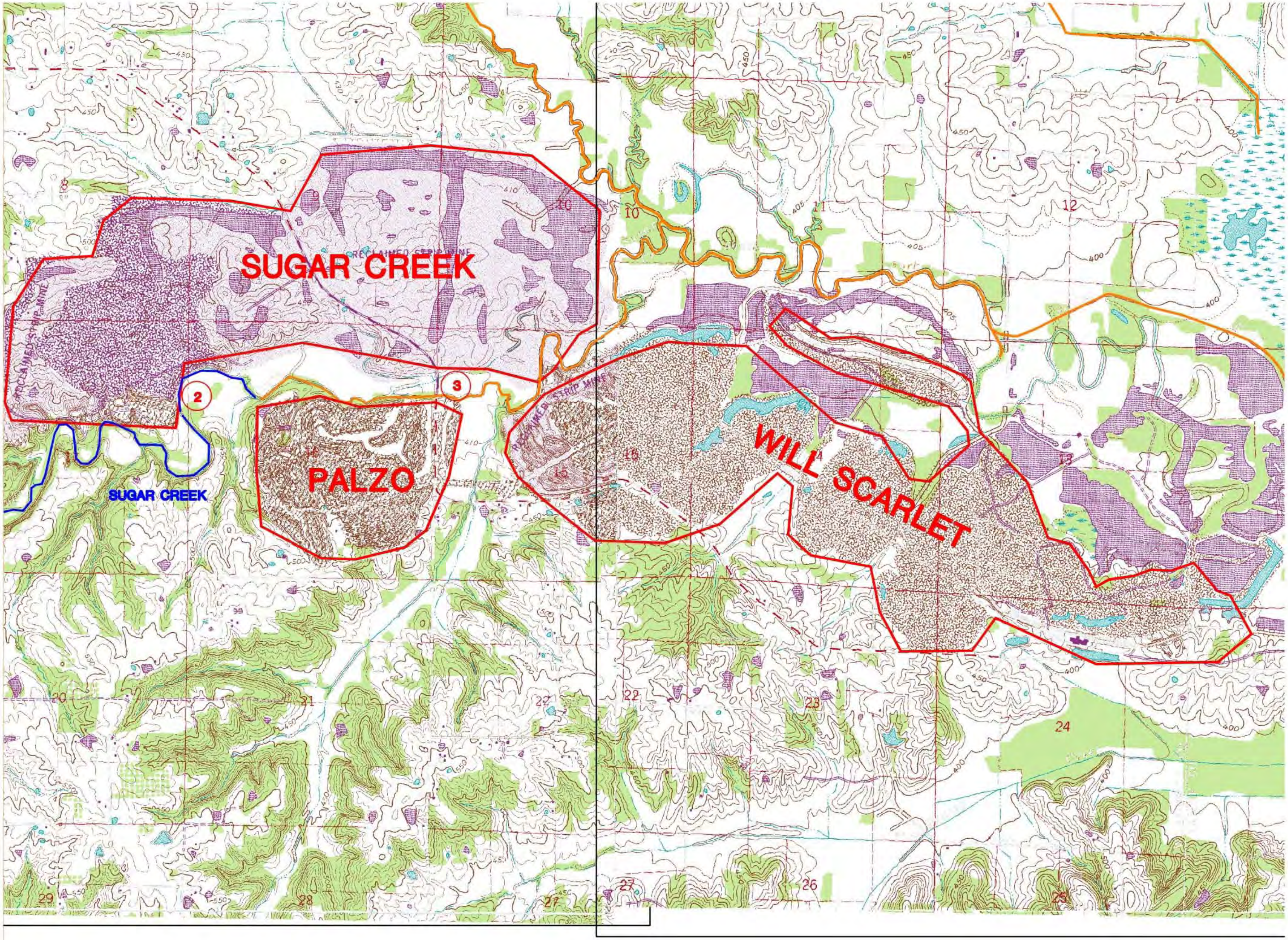
PALZO MINE

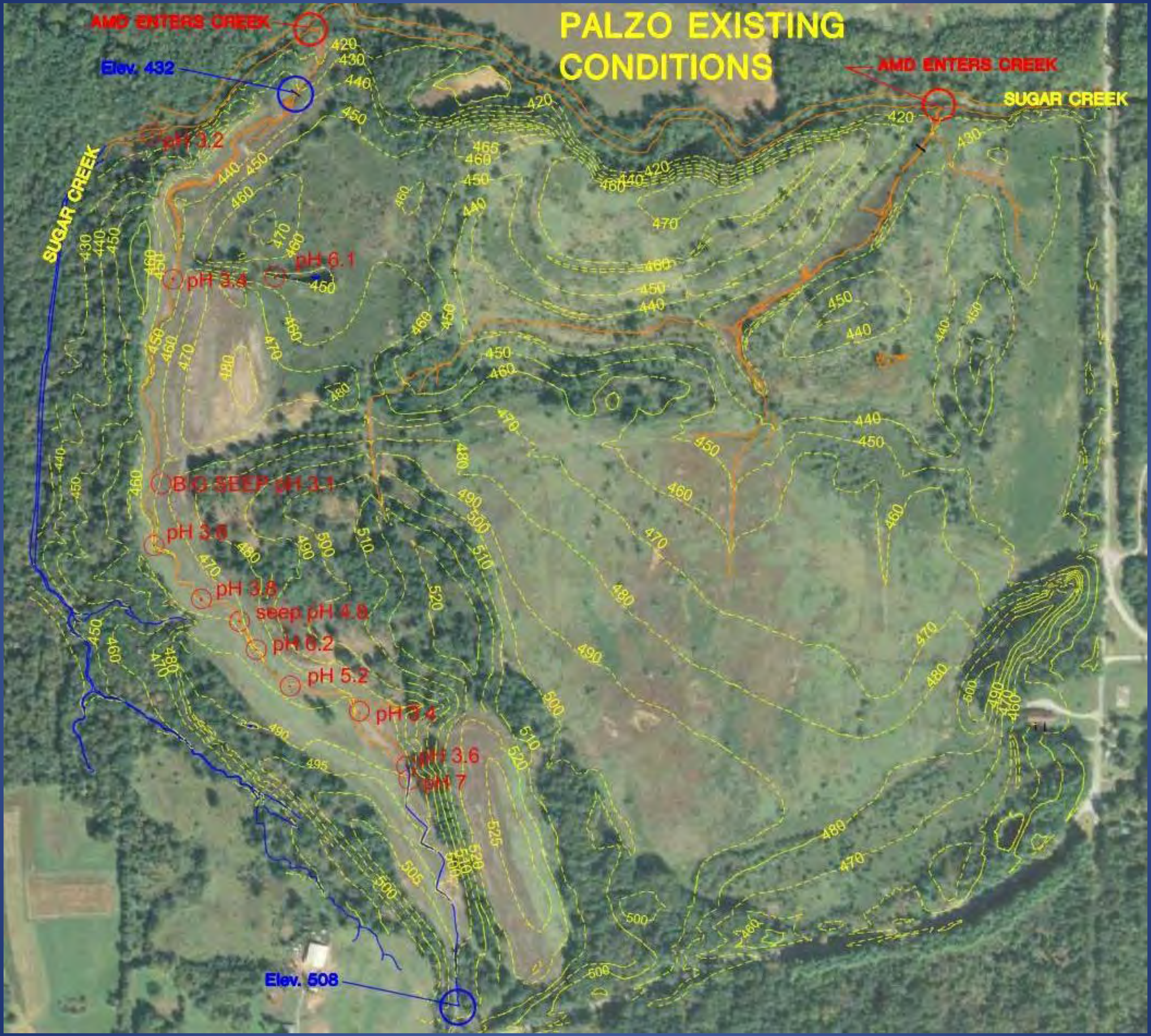

PALZO MINE

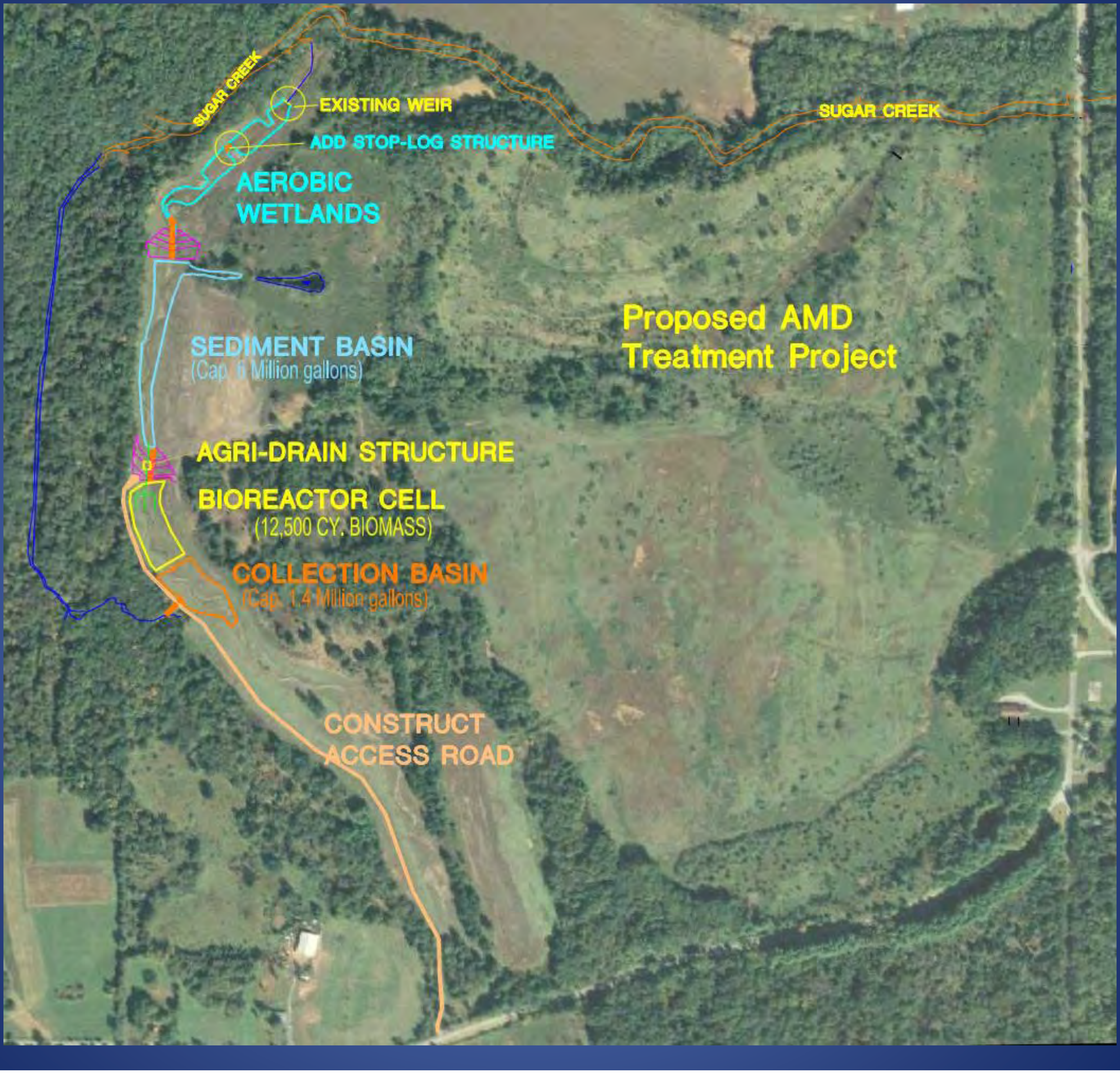

Creek
Sugar Creek
410
437
Springhill Ch
Cem
500
513
419

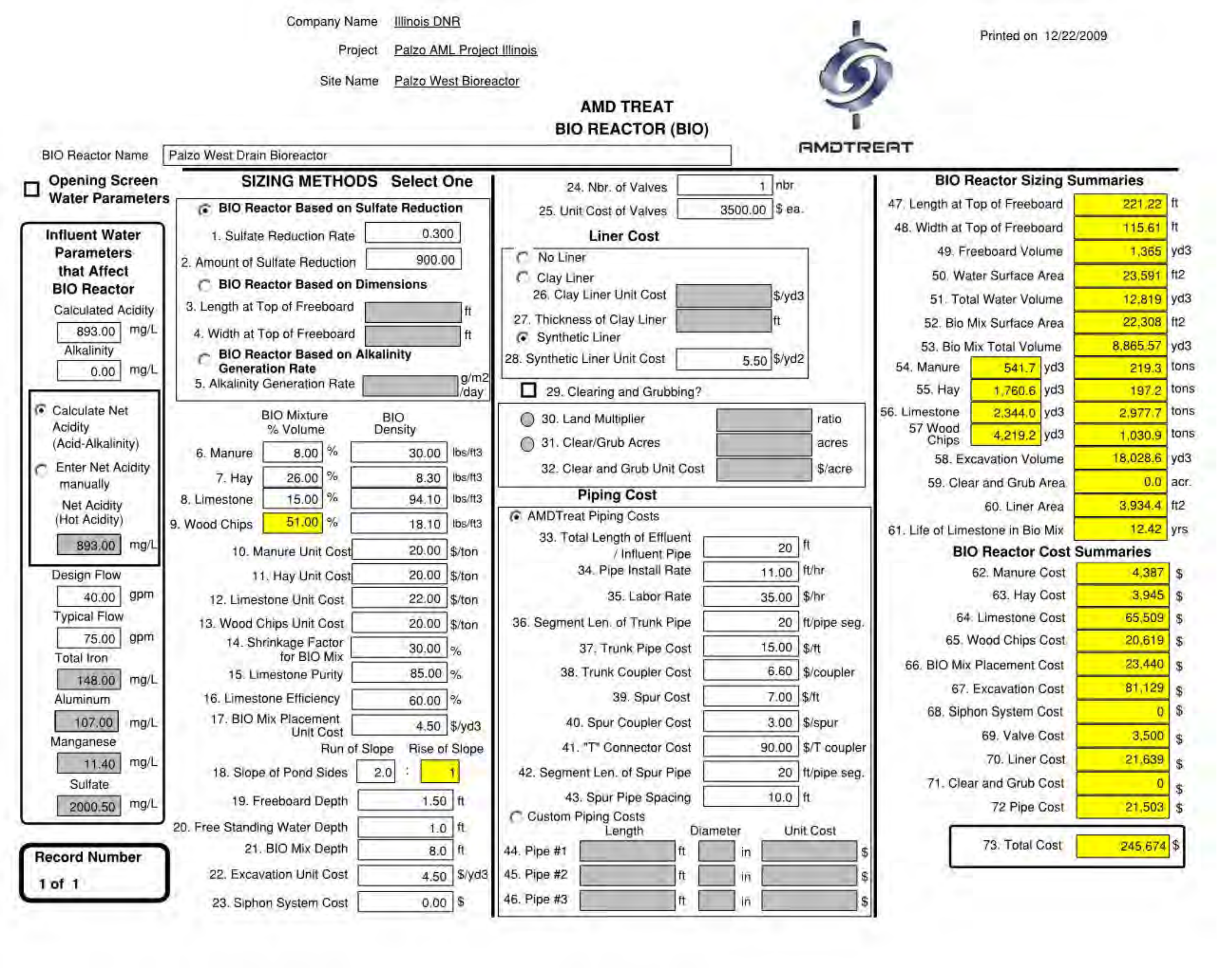

Sugar Creek


DELTA COLLIERIES
THUNDERBIRD COLLIERIES
BLUE BIRD
PITCO
5 SAMPLE PT
7A
7A SAMPLE PT
STRIP MINES
SUGAR CREEK
2
3
SUGAR CREEK
PALZO
WILL SCARLET
DISMANTLED


SUGAR CREEK
RECLAIMED STRIP MINE
PALZO
WILL SCARLET
SUGAR CREEK
2
3
RECLAIMED STRIP MINE
RECLAIMED STRIP MINE
10
10
11
12
13
14
15
16
20
21
22
22
23
24
25
26
27
27
28
29
450
400
405
410
500
550


PALZO EXISTING CONDITIONS
AMD ENTERS CREEK
Elev. 432
pH 3.2
SUGAR CREEK
pH 3.4
pH 6.1
B/O SEEP pH 3.1
pH 3.6
pH 3.8
seep pH 4.8
pH 6.2
pH 5.2
pH 3.4
pH 3.6
pH 7
Elev. 508
AMD ENTERS CREEK
SUGAR CREEK


SUGAR CREEK
EXISTING WEIR
ADD STOP-LOG STRUCTURE
SUGAR CREEK
AEROBIC WETLANDS
Proposed AMD Treatment Project
SEDIMENT BASIN
(Cap. 6 Million gallons)
AGRI-DRAIN STRUCTURE
BIOREACTOR CELL
(12,500 CY. BIOMASS)
COLLECTION BASIN
(Cap. 1.4 Million gallons)
CONSTRUCT ACCESS ROAD



Company Name Illinois DNR

Project Palzo AML Project Illinois

Site Name Palzo West Bioreactor

Printed on 12/22/2009

AMD TREAT
BIO REACTOR (BIO)

AMDTREAT

BIO Reactor Name: Palzo West Drain Bioreactor

☐ **Opening Screen Water Parameters**

Influent Water Parameters that Affect BIO Reactor

Calculated Acidity 893.00 mg/L

Alkalinity 0.00 mg/L

● Calculate Net Acidity (Acid-Alkalinity)

○ Enter Net Acidity manually

Net Acidity (Hot Acidity) 893.00 mg/L

Design Flow 40.00 gpm

Typical Flow 75.00 gpm

Total Iron 148.00 mg/L

Aluminum 107.00 mg/L

Manganese 11.40 mg/L

Sulfate 2000.50 mg/L

Record Number

1 of 1

SIZING METHODS Select One

● **BIO Reactor Based on Sulfate Reduction**

1. Sulfate Reduction Rate 0.300

2. Amount of Sulfate Reduction 900.00

○ **BIO Reactor Based on Dimensions**

3. Length at Top of Freeboard ft

4. Width at Top of Freeboard ft

○ **BIO Reactor Based on Alkalinity Generation Rate**

5. Alkalinity Generation Rate g/m2/day

	BIO Mixture % Volume		BIO Density	
6. Manure	8.00	%	30.00	lbs/ft3
7. Hay	26.00	%	8.30	lbs/ft3
8. Limestone	15.00	%	94.10	lbs/ft3
9. Wood Chips	51.00	%	18.10	lbs/ft3

10. Manure Unit Cost 20.00 $/ton

11. Hay Unit Cost 20.00 $/ton

12. Limestone Unit Cost 22.00 $/ton

13. Wood Chips Unit Cost 20.00 $/ton

14. Shrinkage Factor for BIO Mix 30.00 %

15. Limestone Purity 85.00 %

16. Limestone Efficiency 60.00 %

17. BIO Mix Placement Unit Cost 4.50 $/yd3

18. Slope of Pond Sides (Run of Slope : Rise of Slope) 2.0 : 1

19. Freeboard Depth 1.50 ft

20. Free Standing Water Depth 1.0 ft

21. BIO Mix Depth 8.0 ft

22. Excavation Unit Cost 4.50 $/yd3

23. Siphon System Cost 0.00 $

24. Nbr. of Valves 1 nbr

25. Unit Cost of Valves 3500.00 $ ea.

Liner Cost

○ No Liner

○ Clay Liner

26. Clay Liner Unit Cost $/yd3

27. Thickness of Clay Liner ft

● Synthetic Liner

28. Synthetic Liner Unit Cost 5.50 $/yd2

☐ 29. Clearing and Grubbing?

○ 30. Land Multiplier ratio

○ 31. Clear/Grub Acres acres

32. Clear and Grub Unit Cost $/acre

Piping Cost

● AMDTreat Piping Costs

33. Total Length of Effluent / Influent Pipe 20 ft

34. Pipe Install Rate 11.00 ft/hr

35. Labor Rate 35.00 $/hr

36. Segment Len. of Trunk Pipe 20 ft/pipe seg.

37. Trunk Pipe Cost 15.00 $/ft

38. Trunk Coupler Cost 6.60 $/coupler

39. Spur Cost 7.00 $/ft

40. Spur Coupler Cost 3.00 $/spur

41. "T" Connector Cost 90.00 $/T coupler

42. Segment Len. of Spur Pipe 20 ft/pipe seg.

43. Spur Pipe Spacing 10.0 ft

○ Custom Piping Costs

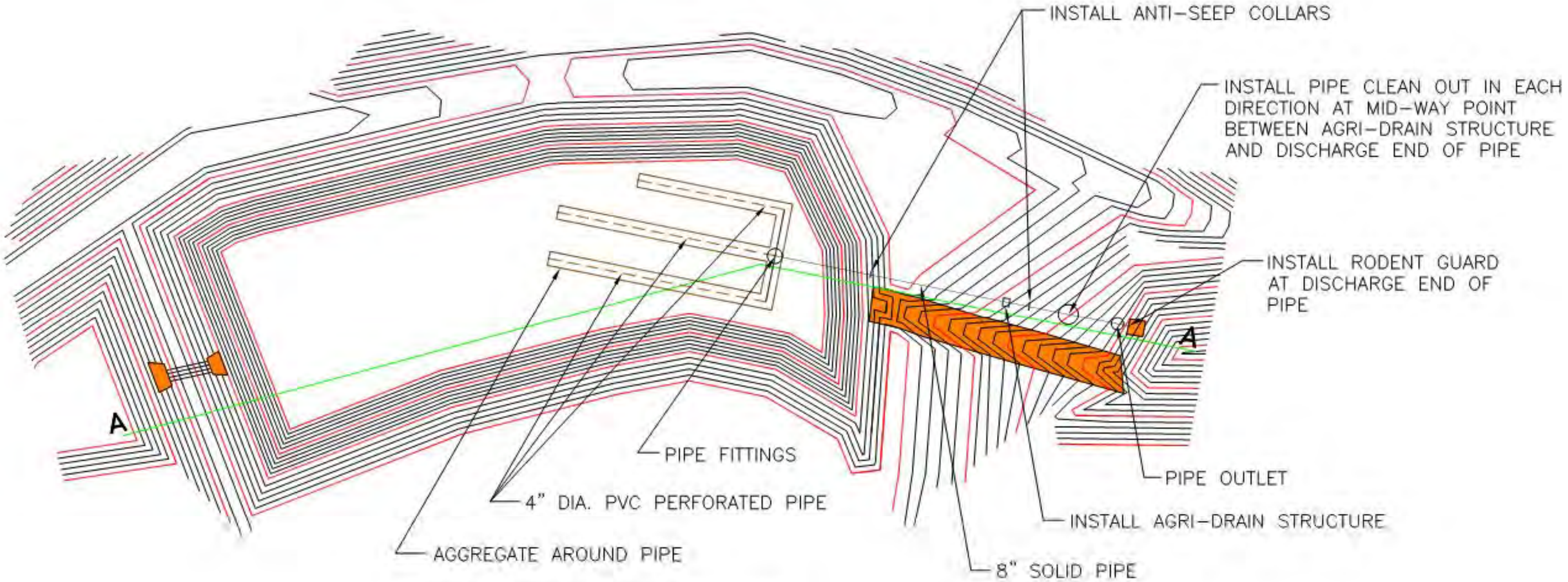
	Length		Diameter		Unit Cost	
44. Pipe #1		ft		in		$
45. Pipe #2		ft		in		$
46. Pipe #3		ft		in		$

BIO Reactor Sizing Summaries

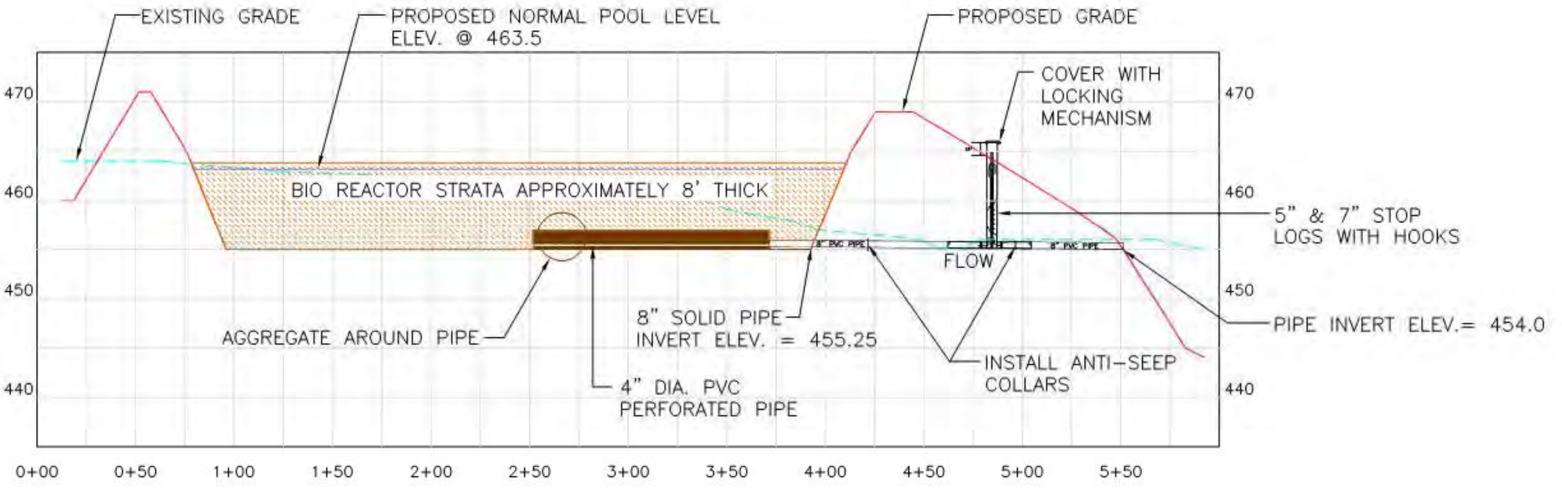
47. Length at Top of Freeboard			221.22	ft
48. Width at Top of Freeboard			115.61	ft
49. Freeboard Volume			1,365	yd3
50. Water Surface Area			23,591	ft2
51. Total Water Volume			12,819	yd3
52. Bio Mix Surface Area			22,308	ft2
53. Bio Mix Total Volume			8,865.57	yd3
54. Manure	541.7	yd3	219.3	tons
55. Hay	1,760.6	yd3	197.2	tons
56. Limestone	2,344.0	yd3	2,977.7	tons
57 Wood Chips	4,219.2	yd3	1,030.9	tons
58. Excavation Volume			18,028.6	yd3
59. Clear and Grub Area			0.0	acr.
60. Liner Area			3,934.4	ft2
61. Life of Limestone in Bio Mix			12.42	yrs

BIO Reactor Cost Summaries

62. Manure Cost	4,387	$
63. Hay Cost	3,945	$
64. Limestone Cost	65,509	$
65. Wood Chips Cost	20,619	$
66. BIO Mix Placement Cost	23,440	$
67. Excavation Cost	81,129	$
68. Siphon System Cost	0	$
69. Valve Cost	3,500	$
70. Liner Cost	21,639	$
71. Clear and Grub Cost	0	$
72 Pipe Cost	21,503	$
73. Total Cost	245,674	$



PLAN VIEW OF PIPING NETWORK

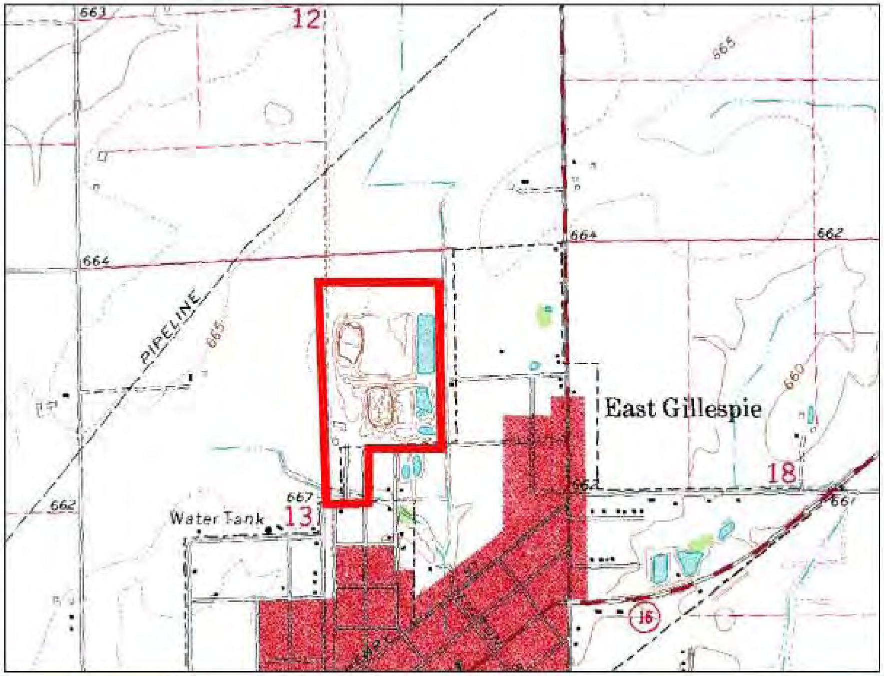


PROFILE A-A THROUGH BIOREACTOR CELL

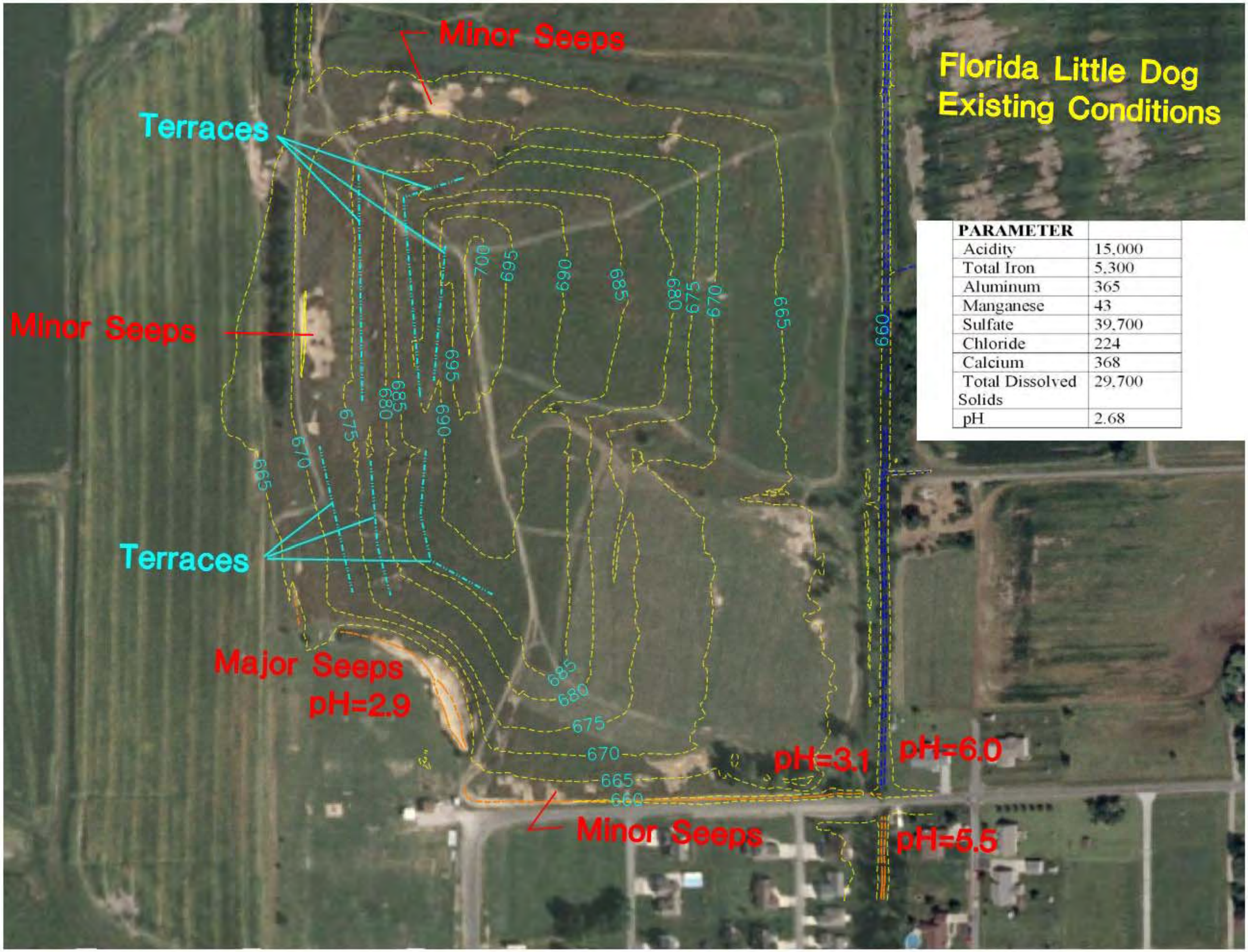
AMD WORKSHOP QUESTIONS ABOUT PALZO

How would you modify the concept proposed in the presentation to improve the quality of water leaving the site?

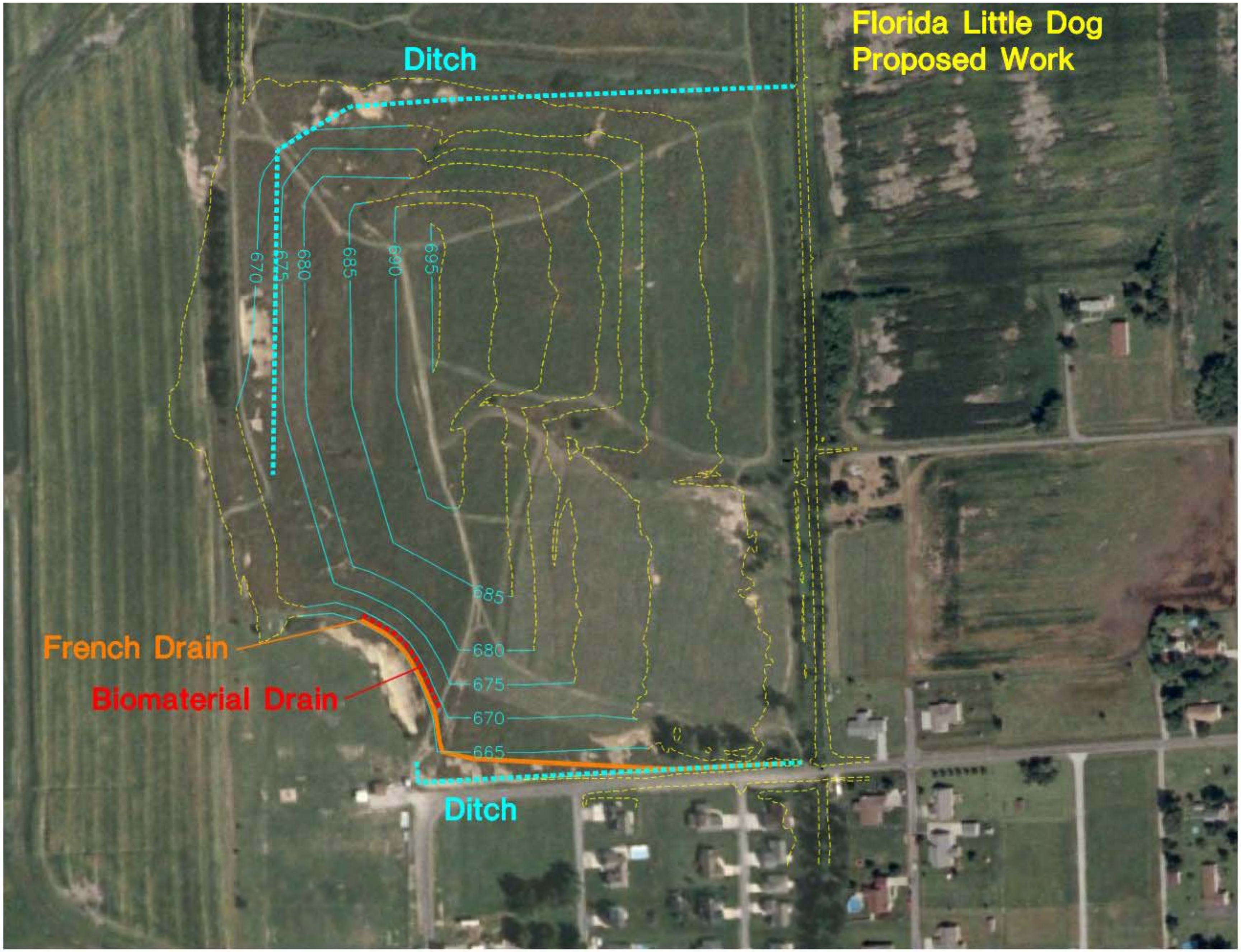
Florida Little Dog Mine



Florida Little Dog Existing Conditions



PARAMETER	
Acidity	15,000
Total Iron	5,300
Aluminum	365
Manganese	43
Sulfate	39,700
Chloride	224
Calcium	368
Total Dissolved Solids	29,700
pH	2.68



Florida Little Dog Proposed Work


EXISTING GRADE
FINAL GRADE
SUB GRADE
FRENCH DRAIN
FILTER FABRIC
BIOMATERIAL
700
690
680
670
660
650
640
630
620
610
600
0
100
200
300
400
500
600
700
800
900
Vertical Scale 10
Horizontal Scale 50

AMD WORKSHOP QUESTIONS ABOUT FLORIDA LITTLE DOG

1. How would you modify the concept proposed in the presentation to improve the quality of water leaving the site?
2. How do you think the Biomaterial drain to outlet seepage from the pile will work?
3. How would you modify it so it will treat AMD that flows through it?

Passive Treatment of AMD: The Enos Loop Wetland Project, Indiana

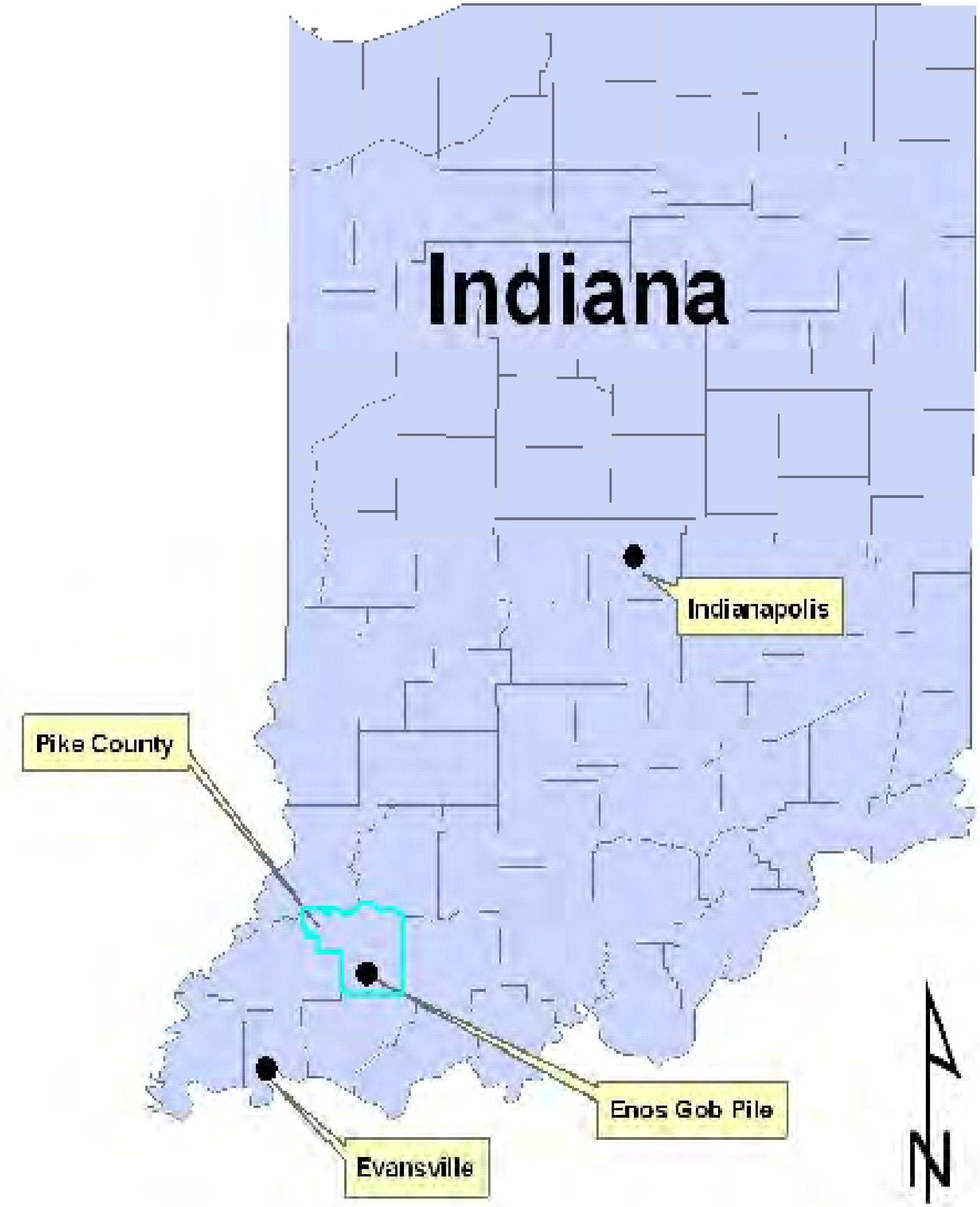
Paul T. Behum, Dan R. Hause, Mark A. Stacy and
Tracy D. Branam [2]

[2]Paul Behum is a Sr. Hydrologist with OSM, Mid-Continent Regional Office, Dan Hause is a Mining Engineer and Mark Stacy an Environmental Specialist with IDOR, Tracy D. Branam is a Research Scientist with Indiana Geological Survey.

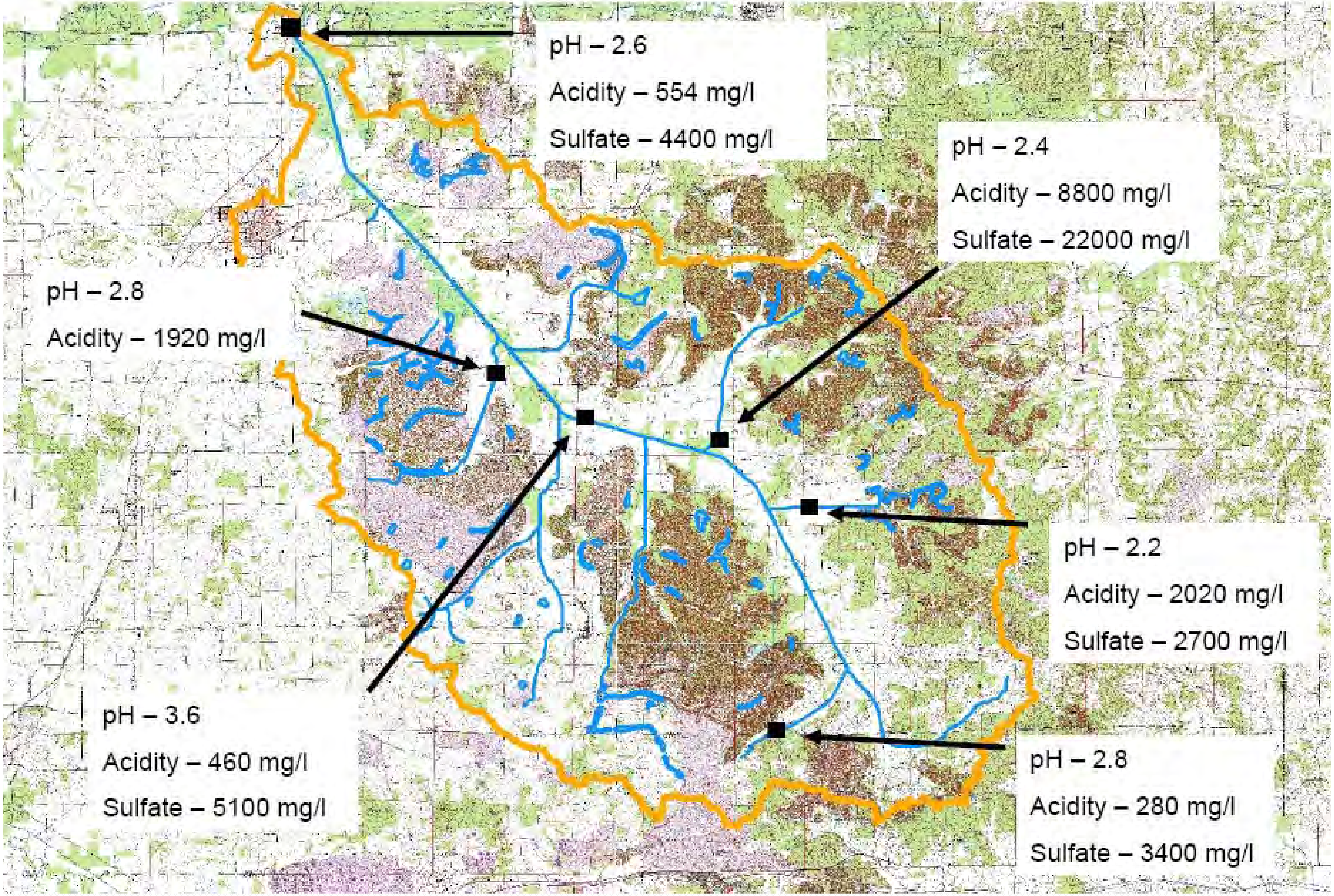
Passive Treatment of AMD

- The Problem: Mine Drainage from the Enos Gob Pile, located in Pike County, Indiana, is a 250-acre refuse disposal area.
- Solution 1: 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 this AMD.
  - The Enos East Wetland (Project 979).
  - The Enos Loop Wetland (Project 898).
- Solution 2: Remining of Enos Gob Pile Slurry under the AML Enhancement Rule.

Project Location



- Located in Pike County, the historic center of the Indiana coalfield.
- Also near the eastern edge if the Illinois Coal Basin.
- Within the Watershed of the Patoka R. South Fk.



pH – 2.6
Acidity – 554 mg/l
Sulfate – 4400 mg/l

pH – 2.4
Acidity – 8800 mg/l
Sulfate – 22000 mg/l

pH – 2.8
Acidity – 1920 mg/l

pH – 2.2
Acidity – 2020 mg/l
Sulfate – 2700 mg/l

pH – 3.6
Acidity – 460 mg/l
Sulfate – 5100 mg/l

pH – 2.8
Acidity – 280 mg/l
Sulfate – 3400 mg/l

Patoka South Fork Watershed AMD Prior to IDNR Reclamation.

Enos Gob Pile Prior to IDNR Reclamation

Enos Loop Wetlands: Site Conditions

- Underlying and surrounding the refuse pile is mine spoil with a generally favorable neutralization potential – Partial *In Situ* neutralization of refuse-derived AMD.
- Alkaline water dilution and metal precipitation in the Enos East Wetland improves AMD.
- Additional seepage along the northern end of the pile degrades the water quality.
- Unusually wet weather and slurry remining are stressing the system!

Passive Treatment System - Design Elements:

- Addition of alkaline water (alkalinity = 242 mg/L) from adjacent pre-SMCRA mine impoundments.
- Construction of two vertical flow ponds (VFP) for additional alkalinity enhancement.
- Excavation of a series of oxidation ponds and aerobic wetlands for metal precipitation.
- Designed for large amount of acidic runoff during storm events -- 1.0 CFS (450 GPM); **actual post-construction peak flow (1.5 to 2.0 CFS or 670 to 900 GPM)!**

Solutions:

1) Enos East Treatment Wetland (Project 979).

2) Coal Fines Recovery via the AML Enhancement Rule.

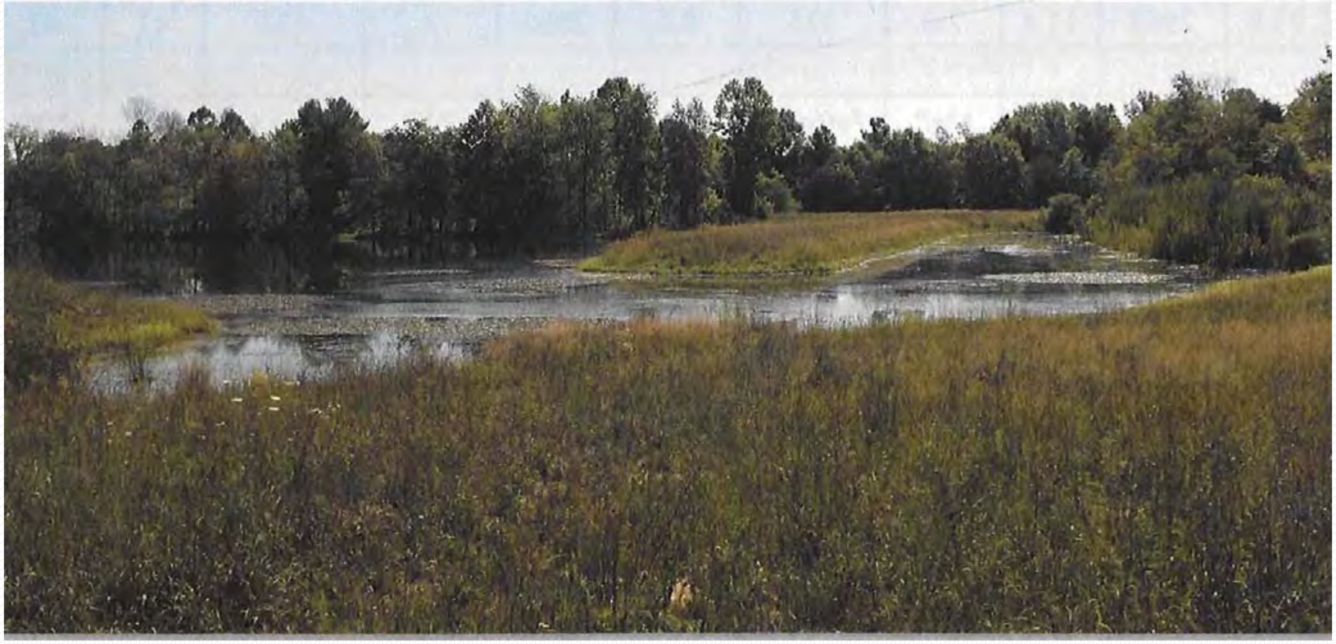
Enos Loop Wetland (Site 898) AMD

- Two AMD sources for East Wetland:
  - East Ditch (Site A) collects AMD from the east side of the gob pile.
  - West Ditch (Site B) collects AMD from southern part of the gob pile

Enos Loop Wetland (Site 898) Dilution

- **Fresh dilution water, regulated by a rebuilt gate valve an a new weir structure (pictured) regulates dilution water from a pre-law pit impoundment.**

Enos East Wetland (Site 979)



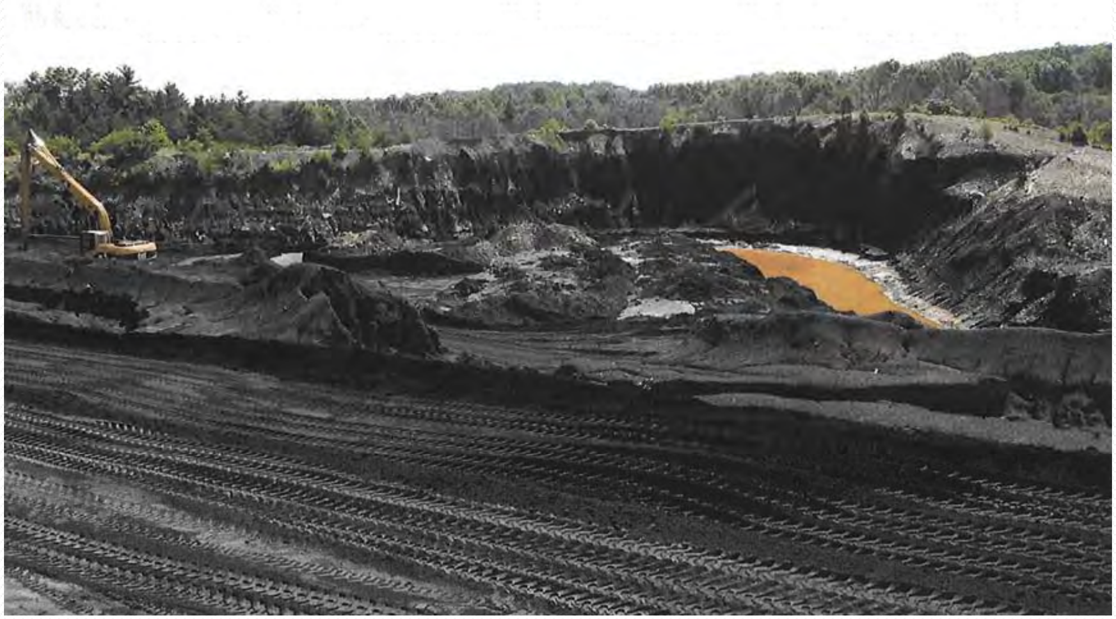
- A large aerobic wetland covering approximately 16 ac.
- Pre-treats AMD removing most of the iron and aluminum before the VFP’s in the Enos Loop Wetland.

Enos East Wetlands: Dilution Water

- Low in iron (0.3 mg/L).
- Low in aluminum (0.1 mg/L).
- Low in manganese (0.28 mg/L).
- Circumneutral pH (7.6).
- A significant amount of alkalinity (217 mg/L).
- Higher TDS (3,300 mg/L): SC = 3, 301.
- Elevated sulfate (1,600 mg/L).
- High hardness:
  - Calcium = 404 mg/L; Magnesium = 260 mg/L.

Solution 2: Remining

Fine Coal Reprocessing



Empty slurry cell and mitigation wetland

<u>Note</u>: Fe-bearing pit water and coarse refuse embankments.

Enos Gob Pile: North Face Seepage.

Parameter	Enos Gob Slurry Cell Discharge (Site F)	Truck Wash Pond *	Units
pH	2.32	4.5	
S.C.			µS/cm
T. Fe	961	36.25	mg/L
T. Al	54.0	1.45	mg/L
T. Mn	11.6	2.65	mg/L
Acidity	3,080**	90.2***	mg/L CCE
Sulfate	4,890	1,050	mg/L

* Partially-treated by lime-bearing acetylene additions.

** Lab analysis.

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

Enos Loop Wetlands: Inlet Water

Enos Loop Wetlands: Inlet Water

- Relatively low in iron (19 mg/L).
- Relatively low total acidity (127 mg/L).
- Moderate manganese (7.0 mg/L).
- Low pH (3.0).
- A significant amount of aluminum (5.2 mg/L).
- Higher TDS (1,800 mg/L): SC = 3, 033.
- Elevated sulfate (1,300 mg/L).

Solutions 3: Enos Loop Wetland

Enos Loop Wetlands: Initial Construction

- Parallel Vertical Flow Ponds (VFP) - Alkalinity Addition:
  - East – Dolomite VFP.
  - West – Limestone VFP.


Enos Loop (AML898) Passive Treatment System
Regulatory Site Treatment System
Surface Flow Wetland 2
Surface Flow Wetland 1
Oxidation Ponds
Surface Flow Wetland 3
East VFP
West VFP
Forebay
Tipple
"Acid Lake"

VFP Organic Layer

- **Estimated 3- to 4-foot thick vs. designed 2-foot thickness.**
- **Traditional organic material such as spent mushroom compost or yard-waste compost was unavailable.**
- **Hay-rich compost material was bulky and initially offered a relatively high hydraulic conductivity.**
- **Water layer is virtually eliminated allowing emergent plant life to grow.**

Placement of the Compost Layer: West VFP.

Emergent Vegetation: West VFP.

Vertical Flow Pond Performance

Parameter	East VFP (dolomite)	West VFP (limestone)	Units
pH	6.40	6.39	
T. Fe	29.40	35.95	mg/L
T. Mn	3.25	3.95	mg/L
T. Al	0.50	0.56	mg/L
Acidity	88.5	108.3	mg/L*
Alkalinity	106.0	82.0	mg/L*
SO_4	1,471	2,097	mg/L
TDS	3,228	3,293	mg/L

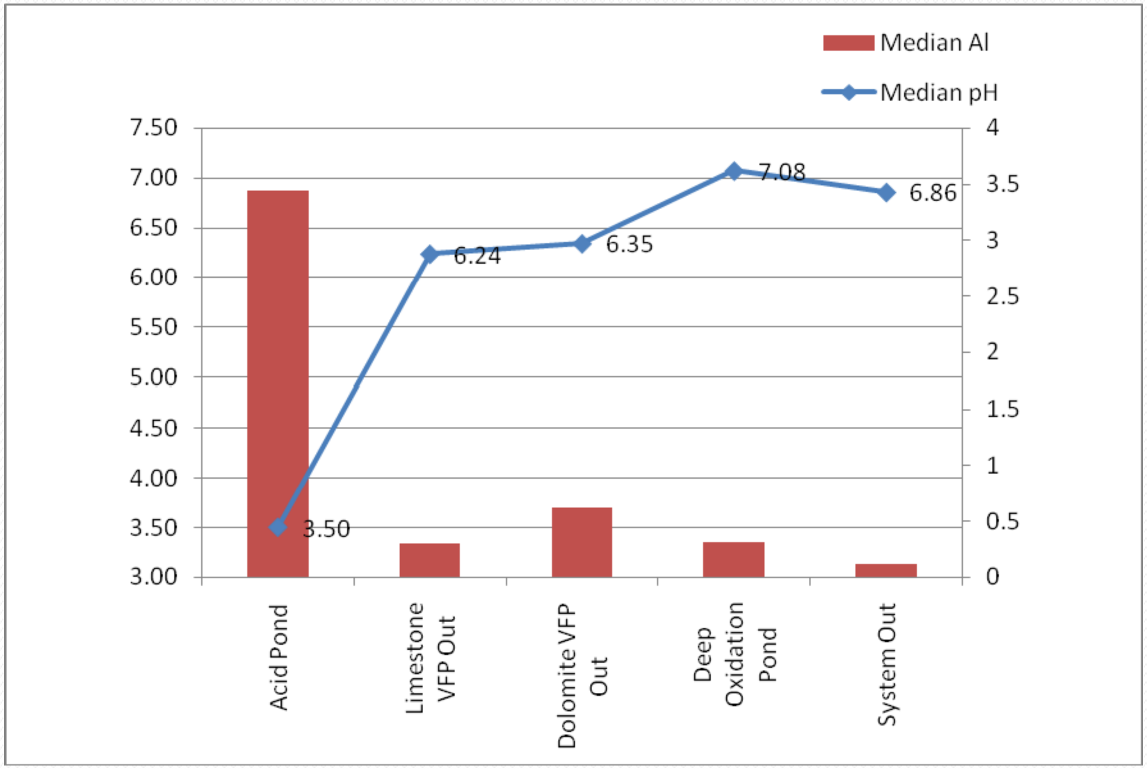
Median Pre-Failure VFP Performance

West (Limestone) VFP

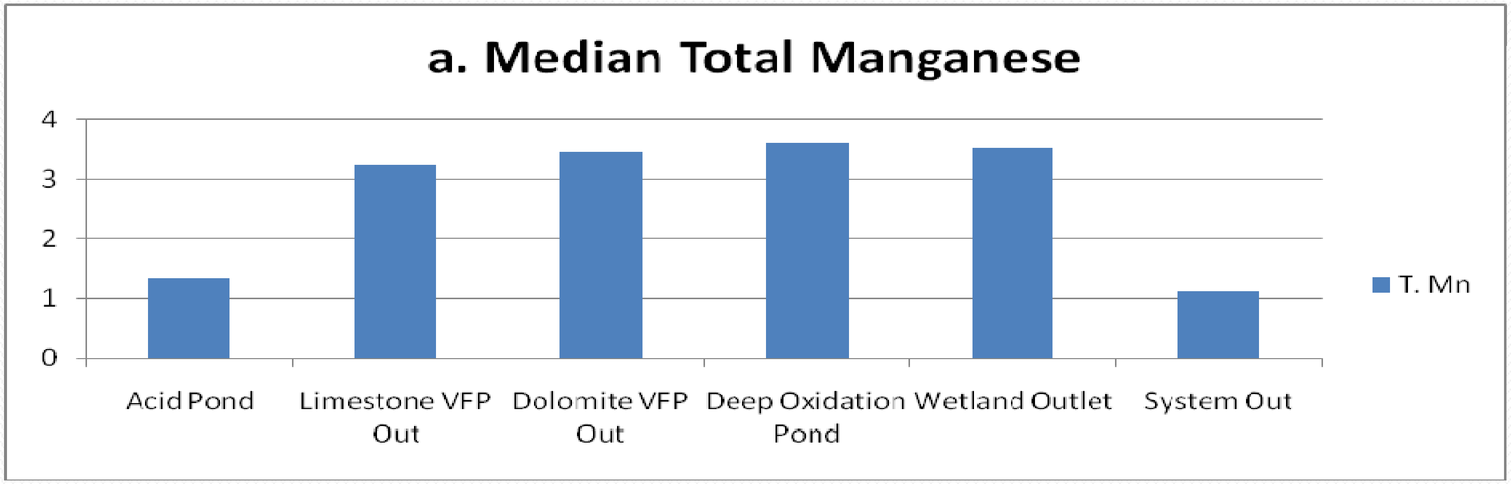
* Calcium carbonate equivalent.

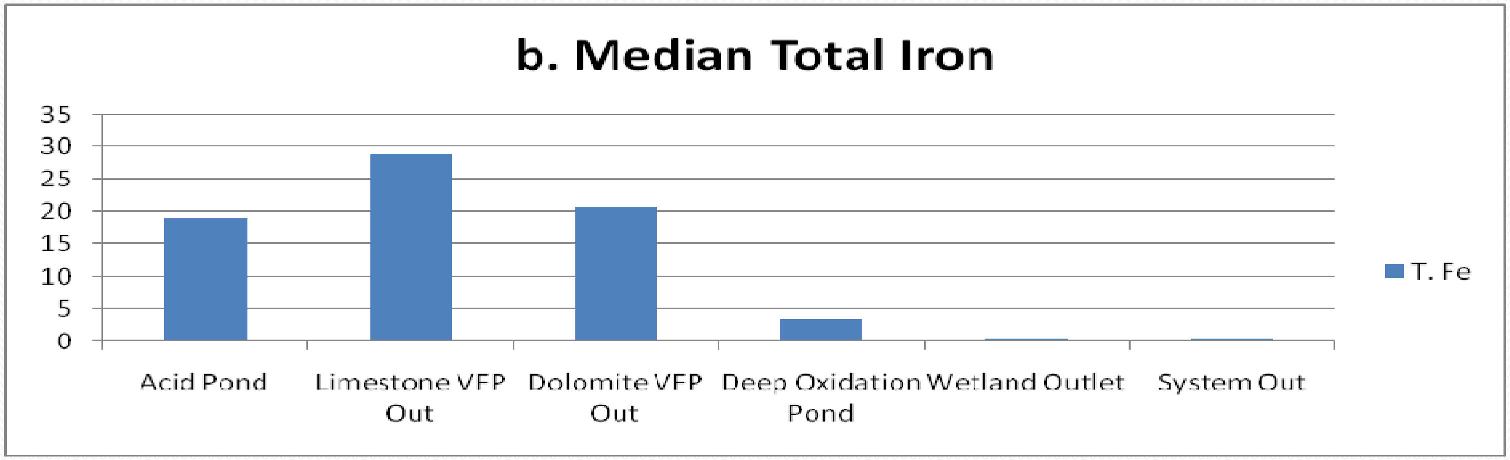
The Impact on the Aluminum Content due to Changes in pH within the Enos Loop Wetland

- Aluminum precipitates at a pH > 4.5



Pre-Reconstruction Enos Loop Wetland Performance





Enos Loop Wetlands: Initial Construction

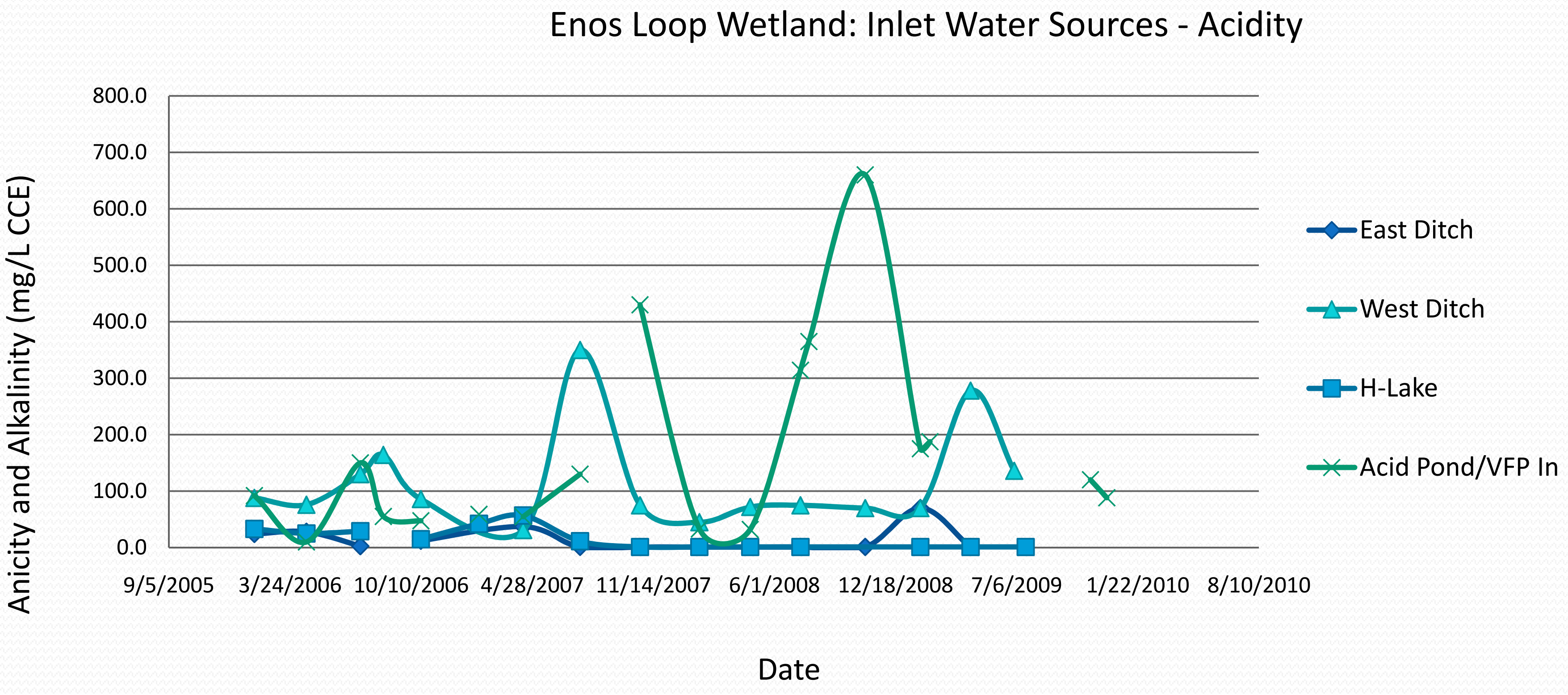
Loop Wetland:
System Discharge (Wetland 2 Outlet).

Parameter	System Outlet	Units
pH	6.81	
T. Fe	0.28	mg/L
T. Mn	1.50	mg/L
T. Al	0.13	mg/L
Acidity	10.0	mg/L*
Alkalinity	66.0	mg/L*
SO_4	1,474	mg/L
TDS	2,020	mg/L

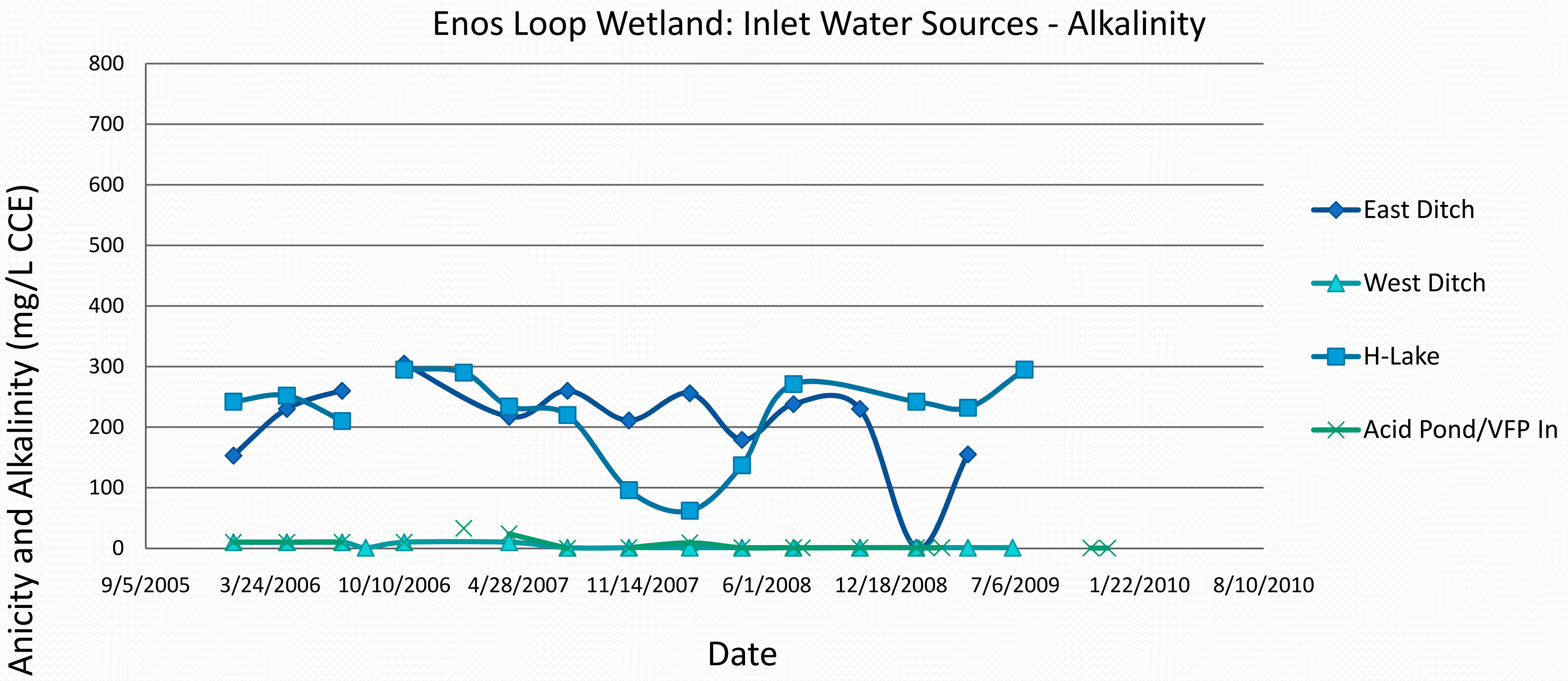
2008 VFP Failure: Possible Mechanisms

- Surface water runoff: variable flow and quality.
  - Treatment of storm water.
  - Unusually wet weather.
  - Seepage/drainage from remining operation.
- Metal accumulation in VFP's.
- Construction issues with VFP's.
- Reduction in available carbon.

2008 System Failure: Impact of Inlet Water Quality - Remining Acidity Increase?

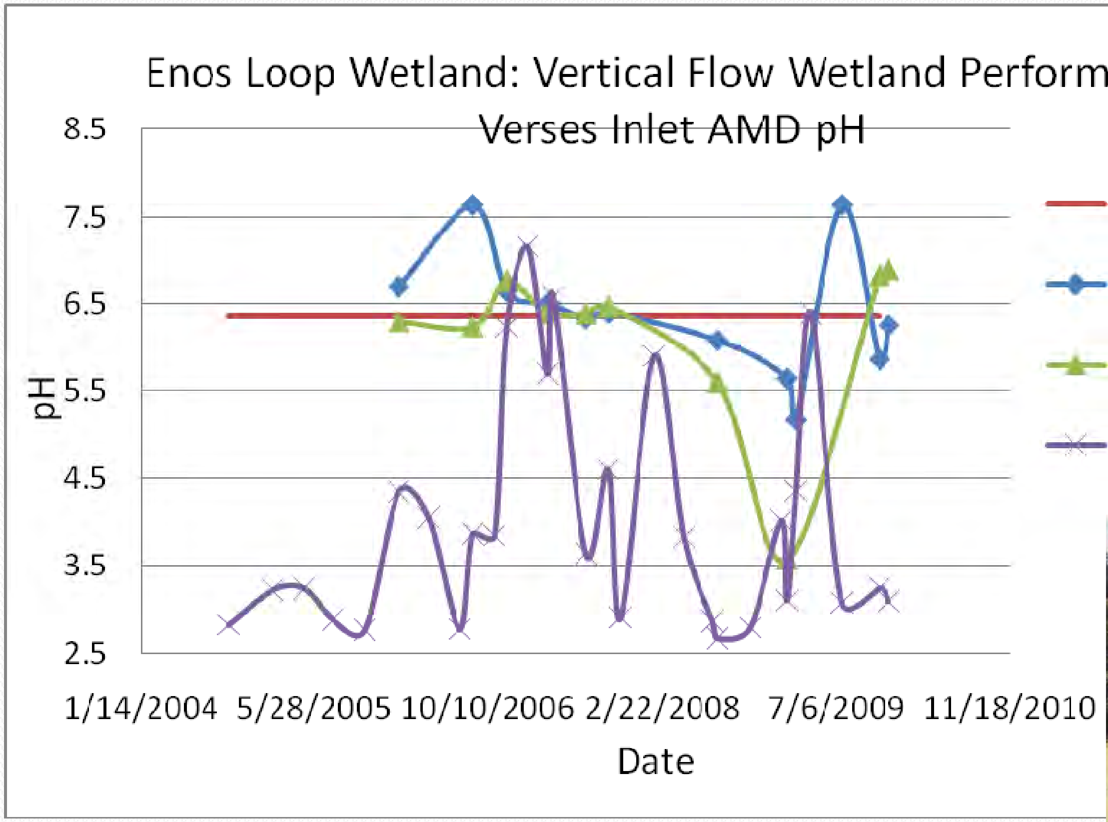


2008 System Failure: Impact of Inlet Water Quality – Reduction in Dilution Water Alkalinity -- Why?



Is the reduction in dilution water due to weather and/or remining?

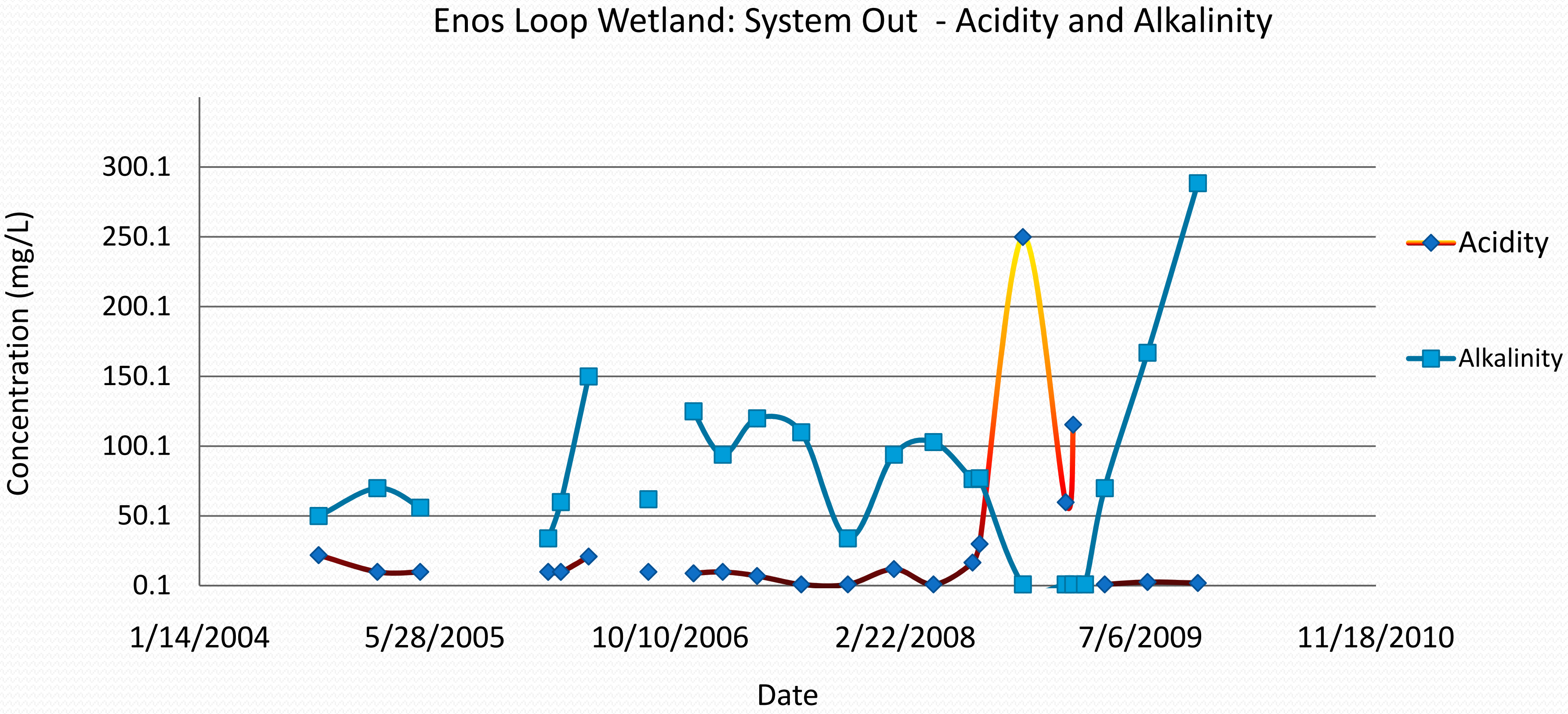
2008 System Failure: Impact of VFP Performance



East VFP

Low pH = high flow?

2008 System Failure: Impact of VFP Performance on Discharge Water Quality



Geochemical Modeling of VFP Discharge

- East (dolomitic limestone) VFP:
  - Saturated with respect to K-jarosite (sample n=4).
  - Variable saturated, unsaturated with respect to:

    Na-jarosite, alunite, gibbsite, calcite, and $Fe(OH)_3$ precipitate.
- West (limestone) VFP:
  - Saturated with respect to K-jarosite (sample n=4).
  - Variable saturated, unsaturated with respect to:

    Na-jarosite, alunite, gibbsite, and $Fe(OH)_3$ precipitate.

Gypsum, anhydrite, and siderite were undersaturated!

Preliminary Post Construction Performance

Parameter	Acid Pond (inlet)	Bioreactor dolomite	West VFP limestone	Units
pH	3,17	6.85	5.86	
T. Fe	17.36	5.86	53.80	mg/L
T. Mn	1.55	2.38	4.21	mg/L
T. Al	4.72	0.88	0.78	mg/L
Acidity	104.2	12.2	374.7	mg/L *
Alkalinity	<1	471	345	mg/L *
SO_4	1,710	1,738	2,267	mg/L
TDS	2,582	2,627	4,870	mg/L

Median Post-Failure VFP Performance

West (Limestone) VFP

* Calcium carbonate equivalent.

*Enos Loop Wetlands: Post-Reconstruction**

Loop Wetland:
System Discharge (Wetland 2 Outlet).

** Preliminary Results*

Parameter	Pre-2008 System Out	Post-2008 System Out *	Units
pH	6.81	7.42	
T. Fe	0.28	0.17	mg/L
T. Mn	1.50	0.81	mg/L
T. Al	0.13	0.07	mg/L
Acidity	10.0	2.4	mg/L*
Alkalinity	66.0	225	mg/L*
SO_4	1,474	1,332	mg/L
TDS	2,020	2,757	mg/L

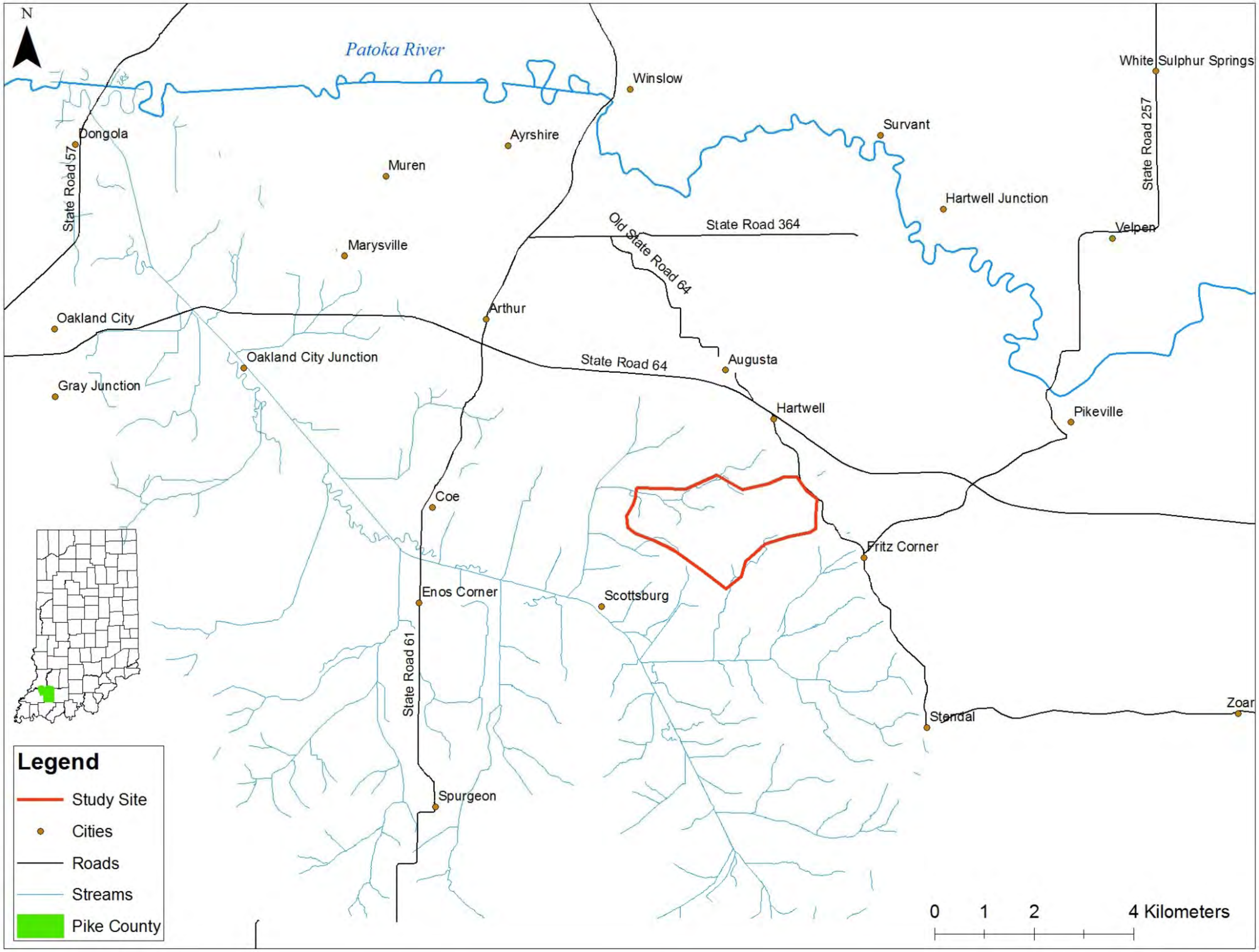
The End: Questions?

Evaluating the Outcomes of an Experiment Aimed at Manipulating the Hydrology in the Vicinity of an Acid Seep

cgda Center for Geospatial Data Analysis

Indiana Geological Survey 1837 Indiana University

- *Water Level and Flow Monitoring*
- *Chemical Sampling and Analysis*
- *Groundwater Flow Modeling*


N
Patoka River
Winslow
White Sulphur Springs
Dongola
Ayrshire
Survant
Muren
State Road 57
State Road 257
Hartwell Junction
State Road 364
Velpen
Old State Road 64
Marysville
Arthur
Oakland City
Oakland City Junction
State Road 64
Augusta
Gray Junction
Hartwell
Pikeville
Coe
Fritz Corner
Enos Corner
Scottsburg
State Road 61
Stendal
Zoar
Spurgeon
Legend
Study Site
Cities
Roads
Streams
Pike County
0
1
2
4 Kilometers


N
W
E
S
East Flume
MOAS
MW2
West Flume
NMW1
MW1
NW2
MW4
MW5
MW6
Legend
● Flumes
● Monitoring Wells
0 50 100 200 Meters

MOAS

pH: 3.5

Acidity: 826 mg/l

Alkalinity: 0 mg/l

Total Al: 98 mg/l

Total Fe: 54 mg/l

Sulfate: 3464 mg/l

pH: 5.9

Acidity: 96 mg/l

Alkalinity: 137 mg/l

Total Al: 1 mg/l

Total Fe: 27 mg/l

Sulfate: 2958 mg/l

Elevation = 490.34 ft (149.45 m)

Seep Discharge ~ 50 – 70 gpm

East Flume

pH: 2.9

Acidity: 1390 mg/l

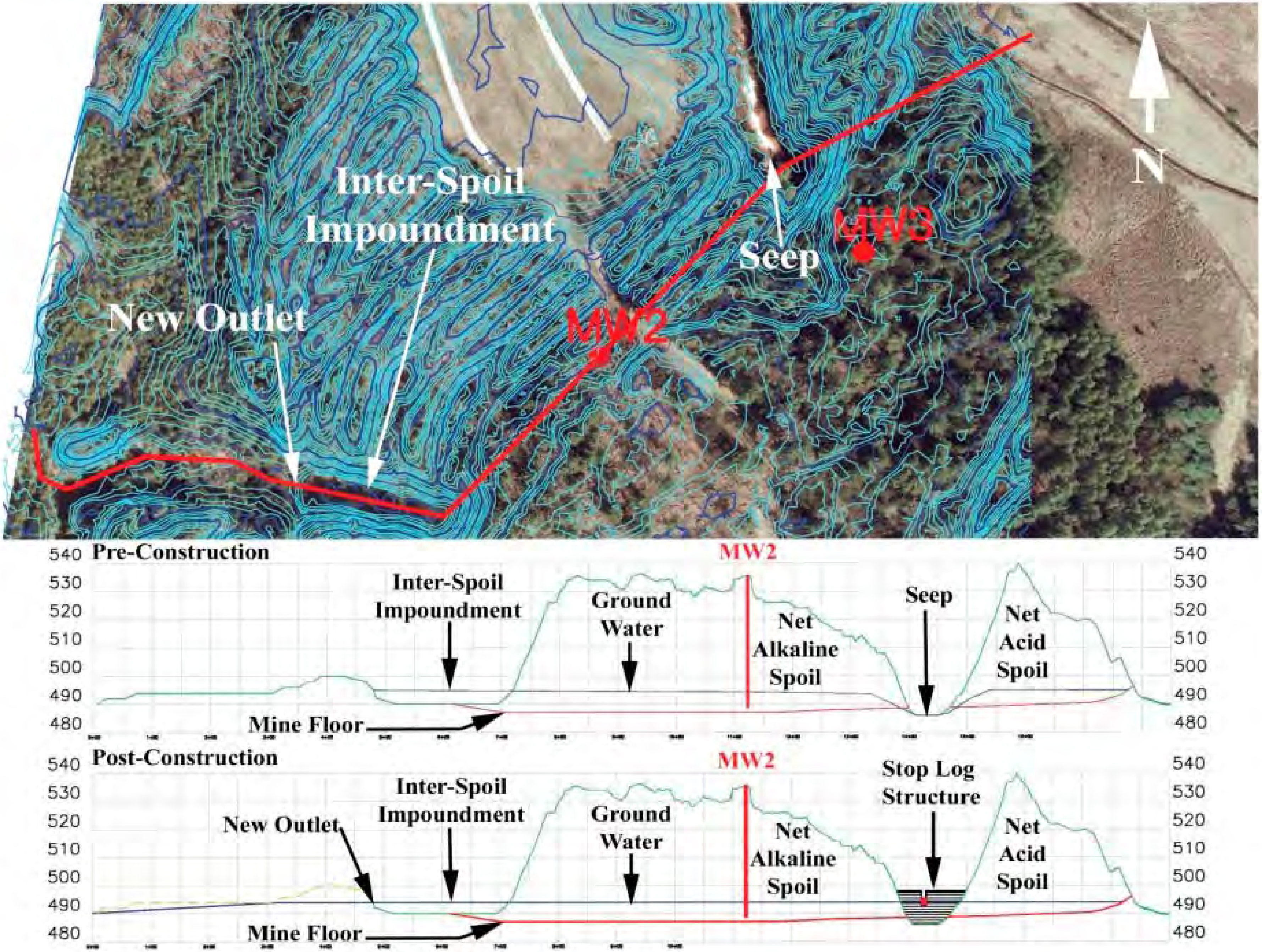
Alkalinity: 0 mg/l

Total Al: 166 mg/l

Total Fe: 133 mg/l

Sulfate: 4910 mg/l

Elevation = 486.9 ft (148.4 m)   Discharge ~ 30 gpm



N
Inter-Spoil Impoundment
Seep
MW3
New Outlet
MW2
Pre-Construction
MW2
Inter-Spoil Impoundment
Ground Water
Net Alkaline Spoil
Seep
Net Acid Spoil
Mine Floor
540
530
520
510
500
490
480
Post-Construction
MW2
New Outlet
Inter-Spoil Impoundment
Ground Water
Net Alkaline Spoil
Stop Log Structure
Net Acid Spoil
Mine Floor
540
530
520
510
500
490
480

West Flume

pH: 6.0

Acidity: 100 mg/l

Alkalinity: 73 mg/l

Total Al: 1 mg/l

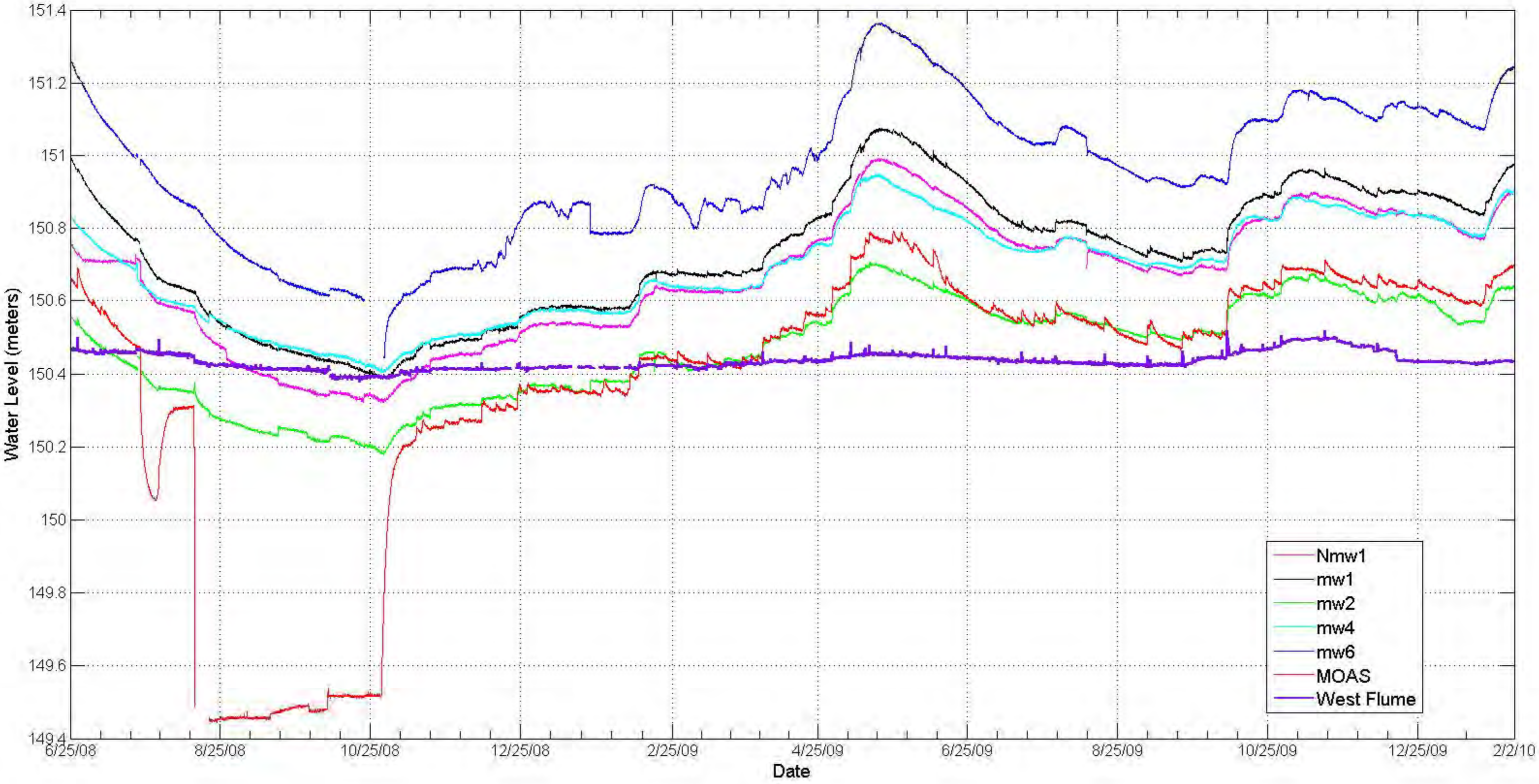
Total Fe: 24 mg/l

Sulfate: 2630 mg/l

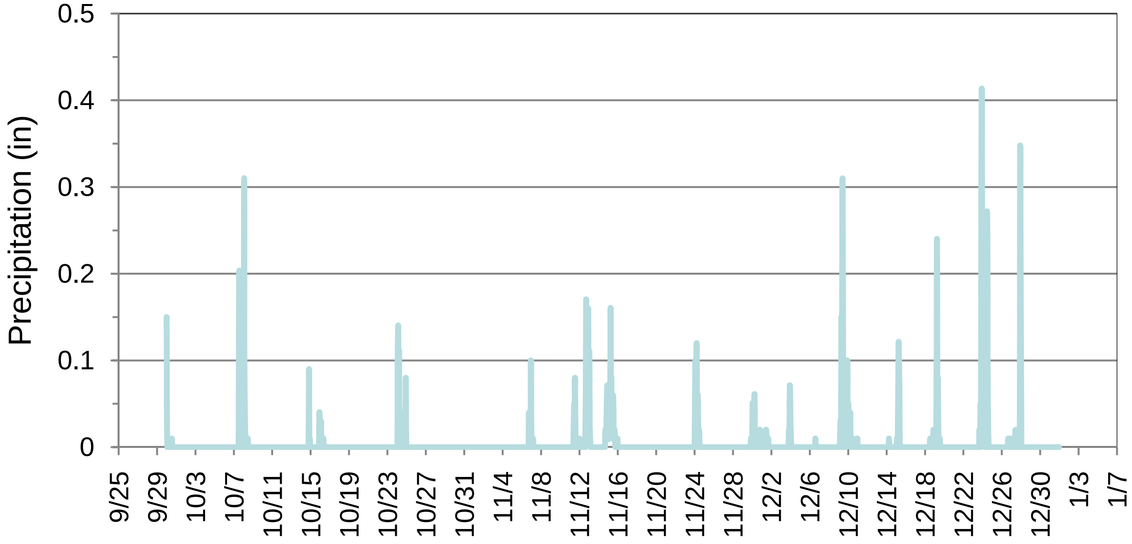
Elevation = 493.4 ft

(150.38 m)

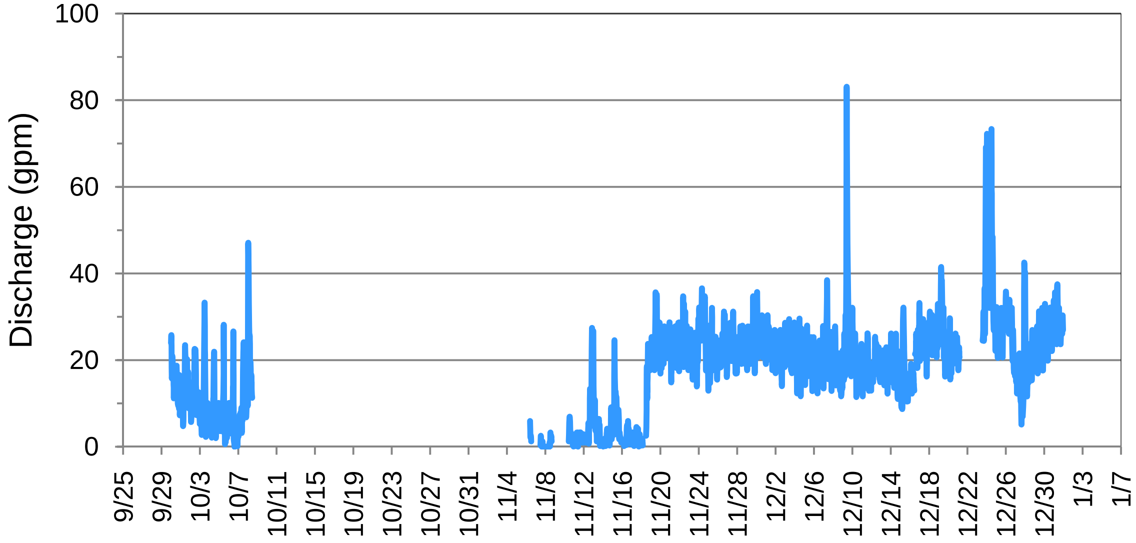
Discharge
~25 gpm


151.4
151.2
151
150.8
150.6
150.4
150.2
150
149.8
149.6
149.4
Water Level (meters)
6/25/08
8/25/08
10/25/08
12/25/08
2/25/09
4/25/09
6/25/09
8/25/09
10/25/09
12/25/09
2/2/10
Date
Nmw1
mw1
mw2
mw4
mw6
MOAS
West Flume

West Flume

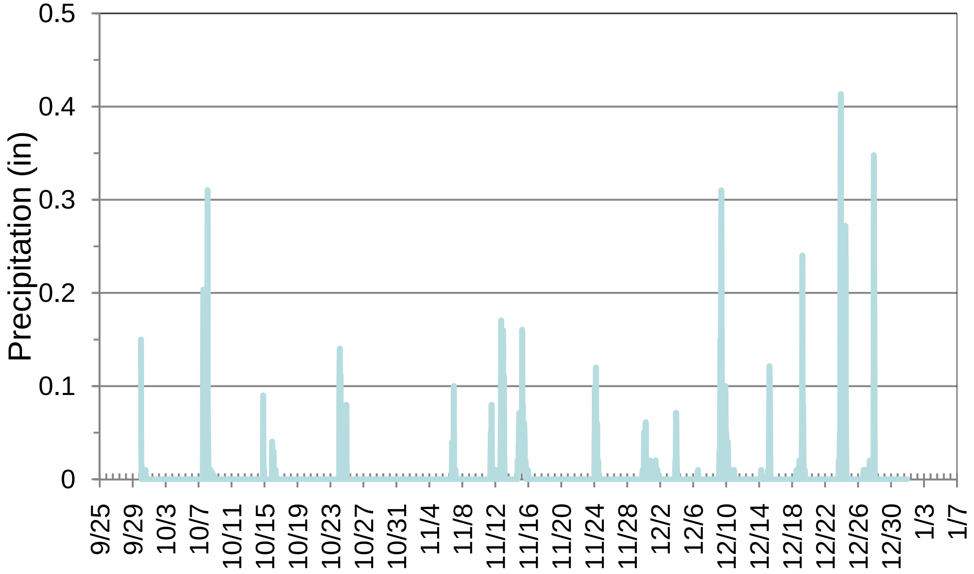


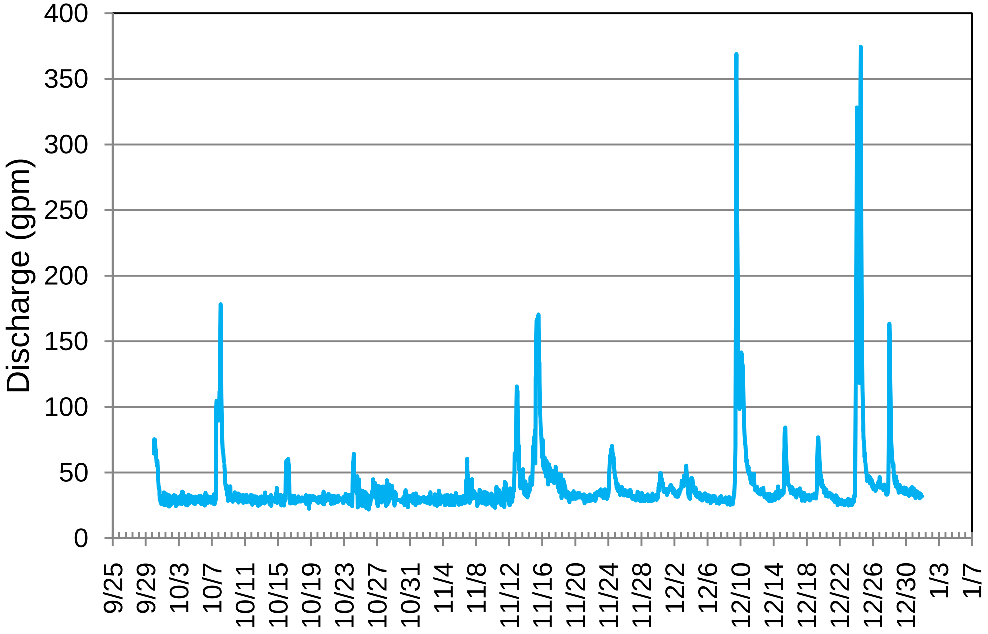
Precipitation (in)
0.5
0.4
0.3
0.2
0.1
0
9/25
9/29
10/3
10/7
10/11
10/15
10/19
10/23
10/27
10/31
11/4
11/8
11/12
11/16
11/20
11/24
11/28
12/2
12/6
12/10
12/14
12/18
12/22
12/26
12/30
1/3
1/7



Discharge (gpm)
100
80
60
40
20
0
9/25
9/29
10/3
10/7
10/11
10/15
10/19
10/23
10/27
10/31
11/4
11/8
11/12
11/16
11/20
11/24
11/28
12/2
12/6
12/10
12/14
12/18
12/22
12/26
12/30
1/3
1/7

East Flume


Precipitation (in)
0.5
0.4
0.3
0.2
0.1
0
9/25
9/29
10/3
10/7
10/11
10/15
10/19
10/23
10/27
10/31
11/4
11/8
11/12
11/16
11/20
11/24
11/28
12/2
12/6
12/10
12/14
12/18
12/22
12/26
12/30
1/3
1/7


Discharge (gpm)
400
350
300
250
200
150
100
50
0
9/25
9/29
10/3
10/7
10/11
10/15
10/19
10/23
10/27
10/31
11/4
11/8
11/12
11/16
11/20
11/24
11/28
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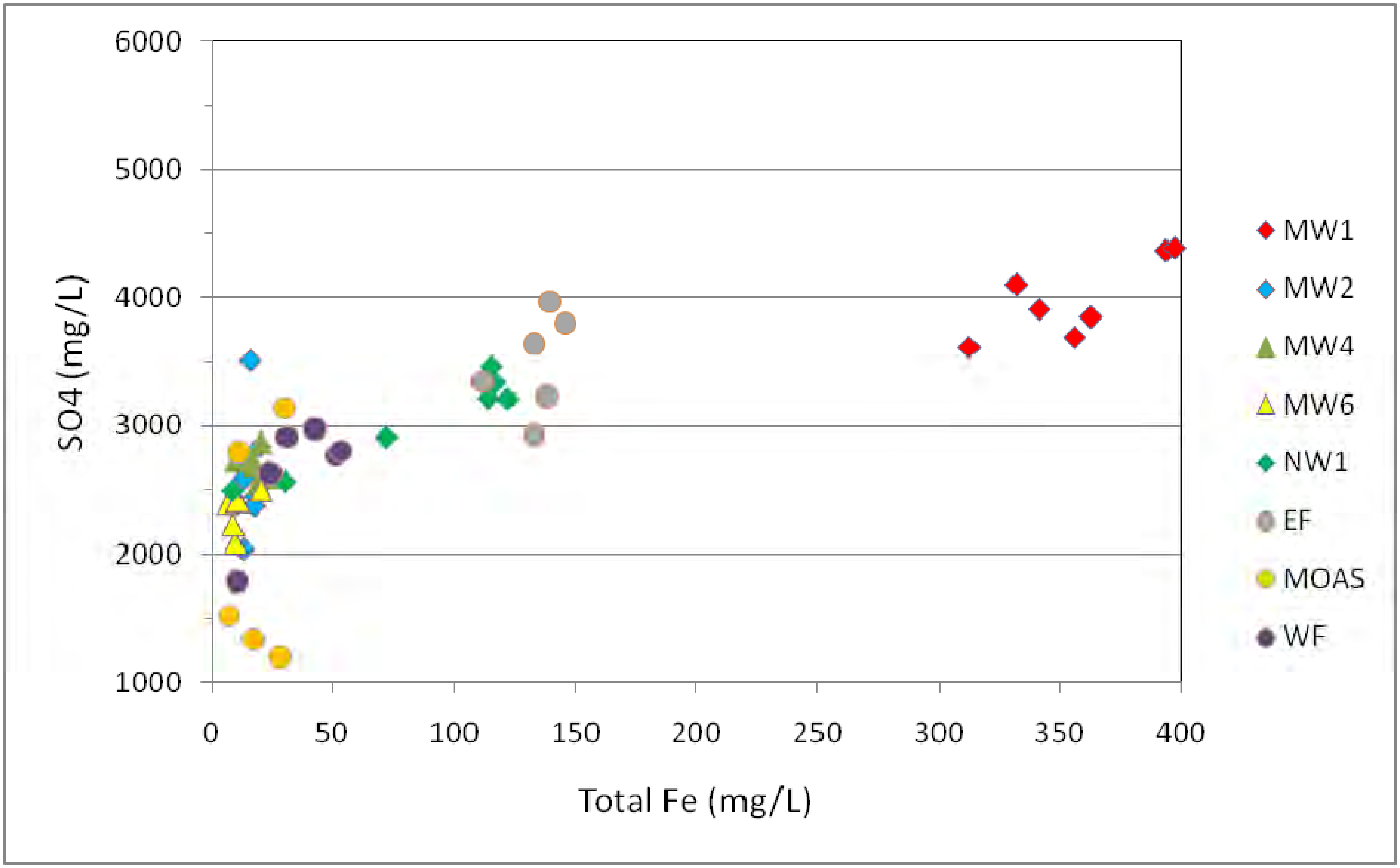
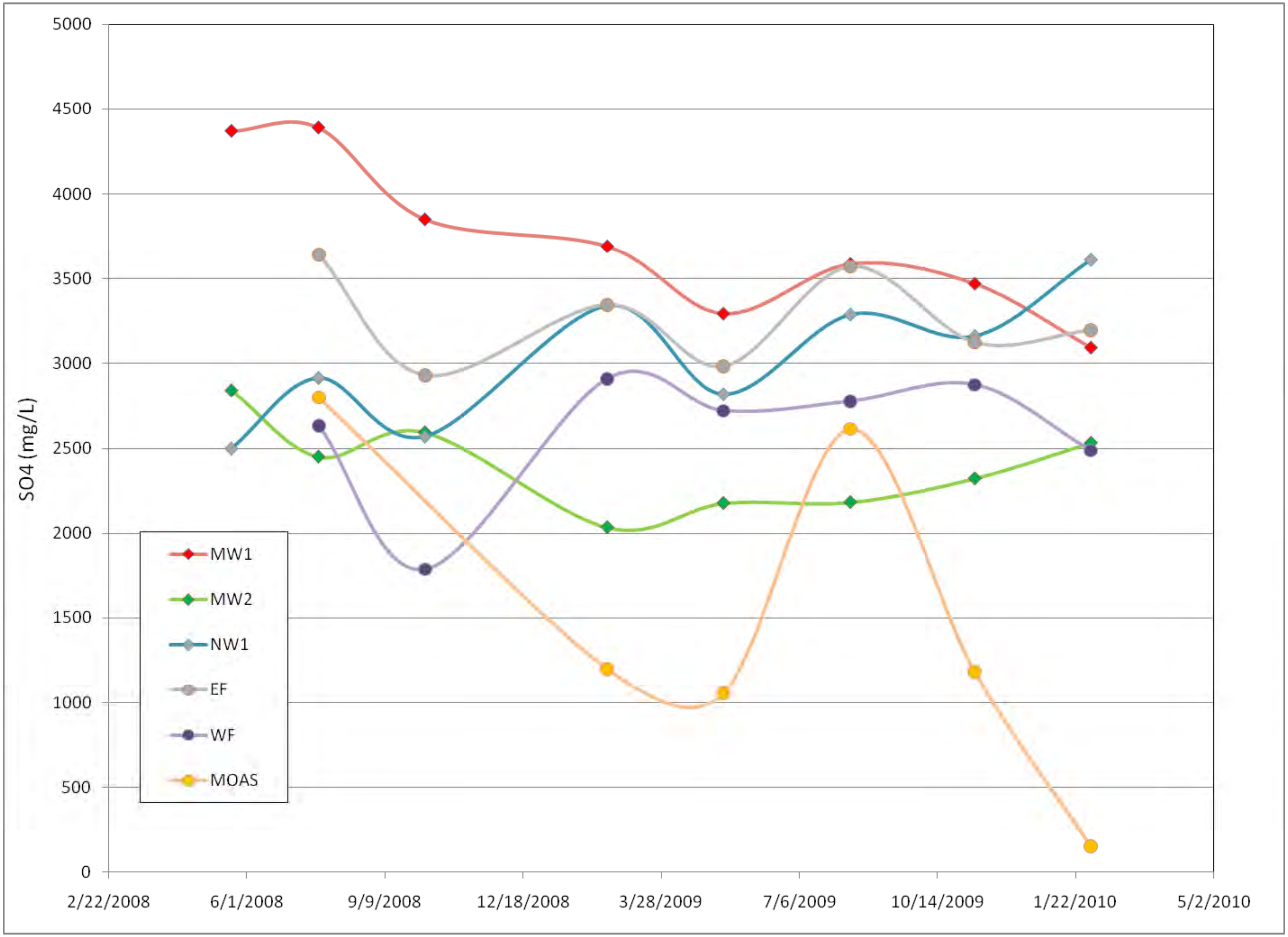
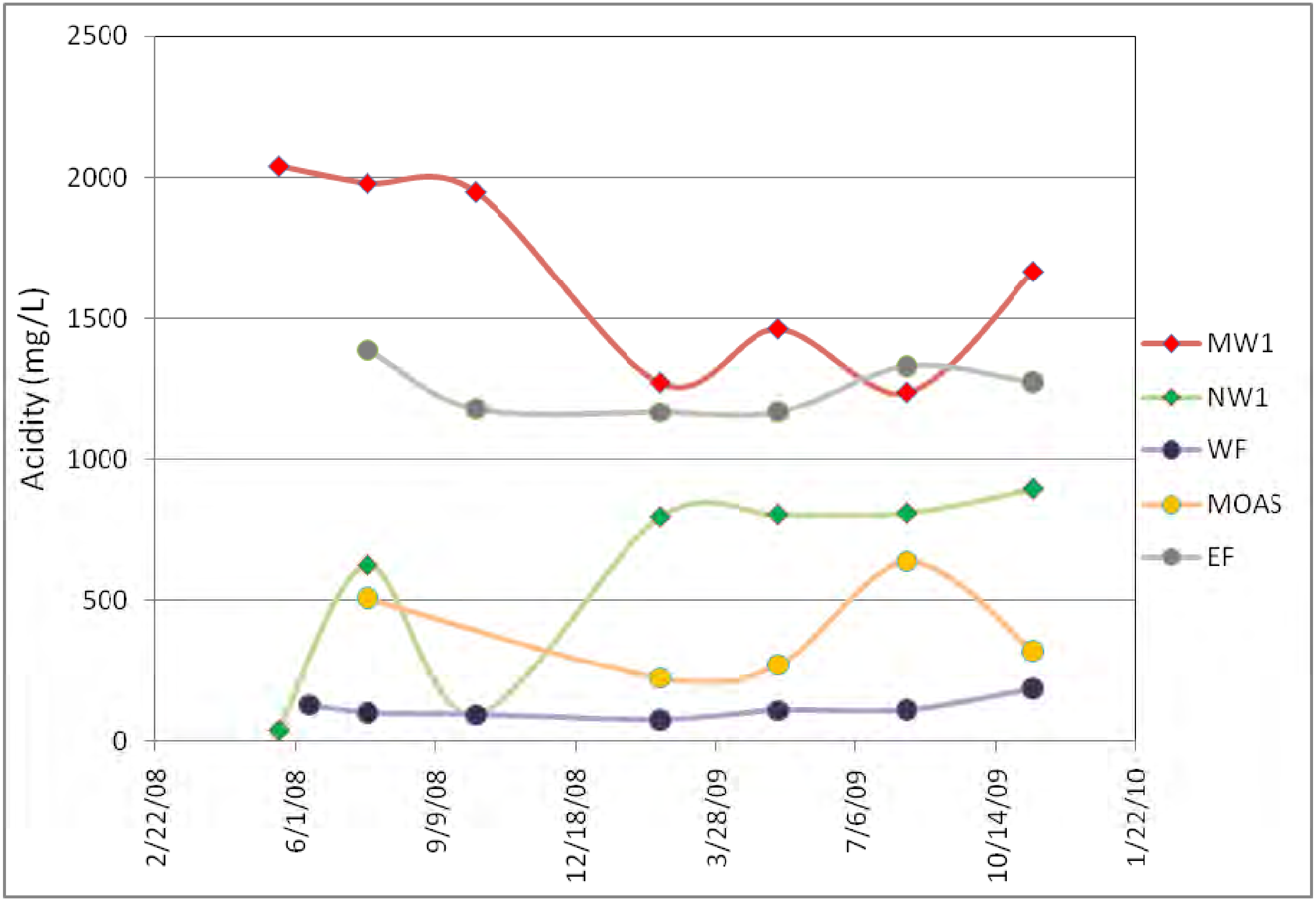
12/6
12/10
12/14
12/18
12/22
12/26
12/30
1/3
1/7

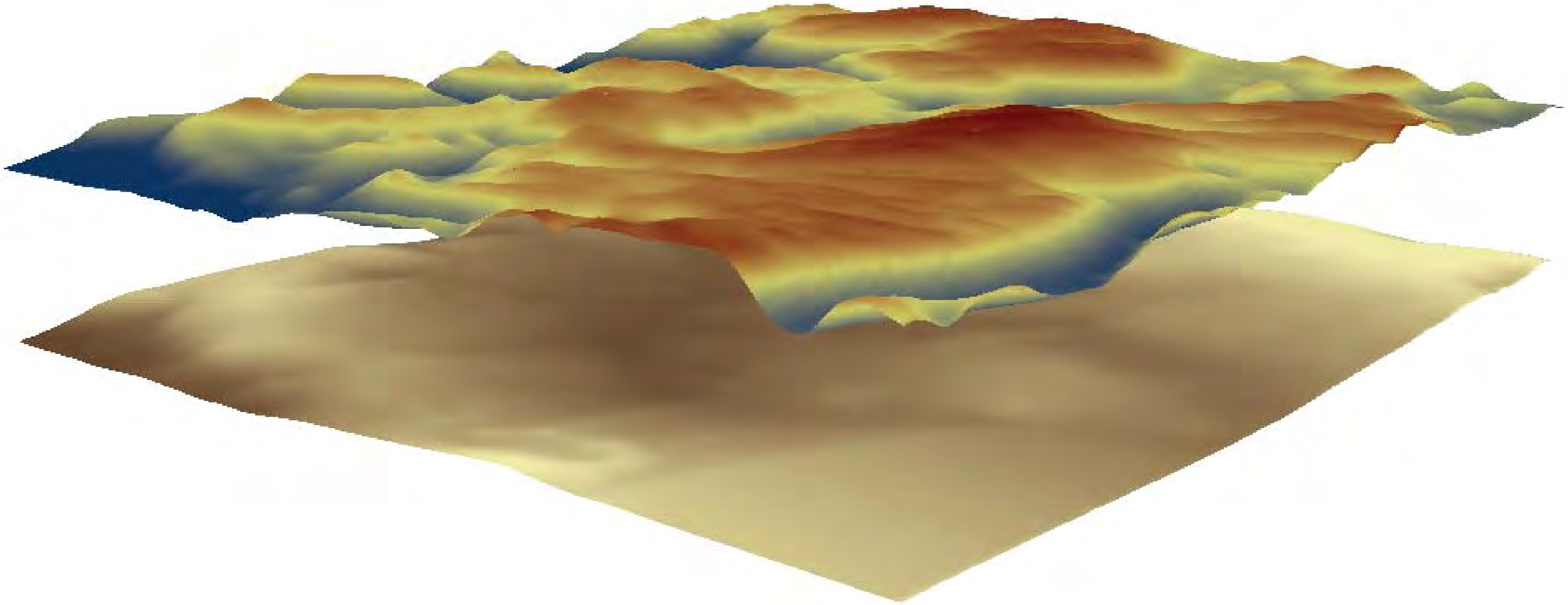

6000
5000
4000
3000
2000
1000
SO4 (mg/L)
0
50
100
150
200
250
300
350
400
Total Fe (mg/L)
MW1
MW2
MW4
MW6
NW1
EF
MOAS
WF

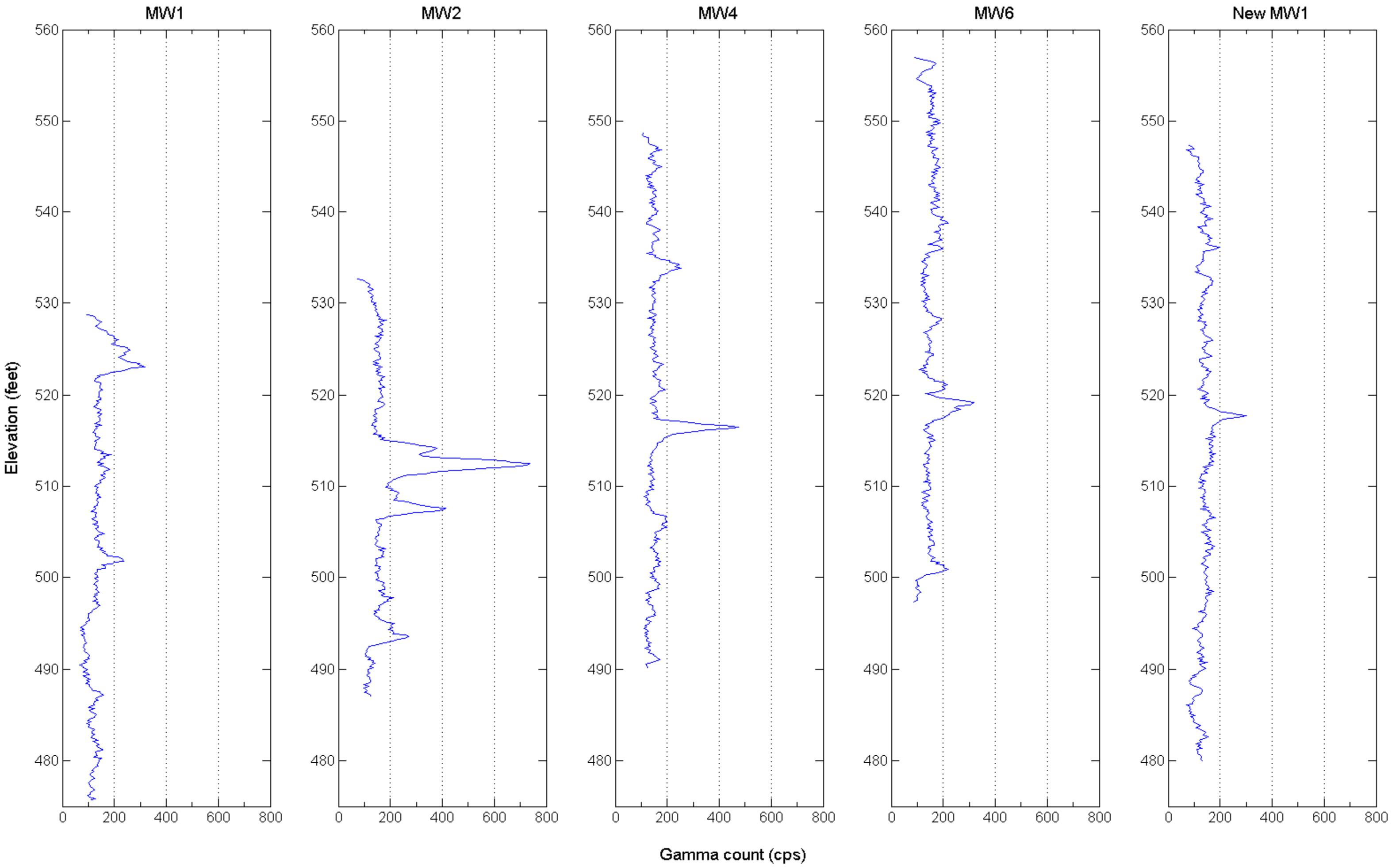

5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
SO4 (mg/L)
2/22/2008
6/1/2008
9/9/2008
12/18/2008
3/28/2009
7/6/2009
10/14/2009
1/22/2010
5/2/2010
MW1
MW2
NW1
EF
WF
MOAS



Acidity (mg/L)
2500
2000
1500
1000
500
0
2/22/08
6/1/08
9/9/08
12/18/08
3/28/09
7/6/09
10/14/09
1/22/10
MW1
NW1
WF
MOAS
EF

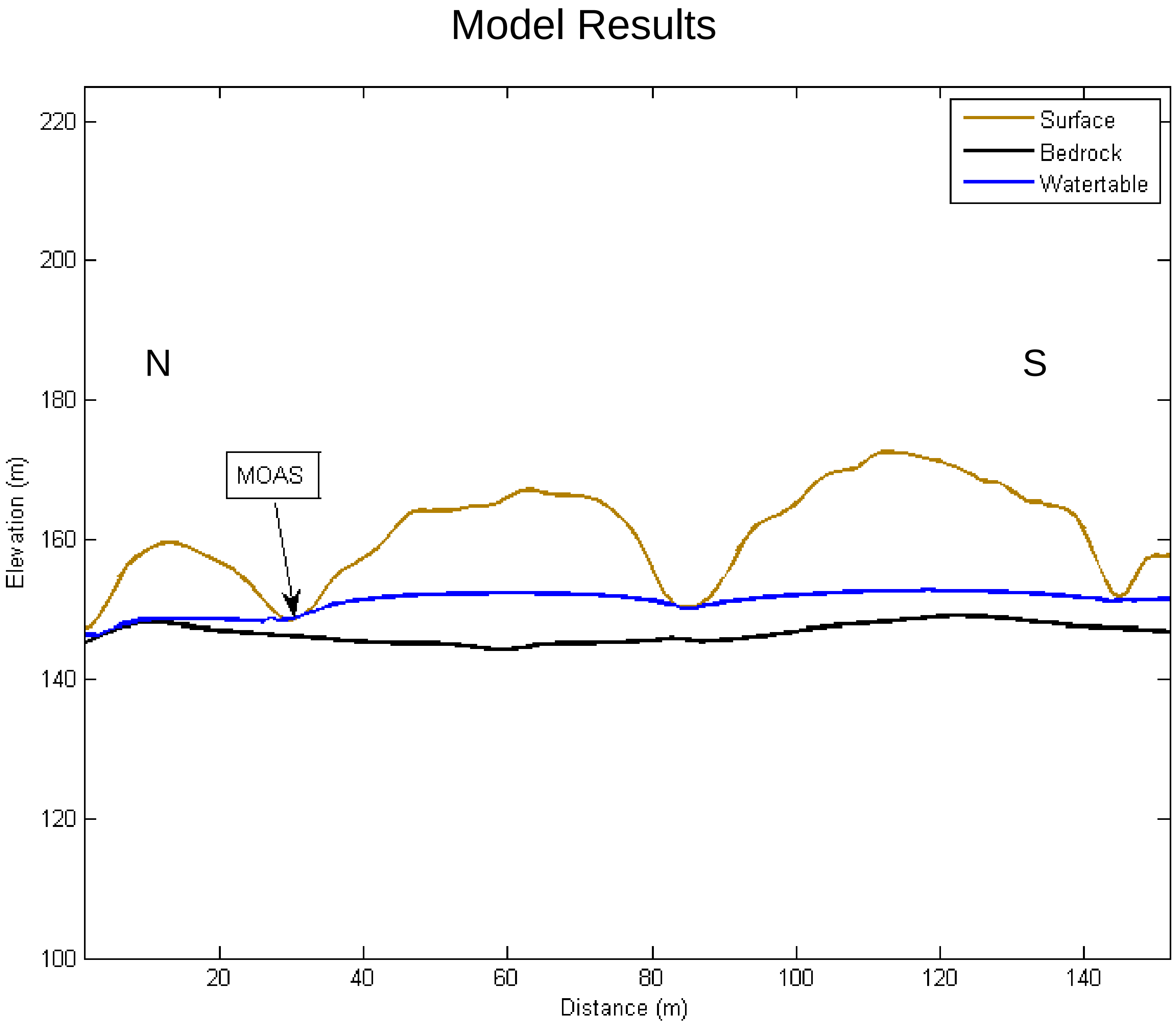
Top and Bottom of 3D Groundwater Flow Model



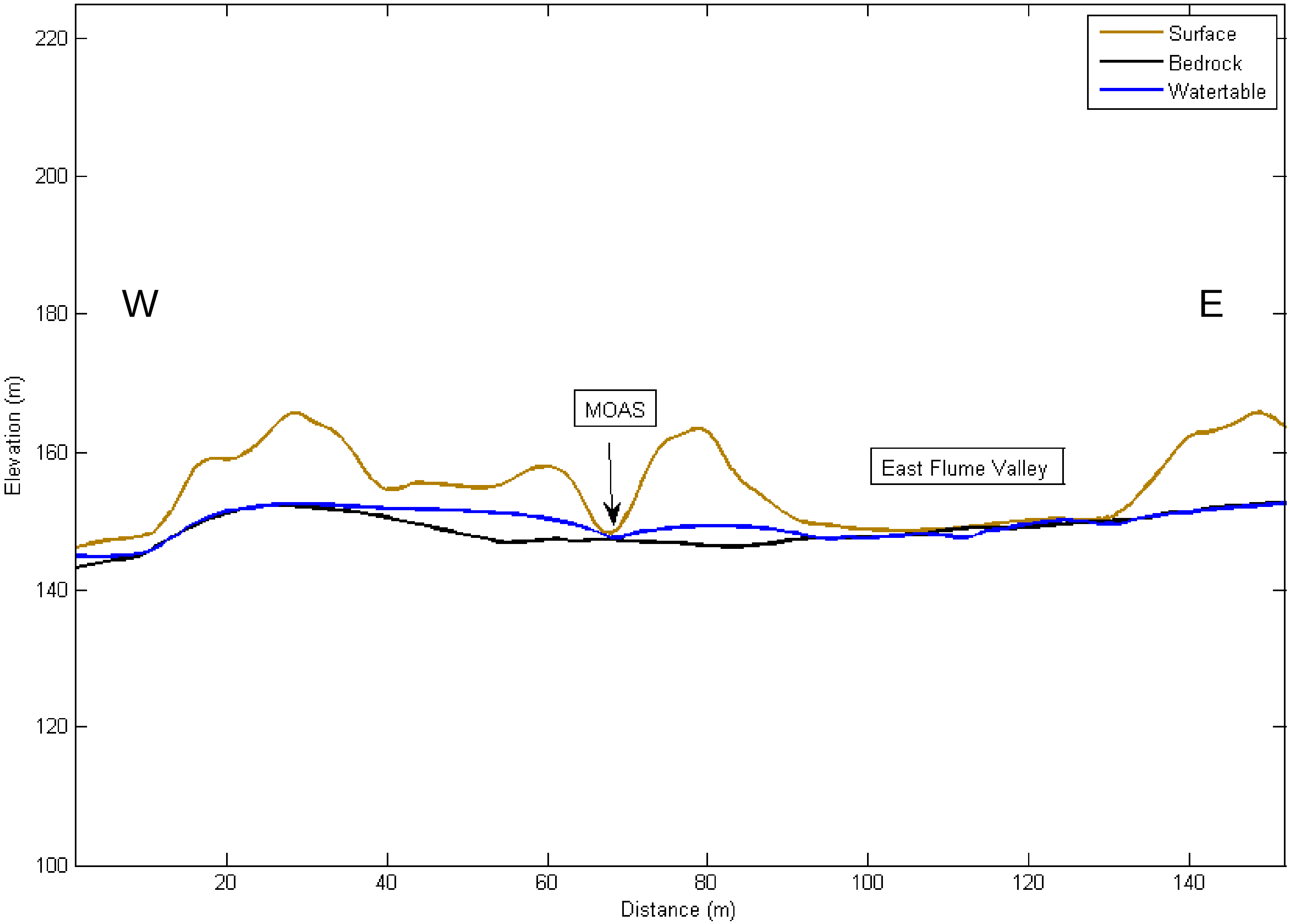


Slug Test Results

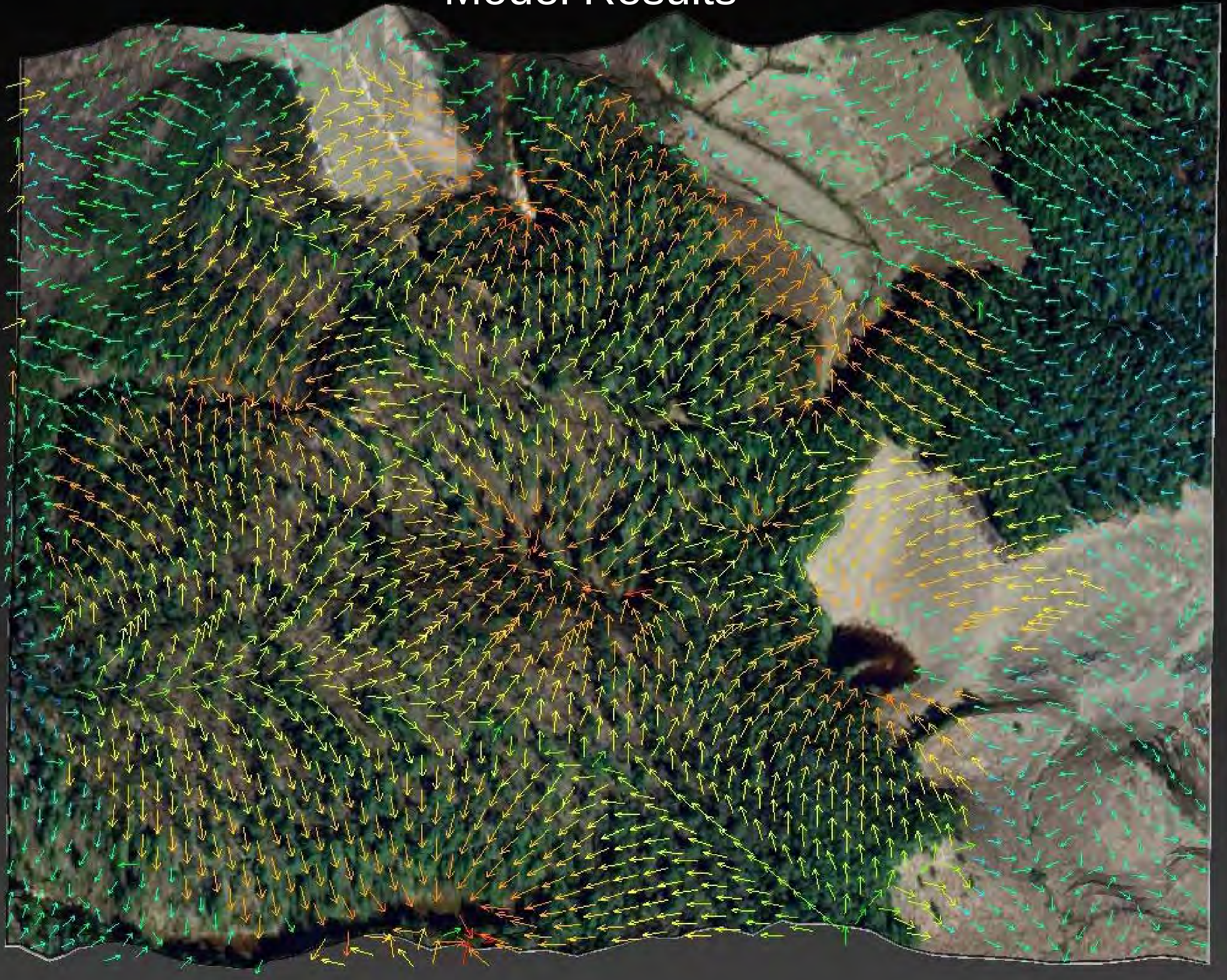
K_s: $1\text{x}10^{-1}$ – $2\text{x}10^{-2}$ cm/s


Model Results
Surface
Bedrock
Watertable
N
S
MOAS
Elevation (m)
220
200
180
160
140
120
100
Distance (m)
20
40
60
80
100
120
140

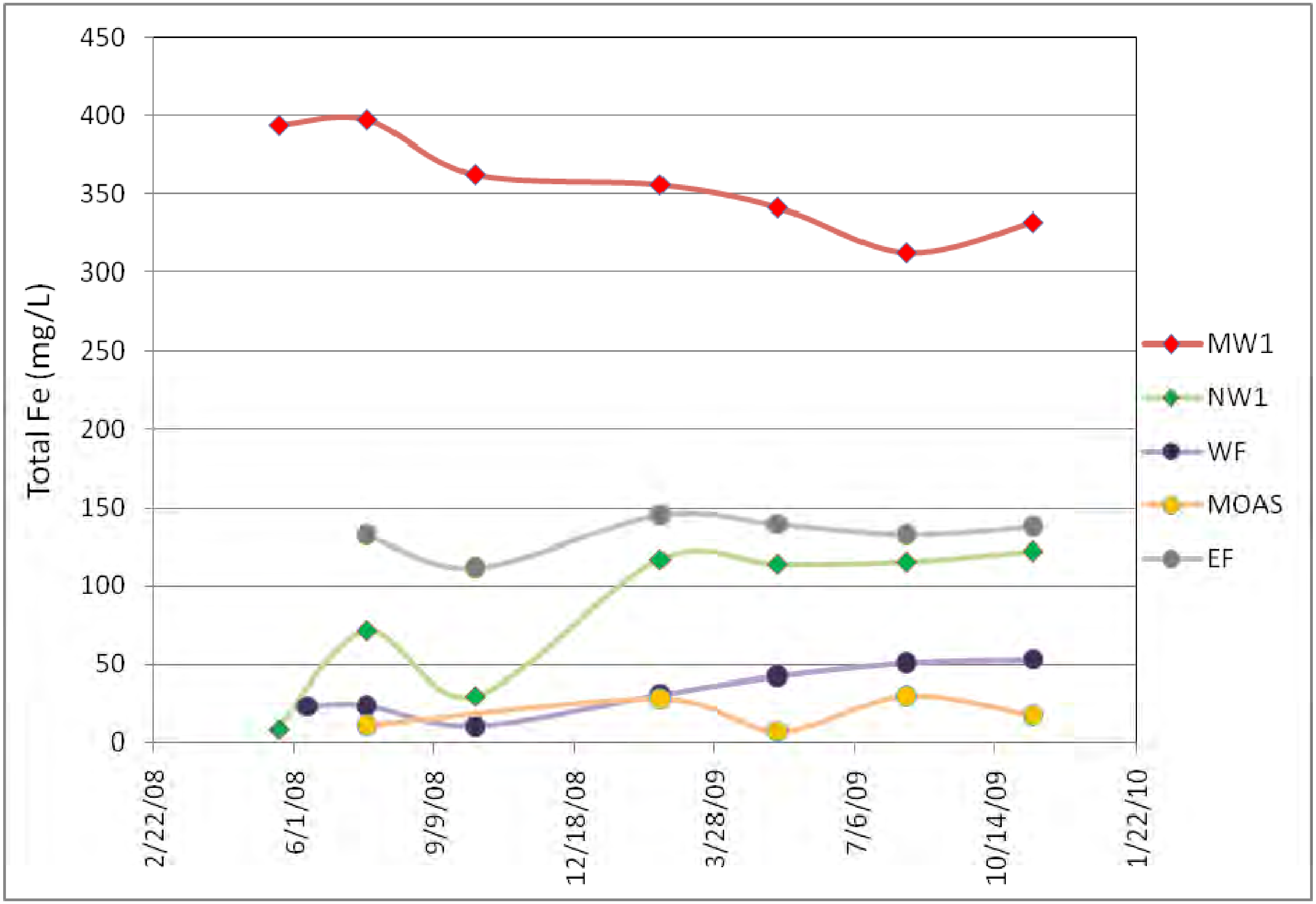
Model Results



Model Results



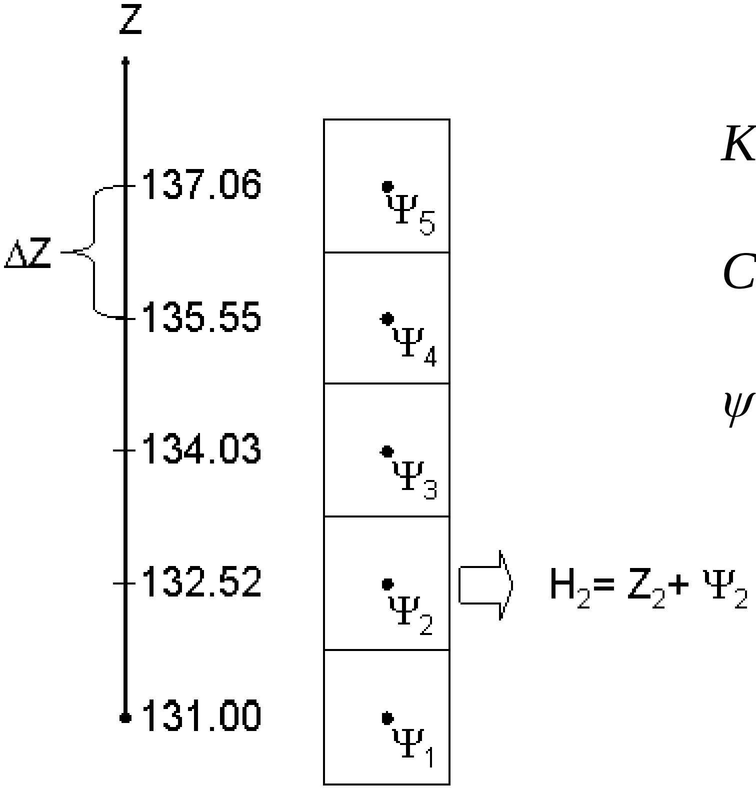
Max = 448 cm/d
Mean = 14 cm/d


Total Fe (mg/L)
450
400
350
300
250
200
150
100
50
0
2/22/08
6/1/08
9/9/08
12/18/08
3/28/09
7/6/09
10/14/09
1/22/10
MW1
NW1
WF
MOAS
EF

Model Equations 1. 3D Variably Saturated Ground Water Flow

from Freeze, 1971

$$\frac{\partial}{\partial x}\left[K(\psi)\frac{\partial \psi}{\partial x}\right]+\frac{\partial}{\partial y}\left[K(\psi)\frac{\partial \psi}{\partial y}\right]+\frac{\partial}{\partial z}\left[K(\psi)\left(\frac{\partial \psi}{\partial z}+1\right)\right]=C(\psi)\frac{\partial \psi}{\partial t}$$



K: hydraulic conductivity, pressure dependent in the unsaturated zone.

$C=\partial\theta/\partial\psi$: specific moisture capacity, pressure dependent in the unsaturated zone.

ψ: pressure head, negative in the unsaturated zone.

Model Equations 2: Soil Water Characteristics

from van Genuchten 1980

$$Se = \frac{\theta(\psi) - \theta_r}{\theta_s - \theta_r} = \left[1 + \left(\alpha|\psi|\right)^n\right]^{-m}$$

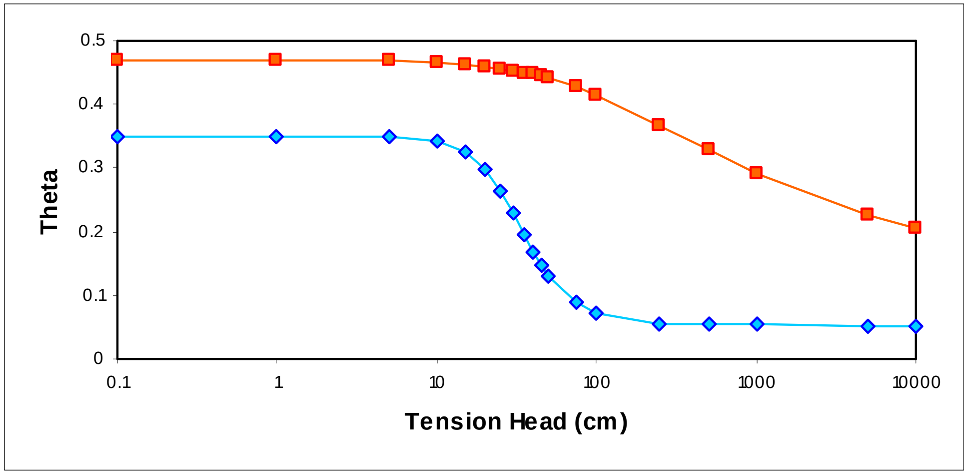
effective saturation in unsaturated zone.
Se = 1 in the saturated zone.

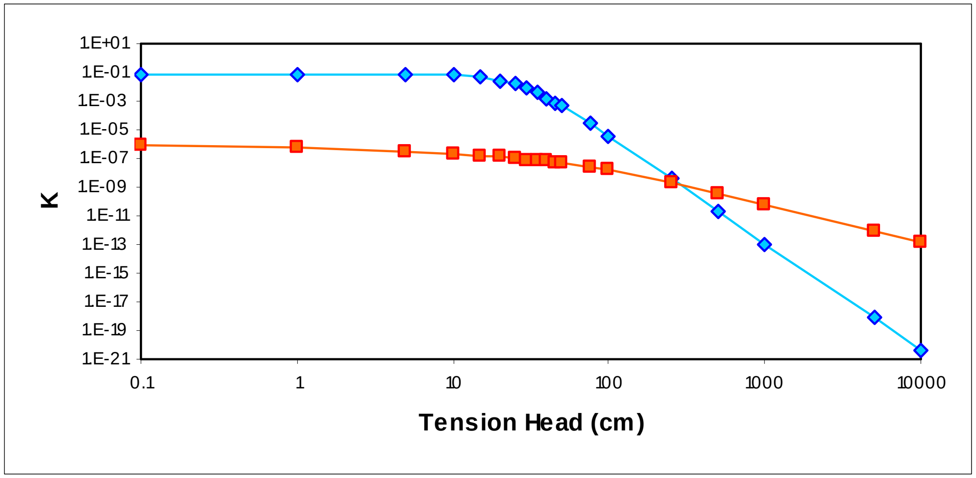
$$K(\psi) = K(Se) = K_s Se^{1/2}\left[1 - \left(1 - Se^{1/m}\right)^m\right]^2$$

$$C(\psi) = \alpha(\theta_s - \theta_r)(n-1)(\alpha|\psi|)^{n-1}\left[1 + (\alpha|\psi|)^n\right]^{\frac{1}{n}-2}$$

$C(\psi)$ = 0 in the saturated zone.

θ_s θ_r K_s α n and $m=1-1/n$ are the parameters of the van Genuchten equations.





θ_s = 0.35, 0.47

θ_r = 0.053, 0.10

α = 0.035, 0.011 cm^{-1}

n = 3.18, 1.27

$K_s = 8\times10^{-2}$, 10^{-6} cm/s

MINE NO. 6 ACID MINE DRAINAGE PROJECT

CENTRAL COAL & COKE

HUNTINGTON, ARKANSAS


Gob pile
State Highway 252
Air shafts and
No. 6 Mine footings
Acid mine drainage
Looking west

DESIGN LOADING CONCENTRATIONS

- DESIGN FLOW = 175 GPM
- TOTAL DISSOLVED Fe = 38.75 mg/L
- DISSOLVED Al = 0.388 mg/L
- DISSOLVED Mn = 1.99 mg/L
- ACIDITY = 158 mg/L
- ALKALINITY = 15.1 mg/L
- SULFATE = 326 mg/L

DESIGN LOADING RATES

- Fe = 36,960 g/day
- Al = 370 g/day
- Mn = 1,898 g/day
- ACID = 136,300 g/day

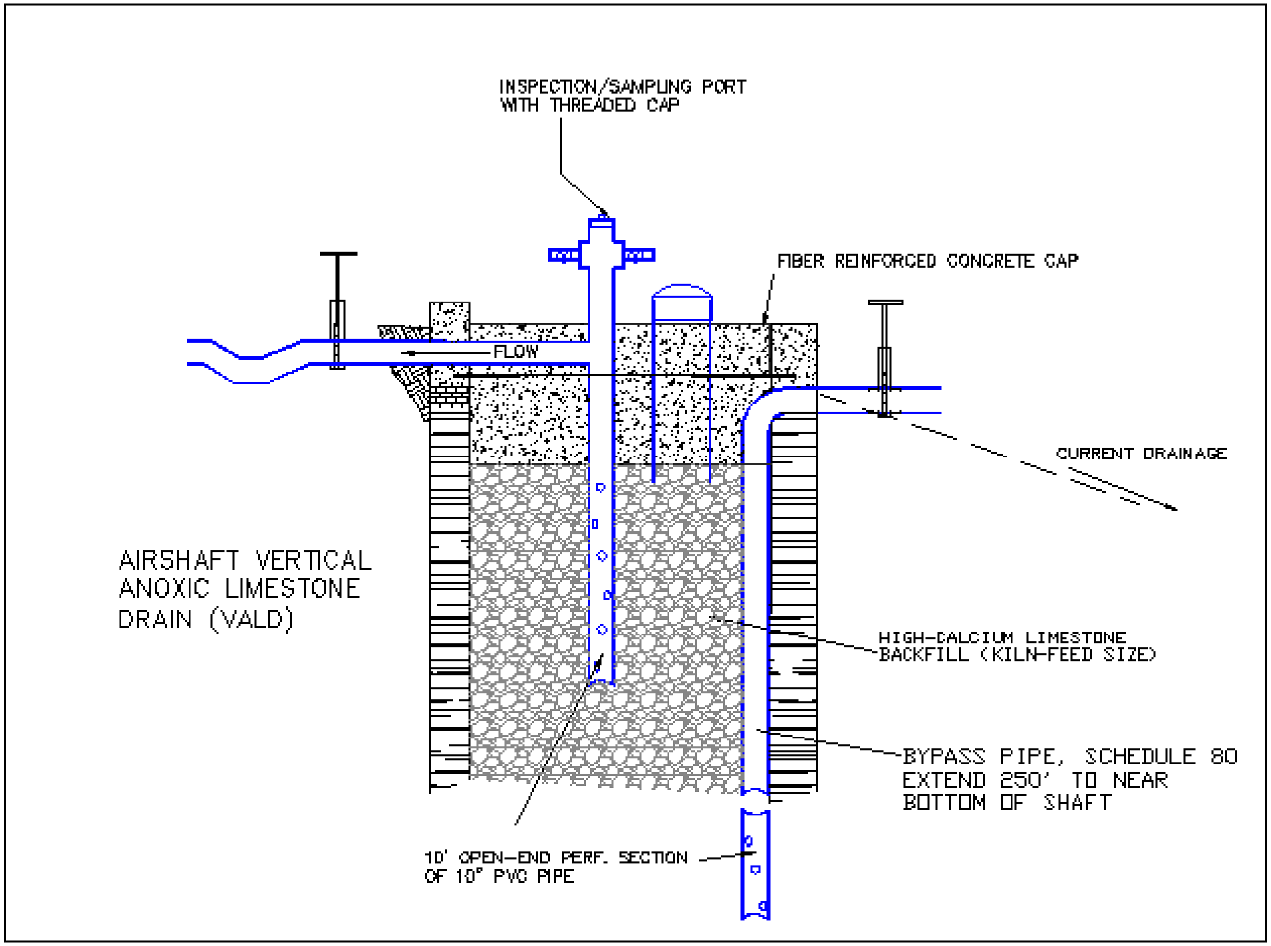
SYSTEM COMPONENTS

- One Vertical Anoxic Limestone Drain
- One Oxidation Pond
- One Vertical Flow Pond
- One Flush/Final Oxidation Pond

VERTICAL ANOXIC LIMESTONE DRAIN

- Existing Shaft in good condition
- Total Depth = 285 ft.
- Dolomitic Limestone in lower half to reduce possible crushing
- High Calcium (96-99% Calcium Carbonate) Limestone in upper half
- Total Limestone = 1300 tons
- Retention Time, Design Flow = 7 hours

VALD/SHAFT SEAL DETAILS



CONSTRUCTION ISSUES

- Shaft Bypass Installation

CONSTRUCTION ISSUES

- Shaft Sidewall Conditions at Top


+0211FT

CONSTRUCTION ISSUES

- Constrained by "historic" structures

OXIDATION POND 1

- Retention Time Design Flow = 18 hours
- As Constructed = 29 hours*

- *Design called for a two level split pond, elevation limitations precluded construction.
- *Flow rate can exceed design

CONSTRUCTION ISSUES

- Excess Material due to elevation
- Size constrained by “historic” structures
- Aeration constrained by available elevation drop
- Excellent clay loam for pond

VERTICAL FLOW POND

- Typical water (1.5 ft.) over compost (1.5 ft.) over limestone (1.75 ft.)
- Design Retention Time in Limestone = 12 hours
- Divided pond into two separate sub-drain systems to adjust as needed in case of short-circuiting. Upstream and downstream systems.
- Water surface dimensions=183’x165’

CONSTRUCTION ISSUES

- Again, elevation caused excessive material excavation
- Must maintain drainage from pond area during construction
- Component installation in broad, single cell pond
- Sub-drain elevation control over the pond area
- Water elevation must be below gob layer
- Available material for compost not adequately digested


LAND

FINAL OXIDATION POND

- Retention Time as Designed = 12 hours
- As Constructed = 19 hours

SYSTEM MODIFICATIONS COMPLETED FALL 2009

- VALD-Discharge Aeration Improvement to increase dissolved oxygen
- Oxidation Pond 1-Increased berm lengths to better distribute flow
- Oxidation Pond 2-Added berm at vertical flow pond discharge to better distribute flow
- Plans are to use dye to evaluate effectiveness of berm modifications


NOV 4 2009

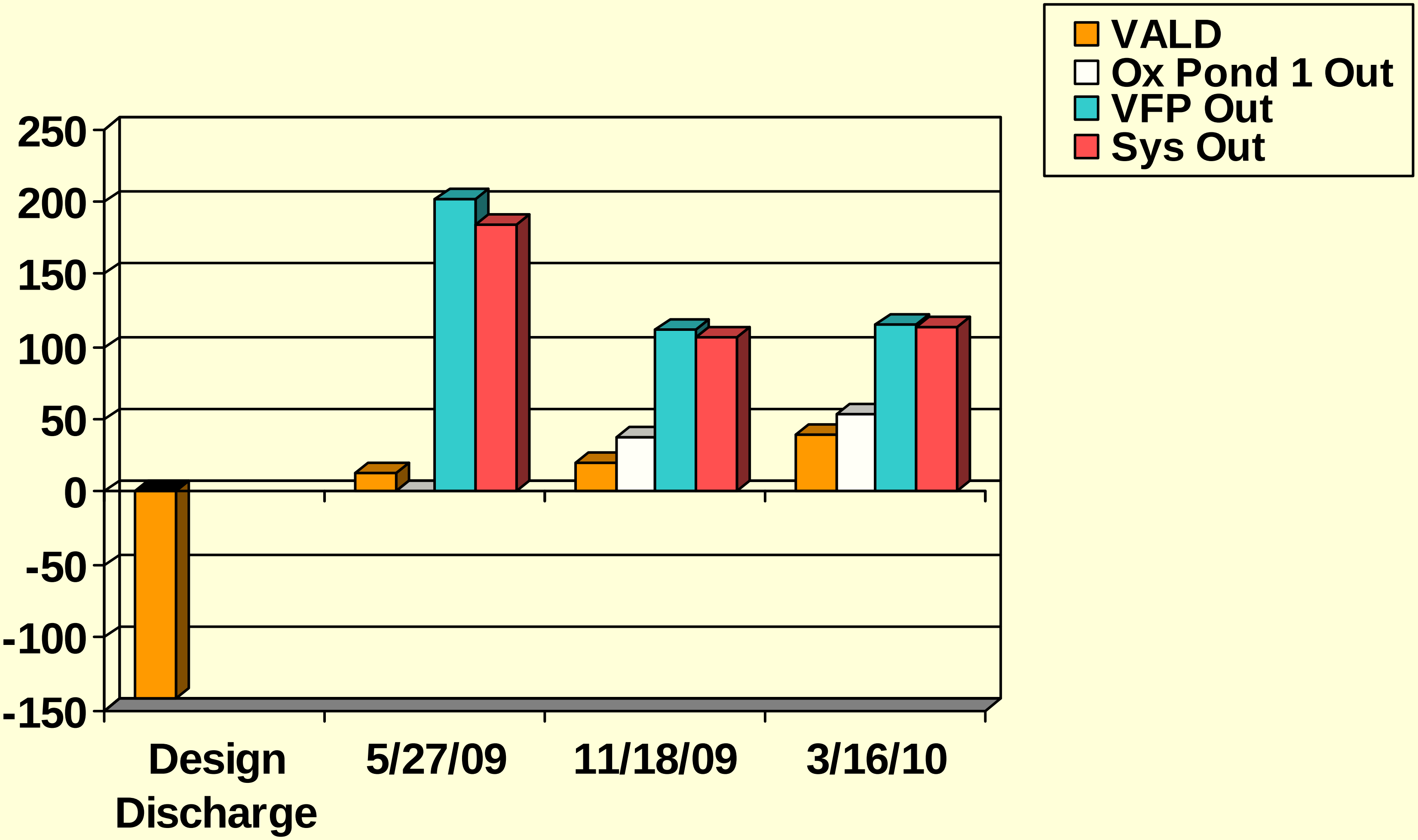
NOV 4 2009

SYSTEM MODIFICATIONS COMPLETED WINTER 2009

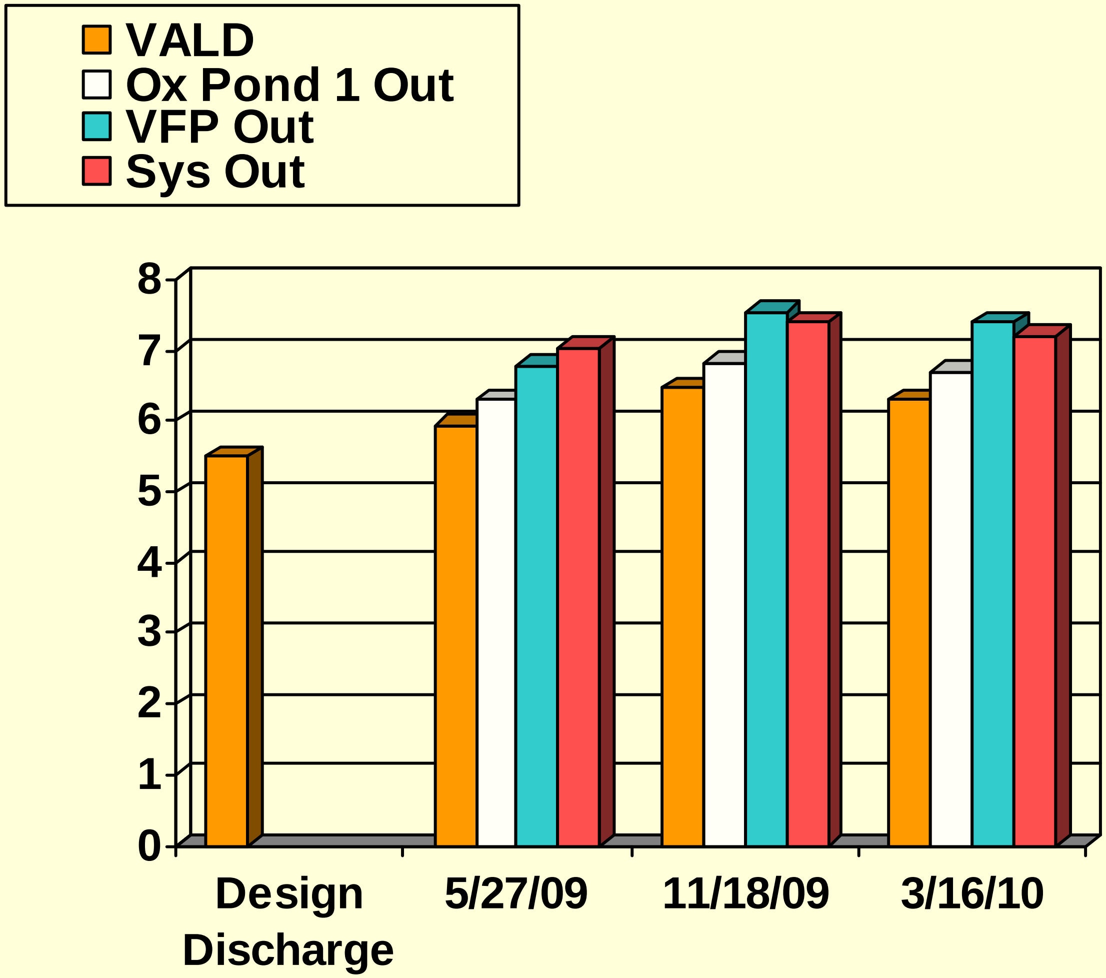
- Installed Off-Grid (solar) aeration system into discharge of vertical flow pond to increase dissolved oxygen available for final polishing and improve H_2S dissipation


NOV 25 2009

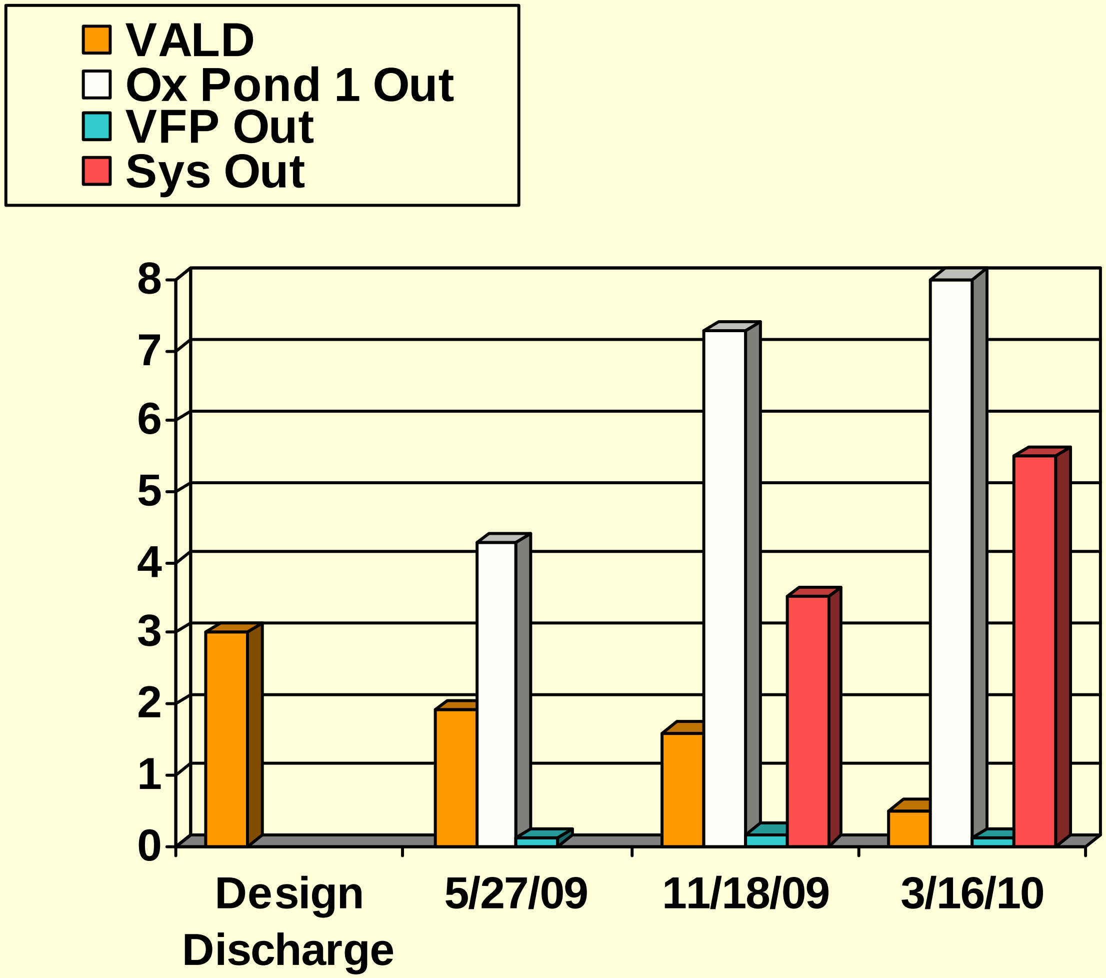
RESULTS – Acidity(-)/Alkalinity(+)



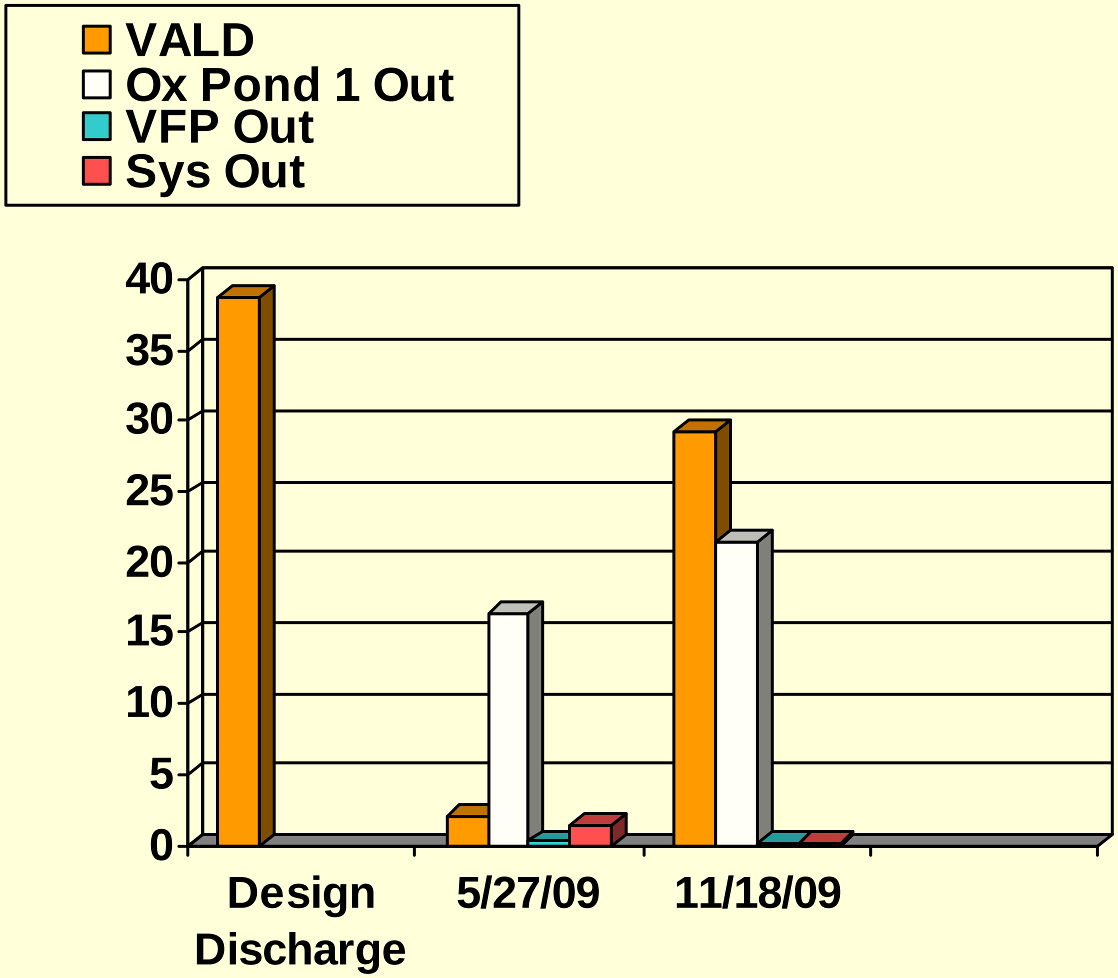
RESULTS – pH


VALD
Ox Pond 1 Out
VFP Out
Sys Out
8
7
6
5
4
3
2
1
0
Design Discharge
5/27/09
11/18/09
3/16/10

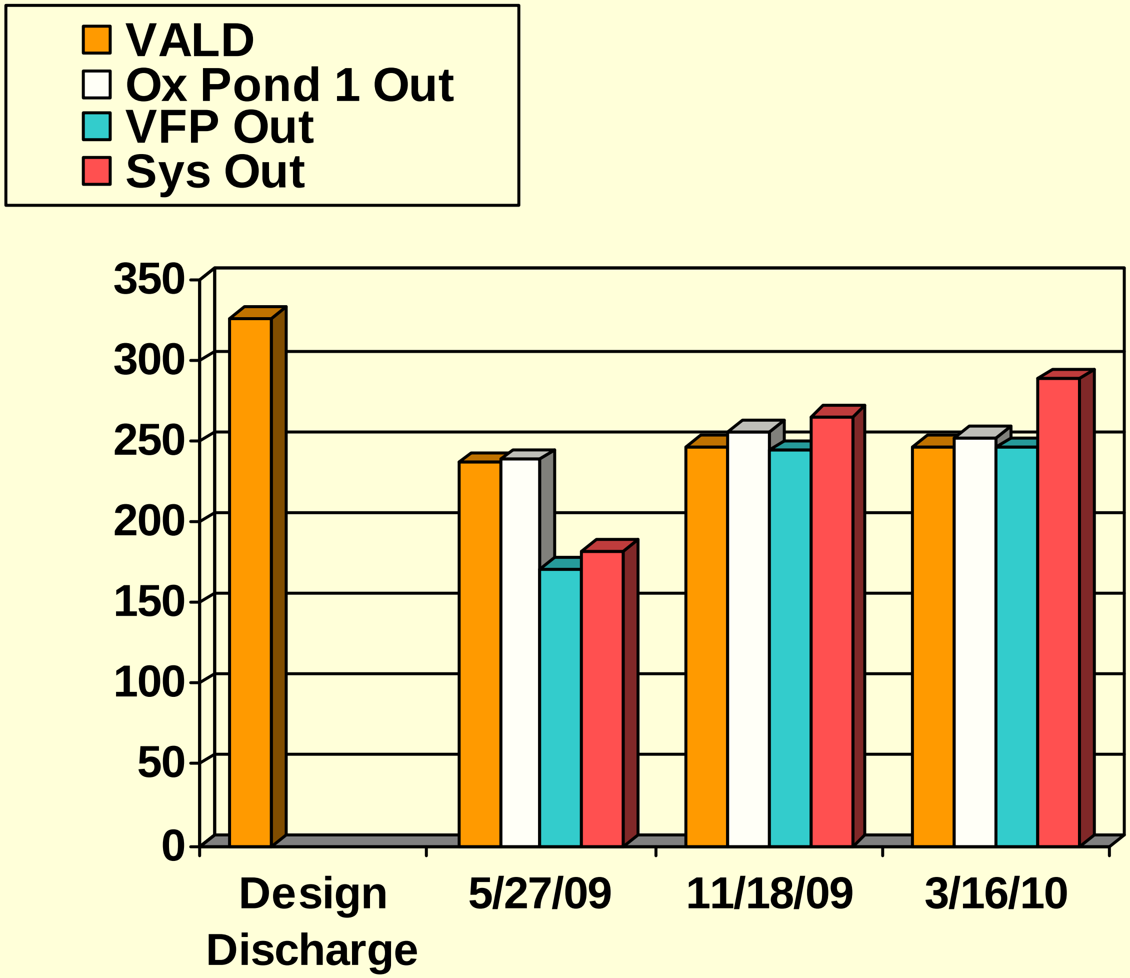
RESULTS – Dissolved Oxygen



RESULTS – Total Dissolved Fe



RESULTS – Sulfates

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Sulfate-Reducing Bioreactors: History and Evolution

Tracy Branam and Denver Harper

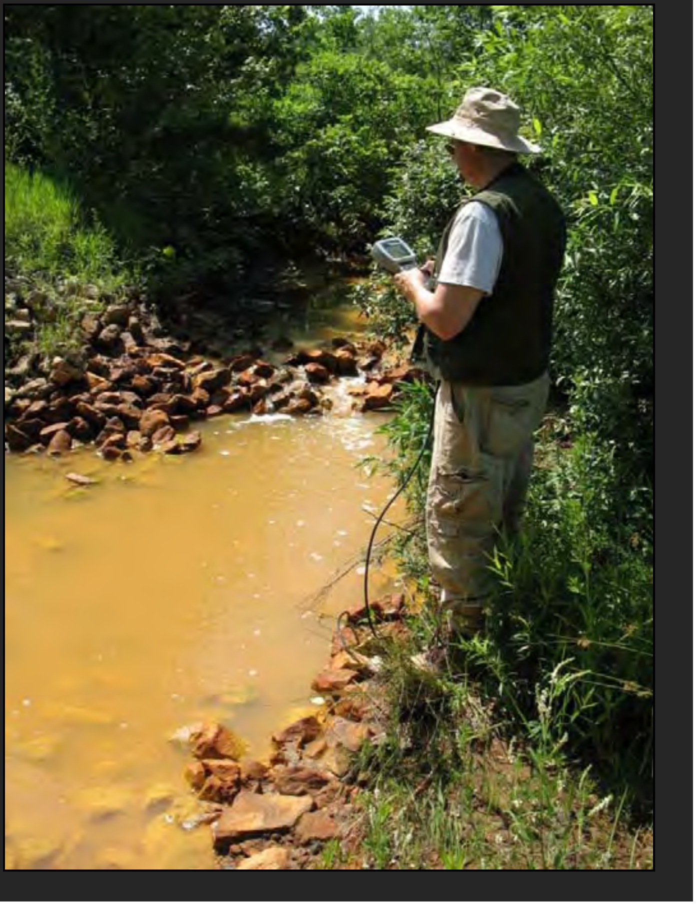
INDIANA GEOLOGICAL SURVEY 1837
INDIANA UNIVERSITY

Sources of AMD

Drainage from flooded underground mines

Sources of AMD

Drainage from deposits of coal-preparation refuse



Sources of AMD

Mineral phases

Sulfides (Pyrite/Marcasite)
Aluminosilicates (Illite)
Carbonates (Calcite)
Hydroxides and Oxides (iron and aluminum)
Sulfates (iron, aluminum and calcium)

Trace metals

Mn, Zn, Ni, Pb, Cu, Cr, Cd, Hg, As, Se, etc.

Microbial influences on AMD Formation

Thiobacillus ferrooxidans
Thiobacillus thiooxidans

$$\boxed{FeS_2 + 3.5O_2 + H_2O \Rightarrow FeSO_4 + H_2SO_4}$$

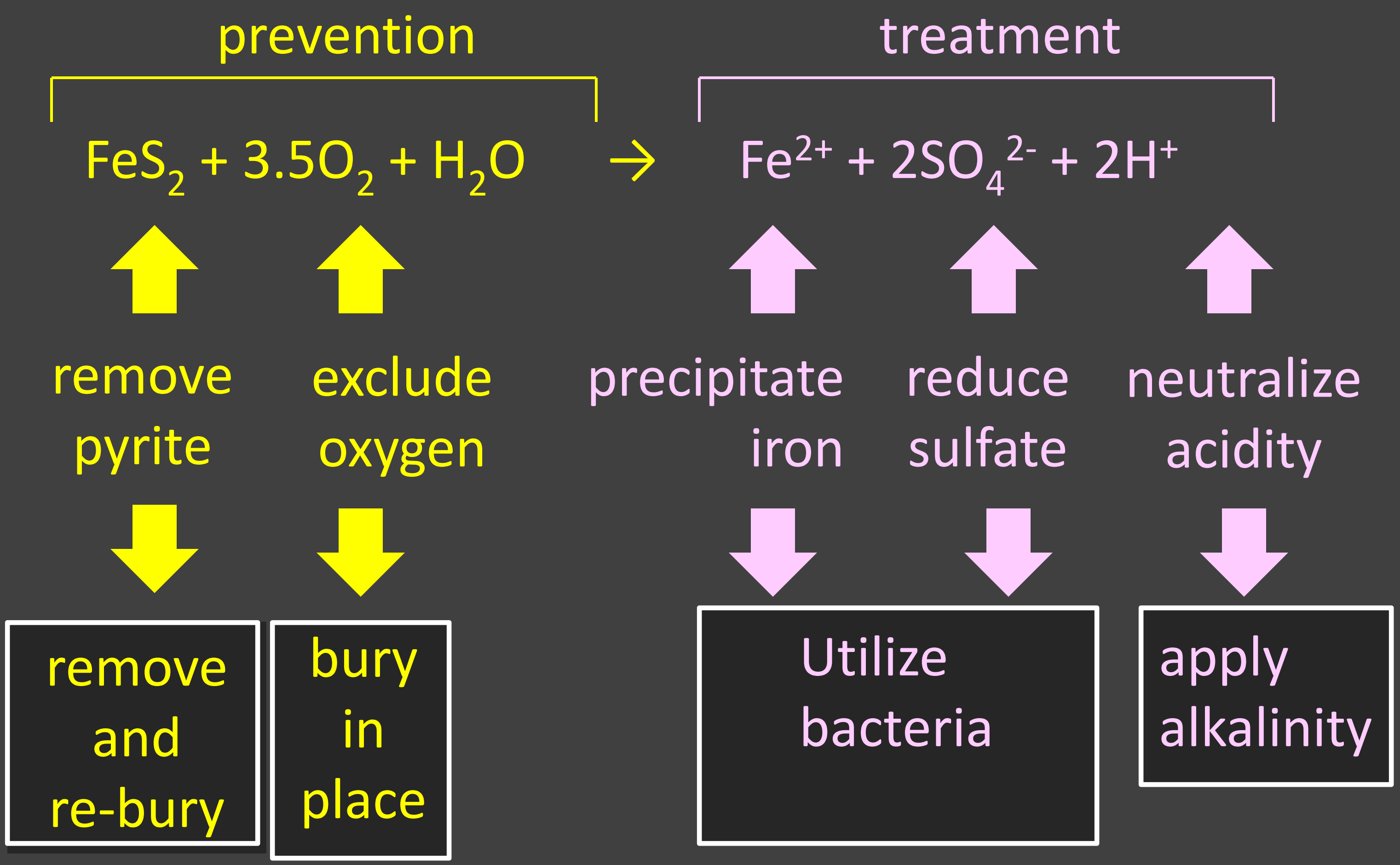
$$FeS_2 + 3.5O_2 + H_2O \Rightarrow Fe^{+2} + 2SO_4^{-2} + 2H^+$$

Thiobacillus ferrooxidans
Leptospirillum ferrooxidans

$$\boxed{Fe^{+2} + 0.25O_2 + H^+ \Leftrightarrow Fe^{+3} + 0.5H_2O} \quad (slow)$$

$$FeS_2 + 14Fe^{+3} + 8H_2O \Leftrightarrow 15Fe^{+2} + 2SO_4^{-2} + 16H^+ \quad (fast)$$

Remediation Strategies



prevention

treatment

$FeS_2 + 3.5O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$

remove pyrite

exclude oxygen

precipitate iron

reduce sulfate

neutralize acidity

remove and re-bury

bury in place

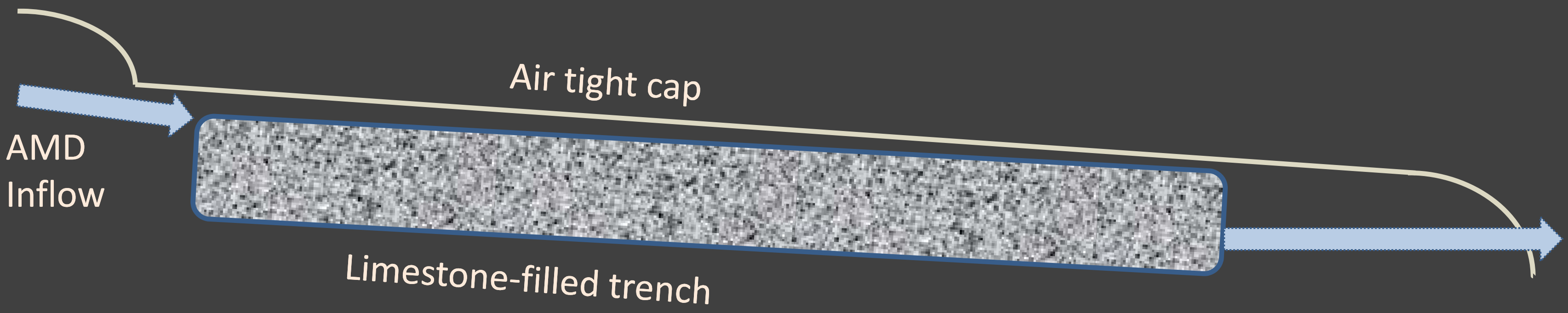
Utilize bacteria

apply alkalinity

A Progression of Passive Treatment Systems

From simple to complex biogeochemical reactions

Anoxic Limestone Drain (ALD)



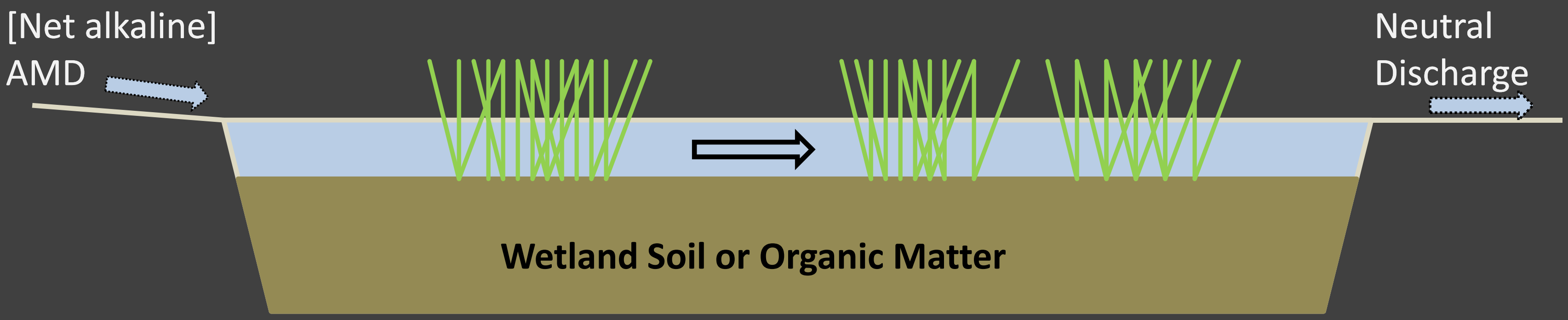
$CaCO_3 + 2H^+ \rightarrow Ca^{+2} + H_2CO_3$ acid neutralization

$H_2CO_3 + CaCO_3 \Leftrightarrow Ca^{+2} + 2HCO_3^-$ alkalinity generation

Restrictions for use on AMD:

No Fe^{+3} and low D.O.
Low (<10 mg/L) Al^{+3}
SO_4^{-2} concentrations generally < 1500 mg/L

Aerobic Wetland (AW)

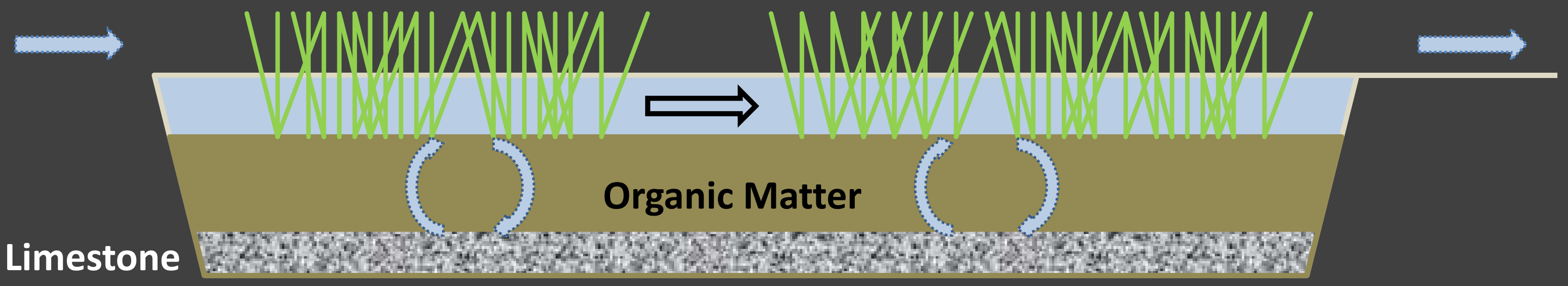


$Fe^{+2} + \frac{1}{4}O_2 + H^+ \Leftrightarrow Fe^{+3} + \frac{1}{2}H_2O$ Iron oxidation (Thiobacillus ferrooxidans)

$Fe^{+3} + 3H_2O \Leftrightarrow Fe(OH)_3 + 3H^+$ Oxidized Iron precipitation

$HCO_3^- + H^+ \Leftrightarrow H_2CO_3 \Leftrightarrow CO_2 + H_2O$ Acid Neutralization

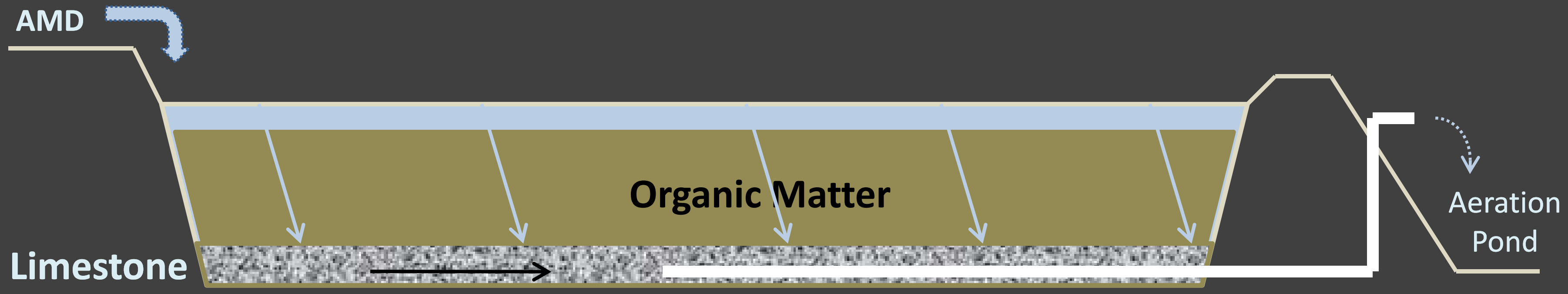
Anaerobic Wetland (AnW)



$CH_2O + O_2 \rightarrow H_2CO_3 \Leftrightarrow HCO_3^- + H^+$	aerobic bacteria removal of oxygen
$SO_4^{-2} + 2CH_2O \rightarrow H_2S + HCO_3^-$	anaerobic bacterial sulfate reduction
$H_2S + HCO_3^- \Leftrightarrow HS^- + H_2CO_3$	pH buffered hydrogen sulfide dissociation
$Fe^{+2} + HS^- \Leftrightarrow FeS + H^+$	ferrous iron sulfide precipitated
$H_2CO_3 + CaCO_3 \Leftrightarrow Ca^{+2} + 2HCO_3^-$	alkalinity generation

Size must be large enough to allow a long residence time for water diffusion to occur through substrate

Vertical Flow Ponds (VFP) and Successive Alkaline Producing Systems (SAPS)



$CH_2O + O_2 \rightarrow H_2CO_3 \Leftrightarrow HCO_3^- + H^+$ aerobic bacteria removal of oxygen

$CaCO_3 + 2H^+ \rightarrow Ca^{+2} + H_2CO_3$ acid neutralization

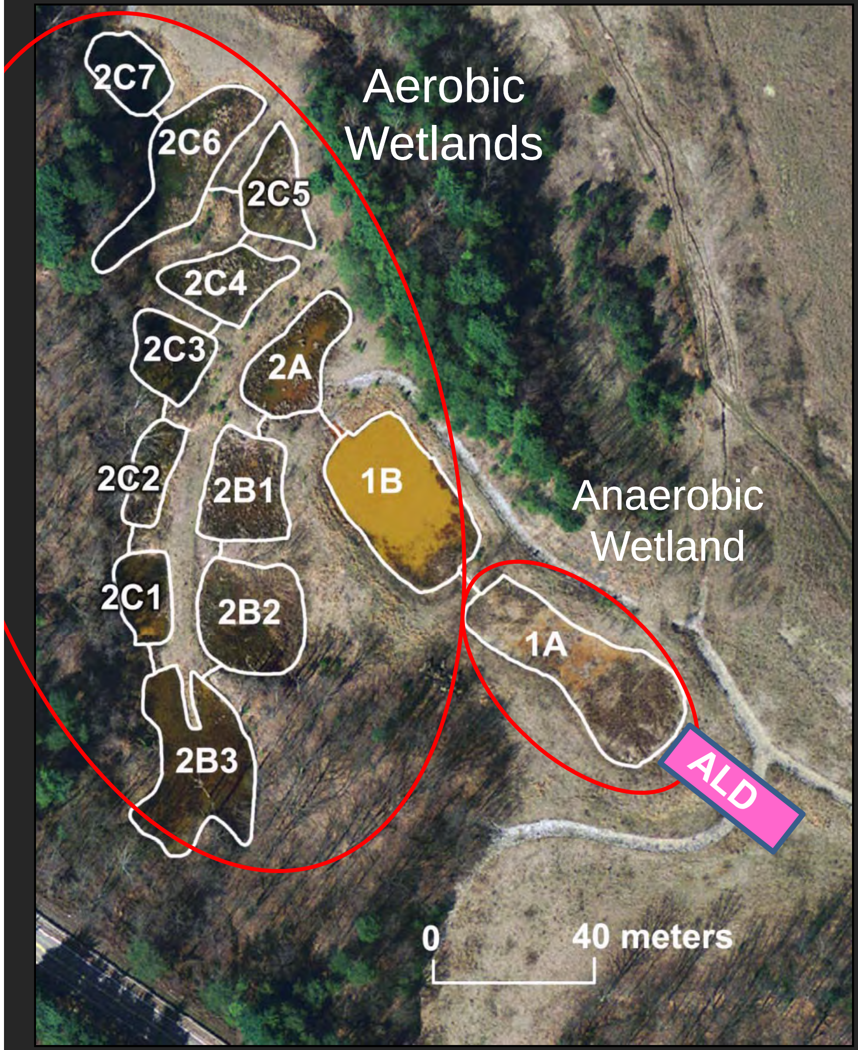
$H_2CO_3 + CaCO_3 \rightarrow Ca^{+2} + 2HCO_3^-$ alkalinity generation

Minor reaction contributions

$SO_4^{-2} + 2CH_2O \rightarrow H_2S + HCO_3^-$ anaerobic bacteria sulfate reduction

$H_2S + HCO_3^- \Leftrightarrow HS^- + H_2CO_3$ pH buffered hydrogen sulfide dissociation

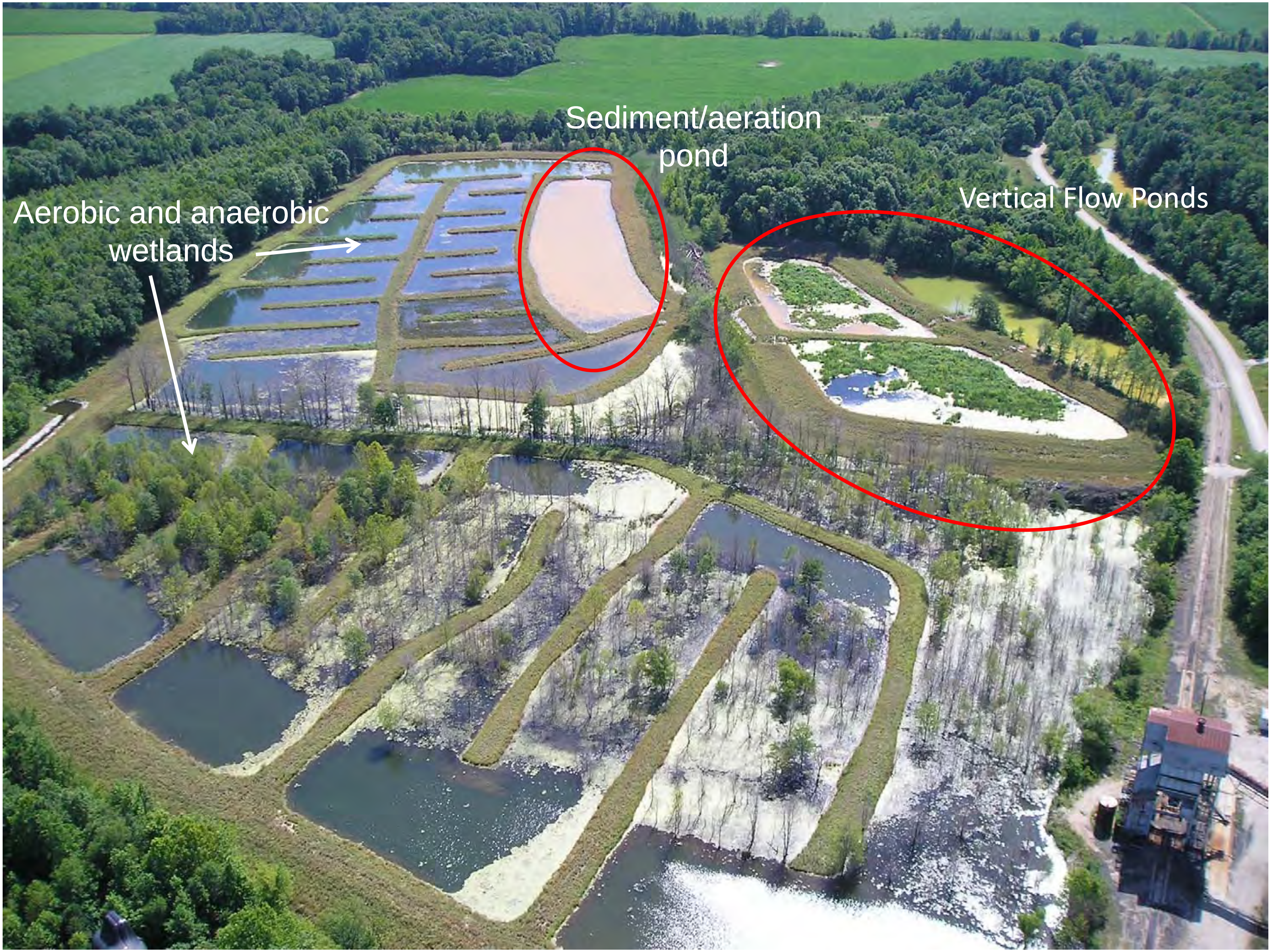
$Fe^{+2} + HS^- \Leftrightarrow FeS + H^+$ ferrous iron sulfide precipitated



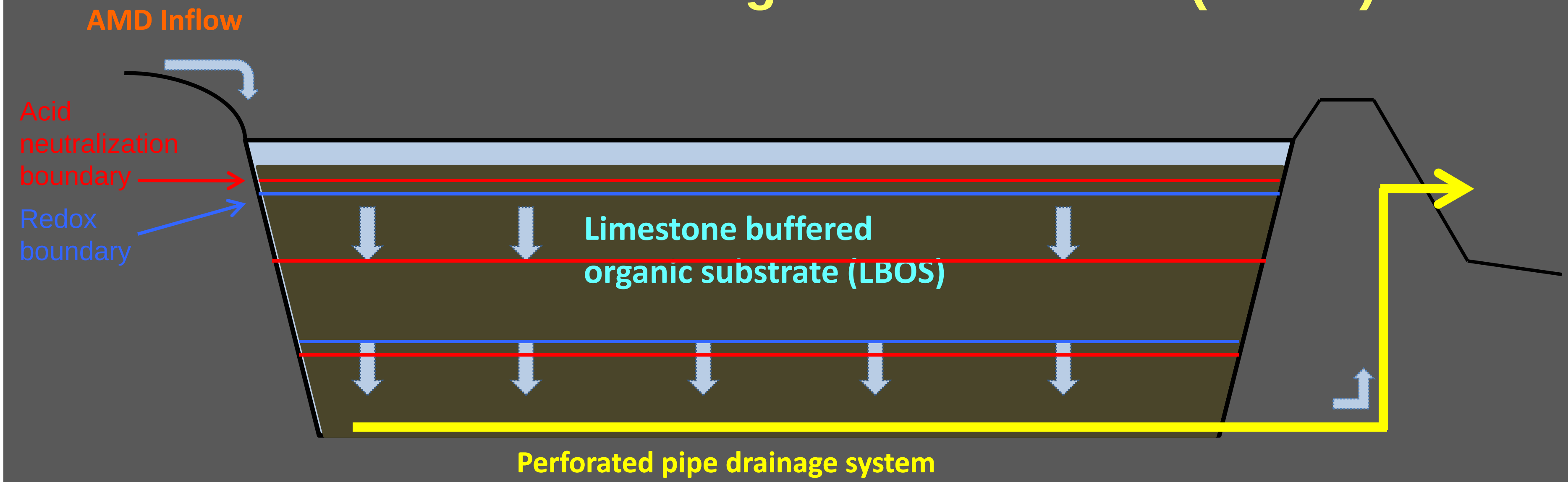
One alternative to treating complex AMD is to combine treatment systems

Considerations:

Required area
Construction costs
Maintenance costs


Sediment/aeration pond
Vertical Flow Ponds
Aerobic and anaerobic wetlands

Sulfate-Reducing Bioreactor Cell (SRBC)



AMD Inflow

Acid neutralization boundary

Redox boundary

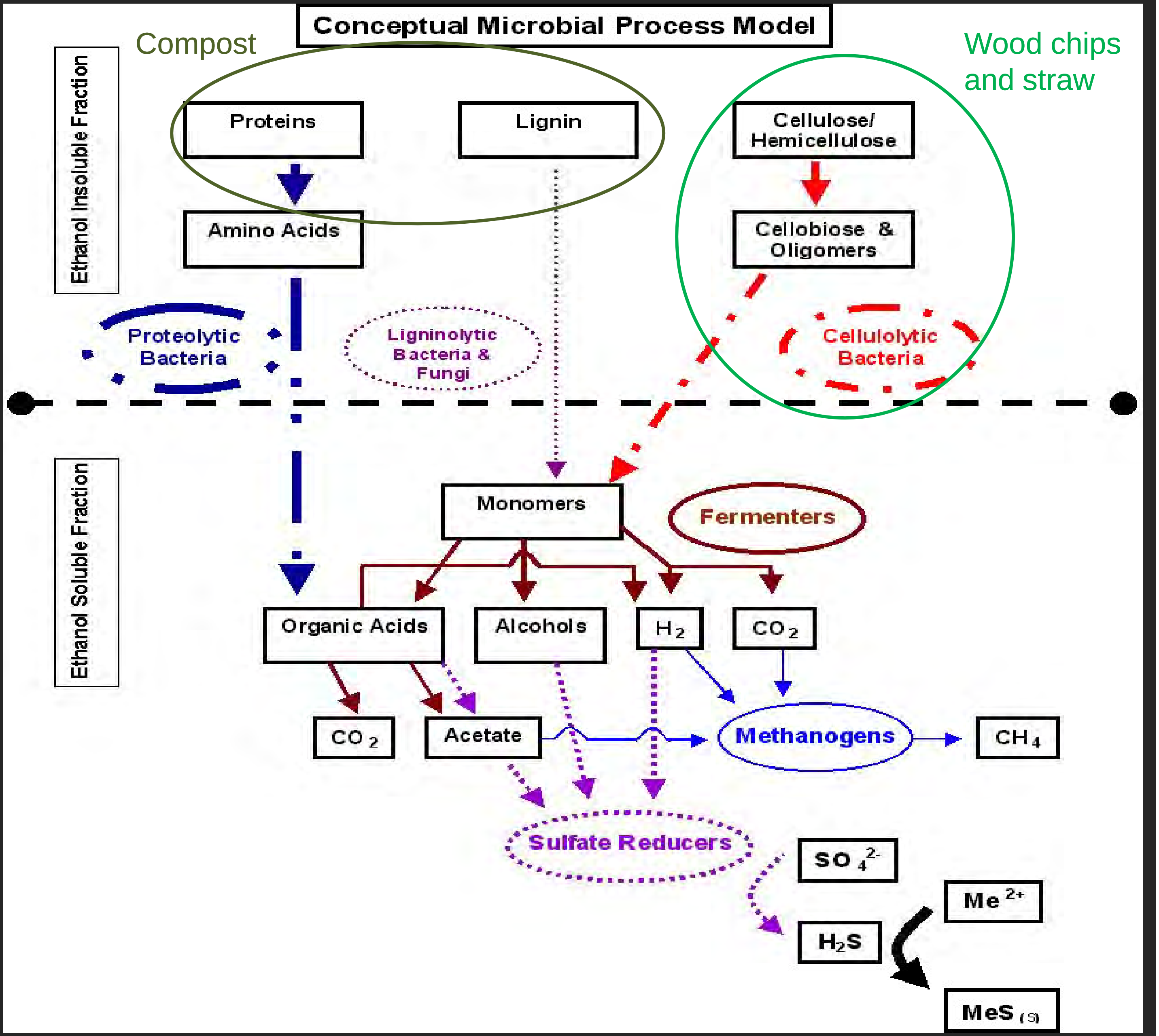
Limestone buffered organic substrate (LBOS)

Perforated pipe drainage system

$CaCO_3 + 2H^+ \rightarrow Ca^{+2} + H_2CO_3$	acid neutralization
$CH_2O + O_2 \rightarrow H_2CO_3 \Leftrightarrow HCO_3^- + H^+$	aerobic bacteria removal of oxygen
$SO_4^{-2} + 2CH_2O \rightarrow H_2S + HCO_3^-$	anaerobic bacterial sulfate reduction
$H_2CO_3 + CaCO_3 \rightarrow Ca^{+2} + 2HCO_3^-$	alkalinity generation
$H_2S + HCO_3^- \Leftrightarrow HS^- + H_2CO_3$	pH buffered hydrogen sulfide dissociation
$Fe^{+2} + HS^- \Leftrightarrow FeS + H^+$	ferrous iron sulfide precipitated

Fermenters, sulfate reducers and methanogens will starve and the bioreactor cease to function if the more complex organic molecules are not broken down to simpler molecules.

Rate of complex molecule decomposition is unknown but an important component for developing predictive model



Bench scale test for substrate compositions conducted by IDNR-DOR

Substrate blend performance determined by alkalinity generation, sulfate-reduction, iron fixing, effluent composition and advance of redox front in LBOS.

Effluent discharge evaluation

Positives

- reduced sulfate
- increased alkalinity
- reduced Fe^{+2}
- decreased trace metals

Negatives

- fecal bacteria
- ammonia
- increased oxygen demand
- suspended FeS

Oxidation ponds (or aerobic wetlands) will improve effluent regarding oxygen demand and suspended FeS

SRBC Considerations

AMD composition restrictions

- suitable for wide range of AMD compositions

Location requirements

- can be constructed in variety of relief settings
- avoid areas receiving high volumes of surface runoff

Size versatility

- can be sized to fit available area

Construction costs compared to similar treatment systems

- smaller size potential → lower cost

Materials

- limestone, wood chips and straw locally available
- labile organic material ← limiting factor – source, composition

Maintenance frequency

- dependent on size and loading criteria

SRBC Optimal Performance Modeling Requirements

- Single inflow into cell
- Lined to prevent leaking → single outflow
- Plumbed to maximize flow through substrate
- Internal 3-D monitoring port network
- Monitoring and sampling schedule
- Monitoring duration to encompass seasonal and substrate depletion trends

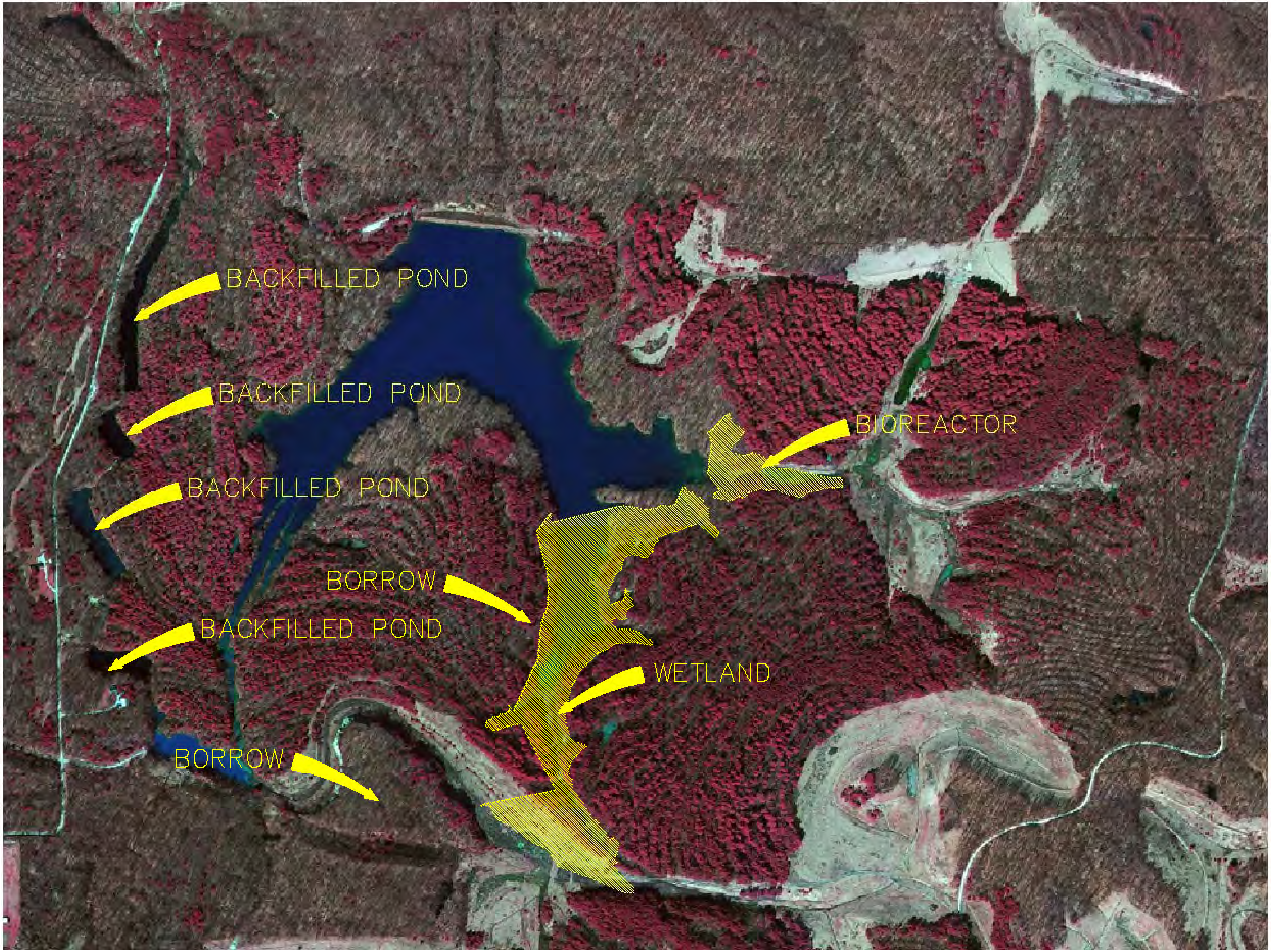
Augusta Lake AMD

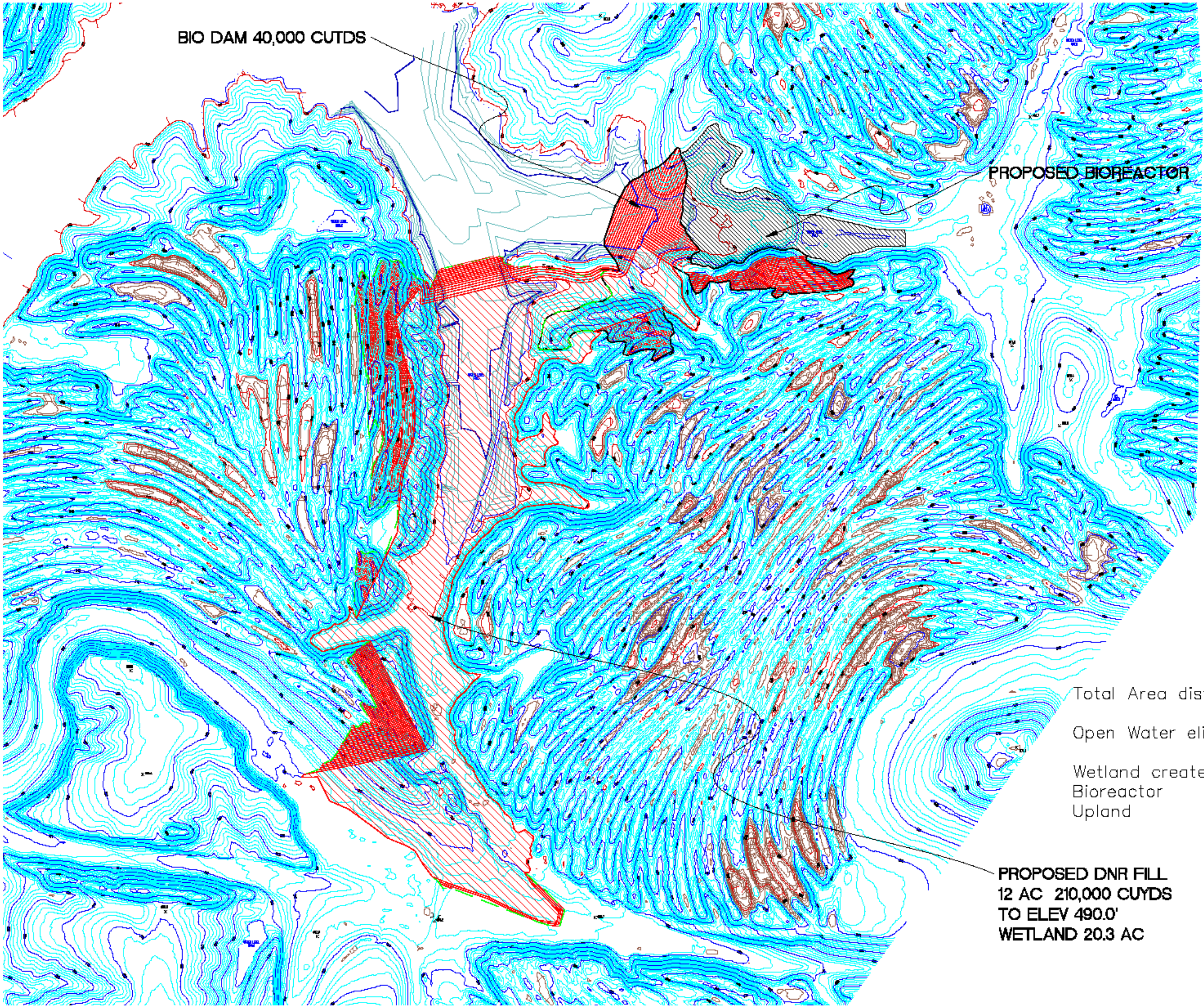
Dan Hause, PE
Chief Engineer
Indiana DNR

Augusta Lake

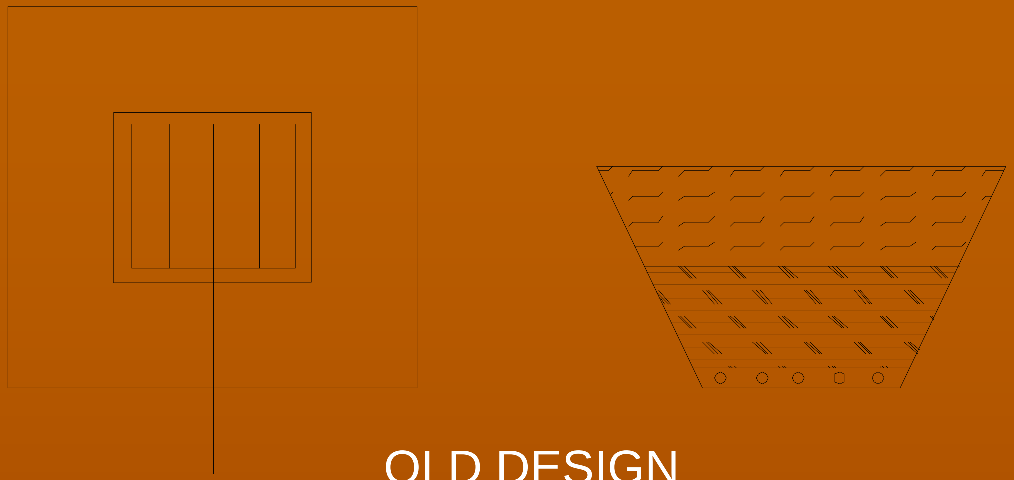
Chemistry

Augusta Lake	East Side Discharge
4.1 pH	3.3 pH
55 acidity	223 Acidity
3.2 Al	7.3 Al
0.06 Fe	26.6 Fe
7.3 Mn	21.3 Mn
959 Sulfate	574 Sulfate

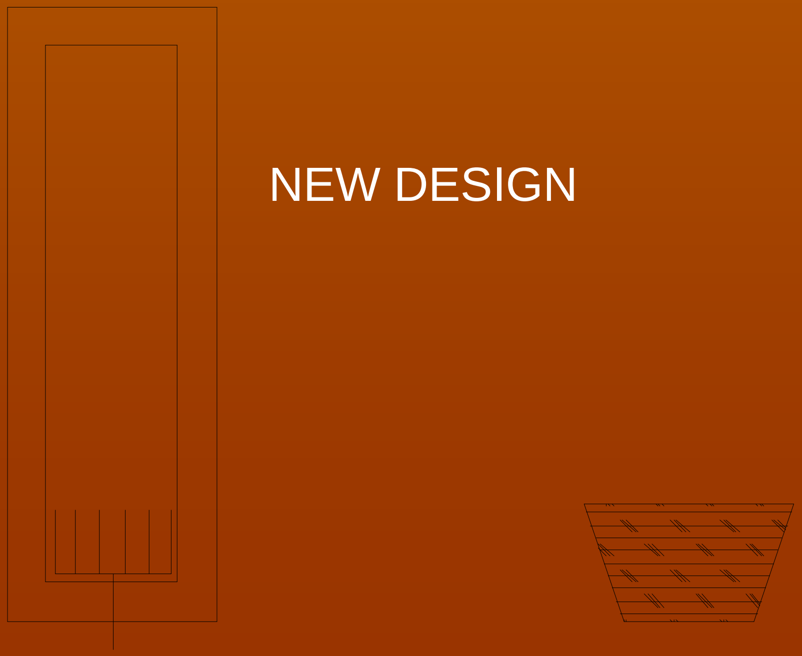

BACKFILLED POND
BACKFILLED POND
BIOREACTOR
BACKFILLED POND
BORROW
BACKFILLED POND
WETLAND
BORROW



Total Area disturbed	32.8 ac
Open Water eliminated	6.8 ac
Wetland created	20.3 ac
Bioreactor	3,4 ac
Upland	9.1 ac



OLD DESIGN



NEW DESIGN

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