THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

JOHN AND WILLIE LEONE FAMILY DEPARTMENT OF ENERGY AND
MINERAL ENGINEERING

CLEANING UP LITTLE LAUREL RUN: DESIGN AND PERFORMANCE OF DIFFERENT CRAB-SHELL MIXTURES FOR SUPPORTING REMEDIATION OF ACID MINE DRAINAGE IN PILOT-SCALE REACTORS AT THE KLONDIKE-1 DISCHARGE

SARA GOOTS

Summer 2012

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree
in Environmental Systems Engineering
with honors in Environmental Systems Engineering

Reviewed and approved* by the following:

Rachel A. Brennan
Associate Professor of Environmental Engineering
Thesis Supervisor

Mark Klima
Associate Professor of Mineral Processing
Honors Adviser

* Signatures are on file in the Schreyer Honors College

ABSTRACT

Traditional means of remediating high-strength acid mine drainage (AMD) using vertical flow ponds (VFP) filled with spent mushroom compost (SMC) and limestone often display inconsistent success. The Klondike-1 treatment system on Little Laurel Run is one such example: the system was under-designed to handle the high iron (140 mg/L) and acidity (380 mg/L as $CaCO_3$) of the discharge, and as a result, iron precipitates clogged the surface of the VFP in less than one year. Laboratory tests have shown that the addition of crab shell substrate can improve the efficiency of SMC, while still remaining cost effective. Therefore, a pilot-scale study was established at Klondike-1 to evaluate if the addition of crab shell to the existing VFP might improve treatment.

For the pilot study, four replicate 1,000-gallon reactors were installed at Klondike-1. Three reactors were filled with a limestone underdrain and an upper substrate layer of: 1) 100% crab shell; 2) 70% crab shell + 30% SMC; and 3) 90% SMC + 10% limestone. A fourth tank containing 70% crab shell + 30% SMC was installed with a sandstone underdrain to determine if similar performance could be achieved without the addition of limestone. In August, 2010, the pilot system went online and began receiving a continuous stream of AMD. After almost two years, the field study is nearing completion, with all tanks nearing exhaustion as designed. Net alkalinity remains highest in the 100% crab shell reactor (37 mg/L as $CaCO_3$), and lowest in the reactor filled with the traditional SMC substrate (3.3 mg/L as $CaCO_3$). The results of this study support the hypothesis that crab shell amended substrates increase the longevity and effectiveness of AMD treatment.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1
Background and Introduction

Mine-influenced water (MIW) or acid mine drainage (AMD) impacts at least 5,000 miles of Pennsylvania streams and causes an estimated $93 million loss in state revenue (PADEP 2007, 2009). Centuries of mining practices have unearthed pyrite and other sulfide minerals, that when exposed to air and water, create sulfuric acid (H_2SO_4) (equation 1). This acidic discharge readily dissolves metals from underlying minerals, resulting in highly acidic and metal-laden waters which can affect downstream ecosystems and humans.

$$4FeS_2(s) + 15O_2(ag) + 14H_2O(l) \rightarrow 4Fe(OH)_3(s) + 8SO_4^{2-}(aq) + 16H^+(aq) \qquad (1)$$

Traditional Treatment

Remediation of impacted waters is largely funded by government environmental agencies. Though some discharges require active treatment, passive treatment systems are preferred due to their low cost and maintenance. Some passive systems rely on microbial activity for the majority of the treatment, oftentimes requiring the addition of a vertical flow pond (VFP). The VFP is a gravity fed pond with a layer of organic substrate, traditionally spent mushroom compost (SMC) amended with limestone, which fuels the anaerobic reduction of sulfate by sulfate reducing bacteria (SRB). Water passes through the substrate layer into an underdrain embedded within a layer of limestone rock, exiting into an aerobic settling pond (figure 1). The optimization of cost and treatment efficiency of the organic substrate is essential in preserving the viability of the passive treatment system. Since funding available for MIW remediation is scarce, priority is given to the "easier to treat" low-strength discharges. If a low-cost substrate were developed that could treat high-strength MIW, a greater number of impacted streams could be saved.

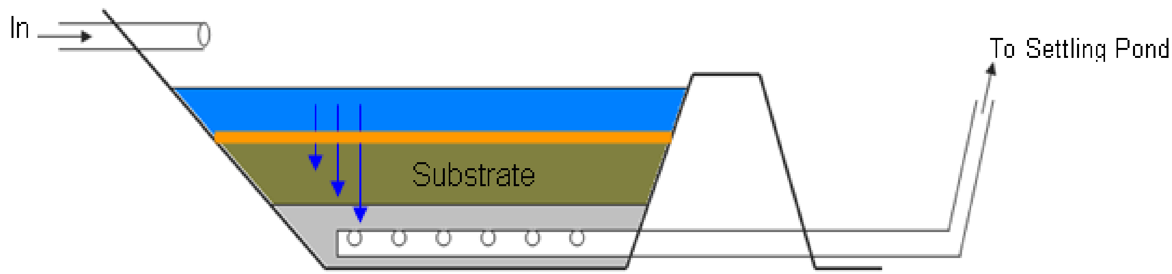

Figure 1 Schematic of the vertical flow wetland of a passive treatment system (citation).

Crab-shell as a Substrate

Recent work has shown that crab-shell amended substrates are capable of biologically, physically, and chemically remediating high strength acid mine drainage more effectively than traditional substrates (Newcome 2009 and Robinson-Lora 2010). Crab-shell is made up of chitin, protein, and calcium carbonate ($CaCO_3$). Chitin, a naturally occurring biopolymer, acts as a slow-release nitrogen and carbon source that supports microbial life such as SRB. Protein also sustains microbial communities by supplying rapidly fermented by-products. Calcium carbonate provides alkalinity to the system. The crab shell's large surface area, a result of fine, microscopic layers, also allows for a small percentage of the dissolved metals in the MIW to sorb to its surface.

Crab-shell chitin (SC-20), a by-product of the seafood industry, is currently available commercially in a stabilized form (dried and crushed) for $0.60/lb.

Although lab-scale column studies have shown that a 100% crab shell substrate is most effective at remediating moderate-strength MIW (Newcombe and Brennan, 2010), this solution would not be economically viable on a large scale. However, further studies comparing a range of crab shell to traditional spent mushroom compost (SMC) substrate amendment ratios for treating high-strength AMD from the Klondike-1 site indicate that a 70% crab shell/ 30% SMC substrate performs almost as well as a 100% crab shell substrate at a fraction of the cost (Grembi 2011).

Klondike -1 Field Site

The Klondike-1 (KL-1) treatment site, located upstream of Little Laurel Run in Cambria County, PA (Figure 2) was designed and constructed by the Clearfield County Watershed Association (CCWA) in 2007. The system was intended to remediate a low flow (15 gpm) discharge with a high- level of acidity (465 mg/L as $CaCO_3$) and metals contamination (140 mg/L Fe). However, after only six months of operation, KL-1 was only partially treating the AMD. Upon draining the VFP, CCWA volunteers observed a 1-in layer of iron oxide ($Fe(OH)_3$) covering the substrate layer. This rapid accumulation of Fe was indicative of a long-term clogging problem, and was most-likely the reason for decreased efficiency. CCWA volunteers removed the Fe layer and added more SMC and limestone to the substrate. Even after these modifications and the installation on two oxidation ditches, the system is currently removing only 75% of the Fe. In cooperation with CCWA and with the support of the Foundation for Pennsylvania Watersheds and the National Science Foundation, this research aims to achieve a higher degree of treatment for the Klondike-1 site within a preexisting small footprint.

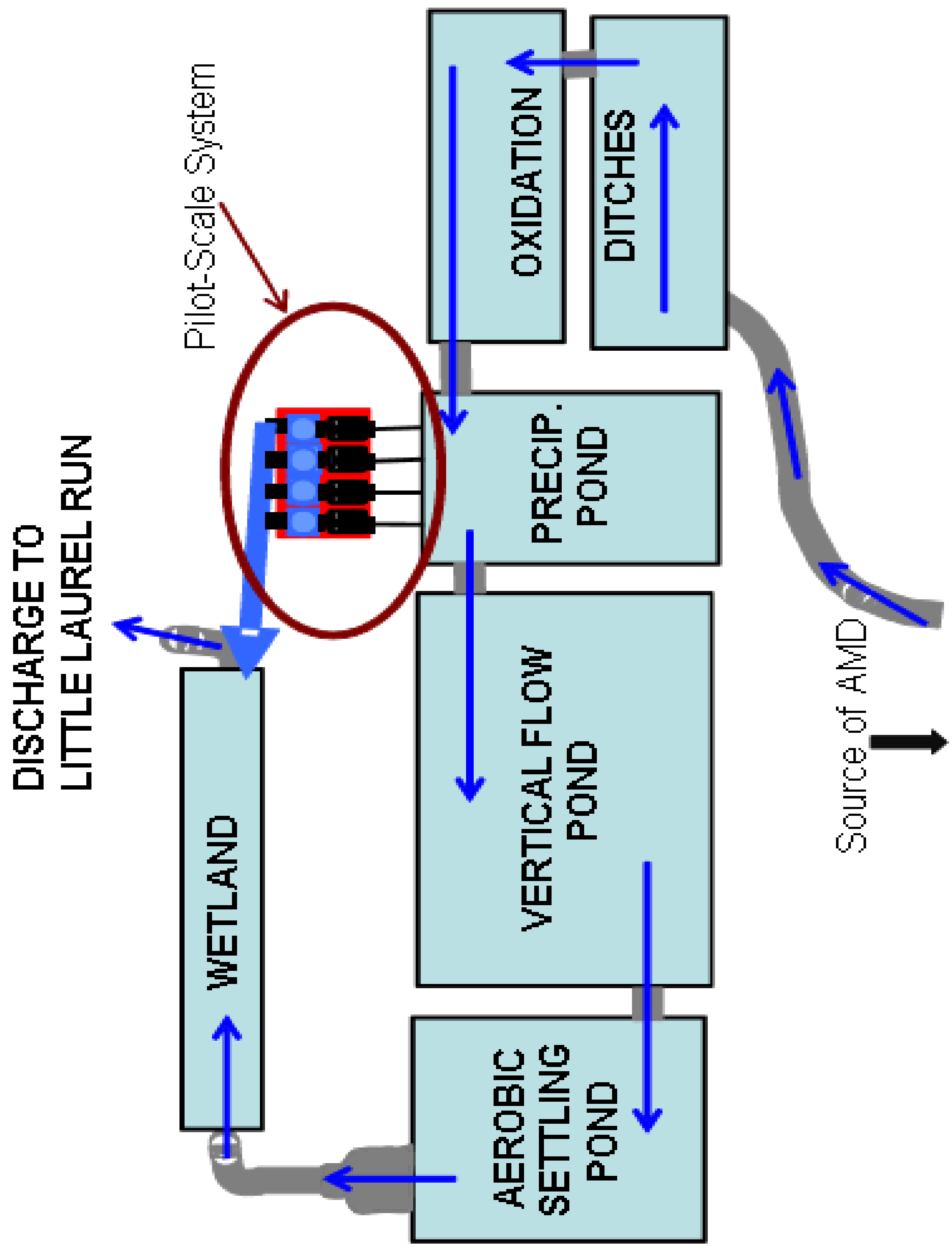

Figure 2 Layout of the existing Klondike-1 Treatment System and location of the pilot scale reactors developed in this work.

Scope of Study

In order to determine the effectiveness of a 70%/30% substrate on a larger scale, a pilot-scale study was initiated utilizing the high-strength, high acidity discharge of the Klondike-1 mine site. Based on a variety of water quality parameters determined from monthly sampling of influent and effluent waters, the effectiveness of crab shell amended substrates will be quantified on a larger scale. If successful, this work may lead to the implementation of crab shell substrates into the existing VFW at the Klondike-1 site, as well as considerations for other planned and existing MIW passive treatment systems.

Chapter 2
Materials and Methods

Site explanation

Due to the site accessibility, need for treatment, and partnership with CCWA, the KL-1 treatment system was the ideal location for a pilot-test installation. Funded through grants from the Foundation for Pennsylvania Watersheds and the National Science Foundation, design and installation of the test site occurred in the summer of 2010. Flow from the existing precipitation pond is diverted at a rate of approximately 0.20 GPM into each of four replicate reactors (1000 gallon plastic septic tanks). Each replicate reactor is then followed by 2 aeration ponds, after which flow is diverted to the existing wetland (Figure 3).

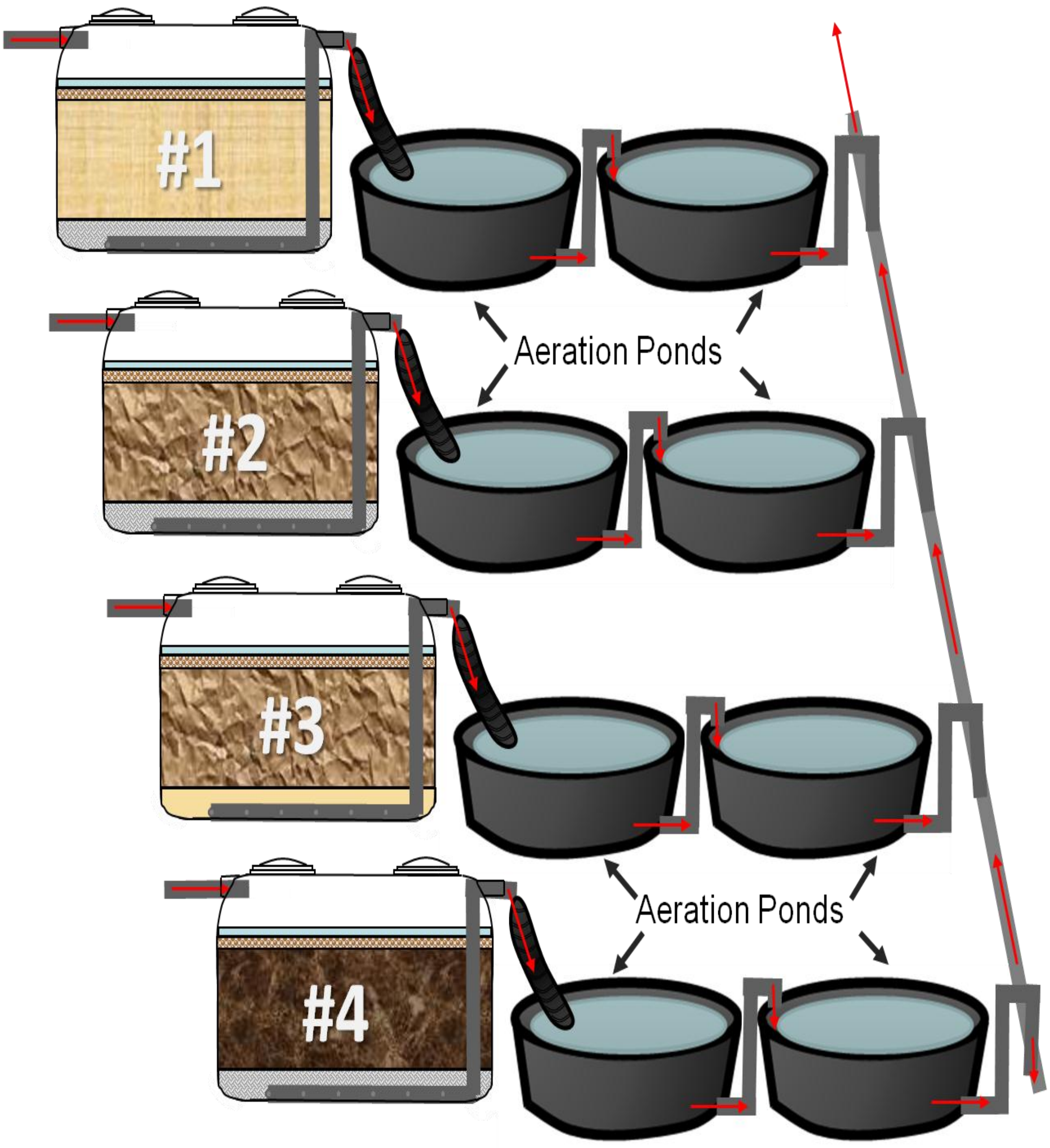

Figure 3 Layout of the pilot-scale reactors

Description of substrates

The replicate reactors were designed to behave as pilot-scale VFPs. Each contains a 2 foot deep rock underdrain to prevent clogging of the effluent pipes, a 2 foot layer of organic substrate, and a 2 inch layer of pea-gravel to prevent floating substrate particles (Figure 4). Each of the four tanks contains a different crab-shell/SMC ratio and underdrain material (Table 1). Tank 1 contains 100% crab-shell in 1:10 ratio by weight with sand, and a limestone underdrain. Tanks 2 and 3 both contain a 70% crab-shell and 30% SMC mixture amended in a 1:10 ratio by weight with sand. Tank 2 contains the traditional limestone underdrain, whereas tank 3 has a sandstone underdrain. This is intended to determine whether the high alkalinity contributions of the crab shell will negate the need for a high-alkaline underdrain material, validating instead the use of a cheaper, readily-available rock such as sandstone. Lastly, tank 4 is the negative control, containing the traditional substrate mixture of 90% SMC to 10% limestone chips and a limestone underdrain.

Table 1 Substrate Ratios and Underdrain Materials

Tank	Substrate	Underdrain
#1	100% Crab Shell (CS)	Limestone (LS)
#2	70% CS / 30% SMC	Limestone
#3	70% CS / 30% SMC	Sandstone
#4	90% SMC/ 10% LS	Limestone

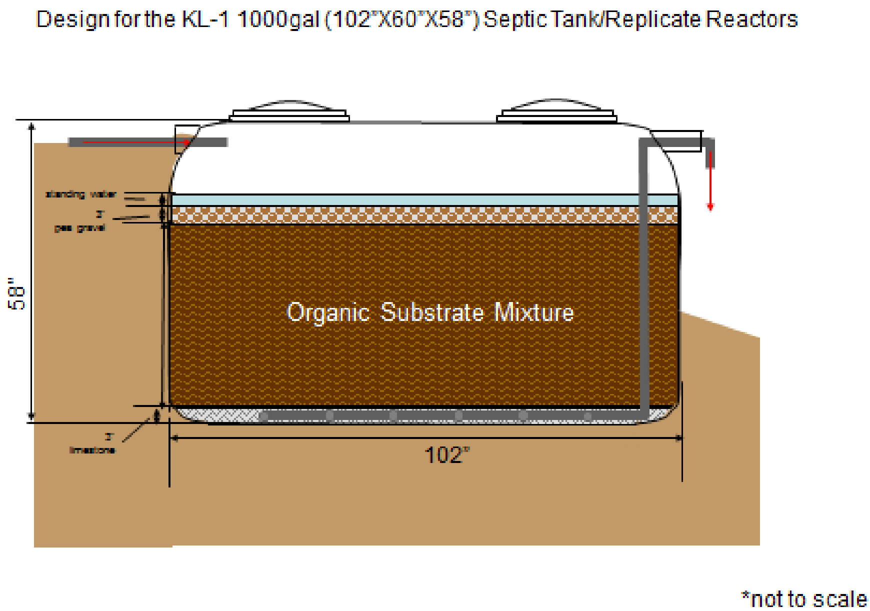

Figure 4 Side View of Pilot-Scale Reactor

Field Site Design

The following substrates were used to promote the remediation of the collected water: ChitoRem® Chitin Complex (grade SC-20, JRW Bioremediation, Lenexa, KS); Spent Mushroom Compost (SMC) (Mushroom Test Demonstration Facility, The Pennsylvania State University); and limestone (0.420-0.841mm, 88.89% $CaCO_3$, New Enterprise Stone and Lime Company, Tyrone, PA). The ChitoRem® Chitin Complex, henceforth referred to as SC-20 crab-shell (or crab-shell), is a product derived from Dungeness crab-shell and contains ~10% chitin, ~12% protein, and ~78% mineral matter (62% as CaCO3) (Robison-Lora and Brennan, 2009). The SMC was from a mixed sample collected from the Mushroom Test Demonstration Facility. Compost analysis on each substrate was conducted by the Pennsylvania State University Agricultural Analytical Services Laboratory.

A sieve analysis was performed to determine the size distribution of the various substrate materials (Table 2).

Table 2 Particle Size Distributions of Substrate Material

		SC-20		Sand		SMC	
Sieve Size	Particle Size (mm)	Amount Retained (g)	% fraction	Amount Retained (g)	% fraction	Amount Retained (g)	% fraction
4	4.75	0.2	0.4	0.0	0.0	38.1	38.4
8	2.36	0.2	0.4	0.0	0.0	17.8	18.0
16	1.2	4.3	9.1	0.0	0.0	15.4	15.5
20	0.85	5.7	12.1	.8	2.0	6.2	6.3
50	0.297	20.5	43.4	7.7	96.2	14.9	15.0
100	0.15	9.7	20.6	.6	1.5	5.8	5.9
200	0.075	4.2	8.9	0.0	0.0	0.4	0.4
Bottom	<.075	.9	4.0	0.1	0.3	0.1	0.1
Losses	------	.5	1.1		0.0	0.4	0.4
	TOTAL	7.2	100	9.2	100	99.1	100

Additionally, compost analysis was conducted on each substrate by the Pennsylvania State University Agricultural Analytical Services Laboratory (Table 3).

Table 3 Carbon:Nitrogen Ratio and Calcium Carbonate Equivalents of Substrate Material

	SC-20	SMC	Limestone	Sand	Limestone Rock Underdrain	Sandstone Rock Underdrain
Total Nitrogen (%)	4.41	1.39	< .01	0.01	0.01	< .01
Carbon (%)	21.83	15.38	11.33	0.02	10.06	0.81
Carbon: Nitrogen Ratio	5	11	----	2	----	----
Calcium Carbonate Equivalence (%)	27	6.8	91	2.1	99.3	0

Field Site Installation

Implementation of the design at the Klondike-1 field site began in July of 2010. The pilot-scale reactors (Norwesco 1000-gal septic tanks) were placed in line 20 feet from the existing oxidation pond. PVC piping (schedule 40) 1.25" diameter was laid to allow flow from the oxidation pond to the reactors, aeration ponds, and to the existing wetlands. An orifice with a 3/8" hole normalized the flow to 0.2 gpm into each of the reactors. Within each reactor a piping system (Figure 5) of 1" PVC piping was designed to transport the gravity-fed water to the aeration pond. Each reactor is followed by two aeration ponds (300 –gal Rubbermaid Stock Tank) to allow for the proper amount of surface area for continued metals precipitation (determined to be 500 sq. ft).

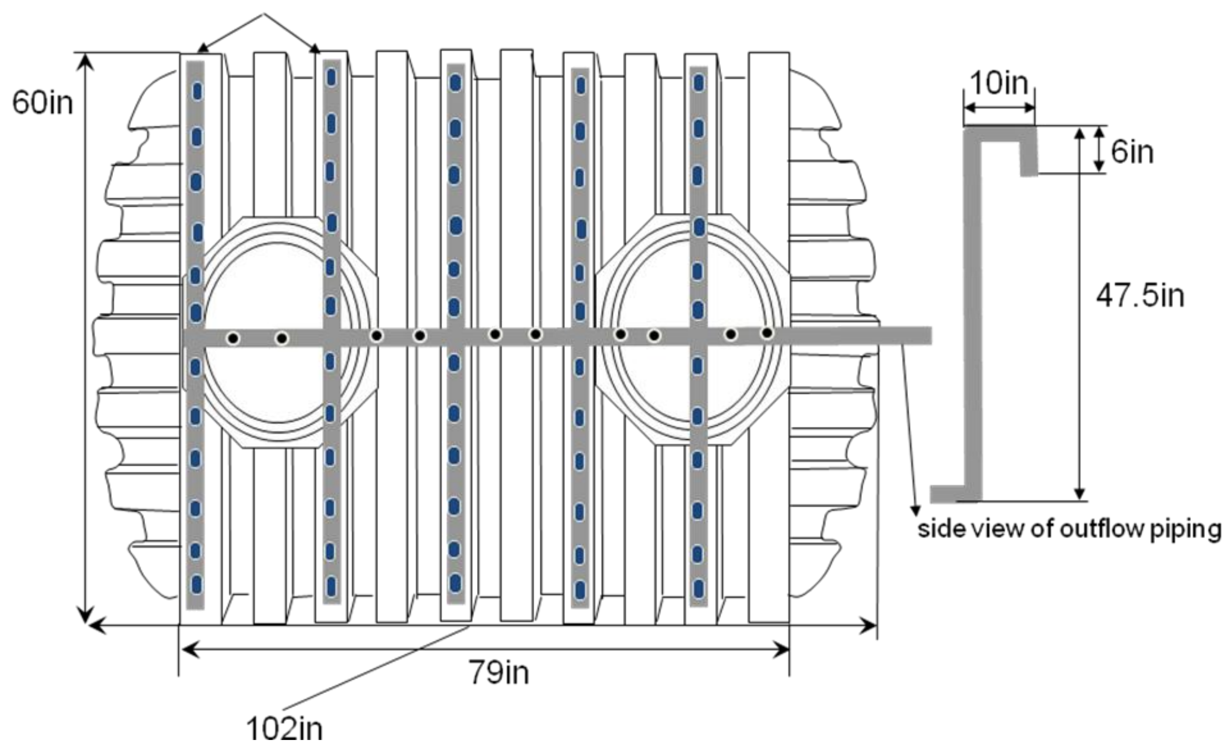

Figure 5 Internal Piping System

Analysis

pH, temperature, conductivity, and salinity were all measured on-site using a multi-parameter field probe (Oakton PCSTestr 35). ORP monitoring was performed on-site using an ORP pocket meter (Oakton ORPTestr 10). pH was also measured on samples returned to the lab using a bench-top electrode (Thermo-ORION) connected to a pH/mV meter (Accumet® Basic AB15, Fisher Scientific). Acidity and alkalinity titrations were performed as described in *Standard Methods for the Examination of Water of Wastewater* (Methods 2310 and 2320; APHA 1998) using the same bench-top electrode and ph/mV meter. Endpoints used for these titrations were pH 4.5 for alkalinity and pH 8.3 for acidity. Ammonium was also measured using an electrode (ISE ORION 9512) and the same pH/mV meter, and compared to 1mg/L, 10 mg/L, and 100 mg/L ammonium standards. pH, ammonium, acidity, and alkalinity were all measured within 3 hours of sample collection. In preparation for dissolved metals analysis, samples were filtered, acidified to pH < 2 with 60-70% HNO_3, and sparged with lab air through a 25 gauge needle for 5 minutes in order to drive off hydrogen sulfide. Dissolved metals analysis was conducted at the Pennsylvania State University Materials Characterization Laboratory using inductively coupled plasma-atomic emission spectrometry (ICP-AEP; Leeman Labs PS300UV).

Chapter 3
Experimental Results and Discussion

Pilot-scale reactors were utilized to compare the treatment efficiency and longevity of the crab shell amended substrates. Samples were collected and analyzed once a week for the first month, once every two weeks for the following month, and then once every four weeks for the remainder of the experiment. During winter months when flow ceased due to freezing, samples were not collected.

The following text, tables, and figures refer to each of the 8 columns as follows:

- "100%: Substrate is 100% crab shell
- "70% LS": Substrate is 70% crab shell and 30% SMC with a limestone (LS) underdrain
- "70% SS": Substrate is 70% crab shell and 30% SMC with a sandstone (SS) underdrain
- "SMC": Substrate is 10% limestone and 90% SMC

Water Neutralization

Influent water enters the tank with an average pH of 3.3. pH increased rapidly within the first 30 days of the study and have remained at near-neutral levels in all reactors thus far (Figure 6). Spikes in pH occur approximately 200 days into treatment due to inactivity over winter months. Another spike occurred around day 400 due to a clogged pipe in the 100% tank. Though all the tanks displayed similar pH levels, substrates containing 100% and 70% crab shell consistently treated water to a higher pH level (average 7.6) when compared to the SMC substrate (average 7.0).

Alkalinity was generated in tanks, to levels as high as 3,000 mg/L as $CaCO_3$ for the 100% tank (Figures 7 and 8). Similarly, there was a great decrease in acidity in substrate containing columns during the first 30 days as low as 4,000 mg/L as $CaCO_3$ for the 100% column. These initial changes in alkalinity and acidity are much more dramatic in crab-shell-containing substrates compared to the limestone control. This is due to the rapid dissolution of fine crab shell particles contained in the substrate upon initiation of the study. Once the fines were rinsed from the substrate, the Alkalinity and Acidity values in all substrates dropped considerably to reasonable levels (200-300 mg/L as $CaCO_3$) and continued to decrease as the study continued. Though all tanks displayed a continual decrease in Alkalinity and Acidity values, no exhaust point has yet been established. The SMC effluent consistently displayed lower Alkalinity values compared to those of the crab shell-containing substrate effluents. As of this publication, Alkalinity remains highest (average 50 mg/L as $CaCO_3$) in the 100% crab shell substrate and lowest in the SMC substrate effluent (nearing 10 mg/L as $CaCO_3$). Alkalinity generation continuously decreases at a slower rate in crab shell substrates. These properties may be attributed to a slower dissolution and degradation of higher performing substrates, and therefore a slower production of chemical buffer, as well as a slower release of nutrients to support biological treatment.

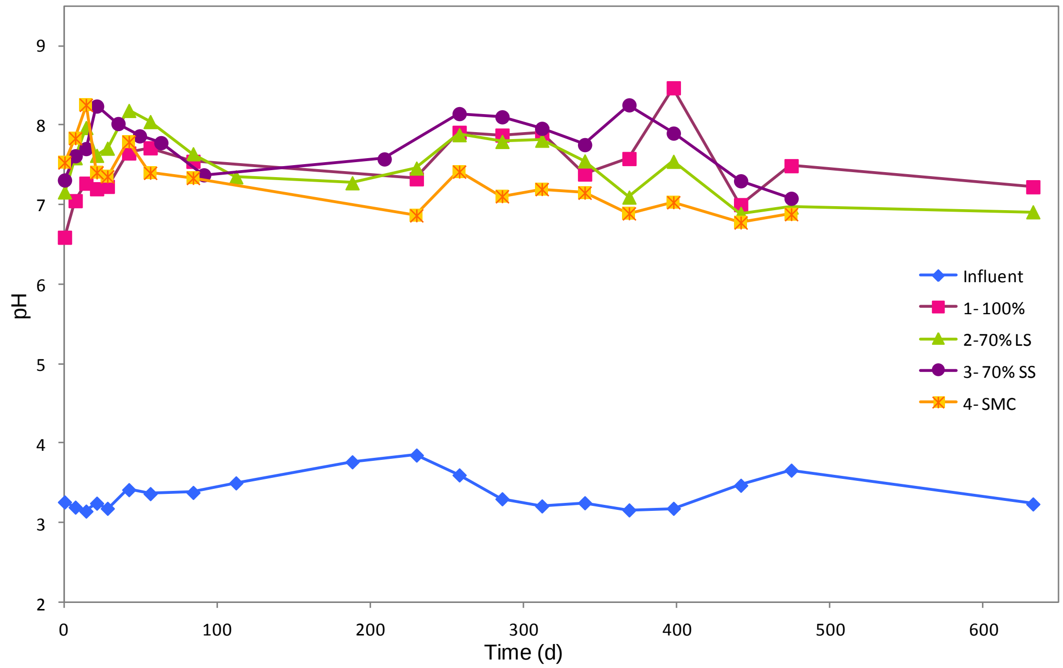

Figure 6 pH Measurements of the Influent and Reactor Effluents

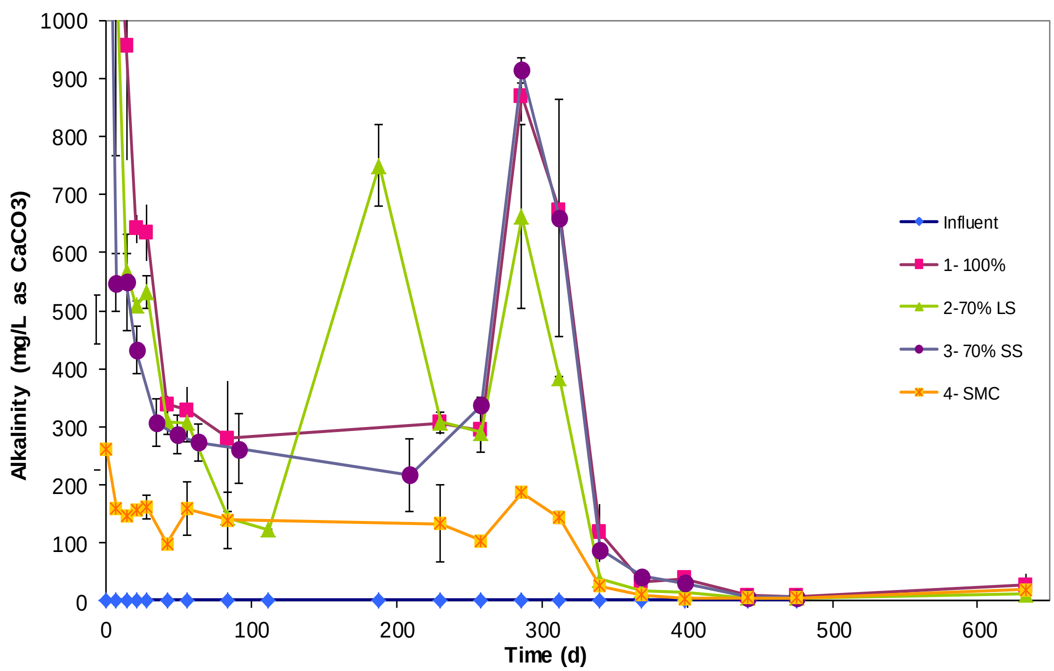

Figure 7 Alkalinity Measurements of the Influent and Treated Reactor Effluents

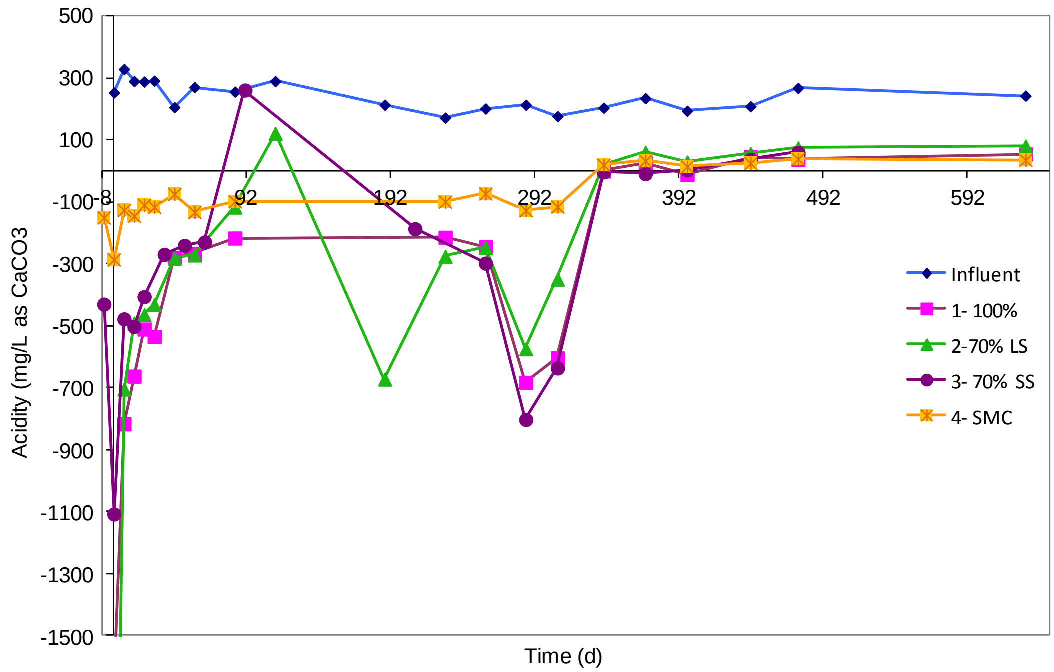

Figure 8 Acidity Measurements of the Influent and Reactor Effluent

Oxygen Reduction Potential

The sustainability of sulfate-reducing bacteria within the system relies on the oxygen reduction potential of the MIW. A value of around -200 mv is the ideal condition for supporting a healthy microbial community and optimizing sulfur removal (Figure 9). All 4 reactors initially displayed optimal ORP values for the first 50 days. However, the SMC-containing reactor ceased to provide proper ORP levels first (around day 100); whereas crab shell-containing reactors sustained the proper ORP level until around day 450. Even up until the present, the 100% crab shell tank displays near-optimum levels of ORP, as does the 70% SS tank. The SMC tank now contains a positive ORP value, meaning that the water is no longer in reducing conditions and a sulfate-reducing bacteria, essential to sulfur removal, will not be properly maintained.

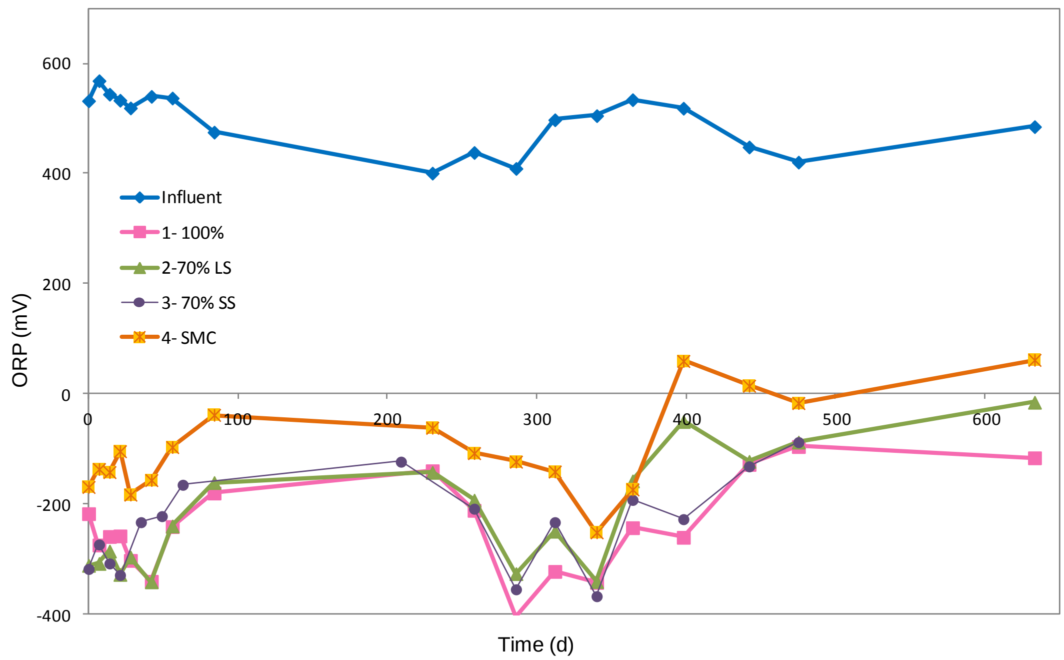

Figure 6 Field-Measured ORP Measurements of the Influent and Reactor Effluents

Metals Removal

At the Klondike 1 discharge, as well as most AMD sites found in the mid-Atlantic region, metals of concern at are iron, aluminum, and manganese. Inductively coupled plasma-atomic emission spectrometry (ICP-AEP) was used to monitor all detectable metals for removal. Samples analyzed were taken from the reactor discharge as well as the discharge from the final aeration bins. Due to the complete and continued removal of metals following the reactors, the graphs displayed represent only the samples taken directly after reactor treatment.

In all four reactors Aluminum, Zinc, Manganese and Cobalt remained completely removed from the effluent water. In the case of Aluminum, influent levels remained at an average of 2.75 ppm. Throughout the study, each tank kept Aluminum below detection levels. This is in part because Aluminum typically re-dissolves into water at a pH of 4. In all tanks, pH remained considerably above 4 until the time of this publication.

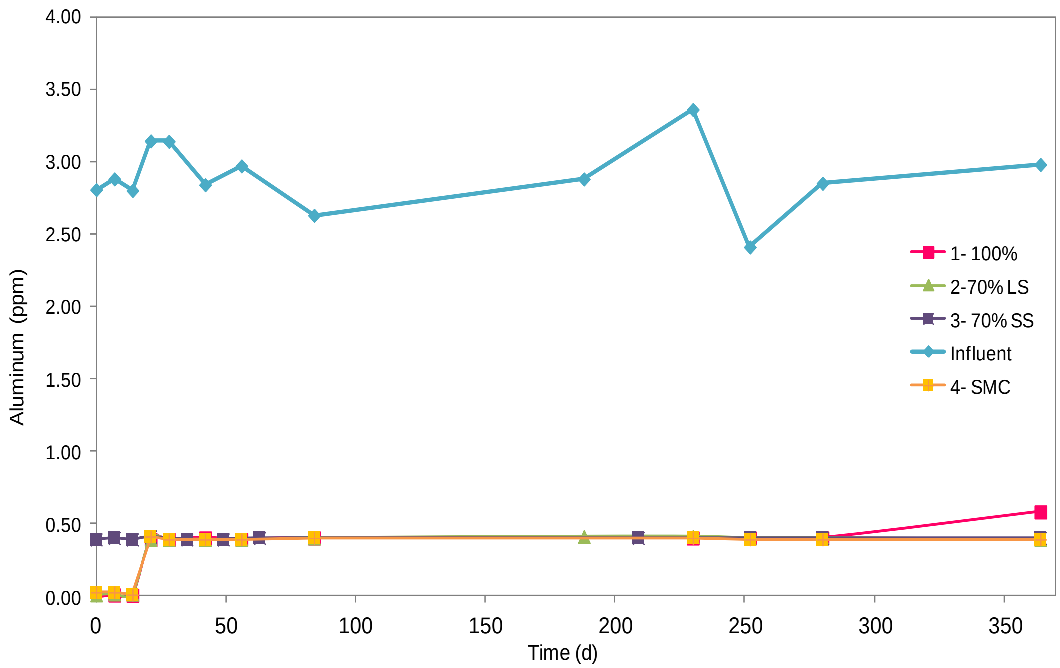

Figure 7 Dissolved Aluminum Concentrations before Aerobic Settling Pond

In the case of Zinc, there were a couple of spike sin concentration early on; however since the detection limit is (0.2 ppm) 200 ppb, those spikes are still insignificant. The influent concentration stayed at an average of 0.7 ppm (700ppb), and zinc was fully removed by each of the substrates for the current duration of the study.

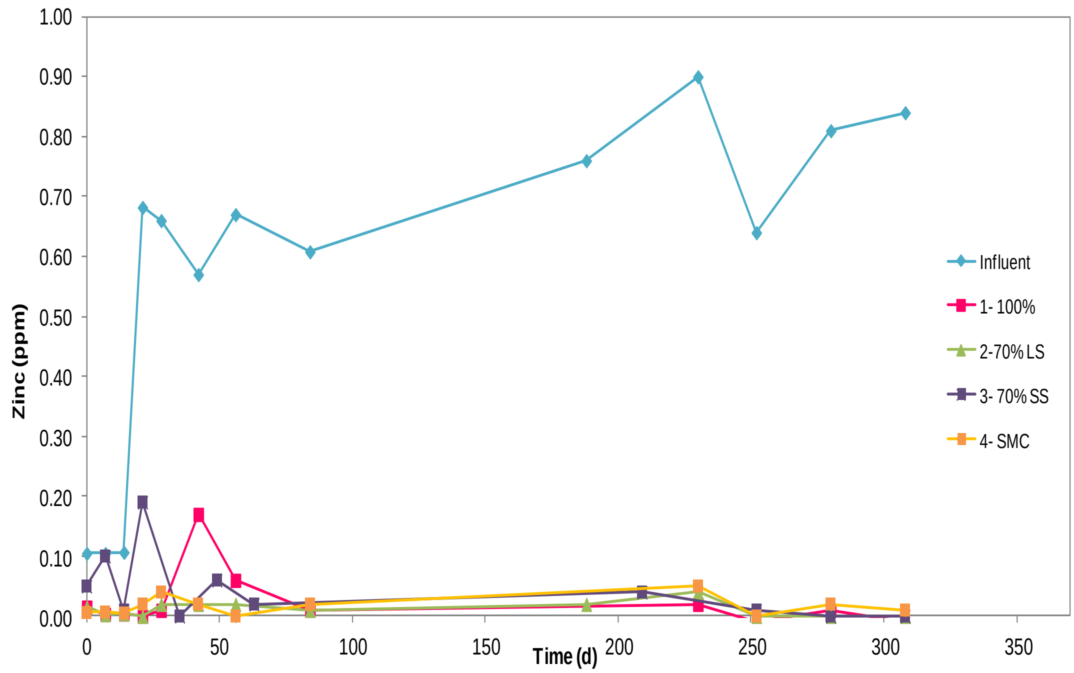

Figure 8 Dissolved Zinc Concentrations before Aerobic Settling Pond

Again, we see that though there are initial spikes in Manganese dissolution which quickly spikes and then ends up below detection even in the case of the influent stream. In Figures 13 and 14 we see that cobalt and iron are both completely removed by all four tanks. In the case of all these metals, it appears that because the study has not yet run to completion, and the pH values in the effluents from all tanks have not yet dipped to a acidic level such as is found in the influent (average 3.2), all of the metals are remaining out of solution. Metal removal efficiency will become more evident as the study continues and the substrates begin to exhaust. Since trends in the Alkalinity and Acidity graphs suggest that the SMC amended substrate is exhausting quicker than the 100% or 70% crab-shell substrate, then similar trends in metals removal can be expected.

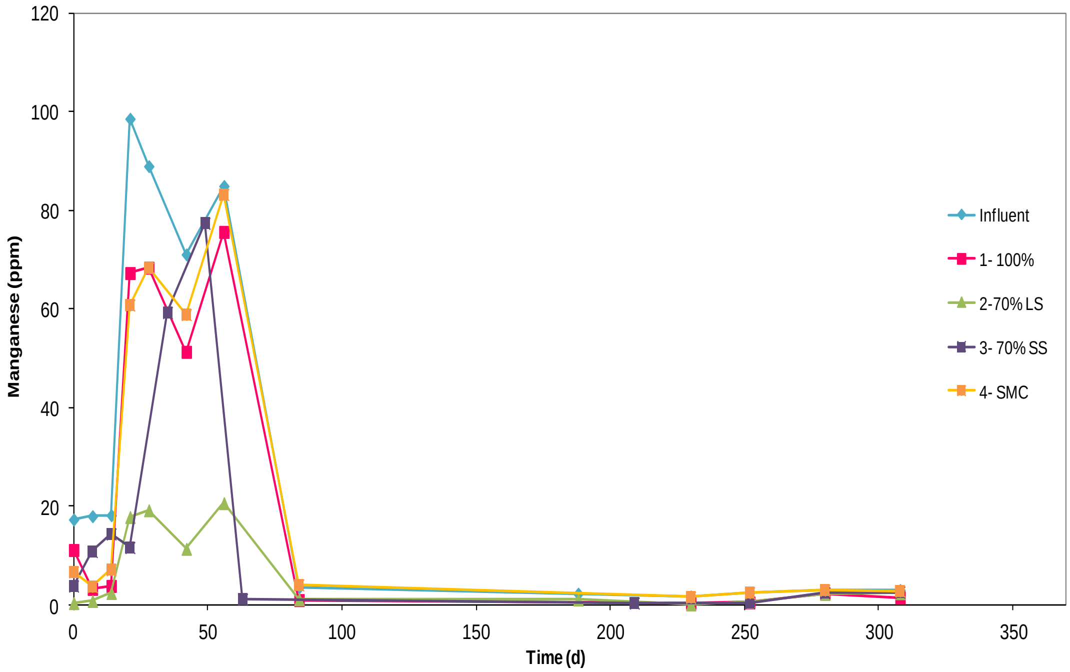

Figure 9 Dissolved Manganese Concentrations before Aerobic Settling Pond

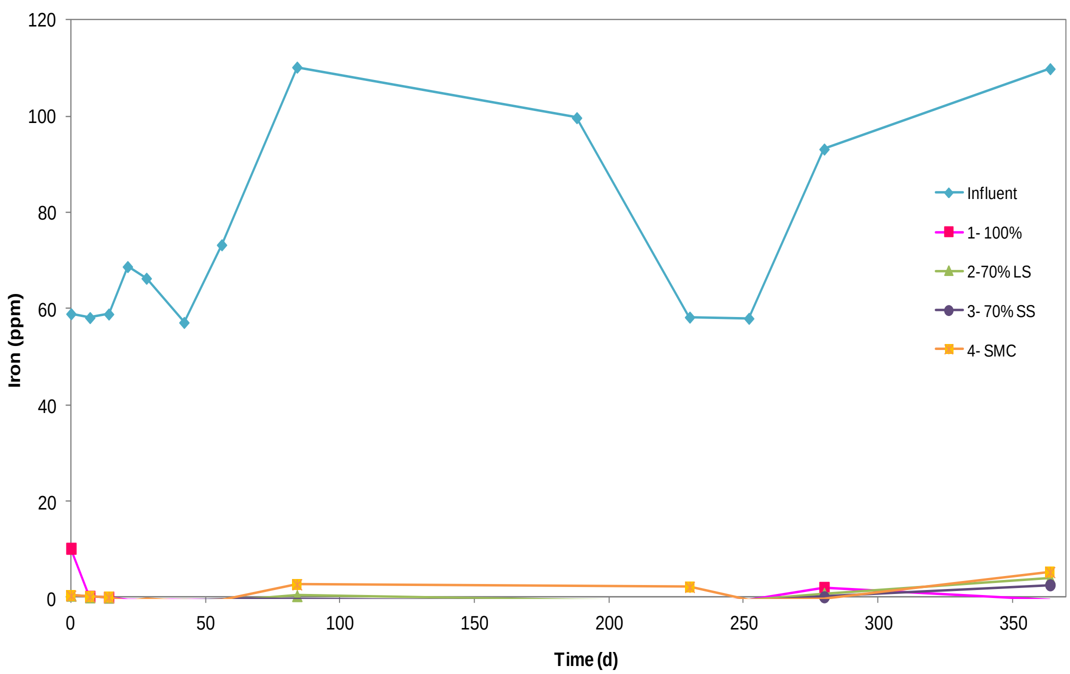

Figure 10 Dissolved Iron Concentrations before Aerobic Settling Pond

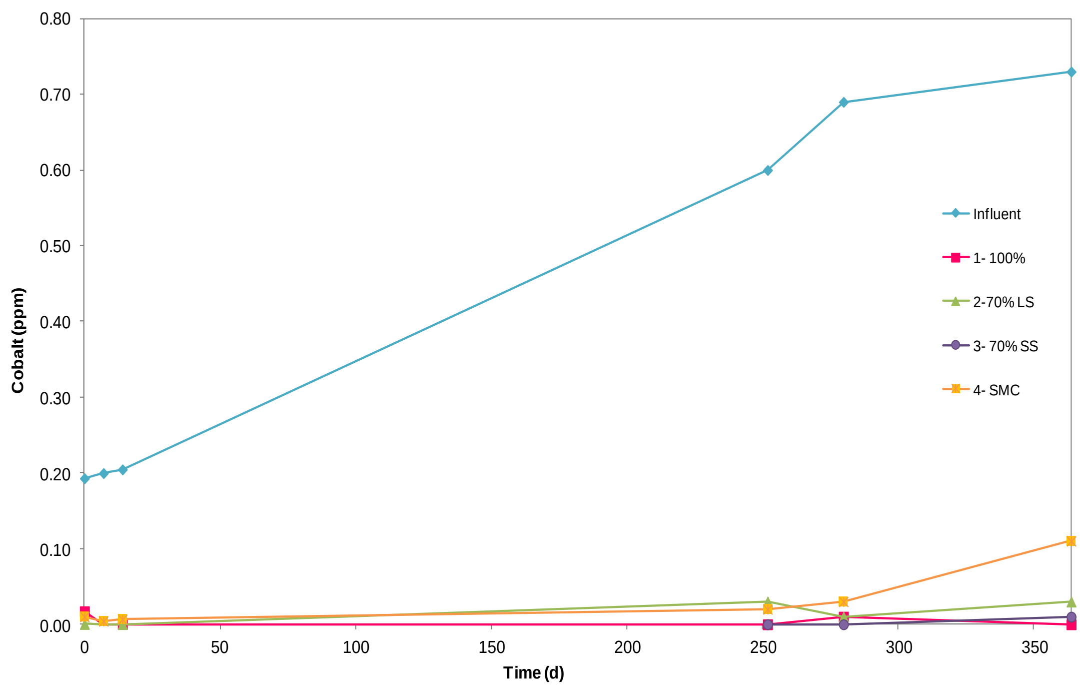

Figure 11 Dissolved Cobalt Concentrations before Aerobic Settling Pond

Ammonium Release

Ammonium concentrations were measured to observe the levels of ammonium released into the effluent – a potential hazard for aquatic life at high concentrations depending on temperature and pH. Ammonium concentrations (Figure 15) were found to be very high after initially in all reactors, although the levels were greater (around 45 mg/L NH_4 +-N) most likely due to the quick dissolution of fine crab shell particles. Substrates containing crab-shell were found to release slightly larger concentrations of various ions compared to the SMC and LS control.

Ammonium levels remained volatile throughout the experiment which could be due to a number of factors, chief of which is a dysfunctional probe, as well as the stopping and starting of flow during winter freeze and thaw.

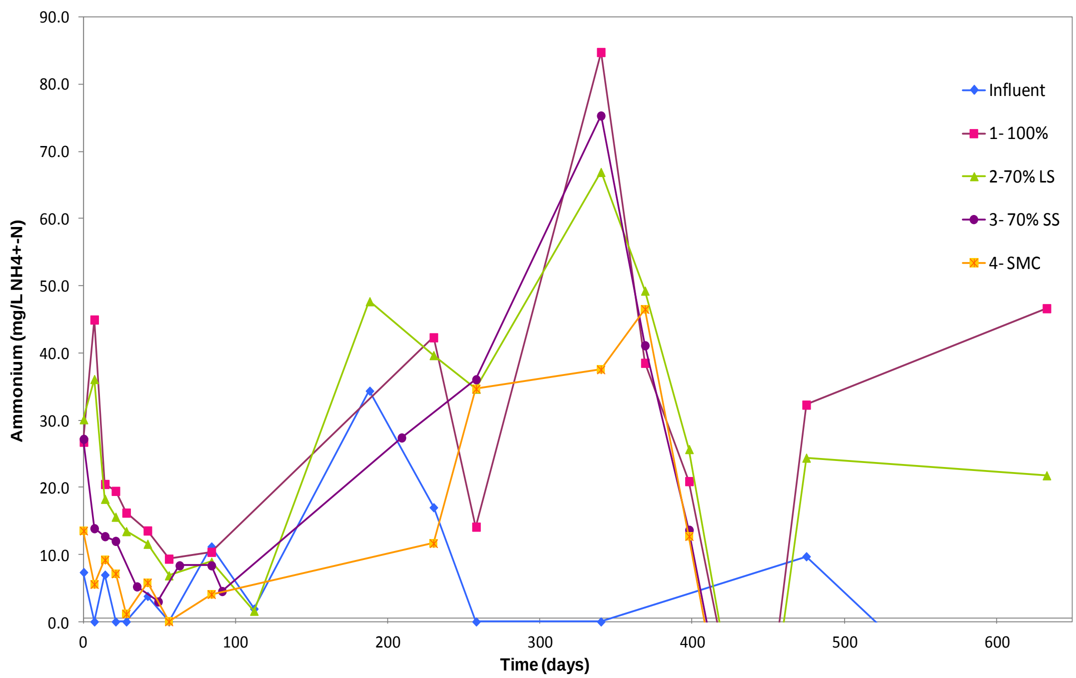

Figure 12 Ammonium Measurements of Influent and Reactor Effluent

Chapter 4
Conclusions and Future Work

Conclusions

Based on the results of the Klondike-1 pilot-scale study using various fractions of crab-shell as an amendment to SMC for the remediation of MIW:

- Substrates containing crab shell generate considerably larger amounts of alkalinity (average 680 ± 1421 mg/L as $CaCO_3$ before breakthrough) than the traditional SMC substrate (136 ± 65 mg/L as $CaCO_3$ before breakthrough);
- Under the design conditions, both crab shell-amended substrates and the traditional SMC substrate maintained a pH over 6 for the duration of the study thus far. However, water treated by the crab shell-amended substrates consistently presented higher pH values (average 7.6) when compared to the traditional SMC substrate (average 7.0).
- Oxygen reduction potential (ORP) remained at the optimum level (-200 MV) in the 100% crab shell substrate, where as both the 70% crab shell substrates and the SMC substrate could not sustain the proper ORP level. Thus, the greater the amount of crab shell in the substrate, the better the oxidation/reduction conditions for the sulfate-reducing bacteria.
- Because all substrates tested have kept the pH at near neutral levels thus far, metals remained virtually completely precipitated and absent from the treated water. Continuation of the study to exhaustion will better evaluate metals-removal efficiency.

Future Work

- The Klondike-1 Pilot-Scale study has not yet run to completion:
    - Points of exhaustion for each substrate should be reached in order to draw conclusions on the longevity of treatment, metals removal;
    - A tracer test performed to determine accurate pore volumes for each reactor;
    - Total carbon and total organic carbon analysis to determine organic matter content in each substrate;
    - Total iron and iron speciation of all sampling times.
- In the future, tracer tests should be run periodically throughout the course of a study to determine changes in pore volume due to the breakdown and settling of organic matter and precipitation of metals.
- Further exploration of the difference between limestone and sandstone underdrains to determine differences in treatment efficiencies with each;
- 16 sample packets (Figure 16) were installed in each reactor at the start of the study. The packets are made of a permeable nylon mesh and filled with a 10g sample of the substrate in which they are submersed. It is expected that the microbial community will be similar within the tank and sample packet. Once a month, the packets were pulled and stored in a -80C freezer for DNA sequencing. A full-scale exploration and analysis of the microbial communities within the various substrates is in process. The differences in microbial activity over time and throughout the varying substrates will help determine the influence of sulfate-reducing bacteria in the treatment of the MIW.

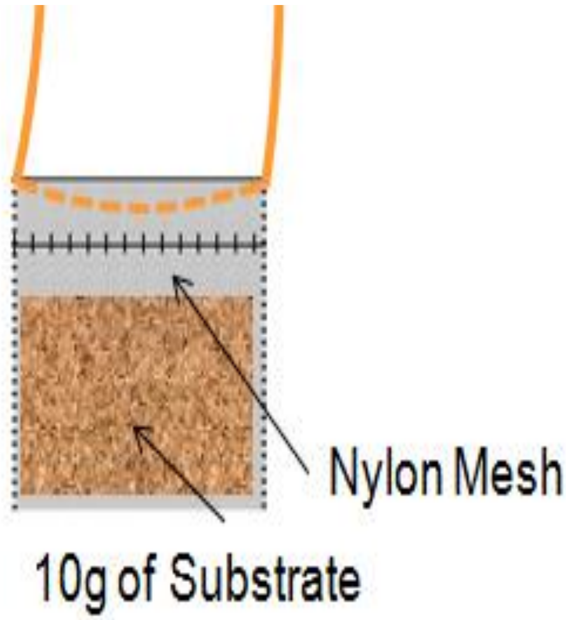

Figure 13 Microbial Sample Packet Design

Appendix

Klondike 1 – Map of Location

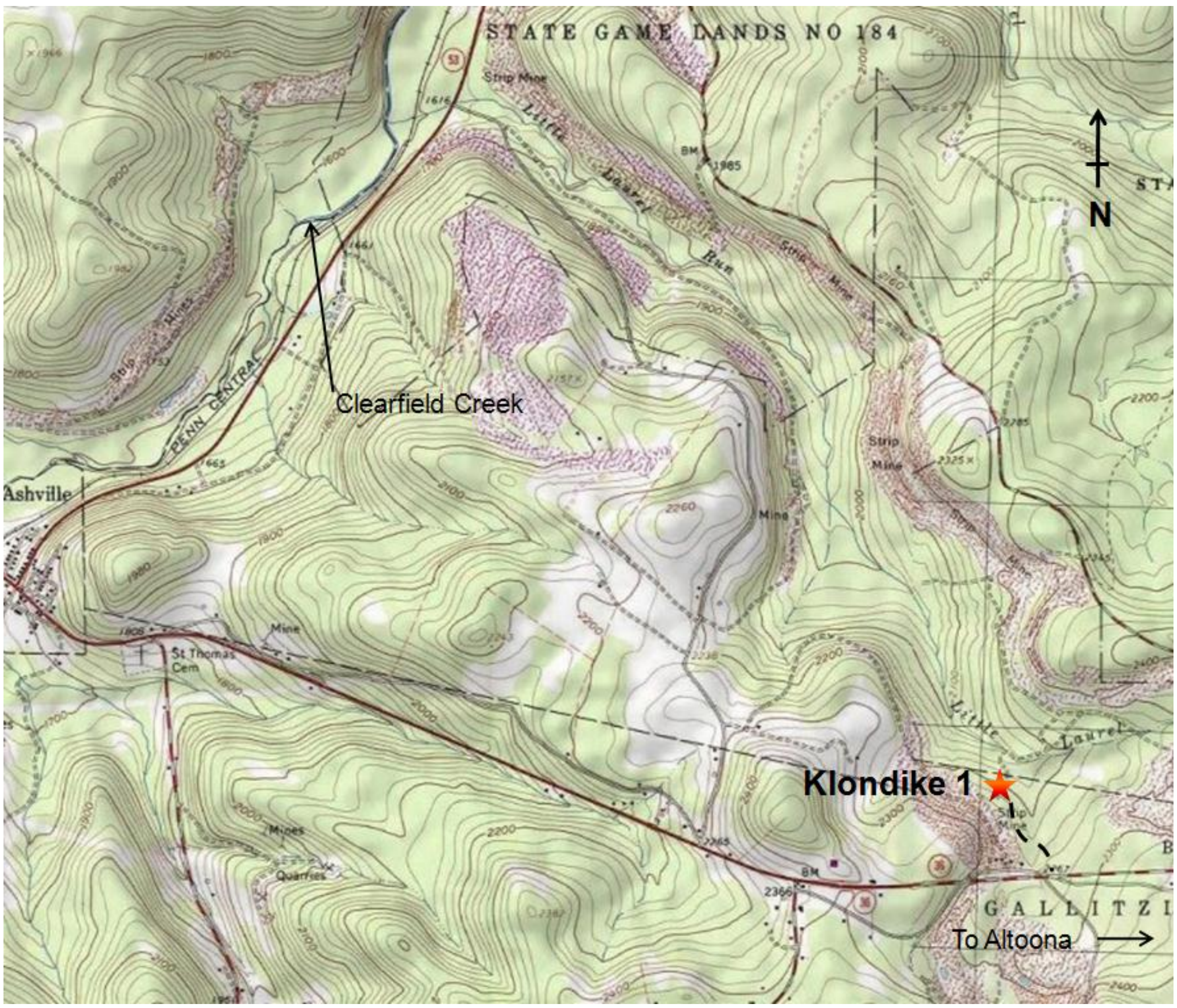

Figure 14 Location of Klondike-1

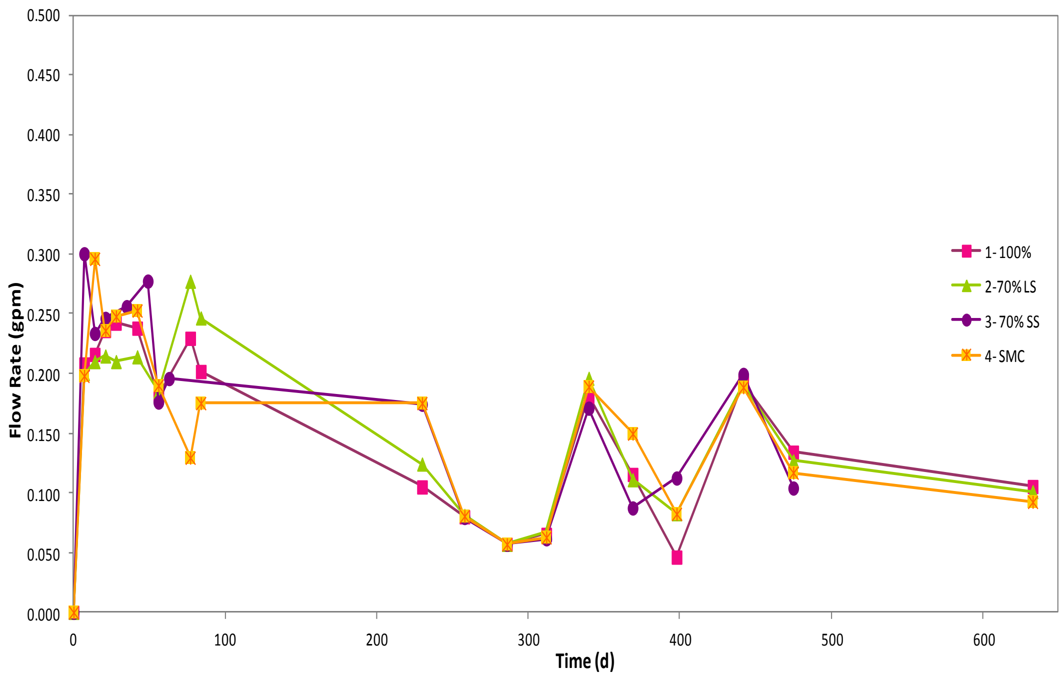

Figure 15 Flow Rate over Time

Retention-time and tank size were designed based on an average flow of 0.2 gallons per minute. However, due to small pipe diameter and orifice-sizing, flow ended up decreasing to an average value of 0.125 for all 4 tanks.

Figure 16 Author during Site Construction, July 2010

Figure 17 Color difference in reactor effluents, September 2010

Differences in treatment efficiency can be observed just by noticing the variance of effluent coloration amongst the 4 tanks. Tank 4, containing the SMC substrate is in the foreground, followed by the tanks containing the 70% crab shell amended substrate, with the 100% crab shell-substrate in the background.

Figure 18 Image displaying lack of flow during winter months, December 2010

Due to the small pipe diameters of the pilot system, freezing temperatures caused flow to cease during winter months. Once thawed, flow would continue, however initial spikes in alkalinity and acidity were observed as longstanding water left the system. These spikes can be observed in the graphs of alkalinity, acidity, ORP, and pH values around days 200 and 500 .

References

APHA, AWWA, and WEF. "Standard Methods for the Examination of Water and Wastewater: 20th Edition." Eds. Clesceri, L.S., Greenberg, A.E., and Eaton, A.D. Baltimore: APHA, 1998.

Daubert, L. N., and Brennan, R. A. (2007) "Passive remediation of acid mine drainage using crab shell chitin." *Environmental Engineering Science*, 24 (10): 1475 - 1480.

Grembi, Jess. (2011). "Remediation of high-strength mine impacted water with crab-shell substrate mixtures: laboratory column and field pilot tests." M.S. Thesis, Penn State University.

Newcombe, C.E. (2009). "Effective and low-cost treatment of acid mine drainage using chitin as a fractional amendment to compost." M.S. Thesis, The Pennsylvania State University.

Newcombe, C.E., and Brennan, R.A (2010). "Improved passive treatment of acid mine drainage in mushroom compost amended with crab-shell chitin" *ASCE Journal of Environmental Engineering.* In press.

Pennsylvania Dept of Environmental Protection (2007) 2006 Pennsylvania integrated water quality monitoring and assessment report–clean water act section 305(b) report and 303(d) list. PA DEP, Bureau of Watershed Mgmt, Harrisburg, PA, USA, p 55, http://www.depweb.state.pa.us/watersupply/lib/watersupply/MasterNarrative.pdf

Pennsylvania Dept of Environmental Protection (2009) Recreational use loss estimates for PA streams degraded by AMD 2006. Bureau of Abandoned Mine Reclamation acid mine drainage setaside program–program implementation guidelines, PA DEP Bureau of Abandoned Mine Reclamation, Harrisburg, PA, USA, p C1-C14, http://www.depweb.state.pa.us/portal/server.pt/community/abandoned_mine_reclamation/13961

Robinson-Lora, M. A., and Brennan, R. A. (2010) "Chitin complex for the remediation of mine impacted water: geochemistry of metal removal and comparison with other common substrates." *Applied Geochemistry*, 25 (3): 336 - 344.

Robinson-Lora, M.A., and Brennan, R.A. (2009a). "Efficient metal removal and neutralization of acid mine drainage by crab-shell chitin and continuous-flow conditions." *Bioresource Technology*, 100 (2009) 5063-5071.

Rose, Arthur. (2008) Klondike AMD Treatment Project Final Report. Prepared for Clearfield Creek Watershed Association, 8pp.

U.S. Department of the Interior. Office of Surface Mining. (2008). AMDTreat v4.1c.

Academic Vita

Sara Sinclair Goots

224 S. Burrowes St., Apt. 304
State College, PA 16801
ssg5074@psu.edu
(216)-272-4611

Education

The Pennsylvania State University, University Park, PA
B.S. Environmental Systems Engineering
Minors: Geography; Watersheds and Water Resources
Graduation: August 2012
Schreyer Honors College Scholar

Experience

Health, Environment, and Safety Intern
Chevron- San Joaquin Valley Business Unit
May-August 2011, 40 hours/week

- Analyzed the waste streams generated by drilling rigs.
- Created a guideline for the management of waste at drilling sites.
- Initiated a recycling program at drilling rig locations.
- Aided in on-site safety observations.

Undergraduate Researcher
Penn State University- Civil and Environmental Engineering Department May 2010-Present, 10 hours/week during school year

- Studied the benefits of crab shell mixtures in remediating acid mine drainage.
- Aided in the design and installation of a pilot-scale remediation site.
- Performed lab testing, data analysis, DNA extraction, and field sampling.

Education Abroad Student
AESEDA Parks and People Program
January-March 2010

- Studied and performed field testing at a nature reserve in South Africa.
- Assisted authoring of research proposal.

Honors

Dean's List, Fall 2009, Spring 2010, Fall 2010, Fall 2011
1st Place Engineering Poster, Penn State Undergraduate Exhibition, 2011
1st Place Undergraduate Poster, College of Engineering Research Symposium, 2011
Gerard L. Bayles Memorial Scholarship, 2010-2011
Chevron Environmental Systems Scholarship, 2008-2011
EMS Centennial Scholarship, 2010