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Constructed Wetland Project for the Illinois River

Oklahoma State University

April 29, 2010

Contents

Introduction

Figure 1. *Illinois River near Lake Francis in Adair County.*

Problem Statement

Flowing from northwestern Arkansas into northeastern Oklahoma, the Illinois River is a source for recreation and drinking water in both states. The Illinois River Basin covers 1,645 square miles between Oklahoma and Arkansas and is dammed south of Tahlequah, Oklahoma to form Lake Tenkiller Ferry. **Figure 1** above shows the river near Watts, Oklahoma. The river and lake are used for recreational activities such as fishing, water skiing, swimming, diving, noodling and floating. Communities which rely on the river and lake for drinking water include Siloam Springs, Arkansas and Tahlequah, Oklahoma. The river and lake also support a diverse habitat which is heavily used for hunting and other recreational activities. Lake Tenkiller Ferry is becoming increasingly eutrophic because of excess nutrients, primarily phosphorus, conveyed by the river[1]. Eutrophication causes algal blooms, limiting the oxygen availability for fish and other aquatic wildlife.

Phosphorus in the river comes from point and non-point sources originating mostly from municipal wastewater treatment plants and runoff from agricultural fields respectively. Point sources can be easily identified, given they come from a single point and are essentially constant. Efforts have been made, and are still ongoing, to reduce the amount of phosphorus being discharged from the six major wastewater plants in Arkansas within the Illinois Basin. These plants account for about 32% of the phosphorus load and are the main source of phosphorus during base flow in the Illinois River[2]. Non-point sources are more difficult to quantify. Due to the commanding presence of the poultry industry in northwestern Arkansas, 210 million kilograms of poultry litter is produced each year, most of which is used to fertilize agricultural fields in the region. The litter contains 2.9 million kilograms of phosphorus, and during storm events much of this phosphorus is washed off the fields and into streams, which eventually drain into the Illinois River. The non-point source pollution, which accounts for about 66 percent of the total phosphorus load, has the greatest effect during high flow and storm events[2].

The Illinois River has been a source of legal disputes for over a decade. The river has been declared a “Wild and Scenic River” by the state of Oklahoma, and with that designation comes a numerical criterion of 0.037 mg/l phosphorus. This criterion is not currently being met

[1] Meo, Mark. "The Illinois River Project and Oklahoma's Quest for Environmental Quality." Journal of Contemporary Water Research & Education 136 (2007): 56-67.

[2] Storm, Daniel, George Sabbagh, Mark Gregory, Michael Smolen, Dale Toetz, David Gade, C. Tom Haan, Ted Kornecki. “Basinwide Pollution Inventory for the Illinois River Comprehensive Basin Management Plan.” Submitted to the Oklahoma Conservation Commission, 1996.

as shown in **Figure 2** below, and the U.S. Supreme Court has ruled the state of Arkansas must comply with Oklahoma's water quality standards[3]. *The Environmental Protection Agency* has recently commenced a two-year study investigating the entire Illinois River watershed to provide a "Total Maximum Daily Loads" study for Lake Tenkiller Ferry[4]. This study would provide a further limit on the amount of nutrients flowing through the river to the lake.

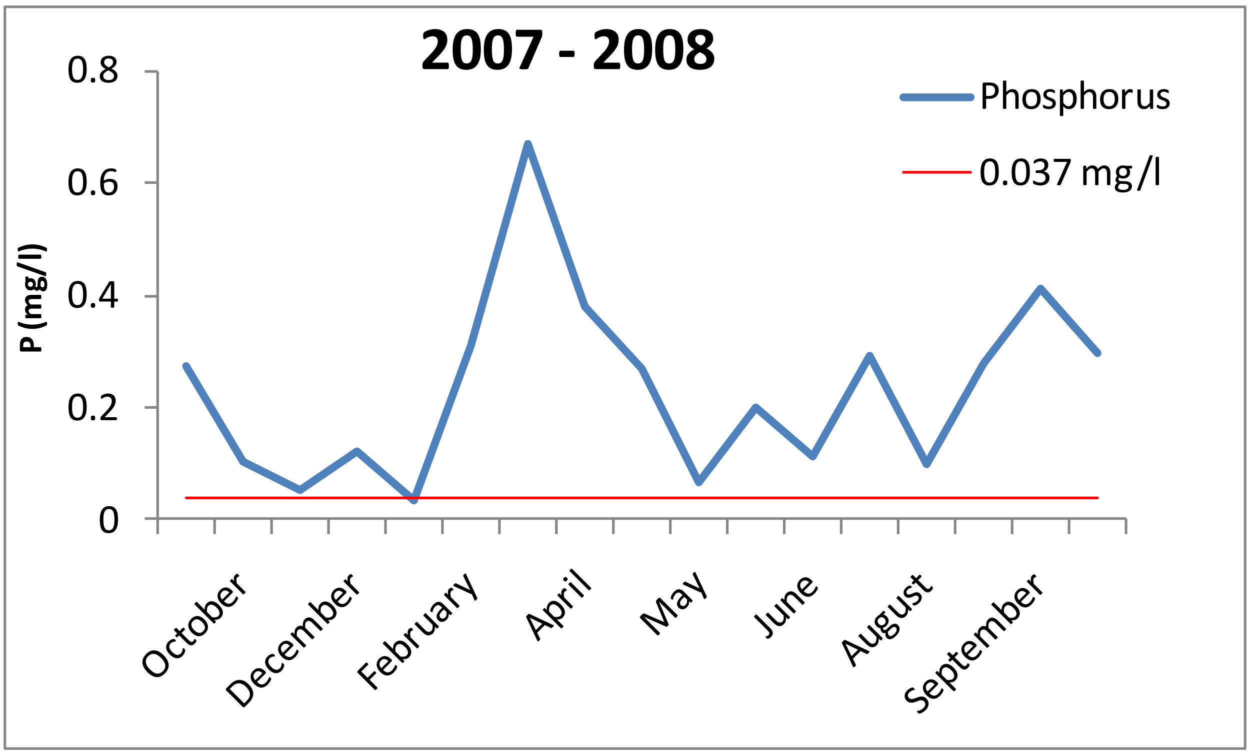

Figure 2. *Phosphorus level in the Illinois River from October 2007 to October 2008. Data obtained from the USGS.gov website from the Watts, Oklahoma USGS gage station.*

Proposed Solution

Figure 3 shows a site on the Illinois River near the Oklahoma/Arkansas state line. The shaded area highlights a dry lake bed where a wetland could be constructed. Wetlands are a

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[3] Arkansas v. Oklahoma Environmental Protection Agency. 503 U.S. 91 Openjurist.org. U.S. Supreme Court. 26 Feb. 1992.

[4] Brocksmith, Ed, "Oklahoma phosphorus limit on Illinois River a viable number." Muskogee Phoenix. Web. April 21, 2010. http://muskogeephoenix.com/columns/x794089743/ Oklahoma-phosphorus-limit-on-Illinois-River-a-viable-number.

natural ecosystem with biological, chemical, and physical processes which function to remove pollutants from water over a period of time. *Scenic Solutions* proposes a constructed wetland to treat the Illinois River water, specifically for phosphorus removal. In order to enhance the effectiveness of phosphorus removal, *Scenic Solutions* proposes to couple this wetland with a chemical injection system and effluent polisher. Alum ($Al_2(SO_4)_3$) has been shown to effectively remove phosphorus in a wetland system by previous research[5]. In order to further increase the phosphorus removal efficiency, *Scenic Solutions* proposes running the water through a steel slag polisher after it has left the wetland. Steel slag has been shown to be efficient in removing soluble phosphorus[6]. The alum and slag would combine forces to effectively remove phosphorus from the water. This solution is meant to provide both states an option for improving Illinois River water quality. The wetland solution would provide a natural setting for biological processes aided by alum and steel slag.

The wetland would serve as an excellent habitat for ducks and other water fowl and would be a good arena for hunting. Removing the excess nutrients from the Illinois River will positively affect Lake Tenkiller; increasing the overall clarity and appeal of the lake[7].

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[5] Malecki-Brown, Lynette M., John R. White, and M. Sees. "Alum Application to Improve Water Quality in a Municipal Wastewater Treatment Wetland." Journal of Environmental Quality 38 (2009): 814-21.

[6] Parent, Serge, Jean Bouvrette, Rachel Leger, Yves Comeau. "Use of Steel Slag to Remove Soluble Phosphorus from Closed Marine Systems." 2005. Biodome of Montreal.

[7] Meo, Mark. 56-67.

Figure 3. *Illinois River on Oklahoma/Arkansas Border (Thick Yellow Line). Source: goole.com/maps*

Purpose

The main purpose of this senior design project is to provide a proof of concept for the proposed integrated wetland system to treat Illinois River water.

Objectives

The overall objective of the project is to evaluate the applicability and effectiveness of an integrated wetland system to remove phosphorus from the Illinois River. Specific objectives include:

1. To conduct a strategic literature review to establish the current status of combined constructed wetland, chemical addition technology, and polisher for phosphorus removal from surface waters.

2. Determine through a pilot scale study if combined constructed wetlands, chemical addition, and polisher can sustainably and cost-effectively achieve phosphorus concentrations in the Illinois River near the state line that meet the Oklahoma Water Quality concentration of 0.037 millig/l limit of total phosphorus.
3. Produce performance-based design criteria that could result in the successful application of this technology.
4. Evaluate the costs and benefits of capital investment and operation/maintenance for the combined constructed wetland, chemical addition technology, and polisher for phosphorus removal.
5. Disseminate the results of the study through technical papers and presentations so others can benefit from the research.
6. Organize a campaign incorporating video, websites, billboards, factsheets and a public service announcement to communicate to the public the need for a constructed wetland system of the Illinois River.

Statement of Work

Initial activities included jar tests to compare alum injection concentrations to flocculent settling times and dissolved phosphorus and sediment removal efficiencies in water samples from the Illinois River. Due to time restrictions, seasonality was not addressed in this study and water was only acquired in late February for the jar tests at a location just downstream of the proposed site for the constructed wetland.

The results from the jar tests were used to determine the optimal alum injection concentration which was incorporated into a subsequent mesocosm study. Following the development and evaluation of potential design alternatives for the wetland system, testing of the selected design was conducted. These tests provided phosphorus removal efficiencies of the design. Results from the mesocosm study were used to evaluate applicability and effectiveness of the proposed wetland system design to make recommendations for in situ phosphorus attenuation in the Illinois River.

The public good of recreational uses has been evaluated through the travel cost and total willingness to pay equations and estimates. A cost effective analysis has been conducted which compares alternatives for reducing phosphorus in the Illinois River. Communication materials produced include a billboard design, public service announcement, team website, educational website, wetlands educational factsheet, YouTube video, and an educational video.

Impacts

A constructed wetland to remove phosphorus for the Illinois River will have many important impacts on the region. Environmentally, it will provide clean water for the Illinois River in northeastern Oklahoma while creating a valuable habitat for native species. The wetland system can be used as an education tool and will make society more aware of the need to keep water clean and the significance of completing the goal with natural processes. The wetland will provide a long term clean water source as well as an excellent supply of recreational activities. Growing tendencies to use wetlands as natural pollutant removers will create more natural habitats globally for wildlife and recreation, while protecting rivers and lakes throughout the world.

Background

Project Motivation

Environmental engineering is a sector that is experiencing increasing growth. Water quality research has experienced considerable growth since the passage of the *Clean Water Act* in the 1970s. A growing level of environmental awareness is leading to an increase in regulations to control and improve present conditions. The degree of surface water degradation is becoming increasingly apparent and the motivation to fix these problems is becoming stronger. Increasing population and strain on rivers and lakes is also bringing this issue to the forefront. Even in times of economic downturn, environmental laws are still in effect and the population should continue to be concerned with clean water supplies.

The main motivation for this project is the condition of the water in the Illinois River and Lake Tenkiller Ferry. Increased nutrient concentrations, including phosphorus, have caused habitat degradation in the river. This is indicated by the loss of macro-invertebrates in the water. Increases in algal production are expected due to loss of riparian buffers and nutrient enrichment. At some sites on the river, the dissolved oxygen demand exceeds the *EPA* criterion[8].

There are other motivations for this project and the following section describes three court cases concerning the Illinois River Watershed. The first resulted in Arkansas being forced to follow Oklahoma's water quality criterions, and the last two specifically target the poultry industry.

[8] PARSONS and Ecological Engineering Group of the University of Arkansas. "Water Quality and Biological Assessment of Selected Segments in the Illinois River Basin and Kings River Basin, Arkansas." Dallas: US EPA Region 6. November 2004.

State of Arkansas v. State of Oklahoma

In 1991, the state of Arkansas filed for an *EPA* permit to allow a point source discharge into an Arkansas creek following the National Pollution Discharge Elimination System (NPDES) under the *Clean Water Act* Section 402(a)(1). The EPA granted the permit, providing Arkansas would follow all relevant Oklahoma water quality standards because the Arkansas creek eventually flows into the Illinois River which then crosses into Oklahoma. Under Oklahoma law, the Illinois River is regarded as a "Wild & Scenic River" which outlaws any degradation of water quality. This standard would prevent Arkansas from discharging pollution into the creek at all. Oklahoma challenged the permit, claiming the point source would degrade water quality in the Illinois River. The *EPA* decided that the discharge would provide no noticeable water quality difference, therefore the permit stood. The *EPA* still stressed that Arkansas must meet all Oklahoma water quality standards. An appellate court overturned the *EPA*'s ruling, stating that any addition of pollution to the river would break Oklahoma law. Finally, the U.S. Supreme Court overturned the appellate court and allowed the permit to stand. The U.S. Supreme Court also ruled that the *Clean Water Act* does not require states to respect downstream states' water quality standards, but gave the *EPA* authority to enforce state adherence to other states' water laws if necessary. The *EPA* also had the authority to interpret state's water quality standards themselves and not necessarily follow the interpretation by another state's courts. In conclusion, the U.S. Supreme Court said the original *EPA* ruling stood that allowed the point discharge, but would not allow Arkansas to degrade Oklahoma's water in any measureable fashion[9].

[9] Arkansas v. Oklahoma Environmental Protection Agency. Feb. 1992.

City of Tulsa v. Tyson Foods, Inc.

In 2003, Tulsa sued the poultry industry including Tyson Foods Inc., Cobb-Vantress Inc., Cargill Inc., George's Inc., Peterson Farms Inc., and Simmons Foods Inc. because of the increasing pollution in Tulsa's water which flows from northwest Arkansas. The city of Tulsa determined that the pollution was mainly from poultry producers and a municipal wastewater treatment facility in Arkansas. In 2003 the U.S. District Court for the northern district of Oklahoma ruled that poultry litter application was subject to the *Comprehensive Environmental Response Compensation and Liability Act of 1980* (CERCLA)[10]. This act is also referred to as the Superfund Act. The Superfund Act allows for liability to be held against parties who release hazardous waste into hazardous waste sites[11]. The two parties settled out of court.

State of Oklahoma v. Tyson Foods, Inc.

In 2005 the Oklahoma Attorney General, Drew Edmondson, filed a lawsuit against the dominant poultry producers in the Illinois River Watershed. These producers included Tyson Foods Inc., Cobb-Vantress Inc., Aviagen Inc., Cal-Maine Foods Inc., Cargill Inc., George's Inc., Peterson Farms Inc., Simmons Foods Inc., and Willow Brook Foods Inc. Edmondson claimed the poultry producers' practices of waste disposal were not following federal and state laws and therefore damaging the natural resources of the Illinois River Watershed. He also claimed these poultry producers were endangering the public health and safety because of these practices[12]. Edmondson used the *Superfund Act* to hold the poultry producers responsible. This act gives the

[10] Warren, Donald. "City of Tulsa v. Tyson Foods: CERCLA Come to the Farm-But Did Arranger Liability Come with it." Arkansas Law Review 59.169 (2003).

[11] 42 U.S.C. 9601-9675. 1980

[12] Burnett, LeAnne. State of Oklahoma, ex rel. W.A. Drew Edmondson v. Tyson Foods, Inc.: A Bird's Eye View. Rep. Oklahoma City: Oklahoma Farm Bureau, 2009. Poultry Litigation. Web. 1 Dec 2009. http://www.okagpolicy.org/index.php?option=com_content&view=article&id=85:poultry-litigation &catid=44:animal-agriculture&Itemid=54.

government authority to respond to hazardous material releases into the environment which may harm the public or environment[13]. It also holds the responsible parties liable for all damages caused by the release. Edmondson was pursuing an injunction to halt all poultry litter application in the area and monetary reimbursement to the state for remediation, court, interest, and attorney costs. In 2010, the court denied the injunction because of the lack of proof that the water degradation was caused by the poultry litter fertilizer[14].

Groups Concerned with Water Quality

One of the key groups in the Illinois River basin is the Cherokee Nation. The Cherokee Nation has authority over the Illinois River and Lake Tenkiller Ferry, which gives them water rights to the river. The Cherokee Nation has also been involved in the legal disputes with the poultry industry over water quality.

Another major group is the general public who use the river for recreational purposes such as fishing, floating, hunting and camping. The wetlands project would appeal to this demographic for conservation of the river and wildlife. The communications campaign will target this demographic.

The economic status of the groups concerned with water quality was measured through the greater good of the environment. Currently, the public consider the use values the most important over any nonuse values or option values. The design of the wetland will be beneficial for the ecological, industrial, municipal, recreational and irrigational uses for the surrounding area. This issue is addressed further in the Benefit/Cost section of this report.

[13] 42 U.S.C. 9601-9675. 1980

[14] Oklahoma v. Tyson Foods, Inc., et al. US District Court for the Northern District of Oklahoma. Case no. 4:05-cv-00329-GKF-PJC. Document # 2891. 1 March 2010. https://ecf.oknd. uscourts.gov/cgi-bin/DisplayPDF.pl?dm_id=963878&dm_seq=0

Government Regulations

In order to construct a wetland, The Army Corps of Engineers, an enforcement agency, mandates that instructions specified in Section 404 of the *Clean Water Act*[15] are followed. Section 404 defines regulations of the restoration, enhancement, construction, or preservation of a wetland. Valid approval may be needed from the *Oklahoma Water Resources Board*, *Department of Environmental Quality*, *Oklahoma Historic Society* and the *Oklahoma Scenic Rivers Commission*.

The *EPA* has a design manual specifically for wetlands[16]. *Scenic Solutions* will refer to this manual for the design of the wetland.

The *EPA* manual will be a valuable resource to determine industrial standards of wetland process designs, vegetation, and physical features.

The chief concern of the government agencies that will pay for the constructed wetlands is providing for the tax payer in an efficient matter. Governmental contracts are closely scrutinized, and all regulations must be followed when working with the government.

Key People and Organizations

Scenic Solutions depended on several key people from different organizations to fulfill its objectives. Dr. Daniel Storm from *Oklahoma State University (OSU)* was the chief advisor to *Scenic Solutions*. Dr. Storm has past experience with wetland design and ample knowledge of the current litigation between the state of Oklahoma and the chicken industry involving nonpoint source pollution in the Illinois River. Other faculty advisors for *Scenic Solutions* from *OSU*

[15] 33 U.S.C. 1251 et seq. 1972

[16] United States. Environmental Protection Agency. Office of Research and Development. Design Manual: Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment. Cincinnati, Ohio. 1988.

include Drs. Chad Penn and Garey Fox. Dr. Chad Penn allowed *Scenic Solutions* to use his laboratory for sample processing and provided advice on the use of steel slag as a polisher for the wetland system. Dr. Garey Fox provided support for data analysis.

Scenic Solutions' industry consultant was Steve Patterson of *Bio x Design*, an environmental consulting and ecological restoration company in Poteau, Oklahoma. Mr. Patterson is the owner and main contact at *Bio x Design*. Mr. Patterson has experience with wetland design, regulatory permitting, ecological assessments, and ecological restoration.

The *USDA-ARS Hydraulics Lab* in Stillwater, Oklahoma has also allowed for the use of a flume on their property for the mesocosm tests. Kem Kadavy, Sherry Hunt, and Greg Hanson at the Hydraulics Lab have provided instructions and resources to build the mesocosm. The majority of funding was provided by the *Oklahoma Scenic Rivers Commission (OSRC).*

Other resources include the Biosystems and Agricultural Engineering Laboratory for fabrication advice and tools and the Soil Water and Forage Analytical Lab (SWFAL) for sample processing. The USGS gage stations on the Illinois River located at several key spots near the proposed wetland location were key in determining phosphorus levels and flow rates.

Of significance to *Scenic Solutions* is the team at the *University of Arkansas* (*U of A). An* equivalent senior design group has been established at the *U of A* which is investigating point source pollution water treatment for the Illinois River watershed. This team worked in parallel with *Scenic Solutions* because the implications of both projects are related. Dr. Tom Costello is an associate professor at the *U of A* whose research involves animal waste, water quality, and chicken and livestock environments. Dr. Costello is the senior design instructor at the *U of A*. Dr. Marty Matlock is a professor at the *U of A* who has provided direction and support for *Scenic*

Solutions. His research involves ecological design, water quality modeling, and ecological risk assessment.

Scenic Solutions was advised by Dr. Tracy Boyer, Dr. Damian Adams and Dr. Al Tongco evaluating the benefit the public good would gain with phosphorus removal from the wetland. Drs. Rodney Holcomb and Dan Tilley were instrumental with developing benefit and cost scenarios throughout the project. Dr. Jason Vogel assisted with editing and direction of the wetlands factsheet. Dr. Dwayne Cartmell and Rachel Hubbard provided information and assistance with the public service announcement. Dr. Cindy Blackwell also served as the main advisor for the communications aspect of this project.

Patent Search

An extensive patent search has been conducted. All patents discussed below are included in Appendix C.

Alum Recover and Waste Disposal in Water Treatment[17]**-** This patent describes a process by which alum from wastewater treatment plants can be recycled and reused. This may be applicable because reusing alum from a wastewater treatment plant could reduce material costs.

Constructed Wetlands System, Treatment Apparatus and Method[18]**-** This patent describes an apparatus for a landscape pond which enhances water quality. The treatment pond

17 Fulton, George. "Alum Recovery and Waste Disposal in Water Treatment." US Patent 3,959,133. 25 May 1976.
18 Beaulieu, Edgar. "Constructed Wetlands System, Treatment Apparatus and Method." US Patent 6,740,232. 25 May 2004.

includes vegetation, bacteria, substrate material, and treatment apparatus. This pond is similar to the settling basin proposed for the wetland design.

Constructed Wetlands to Control Nonpoint Source Pollution[19]**-** This patent describes a generalized wetland design that includes a sediment basin, spreader, grass filter, wetland, and deep pond. This patent discusses many of the issues that a wetland design will face. The system has a runoff conduit to control the amount of water entering the system. The next step is the sediment basin. Basically, this basin slows the water down to allow the larger particles to settle out. The basin also serves to regulate flow into the downstream wetlands and grass filter. This basin was designed to allow easy excavation. The level lip spreader controls the flow of water from the basin to the grass filter. The purpose of the spreader is to provide uniform flow to the grass filter. Native grasses are used for the grass filter. It is designed to maintain sheet flow from the spreader. Sometimes, this filter will require a subsurface drainage system to allow aerobic conditions for the plants if the filter will experience long term saturation. The wetland is constructed to maintain saturated conditions and shallow water. Aquatic vegetation is encouraged to grow in the wetland to provide an environment for multipule organisms. The deep pond is a place for limnetic treatment and fine particle of solids. Fish can be added to the pond to enhance the use of nutrients. The results from this system include a total phosphorus (TP) removal of 88% to 100%. Total suspended solids and volatile suspended solids were also reduced by 95%. The system experienced a large rain event where it performed very well. A final design of an Illinois River wetland could easily follow this same logic.

[19] Wengrzynek, Robert. "Constructed Wetland to Control Nonpoint Source Pollution." US Patent 5,174,897. 29 Dec 1992.

Enhanced Subsurface Flow Constructed Wetland[20]**-** This patent considers a subsurface flow wetland to treat water. This wetland includes an intake, a nutrient addition chamber, and a flow divider. Wastewater is treated by various soil media mixtures.

Contaminant Removal Method for a Body of Water[21]**-** This patent describes a process to add a coagulent to a mass of water, mixed, and then allowed to settle out. Water is then removed, and new water is re-added to the body. The coagulant is then mixed again and the process is repeated. This can be repeated until the coagulant no longer exhibits maximum pollutant removal capacity. This is related to the goals of *Scenic Solutions* because the same logic is being implemented with the alum injection system.

Automated Chemical Metering System and Method[22]- This patent discusses a metering and control system for use in a stream or river for chemical injection. This patent is related to *Scenic Solutions'* wetland design because a system is to be designed which adds alum to the variable flow entering the wetland. The actual injection system for the alum into the wetland was not addressed in this project, but this patent would be useful when a wetland system was fully designed in the future.

Flow-Based Chemical Dispense System[23]**-** Again, this patent discusses the injection of chemicals into a variable flowrate stream. Again, the actual injection system for the alum into the

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[20] Eifert, Walter. "Enhanced Subsurface Flow Constructed Wetland." US Patent 5,893,975. 13 Apr 1999.

[21] DeBusk, Thomas. "Contaminant Removal Method for a Body of Water." US Patent 7,014,776. 21 Mar 2006.

[22] Lichtwardt, Mark and David Sisneros. "Automated Chemical Metering System and Method." US Patent 5,902,749. 11 May 1999.

[23] Jungmann, Ronald, et al. "Flow-Based Chemical Dispense System." US Patent 6,763,860. 20 Jul 2004.

wetland was not addressed in this project, but this patent would also be useful when a wetland system was fully designed in the future.

Testing/Experimental Methodology

Initial Jar Tests for Alum Injection Rate

In order to determine the ideal concentration of alum that would be added, a series of jar tests were performed. The goal of these tests was to determine the removal efficiencies of phosphorus based on the concentration of alum.

Materials

Required materials consisted of settling tubes, alum, water from the Illinois River collected during a high flow event, filters and a filtration device, a peristaltic pump and bottles for sample storage. The settling tubes were constructed for a previous project and were ready to be used. These consist of 12, one meter tall settling tubes with a volume of eight liters constructed of PVC as seen in **Figure 4**. The pump and bottles were obtained from a previous project as well. There were also five gallons of alum available for use. In order to get an accurate representation of conditions on the Illinois River it was necessary to obtain water from a high flow event with a high level of phosphorus expected from non-point source runoff.

Figure 4. *The Settling Tubes in which the jar tests were conducted. Alum was allowed to settle with time in the Illinois River filled tubes and samples were taken at different depths. The concentration of alum was varied.*

Procedures

The 12 settling tubes will be filled with the high flow water collected from the river. Alum was added to three sets of four tubes until they reach desired concentrations of 10 mg/l Al, 1 mg/l Al and 0.1 mg/l Al. Once the alum was added and well mixed, the tubes were allowed to settle for 12 hours. After the 12 hours passed, one tube from each set was removed for testing. A water sample was pulled from each removed tube for nutrient level analysis. Each tube was then separated into four sections from top to bottom of two liters in volume. These samples were run through the filters to determine the amount of suspended solids in each layer. The filtration process can be seen in **Figure 5**. The process was repeated for 24, 36 and 48 hour time intervals. Water samples were sent to SWAFL for analysis, and sediment data was compared to determine settling rates.

Figure 5. *A vacuum filtration device was used to separate the suspended solids from the water. The filter was then weighed and recorded.*

Results

The data obtained from the initial jar tests show high removal rates of phosphorus for all concentrations of alum shown in **Figure 6**. The results indicated increased removal rates based on retention time and alum inoculation concentrations.

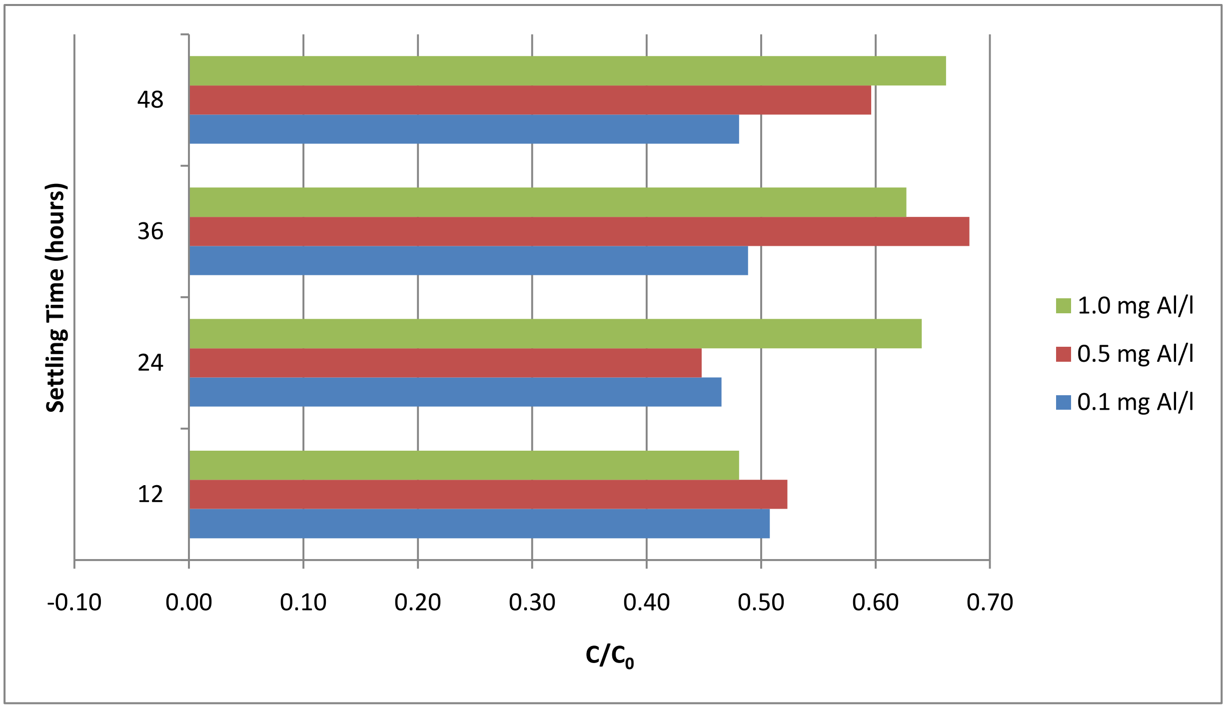

Figure 6. *Removal efficiencies of the settling tubes against time and alum concentrations for the preliminary test.*

Outcomes

Scenic Solutions observed an indication that short wetland retention times (12 hrs or less) could be used in wetlands of comparable depths to the jars and still provides substantial phosphorus removal. There was also little benefit observed in increasing alum concentration an order of magnitude.

Second Jar Tests for Alum Injection Rate

A secondary jar test study was conducted with multiplicative treatments to increase confidence in the hypothesized effect of retention time and alum inoculation concentrations.

Materials

The materials for this set of tests were the same as the first set of jar tests, except ports were added to the settling tubs so that was easier to take samples.

Procedures

The settling tubes were again filled with the high-flow water acquired from the Illinois River. With each tube, three ports were used to obtain samples from different levels in the settling tube. By taking one sample from the top and utilizing each port, four samples were taken for each settling time. The three aluminum concentrations used were 1 mg/l, 0.5 mg/l and 0.1 mg/l. Each concentration was tested in triplicates to ascertain the best results. Samples were also taken at three time intervals: 12, 24 and 36 hours. The 48 hour settling time was eliminated from the test to provide more replications of the lower time intervals. Water samples were sent to SWAFL to obtain dissolved phosphorus levels and lab work was done by *Scenic Solutions* to determine total phosphorus concentrations.

Results

A General Linear Model (GLM) analysis of the results indicated retention times of 12, 24, and 36 hours were not statistically significant at a significance level of 0.05. The analysis found an alum inoculation concentration of 1 mg/l led to increased removal from 0.5 and 0.1 mg/l. The two weaker alum concentrations did not create significantly different P removal from each other. However, although retention time was not a significant factor, an interaction effect between retention time and alum inoculation concentration was significant. It appeared increasing alum concentrations and increasing retention times led to increased removal. Follow-up studies on this interaction need to be conducted in order to determine the actual relationship between P removal and the factor levels. The averaged results can be seen in **Figure 7** below.

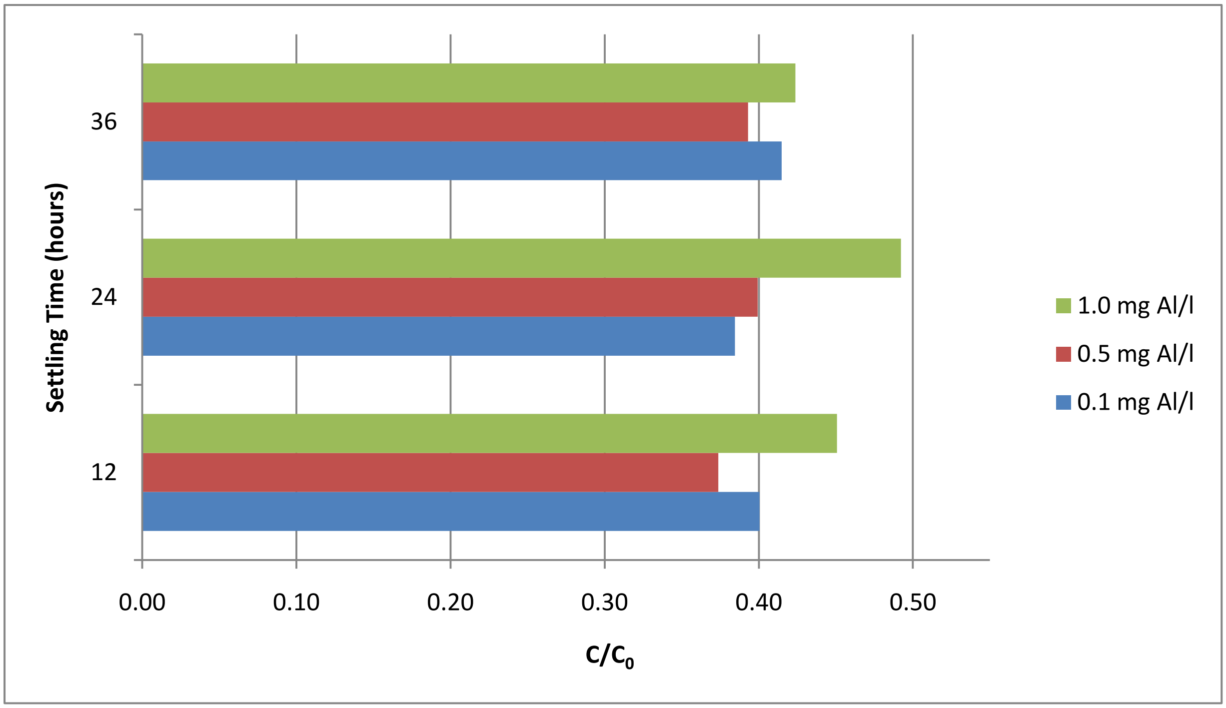

Figure 7. *Results from the second set of jar tests.*

Outcomes

Based on the data of the second set of jar tests, phosphorus removal is not affected by retention times greater than 12 hours. This suggests retention times greater than 12 hours in wetlands of comparable depth will not lead to significantly increased P removal. Additionally, increasing alum inoculation concentrations were not found to increase P removal until they reached 10x the lowest concentration tested, 0.1 mg/l alum. Therefore, *Scenic Solutions* suggests using 0.1 mg/l alum since P removal with increasing alum concentrations cannot be economically validated. This study was completed in order to establish estimates for retention times and inoculation concentrations for a wetland. However, this data was collected from a quiescent system so actual effects of retention time and inoculation concentrations were investigated through a mesocosm study.

Mesocosm Study for Wetland Design

A mesocosm study was conducted in order to determine retaining and removal efficiencies of the proposed wetland design. Large amounts of Illinois River water were needed to run the experiments. This required the purchase of a tank to transport the water and a separate, larger tank to store water from multiple collection trips. The pilot scale model was used to evaluate the feasibility of implementing a chemical injection system in conjunction with a wetland and polishing system, as well as to identify potential benefits and limitations. Basic features of the mesocosm include:

- containment structure
- influent water storage tank
- pump and flow control devices
- alum injection system
- soil and fill material
- artificial wetland plants

Mesocosm Structure Design Alternatives

Several alternatives for the mesocosm structure were discussed. Descriptions of several of the alternatives are described below.

Alternative 1:

Four mesocosms connected to a detention/settling basin. This is shown in **Figure 8**.

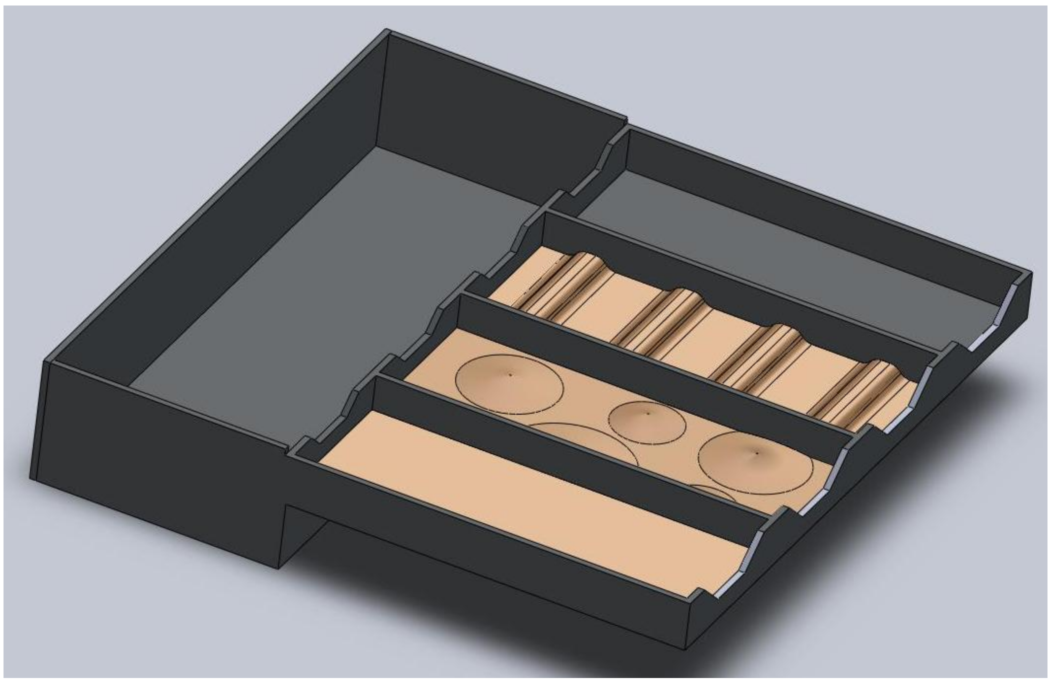

Figure 8. *Design of four mesocosms shown with differing characteristics.*

Designing the soil in rows and in circular mounds would allow for variation in the flow and plant placement. However, in a real case scenario, plants would not only grow where they were placed and this system would need several months to come to equilibrium. Therefore, this alternative is not feasible with current time constraints.

Alternative 2:

Six mesocosms connected to a detention/settling basin as shown in **Figure 9**.

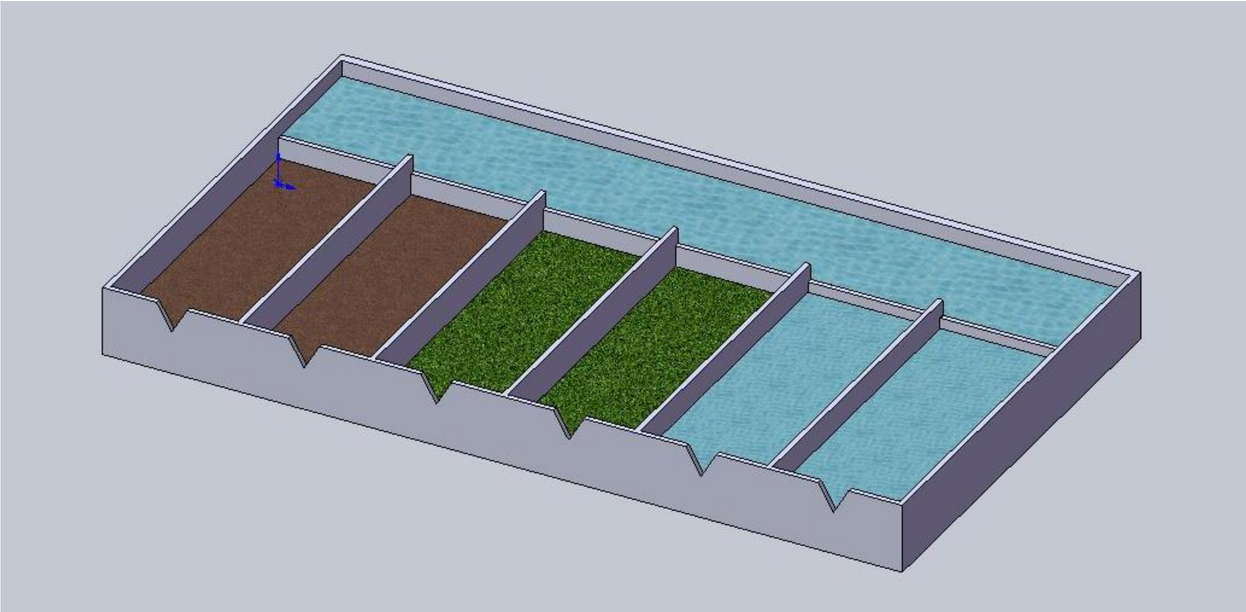

Figure 9. *Design of six mesocosms shown with non vegetated, vegetated, and detention basin mesocosms.*

Having six mesocosms with three duplicates would allow for greater time efficiency and less replication. However, having two mesocosms with only soil is not feasible for real-world modeling. In northeastern Oklahoma, the vegetation is thick and there would be no actual case with only soil and no vegetation. So it was decided that it is not feasible to have only soil in a mesocosm.

Alternative 3:

Four mesocosms connected to a detention/settling basin as shown in **Figure 10**.

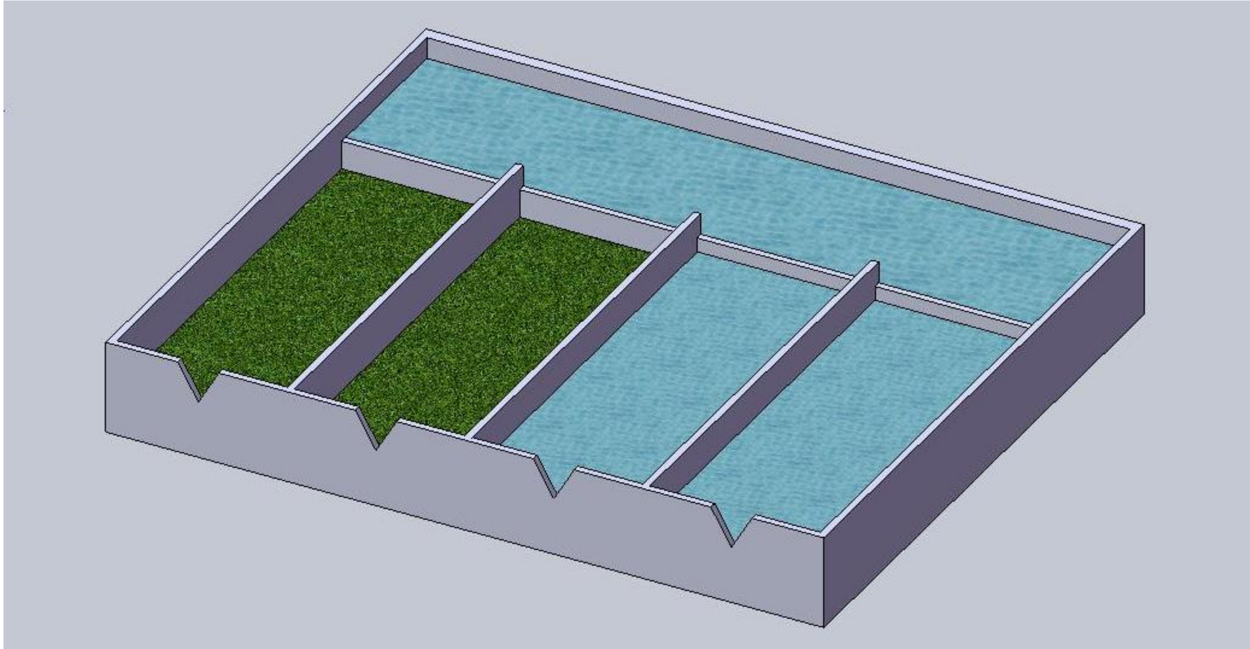

Figure 10. *Design of four mesocosms shown with vegetated and detention basin cells.*

Duplicating the detention basin control and the vegetated mesocosms will allow for time efficiency and easier replication. This alternative is the most feasible for a simplified study of how a wetland will remove phosphorus from the Illinois River. However, two detention basins are not required as there will be very little variability in the two basins. Experiments will be replicated regardless, so two controls are not required.

Alternative 4:

Six mesocosms connected to a detention/settling basin as shown in **Figure 11**.

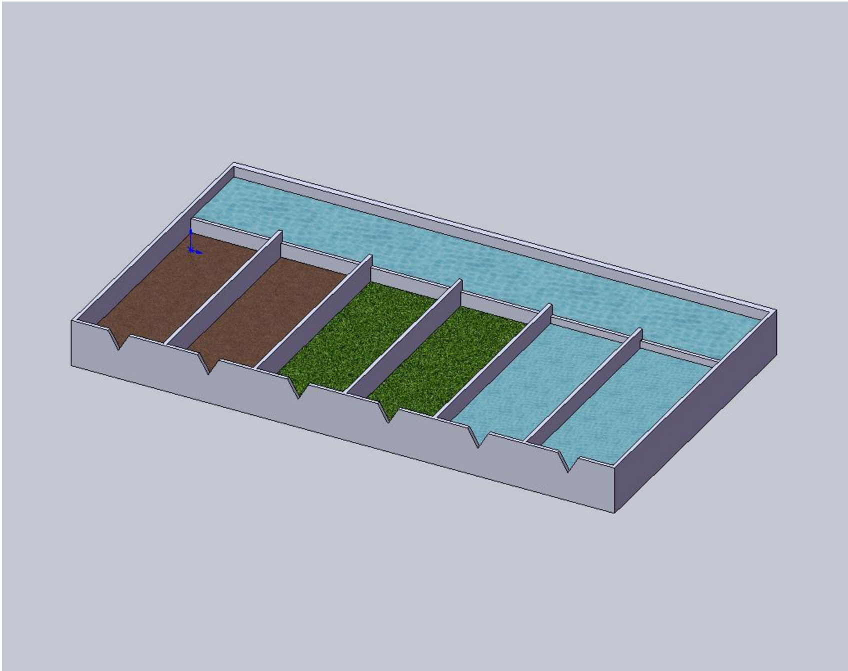

Figure 11. *Alternative 4 SolidWorks Drawing.*

This was a feasible option because it allows for easy replication of the wetland study and data collection. Data would be collected before the actual mesocosm to see how much phosphorus is settled out in the settling basin, and after the water leaves the mesocosm through the v-notch weir.

Alternative 5:

Six cells designed for USDA Hydraulics lab small flume seen in **Figure 12**.

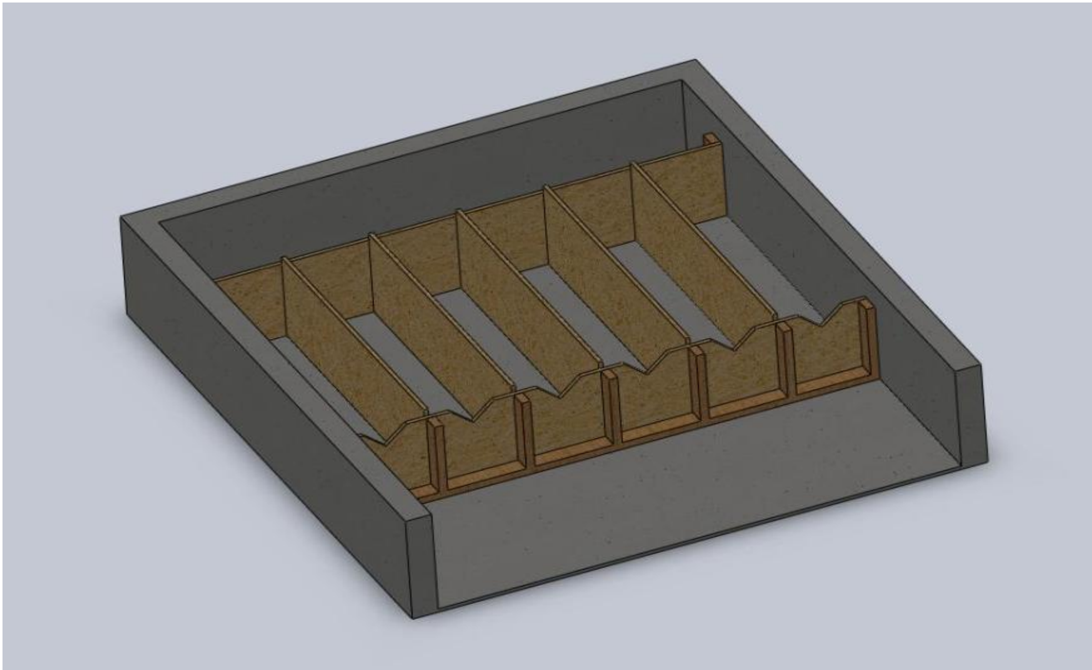

Figure 12*. Six cells designed for small flume at USDA ARS Hydraulics lab.*

This design was specifically for a smaller flume at the Hydraulic Lab. With the incorporation of steel slag, more phosphorus would be removed from the water. It was decided that since the steel slag is at the end of the mesocosm, samples could be taken before the water comes in contact with the slag to ascertain how much phosphorus is removed by a wetland with only an alum injection system.

Alternative 6:

The final design is shown in **Figure 13**. It consists of six mesocosms including three detention basins for controls and three wetland mesocosms with steel slag at the end.

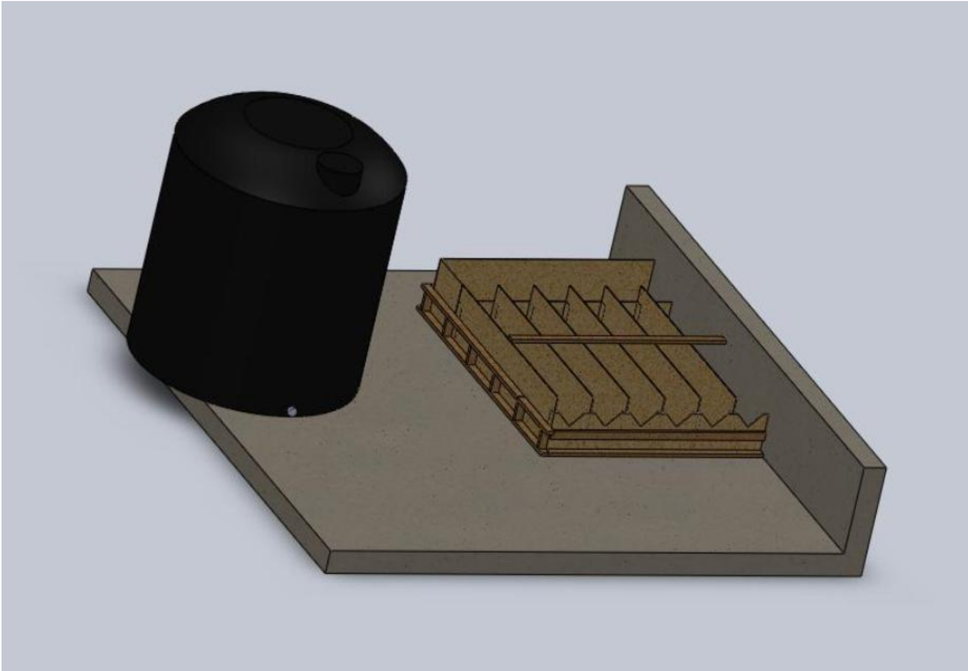

Figure 13. *Final design consisting of six mesocosms with water storage tank shown.*

Scenic Solutions ultimately decided to use a larger flume at the USDA-ARS Hydraulic Lab shown in **Figure 14** to better accommodate the mesocosm and water storage tank. The design is similar to Alternative 5, but due to the larger flume, the mesocosm only incorporates one wall of the flume while the other side had to be properly reinforced. The containment structure was designed to be impermeable and rigid enough to support the soil and water inside the individual cells and settling basin. To achieve this, polyurethane-coated plywood was used for the structure while silicone was applied to all joints.

Figure 14. *The larger flume located at the USDA ARS Hydraulics Lab in Stillwater, Oklahoma.*

Design of Mesocosm Delivery System

The Illinois River water was stored in a 3000 gallon black storage tank inside building that houses the flume shown above at the *USDA ARS Hydraulics Lab*. This is a heated building where the water was kept at a constant temperature. This can be seen in **Figure 15**. The alum was diluted with Illinois River water and stored in a mixed alum storage tank as seen in **Figure 16**. Both the alum mix and Illinois River water was then pumped into a common black mixing tank as shown in **Figure 17**. The mixing tank was kept turbulent with a submersible pump located in the bottom of the tank. The alum mix injection rate was regulated by a peristaltic pump which was manually set to provide the required mass flowrate of alum to the system. An overflow device was installed on this tank so when the water reached a certain level it overflowed into the settling basin of the mesocosm structure. This device provided distributed flow over the width of the settling basin as to prevent any preferential flow. This can be seen in

Figure 18. Water from the settling basin then flowed over a weir to feed the individual mesocosm cells. Three of the cells were detention basins with only six inches of sand lining the bottom. The other three cells had plastic cattails to provide the hydraulic characteristics of a wetland with vegetation. All six cells can be seen in **Figure 19**. Each cell was filled with six inches of clean masonry sand. Real cattails were not used because the biological effects on the phosphorus concentrations were not desired. *Scenic Solutions* simply wanted to determine if the hydraulic characteristics of a vegetated wetland provided a quantifiable difference in the settling of alum which should be indicated by the phosphorus concentrations. Finally, the water flowed over a v-notch weir into the slag baskets. Water was then drained from the slag baskets and allowed to discharge as seen in **Figure 20**. After passing through the system, this water was no longer characteristic of the Illinois River, and therefore could not be circulated again.

The first two experiments were conducted using the exact procedure above. Theoretically, the design should provide phosphorus removal in the settling basin, in each cell, and finally as the water passes through the slag. In case the alum was efficient enough to pull all the phosphorus out of solution in the settling basin and settled to the bottom of the settling basin, *Scenic Solutions* conducted a third and final test in which the settling basin was bypassed. The modification to the mesocosm structure can be seen in **Figure 21**.

Figure 15. *The Illinois River water was stored in the black tank seen above. Also shown is the small pump which took the water from the storage tank to the alum mixing tank.*

Figure 16. *The concentrated alum was mixed with a known amount of Illinois River water and stored in the small black alum storage tank shown above. A peristaltic pump took this alum mix and pumped it to the mixing tank where it joined the Illinois River water.*

Figure 17. *The alum mix and Illinois River water was mixed in the tank above. A submersible pump was dropped to the bottom of the tank to keep the water thoroughly mixed. The PVC then acted like an overflow device to drain the mixed water to the settling basin of the mesocosm.*

Figure 18 *The overflow flow from the mixing tank was piped to the settling basin of the mesocosm structure. The pipe provided distributed flow along the width of the settling basin.*

Figure 19. *Water overflowed from the settling basin into the six mesocosm cells. Three of the cells were detention basins, and the other three provided the hydraulic characteristics of a wetland.*

Figure 20. *The water overflowed from the cells into the PVC discharge pipes into the slag baskets. Holes were drilled in the slag baskets to allow the water to drain. The water was then discharged.*

Figure 21. *For the third and final test, the mesocosm structure was modified to bypass the initial settling basin. This allowed Scenic Solutions to examine the effects of the individual cells more thoroughly.*

Results

The results show that phosphorus was removed from the water throughout the system. Average phosphorus removal for the total system was 61%. The average final phosphorus level was 0.0368 mg/L P. **Table 1** shows the average initial, final, and percent removal for all three runs. Run III had the lowest overall removal rate, while Run I and Run II were very similar. **Table 2** shows the different removal rates between the settling basin, cell, and slag basket and the percentage of initial phosphorus leaving the mesocosm structure for each run. Run III had much higher removal rates in the cells than the other two runs. Also, the amount of phosphorus removed by the slag decreased with time from Run I to Run III.

Table 1. *This table shows the average initial and final phosphorus and total percent removal for all three runs.*

	Run I	Run II	Run III
Initial P levels	0.105	0.093	0.088
Final P levels	0.033	0.033	0.046
Removal %	69.01	64.35	47.70

Table 2. *This table shows the removal percentage for each section of the mesocosm structure. Since Run III did not have a settling basin, it had no removal in that area.*

	Run I	Run II	Run III
% Removed in Settling Basin	9.23	19.46	n.a.
% Removed in Wetland Cells	13.34	20.54	36.54
% Removed by slag	46.44	24.35	11.80
% Exiting the wetland	30.99	35.65	51.65

Figure 22 shows the removal of each component of the mesocosm structure. It is evident from this graph that the slag had a major impact on the phosphorus removal, but decreased over time. **Table 3** compares the removal rates of the settling basin and cells for each run. It can be seen that Run II had higher removal rates for both the settling basin and cells than Run I. Also, Run III had much higher removal rates in the cells. In **Figure 23** the decreasing effectiveness of the slag can be observed. The data showed that some of the slag baskets released phosphorus

after the mesocosm structure and slag baskets sat overnight between Run II and Run III. Statistical calculations can be found in Appendix B.

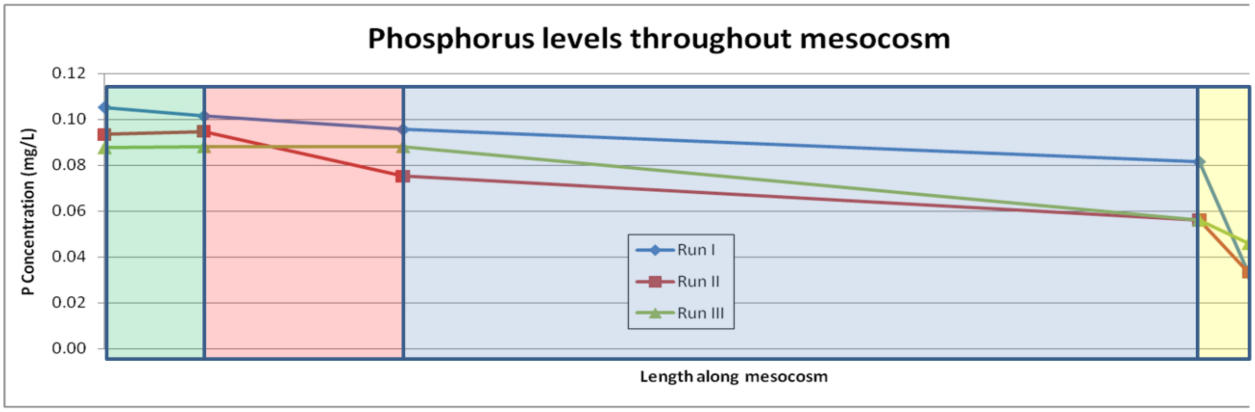

Figure 22. *The removal of each component (green=mixing tank, pink=settling basin, blue=cells, and yellow=slag baskets) can be seen for each run and compared to the other runs.*

Table 3. *This table compares the three runs with respect to the % removal in the settling basin and wetland cells.*

	Run I	Run II	Run III
% Removed in Settling Basin	**9.23**	**19.46**	**n.a.**
% Removed in Wetland Cells	**13.34**	**20.54**	**36.54**

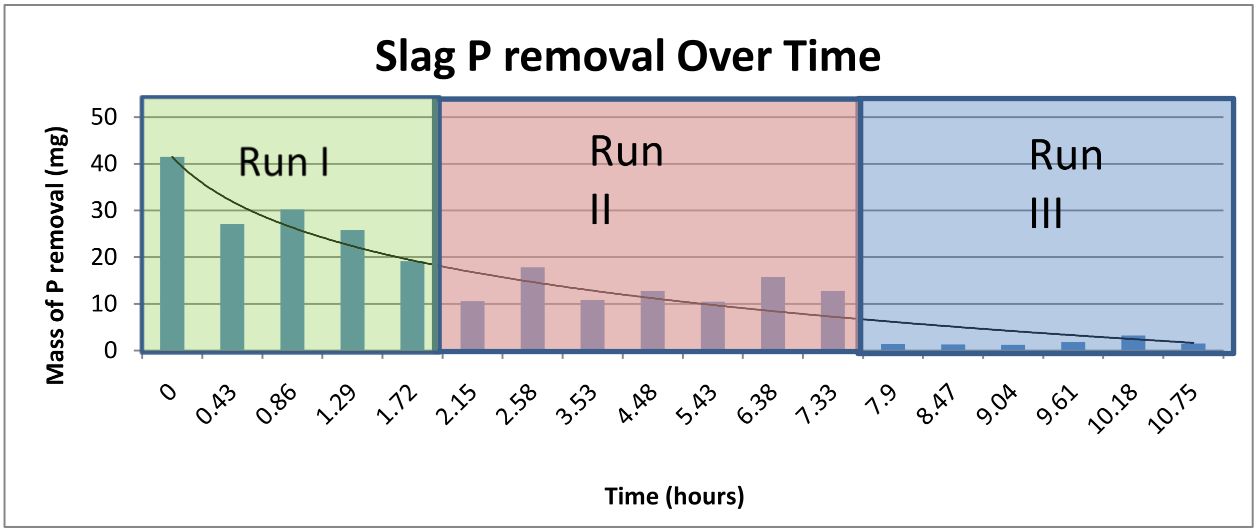

Figure 23. *This graph shows the decreasing removal trend of the slag as the experiment went on.*

Modeling

Phosphorous/alum flocculent removal was modeled as plug flow with the one-dimensional advection equation and a 1st order reaction term:

$$\frac{\partial C}{\partial t} = -u\frac{\partial C}{\partial X} - kC \qquad (1)$$

where the term on the left is concentration with respect to time, the first term on the right is concentration with respect to location as a function of velocity, and the second term on the left is a first order decay reaction term. The first order decay term is included to model phosphorous/alum flocculent settling with the system. The solution to *Equation 1* is of the form

$$C(x,t) = C_o exp^{\frac{-kt}{u}} \qquad (2)$$

where C is the concentration, C_o is initial concentration, k is a reaction coefficient, t is time, and u is velocity. For a given experiment, the reaction term, k, is solved for by taking C0 as the average inflow concentration for a given experiment and C as the average concentration after one retention time and solving with known values of x, u, and t. Values found are given in **Table 4** below.

Table 4. *Experimentally derived k (1/s) for settling basin, SB and wetland basins, WB.*

Exp	I	II	II	Average
SB	3.70E-05	3.70E-05	n/a	3.70E-05
WB	5.40E-05	1.30E-05	5.40E-05	4.03E-05

These values were used with Equation 2 to model expected removal rates in an actual scale wetland. Phosphorous data from the USGS website was could not be used due to sampling irregularity and infrequency. Therefore, input vales of C0 and U were created from the LoadEst Model which predicts daily Phosphorous output and flow rates based on statistical calibration from input data. The data used in this simulation was from the Illinois River gage at Watts, Ok. Since LoadEst outputs daily average Phosphorous concentration with daily average flow rates the coarse time step was one day and a fine time step was 1/7 a day. This fine time step is apparent in the static portions of the output chart seen in **Figure 24**. Different wetland and detention basin dimensions were input into the model to evaluate the performance for each system for a given ten-day event with dynamic phosphorous concentrations and dynamic flow rates as seen in **Table 5**.

Table 5. Flow and P concentrations inputs for the ten day event used in the model

Day	1	2	3	4	5	6	7	8	9	10
P (mg/l)	0.16	0.21	0.18	0.16	0.15	0.15	0.14	0.14	0.14	0.15
Q (cfs)	843	2889	1849	1140	867	702	608	538	491	843

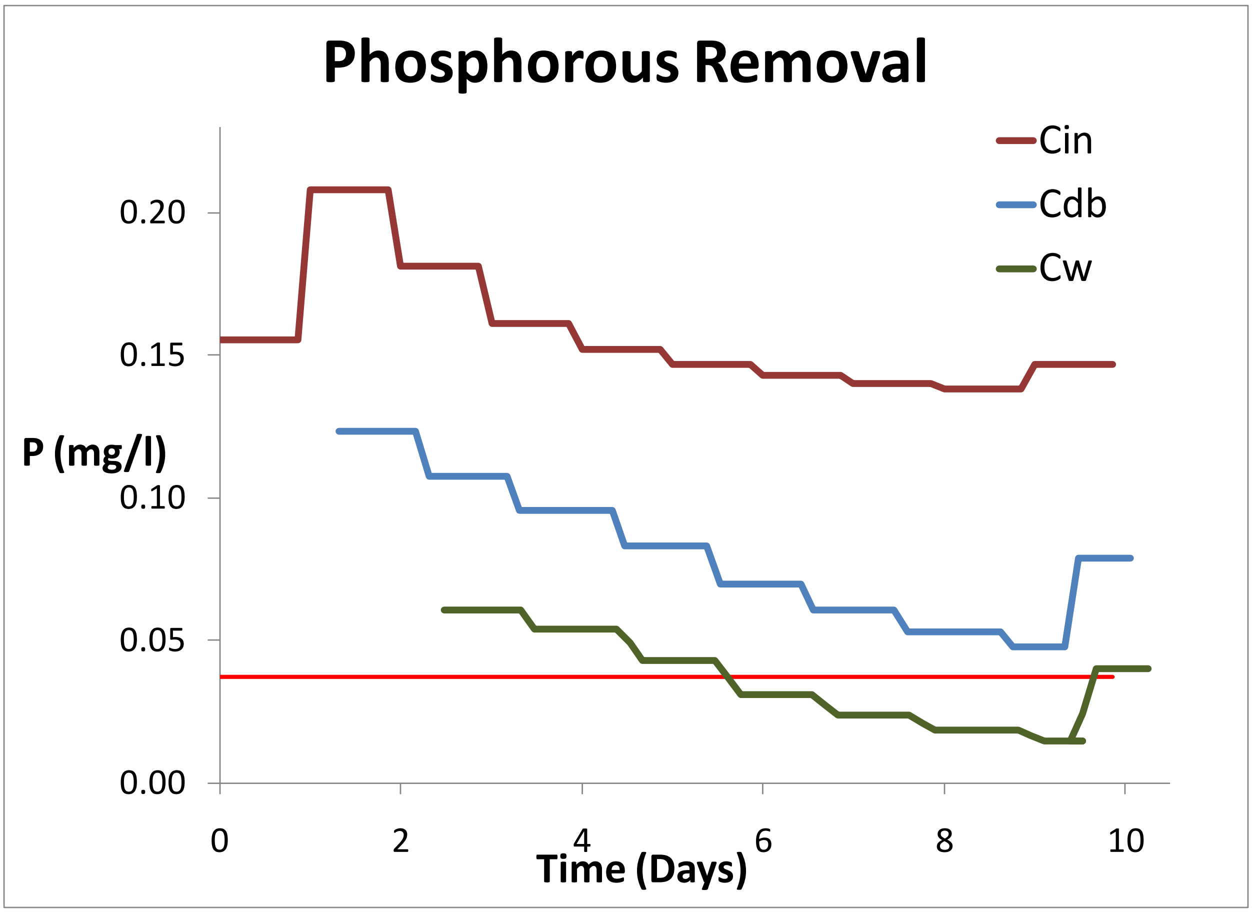

***Figure 24**: Cin is input concentration, Cdb is concentration out of the detention basin, and Cw is concentration out of the wetland. The red line is the 0.037 mg p/l criterion.*

This is the output for a 50 acre, 2 meter deep acre detention basin with 100 acre, 1 meter deep wetland system. Significant removal occurs in both detention basin and wetland. The influence of flow rate can be seen in the later portions of the curves where the difference between Cin and Cdb increases as flow rate decreases. This means at lower flow rates, higher removal efficiencies can be expected. The lack of data in the beginning portion of Cdb and Cw is the time delay associated with flow through the system. **Figure 25** shows a model of the same flow event through a 5 acre, 2 meter deep detention basin and 100 acre, 1 meter deep wetland.

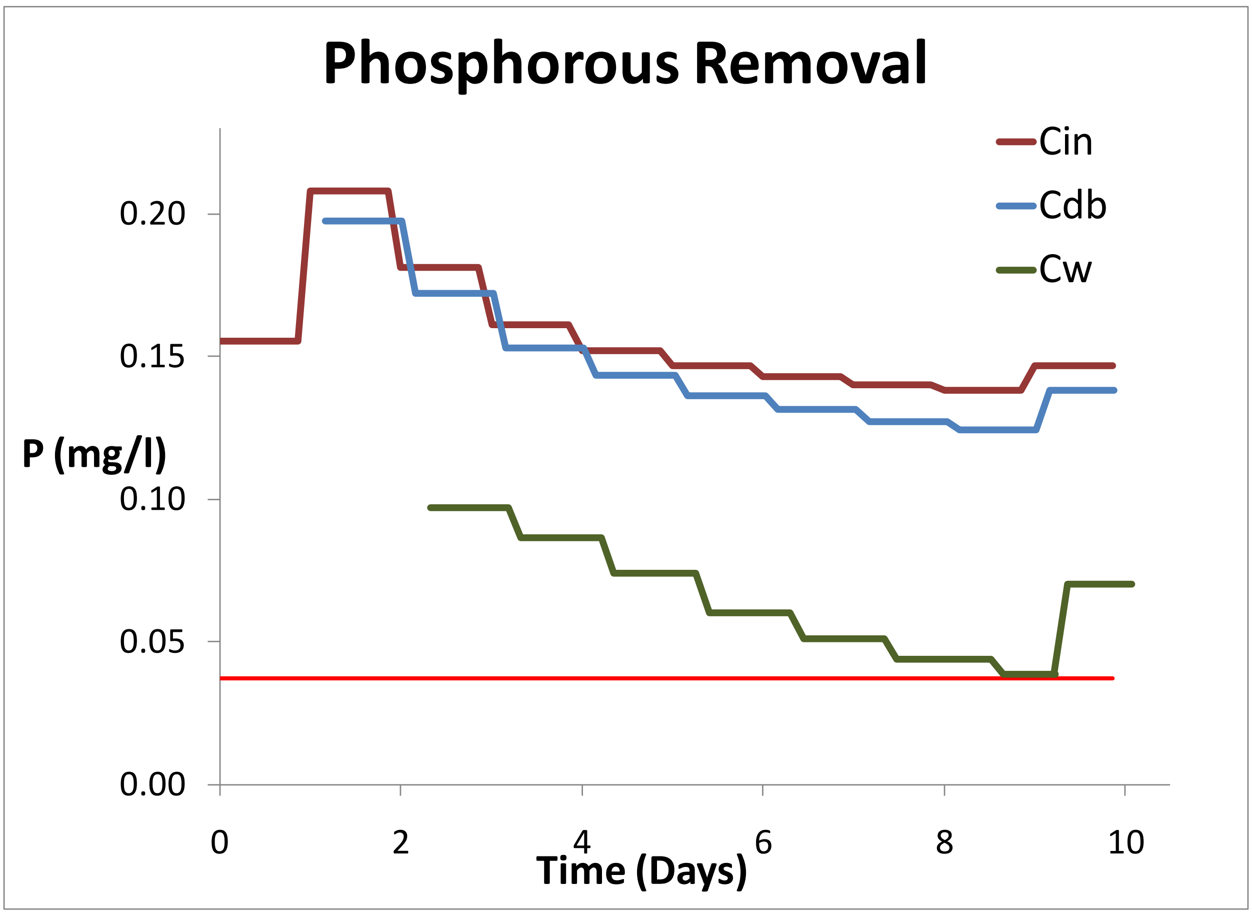

***Figure 25**: Cin is input concentration, Cdb is concentration out of the detention basin, and Cw is concentration out of the wetland. The red line is the 0.037 mg p/l criterion.*

The small shift in Cw as opposed to **Figure 24** demonstrates the capability of a stand-alone wetland to remove Phosphorous/alum flocculants. It is also important to consider the assumptions and limitations incorporated into this model when interpreting outputs. This model assumes an idealized geometry with uniform flow throughout the system. It does not account for storage or losses of flow (i.e. retention or infiltration), biological phosphorous removal, or sediment transport which significantly impacts phosphorous transport. However, it is expected all these processes would generally decrease phosphorus transport through the system. It must also be noted the removal parameter was based on a small scale experiment and may not be accurate for an actual sized system. Therefore, with these assumptions and limitations, *Scenic Solutions* is not using this model to predict actual expected efficiencies of various scenarios, but, rather as a tool in evaluating the qualitative impact of various design scenarios on phosphorous/alum flocculent removal.

Outcomes

Several things can be concluded from this experiment. First, the mesocosm system as designed was successful in removing phosphorus. Run I had the lowest removal for the individual cells. This could be due to the higher flowrate and tendency of the water to be more turbulent due to the faster pumping rate. The dominate removal component of Run I was the slag, where it removed 47% of the initial phosphorus. Run II had a slower flowrate and calmer water, so the removal capacity of each component was more balanced. The dominate removal in Run III occurred in the cells. The slag became spent and only provided 11% removal of initial phosphorus during Run III.

Public Relations/Education Campaign

The intent of the public relations/communications plan was to express to the audience that the wetland will optimally increase the quality of recreation and help the aquatic wildlife flourish by lowering the high phosphorus levels in the Illinois River. The targeted audience was everyone who is affected by the Illinois River including the 250,000 people who visit the site annually[24]. Benefits of the wetland were addressed including the increased quality of recreational activity and the lower phosphorus levels for the affected population. The communications plan was comprised of different kinds of media which included a video, a website, and public service announcement. Other forms of the public relations/education campaign included a factsheet and billboard.

Two separate websites were created for the project. The first website focuses on the senior design team and includes group photos, individual member photos and information regarding team members. The mission statement of *Scenic Solutions* and information regarding the wetlands project is also included. The website is centered on the group members and overview of the project. The second website focuses on the wetland project. This website is used as an educational tool for the general public. It describes the problems of the Illinois River and the proposed wetland to lower the phosphorus level. All of this is to educate people of all ages so it is primarily explained at an eighth grade level.

The second website also explains how wetlands are beneficial for recreation and wildlife. It gives background information on how *Scenic Solutions* developed a wetland through different experiments and includes video and photos of the tests conducted. Other website links are also

[24] Fite, Ed. Oklahoma Scenic Rivers Commission

provided. There is also a short video showing the mesocosm experiment. Footage includes images and video of the experiment from beginning to end. The video is posted on YouTube as well as the educational website.

A public service announcement (PSA) was prepared to broadcast on a local radio station. The PSA is a 30 second announcement to raise awareness of the Illinois River and briefly informs of the wetland processes that are being enacted to lower the phosphorus levels and what will happen to the aquatic life if nothing is done to eliminate the excess phosphorus. A factsheet was created to give more in-depth information about wetlands. The factsheet distinguishes between natural and constructed wetlands, explains components and advantages of wetlands, and shows pictures and descriptions of the project.

An advertisement was created for a billboard sign. The billboard could be placed near the Illinois River and Lake Tenkiller. It would help create a positive public relations plan for the wetland. The design is simple, but encourages support for a wetland on the Illinois River. Gordon Outdoor Advertising was contacted about the location of a possible billboard. The closest billboard to the Illinois River is located in Tahlequah, Oklahoma. The dimensions for the actual billboard are 48 by 14 feet[25]. Lamar Advertising was also contacted to ascertain the correct format for the billboard file. Files were made in Photoshop, then made into a PDF, TIFF, or EPS. InDesign was not the primary designer program, but is an alternative as long as files were converted to the formats previously mentioned[26]. This is the alternative taken for the design. Overall the materials for the project will be similar, but each will have a targeted

[25] Phone Interview. *Gordon Outdoor Advertising*, Jeff Gordon. February 17, 2010.
[26] Phone Interview, *Lamar Advertising*, Pete Hounslow, April 13, 2010

audience. The billboard design, homepage of the website, and the factsheet are located in Appendix A.

Benefit/Cost Analysis

Constructed Wetland Cost

The cost of constructing a wetland is highly variable depending on the type, location and size of the wetland. From Baca and Florey, freshwater wetlands cost more than salt water wetlands, and price per acre tends to be lower in the southeast United States. According to Baca and Florey, wetland cost can be summed up in three categories.[27] This can be seen in **Figure 26**.

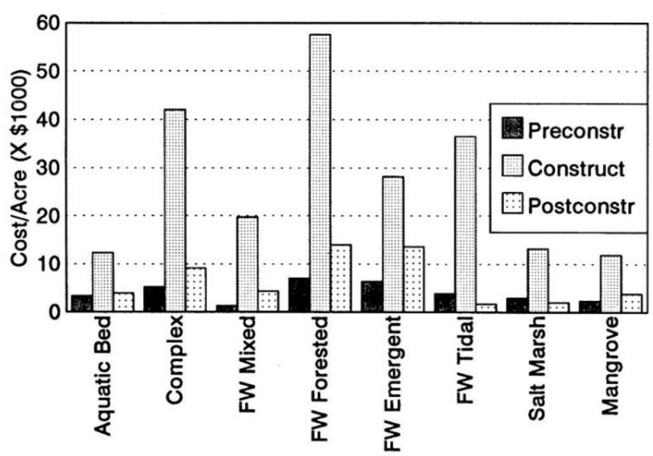

Figure 26. *This graph shows cost/acre for various wetland types and uses.*[28]

The cost of constructing a wetland will vary depending on the geography, soil types, climate and location. A freshwater wetland with emergent vegetation would be great for the ecosystem of the Lake Francis area. This wetland project will cover a 60 acre area. The first cost to consider is the preconstruction cost, encompassing all logistical matters such as purchasing the

[27] Baca, B., et. Al. "Economic Analyses of Wetlands Mitigation Projects in the Southeastern U.S." Report prepared for the Maryland International Institute for Ecological Economics.
[28] IBID 25

land, permitting and surveys. Instructions specified by the Army Corps of Engineers in Section 404 of the Clean Water Act define regulations of restoration, enhancement, construction, or preservation of a wetland.[29] Also, valid approval may be needed from the Oklahoma Water Resources Board, Department of Environmental Quality, Oklahoma Historical Society and the Oklahoma Scenic Rivers Commission.

As **Figure 26** depicts, there is little variance in the preconstruction cost of the various wetland types and classifications. The preconstruction cost estimate for a freshwater wetland with emergent vegetation is $8,000/acre.[30]

The next cost of constructing a wetland is the stage taking into consideration design activities, dirt work, manufacturing and vegetation. Nationwide total price per acre of construction averaged around $45,000/acre for freshwater emergent wetlands, as seen in **Figure 27**.[31] The design area for this wetland in northeastern Oklahoma is estimated to be 60 acres.

[29] U.S. Army Corps of Engineers. "U.S. Army Corps of Engineers 404 Permit." *Maryland Department of Agriculture*. Web. 25 Apr. 2010. <http://www.mda.state.md.us/licenses_permits/env/us_army_corps_engineers_404_permit.php>.
[30] IBID refer to 25
[31] IBID refer to 25

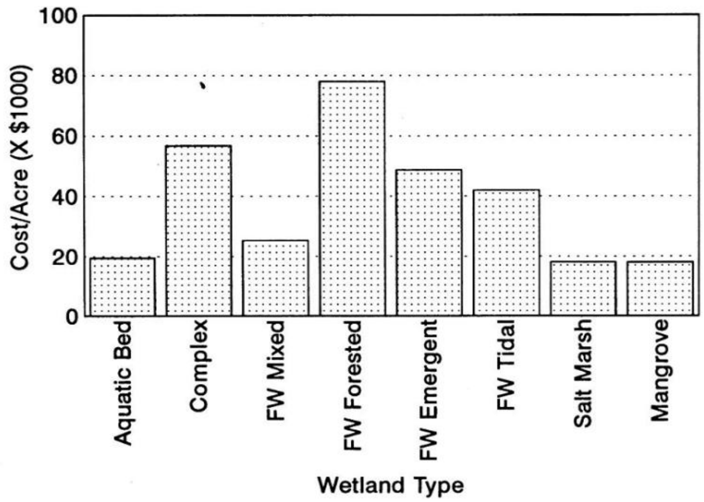

Figure 27. *Wetland Construction Costs* [32]

Under the cost of construction, the price for an alum injection system ranges from $135,000 to $400,000 depending on the size of the treatment volume.[33] Average flow rates for alum injection will be 0.07128576 lbs/sec for the proposed wetland. *Scenic Solutions* estimates the construction cost for the alum injection system to be $225, 000 for the Lake Francis area.

The cost of communication and education for the wetland is estimated to be $1500 for graphic design, printing and installation of a billboard located in Tahlequah, OK. The cost of $1.23 per printing will be added for each copy of the Wetland Fact Sheet.[34] There is also a cost incurred of $35-$50 per spot for a radio public service announcement (PSA).[35] Assuming the radio public service announcement is played three times a day throughout the construction

[32] IBID refer to 25

[33] United States. Environmental Protection Agency. *Alum Injection*. May 2006. Web. 25 Apr. 2010. <http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=80>.

[34] Advertisement. *FedEx | Redirect*. 2010. Web. 27 Apr. 2010. <https://www.fedex.com/us/office/copyprint/online/print/packages/sellsheet.html?lid=choose_polindex_sellsheets>.

[35] Hubbard, Rachel. "Question about Radio." Message to Mattie Nutley. 4 Mar. 2010. E-mail.

period, the PSA will cost an average of $127.50/day. In one year's time, the total cost will be just over $46,500. The summary of our pre construction and construction cost are shown in **Table 6**.

Table 6. *This table shows estimates for construction costs for the wetland.*

Preconstruction Cost		
Cost/Acre	$ 8,000	
Total Number of Project Acres	90	
Permitting and Surveys	$ 720,000	
Total Preconstruction Cost		$ 720,000
Construction Cost		
Engineering		
Wetland Cost/Acre	$ 45,000	
Number of Wetland Acres	90	
Total Cost of Wetland	$ 4,050,000	
Alum Injection System Cost	$ 225,000	
Detention Basin Cost/yd^2	$ 2	
Number of Detension Basin Acres	0	
Detention Basin Depth in Feet	6.6	
Total Dirt yd^2 handled	0	
Total Cost for the Detention Basin	$ -	
Communication Expense		
PSA $/announcement	$ 42.50	
PSA $/day	$ 127.50	
PSA $ for 12 month period	$ 46,537.50	
Fact Sheet Expense	$ 175	
Billboard Installation	$ 1,500	
Total Construction Cost		$ 4,323,212.50
Total Preconstruction Cost and Construction Cost		$ 5,043,212.50

Under the Baca and Florey theory, the third cost segment is the post-construction cost of the wetland. This cost includes maintenance for the alum injection system which ranges from $6,500 to $25,000 per year.[36] A predicted estimate of $20,000 will be used for this cost. The

[36] IBID refer to 25

main expense for the wetland will be the cost of alum which currently costs \$250/ton.[37] Alum will be injected at a mass flow rate of 0.07128576 lbs/second. This comes out to 3.079 tons of alum used each day, to match the river flow rate of $224ft^3/s$. At this rate the alum will cost \$769.89/day, which annually will cost \$281,008.47 in alum expense alone.

A post construction cost of \$490,776 covers the cost of dredging the wetland periodically. Dredging will occur when 726,000 cubic yards of material settles to the bottom of the wetland. MudCat Dredgers estimates the maximum amount of dredging cost to be \$0.676 per cubic yard of settlement.[38] Dredging is estimated to occur once every two years. The post-construction cost for communication materials is \$15,000 annually. This cost will cover the monthly flight rate of \$1,250/month for a billboard rental in the Tahlequah, OK area.[39] Together, the estimated annual cost of the wetland will be \$562,000 through the life of the wetland. A summary of the yearly post constructional cost can be seen in **Table 7**.

[37] "Aluminum Sulfate and Alums." *Scribd*. 18 Apr. 2010. Web. 20 Apr. 2010. <http://www.scribd.com/doc/30127031/Aluminum-Sulfate-and-Alums>.
[38] "Lake Maintenance, Auger Dredge, Dredge Equipment, Dredging, Rental Dredge, Dredges, from MudCat.com." *Dredging, Used Dredges, Small Dredge, Sand Dredging, Lake Management, Dredges, from MudCat.com*. Liquid Waste Technology, LLC. Web. 4 Apr. 2010. <http://www.mudcat.com/lake-restoration-pond-dredging/lake-restoration-4.htm>.
[39] Phone Interview. *Gordon Outdoor Advertising*, Jeff Gordon. February 17, 2010.

Table 7. *This table shows estimates for post construction costs for the wetland.*

Post Construction Cost		
Maintenance		
$/year	$ 20,000	
Alum Injected		
Applied Aluminum Concentration mg/L	0.1	
Applied Alum Concentration mg/L	5.1	
Applied Alum Concentration lbs/ft^3	0.00031824	
Flowrate (ft^3/second)	224	
Mass flow of alum (lbs/second)	0.07128576	
Pounds of alum/day	6159.089664	
Tons of alum/day	3.079544832	
Cost of Alum/ton	$ 250.00	
Alum $/day	$ 769.89	
Alum $/year	$ 281,008.47	
Detention Basin		
Dredging $/yd^3	$ 0.676	
Amount dredged yd^3/dredge	726,000	
Dredges/year (bi-annual)	0.5	
Dredging Cost $/year	$ 245,388.00	
Communication Expense		
Billboard Flight $/month	$ 1,250	
Billboard Flight $/year	$ 15,000	
Total Post Construction Cost		$ 561,396.47

Below in **Figure 28**, is a visual representation of the total present value of the wetland cost over 20 years. A total net present value of $11,082,774 over the 20 years is calculated using a 4% annual net present value discount rate, which is commonly used for internal government investments.[40] When reading the graph left to right, the high point begins the present value cost of the wetland and shows the measure of the initial present value cost of $3,453,212 in year zero.

[40] Regional Disaster Information Center for Latin America and the Caribbean. *Discount Rates and Multipliers*. Rep. Oct. 1992. Web. 25 Apr. 2010. <http://www.crid.or.cr/cd/CD_Inversion/pdf/eng/doc8049/doc8049-2a.pdf>.

At time zero, the present value for year one is $539,804 and $256,214 for year 20. The graph in **Figure 28** represents all post constructional values for the wetland.[41]

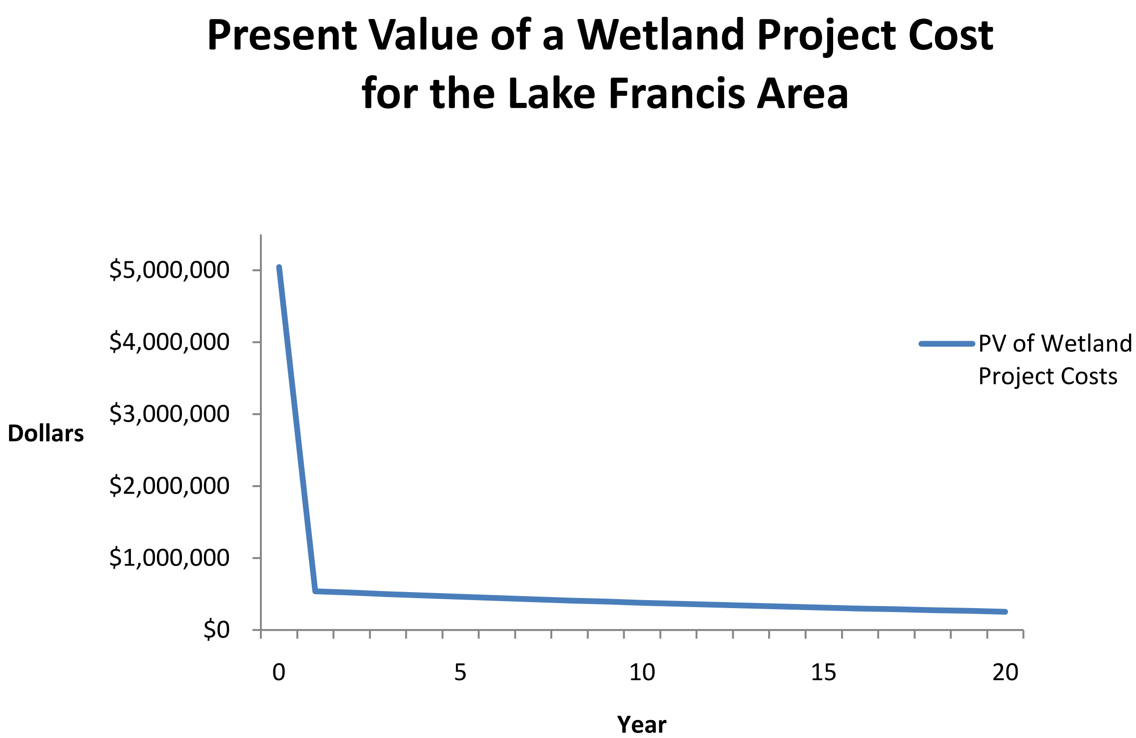

Figure 28. *This figure illustrates the present value of the wetland over 20 years.*

[41] Regional Disaster Information Center for Latin America and the Caribbean. *Discount Rates and Multipliers*. Rep. Oct. 1992. Web. 25 Apr. 2010. <http://www.crid.or.cr/cd/CD_Inversion/pdf/eng/doc8049/doc8049-2a.pdf>.

Constructed Wetland Benefits

By law, improvements need to be made to remove excess phosphorus from the Illinois River because of its designation as a “Wild and Scenic River”.[42] The phosphorus could be removed using a detention basin, a wetland, a water treatment plant, or a combination of all components.

The Illinois River has considerable recreational benefits. Approximately 120,000 people check into 23 different resorts along the Illinois River each year to float the river.[43] While an additional 250,000 people visit the Illinois River each year for other recreational uses such as fishing, camping and hunting.[44] Float trips on the Illinois River alone are claimed to have a $9 million per year economical impact.[45] A more exact determination of the people who float the river, which is a direct impact of the beneficial gains from the Illinois River can be determined with the average float rate of $20 per person multiplied by the 120,000 people who float the river.[46] This $2.4 million revenue was used in comparing the value a phosphorus removal system will save over a 20 year period.

Figure 29 is a representation with reference to 16,000 floaters who have traveled to the Illinois River from 624 different zip codes within a 600 mile radius of Tahlequah, OK in 2008.[47] It is estimated that annually 80% of all floaters come from Oklahoma, 5% from Texas, 5% from Arkansas, 5% from Kansas and 5% from all other states.[48]

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[42] "Oklahoma Scenic Rivers - Programs." *Oklahoma Scenic Rivers - Home*. 2002. Web. 3 Apr. 2010. <http://www.oklahomascenicrivers.net/programs_next3.asp>.
[43] "Illinois River User Fees." Message to Dell Farris and Larry Setters. 10 Feb. 2010. E-mail.
[44] "Questions on Illinois River Visitor Data." Telephone interview. 10 Feb. 2010.
[45] Soerens, Thomas S., Edward H. Fite, and Janie Hipp. "Water Quality in the Illinois River: Conflict and Cooperation Between Oklahoma and Arkansas." Proc. of Diffuse Pollution Conference, Dublin, Ireland. University College Dublin, 2003. Web. 25 Apr. 2010. <http://www.ucd.ie/dipcon/docs/theme09/theme09_03.PDF>.
[46] "Visitor Data and Cost Consultation." Telephone interview. 29 Mar. 2010.
[47] EBIT refer to 18
[48] EBIT refer to 41

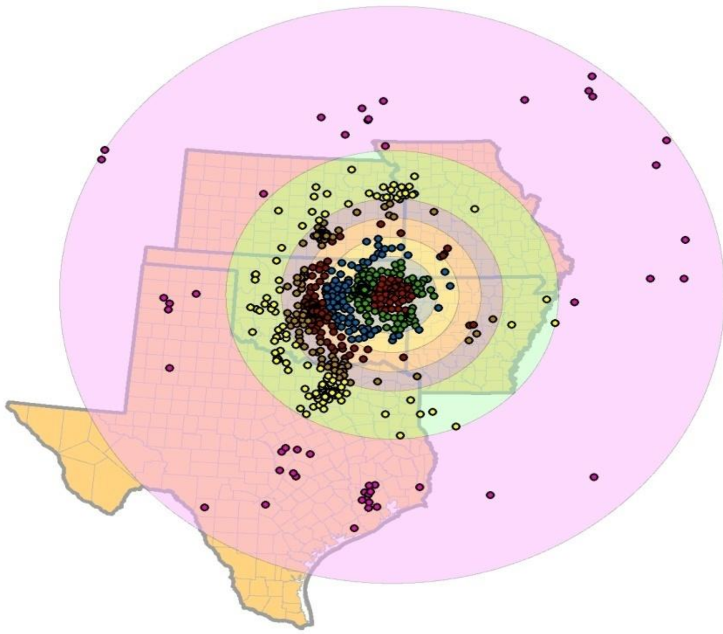


Figure 29. *Illustration of origin of visitors to the Illinois River.*

The construction of a phosphorus removal system has significant potential on the $2.4 million floater ticket sales of the Illinois River. If, over the course of time, no phosphorus removal system is implemented, the value of visitor's willingness to visit the Illinois River could decline due to poor water quality, reducing the economic value significantly.

Scenic Solutions is proposing a wetland for the Lake Francis area to be the most cost effective approach for removing the high phosphurus levels from the Illinois River. A wetland is the most inexpensive and easily constructed project to build and maintain the phosphorus removal over any course of time. Throughout the next 20 years, the net present value of a wetland for the Illinois River is estimated at $12,672,774, which is illustrated in **Figure 28**.

Considering the annual $2.4 million floatering ticket sales revenue, an estimated present value over a 20 year period today would be would be $35,205,091. From this approximation, a net present value of a wetland cost would represent 64% of the present value of the floaters ticket sales of the Illinois River. A comparison of the net present value of the wetland cost benefit can be seen in **Table 8**.

Total Floater Ticket Sales PV	$35,205,091
Total PV of Wetlands Costs	$12,672,774
NPV Wetland Cost Benefit	$22,532,317

Table 8. *Net positive value for the wetland considering floating benefits.*

Figure 30 is another visual look at a 5 year cost benefit spread a wetland will have on the Illinois River Floating Industry. This figure, also illustrates the frame the present value cost of the wetland will need to pay for itself just considering the floater present value economic impact.

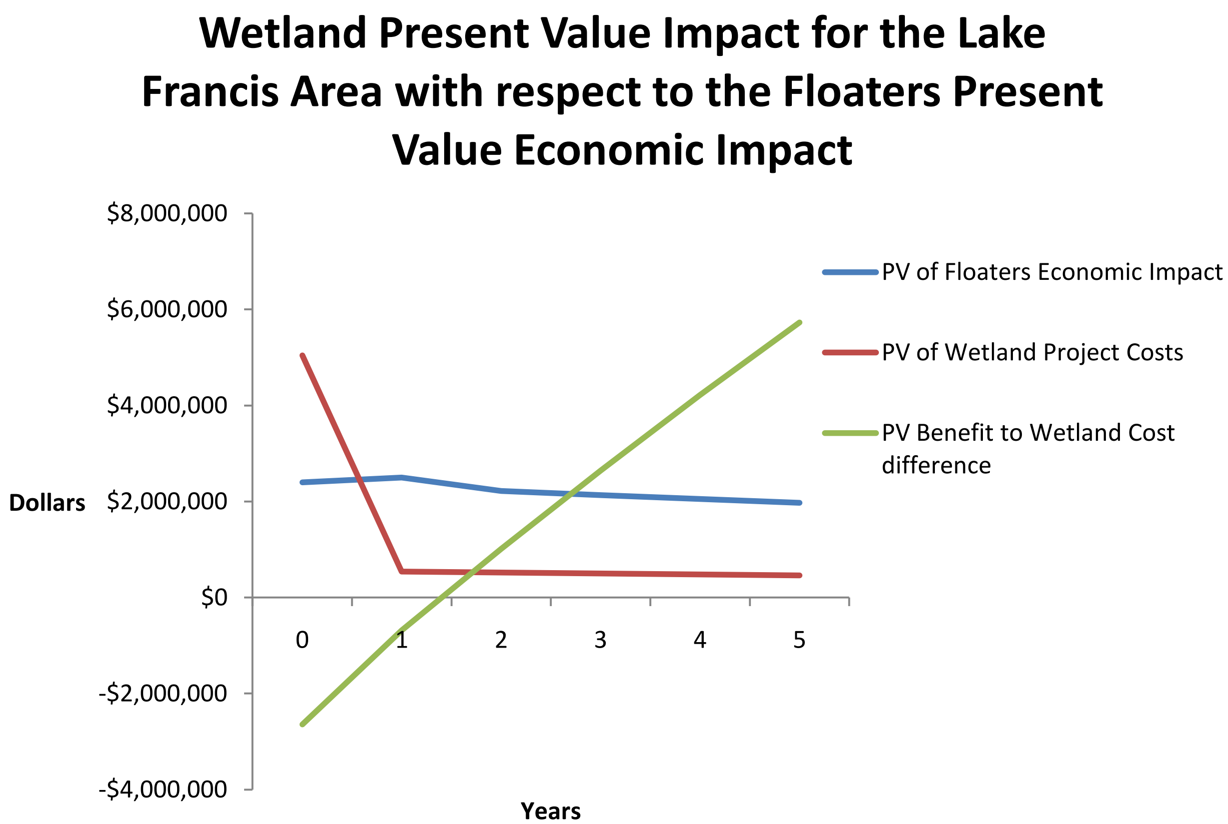


Figure 30. *Present value impact of the wetland considering floating present value.*

The wetland *Scenic Solutions* proposes for the Lake Francis area will be 90 acres in construction size. At this size, the wetland is estimated to have a phosphorus removal rating of 75% at maximum design flow rate, at a dynamic flow rate of up to 1000 cubic feet per second. The alternative of removing phosphorus through a water treatment plant is not an option for the Lake Francis area. The percent removal rating from a water treatment plant is hard to determine while the cost is much higher. Fayetteville, AR is home to the West Side Wastewater Treatment Facility, which had a project construction cost of $60 million in 2008. For a comparison of the intial cost to construct a wetland versus a water treament plant, refer to **Figure 31**.

This difference in cost comparison of a wetland and a water treatment plant is largly due to the amount of construction and infrastructure needed. Not only is the initial cost of construction tremendously higher for a water treament plant, but so is the annual cost of operation. **Figure 31** illustrates the present value estimated cost for operating a wetland and a water treament plant over a 20 year period. From the graph, one can see the differnce in annual present value cost.

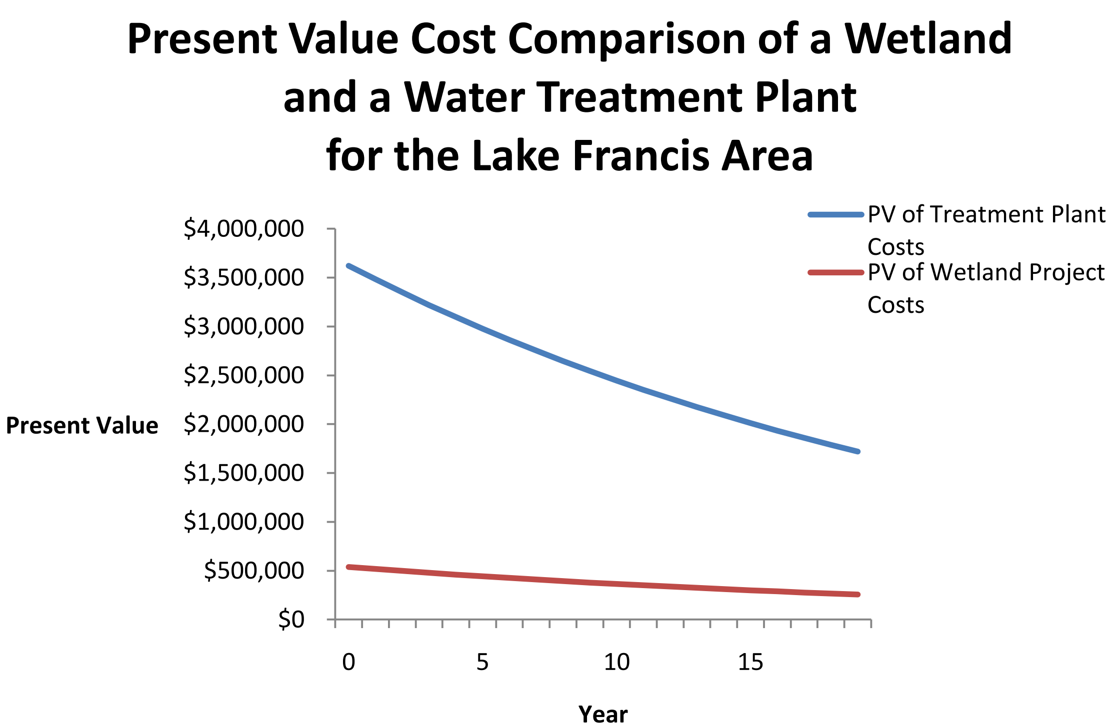


Figure 31. *Present value comparison of a wetland versus a water treatment plant.*

Another possibility for phosphorus removal is the design of a detention basin. A 60 acre constructed detention basin is approximated to reduce phosphorus in the water by 55%. This is less than the proposed wetland. Though over a 20 year period, a detention basin project design cost is less than a wetland with a present value of $12,216,054, this design is not more beneficial than the wetland design.

Another possibility for phosphorus removal is the combination of a detention basin and wetland design. A 40 acre wetland and a 50 acre detention basin are estimated to remove 78% of phosphorus in the Illinios River. This is slightly better than the proposed wetland, but this better removal rating comes with a greater cost. Over a 20 year period, a detention basin and wetland project design has an estimated present value cost of $13,617,174. To illustrate these present value cost comparisons and why a proposed wetland is the best fit for the Lake Francis area, please refer to **Figure 32**.

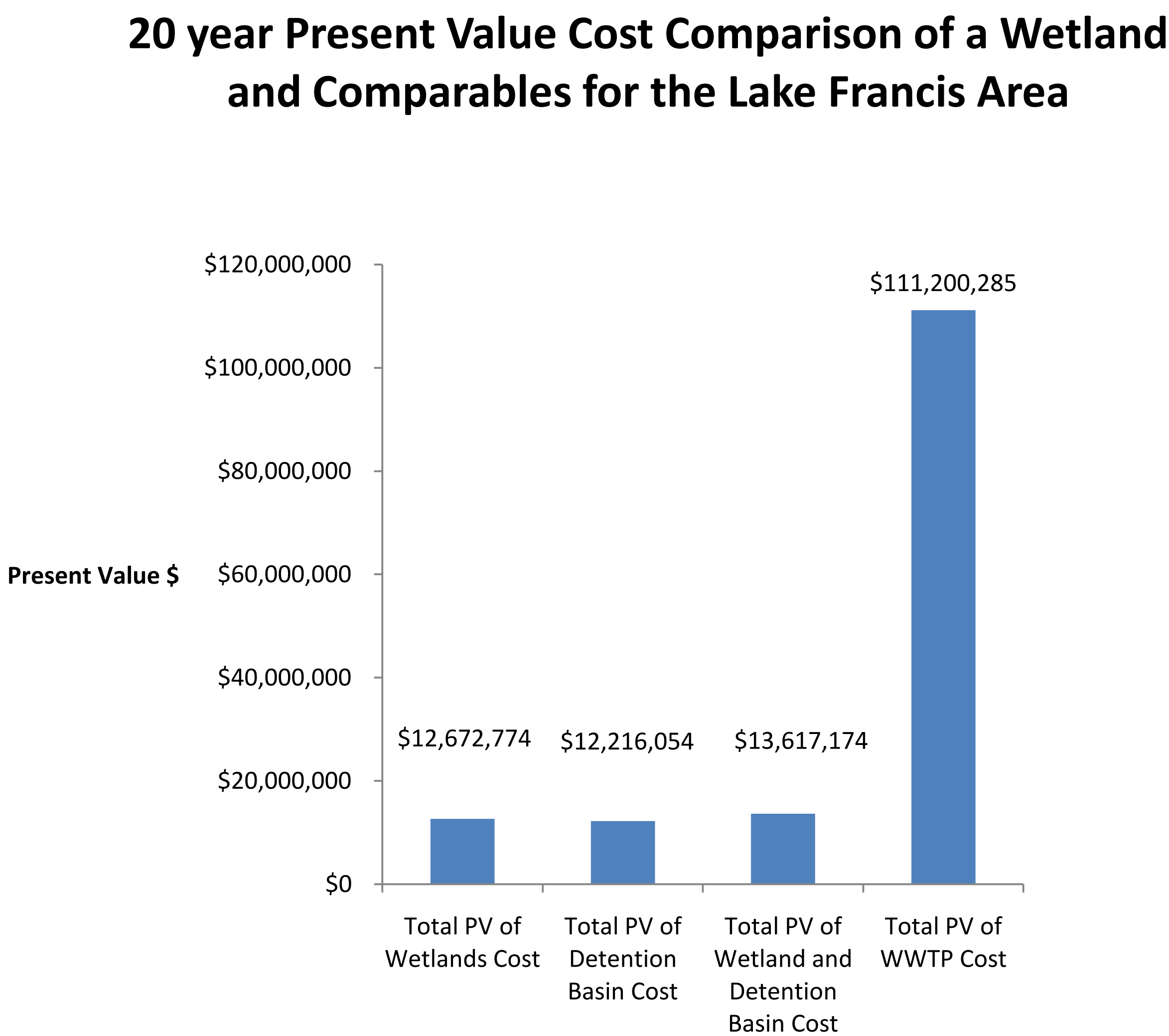


Figure 32. *Comparing present values for different alternatives.*

Project Conclusions

This project investigated the use of an integrated wetland system to treat the water of the Illinois River. Research and experiments conducted by *Scenic Solutions* have shown that an alum concentration of 0.1 mg/L can efficiently reduce phosphorus levels. This is a much lower concentration than previous studies have used and greatly reduces the cost of the wetland system.

Scenic Solutions also concludes that a steel slag polishing system can retain large amounts of phosphorus, but quickly becomes phosphorus saturated and would need to be replaced often. For the purposes of the wetland system, *Scenic Solutions* does not recommend a steel slag polishing system. Data from the mesocosm tests was used to create a model that gives an estimate of the removal efficiencies of an actual wetland. This model makes many assumptions, but should give an indication of the removal rates expected. The cost benefit analysis has shown that a wetland for the Illinois River is an effective and cost worthy approach to addressing the phosphorus pollution problem in the river. *Scenic Solutions* believes that an integrated wetland system is the best option for the Illinois River and encourages further research and development of the design.

Bibliography

33 U.S.C. 1251 et seq. 1972

42 U.S.C. 9601-9675. 1980

Advertisement. *FedEx | Redirect*. 2010. Web. 27 Apr. 2010. <https://www.fedex.com/us/office/copyprint/online/print/packages/sellsheet.html?lid=choose_polindex_sellsheets>.

"Aluminum Sulfate and Alums." *Scribd*. 18 Apr. 2010. Web. 20 Apr. 2010. <http://www.scribd.com/doc/30127031/Aluminum-Sulfate-and-Alums>.

Arkansas v. Oklahoma Environmental Protection Agency. 503 U.S. 91 Openjurist.org. U.S. Supreme Court. 26 Feb. 1992.

Auvray, Franck, van Hullebusch, Eric D., Deluchat, Veronique, Baudu, Michel. "Laboratory investigation of phosphorus removal (SRP and TP) from eutrophic lake water treated with aluminium." Water Research 40 (2006) 2713-2719.

Baca, B., et. Al. "Economic Analyses of Wetlands Mitigation Projects in the Southeastern U.S." Report prepared for the Maryland International Institute for Ecological Economics.

Beaulieu, Edgar. "Constructed Wetlands System, Treatment Apparatus and Method." US Patent 6,740,232. 25 May 2004.

Black, Courtney A., Wise, William R. "Evaluation of past and potential phosphorus uptake at the Orlando Easterly Wetland." Ecological Engineering 21 (2003) 277-290.

Burnett, LeAnne. *State of Oklahoma, ex rel. W.A. Drew Edmondson v. Tyson Foods, Inc.: A Bird's Eye View.* Rep. Oklahoma City: Oklahoma Farm Bureau, 2009. *Poultry Litigation.* Web. 1 Dec 2009. http://www.okagpolicy.org/index.php?option=com_content&view=article&id=85:poultry-litigation &catid=44:animal-agriculture&Itemid=54.

Cooke, G. Dennis, Welch, Eugene B., Martin, Angela B., Fulmer, Donald G., Hyde, James B., Schrieve, Garin D. "Effectiveness of Al, Ca, and Fe salts for control of internal phosphorus loading in shallow and deep lakes." Hydrobiologia 253 (1993): 323-335.

DeBusk, Thomas. "Contaminant Removal Method for a Body of Water." US Patent 7,014,776. 21 Mar 2006.

Eifert, Walter. “Enhanced Subsurface Flow Constructed Wetland.” US Patent 5,893,975. 13 Apr 1999.

Fulton, George. “Alum Recovery and Waste Disposal in Water Treatment.” US Patent 3,959,133. 25 May 1976.

Gebhardt, Karl, Ervin Cowley, Don Prichard, and Mike Stevenson. *Riparian and Weland Classification*. Technical Reference 1737-21. Denver: U.S. Department of Interior, 2005.

Hubbard, Rachel. "Question about Radio." Message to Mattie Nutley. 4 Mar. 2010. E-mail.

"Illinois River User Fees." Message to Dell Farris and Larry Setters. 10 Feb. 2010. E-mail.

Jungmann, Ronald, et al. “Flow-Based Chemical Dispense System.” US Patent 6,763,860. 20 Jul 2004.

"Lake Maintenance, Auger Dredge, Dredge Equipment, Dredging, Rental Dredge, Dredges, from MudCat.com." *Dredging, Used Dredges, Small Dredge, Sand Dredging, Lake Management, Dredges, from MudCat.com*. Liquid Waste Technology, LLC. Web. 4 Apr. 2010. <http://www.mudcat.com/lake-restoration-pond-dredging/lake-restoration-4.htm>.

Lichtwardt, Mark and David Sisneros. “Automated Chemical Metering System and Method.” US Patent 5,902,749. 11 May 1999.

Lorion, Renee. *Constructed Wetlands: Passive Systems for Wastewater Treatment*. Rep.

Malecki-Brown, Lynette M., John R. White, and K. R. Reddy. "Soil Biogeochemical Characteristics Influenced by Alum Application in a Municipal Wastewater Treatment Weland." *Journal of Environmental Quality* 36 (2007): 1904-913.

Malecki-Brown, Lynette M., John R. White, and M. Sees. "Alum Application to Improve Water Quality in a Municipal Wastewater Treatment Wetland." *Journal of Environmental Quality* 38 (2009): 814-21.

Malecki-Brown, Lynette M., White, John R. “Effect of Aluminum-Containing Amendments on Phosphorus Sequestration of Wastewater Treatment Wetland Soil.” Soil Science Society of America Journal 73 (2007): 852-861. Phoenix: National Network for Environmental Management Studies, 2001.

Meo, Mark. "The Illinois River Project and Oklahoma's Quest for Environmental Quality." *Journal of Contemporary Water Research & Education* 136 (2007): 56-67.

"Oklahoma Scenic Rivers - Programs." *Oklahoma Scenic Rivers - Home*. 2002. Web. 3 Apr. 2010. <http://www.oklahomascenicrivers.net/programs_next3.asp>.

Phone Interview. *Gordon Outdoor Advertising*, Jeff Gordon. February 17, 2010.

Phone Interview, *Lamar Advertising*, Pete Hounslow, April 13, 2010

"Questions on Illinois River Visitor Data." Telephone interview. 10 Feb. 2010.

Regional Disaster Information Center for Latin America and the Caribbean. *Discount Rates and Multipliers*. Rep. Oct. 1992. Web. 25 Apr. 2010. <http://www.crid.or.cr/cd/CD_Inversion/pdf/eng/doc8049/doc8049-2a.pdf>.

Soerens, Thomas S., Edward H. Fite, and Janie Hipp. "Water Quality in the Illinois River: Conflict and Cooperation Between Oklahoma and Arkansas." Proc. of Diffuse Pollution Conference, Dublin, Ireland. University College Dublin, 2003. Web. 25 Apr. 2010. <http://www.ucd.ie/dipcon/docs/theme09/theme09_03.PDF>.

Storm, Daniel, George Sabbagh, Mark Gregory, Michael Smolen, Dale Toetz, David Gade, C. Tom Haan, Ted Kornecki. “Basinwide Pollution Inventory for the Illinois River Comprehensive Basin Management Plan.” Submitted to the Oklahoma Conservation Commission, 1996.

U.S. Army Corps of Engineers. "U.S. Army Corps of Engineers 404 Permit." *Maryland Department of Agriculture*. Web. 25 Apr. 2010. <http://www.mda.state.md.us/licenses_permits/env/us_army_corps_engineers_404_permit.php>.

United States. Environmental Protection Agency. *Alum Injection*. May 2006. Web. 25 Apr. 2010. <http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=80>.

United States. Environmental Protection Agency. Office of Research and Development. Design Manual: Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment. Cincinnati, Ohio. 1988.

"Visitor Data and Cost Consultation." Telephone interview. 29 Mar. 2010.

Warren, Donald. "City of Tulsa v. Tyson Foods: CERCLA Come to the Farm-But Did Arranger Liability Come with it." *Arkansas Law Review* 59.169 (2003).

Welch, Eugene B., and Garin D. Schrieve. "Alum Treatment Effectiveness and Longevity in Shallow Lakes." *Hydrobiologia* 275/276 (1994): 423-31.

Wengrzynek, Robert. “Constructed Wetland to Control Nonpoint Source Pollution.” US Patent 5,174,897. 29 Dec 1992.

White, John R., Reddy, K. Ramesh, Moustafa, M. Z., "Influence of hydrologic regime and vegetation phosphorus retention in Everglades stormwater treatment area wetlands." Hydrological Processes 18 (2004) 343-355.

Zhao, Y. Q., Babtunde, A. O., Zhao, X. H. and Li, W. C. "Development of alum sludge-based constructed wetland: An innovative and cost effective system for wastewater treatment." Journal of Environmental Science and Health Part A, 44:8(2009): 827-832

Scenic Solutions

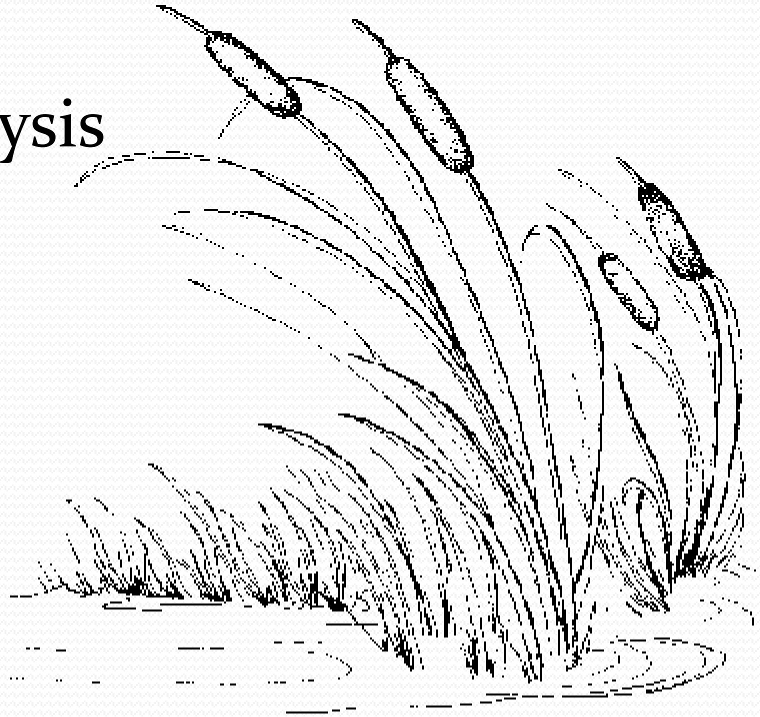
Rachel Carson Taber Midgley
Dell Farris Mattie Nutley
Karl Garbrecht Kevin Stunkel

Mattie Nutley, Dell Farris, Karl Garbrecht, Kevin Stunkel, Taber Midgley, and Rachel Carson

Agenda

- Problem Statement and Background
- Objectives
- Educational Campaign
- System and Engineering Analysis
- Results
- Economic Analysis
- Conclusions

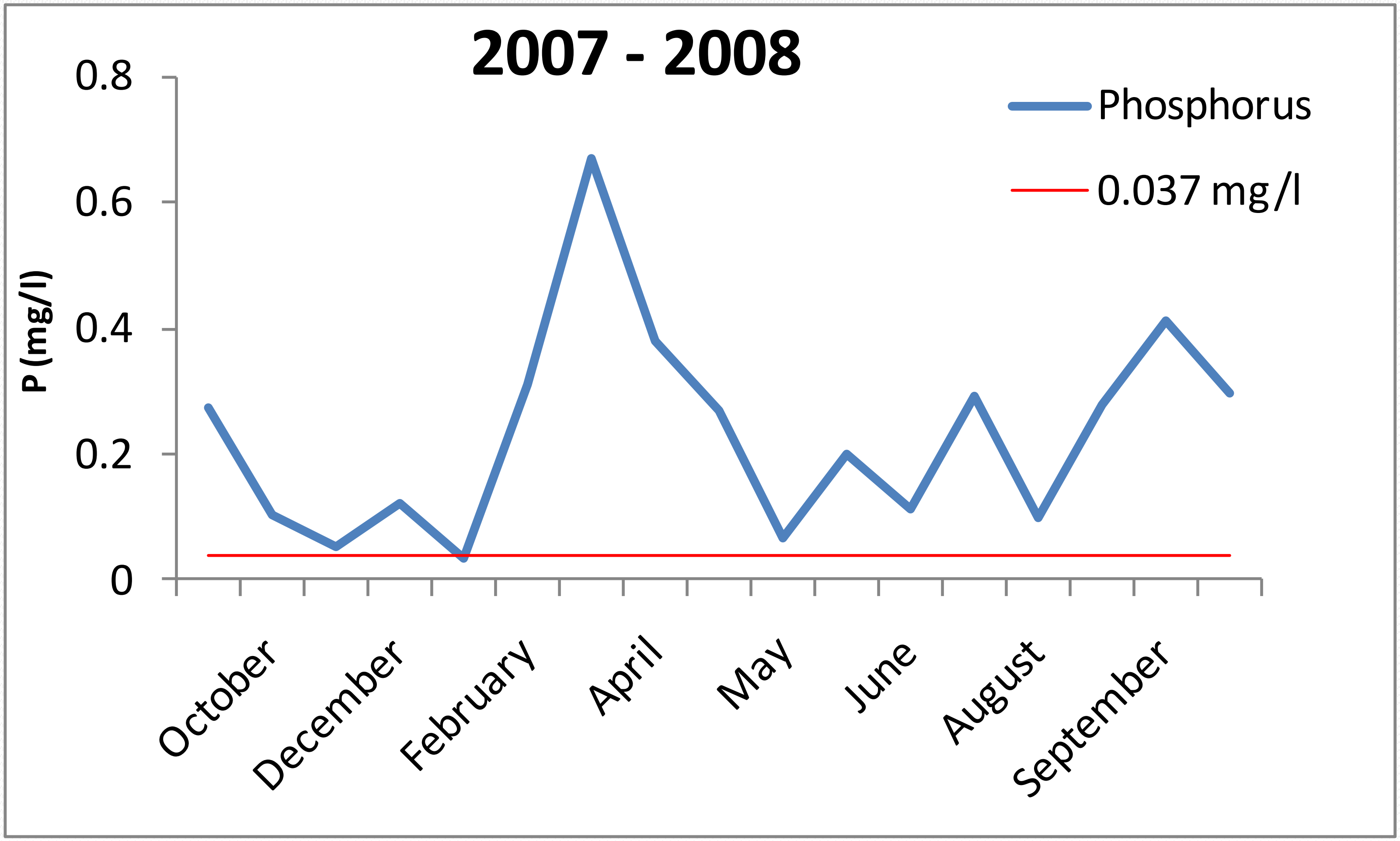
But First A PSA….



Problem Statement

- High phosphorus levels in the Illinois river have led to water quality issues and habitat degradation.
- The state of Oklahoma has established an average phosphorous concentration of 0.037 mg/L which is not currently being met.

Phosphorous levels near Watts, OK



Source: usgs.gov

Objectives

Communications

Educate audiences on the significance of high phosphorus concentrations and the positive impacts of wetland on the Illinois River

Engineering

Evaluate effectiveness of alum injection and wetland system to remove phosphorus

Economics

Quantify the cost effectiveness of the proposed wetland system

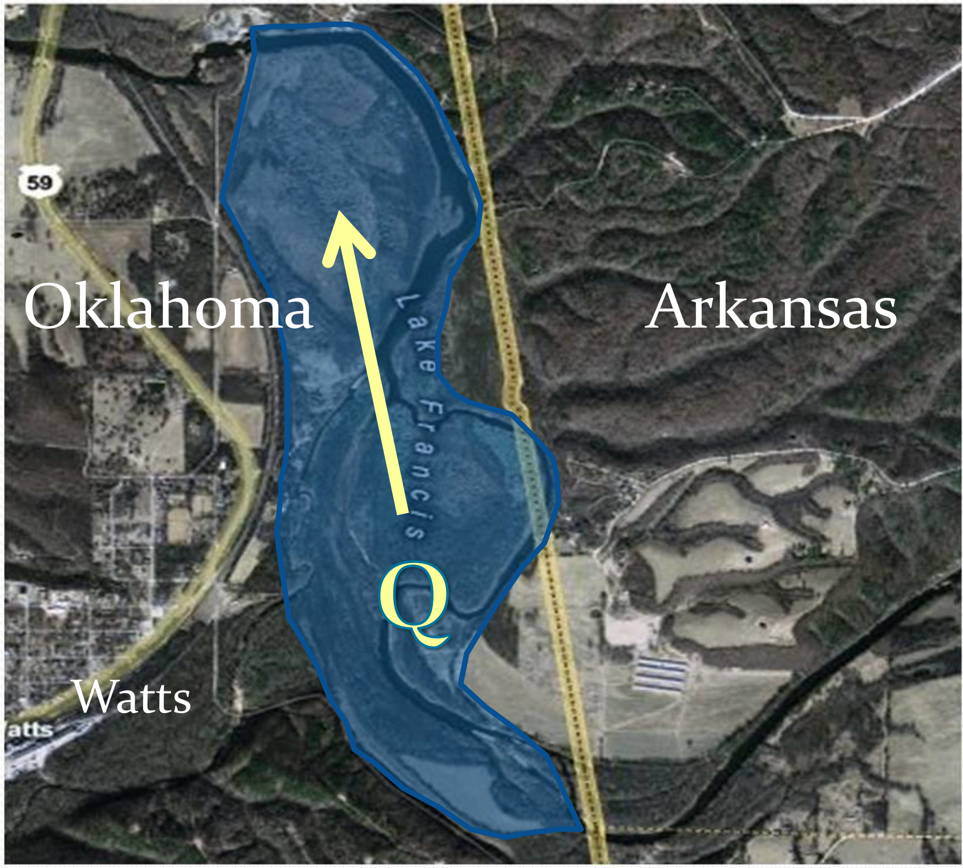
Preliminary Proposal

- Use a chemical injection system in series with a wetland to reduce P concentrations at Lake Frances near Watts, OK

- Include a steel slag polisher for subsequent phosphorus reduction

Lake Frances

- River crosses border at Watts, Oklahoma
- Potential site for wetland
- Dam was breached in 1992, but remnants of the structure hold back some water
- 500 acres of former lakebed exposed



Source: www.bing.com/maps

Alum

- Aluminum Sulfate, $Al_2(SO_4)_3$
- Is well studied and has been used in wastewater treatment for years
- Aluminum Phosphate precipitates to form snowflake-like particles
- Resulting flocs settle out of water

Steel Slag

- Granular by-product of steel manufacturing, and is cheap and abundant

- Studies have shown slag is extremely efficient at adsorbing P

- Potential to release P if oversaturated

Educational/Public Relations Campaign Materials

- Billboard design

Factsheet

Scenic Solutions

Wetlands Factsheet

What is a wetland and how do we identify them?

Wetlands located in Stillwater, Oklahoma. Photo by Mattie Nutley

Wetlands are areas that are "inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions (*Oklahoma Conservation Commission*, April 2010)."

Wetlands are identified a few ways. They must contain all of the following characteristics to be considered a wetland (*Ohio Environmental Protection Agency*, February 2007):

1. *Hydrology*- A wetland occurs when flooded or overflowed soils are sustained for a duration of time during the growing season.
2. *Soil*- When wetlands drain poorly and have low oxygen because of saturation or overflow of water (also called hydric soils).
3. *Vegetation*- Wetlands can contain certain vegetation like cattails, but can also have trees, annual and perennial herbaceous plants, shrubs, vines and grasses. This is called hydrophytic vegetation.

Why wetlands are valuable

Wetlands can be described as "nature's kidneys" because they are able to filter pollutants and other impurities from the water (*U.S. Enivronmental Protection Agency*, 2004). Particles can settle down in the wetlands, while other impurities bind to plant surfaces or are degraded by microbes, improving the quality of water.

Wetlands are beneficial to the environment by providing a home for endanged plants which are found only in wetlands. Wetlands are also important to fish, birds, and other types of wildlife because they benefit water quality and plant life.

Wetlands also help with preventing flooding and controlling "shoreline erosion," while improving recrecreation such as as fishing, floating and swimming (*Ohio Environmental Protection Agency*, February 2007).

What are the types of wetlands?

There are four different categories of wetlands: marshes, swamps, bogs and fens (*U.S. Environmental Protection Agency*, December 2004).

Marshes are wetlands that have soft-stemmed vegetation and no trees. Bogs are wetlands with freshwater, and can be formed from glacial lakes. Fens are peat-forming wetlands covered by "grasses, sedges, reeds, and wildflowers." Swamps are marshes that become shallow from soil and water (*Oklahoma Conservation Commission,* April 2010).

Wetlands in Oklahoma

About 950,000 acres of Oklahoma are covered by wetlands, approximately 2 percent of the state. Most wetlands are found in eastern Oklahoma where precipitation is high and evaporation is low.

Oklahoma wetlands include "bottom-land hardwood forests and swamps; marshes and wet meadows; aquatic-bed wetlands." About two-thirds of Oklahoma's wetlands have disappeared from changes in "agricultural conversions, channelization, impoundment, streamflow regulation and other causes (Yuhas, 2003)."

Natural wetlands v. constructed

Since natural wetlands have such a positive benefit to the environment, many scientists and engineers create wetlands systems that function just like a natural wetlands (*U.S. Environmental Protection Agency*, 2004)

These constructed wetlands are sometime called "treatment wetlands," because they are treating stormwater runoff or river water for such pollutants as nitrogen and phosphorus. These treatment wetlands can be a more cost efficient way of treating pollutants and add beauty to an environment while also reducing unwanted odors (*U.S. Environmental Protection Agency*, 2004).

How are the wetlands built?

Treatment or constructed wetlands are mostly built in areas outside flooded land to avoid damage to the natural environment or aquatic life (*U.S. Environmental Protection Agency*, 2004). They are made with natural plant life in soil and constructed to establish a "desired hydraulic flow" so pollutants can be lowered while flowing through the wetland.

Advantages v. disadvantages of a constructed wetland

There are several advantages to constructed wetlands. They cost less than many other alternatives to lowering pollutants. They provide a habitat for aquatic and wildlife, and allow hunting. Wetlands also protect against floods and make the environment more appealing as a whole.

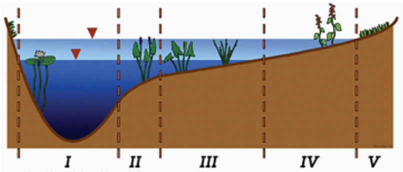
There are some disadvantages to a constructed wetland system. They aren't as easy to control compared to traditional methods, and can potentially be damaged by high flow events. They also require more space, and the amount of removal rates vary from season to season (BAE, 2010).

Cost of a constructed wetlands

Constructed wetlands vary in cost according to the "number and sizes of treatment cells required." They can range from $35,000 to $150,000 per acre (*Brookhaven National Laboratory,* April 2010).

Zones of a wetlands

The picture below shows the zones of the interior areas of a wetland. There a five different zones. The first zone consists of deep pools, which can dissipate "flow energy, trap sediment coming in with stormwater and provide anaerobic environment for enhanced nitrate treatment." Zone II is deep to shallow water transitions and the average depth is 18 to 30 inches for deep pools and 2 to 4 inches for shallow water. This zone has slight slopes that connect to the deep pool. Zone III is shallow water zones that "retain water following a storm event." When flows are low, water entering the wetland should go through the shallow water zone. The depth is approximately 6 to 12 inches.



Above are the five zones of a wetlands. Graphic courtesy of North Carolina State University.

Zone IV is the temporary inundation which is an internal flood area. It "surround the channel of shallow water and extends to the wetland's lower bank. It is designed for inundation or overflow when a storm larger than the design"water-quality event" occurs. Zone V is "the upperbank" which is the upper area of the wetland.This is the part of the wetland that ties back to the surround area (*North Carolina State University*, 2007).

Riparian areas and wetlands

Are located adjacent to streams or lakes. There is direct hydrologic interaction (the wetland is connected directly to the water body) between wetland soils and biota in laminar flow regimes (slow moving flow regimes). Nutrient and pollutant removal can occur through a variety of biological and physical processes, which improves water quality of the stream or lake (*Water Encyclopedia*, April 2010).

Constructed wetlands project at Oklahoma State University

Students at Oklahoma State University created a wetlands pilot study with an alum injection to possibly help treat the high phosphorus levels of the Illinois River in Oklahoma.

Illinois River background

The Illinois River flows from northwestern Arkansas to northeastern Oklahoma and is used for recreation as well as drinking water for cities in both states. The Illinois River Basin covers 1,645 square miles of land between Oklahoma and Arkansas. The river is dammed near Tahlequah, Oklahom where Lake Tenkiller Ferry is formed.

The river has become polluted with high phosphorus levels which make the river eutrophic (*Meo, 2007*). Eutrophication causes algal blooms, which causes fish and other aquatic life to not receive enough oxygen to survive.

Point and non-point sources

According to the Oklahoma Scenic Rivers Commission, the Illlinois River is a "Wild and Scenic River" in Oklahoma and must meet a water quality standards of 0.037 mg/liter or lower of phosphorus.

The phosphorus comes from point and non-point sources. A point source can be identified easily because they come from a single point like a waste water treatment plant. Non-point sources can be difficult to identify because they are usually run-off from fields and cannot be pinpointed or quantified (BAE 2010).

Alum testing

Scenic Solutions, the group of students at Oklahoma State University conducted a pilot study to show how effective a wetland would be with an alum ($Al_2(SO_4)_3$) injection.

To determine the level of alum needed, several jar tests were conducted on the Illinois River water. Jar tests survey the settling time and amount of phosphorus dissolved by the alum. The picture to the right shows a jar test being conducted (BAE 2010).

Pictured above are Taber Midley and Dell Farris running jar tests. Photo by Mattie Nutley

Mesocosm pilot study

A mesocosm was built as a wetlands pilot design. The mesocosm consisted of a settling basin and six detention basins. Half of the detention basins were filled with sand, while the other half were filled with sand and cattails.

The Illinois River water was mixed with alum diluted water then sent through the setteling basin. Once in the setteling basin, the water goes through the detention basin which is the wetland model of the design. After water went through the detention basin, it then went through steel slag where tests where taken for phosphorus reduction (BAE 2010).

Above is a the mesocosm pilot study of a wetland. Photo by Mattie Nutley

Results of testing

The test results of the water after going through a mesocosm with an alum injection were substantial. More than 60 percent of phosphorus was removed. This varied from each detention basin and flow rate, but the final levels where below 0.037 mg/liter of phosphorus. Concluding that a mesocosm pilot study coupled with an alum injection system is a valid proposal for the Illinois River (BAE, 2010).

Authors

Co-authors of this factsheet are: Rachel Carson, Karl Garbrecht, Dell Farris, Taber Midgley, Kevin Stunkel and Mattie Nutley

Special thanks to Dr. Jason Vogel for assistance.

Website

CLEAR THE WATER...
FROM THE RIVER TO YOUR HOME.
INTRODUCTION
MEDIA
OTHER LINKS
Scenic Solutions

Educational video and PSA

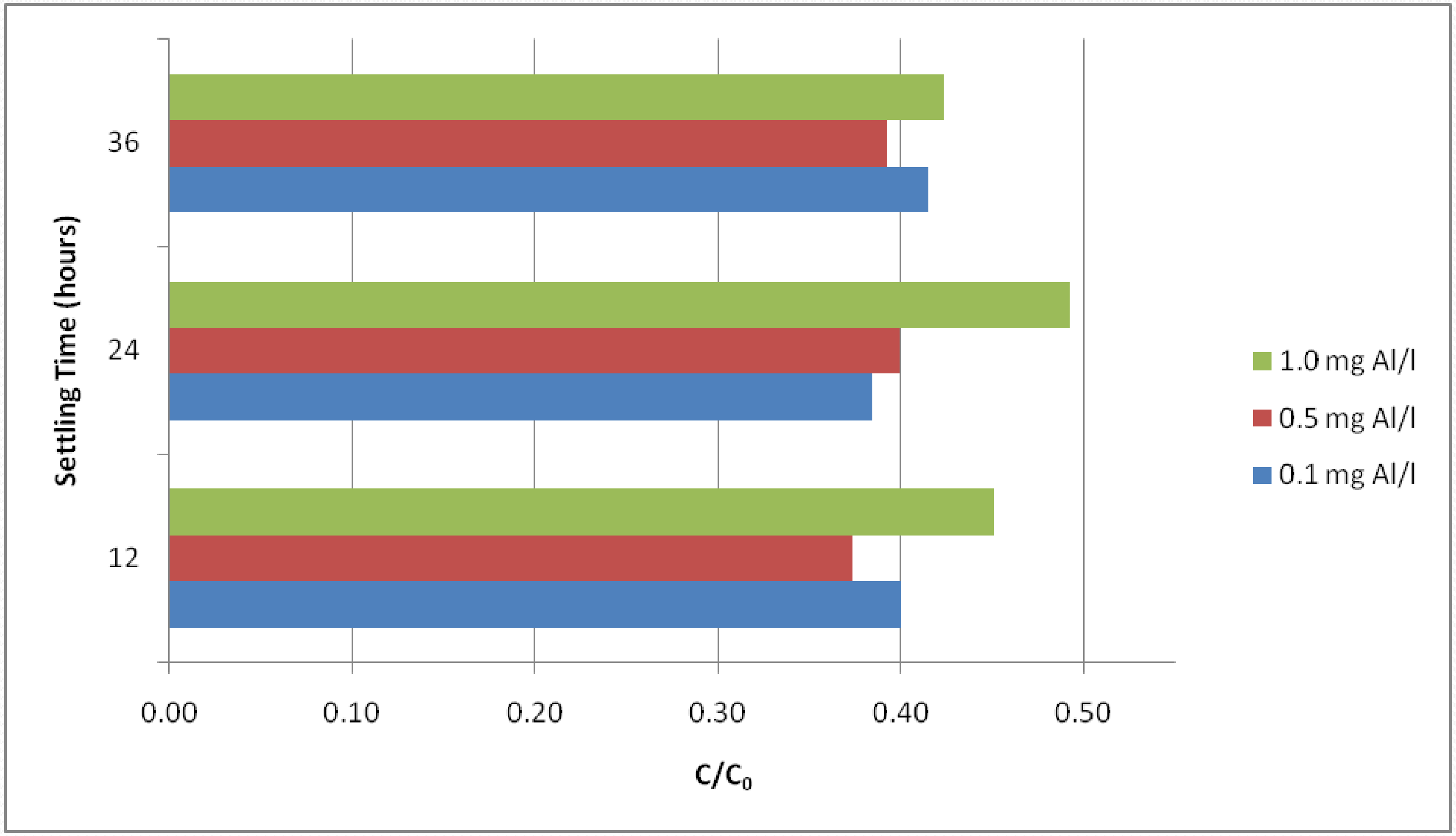
- Educational video
  - Two minute video
  - Put on YouTube

- Radio Public Service Announcement
  - 30 seconds
  - Describing the problem and proposal to resolve it.

Jar Tests

- Ran a series of “jar tests” to determine the effect of alum dosage
  - Test for phosphorus removal efficiencies as well as settling times
  - Ensure there is no over-dosing, which would increase costs

Jar Test Phosphorus Results




ALL-PURPOSE
2

Trials I and II

- Flowrate of 4 gpm and 1.7 gpm
- Ran for 1.5 retention times

Trial III

- Bypassed the Settling Basin
- Flowrate of 1.7 gpm
- Ran for 1.5 retention times

Results - Overview

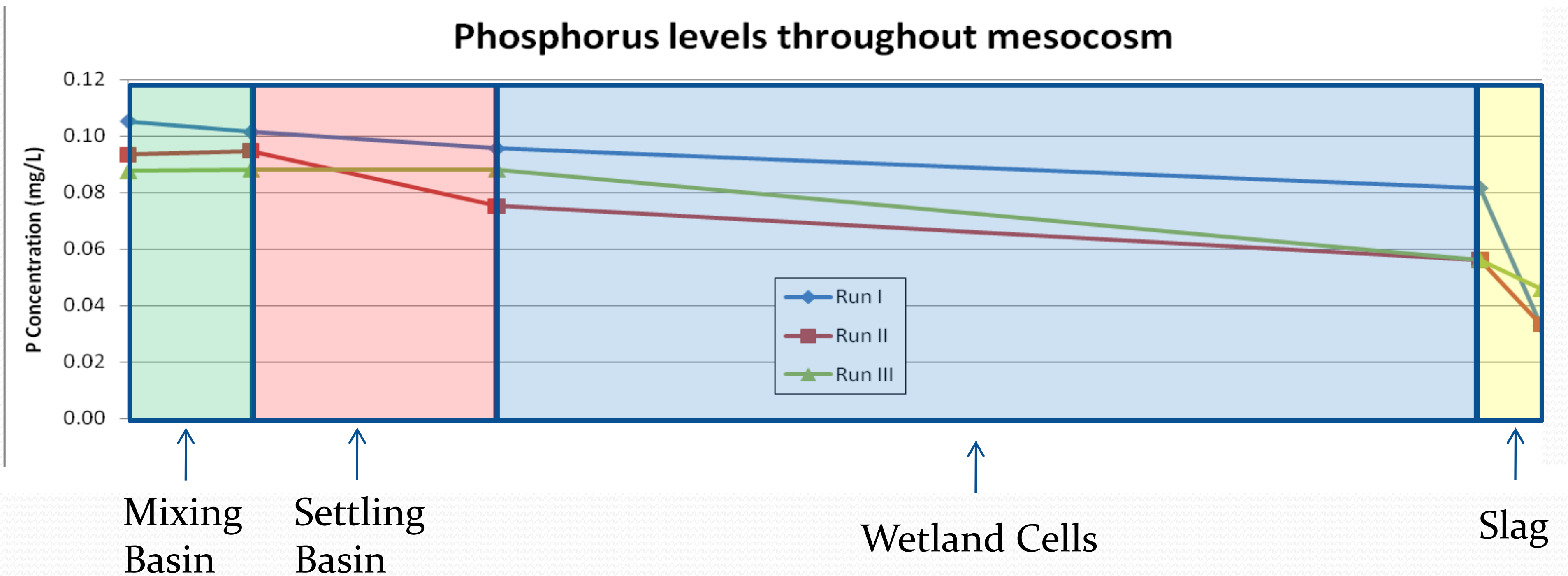
- Phosphorus was removed from the system
- 61% Removal
- Final concentration of 0.0368 mg P/L

	Run I	Run II	Run III
Initial P levels	0.105	0.093	0.088
Final P levels	0.033	0.033	0.046
Removal %	69.01	64.35	47.70

Results – Difference Between Trials

C/C_o	Run I	Run II	Run III
% Removed in Settling Basin	9.23	19.46	n.a.
% Removed in Cells	13.34	20.54a	36.54a
% Removed by Slag	46.44	24.35	11.80
% Exiting the System	30.99b	35.65b	51.65

Results – Losses in the Mesocosm



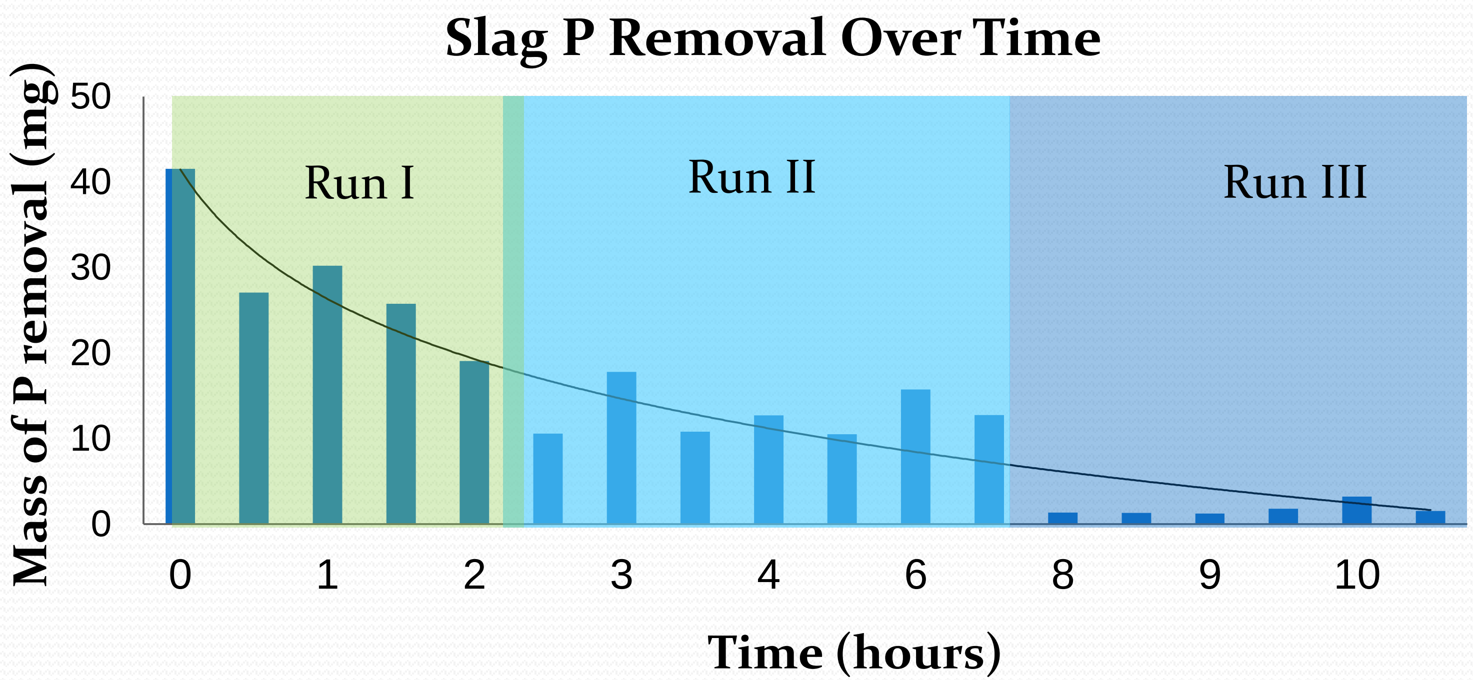
Results – Alum/P Flocculation

- Alum/P Flocs removed within the system
- Highest removal in the low flow Trials II and III.
  - Longer retention time facilitated increased settling resulting in lower P concentrations

Experiment	Run I	Run II	Run III
% Removed in Settling Basin	9.23	19.46	n.a.
% Removed in Wetland Cells	13.34	20.54a	36.54a

Results – Steel Slag Adsorption

- Removed 19.5 mg of P/kg of slag
- Decreased removal as the slag became saturated with Phosphorous



Modeling

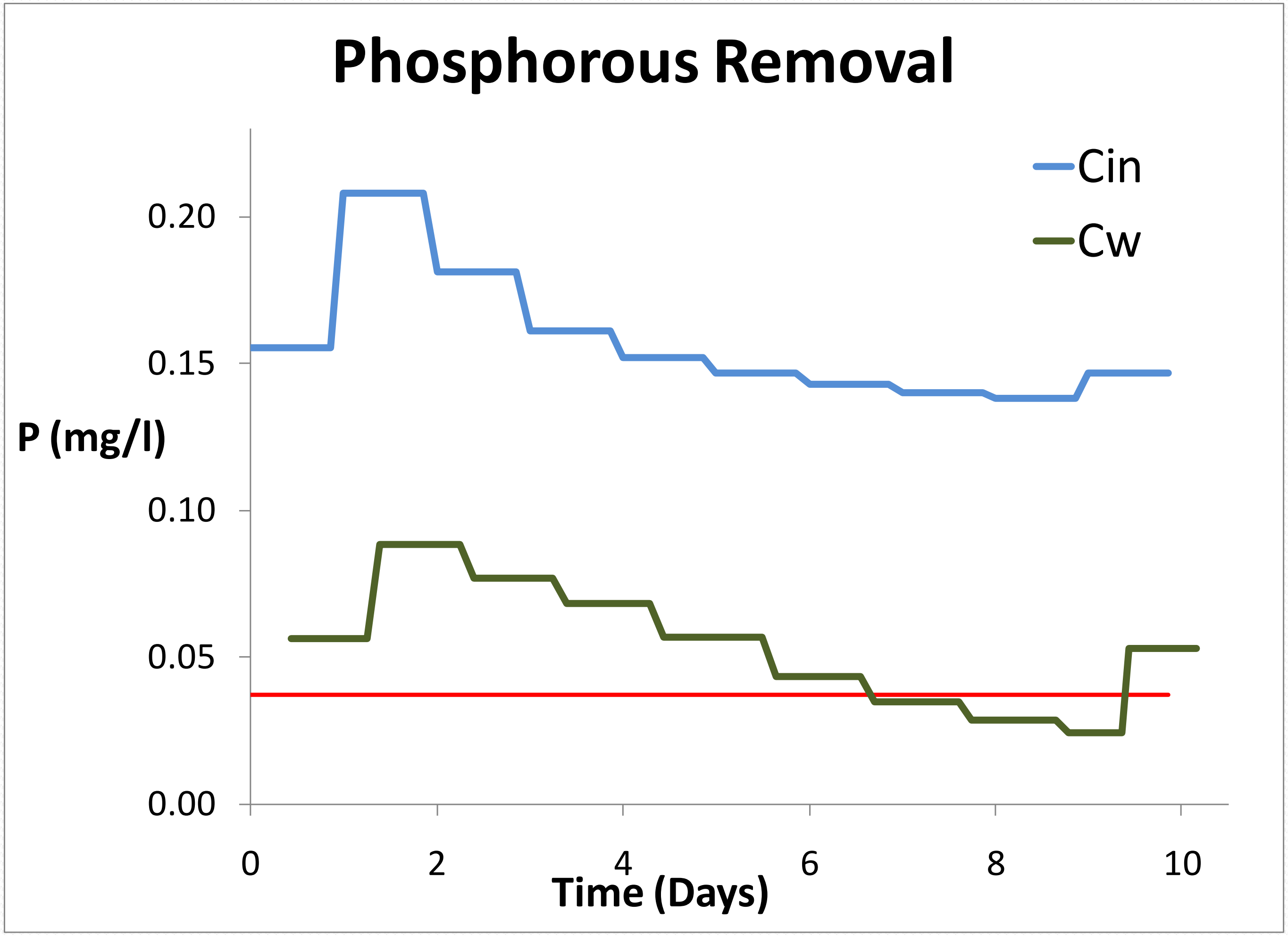
1-D Plug Flow Reactor Model

$$\frac{\partial C}{\partial t} = -u\frac{\partial C}{\partial X} - kC$$

Solution

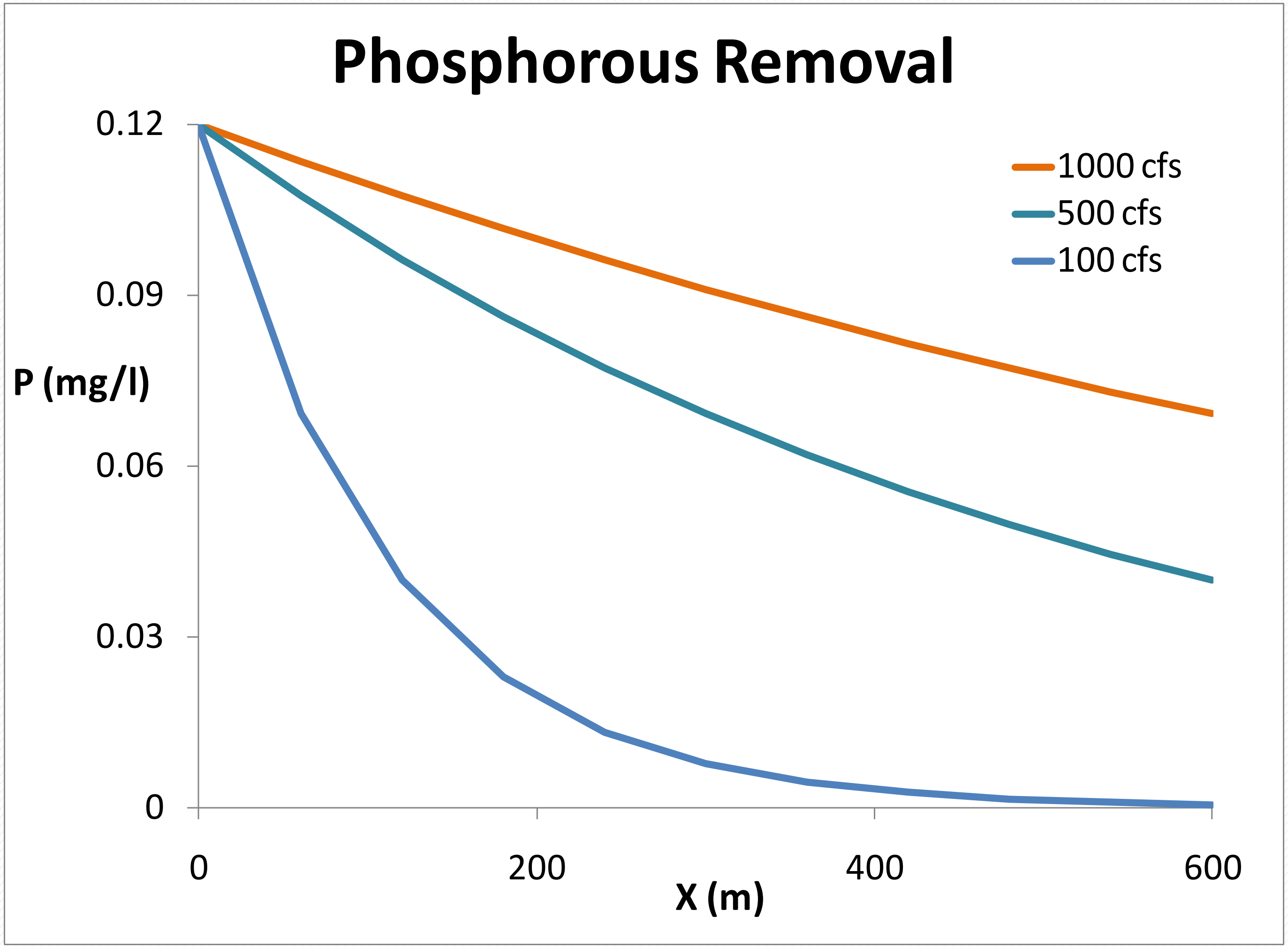
$$C(x,t) = C_o exp^{\frac{-kx}{u}}$$

Modeling



Phosphorous Removal
Cin
Cw
P (mg/l)
0.20
0.15
0.10
0.05
0.00
0
2
4
6
8
10
Time (Days)

Modeling



Phosphorous Removal
0.12
0.09
0.06
0.03
0
P (mg/l)
0
200
400
600
X (m)
1000 cfs
500 cfs
100 cfs

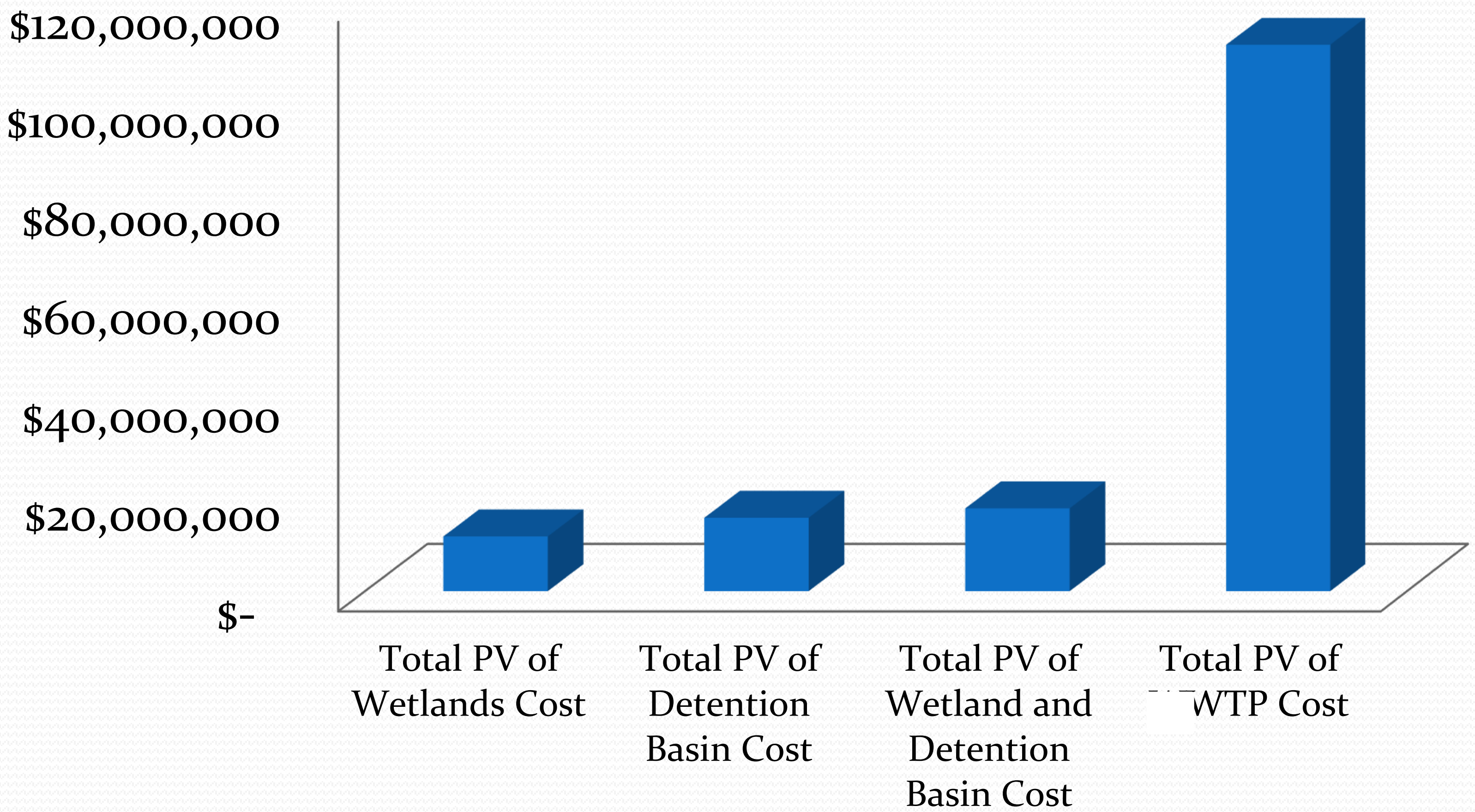
Considerations

- Sediment transport
- Biological process
- Flow in = Flow Out
  - No storage of flow
  - No infiltration or evapotranspiration

Economic Analysis

- Create a wetland design that removes the phosphorus below the state of Oklahoma standards of 0.037 mg/L
- To be effective as well as cost worthy in order that the benefits exceed the cost
- Provide a removal system which will continue to provide high-quality public good and valuable uses

Initial Present Value Comparison of a Wetland and the Comparable for the Lake Francis Area



Suggested Wetland Design

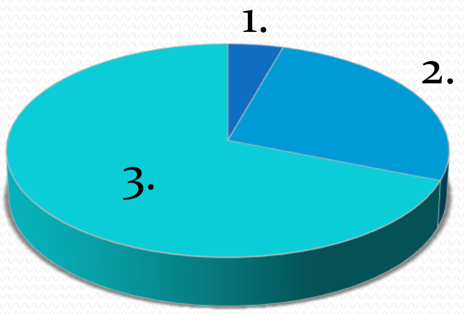
- Based on the modeling results and 20 year NPV cost, the most efficient design was determined

	Wetland	Detention Basin	Wetland & Detention Basin Combination	Treatment Plant
Acres Wetland	90		100	
Acres Detension Basin		200	70	20
20yr NPV Cost	$ 12,700,000	$ 15,000,000	$ 13,700,000	$ 110,000,000
% Removal	75%	90%	80%	95%
Cost/% Removal	$ 166,000	$ 205,000	$ 171,000	$ 1,100,000

Wetland Construction Cost

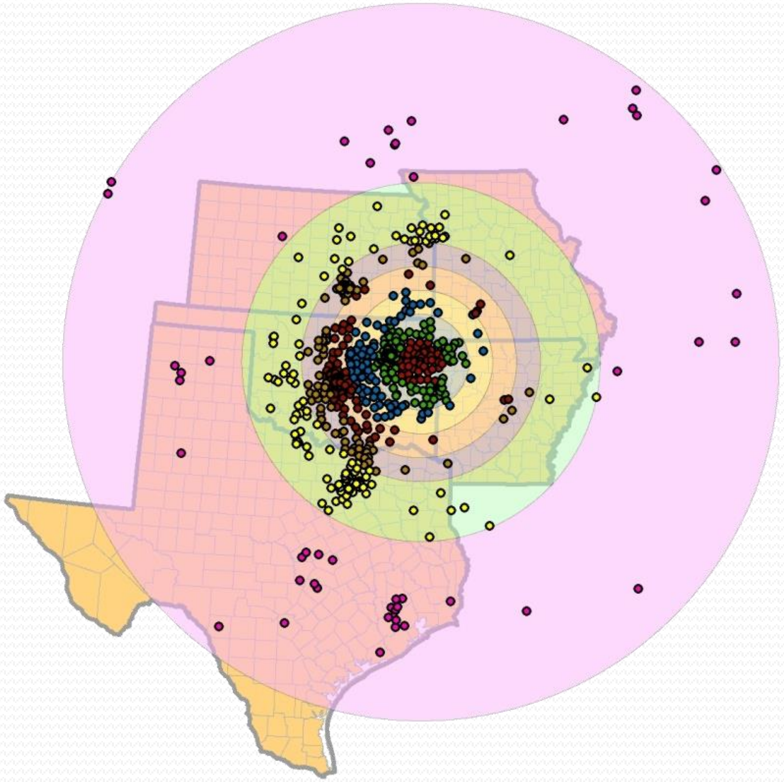
1. Pre Construction Cost
   - Land Purchasing
   - Permitting and Surveys
2. Construction Cost
   - Engineering
   - Alum Injection System
   - Communication Expense
3. Post Construction Cost
   - Maintenance
   - Alum
   - Dredging
   - Communications

- Total Estimate Net Present Value Cost is $12.7 million



Public Good Economical Evaluation

- 250,000 visit the Illinois River each year
- 120,000 visitors float the river each year
- Floaters economic impact is estimated at $9 million



Conclusions

- Our system can remove phosphorus
- A 90 acre wetland and alum system is the ideal design
- Slag works, but will be too costly
- A wetland system is more cost-effective than a water treatment plant

Future study

- Pilot scale wetland study is the next step
  - Better understand estimation of phosphorous/alum flocculent settling (k values)
  - Increase similitude between proposed and experimental systems
  - Incorporate influence of biological and other processes on a longer time scale

Acknowledgements

- Oklahoma Scenic Rivers Commission
- USDA-ARS Hydraulic Lab
- Steve Patterson
- Dr. Daniel Storm
- Dr. Tracy Boyer
- Dr. Chad Penn
- Dr. Jason Vogel
- Innovations Instructors

Rachel Carson

Dell Farris

Karl Garbrecht

Taber Midgley

Mattie Nutley

Kevin Stunkel

Dec. 4, 2009

Design Proposal Report

Submitted to Senior Design Faculty

Contents

Introduction

Figure 1. Illinois River near Lake Francis in Adair County.

Problem Statement

Flowing from northwestern Arkansas into northeastern Oklahoma, the Illinois River has been a source of legal disputes for over a decade. The Illinois River Basin covers 1,645 square miles between Oklahoma and Arkansas and is dammed south of Tahlequah, OK to form Lake Tenkiller Ferry. High phosphorous levels in the Illinois River and Lake Tenkiller Ferry have caused both to become increasingly eutrophic. Phosphorus loads into Lake Tenkiller Ferry are affected by phosphorous from the Illinois River. Decreasing phosphorus levels in the Illinois River will decrease the potential for eutrophication in both water bodies.

The Illinois River has been declared a "Wild and Scenic River" by the state of Oklahoma, and with that designation comes a numerical criterion of 0.037 mg phosphorus per liter. This criterion is not currently being met, and the United States Supreme Court has ruled the state of Arkansas must comply with Oklahoma's water quality standards. Figure 1 shows the site where the Illinois River crosses the Oklahoma/Arkansas (left/right) border. The shaded area highlights a dry lake bed where a proposed wetland integrated with a chemical injection system could be constructed to attenuate phosphorous loads in the Illinois River.

Figure 2. Illinois River on Oklahoma/Arkansas Border

The phosphorous comes from two types of sources; point source, i.e. municipal wastewater treatment plants, and non-point source, mainly runoff from agricultural fields. Point sources can be easily identified, since they come from a single point and are essentially constant. Efforts have been made, and are still ongoing to reduce the amount of phosphorous being discharged from six major wastewater plants within the Illinois Basin. These plants account for about 32% of the phosphorus load and are the main source of phosphorus during base flow (Storm et al., 1996). Non-point sources are not so simple to quantify. Due to the huge presence of the poultry industry in this part of Arkansas, 210 million kg of poultry litter is produced each year, most of which is used to fertilize fields. This litter contains 2.9 million kg of phosphorus, and during storm events much of this phosphorus is washed off of the fields and into streams, which eventually drain into the Illinois. Thus, non-point sources, which account for about 66% of the total phosphorus load, have the greatest effect during high flow and storm events (Storm et al., 1996).

Objectives

1. Conduct a strategic literature review to establish the current status of combined constructed wetland and chemical addition technology for phosphorous removal from surface waters.
2. Determine through investigation of pilot scale units if combined constructed wetlands and chemical addition can sustainably and cost-effectively achieve phosphorus concentrations in Illinois River near state line that are acceptable to meet Oklahoma Water Quality concentration or 0.037 mg/l total phosphorus.
3. Produce performance based design criteria that could result in the successful application of this technology.

4. Evaluate the cost benefit of capital investment and operation/maintenance for combined constructed wetland and chemical addition technology for phosphorus removal.
5. Disseminate the results of the study through technical papers and presentations so others can benefit from the research.

Statement of Work

The objective of the proposed project is to evaluate the applicability and effectiveness of an integrated chemical injection and wetland system to remove phosphorus from the Illinois River. Initial activities include jar tests to compare alum injection concentrations to flocculent settling times and dissolved phosphorus and sediment removal efficiencies in water samples from the Illinois River.

These results will be used to determine optimal injection concentrations incorporated into a subsequent mesocosm study. Following development and evaluation of potential design alternatives for the wetland system, testing of the selected design/designs with mesocosm studies will be conducted to determine phosphorous removal efficiencies. Results from the mesocosm study will be used to evaluate applicability and effectiveness of the proposed wetland system design to make recommendations for in situ phosphorous attenuation in the Illinois River.

Work Breakdown Structure

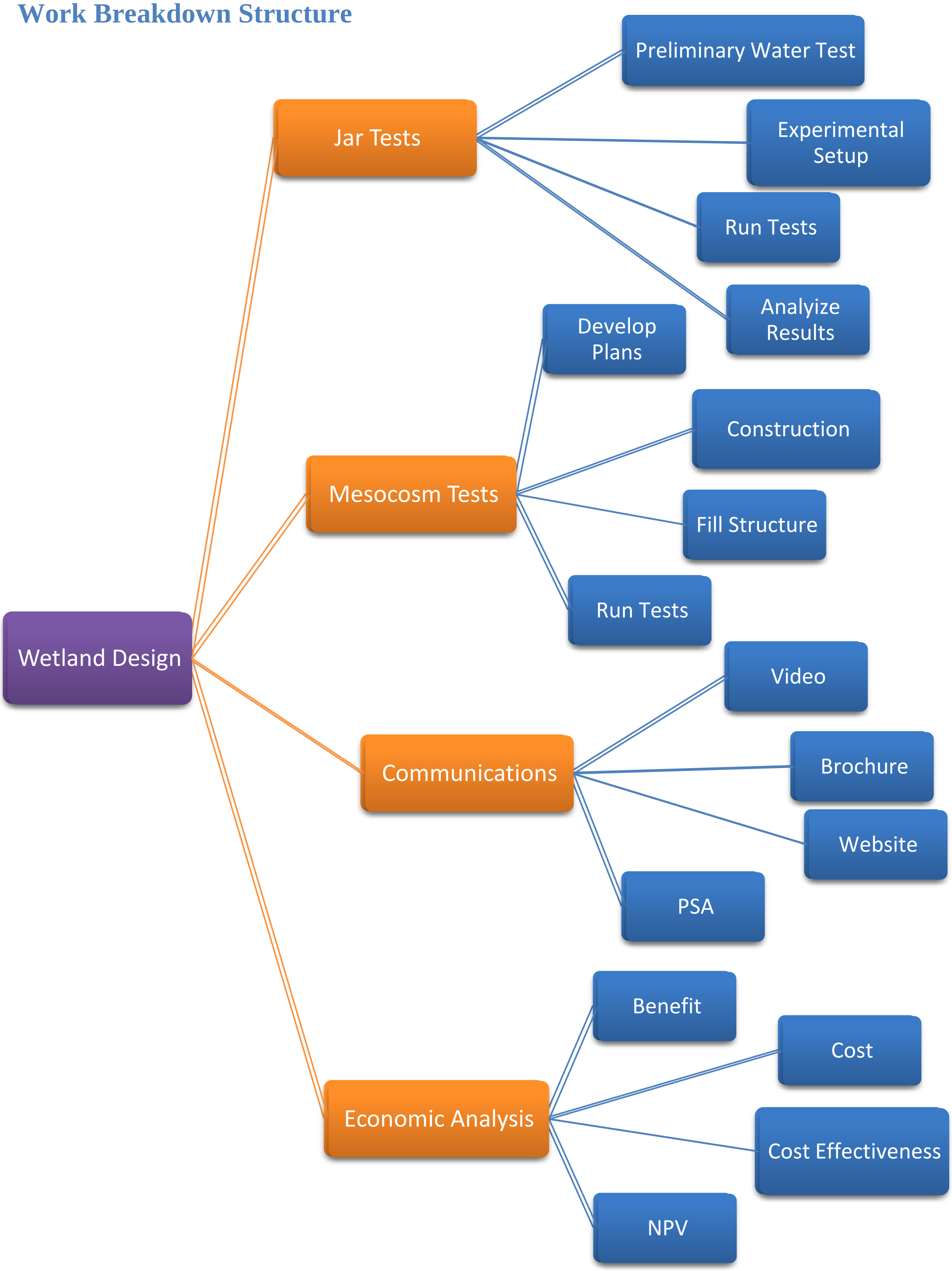


Figure 3. Work Breakdown Structure for *Scenic Solutions*

Task List

See Appendix 2C.

Industry Analysis

Guiding Principals

Environmental engineering is a sector that is experiencing increasing growth. Water quality research has experienced huge growth since the passage of the Clean Water Act in the 1970s. A growing level of environmental awareness is leading to an increase in regulations to control and improve present conditions. The degree of surface water degradation is becoming increasingly apparent and the motivation to fix these problems is becoming stronger. Increasing population and strain on rivers and lakes is also bringing this issue to the forefront. Even in times of economic downturn, environmental laws are still in effect and people are still entitled to clean water supplies.

Policy Analysis

There are multiple motivations for this project and the following section describes three court cases concerning the Illinois River Watershed. The first resulted in Arkansas being forced to follow Oklahoma's water quality criterions, and the last two specifically target the poultry industry.

State of Arkansas v. State of Oklahoma

In 1991, the State of Arkansas filed for an EPA permit to allow a point source discharge into an Arkansas creek following the National Pollution Discharge Elimination System (NPDES) under the Clean Water Act Section 402(a)(1). The EPA granted the permit, providing Arkansas follows all relevant Oklahoma water quality standards since the Arkansas creek accepting the discharge flowed into the Illinois River which flows into Oklahoma. Under Oklahoma law, the Illinois River is regarded as a Wild & Scenic River which outlaws any degradation of water quality. This standard would prevent Arkansas from dumping into the creek at all. Oklahoma challenged the permit, claiming the point source would degrade water quality in the Illinois River. The EPA decided that the discharge would provide no noticeable water quality difference, therefore the permit stood. The EPA still stressed that Arkansas must meet all Oklahoma water quality standards. The damage to water quality would have to be quantified in order to break Oklahoma water quality standards. An Appellate Court overturned the EPA's ruling, stating that any addition of pollution to the river would break Oklahoma law. Finally, the Supreme Court overturned the Appellate Court and allowed the permit to stand. The Supreme Court also ruled that the Clean Water Act does not require states to respect downstream states' water quality standards, but gave the EPA authority to enforce that rule if necessary, and to interpret state's water quality standards themselves and not necessarily follow the interpretation by that state's courts. To sum up, the Supreme Court said that original EPA ruling stood that allowed the point discharge, but would not allow Arkansas to degrade Oklahoma's water in any measureable fashion (Arkansas, 1992).

City of Tulsa v. Tyson Foods, Inc.

In 2003, Tulsa sued the poultry industry including Tyson Foods Inc., Cobb-Vantress Inc., Cargill Inc., George's Inc., Peterson Farms Inc., and Simmons Foods Inc. because of the increasing pollution in Tulsa's water which flows from northwest Arkansas. The City of Tulsa determined that the pollution was mainly from poultry producers in the State of Arkansas and a municipal wastewater treatment facility in Arkansas. In 2003 the US District Court for the Northern District of Oklahoma ruled that poultry litter application was subject to the Comprehensive Environmental Response Compensation and Liability Act of 1980 (CERCLA). This act is also referred to as the Superfund Act. The two parties settled out of court (Warren, 2003).

State of Oklahoma v. Tyson Foods, Inc.

In 2005 the attorney general of the State of Oklahoma, Drew Edmondson, filed a lawsuit against the dominant poultry producers in the Illinois River Watershed. These producers include Tyson Foods Inc., Cobb-Vantress Inc., Aviagen Inc., Cal-Maine Foods Inc., Cargill Inc., George's inc., Peterson Farms Inc., Simmons Foods Inc., and Willow Brook Foods Inc. Mr. Edmondson claimed the poultry producers' practices of waste disposal were not following federal and state laws and therefore damaging the natural resources of the Illinois River Watershed. Also, he claimed these poultry producers were endangering the public health and safety because of these practices (Burnett, 2009). Mr. Edmondson used the Comprehensive Environmental Response Compensation and Liability Act of 1980 (CERCLA) to hold the poultry producers responsible. CERCLA is also referred to as the Superfund Act, and gives the government authority to respond to hazardous material releases into the environment which may harm the public or environment. It also holds the parties responsible liable for all damages caused by the release. Mr. Edmondson was pursuing an injunction to halt all poultry litter application in the area and monetary reimbursement to the state for remediation, court, interest, and attorney costs. In 2008, the court denied the injunction because of the lack of proof that the bacteria in the water was caused by the poultry litter fertilizer.

Government Regulations/ Industry Standards

In order to construct a wetland, The Army Corp of Engineers, an enforcement agency, mandates that instructions specified in Section 404 of the Clean Water Act to be followed. Section 404 defines regulations of the restoration, enhancement, construction, or preservation of a wetland. Furthermore, valid approval may be needed from the Oklahoma Water Resources Board, Department of Environmental Quality, Oklahoma Historic Society and the Oklahoma Scenic Rivers Commission.

The Environmental Protection Agency (EPA), a government body for the development and interpretation of environmental policy, has a design manual specifically for wetlands. *Scenic Solutions* will refer to this manual for the design of the wetland. The EPA manual will be a valuable resource to determine industrial standards of wetland process designs, vegetation, and physical features.

Key Industry Gatherings

Many relevant industry gatherings relating to water quality improvement are hosted throughout the year. *The Society of Wetland Scientists*' Web site has posted several meetings about wetlands projects in different areas of the country. These meetings are for learning different strategies to preserve the environment through different types of wetlands.

An annual local meeting that occurs every fall is the Oklahoma Water Resources Research Institute (OWRRI) in Oklahoma City, OK. OWRRI brings researchers and public officials from throughout Oklahoma to convene and discuss Oklahoma's comprehensive water plan and current research being funded through the organization.

The *American Society of Civil Engineers* and the *Environmental and Water Resources Institute* host a conference every year in the United States. The conference, called the *World Environmental and Water Resources Congress*, highlights research in the field of water resources and sustainability. Students and professionals alike gather to discuss important issues relating to the environment and its impacts. It will be held May 16-20th in Providence, RI.

Another applicable conference is the American Water Resources Association (AWRA) Annual Water Resources Conference, which is being held Nov. 9 -12 in Seattle, Washington. This meeting is to educate participants about water restoration tactics including watershed management, river operations, flow management, and others.

Key Resources

Key resources for *Scenic Solutions* are the faculty members at Oklahoma State University and the University of Arkansas. These relationships are defined in the Management Team section of Client Company/Agency division of the report. Other resources include the Biosystems and Agricultural Engineering Laboratory and the USGS gage stations on the Illinois River located at several key spots near the wetland location. There is potential funding through waste water treatment plants in Northwestern Arkansas, however, currently Dr. Dan Storm is funding in-progress purchases.

Customers/Buyers

Buying Practices

There are several viable options to attenuate phosphorus loads in the Illinois River with specific advantages and limitations that ultimately dictate the applicability of implementation for each approach. Proposed approaches include a conventional wetland system, a wetland system integrated with chemical injection, a water treatment plant, and point source control methods such as algal turf scrubbers in conjunction with waste water treatment plants. A wetland system offers a way to biologically remove phosphorous while creating valuable habitat for local fauna. Removal efficiencies in wetlands can be increased by adding a chemical injection system in series as a primary treatment stage to flocculate out phosphorous, however, wetlands are prone to wash out during high flow conditions, so care must be taken to limit velocities of water. A water treatment plant allows for high removal efficiencies under controlled conditions. Algal turf scrubbers have the advantaged of removing phosphorus from sources before it reaches the Illinois River. The scrubber system requires a minimal investment compared to wetlands or a wastewater treatment plant, but because scrubbers only intercept water from point sources they do not treat phosphorus from non-point sources, which is a major contributor in downstream lakes. Wetlands integrated with chemical injection offer high removal efficiencies while providing habitat for local fauna.

Current and Potential Market Size

Excess nutrients in surface water systems in Northeastern Oklahoma are affecting recreational opportunities and decreases aesthetics of many streams and lakes. As decisions involving the dispute between Oklahoma Stakeholders in the Illinois River and major phosphorus contributors are reached, the rest of the country will be watching. The potential market for phosphorous attenuation systems in the United States is large and will be growing in the near future. *Scenic Solutions* has identified this as potential opportunity for growth and will demonstrate the applicability of constructed wetlands coupled with chemical injections systems to remove phosphorus from water systems.

Business to Business, Government Agencies, and/or Consumers

The construction of a wetland is significantly different than the other senior design projects. In this project, funds are not available to construct an actual wetland, therefore the testing and design for the constructed wetland is the objective due to lack of funding. Information on new practices and ideas is spread through journals, conferences and government publications. Institutions and private organizations perform research on the efficiencies of wetlands and additional practices at removing phosphorus and other pollutants from water. Agencies like the EPA, USGS and Oklahoma Scenic River Commission set standards and collect information on a variety of environmental issues. These standards drive the industry as states, communities and companies work to meet them and avoid fines and citations. The government is the force that cultivates this industry, with its laws and often times funding. There are many countries that are facing detrimental health problems due to water quality degradation; the U.S. Government is trying to keeping this from happening here. Since there are few immediate monetary benefits of a wetland it is usually necessary to require their construction, or use tax benefits to encourage it.

Economic Status of the Customer/Buyer

The economic status of the potential customers will be measured through the greater good of the environment. Currently, customers value the use values to the highest degree over any nonuse values or option values. The design of the wetland will be for the beneficial uses of ecological, industrial, municipal, recreational and irrigational uses for the surrounding area.

Demographic Characteristic

One of the key demographic groups in the Illinois River basin is the Cherokee Nation. The Cherokee Nation has authority over the Illinois River and Lake Tenkiller Ferry, which gives them water rights to the river. This is important because the Cherokee Nation has been involved in legal disputes with the poultry industry over water quality.

Another major demographic is tourists who use the river for recreational purposes such as fishing, floating, hunting and camping. The wetlands project would appeal to this demographic for conservation of the river and wildlife. Most of the educational materials for the wetlands project will be directed towards this demographic.

Characteristics of Buying Firms/Government Agencies

The government agencies that will pay for constructed wetlands chief concern is providing for the tax payer in an efficient matter. Governmental contracts are closely scrutinized, and all regulations must be followed when working with the government.

Psychographic Characteristics

The Illinois River in Oklahoma is used for a variety of purposes. Lake Tenkiller Ferry is fed by the Illinois River and is currently becoming increasingly eutrophic because of excess nutrients brought in by the river. Eutrophication causes algal blooms, cutting off much of the oxygen needed for fish and other aquatic wildlife. The Illinois River and Lake Tenkiller is used for recreational activities such as fishing, water skiing, swimming, diving, noodling and floating. There are also communities in Oklahoma that rely on the river and lake for drinking water such as Siloam Springs, AR. Hunting is also a favored sport for people living in the area. The wetland could serve as excellent habitat for ducks and other water fowl and could prove to be a good arena for hunting. Removing the excess nutrients from the lake by way of the river will increase the overall clarity of Lake Tenkiller, thereby increasing the appeal for divers to use the lake.

Product Use

The final design of a constructed wetland with alum injection may be used in the construction of an actual wetland to decrease phosphorus in the Illinois River. The design will incorporate an alum injection system to increase phosphorus in addition to the traditional wetland removal rate of phosphorus. The removal of phosphorus in the Illinois River will also decrease eutrophication occurring in Lake Tenkiller Ferry. Wetlands also serve to create a natural ecosystem where plants and animals can thrive.

Client Company/Agency and Its Resources

Management Team- Key People and Experience

Scenic Solutions depends on several key people from different organizations to fulfill its mission. Dr. Daniel Storm from *Oklahoma State University* is the chief advisor to *Scenic Solutions*. Dr. Storm has past experience with wetland design and ample knowledge of the current litigation between the state of Oklahoma and the chicken industry involving non point source pollution in the Illinois River. Also of great importance to *Scenic Solutions* is the team at the *University of Arkansas (U of A).* An equivalent group has been established at the *U of A* which is investigating point source treatment for the Illinois River watershed. This team works in parallel with *Scenic Solutions* because the implications of both projects are related. Faculty at the *U of A* also provided endless support to *Scenic Solutions*. Dr. Tom Costello is an associate professor at U of A whose research involves animal waste, water quality, and chicken and livestock environments. Dr. Costello is the senior design instructor at the *U of A*. Dr. Marty Matlock is a professor at the *U of A* who has provided much needed direction and support for *Scenic Solutions*. His research involves ecological design, water quality modeling, and ecological risk assessment. *Scenic Solutions* also has the support of *Bio x Design*, an environmental consulting and ecological restoration company from Poteau, Oklahoma. Steve Patterson is the owner and main contact at *Bio x Design*. Mr. Patterson has experience with wetland design, regulatory permitting, ecological assessments, and ecological restoration. *Scenic Solutions*, with the help of Dr. Storm is in the process of applying for funding from several other organizations to support this project.

Product Line

Bio x Design has experience with wetland design, regulatory permitting, ecological assessments, and ecological restoration.

Manufacturing Expertise and Capacity

Each wetland is designed and constructed specifically for the area and requirements. They are a natural ecosystem with biological, chemical, and physical processes which must be accounted for. *Scenic Solutions* will rely on Steve Patterson of *Bio x Design* who will provide the manufacturing expertise because of his long background in constructed wetlands. For the manufacturing of the mesocosm for the small scale study, *Scenic Solutions* will utilize the tools available at the Biosystems Engineering laboratory and manual labor. Manufacturing capacity will not be an issue.

Input Suppliers

The main input that will be required for this wetland will be alum. Alum can be purchased from chemical companies around the country and is currently priced around $250/ton. Companies include *USALCO, CQ Concepts and Delta Chemical*. Concrete can be purchased from a local supplier such as *Mid Continent Concrete* and *Tune Concrete* in Siloam Springs, AR.

Marketing Expertise

The marketing expertise will be comprised of educational materials for the general public. These materials will take into consideration the different types of wetlands, such as constructive and natural. It will also show the scenic and wildlife benefits to wetlands, as well as water quality advantages.

Recreation will be used as an outreach to the general public. This will include billboards to advertise the benefits of a wetland for wildlife. Public service announcements will also be utilized on the radio to educate people. A *YouTube* video will also be put together to show actual footage of the river and how wetlands help the environment. This will also help reach a wider audience. Brochures will also be printed and put in such places as *Bass Pro Shop* and other recreational stores.

Product

Wetland pricing is highly variable depending on the type of wetland, location, and size. A study found fresh water wetlands cost more than salt water wetlands and prices per acre are generally lowest in the southeast United States (Baca and Florey). The authors also investigated the contribution of three construction phases to the total cost. Pre-construction cost consisted of design activities; construction costs were earthwork and vegetation costs; and post construction costs included maintenance. In this study, the proposed wetland system at the Lake Francis site is classified as a freshwater wetland with emergent vegetation. The type of wetland is generally dictated by environmental conditions such as climate and location. For instance, mangroves are costal ecosystems and forested wetlands are appropriate for climates that can support such flora based on site characteristics, a freshwater wetland with emergent vegetation is the most ideal ecosystem for Lake Francis. Nationwide total price per acre averaged around $45,000/acre for freshwater emergent wetlands (Figure 4).

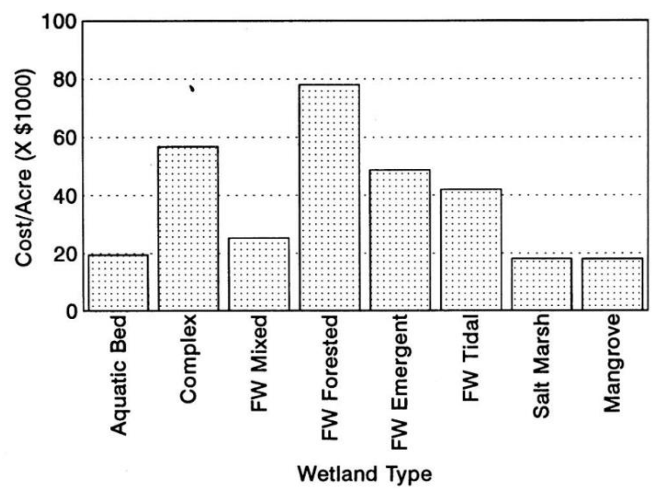


Figure 4. (Baca & Florey)

Additionally, the study found construction constitutes the bulk portion of the costs (Figure 5). Emergent wetlands also have a relatively high post construction cost in comparison to other types of wetlands.

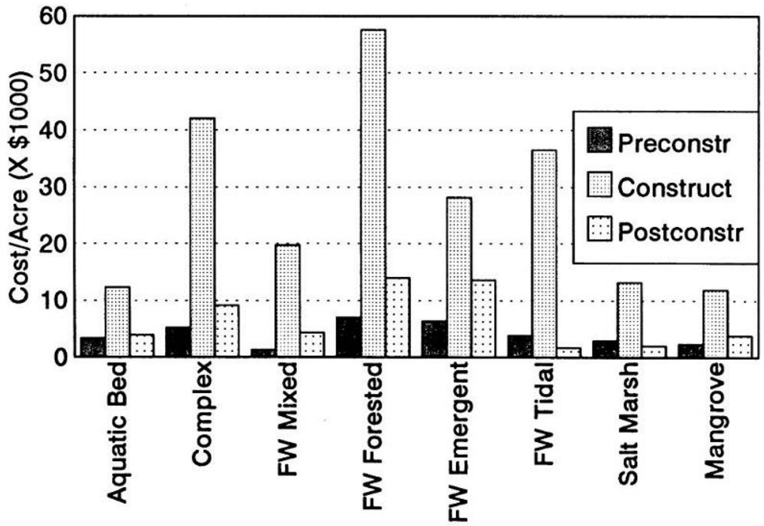


Figure 5. (Baca & Florey)

Prices for alum injection systems range from $135,000 to $400,000 depending on the size of the treatment volume (EPA). Maintenance and operation costs for alum injection systems were found to range from $6,500 to $25,000 per year (EPA).

Competitors and their Resources

Competitors to *Scenic Solutions* would be other environmental engineering firms. In a governmental bidding process, they could potentially win the bid and use their design. For the purposes of this project, this means making the design as cheap as possible while maximizing efficiency. Other options for increasing water quality of the Illinois River could also negate the need for a wetland in eastern Oklahoma.

Patent Search

An extensive patent search has been conducted and is still in progress. All patents discussed below are included in Appendix A.

Alum Recover and Waste Disposal in Water Treatment (May 25, 1974) 3,959,133**-** This patent describes a process by which alum from wastewater treatment plants can be recycled and reused. This may be applicable to this project because reusing alum from a wastewater treatment plant could reduce material costs.

Constructed Wetlands System, Treatment Apparatus and Method (May 25, 2004) 6,740,232**-** This patent describes an apparatus for a landscape pond which enhances water quality. The treatment pond includes vegetation, bacteria, substrate material, and treatment apparatus.

Constructed Wetlands to Control Nonpoint Source Pollution (Dec 29, 1992) 5,174,897**-** This patent describes a generalized wetland design that includes a sediment basin, spreader, grass filter, wetland, and deep pond. This patent discusses many of the issues that *Scenic Solutions* will face down the road. The system has a runoff conduit to control the amount of water entering the system. The next step is the sediment basin. Basically, this basin slows the water down to allow the larger particles to settle out. It also serves to regulate flow into the downstream wetlands and grass filter. This basin was designed to allow easy excavation. The level lip spreader controls the flow of water from the basin to the grass filter. The purpose of the spreader is to provide uniform flow to the grass filter. Native grasses are used for the grass filter. It is designed to maintain sheet flow from the spreader. Sometimes, this filter will require a subsurface drainage system to allow aerobic conditions for the plants if the filter will experience long term saturation. The wetland is constructed to maintain saturated conditions and shallow water. Aquatic vegetation is encoraged to grow in the wetland to provide an environment for multipule organisms. The deep pond is a place for limnetic treatment and fine particle of solids. Fish can be added to the pond to enhance the use of nutrients. The results from this system include a total phosphorous (TP) removal of 88% to 100%. Total suspended solids and volatile suspended solids were also removed by 95%. The system experienced a large rain event where it performed very well.

Enhanced Subsurface Flow Constructed Wetland (Apr 13, 1999) 5,893,975**-** This patent considers a subsurface flow wetland to treat water. This wetland includes an intake, a nutrient addition chamber, and a flow divider. Wastewater is treated by various soil media mixtures.

Contaminant Removal Method for a Body of Water (Mar 21, 2006) 7,014,776**-** This patent describes a process to add a coagulent to a mass of water, mixed, and then allowed to settle out. Water is then removed, and new water is re-added to the body. The coagulant is then mixed again and the process is repeated. This can be repeated until the coagulant no longer exhibits maximum pollutant removal capacity. This is related to the goals of *Scenic Solutions* because the same logic is being implemented with the alum injection system.

Automated Chemical Metering System and Method (May 11, 1999) 5,902,749**-** This patent discusses a metering and control system for use in a stream or river for chemical injection. This patent is related to *Scenic Solutions'* wetland design because a system is to be designed which adds alum to the variable flow entering the wetland.

Flow-Based Chemical Dispense System (Jul 20, 2004) 6,763,860- Again, this patent discusses the injection of chemicals into a variable flowrate stream.

Testing/Experimental Plan

Jar Tests for Alum Injection Rate

In order to determine the necessary concentration of alum that will be added, a series of jar tests will be performed. The goal of these tests is to determine the removal efficiencies of phosphorous based on the concentration of alum.

Materials

Required materials consist of settling tubes, alum, high-flow water from the Illinois River, filters and a filtration device, a peristaltic pump and bottles for sample storage. The settling tubes have already been constructed for a previous project and are ready to be used. The pump and bottles will most likely not need to be purchased. These consist of 12, one meter tall settling tubes with a volume of eight liters constructed of PVC. There are also five gallons of alum available for use. Purchases for this portion of the experiment will need to include filters capable of handling high levels of sediment and a filtration system to match. In order to get an accurate representation of conditions on the Illinois River it will be necessary to obtain actual high flow water from the river. This will require the purchase of a tank to transport the water. Funding will also be needed for running nutrient tests at the Soil, Water and Forage Lab (SWAFL).

Procedures

The 12 settling tubes will be filled with the high flow water collected from the river. Three sets of four tubes will have alum added until they reach a desired concentration to be determined (eg. 10 mg/l Al, 1 mg/l Al and 0.1 mg/l Al). Once the alum has been added and well mixed, the tubes will be allowed to settle for 12 hours. After the 12 hours has passed, one tube from each set will be removed for testing. A water sample will be pulled from each removed tube for nutrient level analysis. Each tube will then be separated into four sections from top to bottom of two liters in volume. These samples will be run through the filters to determine the amount of sediment in each layer. The process will be repeated for 24, 36 and 48 hour time intervals. Water samples will be sent to SWAFL for analysis, and sediment data will be compared to determine settling rates.

Mesocosm Study for Wetland Design

A mesocosm study will be conducted in order to determine retaining and removal efficiencies of the proposed wetland design. The pilot scale model will be used to evaluate the feasibility of implementing a chemical injection system in conjunction with a wetland, as well as identify potential benefits and limitations. Basic features of the mesocosm will include:

- containment structure
- influent and effluent water storage tank
- pump and flow control devices
- water temperature control system
- alum injection system
- soil and fill material

- wetland plants

The containment structure must be impermeable and rigid enough to support saturated conditions within the soil and fill material. Acrylic is a possible material satisfying both conditions, but a wooden structure with a water proof liner may be more cost efficient. The system will also need a water storage tank to hold water from the Illinois River to serve as an effluent solution during experiments. After passing through the system, this water will no longer be characteristic of the Illinois River, therefore cannot be circulated again and must be sent to a second effluent holding tank because of elevated phosphorus levels. If it is determined the effluent water doesn’t need treatment before discharge, the tank will not be necessary. The pump and flow control devices need to be able to maintain sufficient and constant flow over extended periods. It is possible that based on the size of the wetland system a small variable flow pump will be adequate.

A system to maintain the water at an appropriate temperature will be needed due to fluctuating ambient temperatures. The alum injection system is required to vary injection rates according to various flow rates. This could be accomplished with a peristaltic pump manually adjusted to injection/flow rate ratios as desired. Soil and other fill material from the prospective wetland site will be used to produce results as accurately as possible. Finally, wetland plants will be chosen according to climate and soil properties at the anticipated wetland site.

Customer Requirements

The constructed wetlands design project is being completed in conjunction with a corresponding design team at the *University of Arkansas* in Fayetteville, AR. The *University of*

Arkansas students are focusing on treated waste water from waste water treatment plants in northwest Arkansas analogous to the base flow in the Illinois River. *Scenic Solutions* has therefore decided to concentrate on treating the high flow that results from storm events and would carry most of the non-point source pollution. The goal is to reduce the phosphorus concentration in the Illinois River to 0.037 mg/L as this is the standard that Arkansas must meet for surface water flowing into Oklahoma.

Impacts

A constructed wetland to remove phosphorus for the Illinois River will have many important impacts on the region. Environmentally, it will make society more aware of the need to keep water clean and the significance of completing the goal with natural processes. Water quality degradation in the Illinois River and Lake Tenkiller Ferry due to excess phosphorus has become a major problem. A constructed wetland to decrease phosphorus concentrations to acceptable levels will increase the quality of water over time. The design will impact the regional society as a natural place for recreational activities and for wildlife to flourish. Growing tendencies to use wetlands as natural pollutant removers will create more natural habitats globally for wildlife and recreation and help protect rivers and lakes.

Engineering Specifications

The design for the mecosom must meet several specifications in order for it to successfully model potential alum removal. Three different flow rates will be tested through the wetland with two replications for a total of six trials. The total amount of water used in these six trials must not exceed 2,400 gallons to ensure that water supply amounts are not exceeded. An amount of 2,600 gallons of water must be obtained for testing and stored in a 3000 gallon tank. The storage tank needs to be mixed to ensure that settling doesn't occur prior to entrance into the mesocosm. Constant and controlled flow must be ensured from the holding tank into the mesocosm. A pump must be provided to administer a constant dose of alum. Alum needs to be fully mixed with the water before it enters into the primary detention pond. The surface area of the individual wetland cells is specified to be 10 square feet. The experimental trials must be run for at least eight hours longer than the detention time for the given flow rate.

Media/Communications Plan

The communications objective is to educate audiences on the background of the Illinois River and how a high level of phosphorus can affect the water and how damaging it can be to aquatic wildlife in the river if not properly managed. The intent is to express to the audience that the wetland will not decrease recreation like boating, fishing and hunting and will optimally increase the quality of recreation and help the aquatic wildlife flourish.

The audience will be all ages that use the Illinois River for recreation, farming, and people who live near the Illinois River or Lake Tenkiller. Benefits will be addressed of how the wetland will help make recreational activity and farming better for the affected population.

The communications plan of the wetlands projects is comprised of different kinds of media which include a video, websites, and public service announcement. Other forms of communications will be a brochure and billboard. These materials are meant to educate the general public on the benefits of wetlands and outcomes it will have on lowering the phosphorus levels of the Illinois River, making a better environment for wildlife.

There will be a *Scenic Solutions* group website that will include group photos, individual member photos and information regarding group members. The mission statement of Scenic Solution and information regarding the wetlands project will also be included. The website will be centered towards the group members and an overview of the project.

There will also be a second website that will be more focused on the wetland project. This website will be used as an educational tool for the general public. It will describe the problems of the Illinois River and the solution of a wetland to fix the phosphorus level. All of this will be to educate all ages (from children to older adult), so it will primarily be explained at an eighth grade level.

The website will also tell how wetlands are beneficial for such purposes like recreation, farming, and wildlife. It will also give background information on how *Scenic Solutions* developed a wetland through different testing and experiments and include video and photos of the tests conducted. There will be other website links provided. *Scenic Solutions* will also display the other types of communications materials to be used, such as brochures and a radio service announcement.

As the internet has become the best means to communicate to a large audience, www.youtube.com will be used for promotional videos. The video will show the Illinois River, along with recreation and wildlife. Benefits of the wetland will be advertised and it will illustrate the different experiments performed. This video will be educational and show how important wetlands are in naturally protecting the environment. The video will be posted on YouTube to obtain the widest range of viewers.

There is also a possibility to make a radio public service announcement to broadcast on several radio stations. This should be about one minute long to raise awareness of the Illinois River and to tell of the processes that are being enacted to lower the phosphorus levels, including the wetland project and what will happen to the aquatic life if nothing is done to eliminate the excess phosphorus.

Since the Illinois River is a major recreational venue, a brochure will be made to target a recreational audience. The brochure will be placed at businesses such as Bass Pro Shop, or other sporting goods stores. Experiments would not be included in the brochure unlike the video or website, but it would focus on the effects of high phosphorus levels in the Illinois River. The brochure would also highlight a brief overview of how the wetlands are constructed and that it will not detract from the Illinois River. The plan is for a tri-fold brochure that interested parties could pick up from their favorite sporting goods store.

An advertisement will be created as a prototype that could be used for a billboard sign. The billboard could be placed near the Illinois River and Lake Tenkiller. It would help create a positive marketing plan for the wetlands. The design should be simple, but will describe what a wetland is to the general public and make a statement of the benefits to the Illinois River and the communities in the surrounding areas.

Overall the materials for the project will be similar, but each will have a targeted audience. The brochure will be centered on people concerned with recreation and more aware of the physical aspects of the Illinois River, while the video will be targeted towards a more general audience.

Financial Analysis

The proposed business analysis for *Scenic Solutions* will involve the economic outlay for measuring the benefits versus the costs. When evaluating the economic conditions of a wetland, it is more difficult to evaluate the costs to benefits than many ordinary products since there is no controlled market. This wetland is an externality, with several hidden costs and no private firms for controlling the public good.

For evaluating the benefits, there is a need to consider many factors. Factors will come from five categorical uses: ecological, industrial, municipal, recreational and irrigational. Differences between each of the potential wetland designs will be estimated with the different variables as plants, soil, detention time and flow. Other benefits to consider will include the avoided damage cost, energy saving cost and future net present values. To estimate the values of benefits, calculations will be performed on the Total Willingness to Pay (TWTP*):*

TWTP= Use Value + Option Value + Nonuse Value

Within the *TWTP* equation, the use value refers to the environmental resources being directly used. With the wetland design this may include aspects like the scenic integrity and recreational use. The option value is the reflection of the value people will place on the future ability to use the environment. It is the willingness to pay for the option of a future use, even if it is not currently in use. Option use is preserving the potential of a resource for a possible future use. The third use, nonuse value, is the reflection of the fact people are more willing to pay for improving or preserving resources that they will never use.

When evaluating the use, option, and nonuse values, the properties will be related back to the categories in which the uses of the benefit will arrive from for each design. These categories will then aid in calculating the direct and indirect values.

The travel cost method will be calculated as well in estimations of placing a value with the wetland. Since the assumption is the wetland will most greatly benefit the recreational uses: canoeing, rafting, hunting, and sightseeing just to name a few. The travel cost method will be a great tool of measure to estimate the economic use values. It will work through placing figures with the time and travel cost expenses that people incur for visiting and accessing a site.

While determining the benefits, the cost will be determined for the several different wetland designs and compared on their impact with the categorical uses. The cost will be more straightforward to calculate than the benefits. When evaluating and comparing the impacts of the wetlands designs, the different variables will once again be considered. Variables of highest consideration may include flow rates, plant life and alum injection amounts. All variables will be considered as they will ultimately determine the wetland engineering plans, preconstruction site preparation, and construction cost. The construction cost will involve the cost of labor, equipment, materials, supervision, maintenance and other indirect or overhead costs.

After benefits and costs of the project are gauged, cost effectiveness will be assessed. The cost effectiveness analysis will determine which of the wetland designs is the most adequate at efficient phosphorus removal and economical within means. This cost effectiveness analysis will be good in determining the opportunity cost of the wetland.

Design Concepts

In order to predict the concentration of alum that will be most effective in removing phosphorus, jar tests were performed with the Illinois River water at different hours and different alum concentrations. The results are pending and more jar tests will have to be completed. Initial results have not been obtained.

The mesocosm design is more complicated as there are several options.

Alternative 1:

Four mesocosms connected to a detention/settling basin. This is shown in Figure 6.

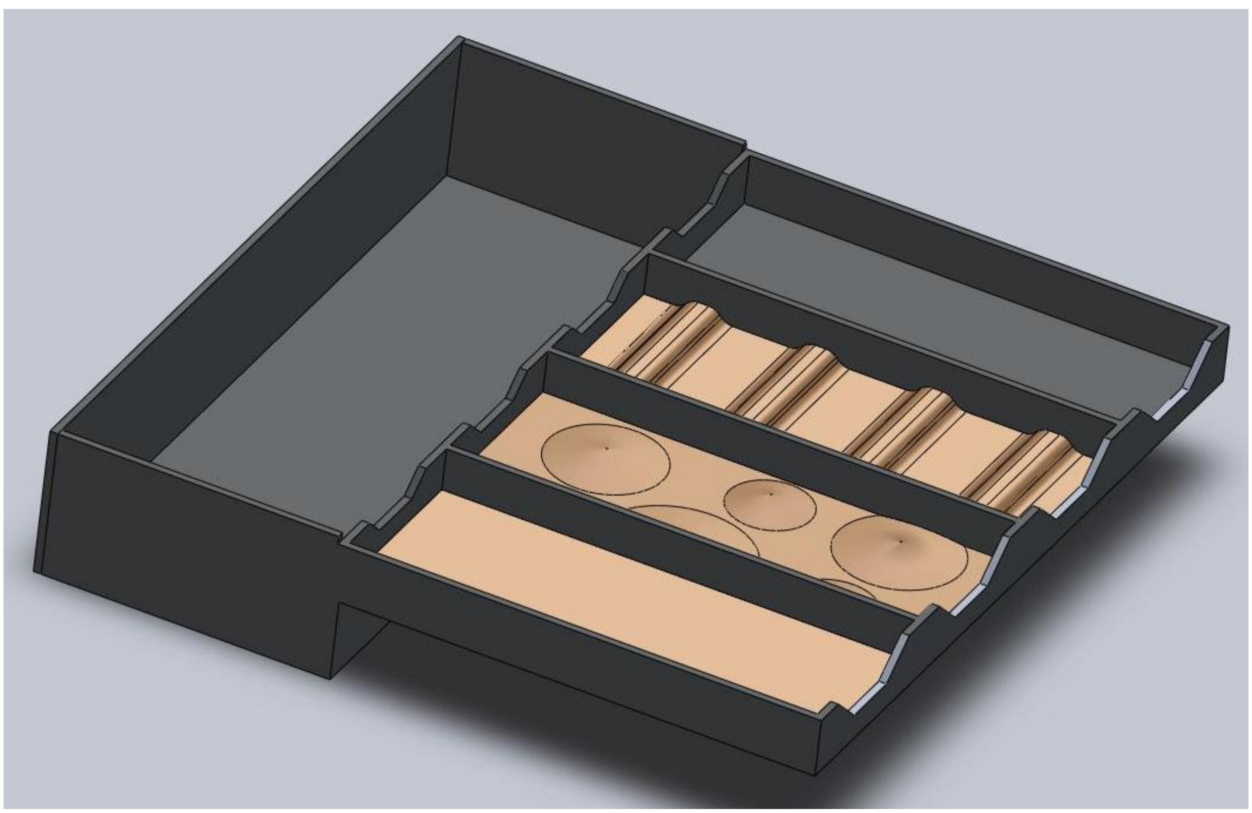


Figure 6. Design of four mesocosms shown with differing characteristics.

Designing the soil in rows and in circular mounds would allow for variation in the flow and plant placement. However, in a real case scenario, plants would not only grow where they were placed and this system would need several months to come to equilibrium. Therefore, this alternative is not feasible with current time constraints.

Alternative 2:
Six mesocosms connected to a detention/settling basin as shown in Figure 7.

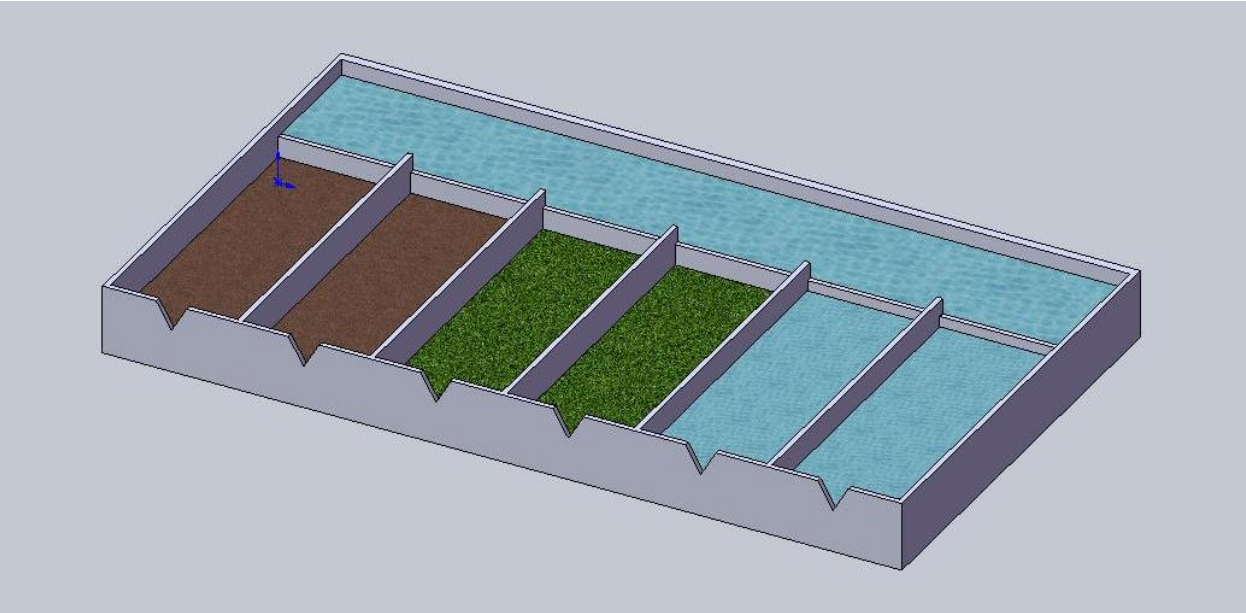


Figure 7. Design of six mesocosms shown with non vegetated, vegetated, and detention basin mesocosms.

Having six mesocosms with three duplicates would allow for greater time efficiency and less replication. However, having two mesocosms with only soil is not feasible for real-world modeling. In northeastern Oklahoma, the vegetation is thick and there would be no actual case with only soil and no vegetation. So it was decided that it is not feasible to have only soil as a mesocosm.

Alternative 3:

Four mesocosms connected to a detention/settling basin as shown in Figure 8.

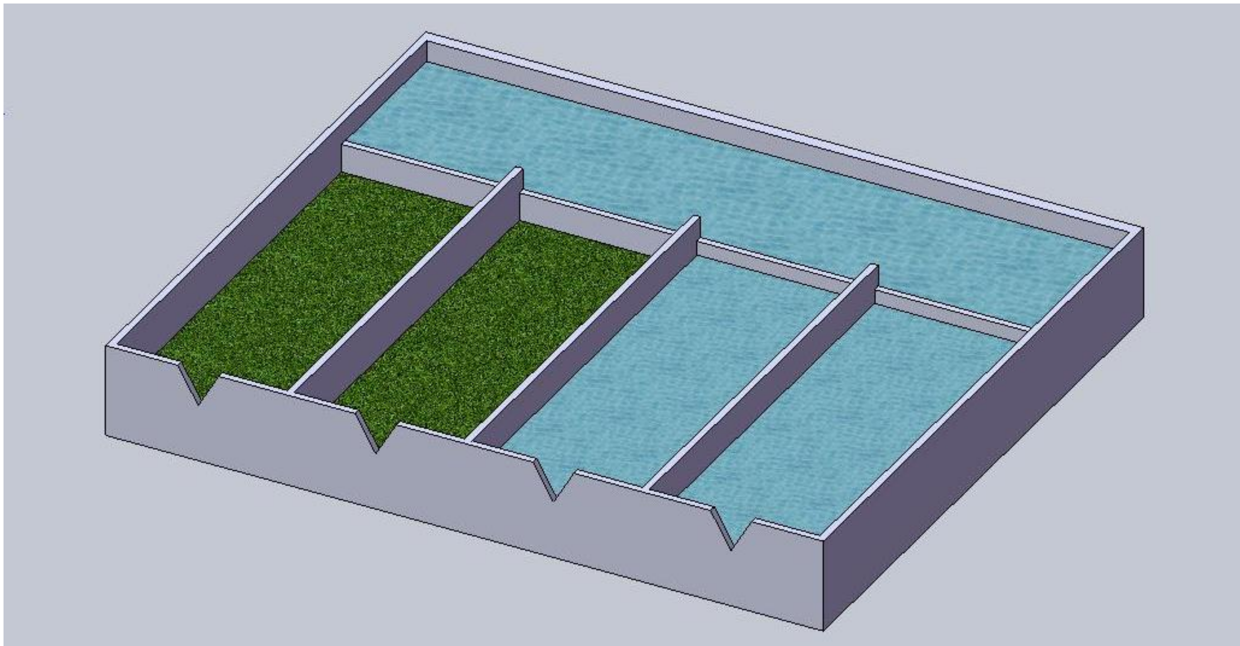


Figure 8. Design of four mesocosms shown with vegetated and detention basin mesocosms.

Duplicating the detention basin control and the vegetated mesocosms will allow for time efficiency and easier replication. This alternative is the most feasible for a simplified study of how a wetland will remove phosphorus from the Illinois River. Two detention basins are not required as there will be very little variability in the two basins. Experiments will be replicated regardless, so two controls are not required. This resulted in alternative three.

Alternative 4:

The summation of the design process resulted in the current best alternative. This alternative includes only one detention basin and two vegetated wetland mesocosms as seen in Figure 9.

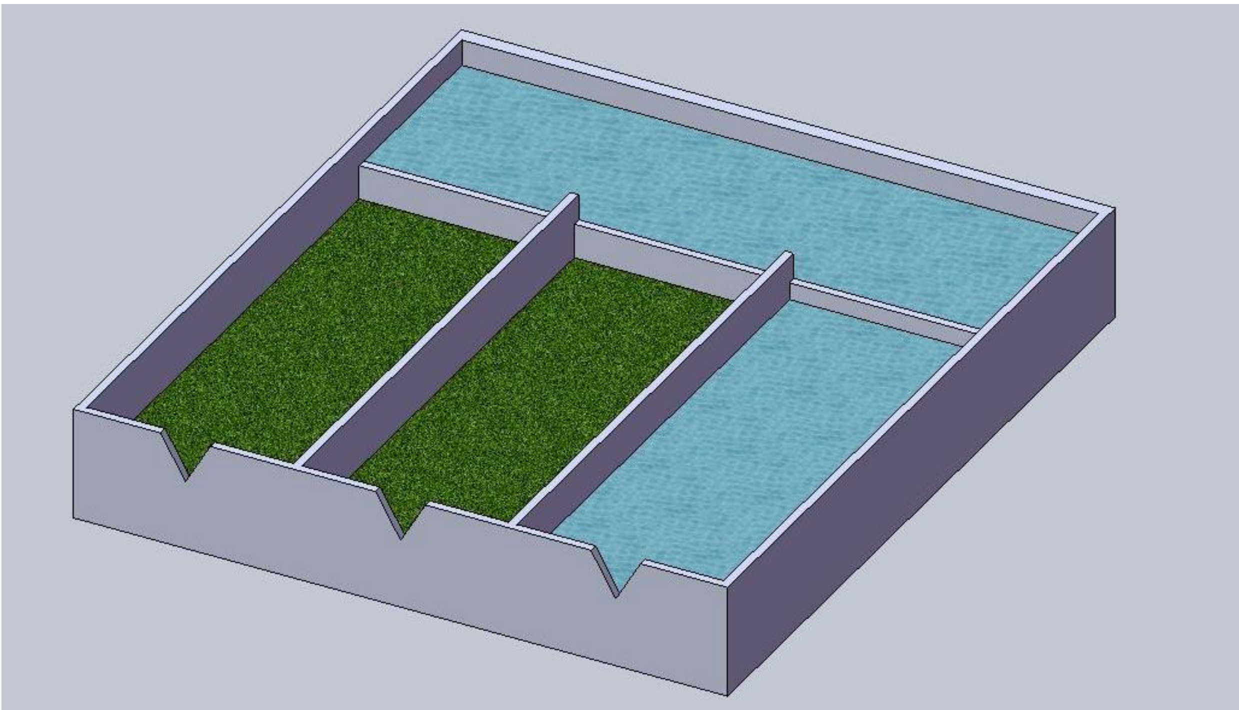


Figure 9. Current mesocosm structure design with three mesocosms.

This is the most feasible option because it allows for easy replication of the wetland study and data collection. Data will be collected before the actual mesocosm to see how much phosphorus is settled out in the settling basin, and after the water leaves the mesocosm through the v-notch weir.

Alternative 1:

Only one detention basin preceded the mesocosms as shown in Figures 6, 7, 8 and 9. It was decided that one detention basin would not allow for proper mixing.

Alternative 2:

A mixing basin was attached to the detention basin preceding the mesocosms as shown in Figure 10.

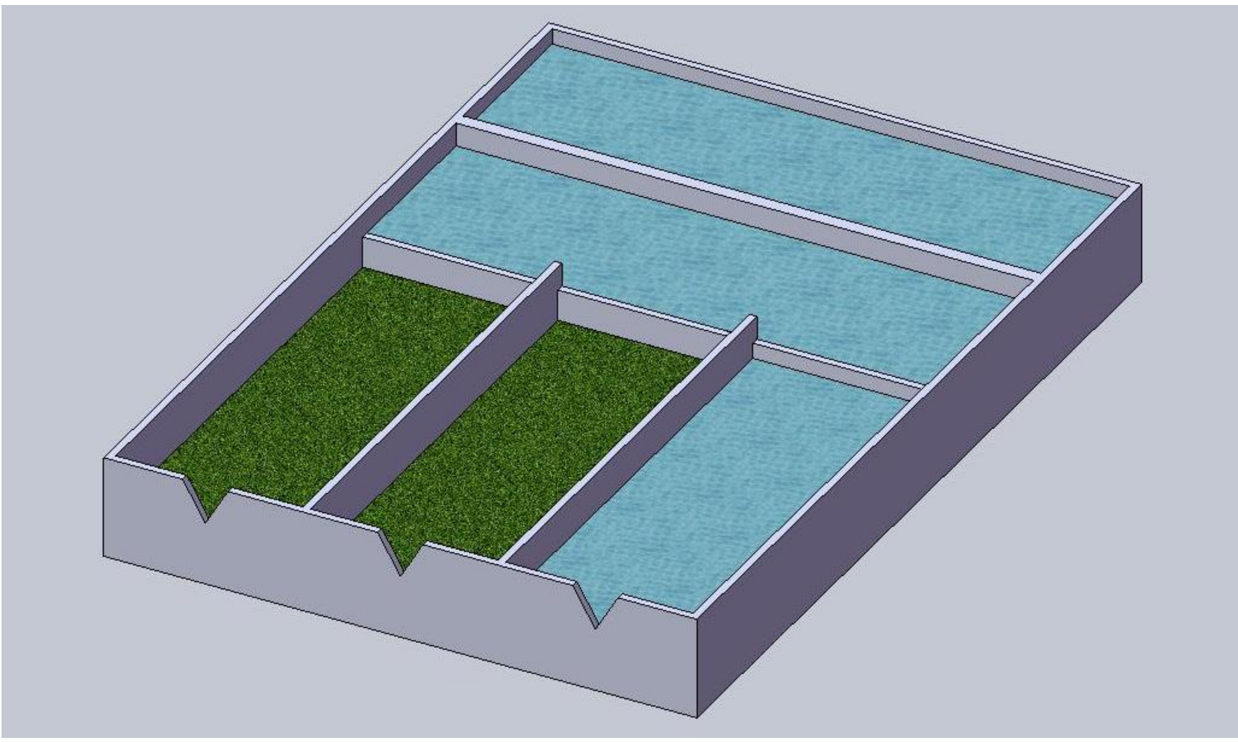


Figure 10. Current mesocosm structure design with three mesocosms (two vegetated wetlands, one detention basin), one settling tank, and one mixing tank.

This is the alternative that was chosen, because it would allow for proper mixing and settling with a mixing basin and a settling or detention basin.

Project Schedule

See Appendix 1C.

Proposed Budget for Testing

Business Operations		
Communication Campaign	$	550
Economics Campaign	$	600
Total		**$1,150**
Materials & Supplies		
3,000 gallon water tank	$	935
1375 gallon water tank	$	1,135
Sampling Supplies and Chemicals	$	700
Wetland Construction (pipes, troughs, plastic, etc)	$	2,000
Total		**$4,770**
Travel		
Haul Water (2 Loads)	$	1,100
Travel etc.	$	500
Total	**$**	**1,600**
Contractual Laboratory Expense		
OSU SWFAL Laboratory	$	8,000
Total		**$8,000**
Total		**$15,520**

The proposed budget is an indication of the cost *Scenic Solutions* will face throughout the duration of the wetland design project. Below is a detailed list of what each sector involves.

- The Communications Campaign covers the cost of two web sites, a public service radio announcement, a billboard ad replication, brochures and an educational video.
- The Economic Campaign covers the cost of a survey, which gathers information for measuring the values associated with a wetland. It also is a reflection of any research, studying and networking of benefit transfers and other materials.
- The Materials and Supplies category covers the cost for the Engineering Campaign of the wetland design project. The materials listed are for the mesocosm construction and study. There will be construction of six different mesocosm studies, which will have varying designs and cost. This figure is also a reflection of the materials and chemicals for the alum jar test studies.
- Travel Cost is to cover the trip to gather water out of the Illinois River to begin testing. There have been two budgeted trips for gathering water. The estimate for “Travel etc.” is for any extra trips that maybe needed for water, research, consulting, communication or site visits.
- The Constructional Laboratory Expense is for the cost of the alum jar test studies to be sent off to the OSU Soil, Water and Forage Analytical Lab.

Works Cited

Burnett, LeAnne. *State of Oklahoma, ex rel. W.A. Drew Edmondson v. Tyson Foods, Inc.: A Bird's Eye View.* Rep. Oklahoma City: Oklahoma Farm Bureau, 2009. *Poultry Litigation.* Web. 1 Dec 2009. http://www.okagpolicy.org/index.php?option=com_content&view =article&id=85:poultry-litigation &catid=44:animal-agriculture&Itemid=54.

Arkansas v. Oklahoma Environmetnal Protection Agency. 503 U.S. 91 Openjurist.org. U.S. Supreme Court. 26 Feb. 1992.

Storm, Daniel, George Sabbagh, Mark Gregory, Michael Smolen, Dale Toetz, David Gade, C. Tom Haan, Ted Kornecki. "Basinwide Pollution Inventory for the Illinois River Comprehensive Basin Management Plan." Submitted to the Oklahoma Conservation Commission, 1996.

Warren, Donald. "City of Tulsa v. Tyson Foods: CERCLA Come to the Farm-But Did Arranger Liability Come with it." *Arkansas Law Review* 59.169 (2003).

Patents

Beaulieu, Edgar. "Constructed Wetlands System, Treatment Apparatus and Method." US Patent 6,740,232. 25 May 2004.

DeBusk, Thomas. "Contaminant Removal Method for a Body of Water." US Patent 7,014,776. 21 Mar 2006.

Eifert, Walter. "Enhanced Subsurface Flow Constructed Wetland." US Patent 5,893,975. 13 Apr 1999.

Fulton, George. "Alum Recovery and Waste Disposal in Water Treatment." US Patent 3,959,133. 25 May 1976.

Jungmann, Ronald, et al. "Flow-Based Chemical Dispense System." US Patent 6,763,860. 20 Jul 2004.

Lichtwardt, Mark and David Sisneros. "Automated Chemical Metering System and Method." US Patent 5,902,749. 11 May 1999.

Wengrzynek, Robert. "Constructed Wetland to Control Nonpoint Source Pollution." US Patent 5,174,897. 29 Dec 1992.

Literature Review

Auvray, Franck, van Hullebusch, Eric D., Deluchat, Veronique, Baudu, Michel. "Laboratory investigation of phosphorus removal (SRP and TP) from eutrophic lake water treated with aluminium." Water Research 40 (2006) 2713-2719.

Black, Courtney A., Wise, William R. "Evaluation of past and potential phosphorus uptake at the Orlando Easterly Wetland." Ecological Engineering 21 (2003) 277-290.

Cooke, G. Dennis, Welch, Eugene B., Martin, Angela B., Fulmer, Donald G., Hyde, James B., Schrieve, Garin D. "Effectiveness of Al, Ca, and Fe salts for control of internal phosphorus loading in shallow and deep lakes." Hydrobiologia 253 (1993): 323-335.

Gebhardt, Karl, Ervin Cowley, Don Prichard, and Mike Stevenson. *Riparian and Weland Classification*. Technical Reference 1737-21. Denver: U.S. Department of Interior, 2005.

Lorion, Renee. *Constructed Wetlands: Passive Systems for Wastewater Treatment*. Rep.

Malecki-Brown, Lynette M., John R. White, and K. R. Reddy. "Soil Biogeochemical Characteristics Influenced by Alum Application in a Municipal Wastewater Treatment Weland." *Journal of Environmental Quality* 36 (2007): 1904-913.

Malecki-Brown, Lynette M., John R. White, and M. Sees. "Alum Application to Improve Water Quality in a Municipal Wastewater Treatment Wetland." *Journal of Environmental Quality* 38 (2009): 814-21.

Malecki-Brown, Lynette M., White, John R. "Effect of Aluminum-Containing Amendments on Phosphorus Sequestration of Wastewater Treatment Wetland Soil." Soil Science Society of America Journal 73 (2007): 852-861. Phoenix: National Network for Environmental Management Studies, 2001.

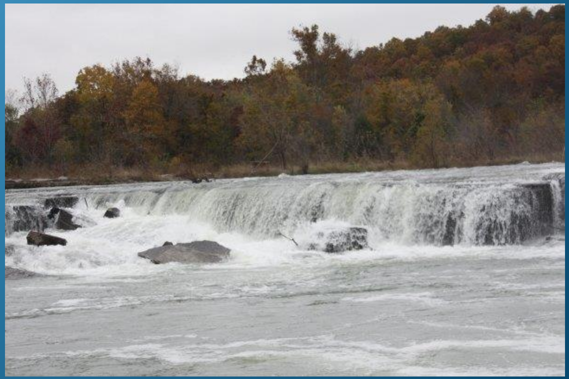
Welch, Eugene B., and Garin D. Schrieve. "Alum Treatment Effectiveness and Longevity in Shallow Lakes." *Hydrobiologia* 275/276 (1994): 423-31.

White, John R., Reddy, K. Ramesh, Moustafa, M. Z., "Influence of hydrologic regime and vegetation phosphorus retention in Everglades stormwater treatment area wetlands." Hydrological Processes 18 (2004) 343-355.

Zhao, Y. Q., Babtunde, A. O., Zhao, X. H. and Li, W. C. "Development of alum sludge-based constructed wetland: An innovative and cost effective system for wastewater treatment." Journal of Environmental Science and Health Part A, 44:8(2009): 827-832

Scenic Solutions

Rachel Carson Taber Midgley
Dell Farris Mattie Nutley
Karl Garbrecht Kevin Stunkel



Mattie Nutley, Dell Farris, Karl Garbrecht, Kevin Stunkel, Taber Midgley, and Rachel Carson

Agenda

- Problem Statement and Background
- Objectives and Scope of Project
- Communications Campaign
- Economic Analysis
- Proposed System and Engineering Analysis
- Project Schedule

Problem Statement

- Flowing from northwestern Arkansas into northeastern Oklahoma, the Illinois River has been a source of legal disputes for over a decade
- High phosphorous levels have caused the river and downstream lakes to become increasingly eutrophic
- The Illinois River has been declared a "Wild and Scenic River" by the state of Oklahoma, and with that designation comes a numerical criterion of 0.037 mg P/L.
- This level is not currently being met, and the United States Supreme Court has ruled the state of Arkansas must meet Oklahoma's water quality standards

Mission Statement

- Evaluate the effectiveness of a constructed wetland with an alum injection system to reduce phosphorus in the Illinois River

Prominent Court Cases

- Arkansas v. Oklahoma 1992 Supreme Court Ruling
  - Arkansas must meet Oklahoma water quality standards
- City of Tulsa v. Tyson Foods et al.
  - Settled out of court
  - Poultry Litter is considered a CERCLA Hazardous Substance
  - CERCLA liability judged on a ‘case by case’ basis
- Oklahoma v. Tyson Foods et al.
  - Attempting to hold poultry producers liable via CERCLA

Burnett, LeAnne. *State of Oklahoma, ex rel. W.A. Drew Edmondson v. Tyson Foods, Inc.: A Bird's Eye View*. Rep. Oklahoma City: Oklahoma Farm Bureau, 2009. *Poultry Litigation*. Web. 1 Dec. 2009. <http://www.okagpolicy.org/index.php?option=com_content&view=article&id=85:poultry-litigation&catid=44:animal-agriculture&Itemid=54>.

Arkansas v. Oklahoma Environmetnal Protection Agency. 503 U.S. 91 Openjurist.org. U.S. Supreme Court. 26 Feb. 1992.

Warren, Donald. "City of Tulsa v. Tyson Foods: CERCLA Come to the Farm-But Did Arranger Liability Come with it." *Arkansas Law Review* 59.169 (2003).

Lake Frances

- River crosses border at Watts, Oklahoma
- Potential site for wetland
- Dam was breached in 1992, but remnants of the structure hold back some water
- 500 acres of former lakebed exposed

Source: www.bing.com/maps

Lake Frances

- River crosses border at Watts, Oklahoma
- Potential site for wetland
- Dam was breached in 1992, but remnants of the structure hold back some water
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Source: www.bing.com/maps

Phosphorus in water

- Phosphorus takes three forms in water
  - Orthophosphate: mainly caused by wastewater and agricultural runoff. Readily available for plant use
  - Polyphosphate: found in detergents, usually transforms into orthophosphates in water
  - Organically bound phosphate: already tied up in organic matter, but can become available to plant growth

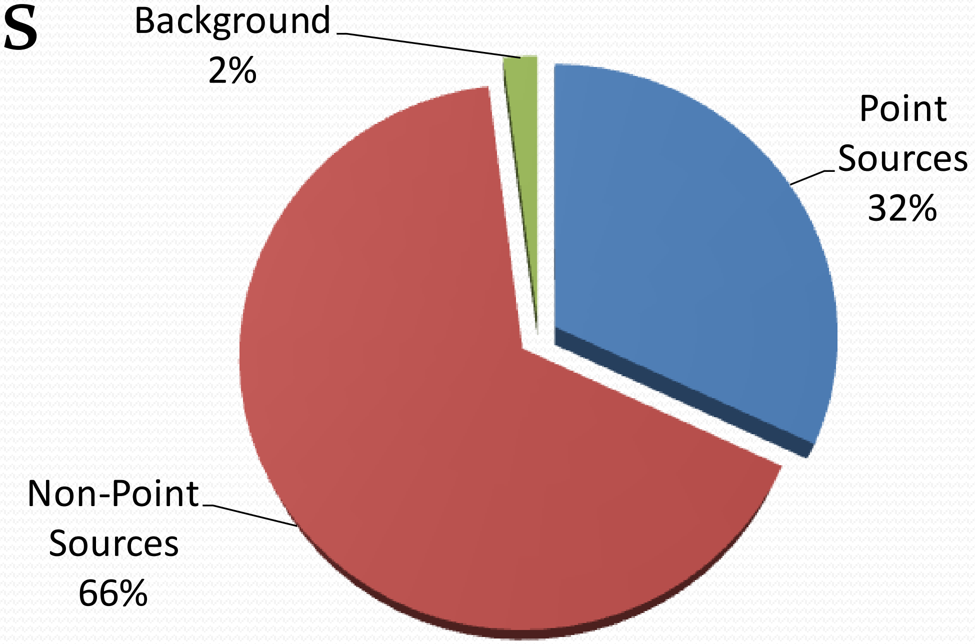
Eutrophication

- Eutrophication occurs when too many nutrients are present
- Increases growth of algae and plants, but decreases biodiversity
- Causes algal blooms, fish kills and drops in water quality
- Nitrogen and Phosphorus are main causes

macalester.edu

Sources of Phosphorus in the Illinois River

- Most phosphorus enters the river in two ways, point and non-point pollution sources



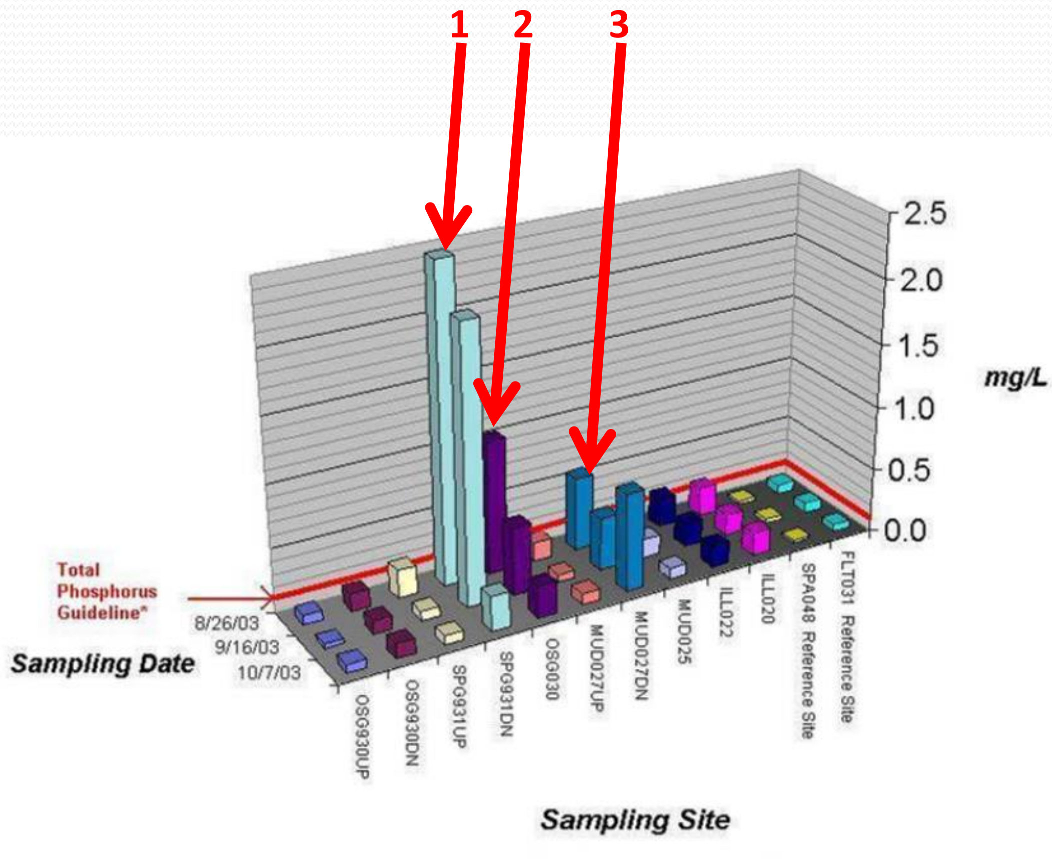
Storm, 1996

Point Sources

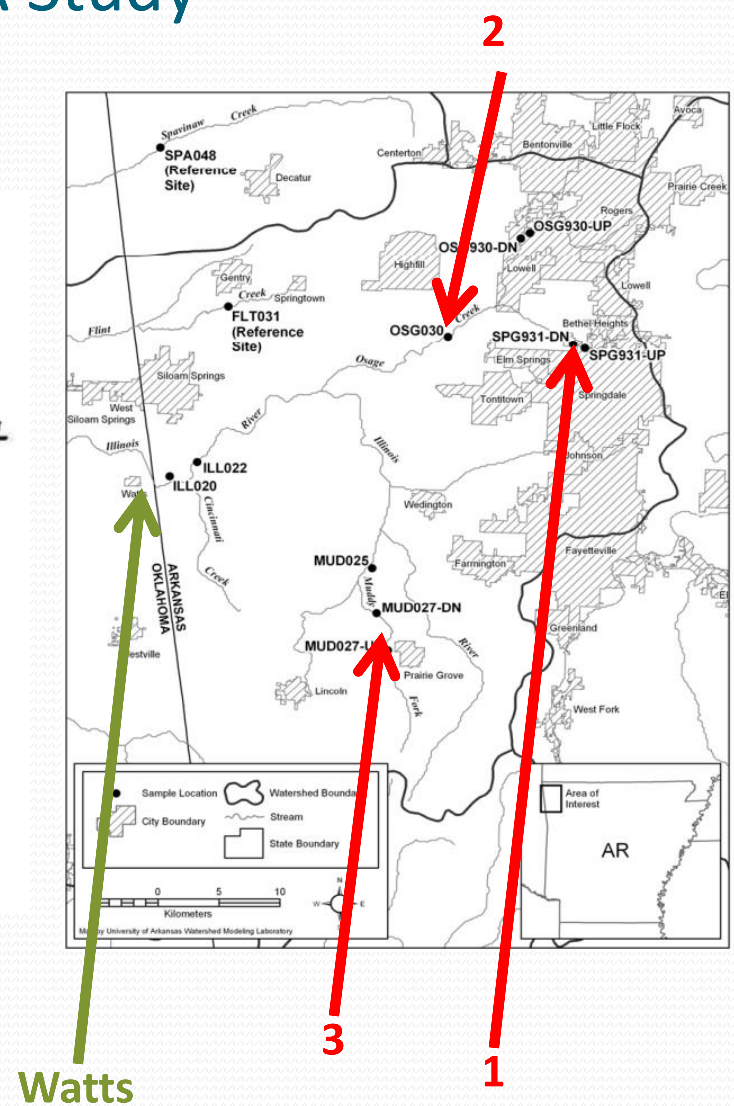
- Mostly Waste Water Treatment Plants
- Nearly constant and effects mostly base flow phosphorus concentrations
- 32% of Phosphorus comes from these sources (Storm, 1996)

Source: accessfayetteville.org

Point Sources- 2003 Base Flow EPA Study

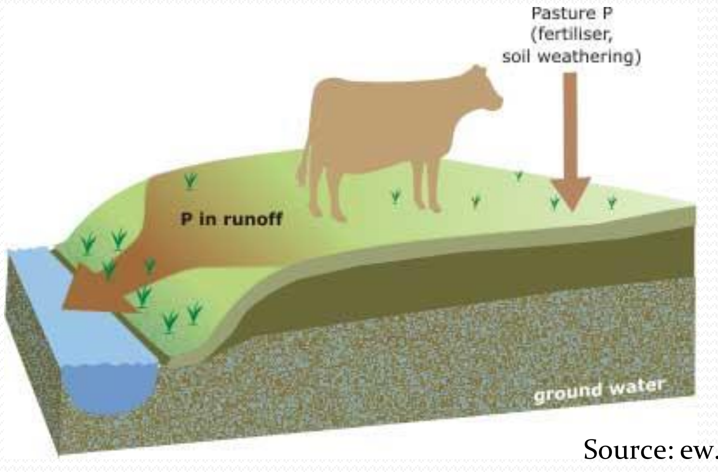


Source: http://www.epa.gov/region6/water/ecopro/watershd/monitrng/studies/ill_kings_finrpt.pdf



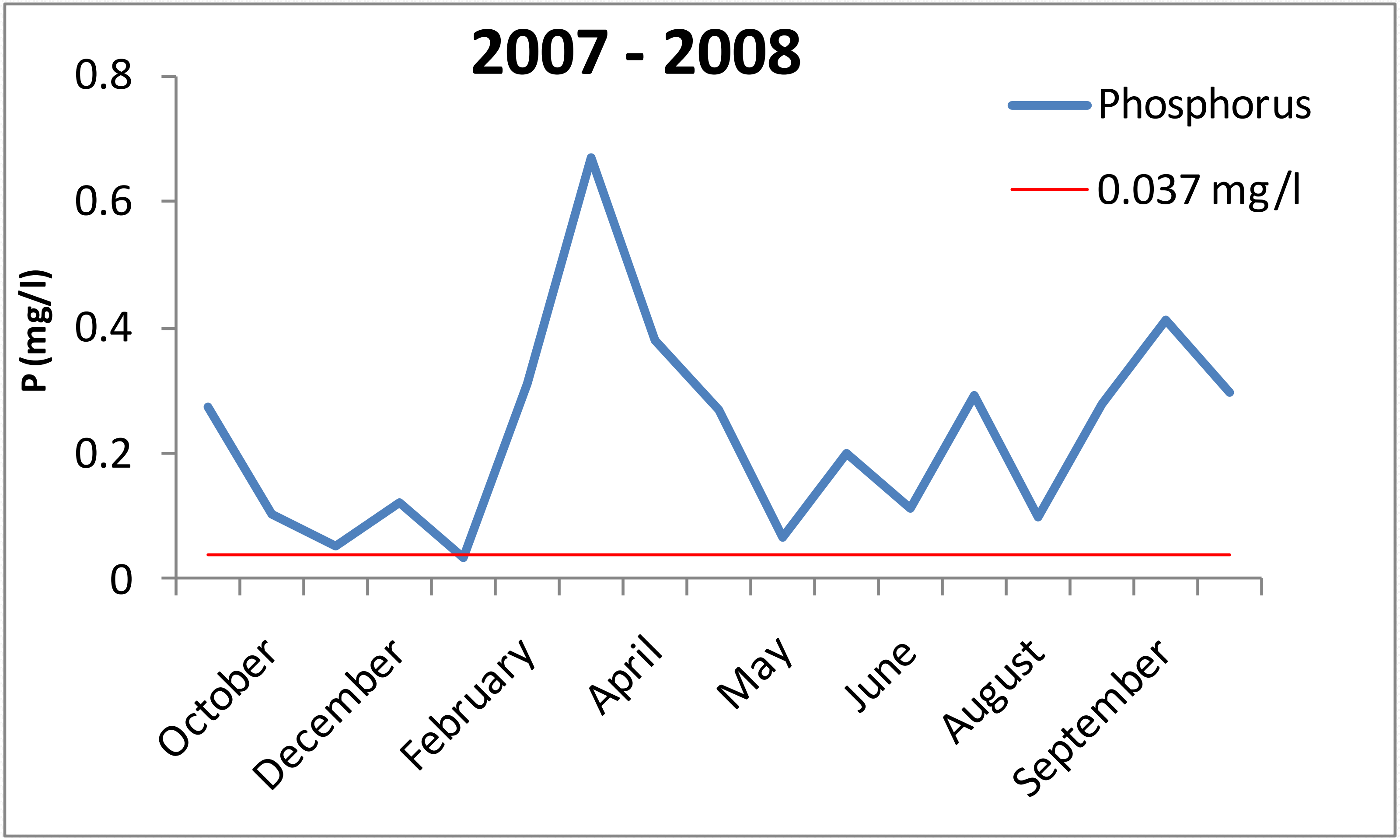
Non-Point Sources

- Non-points sources are storm run-off and effect high flow
- Pollutants from cities and agricultural fields are washed into rivers and streams
- 66% of Phosphorus is from these sources (Storm, 1996)



Source: ew.govt.nz

Phosphorous levels near Watts, OK



Source: usgs.gov

Objectives

- Evaluate the applicability and effectiveness of an integrated chemical injection and wetland system to remove phosphorus from the Illinois River
- The communications objective is to educate audiences on the background of the Illinois River and how the high level of phosphorus in the water will be damaging to aquatic wildlife in the river if not properly managed
- The economic objective is to evaluate the public good and categorical uses of the alternatives to construct a wetland in which the benefits exceed the cost

Joint Project

- Scenic Solutions teamed with a University of Arkansas Senior Design team
- Focus of OSU Team- High flow phosphorus from non-point sources
- Focus to U of A Team- Point source phosphorus from WWTP
- With the efforts of both teams, the final solution will address both sources of phosphorus

Scope of project

- Run jar tests to compare alum injection concentrations to flocculent settling times and efficiencies for dissolved phosphorus and sediment
- Construct a chemical injection system coupled with a wetland mesocosm to quantify phosphorous removal
- Distribute findings to local authorities in order to facilitate data driven decisions regarding the most appropriate approach to attenuating phosphorous in the Illinois River

Site Visit

- Lake Francis/Illinois River
- Collected water samples to use in jar tests

- Also visited a Waste Water Treatment Plant in Fayetteville, AR and met with U of A student group

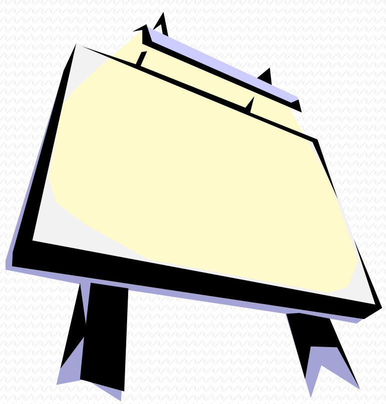
Audience

- Recreational users of the river
  - boating
  - camping
  - fishing
- Farmers
- Residents near Lake Tenkiller and Illinois River
- General public

Proposed materials

- Website
  - Team website
  - Educational website
- YouTube video
- Public service announcement
- Brochure
- Billboard

Source: www.youtube.com



Team Website

Scenic Solutions

Meet the team

Background

Our purpose

Home

Welcome,
Scenic Solutions is a group of students at Oklahoma State University that is focused on producing an optimum wetland design to reduce phosophorus levels in the Illinois River near Watts, Oklahoma. Design aspects include engineering, economic and marketing development. The group consists of six senior design students.

Business Plan

- Create a wetland design that removes the phosphorus below the state of Oklahoma standards
- Be effective and cost worthy
- Provide high-quality public good and valuable uses
- Benefits exceed the cost

Economic Study

- Compare the new phosphorus levels of the various wetland designs verse the designing and construction cost of the wetlands
- Evaluate how the five categorical uses are affected
  - Ecological, Industrial, Municipal, Recreational and Irrigational
- Evaluate how the public good is affected
- Evaluate of the alternatives of different designs
- Determine if the benefits exceed the cost

Economic Study

- Through Surveys and Benefit Transfer Research
  - Estimate the value of the benefits
    - The Total Willingness To Pay
      - TWTP= Use Value + Option Value + Nonuse Value
    - Travel Cost
  - Estimate the value of the cost
    - Engineering, construction, permitting
      - machinery value, labor value, and maintenance cost

Project Budget

Business Operations	
Communications Campaign	$550
Economics Campaign	$600
Materials & Supplies	
3,000 gallon water tank	$935
1,375 gallon water tank	$1,135
Sampling Supplies and Chemicals	$700
Wetland Mesocosm Construction	$2,000
Travel	
Water Hauling	$1,100
Travel etc.	$500
Contractual Laboratory Expense	
OSU SWFAL Laboratory	$8,000
Total	**$15,520**

Project Budget

- Communications Campaign
  - Two web sites, public service radio announcement, a billboard ad replication, brochures and an educational video
- The Cost Benefit Analysis
  - Survey, research and study of benefit transfers and other materials

Engineering Campaign

- Materials and Supplies
  - Mesocosm construction and study
- Travel Cost
  - Water hauling and consulting trips
- Constructional Laboratory Expense
  - Research by the OSU Soil, Water and Forage Analytical Lab

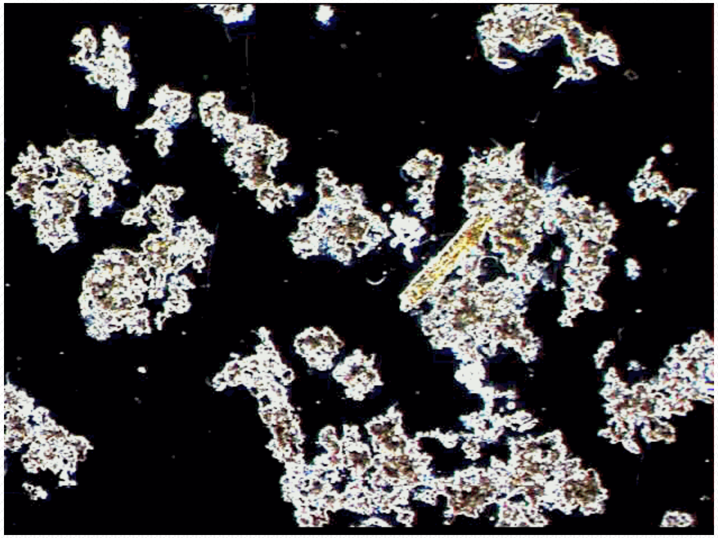
Alum

- Alum is Aluminum Sulfate, $Al_2(SO_4)_3$
- Forms several different hydrates, from $Al_2(SO_4)_3{\cdot}18H_2o$ to $Al_2(SO_4)_3{\cdot}5H_2o$
- Is well studied and has been used in wastewater treatment for years

jzaefk.com

Alum removal mechanisms

- When added to water alum forms snowflake like particles called flocs
- Flocs attract particles out of solution, causing them to get heavy and sink at faster rates
- Alum flocs pull Phosphorus out of the water where it can't be used by plants or algae



wvetc.org

Jar Tests

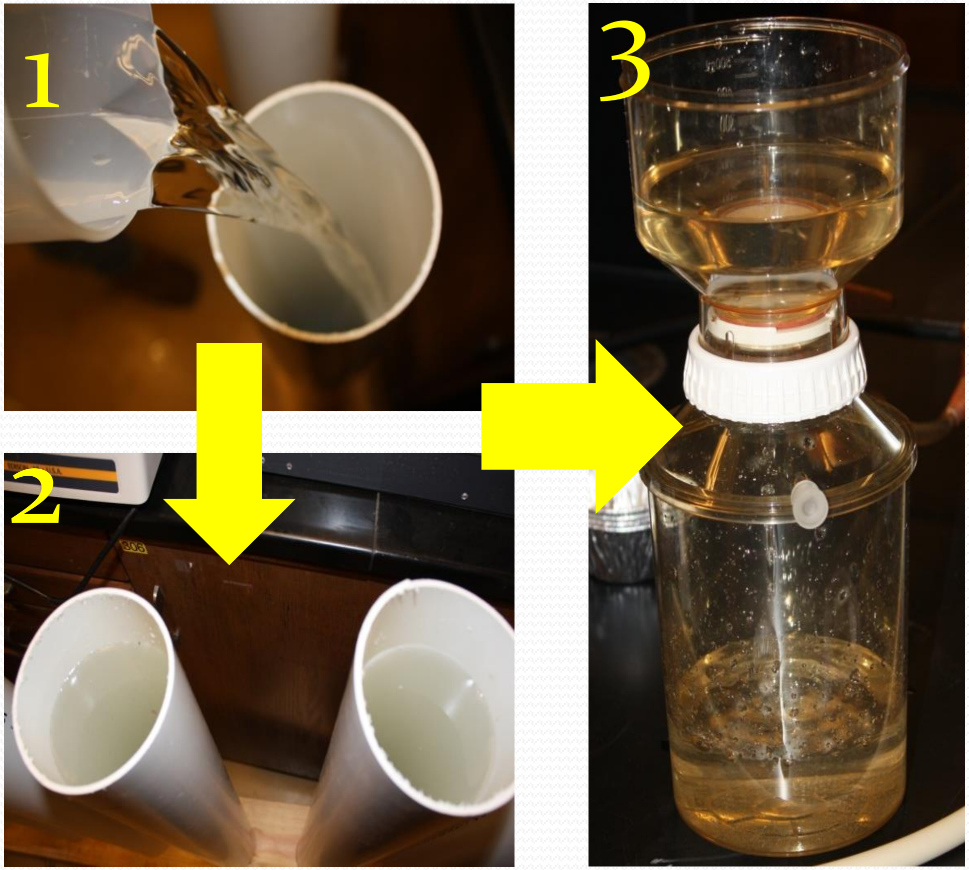
- Ran a series of “jar tests” to determine the effective alum dosage
- Test for phosphorus removal efficiencies as well as settling times
- Ensure there is no over-dosing, which will limit costs

Jar test procedures

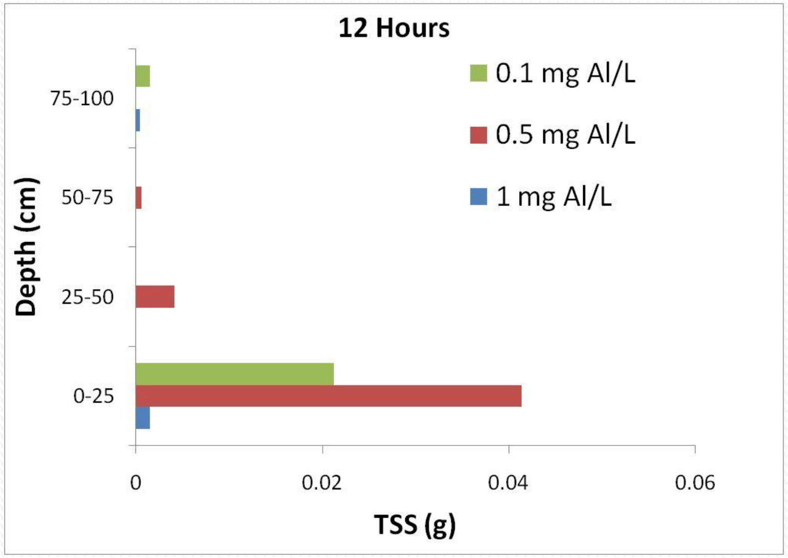
1. Mix alum and collected water samples in jars

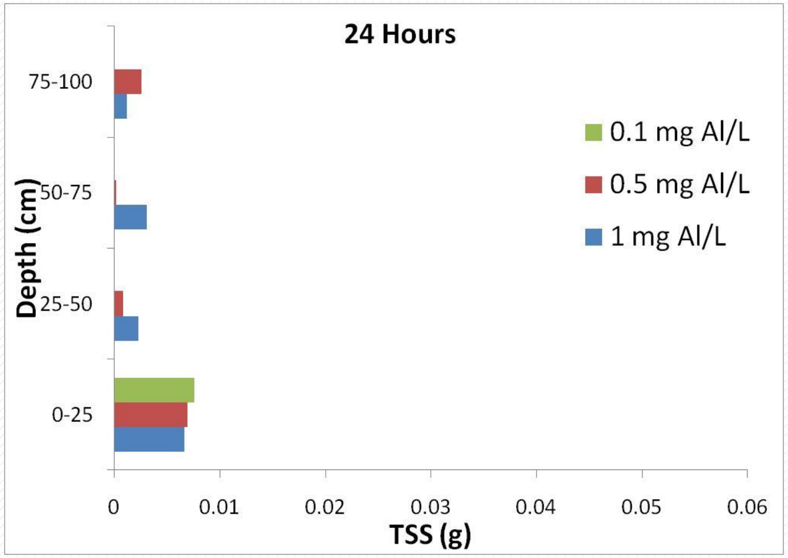
2. Allow flocs to settle

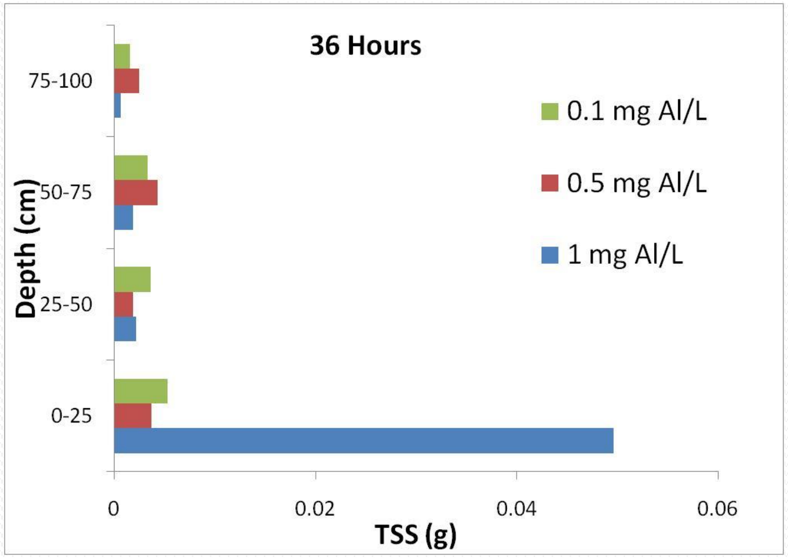
3. Filter solids from solution

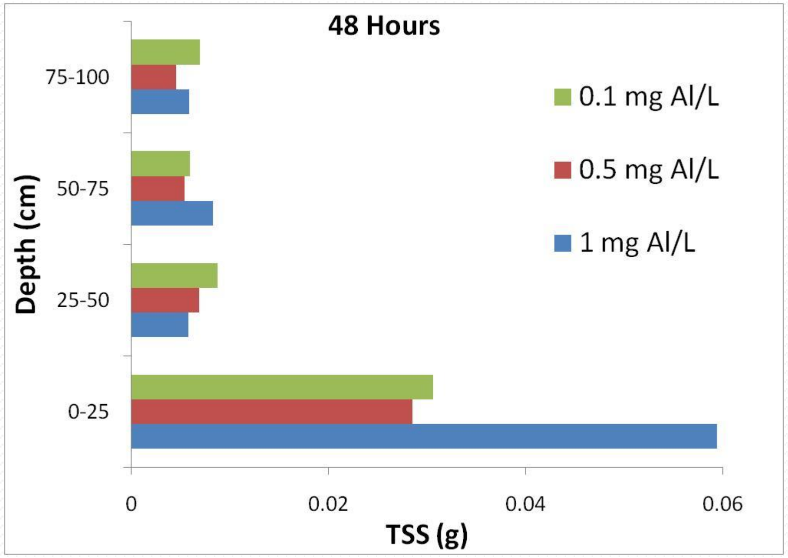


Jar Test TSS Results

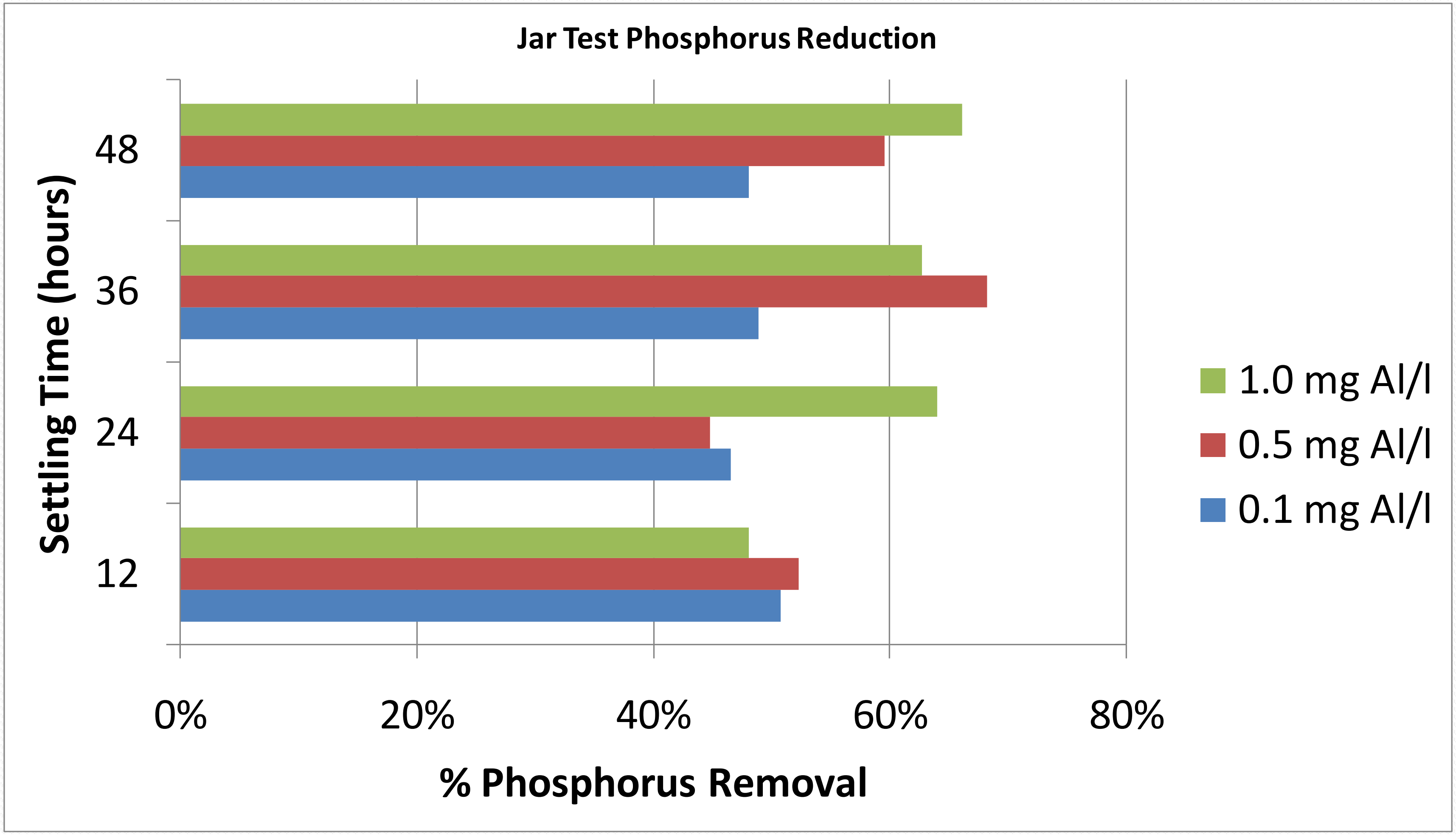






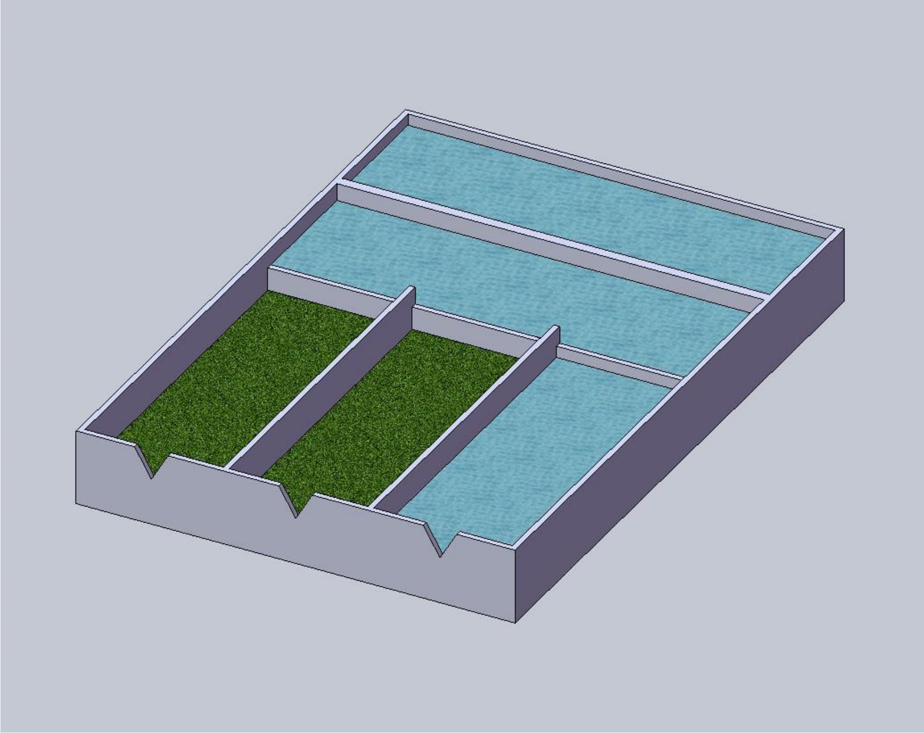


Jar Test Phosphorus Results



Mesocosm Study

- Two different scenarios will be tested
- 10” of soil with plants
- Detention basin with
  no soil



Plants

- Removal mechanisms:
  - Large particle filtration
  - Attachment sites for microorganisms and algae
  - Increasing soil sorption capacity

http://www.bissettnursery.com/Nursery/Images/Aquatic/cattail-narrow-leaf.jpg

Plants

- Narrow Leaf cattail (*Typha angustifolia*)
  - Native to Lake Frances area
  - Low maintenance
  - Easily Established

http://www.bissettnursery.com/Nursery/Images/Aquatic/cattail-narrow-leaf.jpg

Soil

- Removal mechanism in soil:
  - Adsorption
  - Filtration
  - Microbial assimilation
- Soil from Lake Frances' bed will be used to mimic site conditions as closely as possible

Detention Basin

- Allow for absolute comparison
- Isolates effect of settling without the influence of other processes

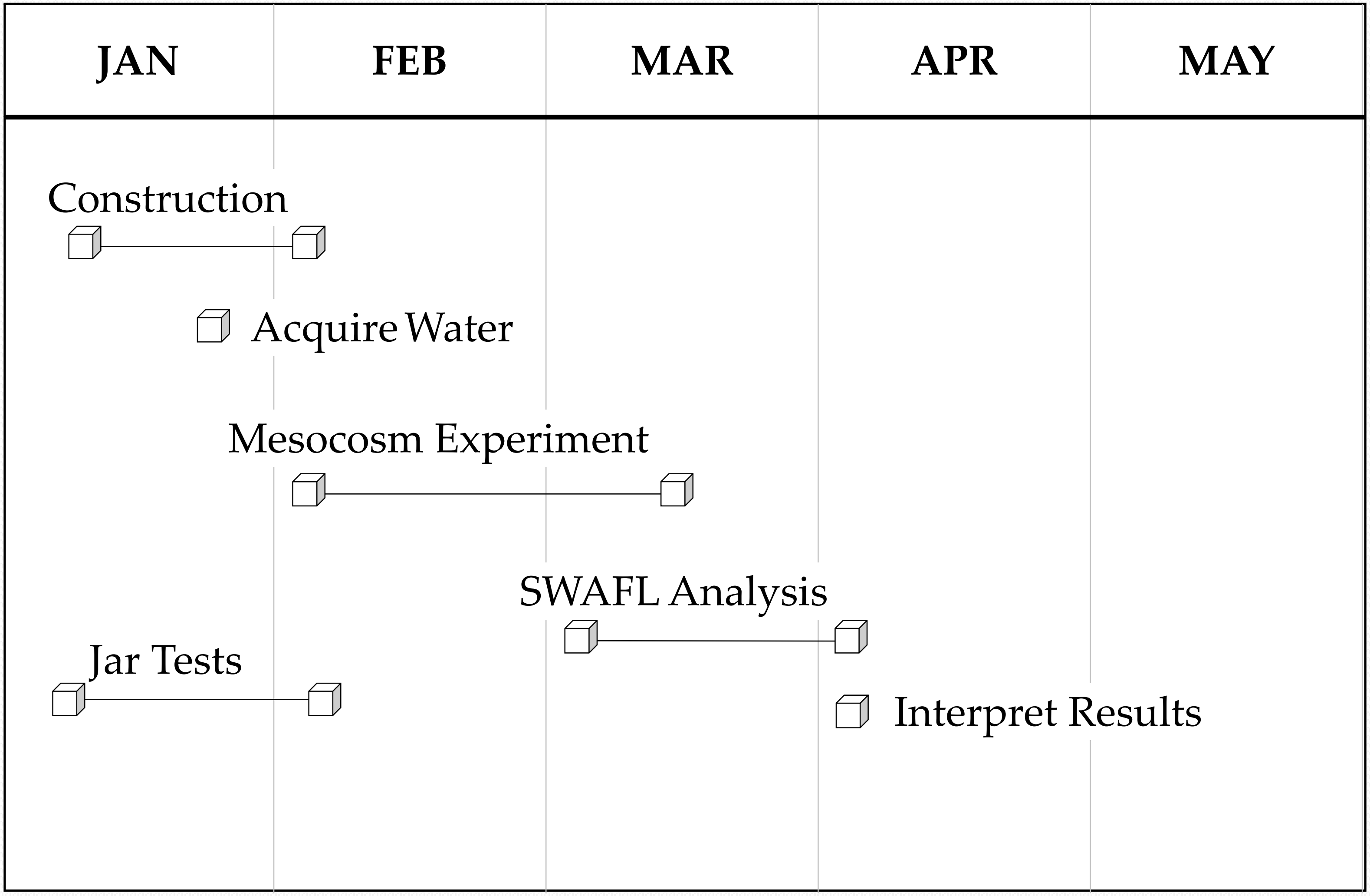
Engineering Tasks Completed

- Literature Review
- Patent Search
- Designed experimental jar test runs
- Preliminary design for mesocosm structure
- Completed initial jar tests
- Purchased tanks
- Purchased greenhouse lights
- Designed experimental flow regime for mesocosm experiment
- Analyze phosphorus data from jar tests

Tasks to be completed before next semester

- Collect plants from local pond
- Setup greenhouse to bring plants out of dormancy during break
- Finish dimensioning and scaling of mesocosm structure
- Consult with Wayne about mesocosm structure construction

Gantt Chart


JAN
FEB
MAR
APR
MAY
Construction
Acquire Water
Mesocosm Experiment
SWAFL Analysis
Jar Tests
Interpret Results

Acknowledgements

- Dr. Daniel Storm
- Steve Patterson
- Dr. Tracy Boyer
- Dr. Damian Adams
- Innovations Instructors