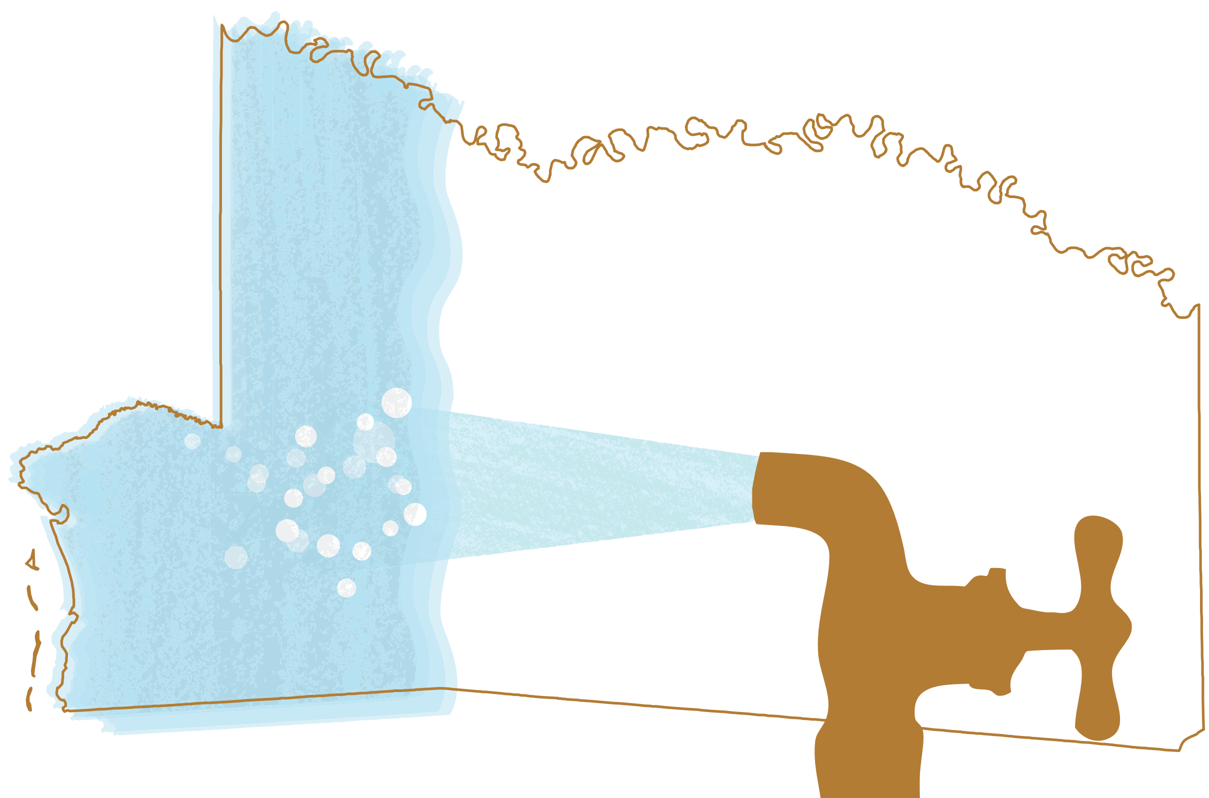
2013

Mississippi Water Resources Conference

Jackson Hilton

Jackson, MS



2013

Mississippi Water Resources Conference

Hilton Jackson | Jackson, MS

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Florence & Hutcheson Inc.
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Effects of Low-grade weir on hydraulic patterns of agricultural run-off in the Mississippi Delta

Brison, A.; Poganski, B.; Kröger, R.

Agricultural best management practices, in the form of low-grade weirs, have demonstrated the ability to mitigate nutrient and sediment loads to downstream aquatic systems. In a recent study, investigations of impacts of artificial low-grade weirs implemented in drainage ditches reported increased hydraulic residence times, an essential component to enhance nutrient reduction. However, research on the success of weirs is currently limited to controlled experiments rather than naturally occurring storm event conditions. This research investigated the effect of low-grade weirs on hydraulic residence time in several agricultural drainage ditches in the Mississippi Delta. Effects of low-grade weirs was assessed by comparing means of storm events and precipitation totals of varying magnitude within drainage ditches between pre- and post- weir implementation. Preliminary results suggest significantly shorter time to peak values between storm events pre- and post-weir implementation ($K=11.522$; $p<0.05$; Kruskal-Wallis) and longer time to base ($K=18.566$; $p<0.05$). No significant difference was found between pre-and post- weir time to maximum peak height ($K=9.334$; $p>0.05$; Kruskal-Wallis). Further research should account for variable physical dimensions, drainage area of each drainage ditch, and the number and spatial arrangement of weirs implemented to understand how weirs impact hydraulic patterns of drainage.

Development and Application of Numerical Models to Environmental Hydraulics

Chao, X.; Zhu, T.; Jia, Y.; Altinakar, M.

Frequent natural and human activity induced disasters are influencing and degrading our water resources. To prevent and mitigate the damages that these disasters bring to our society in terms of water resources and eco-environmental quality, social and human welfare, life and property losses, and economic development, more effective and robust water resource management plans are necessary. The efforts of developing better research design and management tools have led to rapid advances in numerical modeling and computational simulation methodologies in parallel to the rapidly advancing computer technology. Computational models are effective and efficient tools that can be applied to study surface water flows, contaminant transport and environment impacts. Numerical models, CCHE2D and CCHE3D, developed at the National Center for Computational Hydroscience and Engineering of the University of Mississippi, have been applied to simulate the flow, sediment transport, pollutant distribution and water quality in natural water bodies. This paper briefly describes the CCHE2D & 3D models and demonstrate their capabilities by presenting the results of several study cases, including an oxbow lake in Mississippi, where water quality was degraded by excessive agro-chemicals, a hypothetical chemical spill case in a large lake in Mississippi, a salinity intrusion case in Lake Pontchartrain, LA, and hypothetical impact of radioactive chemicals to water quality in Kerr Reservoir and Lake Gaston, VA. The simulation results were validated using field measurements.

Detection and mapping of cyanobacterial harmful algal blooms using satellite data in one Louisiana lake and four Mississippi lakes

Dash, P.

Cyanobacteria represent the major harmful algal group in fresh to brackish water environments. Cyanobacterial blooms are aesthetically undesirable since they discolor the water, cause turbidity in recreational facilities and synthesize a large number of low molecular weight compounds which cause taste and odor problems. Of particular concern are a diverse range of toxins produced by cyanobacteria, termed cyanotoxins, which are hazardous to human, animal and aquatic ecosystem health. Recently, a procedure was developed to estimate cyanobacterial concentrations by quantifying chlorophyll a (Chl a) and the primary cyanobacterial pigment phycocyanin (PC) using OCM satellite data over a small lake- Lac des Allemands in Louisiana, USA. This required the development of an atmospheric correction and vicarious calibration methodology for satellite data. Empirical inversion algorithms were developed to convert the OCM Rrs at bands centered at 510.6 and 556.4 nm to concentrations of PC. For the algorithms to be uniformly valid over all areas (or all bio-optical regimes) of the lake, a holistic approach was developed to minimize the influence of other optically active constituents. Similarly, empirical algorithms to estimate Chl a concentrations were developed using OCM bands centered at 556.4 and 669 nm. The best PC algorithm (R^2=0.7450, p<0.0001, n=72) yielded a root mean square error (RMSE) of 36.92 μ g/L (PC from 2.75 to 363.5 μg/L, n=48). The best algorithm for Chl a (R^2=0.7510, p<0.0001) produced an RMSE of 31.19 μ g/L (Chl a from 9.46 to 212.7 μ g/L, n=48). The results demonstrated the preliminary success of using OCM satellite data to map cyanobacterial blooms in a small lake in Louisiana. In the summer of 2012, five field campaigns were undertaken to four large Mississippi lakes- Lakes Sardis, Enid, Grenada, and the Ross Barnett reservoir in order to obtain a database of photosynthetic pigment concentrations and phytoplankton composition. The objective of this project is to combine multiple satellite data from several sensors such as VIIRS, MODIS AQUA and OCM-2, and developed techniques to quantify cyanobacteria in these four large Mississippi lakes and make the mapped images available through a website for use by water quality managers and general public to rapidly obtain synoptic information on cyanobacterial blooms. Time-series of true color satellite images clearly show the presence of algal blooms. Preliminary analyses of the field data analyzed thus far demonstrate the presence of numerous toxic species of cyanobacteria in these lakes. Preliminary results from this project will be presented.

Factors associated with fate and cycling of nitrogen species in agricultural drainage ditches with implementation of low-grade weirs

Faust, D.; Kröger, R.

The overall objective of this study is to examine factors that may affect the fate and cycling of nitrogen species in agricultural drainage ditches with low-grade weirs installed. Emphasis will be on factors and processes that remove nitrogen from these ecosystems. Particular attention will be paid to factors that have been demonstrated to affect denitrification, as this process results in permanent removal of nitrogen from ecosystems. Three factors that have consistently been implicated in affecting denitrification are nitrate concentration, organic carbon availability, and oxidation-reduction potential. These three factors are the focus under of three specific objective to evaluate effects of these factors on nitrate removal and denitrification potential in sediment pore and overlying water in agricultural drainage ditches. Specific objectives are: 1) Water and sediment samples obtained from ditches at Spruill Farm (Belzoni, MS) will be used in laboratory experiments to determine if organic carbon availability is limiting denitrification potential and whether dissolved or particulate organic carbon is more suitable for denitrification; 2) Results from laboratory experiments will inform conditions used for simulated storm events in experimental v-ditch systems at Mississippi State University's South Farm Aquaculture Facility; 3) Effects of nitrate concentrations, organic carbon availability, and oxidation-reduction potential of sediment pore water and overlying water on nitrogen removal in agricultural drainage ditches at Spruill Farm will then be examined. In addition to best management practices already in use, results from these studies will allow for recommendations to enhance nitrogen removal in agricultural drainage ditch systems.

Evaluating the Variability of Sediment and Nutrient Loading from Crop and Cattle Fields Located in North Mississippi

Guzman, S.; Salazar, G.; Diaz-Ramirez, J.; Schauwecker, T.

Excess nutrients are known as a primary problem facing Gulf of Mexico estuaries and coastal waters, leading to nuisance algal blooms, depletion of dissolved oxygen, and other water quality impairments. Soil and nutrient losses encourage siltation and eutrophication in Gulf of Mexico waters. Soil and nutrient exported from agricultural fields into water bodies in Mississippi is a major environmental concern by local, state, and federal agencies. This poster presents runoff and sediment & nutrient loads from two fields in north Mississippi: a 8.4-ha cattle drainage area located on the agricultural research property of the Mississippi Agriculture and Forestry Experiment Station (MAFES), adjacent to Mississippi State University (MSU); and a 11.3-ha crop drainage area located in Leflore County. The cattle field is monitored since 2011 by researchers from MSU Departments of Civil & Environmental Engineering and Landscape Architecture. At the outlet of the cattle field, MSU researchers are using a pressure transducer and automatic sampler to monitoring water depth and water quality, respectively. Field data (discharge and sediments & nutrient concentrations) from the crop drainage area were collected by the U.S Geological Survey from 1996 to 1999. The goal of this research is quantify sediment and nutrient loads by storm events yielded from fields managed with crops (soybeans and cotton) and beef production grazing pasture. Currently, we are computing and analyzing sediment and nutrient loads by storm events and planning to show results at the conference.

Occurrence and removal of pharmaceuticals and personal care products in different wastewater plants in Mississippi

Kwon, J.; Brown, A.; Rodriguez, J.

Residues of pharmaceuticals and personal care products (PPCPs) have been detected in surface waters. It is well known that effluent from wastewater treatment plants (WWTPs) is a major source of contamination of PPCPs in surface waters. The most frequently detected and toxic PPCPs, according to peer-reviewed articles published in the USA, are carbamazepine, sulfamethoxazole, gemfibrozil, and galaxolide. Three wastewater treatment plants (A, B, and C) in Mississippi, with different treatment technologies, were selected. Influent (law water) and effluent (treated water) were sampled from the three WWTPs over the course of one year. Up-stream and downstream samples of the WWTPs were also collected. All the four PPCPs were detected in all influents, with galaxolide and sulfamethoxazole showing the highest concentrations of 4,020 ng/L and 3,905 ng/L, respectively while carbamazepine was detected at the lowest levels (66-348 ng/L). All the PPCPs were detected in all effluents except sulfamethoxazole. Different PPCPs were removed to different extent in the WWTPs, varying from -99% to 100%. Carbamazepine showed the lowest removal (-99% to 30%) and gemfibrozil showed the highest (73% to 100%) in the WWTPs. WWTP A gave lower removal rates than WWTPs B and C for sulfamethoxazole. WWTP A showed higher removal rates than WWTPs B and C for galaxolide. Comparing the concentrations of upstream PPCPs to the downstream, there is an apparent increase in concentrations.

Efficacy of Innovative Surface Water Capture and Irrigation Re-use Technologies as a Best Management Practice: A Multi-seasonal Assessment in the Mississippi Delta Region

Omer, A.; Kröger, R.

The Mississippi Alluvial Valley is the center for agricultural crop production in the Southeast United States. The necessity for irrigation to maintain maximum yields has led to increased pressure placed on the Mississippi Alluvial Aquifer resulting in a negative balance. As a method of water management, surface water capture and irrigation re-use systems are being implemented into agriculture systems in Mississippi. However, the environmental and economic benefits of these systems have yet to be described and quantified. The main objective of this research is to describe and quantify the potential benefits of surface water capture and irrigation re-use systems for water resource conservation. Four sites located in the Mississippi Delta Region which utilize water capture and irrigation re-use systems will be assessed by monitoring: pumping schedules of re-lift stations, water level of on-farm storage reservoirs and flows of surface water irrigation pumps through irrigation meters. This data will be compared to systems using strictly ground water to understand water saving differences. Three years of data will be used to quantify a water savings budget and assess at a regional scale the contributions of surface water capture to decrease ground water withdrawals. The water savings budget in addition to the potential energy savings will be combined to provide an economic analysis of water capture and irrigation re-use systems. The results of this research will be used to create an economic analysis to provide valuable outreach material for dissemination to Mississippi producers. This potentially will lead to further implementation of water capture and irrigation re-use systems throughout Mississippi.

Rivers and Community Engagement. Regulatory Frameworks and Practices in Europe and USA

Pappalardo, G.

Environmental regeneration is not just a matter of natural science. Laypersons, different stakeholders, associations such as NGOs are crucial actors in managing ecosystems, at the grassroots level as well as at the institutional level. Gunderson, Holland et al (1995) describe the relationship between human organizational structures and nature, underlying how Sustainable Development is a process related to Social Learning. Even if the expressions Sustainable Development and Social Learning may have ambiguous meanings related to every different context, it is possible to find some similar issues at the global scale. The U.N. Rio Declaration on Environment and Development (1992) and its updated version Rio+20 show an arising awareness about the crucial role of local communities in taking care of the environment. Moreover, the Nobel Prize in Economic Science Elinor Ostrom (1991) proves the importance of collaborative practices and institutional reframing in order to overcome the Tragedy of the Commons (Hardin 1968).

This paper is aimed at describing and characterizing the process of Community Engagement in watershed management in Europe and USA. First, a critical review of the regulatory frameworks is examined, in order to explain similarities and differences between these two contexts. In Europe, the Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters (1998) is a milestone on the topic; then, the European Landscape Convention (2000) explains the strong relationship among physical heritage, cultural dimensions and inhabitants' perceptions. Furthermore, the specific Directive in matter of Water (2000/60/EC) is based on the same principles, i.e. broad involvement of the general public and different stakeholders, with different knowledge, values, interests and future perspectives. In U.S.A. the Environmental Protection Agency, with the Clean Water Act (1972) and 40 years of implementation phases, is moving the discussion toward a broader dissemination of participatory practices (Sirianni 2006).

After a comparative analysis of the aforementioned regulations, a multiple case-study research is discussed in order to understand in practice what is engagement, how is it related to watershed management, which are different paradigms and types of community involvement. The cases are selected according to the following characteristics: engagement as an opportunity to define a common vision for the future, starting from history and values of every context; engagement as a way to promote education and responsible behaviors in managing the water; engagement as a moment of dialogue amongst all community members. The outcome of the research is a typology that may operate as a guide in organizing communities that wish to manage ecosystems in a proactive and adaptive way.

Support for a Northeast MS Regional Water Management Plan: Updating the Water Budget for the Tombigbee River Basin

Ramirez-Avila, J.; McAnally III, W.; Tagert, M.

Researchers from Mississippi State University (MSU) are providing assistance to organize and draft a water management plan for selected northeast Mississippi counties, in the context of an overall basin plan, with the guidance and support of the Tennessee River Valley Water Management District (TRVWMD) and its stakeholders. Updating the MSU water budget for the Tombigbee River Basin developed by McKey and McAnally in 2008 is one of the main tasks included in the statement of work for the study in performance. Research activities to complete the proposed task involves the consecution of new information on withdrawals and discharges; the use of hydrologic calculations to fill in gaps of ungaged streams in the basin and identify potential extreme flows; and the statistical analysis of flow data for use in a risk analysis of extreme flows.

Water Resources Protection & Mamagement

Water Resources Protection and Management

Jason Barrett *(Mississippi State University)*	An assessment of private wells used for drinking water in Mississippi
Jamie Crawford *(Mississippi Department of Environmental Quality)*	Source water protection in Mississippi: Just plugging away
Natalie Sigsby *(Mississippi Department of Environmental Quality)*	Integrated desalination and wastewater treatment systems

An Assessment of Private Wells Used for Drinking Water in Mississippi

Barrett, J.

The majority of Mississippians enjoy access to one of the 1200 public water systems in Mississippi. Having access to a public water system provides the citizens with safety and quality of water through the regulatory enforcement of the Mississippi State Department of Health-Bureau of Public Water Supply (MSDH). Mississippi citizens on private wells do not have the luxury of knowing the quality and/or quantity of their water on a regular basis. In this presentation, by comparison of United States Census Data and MSDH data, the areas of Mississippi that have the highest concentrations of citizens on private wells will be derived. Data will be gathered to determine the likely contaminants to private wells in each particular county. This information will highlight the areas that could benefit the greatest from avenues in which private well owners can check the quality of their water as well as inform the surrounding water systems of their capacity to expand.

Source water protection in Mississippi: Just plugging away

Crawford, J.; Payne, M.

Most of the 3,000 public water system (PWS) wells operating in Mississippi are screened in deep confined aquifers, often overlain with multiple confining layers. Due to this favorable hydrogeologic setting, incidences of groundwater contamination impacting PWSs have not been widely reported in Mississippi. State source water protection efforts have mainly focused on addressing abandoned wells identified in delineated protection areas that may serve as potential conduits for the introduction of contaminants. Unfortunately, the success of these past efforts has been limited due to the sizeable number of abandoned wells in need of plugging and the lack of available funding to help offset the prohibitive cost associated with meeting state regulations.

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The well decommissioning program process began with MSDH’s selection of a licensed water well contractor to perform the actual plugging. Accompanying this phase was the decision to contract with MsRWA to coordinate the well abandonment procedure and to assist in prioritizing the plugging of over 200 wells identified thus far. Eleven wells considered moderate risks to contamination (as determined by SWAP) and 13 higher ranked wells have been properly decommissioned and fully funded by the program during 2012. Future plans are to maintain the well decommissioning program provided EPA continues to receive funding from Congress for the capitalization grant.

Mississippi's Dam Safety Program

Sigsby, N.; Myers, D.

Created in 1978, the Mississippi Dam Safety program began the task of identifying dams that were High Hazard and working to get those dams repaired. In 1994, Dam Safety Regulations were defined to classify the hazard potential of dams, establish minimum design and construction criteria, to require regular inspections and to have an emergency action plan for all high hazard dams. These regulations were again revised in 2005 and are currently used today.

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Surface Water Quality

Surface Water Quality

Sameera R Gunatilake *(Mississippi State University)*	Solid phase extraction, QuEChERS cleanup, dansylation with LC-MS/MS detection as an improved method for analyzing five estrogens in wastewater
Thomas A. Kajdan *(University of Mississippi)*	Monitoring fine suspended sediment in streams using high frequency acoustic signal attenuation measurements
Bahareh Kokabian *(Mississippi State University)*	Mississippi's Dam Safety Program
Cory Shoemaker *(Mississippi State University)*	Effects of vegetation and hydrology on Eh in vegetated agricultural drainage ditches with weirs
Caroline Andrews *(Mississippi State University)*	Spring microhabitat oxygen dynamics of Blue Lake, a Yazoo River Oxbow in Berclair MS
Richard E. Lizotte Jr. *(USDA Agricultural Research Service)*	Factors affecting low summer dissolved oxygen concentrations in Mississippi Delta bayous
Xiaobo Chao *(University of Mississippi)*	Development and application of numerical models to environmental hydraulics

Solid phase extraction, QuEChERS cleanup, dansylation with LC-MS/MS detection as an improved method for analyzing five estrogens in wastewater

Gunatilake, S.; Steelhammer, S.; Kwon, J.; Xia, K.; Armbrust, K.; Rodriguez, J.; Mlsna, T.

An improved method for the analysis of estriol (E3), estrone (E1), 17a-estradiol (aE2), 17B-estradiol (BE2), and 17a-ethinylestradiol (EE2) in wastewater is described. The method includes sample preparation using solid-phase extraction followed by a "QuEChERS" (Quick Easy Cheap Effective Rugged Safe) cleanup, and a LC-MS-MS detection. Solid phase extraction was carried out using Oasis HLB cartridges and a dispersive solid phase cleanup pack containing $MgSO_4$, PSA and C-18. The resulting extract was then derivatized with dansyl chloride. Separation was achieved on an Agilent Zorbex Extend C-18, Narrow Bore RR, (2.1 x 100mm, 3.5 µm) column and quantification was accomplished in the positive ion mode using multiple reaction monitoring. The cleanup method is quick, efficient, inexpensive, and requires only 200 ml of water. Reliable linearities were obtained for all the calibration curves ($r_2 > 0.995$). Calculated matrix effects were less than 12% for all the analytes and hence, matrix matched calibration curves were not needed. The recoveries for the estrogens ranged from 81–103% with a high repeatability (n=3, RSD = 9%) and low limits of quantification (0.6–0.9 ng/L). The method was used to analyze effluent and influent wastewaters in three Mississippi wastewater treatment plants but is broadly applicable for the determination of trace estrogens in any municipal wastewater samples.

Monitoring fine suspended sediment in streams using high frequency acoustic signal attenuation measurements

Kajdan, T.; Carpenter Jr., W.; Chambers, J.; Goodwiller, B.; Surbeck, C.

This research focuses on a new device to measure fine suspended sediment particles in rivers and streams using acoustic signal attenuation measurements. The purpose of this device is to create a high frequency signal attenuation system that will be able to measure concentrations continuously without having to physically visit the site in order to obtain the samples. This system will be non-intrusive as well as relatively cost-effective in comparison with the methods that have previously been adopted. Two 20 MHz transducers will be aligned in a pitch-catch configuration at a distance based upon near field effects and noise level caused by the interaction between the transmitting and receiving transducers. The 20 MHz acoustic device will be able to measure particles ranging from 0.2 to 65 μm in size. A vast attenuation database has been created at the National Center for Physical Acoustics (NCPA), located in Oxford, Mississippi, to account for this range of particle sizes. The database includes acoustic signal attenuation measurements of bentonite, kaolinite, illite, and silt, which were used to broaden the sediment range. The database consists of peak-to-peak voltage data that was captured by the receiving transducer during the experiment and displayed and analyzed using LabView 2010. This voltage data corresponds to known particle concentrations. A digital signal processing (DSP) board will be used to process the data obtained from the 20 MHz transducers in the field. The attenuation signal that is measured in the field will be compared with the database so that a sediment concentration can be determined. The 20 MHz acoustic device will be calibrated at the NCPA using the attenuation database. Once the calibration is complete, the 20 MHz acoustic device will be deployed at Harris Bayou, located in Coahoma County, Mississippi. This particular bayou has relatively steady base flow, which is ideal for the acoustic device. The steady base flow of this bayou ensures that the signal produced by the transmitting transducer will not reflect off of the surface of the water causing inaccurate attenuation data. The digital signal processing board will be mounted in the gauging station housing that is currently being used by the United States Geological Survey (USGS). The results that are obtained from the field will be compared with concentrations that the USGS finds from its grab samples.

Integrated Desalination and Wastewater Treatment Systems

Kokabian, B.; Blair, M.; Gude, V. G.

Water, energy and environment play a vital role in the sustainability of mankind. Environmental degradation associated with water and energy production/supply processes is the immediate concern faced by many parts of the world. Utilizing wastewater and produced waters as resources to provide for potable water and energy needs could serve as a sustainable alternative to mitigate environmental degradation. Towards this goal, microbial desalination cells allow for efficient wastewater treatment combined with electricity generation and desalination of saline waters. The premise for this research is based on the principles that the bio-electrochemical (BES) systems convert wastewaters into treated effluents while producing electricity and ionic species migration within the system facilitates desalination. A microbial desalination cell (MDC) can be constructed by including an additional saline water chamber in a microbial fuel cell using anode and cathode exchange membranes. Domestic wastewater can serve as a substrate provider while air cathodes can provide oxygen to accept electrons. A new concept to provide in-situ oxygen generation in the cathode section by algae to increase electron mobility (i.e. electric current) in microbial desalination cells is presented in this paper. Treated wastewater in the anode chamber will be allowed to pass through the cathode chamber to serve as CO2 and nutrient rich medium for algal biomass growth and in-situ oxygen generation. This process eliminates current issues encountered in microbial desalination cells such as salt accumulation in treated wastewater, pH drop and rise in anode and cathode chambers and provision of strong electron acceptors such as oxygen. This paper presents the results from experimental studies and energy analysis on the feasibility of algal microbial desalination cells.

INTRODUCTION

The conventional aerobic wastewater treatment processes such as activated sludge are both energy and cost intensive. An energy cost of 30 kWh per capita per year is needed for aeration of wastewater in aerobic treatment technologies (Aelterman et al., 2006). Considering, sludge disposal and treatment, the overall cost will be about $25 billion per year for all types of wastewater treatment in USA (Wei et al., 2003; Win, 2001). Microbial fuel cell technology can be an alternative to reduce the cost of treatment by recovering electrical energy from wastewater while at the same time treating wastewater. This process will reduce both the energy input and the excess sludge production (Rabaey and Verstraete, 2005) for wastewater treatment. In MFCs, microorganisms oxidize organics in the anode chamber and generate electrons which then flow through a resistor to the cathode chamber to reduce the electron acceptors (typically oxygen) (Logan et al., 2006; Lovley, 2008). However, besides organic removal, water desalination can be achieved by inserting an additional chamber consisting sea water between anode and cathode chambers in a microbial fuel cell. This new configuration is called Microbial Desalination Cell which was first introduced by Cao et al. (2009). A cation exchange membrane (CEM) is inserted next to the cathode chamber while an anion exchange membrane (AEM) is used next to the anode chamber. Due to the difference in anode and cathode potentials, anions move to the anode chamber while cations transfer to the cathode chamber and as a result water is desalinated. Desalination of seawater by reverse osmosis requires a considerable amount of energy (at least 3.7 kWh/m^3) (Mehanna et al., 2010a) while in MDCs water can be desalinated without the use of any external energy source. MDCs can serve as an efficient pretreatment step for RO systems in water and wastewater treatment plants to reduce the energy required in these systems. The researchers used sacrificing catholytes to provide electron acceptors which are not an environmental-friendly approach for long term sustainability of this system. A new concept of MDC is developed in this research which is based on in situ oxygen production by presence of algae in the cathode chamber called "algal biocathode". The effect of algal biocathode on current/ voltage production, organic removal and desalination was examined.

MATERIALS AND METHODS

Microbial Consortium and Algae Preparation

Microbial consortium used in anode compartment was collected from the aerobic sludge of the wastewater treatment plant in Starkville, Mississippi. The sludge was allowed to acclimatize to anaerobic conditions in synthetic wastewater containing 300 mg/l of COD. The microbial consortium grown in air and algal cathode MFCs were further transferred into the air and algal MDCs. The synthetic wastewater used in anode chamber has the following composition: glucose 281.25mg/l, KH_2PO_4 (4.4 g/l), K_2HPO_4(3.4 g/l), NH_4Cl(1.5 g/l), $MgCl_2$ (0.1 g/l), $CaCl_2$ (0.1 g/l), KCl (0.1 g/l), $MnCl_2$4. H_2O(0.005 g/l), and $NaMo.O_4.2H_2O$(0.001 g/l) (Cao et al., 2009). The COD concentration used in MDC anode chamber was 500 mg/l. The microalgae *Chlorella Vulgaris* which was used in cathode compartment was grown in the following mineral solution: $CaCl_2$ (25 mg/l), NaCl (25 mg/l), $NaNO_3$ (250 mg/l), $MgSO_4$ (75 mg/l), KH_2PO_4 (105 mg/l), K_2HPO_4 (75 mg/l) , and 3 ml of trace metal solution with the following concentrations was added to the 1000 ml of the above solution: $FeCl_3$ (0.194 g/l), $MnCl_2$ (0.082 g/l), $CoCl_2$ (0.16 g/l), $Na_2Mo.O_4.2H_2O$ (0.008 g/l), and $ZnCl_2$ (0.005 g/l).

MFC-MDC Construction

The cylindrical-shaped MFC chambers were made of plexiglass with a diameter of 7.2 cm. The anode and cathode chambers were separated by an ion exchange membrane. Graphite papers were used as cathode and anode electrodes. The Volume of the anode and cathode chambers was 180 ml after inserting the electrodes. The MDC reactors were prepared by inserting a desalination chamber between anode and cathode chambers in MFC reactors. Cation exchange membrane (CEM, CMI 7000, Membranes international) separated the cathode and desalination part while an anion exchange membrane (AEM, AMI 7001, Membranes international) separated the anode and desalination chambers. The volume of desalination chamber was about 200 ml3 with a salt concentration of 10 g/l NaCl.

A 10 k ohm resistor was used in closed circuit tests. The voltage was recorded using digital multimeter (Fluke, 287/FVF). The current was calculated using the Ohm's law, $I = V/R$. The Power density was calculated (using $P = V.I$) as per anode volume or cathode surface. COD tests were carried according to Standard methods (APHA, 1992). Electrical conductivity, TDS removal and salinity removal were tested by a conductivity meter (Extech EC400 ExStik Waterproof Conductivity, TDS, Salinity, and Temperature Meter).

RESULTS AND DISCUSSION

Current Production in Air and Algae MFCs and MDCs

Figure 1 presents the voltage profile for air cathode MFC and algal cathode MFC. The maximum open circuit voltage difference between the cathode and anode for air cathode MFC and algal cathode MFC were 0.425 V and 0.488 V, respectively. The maximum power density with algal cathode MFC was 4.06 mW/m^2, about 3 times greater than the air cathod MFC (1.33 mW/m^2). Figure 2 represents the voltage profile for air cathode MDC and algal cathode MDC. The voltage for the air cathode MDC increased slowly for the first 50 hours of operation which can be related to the lag phase for the growth of microbial consortium in anode and the formation of biofilm on the electrodes (Powell et al., 2009). This lag phase was shorter for the algal cathode showing the influence of in situ oxygen generation by algae in the cathode side which increase the electron mobility. The maximum produced voltage in the closed circuit for the algal cathode MDC (0.236 v) was also higher than the air cathode MDC (0.219 V). In another study, an aerobic consortium was used as a bacterial catalyst in the cathode part, which produced maximum voltage higher than that of an air cathode MDC operated under similar conditions (Wen et al., 2012).

Organic Removal Efficiencies

Table 1. shows the COD removal efficiencies of both MFCs and MDC with air and algal cathodes. This table shows that in both MFCs and MDCs, systems with algal biocathode remove higher quantities of organic carbon from synthetic wastewater. This also confirms the higher produced voltage in algal type MDC and MFC compared to the air cathode type. However based on the analysis of coulombic efficiencies, the energetic conversion efficiencies of COD to power are still below the maximum theoretical energetic conversion efficiency which is about 100% (Alterman et al., 2006).

Desalination Profiles

Desalination profile for both air cathode MDC and algal cathode MDC are represented in figure 3. The percentage salinity removal in air cathode and algal cathode MDCs were 24.2 and 40.1 % respectively. The total desalination rate (TDR) of algal MDC was 0.161 $g.L^{-1}.day^{-1}$, about 2 times greater than air cathode MDC with TDR equals to 0.076 $g.L^{-1}.day^{-1}$. The higher salinity removal rate for algal MDC is due to its higher potential difference between anode and cathode which stimulates the transfer of ions in the middle chamber to the anode and cathode chamber. A review of papers of microbial desalination cells showed high removal efficiency of salt was achieved in the cells with high ratio of wastewater volume to sea water (Kim & Logan, 2013). Mehanna (2010b) showed that 43–67% desalination of water is possible using equal volumes of anode solution and salt water. Our result also shows that algal cathode MDC can be used to substantially reduce salt concentrations prior to reverse osmosis and as a result the required energy for RO will also decrease. On the other hand, the RO systems can benefit from power generation of MDC which substantially decrease its energy usage.

Feasibility of Large Scale Application

Economic evaluation of bioelectrical systems for electricity production as well as wastewater treatment has been published recently (Pant et al. 2011). Powell and Hill (2009) studied the economic feasibility of novel CO_2 photosynthetic microalgae MFC that can generate power and oils for biodiesel. The economics of our system can be evaluated by assuming that in a 100,000 population with wastewater generation of 16 billion liters containing 300 mg/l COD has the potential for production of 2.3 MW of electricity annually (Logan, 2005). Based on the wastewater volume, produced power was about 64 mW/m3 in our algal cathode MFC. Considering the amount of wastewater generated, the overall power production will be about 1.024 MW which means about half of the energy in wastewater has been recovered as electricity. Assuming a typical consumption of 1.5 kW electricity per house, 1.024 MW of power can meet energy demand for 682 houses. Based on assumed cost of electricity of $0.07/kWh, this power would be worth$627916.8 which shows the economic potential of this type of MFC.

CONCLUSION

This study has demonstrated that algal MFCs and MDCs can improve electricity production by in situ-oxygen generation. Use of algae in the cathode part of MDC can decrease capital costs for chemicals and aeration while at the same time maintaining the sustainability feature. The salinity removal rate for algal MDC was much better than the air cathode MDC. MFC and MDC Systems can remove organic pollutants from wastewater. Alternatively, MDCs can be used as a pretreatment for downstream RO systems. In conclusion, application of algal biocathode MDCs as a sustainable method for water desalination and wastewater treatment has been proved in this study.

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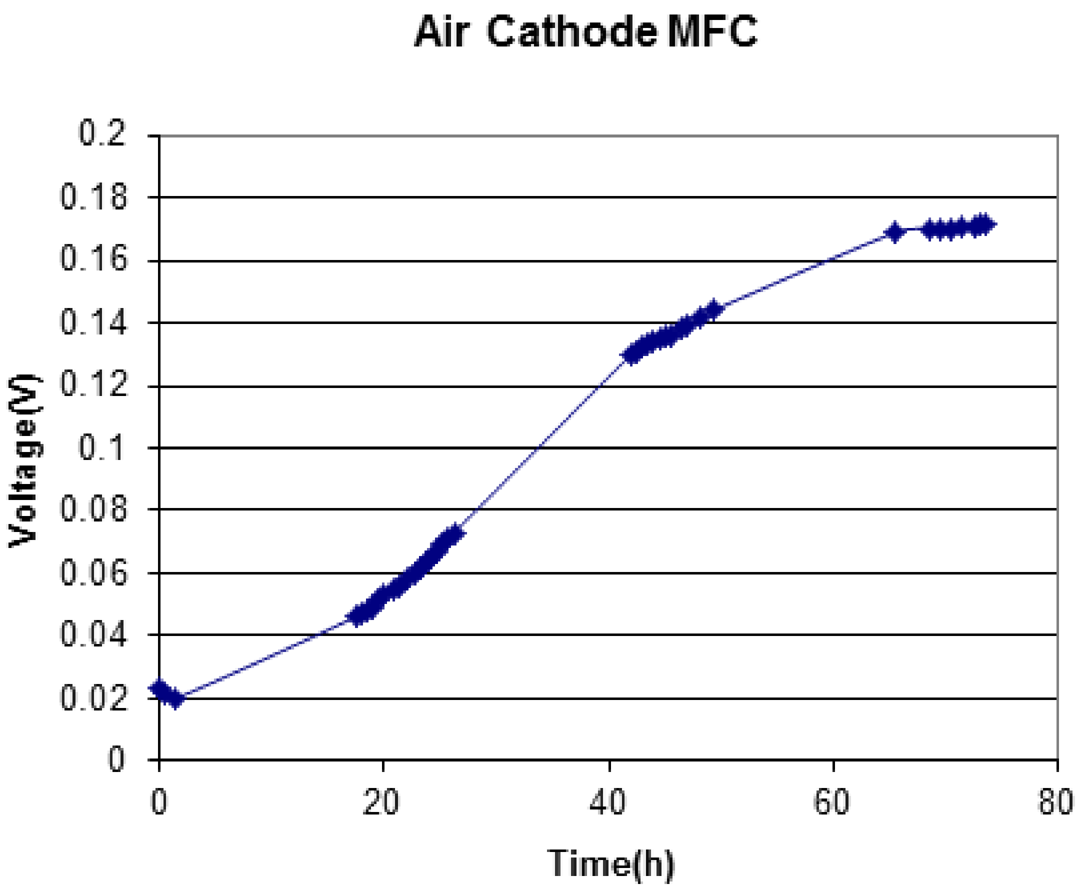
Table1. COD removal efficiencies of MFCs and MDCs

Type of BES	COD Removal %
MFC with air cathode	38.1%
MFC with algal cathode	59.2%
MDC with air cathode	56.65%
MDC with algal cathode	65.62%

Figure 1 Voltage profile for A) Air cathode MFC B) Algal Cathode MFC.



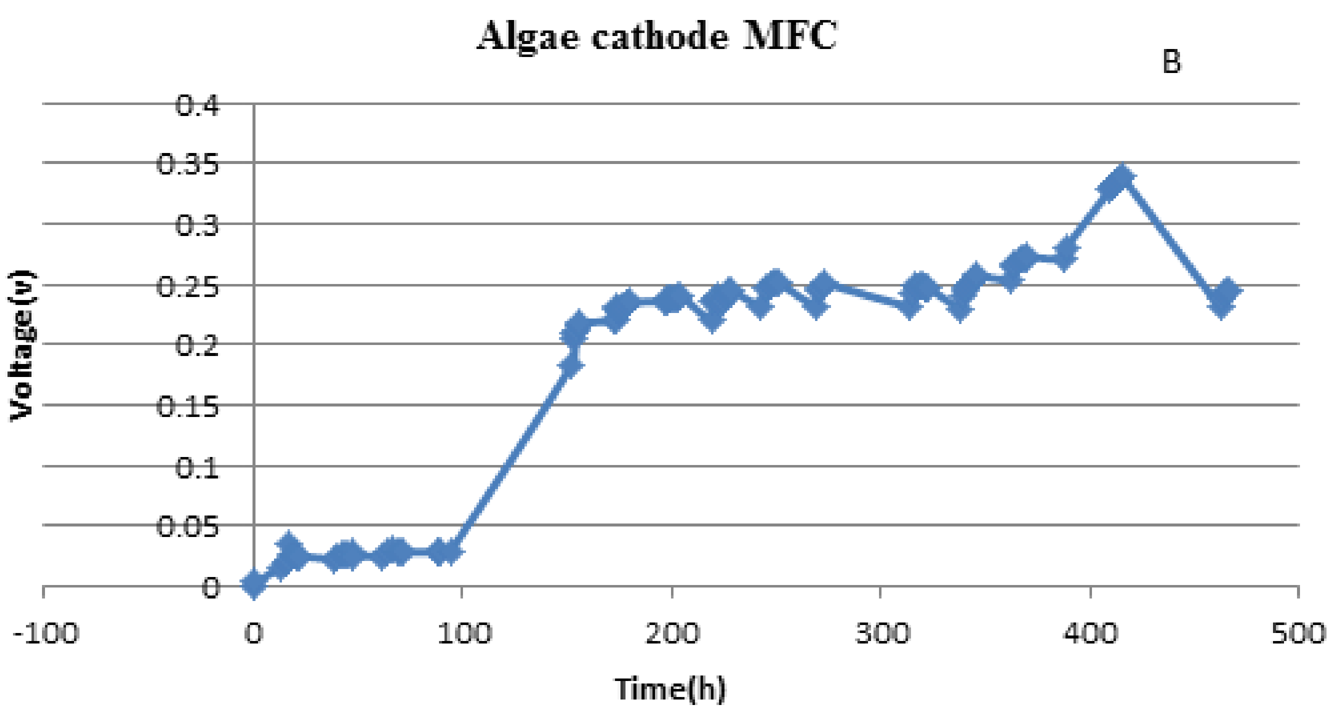


Figure 2 Voltage profile for air cathode MDC and Algal cathode MDC

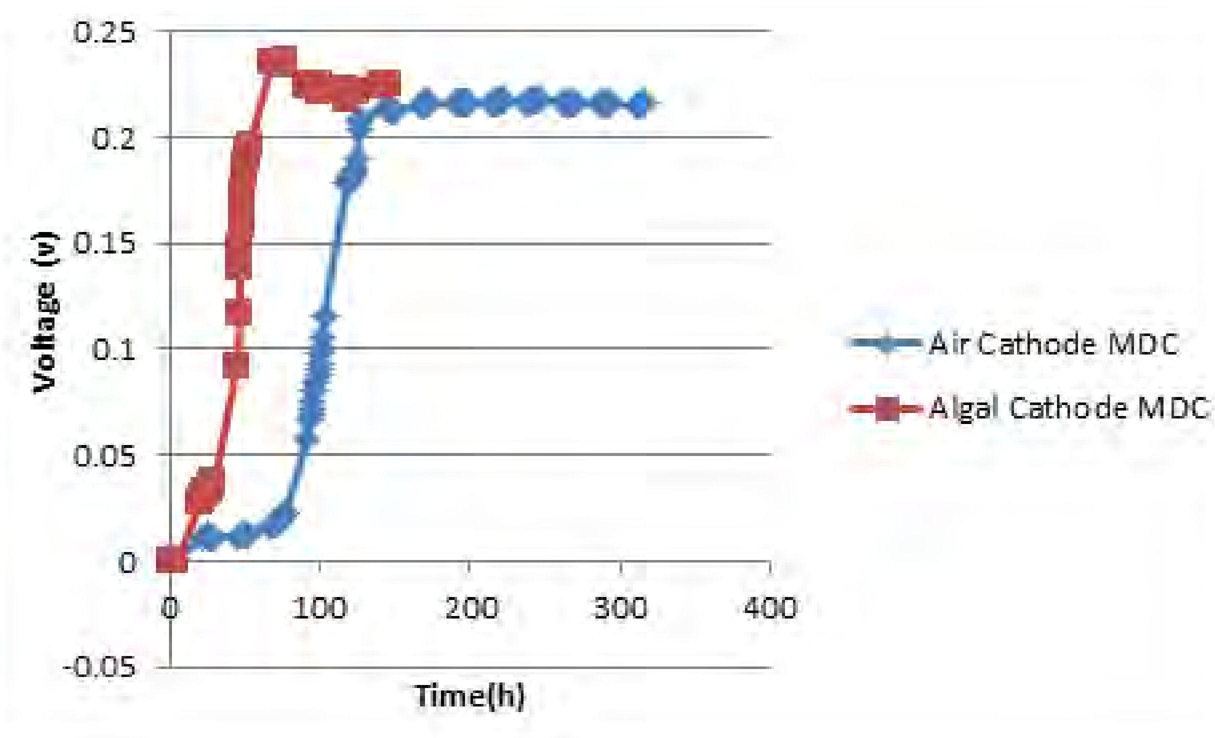
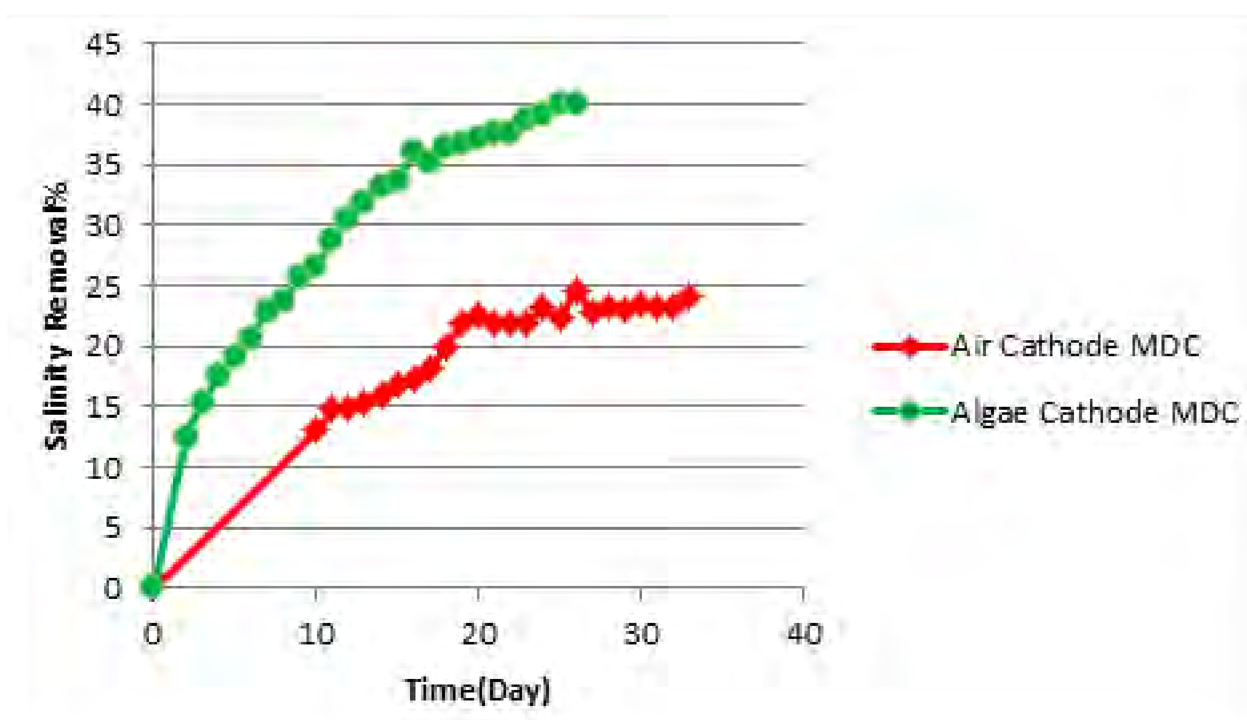


Figure 3 Desalination profile for air cathode and algal cathode MDC



Effects of vegetation and hydrology on Eh in vegetated agricultural drainage ditches with weirs

Shoemaker, C.; Kröger, R.; Pierce, S.

Oxidation-reduction potential (Eh) is an important parameter in predicting biogeochemical reactions occurring in waterlogged soils, including nutrient reduction. Specifically, soil Eh can be used to classify the potential of a system for nitrate reduction, providing a convenient and inexpensive tool for assessing the capacity of primary water bodies for denitrification potential. Continuous automated data loggers were developed, tested, and confirmed for accuracy and precision of Eh measurements. These units were then used to test a vegetated agricultural ditch with weirs in order to assess the influence of hydrology and vegetation on Eh. Six two week testing periods were conducted around two weirs from May-September 2012, with plots above each weir undergoing controlled drainage while plots below each weir functioned as controls subjected to conventional drainage. No differences were observed in the median Eh between vegetated and non-vegetated plots or the median Eh of the location of plot about the weir; however hydrologic changes influenced the range of Eh values regardless of vegetation status. The high levels of temporal and spatial Eh variation inherent in soils make it difficult to determine bulk soil Eh shifts over space and time. A one dimensional moving split window analysis was run to elucidate Eh boundaries by reduction potential. Results of this analysis showed marked shifts of Eh on specific probes, but no overall trends. The standard deviation of probes shifted over time, suggesting the use of controlled drainage coupled with vegetation could increase electrochemical heterogeneity in waterlogged soils. This increase in soil electrochemical heterogeneity may indicate increased denitrification potential as a result of controlled drainage in vegetated ditches.

Spring Microhabitat Oxygen Dynamics of Blue Lake, a Yazoo River Oxbow in Berclair MS

Andrews, C.; Kröger, R.; Miranda, L.

Shallow oxbow lakes carved in rich alluvial floodplains can support multiple microhabitats that maintain aquatic diversity. Oxbow lakes have a high shoreline to surface area ratio and are often connected to or surrounded by inundated wetlands such as cypress and tupelo brakes, creating within-lake structural habitat variability that may influence biotic composition. Furthermore, these microhabitats fundamentally function in different ways. We studied microhabitat oxygen dynamics of an oxbow lake in the Mississippi Alluvial Valley. Blue Lake has over 8 km of shoreline and is permanently connected to a tupelo brake (approximately 350 ha) inundated with 0.5-1 m of water during the spring, an important time for reproduction. Using hourly diel surface dissolved oxygen (DO) data collected in April-July 2012, we investigate several descriptors of DO dynamics including mean DO, daily DO peaks, rate of DO fall, time of DO peaks, and percent of time above minimum DO thresholds (2 and 5 mg/L). We test differences in spring oxygen dynamics between three habitat types (littoral, pelagic, and brake) using a MANCOVA ($p<0.001$) and explore the possibility of oxygen refugia in hypoxic systems. Mean temperature along with four DO metrics: mean, minimum, maximum, and range DO showed significant ($p<0.05$) difference in means and slope between sites. The observed differences promote habitat diversity likely to influence biotic composition and distribution.

Factors affecting low summer dissolved oxygen concentrations in Mississippi Delta bayous

Lizotte Jr., R.; Shields Jr., F.; Locke, M.; Murdock, J.; Knight, S.

Streams in watersheds supporting intensive row-crop agriculture are vulnerable to ecological degradation due to non-point source discharge of pollutants such as nutrients. Low gradient streams such as bayous are especially susceptible due to increased water residence time, and often result in poor water quality and chronic low dissolved oxygen (DO) concentrations (hypoxia). The goal of the current study was to assess physical, chemical, and biological components affecting low DO during summer of 2011 in three Mississippi Delta bayous. Three sites were selected within each bayou: upstream channel, lake or open water in the water body mid-section, and downstream channel. Dissolved oxygen was monitored at 40 cm depth every 15 minutes for 6-7 days on alternate weeks. Stream surface water samples collected biweekly were analyzed for nutrient and chlorophyll a concentrations. Minimum daily DO levels were frequently below the State instantaneous minimum DO standard of 4 mg/L. Diel DO fluctuation (the difference between daily maximum and minimum DO concentrations) reflected large 24-h DO ranges (=10 mg/L) across all three bayous. Pearson product moment correlations showed minimum DO concentrations to be negatively correlated with total phosphorus (TP) concentrations across all habitats. Total nitrogen (TN) concentrations and dissolved organic carbon (DOC) concentrations were negatively correlated with minimum DO concentrations only in lake habitats. Diel DO fluctuation was positively correlated with water column chlorophyll a concentrations across all habitats. Upstream diel DO fluctuation was also positively correlated with water depth and TP concentrations while downstream diel DO fluctuation was positively correlated with TP but not water depth. Low summer DO concentrations and changes in diel DO fluctuations were affected by both nitrogen and phosphorus driving summer algal blooms (eutrophic to hypereutrophic conditions) in Mississippi Delta bayous. Organic carbon inputs may exacerbate DO minimums in these nutrient-rich systems. As a result, nutrient reduction in all habitats in conjunction with increased water depth in upstream habitats is necessary to improve summer DO concentrations in Mississippi Delta bayous.

INTRODUCTION

The availability of dissolved oxygen (DO) in lakes and streams is critical for most aquatic life (Paerl et al. 1998; Garvey et al. 2007; Justus et al. 2012). Hypoxia (low DO) is defined as concentrations that are below either 2 mg/L or 30% saturation (Shields and Knight 2012). Factors such as flow rate and nutrient enrichment resulting from agricultural runoff can have significant impacts on downstream water quality, including DO (Rohm et al. 2002).

Within the lower Mississippi River alluvial plain (i.e. the Delta), are extensive shallow (< 2 m), low velocity stream systems referred to as bayous. These systems exist in a landscape of low relief and modern intensive row-crop agriculture which includes the widespread use of nitrogen fertilizers. The Delta region receives approximately 130-150 cm precipitation annually, with about half occurring during the months of April-October (Sherman-Morris et al. 2012). Additionally, Delta farmers utilize groundwater for irrigation during extended dry periods from June-August, with substantial amounts of irrigation water returning to streams. For these reasons, Delta bayous can receive runoff pollutants from a variety of sources throughout much of the growing season and this, in turn, can affect stream hydrology, nutrient transport, and DO dynamics.

In Mississippi, state standards require that DO concentrations are to be maintained at a daily average of 5.0 mg/L or greater with an instantaneous minimum of 4.0 mg/L or greater at mid-depth in streams and shallow lakes approximately 2 m deep or less (MDEQ 2007). These standards are presumed to be protective of aquatic life and wildlife uses within these habitats and systems that are chronically below these thresholds are considered impaired.

The purpose of the present study was to examine hydrological (water depth), nutrient [nitrogen (N), phosphorus (P), carbon (C)], and biological (chlorophyll a) components that could affect DO concentrations in three Mississippi Delta study bayous located within an agricultural landscape.

MATERIALS AND METHODS

Three Delta bayous were studied: Cow Oak Bayou near Dundee in southern Tunica County, MS; Roundaway Lake Bayou in southern Coahoma County, MS; and Howden Lake Bayou near Alligator in eastern Bolivar County, MS (Fig. 1). Contributing watersheds ranged in size from 17.5-24.3 km^2, with low relief ranging from 17.3-22.6 m and watershed lengths ranging from 6.1-9.7 km (Table 1). All three bayous occur in intensively row-crop cultivated watersheds dominated by soybeans (*Glycine max*), corn (*Zea mays*), cotton (*Gossypium hirsutum*), and rice (*Oryza sativa*). In 2011, soybeans were the dominant row-crop in all three watersheds, followed by cotton in Cow Oak and Roundaway, and corn in Howden (Table 2).

Three sites within each bayou were designated for water quality and hydrological monitoring at locations within the upstream reach, lake reach, and downstream reach (Fig. 1). Mean summer 2011 water depth (±SD) at each site was as follows: Cow Oak, 0.70 (0.12) m upstream, 1.02 (0.06) m lake, 0.36 (0.02) m downstream; Roundaway, 0.20 (0.07) m upstream, 1.45 (0.21) m lake, 0.32 (0.12) m downstream; and Howden, 0.81 (0.03) m upstream, 1.03 (0.02) m lake, 0.61 (0.01) m downstream.

Surface water samples (10 cm below the water surface) were collected every two weeks beginning in January 2011. Samples were preserved on wet ice and transported to the USDA-ARS National Sedimentation Laboratory, Oxford, MS, for nutrient and chlorophyll analysis. *In-situ* DO was measured every 15 minutes at 40 cm depth (or 10 cm above the bayou stream bed when depth was <50 cm) during a one-week deployment period just prior to surface water sampling (one of every two weeks). Daily DO mean, minimum, and range (difference between maximum and minimum) concentrations were used. The current study focuses on summer 2011 water quality since summer is the season with the greatest frequency of hypoxia. Laboratory chemical analysis included soluble reactive phosphorus (SRP, filtered through a 45 µm cellulose nitrate filter and analyzed using the ascorbic acid method), total phosphorus (TP, persulfate digestion with ascorbic acid method), total nitrogen (TN, determined by the summation of NO_x-N and total Kjeldahl nitrogen), and total dissolved organic carbon (DOC, filtered through a 45 µm cellulose nitrate filter and analyzed using the high temperature combustion method) analyzed according to APHA (2005). TP and TN were analyzed using a Lachat Quik Chem 8500 Series 2 analyzer (Lachat Instrument, Loveland Colorado USA) while DOC was analyzed using a Teledyne Tekmar Apollo 9000 combustion TOC analyzer (Teledyne Tekmar, Mason, Ohio USA). Biological analysis included chlorophyll a (pigment extraction and spectrophotometric determination using the trichromatic method) as an indication of overall phytoplankton biomass (APHA 2005). Chlorophyll was analyzed using a Thermo Scientific Genesys 10s UV-Vis Spectrophotometer (Thermo Fisher Scientific, Inc., Waltham, Massachusetts USA). Detection limits were 0.02 mg/L for all nutrients and 0.1 µg/L for chlorophyll a.

Pearson Product Moment correlations generating corresponding correlation coefficients (*r*) were used to determine associations between summer 2011

DO parameters (daily mean, minimum , range) and either nutrients (TP, TN, DOC), chlorophyll a, or water depth within each bayou reach (upstream, lake, downstream) across all three bayous. Significant correlation coefficients were determined with an alpha level of 5% ($p \leq 0.05$).

RESULTS AND DISCUSSION

Dissolved oxygen concentrations within Cow Oak varied considerably across reaches throughout summer of 2011 (Table 3). In general, shallower upstream and downstream reaches had lower mean and minimum DO concentrations than the deeper lake reach. Dissolved oxygen range was greatest within the upstream and lake reaches and lowest in the downstream reach (Table 3). In comparison, Roundaway DO varied less across reaches yet still exhibited a similar trend of lower mean and minimum DO concentrations in shallower upstream and downstream reaches versus the deeper lake reach (Table 4). Dissolved oxygen ranges, in general, were also lower in channel reaches versus the lake reach. In contrast, Howden mean, minimum, and range of DO concentrations were generally greater in the upstream reach, lowest in the downstream reach, and intermediate in the lake reach (Table 5). Across all watersheds, a general summer seasonal trend in DO concentration was exhibited where DO was greatest in early summer and decreased thereafter until September. This indicated that DO deficit stress was greatest in August. Aquatic biota in Mississippi Delta bayous can be increasingly stressed by greater frequency and duration of hypoxic conditions, especially in August, when aquatic invertebrate and fish DO requirements may not be met. When such conditions become chronic, this can result in decreased animal diversity such as those occurring in the Big Sunflower River (Shields and Knight 2012) or in very shallow oxbow lakes (Dembkowski and Miranda 2012) in the lower Mississippi River alluvial plain.

Nutrient concentrations in the Mississippi Delta study bayous ranged from 1.5 to 2.5 fold across different bayous and among different reaches (Table 6). Cow Oak had consistently higher mean TP concentrations across all reaches compared with Roundaway (intermediate) and Howden (lowest). Roundaway had the highest TN concentrations while Cow Oak was intermediate and Howden showed the lowest TN. Mean DOC concentrations were, again, typically greater in Roundaway and lowest in Howden with Cow Oak intermediate. In general, shallower upstream reaches exhibited greater nutrient concentrations than lake reaches and downstream reaches were comparable to, or lower than, the lake reach. Concentrations of TP and TN observed in our study bayous were much greater than those measured in least impaired oxbow lakes in the lower Mississippi River alluvial plain of Arkansas (Justus 2010), but comparable with other shallow water bodies located within agricultural watersheds of the Mississippi Delta in Mississippi (Cullum et al. 2006; Shields et al. 2009; Lizotte et al. 2012; Shields et al. 2013). Mean measured DOC in the study bayous ranged from 7.3 mg/L to 11.5 mg/L with Roundaway usually having higher concentrations than either Cow Oak or Howden. DOC also typically decreased linearly from upstream to downstream within each watershed. Study bayou DOC concentrations were comparable to DOC concentrations occurring in eutrophic streams in the region that ranged from 5 mg/L to 22 mg/L (Bryson et al 2007).

Chlorophyll a concentrations (an estimate of phytoplankton biomass [Reynolds 2006; Bellinger and Sigee 2010]) varied substantially within reaches and among watersheds ranging from 14.8 µg/L to 107 µg/L (Table 6). Within Cow Oak, mean chlorophyll a concentrations were greater in upstream and lake reaches and lowest in the downstream reach. Chlorophyll a in Roundaway was greater in the lake and downstream reach but lowest in the upstream reach. In contrast, Howden had decreasing mean chlorophyll a going from upstream to lake to downstream reaches (Table 6). Observed ranges of chlorophyll a concentrations measured in the study bayous were typical of a variety of Mississippi Delta water bodies. Chlorophyll a concentrations within the Big Sunflower River were typically less than 30 µg/L (Shields and Knight 2012) while chlorophyll a in other Mississippi Delta rivers, streams and backwaters ranged from 18.3 μg/L to 116 μg/L (Bryson et al. 2007; Lizotte et al. 2012; Shields et al. 2013). Oxbow and floodplain lakes of the lower Mississippi alluvial plain had measured chlorophyll a concentrations ranging from 2.13 μg/L to 964 μg/L with most concentrations ranging from 30-100 μg/L (Justus 2010; Dembkowski and Miranda 2012; Knight et al. In Press).

During summer 2011, daily minimums and ranges of DO concentrations fluctuated in association with various nutrient concentrations across all bayou reaches (Table 7). Daily dissolved oxygen minimum concentrations were significantly negatively correlated with both TP and TN across all reaches, whereas DO minimums were negatively correlated with DOC only within the lake reach. These results are indicative of increasing nutrient concentrations leading to depressed daily DO minimum concentrations. In contrast, daily DO ranges were positively correlated with TP across all reaches but only positively correlated with TN in shallower upstream and downstream channel reaches and indicate TP and, to a lesser extent, TN lead to increased daily DO ranges. Daily DO ranges were also positively correlated with chlorophyll a concentrations across all reaches while daily DO minimums were negatively correlated only in the lake reach, suggesting phytoplankton in the bayous drives diel DO ranges but does not primarily determine the daily DO minimums. In conjunction with nutrients and phytoplankton, daily DO ranges were additionally positively correlated with water depth in upstream and lake reaches suggesting hydrological, chemical and biological components in bayous in combination affect observed daily DO concentrations.

The Mississippi Delta is well known for its high row crop productivity with intensive agriculture producing significant agricultural runoff that affects water quality of rivers and streams in the region (Rohm et al. 2002; Bryson et al. 2007; Hicks and Stocks et al. 2010). Excessive TP and TN concentrations leading to eutrophication in rivers and streams of the region are considered to be the primary cause of DO depletion in low-flow lotic waters (Rohm et al. 2002) and this was supported by the results of our study. In addition to eutrophication, the effects of hydrology on DO were shown to be another important factor. Lizotte et al. (2012) indicated that water depth significantly influences water quality such as TP and TN concentrations as well as diel DO ranges whereby increased water depth decreased these water quality parameters. Understanding such complex responses of DO concentrations to hydrological, biological and chemical processes in Mississippi Delta bayous is critical for habitat restoration (Shields et al. 2012; Shields et al. 2013).

Results of this study also have significant implications for determining appropriate nutrient criteria for Mississippi Delta rivers and streams. By showing clear linkages between TP and TN concentrations, water depth, and daily DO minima and ranges, state and federal agencies can produce more scientifically sound criteria for water management, nutrients, and DO concentrations necessary for attaining and maintaining aquatic life use of a Mississippi Delta water body.

Concurrent and future research efforts planned to coincide with the collection and assessment of the water quality data presented in this study include examination of: a) the effects of suspended sediment, turbidity, and light limitation on DO dynamics; b) fish and invertebrate community composition; c) phytoplankton and benthic algal community structure and function; and d) organic matter processing.

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Table 1. Watershed characteristics of the three Mississippi Delta study bayou watersheds.

	Delta Bayou Watershed		
Parameter	Cow Oak	Roundaway	Howden
Watershed perimeter, km	33.2	38.0	37.0
Watershed area, km^2	24.3	17.5	17.9
Maximum elevation, m	192.0	161.3	160.9
Minimum elevation, m	169.4	144.0	142.0
Relief, m	22.6	17.3	19.0
Watershed length, km	7.1	6.1	9.7

Table 2. Watershed row-crop land-use of the three Mississippi Delta study bayou watersheds in 2011.

	Delta Bayou Watershed		
Land-use (%)	Cow Oak	Roundaway	Howden
Soybeans	64	36	57
Cotton	11	20	0
Corn	1	8	27
Rice	9	19	3
Riparian/Trees	6	12	10
Fish Pond	1	2	0
Other	8	3	3

Table 3. Mean, maximum, minimum, and range of dissolved oxygen concentrations measured for one week at 15-min intervals and 40 cm depth (or 10 cm above the bayou stream bed when depth was <50 cm) in upstream, lake, and downstream reaches of Cow Oak Bayou watershed during summer 2011.

		Dissolved oxygen (mg/L)			
Location	**Date**	**Mean**	**Maximum**	**Minimum**	**Range**
Upstream	6/27/2011	6.78	13.60	0.63	12.97
	7/11/2011	6.58	16.70	0.01	16.69
	7/25/2011	7.64	14.78	0.00	14.78
	8/8/2011	ND[a]	ND	ND	ND
	8/22/2011	ND	ND	ND	ND
	9/6/2011	3.57	6.48	0.46	6.02
	9/19/2011	2.74	4.42	0.61	3.81
Lake	6/27/2011	9.65	14.08	5.02	9.06
	7/11/2011	5.29	10.45	0.57	9.88
	7/25/2011	8.90	15.96	1.45	14.51
	8/8/2011	6.98	13.00	1.81	11.19
	8/22/2011	4.71	9.58	1.61	7.97
	9/6/2011	5.25	6.17	3.38	2.79
	9/19/2011	6.98	9.96	4.84	5.12
Downstream	6/27/2011	2.74	7.09	0.81	6.28
	7/11/2011	2.67	6.55	0.00	6.55
	7/25/2011	ND	ND	ND	ND
	8/8/2011	4.26	8.98	1.06	7.92
	8/22/2011	3.04	5.46	0.53	4.93
	9/6/2011	3.15	5.06	1.72	3.34
	9/19/2011	2.40	3.96	1.39	2.57

[a]ND = no data available for this date

Table 4. Mean, maximum, minimum, and range of dissolved oxygen concentrations measured for one week at 15-min intervals and 40 cm depth (or 10 cm above the bayou stream bed when depth was <50 cm) in upstream, lake, and downstream reaches of Roundaway Lake Bayou watershed during summer 2011.

		Dissolved oxygen (mg/L)			
Location	**Date**	**Mean**	**Maximum**	**Minimum**	**Range**
Upstream	6/27/2011	2.63	5.12	0.62	4.50
	7/11/2011	2.82	5.00	0.26	4.74
	7/25/2011	0.90	2.44	0.03	2.41
	8/8/2011	5.53	7.32	1.49	5.83
	8/22/2011	4.41	4.94	3.26	1.68
	9/6/2011	5.19	5.71	4.88	0.83
	9/19/2011	6.40	6.94	5.49	1.45
Lake	6/27/2011	5.48	8.73	1.20	7.53
	7/11/2011	4.22	7.13	0.06	7.07
	7/25/2011	10.22	15.71	5.69	10.02
	8/8/2011	7.34	12.66	3.42	9.24
	8/22/2011	5.65	9.32	2.61	6.71
	9/6/2011	6.01	6.90	5.08	1.82
	9/19/2011	5.98	8.21	3.64	4.57
Downstream	6/27/2011	3.41	8.56	0.00	8.56
	7/11/2011	ND[a]	ND	ND	ND
	7/25/2011	ND	ND	ND	ND
	8/8/2011	7.29	8.24	0.81	7.43
	8/22/2011	ND	ND	ND	ND
	9/6/2011	3.09	5.22	0.24	4.98
	9/19/2011	4.44	6.29	2.83	3.46

[a]ND = no data available for this date

Table 5. Mean, maximum, minimum, and range of dissolved oxygen concentrations measured for one week at 15-min intervals and 40 cm depth (or 10 cm above the bayou stream bed when depth was <50 cm) in up-stream, lake, and downstream reaches of Howden Lake Bayou watershed during summer 2011.

		Dissolved oxygen (mg/L)			
Location	**Date**	**Mean**	**Maximum**	**Minimum**	**Range**
Upstream	6/27/2011	11.48	16.67	6.07	10.60
	7/11/2011	7.46	12.42	3.23	9.19
	7/25/2011	8.55	12.23	4.72	7.51
	8/8/2011	4.30	8.28	1.16	7.12
	8/22/2011	8.26	13.48	3.78	9.70
	9/6/2011	1.32	3.75	0.05	3.70
	9/19/2011	6.00	8.62	3.58	5.04
Lake	6/27/2011	7.33	9.89	3.76	6.13
	7/11/2011	6.64	9.22	4.10	5.12
	7/25/2011	6.38	11.64	2.59	9.05
	8/8/2011	ND[a]	ND	ND	ND
	8/22/2011	7.30	10.40	4.42	5.98
	9/6/2011	4.29	5.83	2.97	2.86
	9/19/2011	4.19	6.55	2.36	4.19
Downstream	6/27/2011	ND	ND	ND	ND
	7/11/2011	4.18	6.47	2.37	4.10
	7/25/2011	2.90	5.89	0.85	5.04
	8/8/2011	2.97	5.42	0.82	4.60
	8/22/2011	2.50	5.97	0.48	5.49
	9/6/2011	4.04	5.45	2.86	2.59
	9/19/2011	4.76	6.93	3.44	3.49

[a]ND = no data available for this date

Table 6. Mean (Standard Deviation) summer 2011 total phosphorus (TP), total nitrogen (TN), total dissolved organic carbon (DOC), and chlorophyll a concentrations in the three Mississippi Delta study bayou watersheds.

		Delta Bayou Watershed		
Location	Nutrient	Cow Oak	Roundaway	Howden
Upstream	TP (µg/L)	319 (173)	132 (20)	142 (26)
	TN (mg/L)	2.9 (1.5)	2.2 (1.2)	1.7 (0.5)
	DOC (mg/L)	11.5 (3.0)	11.1 (5.7)	8.5 (2.6)
	Chlorophyll a (µg/L)	107.0 (69.6)	14.8 (8.9)	43.6 (32.2)
Lake	TP (µg/L)	300 (78)	227 (148)	116 (29)
	TN (mg/L)	2.0 (0.6)	2.2 (1.0)	1.2 (0.1)
	DOC (mg/L)	7.9 (2.5)	10.4 (3.6)	7.2 (2.6)
	Chlorophyll a (µg/L)	106.1 (101.0)	76.0 (63.3)	26.6 (11.2)
Downstream	TP (µg/L)	262 (74)	210 (119)	118 (25)
	TN (mg/L)	1.5 (0.5)	2.6 (1.4)	1.1 (0.2)
	DOC (mg/L)	7.8 (2.7)	10.0 (5.1)	7.3 (2.7)
	Chlorophyll a (µg/L)	39.9 (16.9)	43.7 (24.1)	18.4 (6.3)

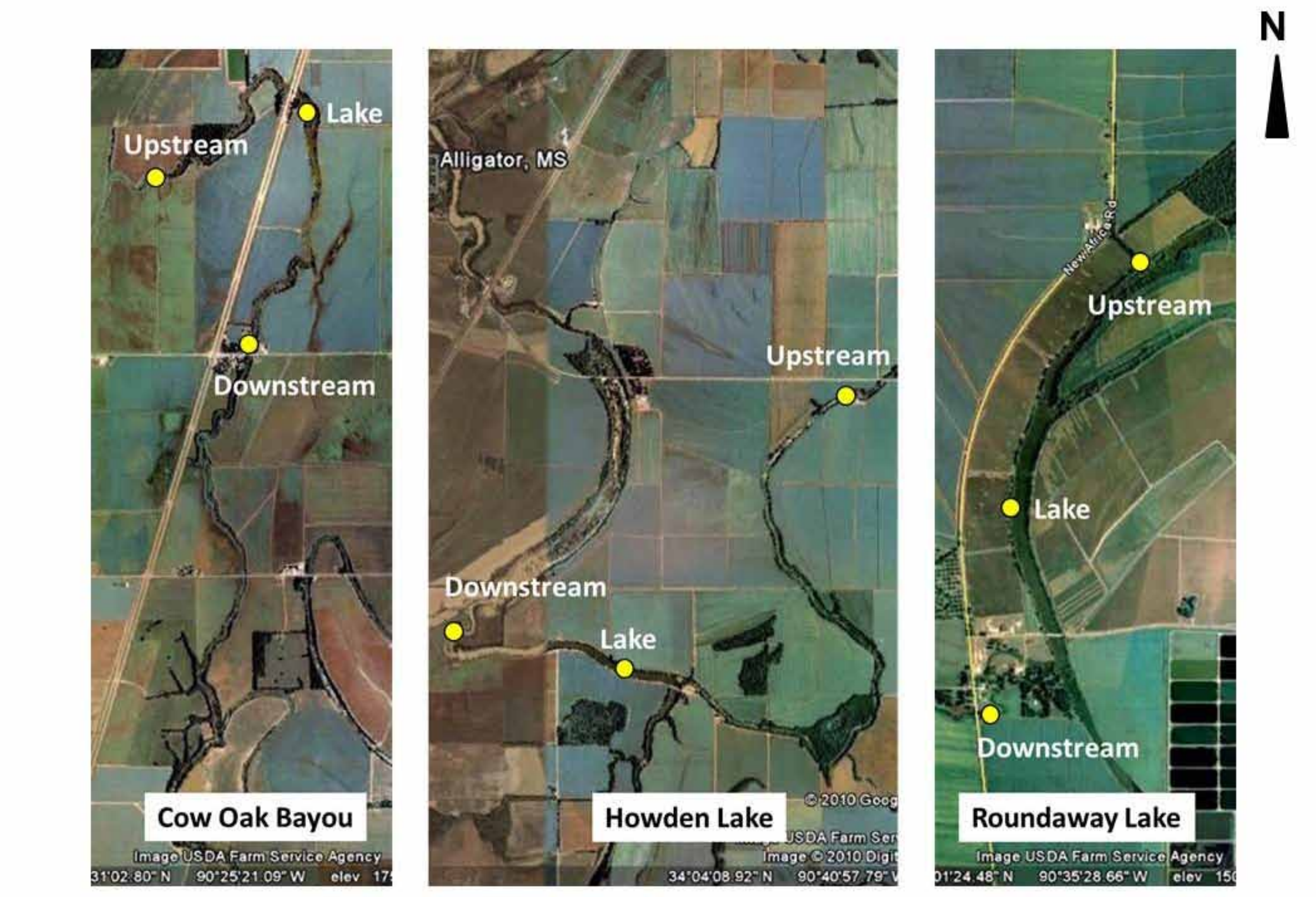
Table 7. Pearson Product Moment correlation coefficients (r) and sample sizes (n) between summer 2011 dissolved oxygen (mean, minimum, range) concentrations and nutrients, chlorophyll a, or water depth in the three Mississippi Delta study bayou watersheds. The asterisk (*) denotes statistically significant r values, p < 0.05.

			Dissolved Oxygen (mg/L)		
Location	Parameter	(n)	Mean	Minimum	Range
Upstream	TP (µg/L)	21	0.117	-0.770*a	0.661*b
	TN (mg/L)	21	-0.044	-0.583*b	0.473*
	DOC (mg/L)	21	-0.172	-0.328a,b	0.071
	Chlorophyll a (µg/L)	21	0.219	-0.524*b	0.656*
	Water depth (m)	17	0.256	-0.328	0.833*a
Lake	TP (µg/L)	20	0.023	-0.627*a	0.489*a,b
	TN (mg/L)	20	0.119a,b	-0.670*a	0.412a,b
	DOC (mg/L)	20	-0.414a,b	-0.750*a	0.054a,b
	Chlorophyll a (µg/L)	20	0.317	-0.515*a,b	0.659*
	Water depth (m)	13	-0.206	0.353a	0.567*a
Downstream	TP (µg/L)	16	-0.084a	-0.730*a	0.784*
	TN (mg/L)	16	0.539*	-0.563*a,b	0.653*b
	DOC (mg/L)	16	0.360	-0.296a	0.196
	Chlorophyll a (µg/L)	16	0.133a,b	-0.434a,b	0.742*
	Water depth (m)	14	0.090	0.453a,b	-0.359a,b

[a] Log_{10} dissolved oxygen

[b] Log_{10} nutrient, chlorophyll a, or water depth

Figure 1. Map of the three study bayous in the Mississippi Delta showing the locations of upstrea, lake, and downstream sampling sites.



Development and Application of Numerical Models to Environmental Hydraulics

Chao, X.; Zhu, T.; Jia, Y.; Altinakar, M.

Frequent natural and human activity induced disasters are influencing and degrading our water resources. To prevent and mitigate the damages that these disasters bring to our society in terms of water resources and eco-environmental quality, social and human welfare, life and property losses, and economic development, more effective and robust water resource management plans are necessary. The efforts of developing better research design and management tools have led to rapid advances in numerical modeling and computational simulation methodologies in parallel to the rapidly advancing computer technology. Computational models are effective and efficient tools that can be applied to study surface water flows, contaminant transport and environment impacts. Numerical models, CCHE2D and CCHE3D, developed at the National Center for Computational Hydroscience and Engineering of the University of Mississippi, have been applied to simulate the flow, sediment transport, pollutant distribution and water quality in natural water bodies. This paper briefly describes the CCHE2D & 3D models and demonstrate their capabilities by presenting the results of several study cases, including an oxbow lake in Mississippi, where water quality was degraded by excessive agro-chemicals, a hypothetical chemical spill case in a large lake in Mississippi, a salinity intrusion case in Lake Pontchartrain, LA, and hypothetical impact of radioactive chemicals to water quality in Kerr Reservoir and Lake Gaston, VA. The simulation results were validated using field measurements.

Nutrient Reduction and Management

Nutrient Reduction and Management

Robert Kröger *(Mississippi State University)*	Discerning BMP effectiveness for nutrient reductions in the Mississippi Delta
Beth Poganski *(Mississippi State University)*	Variable spatial and temporal impacts of low-grade weirs on the agriculture landscape: evaluating the costs and benefits
John J. Ramirez-Avila *(Mississippi State University)*	Effectiveness of low grade weirs to reduce sediment and nutrients loads in agricultural ditches of the Mississippi Delta
J. Larry Oldham *(Mississippi State University)*	Risk assessment for phosphorus movement in nutrient management planning in Mississippi
Corrin Flora *(Mississippi State University)*	Nutrient and suspended sediment mitigation through the use of a vegetated ditch system fitted with consecutive low-grade weirs
Mary Love Tagert *(Mississippi State University)*	Nutrient reduction benefits of on-farm water storage systems in Porter Bayou Watershed
John J. Ramirez-Avila *(Mississippi State University)*	Potential environmental risk of the phosphorus status in soils receiving poultry manure applications in Mississippi

Discerning BMP effectiveness for nutrient reductions in the Mississippi Delta

Kröger, R.; Hicks, M.; Prevost, D.; Thornton, K.

There is a significant impetus within the Mississippi River Basin, at both federal and state levels, to determine the possibility and attainability of nutrient reductions. These questions are being asked at several spatial scales, but ultimately are driven toward the largest spatial scale - Gulf of Mexico hypoxia. The Mississippi approach has been to utilize inter-agency collaboration to identify watersheds where BMP nutrient reductions can be demonstrated and to discern the effectiveness of those BMPs. Harris and Porters Bayous are two HUC 10 watersheds where BMPs have been installed on the landscape, and where tiered water quality monitoring with identical sampling frequencies provides a means for quantifying both reductions in nutrient concentrations and loads. Water quality data is being collected at three tiers. The first Tier (edge of field) is being collected by MSU, while Tiers 2 and 3 are being collected by USGS. Nutrient reductions in concentration, 1-year post BMP implementation are discernible at the Tier 1 scale, but are not yet known at Tiers 2 or 3 due to continued data analysis. Monitoring of multiple watersheds provides environmental variables and landscape characteristics that suggest reasons for the observed reductions. These initial answers provide previously unknown information towards improving in state aquatic ecosystem health as well as critically important BMP attainability estimates to inform Gulf of Mexico restoration recommendations.

Variable spatial and temporal impacts of low-grade weirs on the agriculture landscape: evaluating the costs and benefits

Poganski, B.; Kröger, R.; Pierce, S.

The use of inorganic fertilizers in agricultural production is widely recognized as a source of nitrate contributing to annual hypoxic zones in the Gulf of Mexico. Ecosystem degradation and impacts on freshwater and marine biota from nutrient contamination of surface waters have motivated research efforts to develop and implement innovative nutrient management practices. Such efforts have become a major priority of many landowners, natural resource conservationists, scientists, and government agencies from a local to national scale. The current experiment investigates how frequency and variable spatial arrangements of best management practices (BMPs) within drainage systems impact water quality leaving the agricultural landscape over time. Preliminary water quality results highlight temporal nutrient trends in agricultural effluent, where concentration spikes were observed during seasons that experience heavy rainfalls and when fertilizer application occurs. Results also showed phosphorus concentrations to be higher in run-off during stormflows rather than during baseflows, while nitrate concentrations in run-off were found to be similar regardless of flow regime. Integrating nutrient reduction data, spatial and temporal variables of best management practices, drainage acreage, and fertilizer inputs will help determine factors that affect nutrient reduction efficiencies and drive the adaptation of management strategies to further enhance pollution mitigation. Investigations of nutrient reduction data and environmental factors highlight the short-term benefits of management practices, which include water conservation, pollution reduction, and ecosystem services. Recognizing that decreasing the loss of water resources and nutrients through BMPs may have additional long-term environmental and monetary benefits to all stakeholders from local to regional scales.

Effectiveness of low grade weirs to reduce sediment and nutrients loads in agricultural ditches of the Mississippi Delta

Ramirez-Avila, J.; Poganski, B.; Kröger, R.

Drainage ditches are an essential component of the agricultural landscape. Ditches mediate the flow of pollutants from agroecosystems to downstream water bodies. Low-grade weirs established along drainage ditches, as an agricultural best management practice, have been evaluated as an effective measure to mitigate nutrient and sediment loads to downstream aquatic systems. A study was performed to estimate sediment and nutrient loading reductions and to determine the cost-effectiveness curve of implementing low grade weirs in agricultural drainage ditches systems in the Mississippi Delta. The study goals were addressed by combining field data collection and computational modeling techniques. Runoff volumes flowing downstream of low grade weirs along different drainage ditch systems during stormflow and irrigation events were estimated by using the Hydrologic Engineering Center - River Analysis System (HEC-RAS 4.1) model. Monitored sediment and nutrient concentrations and the generated runoff flows were used to develop representative rating curves for each low grade weir on each drainage ditch system. Runoff hydrograph flows on each event were routed through the generated rating curves to estimate instantaneous and total sediment and nutrient loads at each location. Loads were compared to determine low grade weirs efficiency inside each drainage ditch and between drainage ditch systems. A second part of the study used the System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN 1.2) to determine the most cost-effective solutions for meeting proposed agricultural runoff water quality conditions. Results from this study will provide more insights to further enhance the nutrient reduction strategy within the Mississippi Delta region.

Risk Assessment for Phosphorus Movement in Nutrient Management Planning in Mississippi

Oldham, J.; Ramirez-Avila, J.; Kingery, W.; Jackson, W.

Nutrient Management develops blueprints for using the right amount of the right nutrient source at the right time in the right place. Using poultry litter as a nutrient source in pastures and forages results in increased soil test phosphorus (STP) levels when applications are based on crop nitrogen needs because more phosphorus (P) is provided in each unit of litter than the corresponding unit of grass removes. Increased STP in combination with site-specific soil and field characteristics may lead to P enrichment of surface and ground water. Phosphorus Indices (PI) are state-specific, site-specific algorithms to assess potential P loss that are used in the Nutrient Management Planning (NMP) process. These tools have been developed by individual state Natural Resource Conservation Service (NRCS) agencies under national policy guidance and integrated into the NRCS 590 Nutrient Management Conservation Standard since the late 1990's. Source factors such as STP, and nutrient source and management are used in combination with transport factors including soil characteristics, landscape characterization, and distance to nearest stream in various models to determine relative risk of P movement. Because of the leeway provided to the states, there are numerous versions of PI. Some are quantitative and predict P loss amounts; others, including Mississippi, are qualitative and assign relative risk. With higher risk of P movement to water as determined by PI categories, NMP preparation should assess potential mitigating Best Management Practices adoption. At issue are two recent published southern regional efforts that found differences in PI prediction capacity between state versions, including Mississippi. Individual state NRCS agencies, in cooperation with in-state partners, were asked to update their Nutrient Management Practice Standards in 2012, including reassessment of each state Phosphorus Index. In addition to the in-state standard revision with Mississippi NRCS, Mississippi State University is participating in a multistate effort under the national NRCS Conservation Innovation Grants to coordinate and advance P management in the southern region, ensuring that the PI have been tested based on new guidance in the NRCS 590 standard, and that tools produce more consistent results across physiographic regions in order to promote better consistency between southern state recommendations. This paper provides an overview of NMP, the factors used in the Mississippi Phosphorus Index, and additional efforts regarding NMP process in Mississippi.

Nutrient and Suspended Sediment Mitigation Through the Use of a Vegetated Ditch System Fitted with Consecutive Low-grade Weirs

Flora, C.; Kröger, R.

Mississippi is the largest producer of channel catfish (Ictalurus punctatus) in the United States. Channel catfish ponds cover over 20,000 hectares of land, mainly concentrated in the Alluvial Valley of northwest Mississippi. Water management practices to reduce mass discharge from ponds are currently a major point of concern, especially in light of potential regulations through nutrient criteria development. A vegetated ditch fitted with consecutive low-grade weirs is anticipated to be a practical and effective option of reducing nutrients and suspended solids entering downstream receiving systems. This study assesses the effect of low-grade weirs on chemical retention and settling of aquaculture pond effluent in a single drainage ditch. Nine embankment ponds were discharged at 48 hour intervals into a single vegetated drainage ditch fitted with 3 low-grade weirs. Two additional embankment ponds were discharged into the ditch while boards were removed from weirs, thus acting as a conventional ditch. Data were analyzed to quantify the ability of the low-grade weir system to reduce the levels of ammonia, nitrate, nitrite, total inorganic phosphorus, particulate phosphorus, and dissolved inorganic phosphorus. The levels of total suspended solids and volatile suspended solids will be compared across the system. As water passes each weir the nutrient and suspended solid loads should decrease through the system, overall reducing the load entering the downstream receiving systems.

Nutrient Reduction Benefits of On-Farm Water Storage Systems in Porter Bayou Watershed

Tagert, M.; Paz, J.; Pote, J.; McCraven, K.; Kirmeyer, R.

The Mississippi River Basin contains over 60% of the harvested cropland in the United States, and the Mississippi and Atchafalaya Rivers contribute more than three-fourths of the total nutrient load to the Gulf. Since the 1970's, groundwater levels in the Mississippi Alluvial Aquifer have decreased at a rate of approximately 100,000 acre-feet per year due to increased irrigated acres. Today, there are roughly 18,000 permitted irrigation wells dependent on water from the Mississippi Alluvial Aquifer, with an average addition of approximately 35,000 new irrigated acres per year for the past few years. Adequate supply of good quality water is important to sustaining agriculture, the primary industry in the economically depressed Mississippi Delta. Due to concerns over groundwater declines and increasing fuel costs to run irrigation pumps, farmers have begun implementing irrigation conservation measures, such as creating on farm storage areas to capture irrigation and surface water runoff from the field for later use. These systems offer farmers the dual benefit of providing water for irrigation and also capturing nutrient rich tailwater for on farm reuse. This project includes monitoring of two on farm water storage areas in the Porter Bayou Watershed, Mississippi and has two primary research objectives: a) determine the downstream nitrogen and phosphorous concentrations of effluent from water storage systems and b) quantify the effects of water storage systems on downstream flow levels through a watershed. Data collection began in February 2012, with water samples collected for analysis every three weeks throughout the growing season from March-October. Effluent nitrate and phosphorus levels were significantly lower than the inlet levels at both on farm storage systems.

Potential environmental risk of the phosphorus status in soils receiving poultry manure applications in Mississippi

Ramirez-Avila, J.; Oldham, J.; Kingery, W.; Crouse, K.; Ortega-Achury, S.

Phosphorus (P) enrichment of surface and ground water involves a combination of source factors such as high soil test phosphorus (STP) levels and site-specific soil and field characteristics that influence P transport by water flow overland and through the soils. Long-term applications of manure have generally increased STP levels to a greater degree than has fertilizer application because manure applied to meet the nitrogen (N) needs of crops provides more P than utilized by crops. Preliminary research found that subwatersheds within the poultry production counties in Mississippi have a high potential for soil and water degradation from manure P and N. An assessment was developed to increase understanding of STP levels in soils of the top 20 poultry production counties in Mississippi. The study performed a descriptive summary and analysis of temporal dynamics of STP in 15,057 soil samples, submitted for forage and pasture crop recommendations, after analysis by the Mississippi State University Extension Service Soil Testing Laboratory for 10 annual periods from 2002-2003 to 2011-2012. There were gradual annual changes in STP level ranges from the first (5 to 3780 lb ac^{-1}) to the last year (5 to 3980 lb ac^{-1}). Individual peak STP values of 5990 and 4840 lb ac^{-1} were observed in the 2nd and 7th year, respectively. However, mean STP levels increased from 113 lb ac^{-1} to 302 lb ac^{-1} from the first to the last year with the highest mean STP level of 356 lb ac^{-1} in the 7th year. The MSU Extension Service would not recommend additional external P for 69% of the soils sampled in the last year of the dataset; in the first year this value was 38%. These results indicate increased STP in these soils that could contribute P to runoff and leaching flows. Because of the susceptibility of these areas to manure source P leaching and runoff, Best Management Practices should be implemented that manage P source and off-field transport to minimize environmental impacts. Balancing P inputs with crop removal is an essential part of a sustainable practice to controlling P losses. Maintaining moderate STP levels or reducing high STP levels can reduce the potential for transport of P from both particulate and dissolved P. Comprehensive nutrient management plans should be developed and implemented for all poultry production operations for the optimal use of poultry manure.

Watershed Assessment and Mangement

Watershed Assessment and Management

Anna C. Linhoss *(Mississippi State University)*	Decision analysis for species preservation under sea-level rise
Brad Maurer *(The Nature Conservancy)*	Design and construction of Quarry capture prevention BMPs on the Buttahatchie River
Jonathan W. Pote *(Mississippi State University)*	Modeling the potential for water supply from a constructed lake in South Mississippi under present climate and projected climate change
Giusy Pappalardo *(Mississippi State University)*	Rivers and community engagement. Regulatory frameworks and practices in Europe and USA
Amy B. Alford *(Mississippi State University)*	Crayfish harvesting: Alternative opportunities for landowners practicing moist-soil wetland management

Decision analysis for species preservation under sea-level rise

Linhoss, A.; Kiker, G.; Aiello-Lammens, M.; Chu-Agor, M.; Convertino, M.; Munoz-Carpena, R.; Fischer, R.; Linkov, I.

Sea-level rise is expected to dramatically alter low-lying coastal and intertidal areas, which provide important habitat for shoreline-dependent species. The Snowy Plover (Charadrius nivosus) is a threatened shorebird that relies on Gulf Coast sandy beaches for nesting and breeding. Selecting a management strategy for the conservation of this species under sea-level rise is a complex task that entails the consideration of multiple streams of information, stakeholder preferences, value judgments, and uncertainty. We use a spatially explicit linked modeling process that incorporates geomorphological (SLAMM), habitat (MaxEnt), and metapopulation (RAMAS GIS) models to simulate the effect of sea-level rise on Snowy Plover populations. We then apply multi-criteria decision analysis to identify preferred management strategies for the conservation of the species. Two decision analysis techniques are compared: Multiple Attribute Utility Theory and Stochastic Multi-criteria Acceptability Analysis. We investigate four conservation strategies including no action, beach nourishment, nest exclosures, and predator management. Results show that predator management and nest exclosures are the most promising conservation strategies. This is an innovative method for planning for sea-level rise through pairing a linked modeling system with decision analysis to provide management focused results in an inherently uncertain future.

Design and Construction of Quarry Capture Prevention BMPs on the Buttahatchie River

Maurer, B.

Alluvial deposits (Holocen) have made the harvest of sand and gravel profitable in the Buttahatchie River watershed. Historically, excavations in and adjacent to the river have altered the location and stability of the channel. Many inactive, pre-regulation quarries are still found concentrated along the lower 20 km of the main channel. Construction of the Tennessee-Tombigbee Watershed, of which the Buttahatchie River is a tributary, and the resultant head-cutting, have further exacerbated the process of "quarry capture", whereby the river channel changes course into a quarry.

With partners from Mississippi State University, and with support from the US Fish & Wildlife Service, The Nature Conservancy has undertaken a project to develop and implement stabilization BMPs to prevent further quarry capture on the Buttahatchie River. Utilizing LiDAR mapping of the area and modeling of flow patterns, this project will identify points vulnerable to quarry capture, and design and construct appropriate stabilization techniques. Techniques are expected to be both specific to the individual characteristics of each site, and exportable to vulnerable channels in other watersheds.

Construction on the first stabilization project will be completed in the winter of 2013 in Monroe County, Mississippi, and will stabilize 1300 feet of river bank to prevent the river from changing course into several inactive gravel quarries adjacent to the river. This presentation will detail the project design, the selection of BMPs, the construction, and the outcome of the project. The BMPs will include bendway weirs, locked logs, and customized planting installed under very difficult conditions.

Modeling the Potential for Water Supply from a Constructed Lake in South Mississippi Under Present Climate and Projected Climate Change

Pote, J.; Wax, C.; Tagert, M.

The daily volume of water in a 5200 acre lake with a full capacity of 104,000 A-F in a coastal Mississippi location is simulated from 1961-2010. The lake basin is 17,550 acres, a runoff coefficient of 0.7 is used, base flow is set at 3 A-F/d, infiltration rate is set at 12 A-F/d, and outflow is set at 3 A-F/d. Inputs from the present climate regime are precipitation (P) minus potential evaporation (PE). Positive daily P-PE adds water to the lake and daily negative P-PE subtracts water from the lake. Climate change is projected by reducing daily P by 1.57% and increasing daily PE by 9.73%.

Cumulative P-PE for the average of all 50 years, the wettest year (1961), the median year (1993), and the driest year (2000), with and without climate change, is calculated. Factoring in the daily interaction between P and PE and comparing the present and changed climate by graphing the cumulative effect through the year shows that the annual pattern stays relatively the same day-by-day through each of the years and that the modeled climate change does reduce the end result in each of the years. For example, the average curves in both graphs show that under present climate the year ends at 19.77" but with climate change it ends at 13.85", a reduction of 5.32" or about 28% of the extra water. The median year curves show that without climate change the year ends at 24.55" but with climate change it ends at 19.75", a reduction of 4.8" or about 20% of excess water. The wettest year curves show the year ending at 54.65" but with climate change it ends at 48.40", a reduction of 6.55" or about 12% of extra water. The driest year curves show the year ending at -10.93" but with climate change it ends at -15.97, an increase in the year's deficit of 5.04" or about 46%.

Even in light of these potential changes in the average and extreme years, a 50-year daily analysis shows that both without and with climate change, the lake's volume drops no lower than about 97,000 A-F at any point in the period. The conclusion is that the climate of coastal Mississippi will sustain a surface water supply from a lake through known climate variability and proposed climate change in the future.

Rivers and Community Engagement. Regulatory Frameworks and Practices in Europe and USA

Pappalardo, G.

Environmental regeneration is not just a matter of natural science. Laypersons, different stakeholders, associations such as NGOs are crucial actors in managing ecosystems, at the grassroots level as well as at the institutional level. Gunderson, Holland et al (1995) describe the relationship between human organizational structures and nature, underlying how Sustainable Development is a process related to Social Learning. Even if the expressions Sustainable Development and Social Learning may have ambiguous meanings related to every different context, it is possible to find some similar issues at the global scale. The U.N. Rio Declaration on Environment and Development (1992) and its updated version Rio+20 show an arising awareness about the crucial role of local communities in taking care of the environment. Moreover, the Nobel Prize in Economic Science Elinor Ostrom (1991) proves the importance of collaborative practices and institutional reframing in order to overcome the Tragedy of the Commons (Hardin 1968).

This paper is aimed at describing and characterizing the process of Community Engagement in watershed management in Europe and USA. First, a critical review of the regulatory frameworks is examined, in order to explain similarities and differences between these two contexts. In Europe, the Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters (1998) is a milestone on the topic; then, the European Landscape Convention (2000) explains the strong relationship among physical heritage, cultural dimensions and inhabitants' perceptions. Furthermore, the specific Directive in matter of Water (2000/60/EC) is based on the same principles, i.e. broad involvement of the general public and different stakeholders, with different knowledge, values, interests and future perspectives. In U.S.A. the Environmental Protection Agency, with the Clean Water Act (1972) and 40 years of implementation phases, is moving the discussion toward a broader dissemination of participatory practices (Sirianni 2006).

After a comparative analysis of the aforementioned regulations, a multiple case-study research is discussed in order to understand in practice what is engagement, how is it related to watershed management, which are different paradigms and types of community involvement. The cases are selected according to the following characteristics: engagement as an opportunity to define a common vision for the future, starting from history and values of every context; engagement as a way to promote education and responsible behaviors in managing the water; engagement as a moment of dialogue amongst all community members. The outcome of the research is a typology that may operate as a guide in organizing communities that wish to manage ecosystems in a proactive and adaptive way.

Crayfish Harvesting: Alternative Opportunities for Landowners Practicing Moist-soil Wetland Management

Alford, A.; Grado, S.; Kaminski, R.

Harvest of crayfish (*Procambarus* spp.) for human consumption in the United States and beyond is considerable, amounting to an annual value of $150-170 million annually in the southern United States alone. Most crayfish harvested for human consumption are cultivated in rice fields in southern Louisiana. Management of emergent vegetation in moist-soil wetlands is similar to cultivation of rice where the seasonal wet-dry cycle of these wetlands encourages the growth of annual plants that produce abundant seeds and tubers for waterfowl forage. Recent aquatic invertebrate studies in moist-soil wetlands suggest that populations of crayfish in these habitats may be large enough to warrant a harvest for human consumption. To estimate the economic potential of crayfish harvests in moist-soil wetlands, crayfish yield was estimated from moist-soil wetlands on public and private lands in the MAV in Arkansas, Louisiana, Mississippi, and Missouri in spring-summer 2009-2011 using typical crayfish harvest strategies practiced in commercial rice-crayfish fields of Louisiana. Average daily yields of crayfish from moist-soil wetlands ranged from 0.08 kg/ha to 23 kg/ha with an overall mean yield of 2.73 kg/ha ($n = 42$, $CV = 21\%$). Whereas the mean daily yield of crayfish from moist-soil wetlands was >3 times less than the yield expected from a high production rice-crayfish culture system (e.g., 8-10 kg/ha), estimated cost associated with harvest of crayfish from moist-soil wetlands were $529/ha and were lower compared to costs associated rice-crayfish harvest practices which were estimated to be $1,856/ha. However, the estimated break-even selling price for crayfish harvested from moist-soil wetlands was $4.90/kg compared to $2.75/kg estimated for rice-crayfish practices. The estimates of break-even selling prices for crayfish harvested from moist-soil wetlands were higher than the 2012 estimate of $2.75/kg price for single crop production of crayfish in Louisiana. However, in areas where crayfish markets are sparse, such as the North Mississippi Delta, landowners may still realize economic potential from this fishery. Harvesting crayfish from moist-soil wetlands may provide a small profit to landowners but will likely provide additional recreational opportunities and can serve as additional extension vehicles to encourage wetlands conservation throughout the MAV.

Stormwater Assessment and Mamagement

Stormwater Assessment and Managment

Tahmina Shirmeen *(University of Mississippi)*	Modeling rainfall runoff using 2D shallow water equation
Emily Overbey *(Mississippi State University)*	Urban flow-through facilities' soil media compositions for stormwater quality and quantity improvements
Jejal Reddy Bathi *(Global Solutions International, LLC)*	Introduction to changing site design standards for stormwater management
Warren "Cory" Gallo *(Mississippi State University)*	Implementing green infrastructure through new policies and tools
Xiaobo Chao *(University of Mississippi)*	Numerical modeling of sediment-associated water quality processes in natural lakes

Modeling Rainfall Runoff using 2D Shallow Water Equation

Shirmeen, T.; Jia, Y.

Torrential storms often trigger flooding that causes damage in properties and loss of life. In this study a numerical simulation module is developed to enhance the capability of a 2D surface flow model, CCHE2D. Following the procedure for numerical model verification and validation of ASCE, the developed module is tested using both analytical solutions and experiment data.

The analytical solutions of kinematic wave equation for runoff occurring on a sloping plane subject to a constant rainfall of indefinite duration and finite duration were used to compare to the results of the numerical model with good agreements. Runoff processes measured in laboratory experiments were also simulated in this study using the 2D model. The simulated runoff processes and the observed physical processes again showed excellent agreements. These tests indicate that the CCHE2D model is capable of modeling rainfall-runoff and kinematic overland flows.

INTRODUCTION

Modeling rainfall-runoff is necessary to understand the physical process, predict what would happen on the ground and better protect the stormed areas from flooding and enhance public safety. When the rainfall intensity exceeds soil infiltration, water begins to accumulate on the ground surface and then flows as overland flow under the force of gravity. In order to simulate the rainfall-runoff process, the depth averaged shallow water equations known as Saint-Venant (SV) equations or 2D shallow water equations are usually applied. Zhang and Cundy (1989) used a finite-difference 2D shallow water model to simulate the rainfall-runoff experiments performed by Iwagaki (1955) in a three-slope laboratory flume. Shallow water models based on the depth averaged shallow water equations (2D-SWE) were extensively used to compute the flow field (Zhang & Cundy 1989, Kivva and Zheleznyak, 2005). 1D Kinematic wave theory has been used successfully to describe overland flows (Woolhiser and Ligget, 1967; Freeze, 1978; Cundy and Tento, 1985). Kinematic wave modeling requires the specification of geometry, kinematic equations, inflow, and initial and boundary conditions (Singh and Regl, 1981). Depending on the terms of the momentum equation which are considered, various approximations of these equations are used. The kinematic approximation is the simplest; where the friction slope is set equal to the bed slope and the pressure and inertial terms are ignored (Book et al, 1981).

In this study the model verification was carried out analytical solutions to compare the performances of the kinematic wave equations by Singh and Regl (1981) and Singh (1983). The first test case was derived using analytical solutions of kinematic equations for erosion occurring on a sloping plane which is subject to a constant rainfall of indefinite duration and the second test case was derived using constant rainfall of finite duration. Both test cases have been studied for a one dimensional plane.

In this paper, in particular two laboratory experiments used to compare the performances of enhanced numerical model. The first test case was obtained by Gottardi and Venutelli (2008) which involves a comparative analysis of 2D numerical models for overland flow simulations. The second test case obtained by Cea et al. (2008) presents some results which include rainfall runoff experimental results obtained in a 2D laboratory model.

Numerical solution scheme

A developed shallow water flow model called the CCHE2D (Jia et al. 2002) is used as the hydrodynamic flow model for simulating the rainfall-runoff overland flow. CCHE2D is a hydrodynamic model for unsteady turbulent open channel flow and sediment transport. The governing equations for hydrodynamics are as follows:

$$\frac{\partial h}{\partial t}+\frac{\partial uh}{\partial x}+\frac{\partial vh}{\partial y}=R \tag{1}$$

$$\frac{\partial uh}{\partial t}+\frac{\partial uuh}{\partial x}+\frac{\partial vuh}{\partial y}=-gh\frac{\partial \eta}{\partial x}+\left(\frac{\partial h\tau_{xx}}{\partial x}+\frac{\partial h\tau_{xy}}{\partial y}\right)-\frac{\tau_{bx}}{\rho}+f_{Cor}v \tag{2}$$

$$\frac{\partial vh}{\partial t}+\frac{\partial uvh}{\partial x}+\frac{\partial vvh}{\partial y}=-gh\frac{\partial \eta}{\partial x}+\left(\frac{\partial h\tau_{yx}}{\partial x}+\frac{\partial h\tau_{yy}}{\partial y}\right)-\frac{\tau_{by}}{\rho}-f_{Cor}u \tag{3}$$

where *u,v* depth-integrated velocity components in *x* and *y* directions, *g* the gravitational acceleration, *η* is the water surface elevation, *h* is the local water depth f_{Cor} is the Coriolis parameter, T_{xx}, T_{xy}, T_{yx}, T_{yy} are depth integrated Reynolds stresses, T_{bx}, T_{by} shear stresses on the bed, *R* rainfall intensity. The 2D shallow water equations are solved using mixing finite element and finite volume methods with structured rectangular grid. Partially staggered grid is used for solving these equations. When runoff process is computed, the turbulence stress terms are neglected, because under this condition, the dominant forcing of the flow is the gravity term, momentum advection and bed shear stress. In the present simulation the Manning formula has been used to express the bed friction as

$$\tau_{bx}=\frac{1}{h^{1/3}}\rho g n^2 uU \tag{4}$$

$$\tau_{by}=\frac{1}{h^{1/3}}\rho g n^2 vU \tag{5}$$

Because

$$\frac{\partial \eta}{\partial x}=\frac{\partial h}{\partial x}+\frac{\partial b}{\partial x}$$
$$\frac{\partial \eta}{\partial y}=\frac{\partial h}{\partial y}+\frac{\partial b}{\partial y} \tag{6}$$

where, *h* is the local water depth and *b* is the thickness of the bed. When runoff is simulated, the water depth is very small and parallel to the runoff slope, one has

$$\frac{\partial \eta}{\partial x}\approx\frac{\partial b}{\partial x} \quad and \quad \frac{\partial \eta}{\partial y}\approx\frac{\partial b}{\partial y} \tag{7}$$

Equation (2) and (3) are simplified approximately to kinematic wave equations. Therefore they can be tested using analytical solutions for the kinematic wave equation. The general forms of these equations make them applicable for general flow conditions.

Analytical solution

The analytical solution for the model tests was obtained by Singh and Regl (1981) and Singh (1983), for solving one-dimensional kinematic equation for rainfall generated runoff. The first test case involves analytical solutions of kinematic wave equation for runoff occurring on a sloping plane subject to a constant rainfall of indefinite duration and the second test case uses the constant rainfall of finite duration. The governing one dimensional kinematic equation can be obtained be simplification of Eq. (1) and (2), and written as:

$$\frac{\partial h}{\partial t}+u\frac{\partial h}{\partial x}=R \tag{8}$$

$$u=\alpha h^{n-1}; \quad Q=uh=\alpha h^{n} \tag{9}$$

where *h* is depth of flow *(m)*, *u* velocity of flow *(m/s)*, *Q* discharge of water per unit width *(m²/s)*, *R* lateral inflow or the effective rainfall *(m/s)*, *a* depth-discharge coefficient m^{2-n}/s and *η* an exponent (=5/3) Substituting Eq. (9) into Eq. (8) , the kinematic-wave equation can be then written as:

$$\frac{\partial h}{\partial t} + n\alpha h^{n-1}\frac{\partial h}{\partial x} = R \tag{10}$$

Table 1 shows the conditions of the two analytic cases.

The analytical solution described above has been verified using numerical model. Figure 1 and Figure 2 show the comparisons of the analytical solutions. In the numerical simulation, verification is necessary because one must need to assure that the numerical model is free of faults in mathematical formulations. Figure 1 shows the runoff hydrographs of Case 1 at several locations of the slope including the downstream boundary, obtained by analytical solution by Singh and Regl (1981) and numerical solutions by CCHE 2D model. The mesh resolution affects the results slightly particular at the very downstream of the domain. Figure 2 showing the analytical solution (Singh, 1983) and simulated runoff hydrographs of Case 2 at several locations of the slope. Because this is a case with a rainfall of finite duration, the hydrographs have a difference pattern.

MODEL VALIDATION

The enhanced model is tested using four laboratory experiments. All of the cases are validated using the analytical solution and also using numerical solution of CCHE2D. The application carried out on impervious surface, so that the lateral inflow *R* coincides with the rainfall. Various situations are examined for the validation test, particularly the rainfall intensity variable in time is considered.

Test Case 1

This runoff laboratory experiments was conducted by Gottardi and Venutelli (2008). They proposed an accurate time integration method for the diffusion-wave and kinematic-wave approximated models for the overland flow obtained by using the second-order Lax-Wendroff and the three-point centered finite difference schemes. This simple example of flow was carried out along an inclined plane of length L = 200m and of unit width with uniform rainfall of R = 60 mm/h for t = 1 hr. The slope of the plane was 0.001 and Manning roughness n_m = 0.03 $m^{-1/3}s$. The time of concentration t_c, for this experiment, when the outflow equals the rainfall rate, is t_c = 31.6 min. Figure 3 shows the runoff hydrographs at the downstream boundary, obtained by the experimental case Gottardi and Venutelli (2008), analytical solution by Singh and Regl (1981) and by CCHE2D model. In Figure 3 the simulated processes and the observed physical processes showed excellent agreements and the arrival time and the maximum discharge are in good agreement with the analytical solution.

Test Case 2

Runoff laboratory experiments over simple geometries were also modeled recently by Cea et al. (2008). These experiments originally carried out by Iwagaki (1955) in a two dimensional geometry and used as a validation test in Cea et al. (2008). In this 2D rainfall-runoff test case, the watershed is a rectangular basin made of three stainless-steel planes (2m x 2.5m). Each of the planes has a slope of 0.05. Two dikes are located at a distance of 0.32m and 1.74m from the bottom left plane and 0.56m and 1.18m from top plane respectively. Height of the dikes was 1.86m and 1.01m respectively. Figure 4 shows the 3D mesh and the flow field near the dike. As the bed surface is impervious, infiltration was not involved for three test scenarios.

Test Case 2A

Three scenarios have been modeled using three different rainfall patterns. In the first scenario (test case 2A) rainfall intensity was 317 mm/h and the duration is 45s. Figure 5 shows the comparison between the numerical and experimental outlet hydrograph. The simulated processes and the observed physical processes showed excellent agreements. The shape of the hydrograph is well predicted and also the peak discharge.

Test Case 2B

In the second scenario (test case 2B) rainfall intensity was 320 mm/h, the rain has two peaks of 25s with 4 seconds apart. Figure 6 shows the comparison between the numerical and experimental runoff hydrograph. Again the simulated processes and the observed physical processes showed excellent agreements. The shape of the hydrograph is well predicted and also captured both of the peak discharge.

Test Case 2C

In the third scenario (test case 2C) rainfall intensity was 328 mm/h, similar to second test, but the rainfall paused for 7s before the second peak. Figure 7 shows the comparison between the numerical and experimental runoff hydrograph. The simulated processes and the observed physical processes showed excellent agreements. The shape of the hydrograph is well predicted and both of the peak discharges are captured well.

CONCLUSION

In this paper a comparative analysis a 2D shallow water model, CCHE2D have been performed to simulate rainfall runoff and overland free surface flows. The depth averaged mass and momentum conservation equations are solved, considering the effects of bed friction, bed slope and precipitation. For the verification and validation tests, analytical and experimental cases and numerical simulation results are presented. Spatial variation of rainfall is incorporated in the model and good agreement between the observation and simulation is obtained. The experimental validation of the model are also encouraging and indicated that the CCHE2D model is capable of modeling rainfall-runoff and kinematic overland flows. Future investigations will focus on more complex, real world scenarios such as watershed and urban flood simulation due to storm events as well as in the design of hydraulic structures to mitigate and control flood risks.

ACKNOWLEDGMENT

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Table 1. Rain rate and conditions for Figures 1 and 2

Test Case	Rainfall, *R* (m/s)	Depth discharge coefficient, *a* (m^{2-k}/s)	Manning, *n* ($m^{-1/3}s$)	Duration, T (s)
Case1 (Singh and Regl, 1981)	2.7×10^{-5}	5	0.02	1000
Case2 (Singh, 1983)	2.7×10^{-5}	5	0.02	200

Table 2. Rain rate and conditions for Figures 3, 5, 6 and 7

Test Case	Slope, S	Manning, *n* ($m^{-1/3}s$)	Rainfall, *R* (mm/hr)
Case1	0.001	0.03	60
Case 2A	0.05	0.02	317
Case 2B	0.05	0.02	320
Case 2C	0.05	0.02	328

Figure 1: Runoff hydrograph for analytical solution and numerical solution by CCHE 2D for rainfall of indefinite duration.

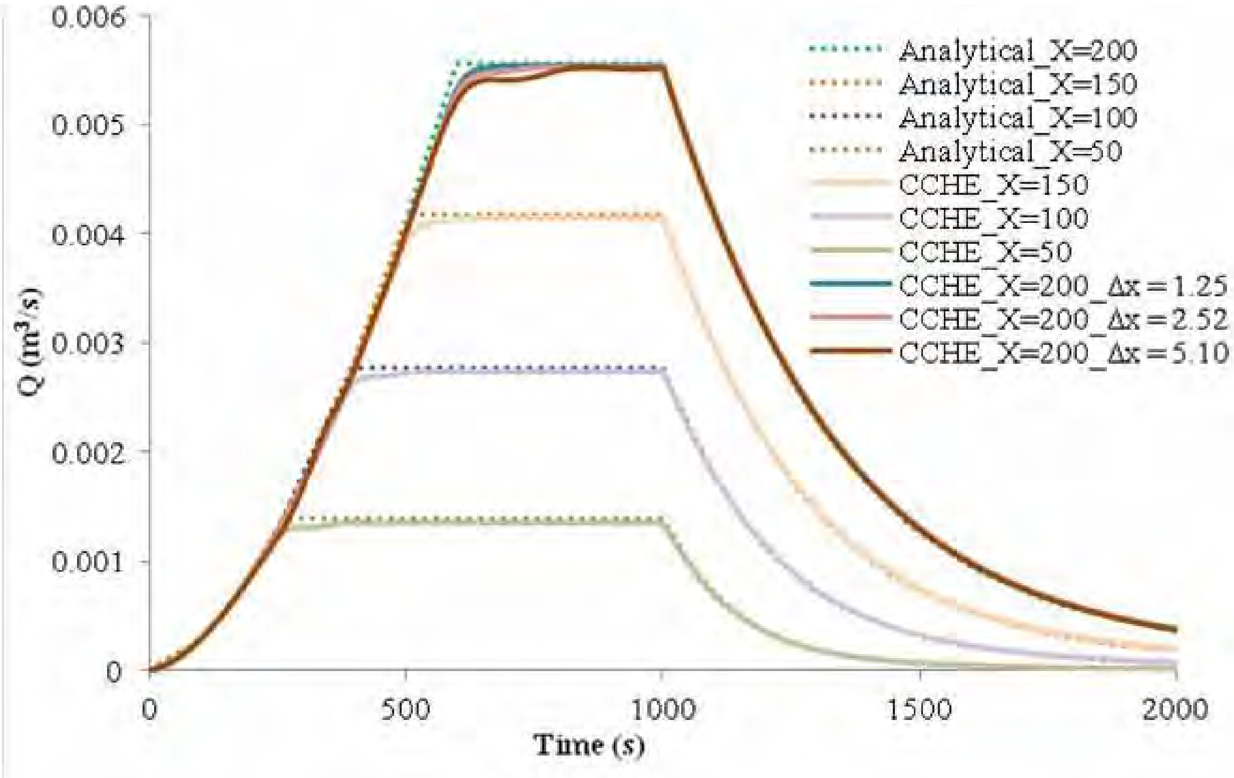


Figure 2: Runoff hydrograph for analytical solution and numerical solution by CCHE 2D for rainfall of finite duration.

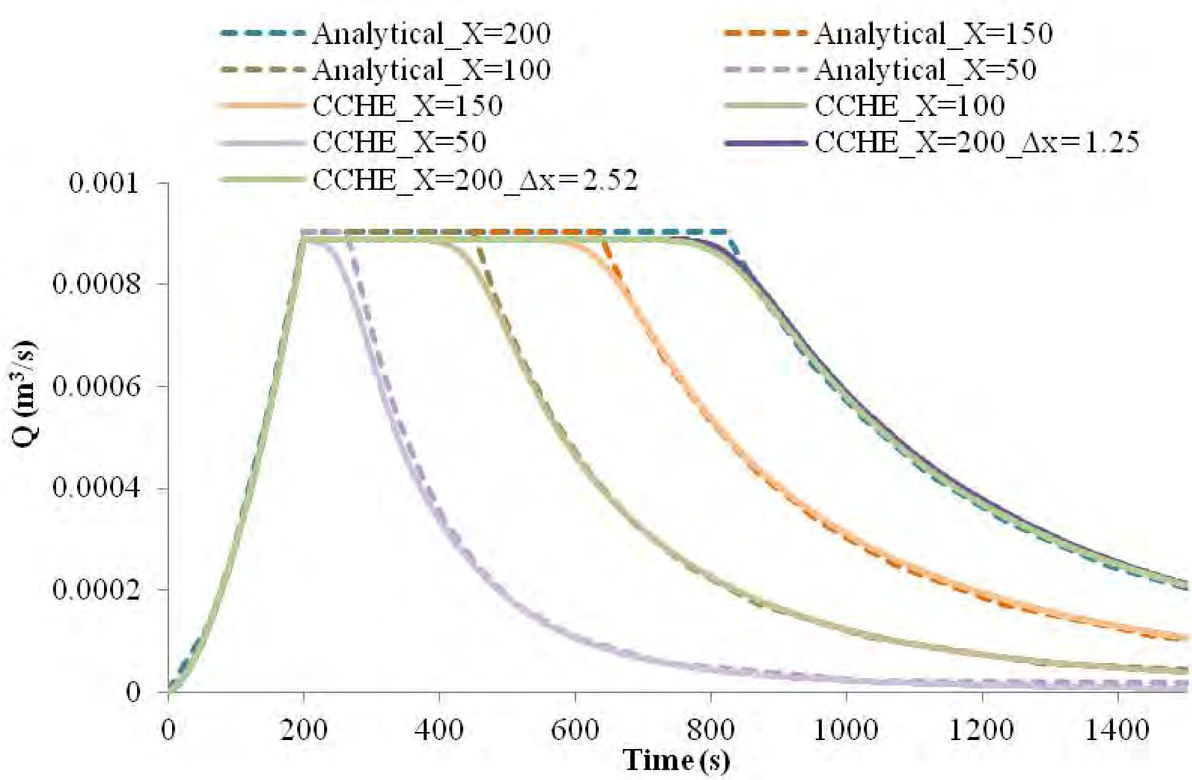


Figure 3: Runoff hydrograph for analytical solution, experimental data (Gottardi et al. 2008) and numerical solution by CCHE2D

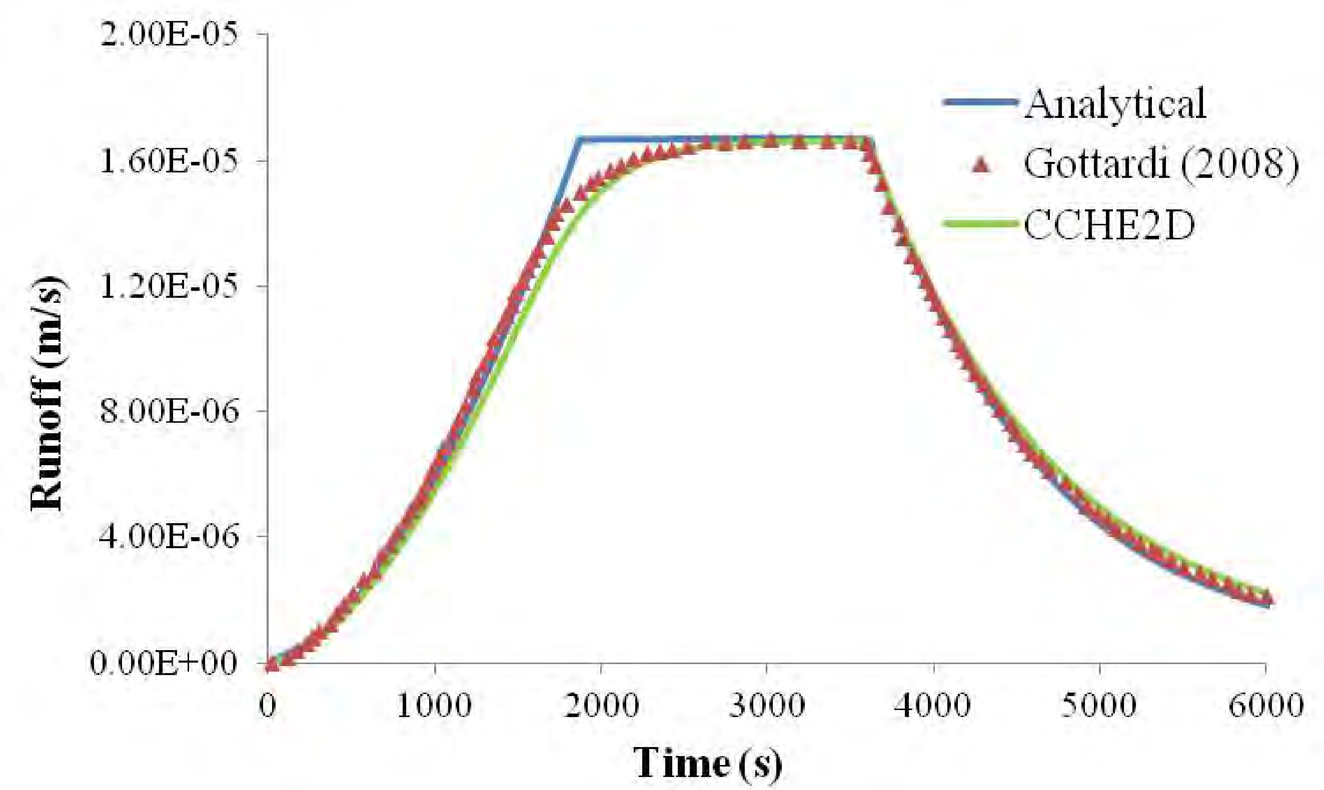


Figure 4: 3D mesh geometry (left) and water depth and velocity after the rain stops (T = 50s) (right) for test case 2

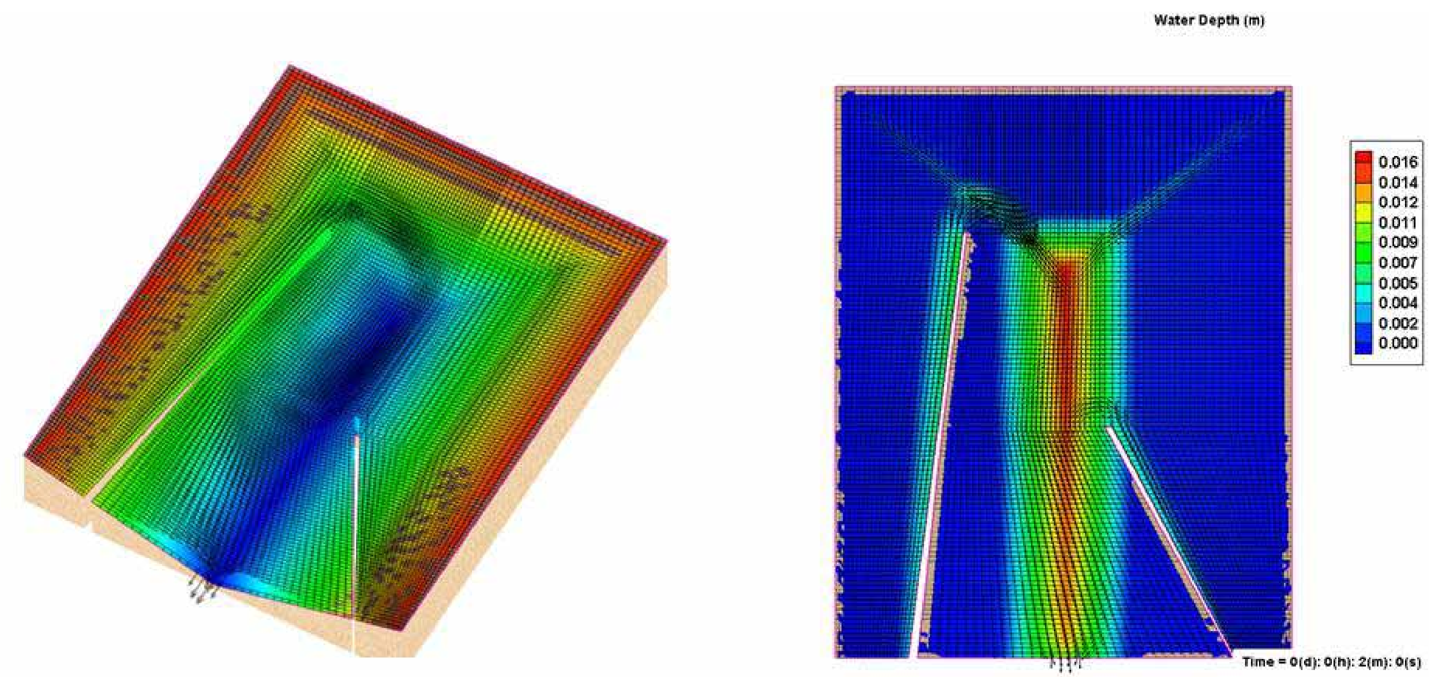


Figure 5: Runoff hydrograph for 2D validation test case 2A

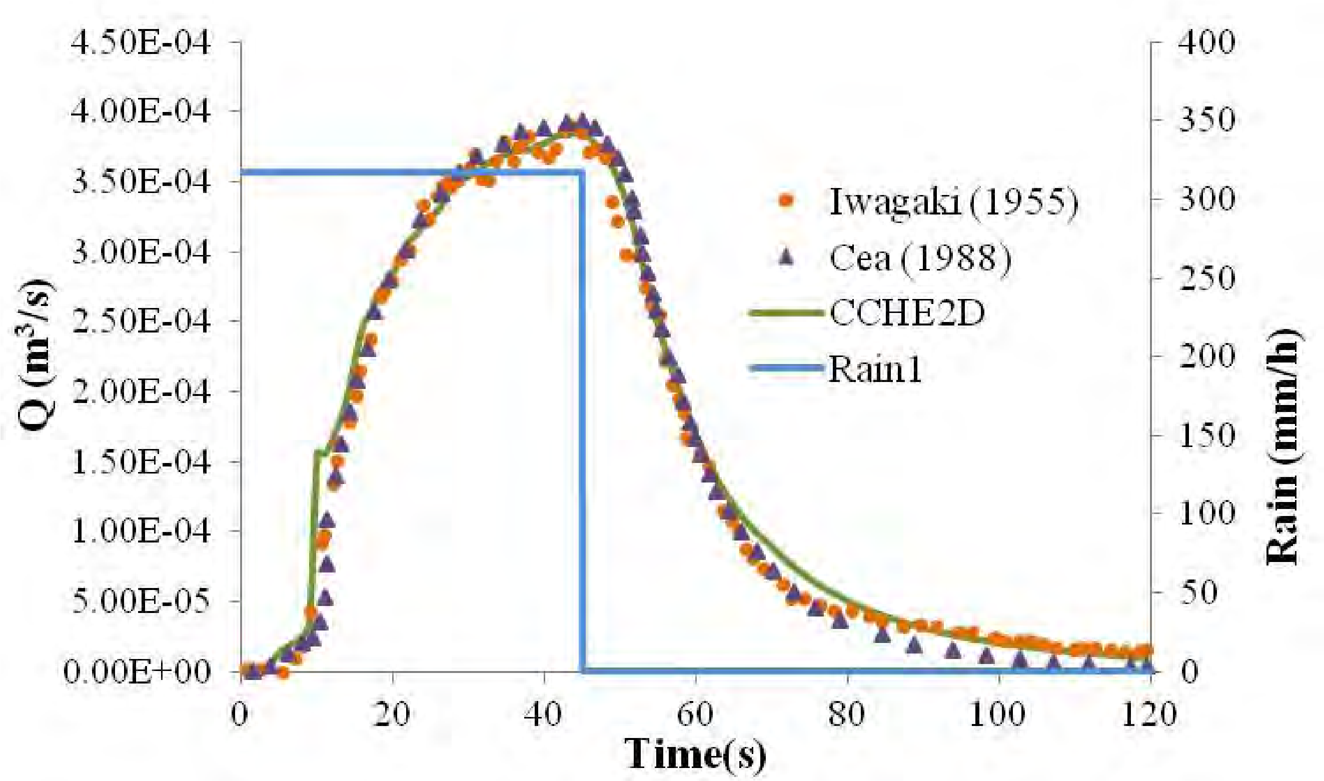


Figure 6: Runoff hydrograph for 2D validation test case 2B

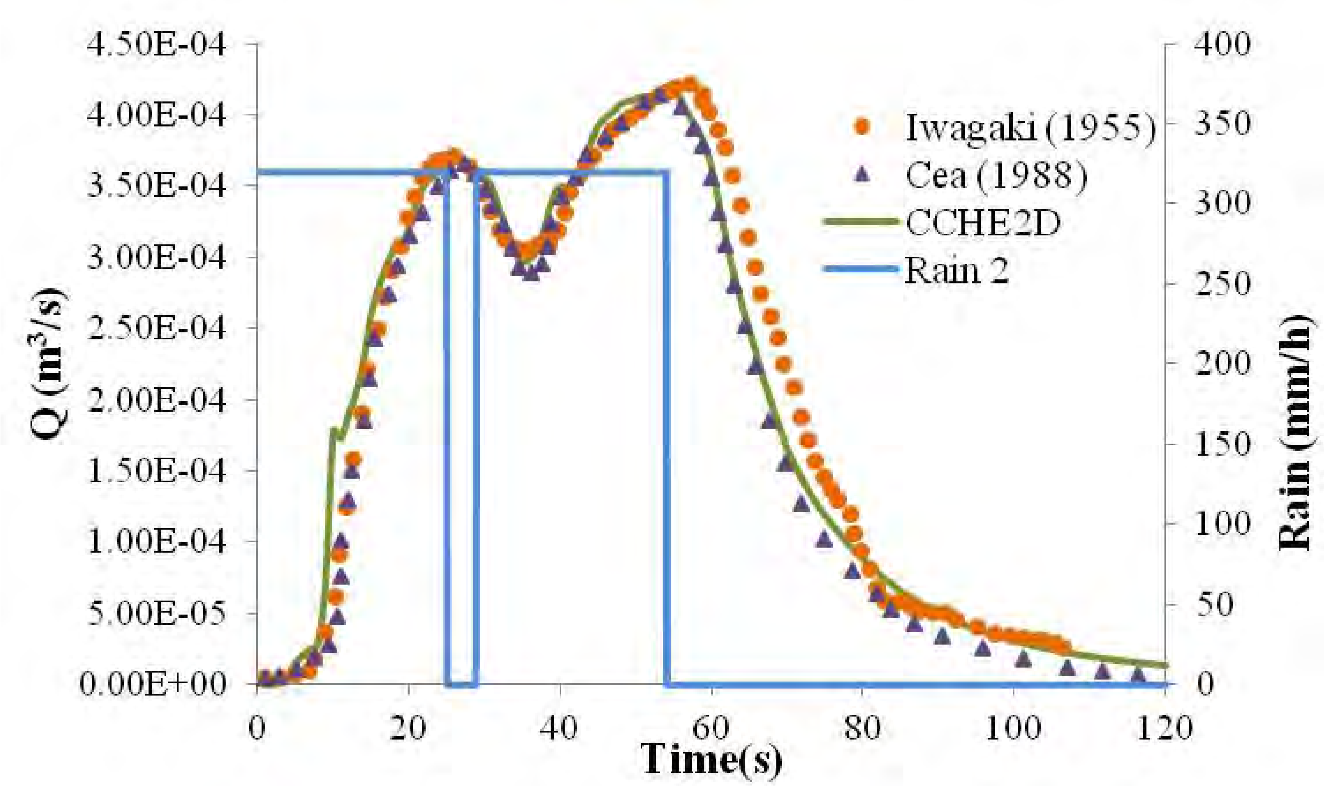
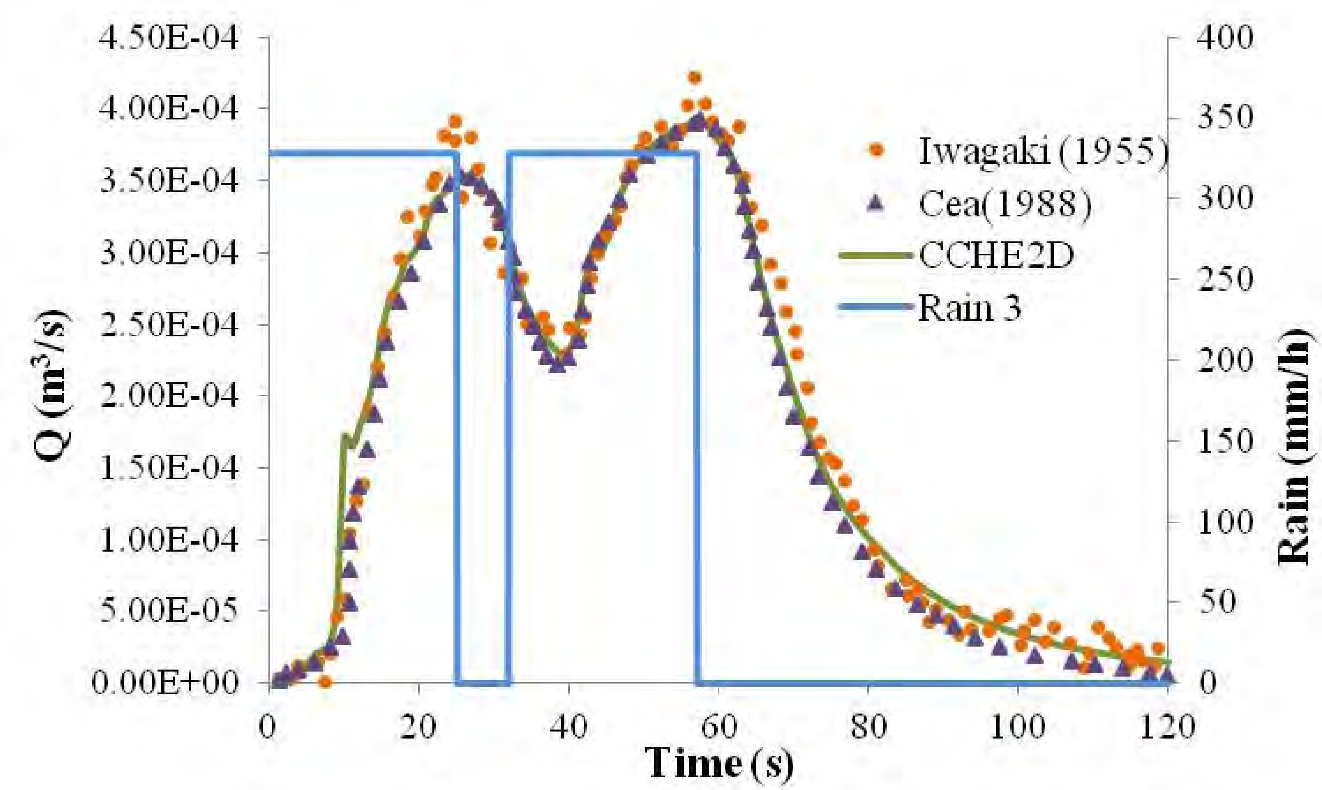


Figure 7: Runoff hydrograph for 2D validation test case 2C



Urban Flow-Through Facilities' Soil Media Compositions for Stormwater Quality and Quantity Improvements

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An emerging practice for reducing the amount of nutrients and pollutants entering receiving waters is to filter urban stormwater runoff with infiltration based best management practices (BMPs). Small-scale BMPs for urban environments such as rain gardens, bioretention facilities, flow-through planters, and green roofs have been shown to slow peak flows and reduce the amount of nutrients that are washed from impervious surfaces during storm events. These BMP technologies are relatively new in design practice and all aspects of their structural design, potential for nutrient removal, and peak flow reduction is yet to be fully examined. The objective of this study is to provide understanding of different soil compositions in flow-through planters currently used in practice and determine their potential for water quality and quantity improvements. Eighteen 30"x18"x12" aquaria were modified to model flow-through facilities in a practical application using synthetic runoff which contained a 2ppm mixture of nitrogen and phosphorus. Soil mixtures varied across treatments and were composed of different percentages of sand, topsoil and compost. A hydrograph was used to simulate the most intense 4.5 hours of a 2-inch, Type II 24-hour rainfall event and was applied to the aquaria using manually controlled flow rate pumps. The outflow hydrograph was recorded to determine if peak flow was reduced and water quality samples were collected and analyzed to determine if nitrate and phosphate retention differed between soil treatments. Water quality data analyses indicate phosphate retention values ranged from (33-81%) and poor retention of nitrate (4- 23%). Nitrate values showed increases in concentration for some treatments. Preliminary results indicate the need for modification of the study design as higher infiltration rates in soil treatments reduced the residence time expected for the stormwater runoff in these facilities and as a result did not allow for the desired reduced peak flow. Further research is needed to test structural design modifications of flow-through facilities in order to increase their quantity reduction performance.

Introduction to Changing Site Design Standards for Stormwater Management

Bathi, J.; Rhoads, S.

A recent regulatory trend is to base storm water control requirements on the total volume of storm water runoff from a site rather than on runoff rates or a specific pollutant removal rate. This trend is based on a growing body of research which has concluded that volume-based controls accomplish the concurrent benefits of pollutant reduction, peak flow reduction, and base flow protection. The focus on runoff volume as the common currency for best management practices evaluation is gaining wider acceptance across the country. Current regulations in the region demand a high level of stormwater infrastructure to meet the total volume of detention storage required. Instead, the evolving volume based controls have been proving to be less cost intensive with distributed green technologies at the source level. The purpose of this paper is to provide an overview of new volume based standards and rainfall frequency analysis procedures for selecting the appropriate control matrix for an area. In addition, we have summarized commonly used green infrastructure practices, and outlined available computer models for designing and evaluating site level green infrastructure techniques.

INTRODUCTION

As the modern world continues to develop, stresses on the natural environment continue to increase as well. Urbanization and development in recent decades have escalated drastically which has only augmented these stresses on the natural environment. A major issue with urbanization is the increase in stormwater runoff and its negative effects on the natural surroundings. Stormwater runoff changes predevelopment hydrologic conditions and carries pollutants into the watershed which obviously is undesirable and negatively impact ecosystems, stream channels, and all aspects of the natural environment. Currently regulations are in place which primarily requires developers to design stormwater detention/retention such that the post-development runoff rate equals the pre-development runoff rate. Commonly detention/retention facilities are required to design for 25 year event with outlet structure or a spill way and emergency spill way for 100 year event. Removal of 80% of total suspended solids (TSS) from the post-development site runoff on an annual basis is commonly used as the water quality control requirement. However the changing approach is the use of Green Infrastructure (GI) at the site level. GI is a concept which implements natural elements to treat rainwater close to its source in an attempt to minimize and manage stormwater runoff volume, runoff pollution, and changes in natural hydrologic conditions. GI focuses on long term sustainability and affordable solutions to the issues presented by increasing urbanization.

Growing research and scientific development has proven that required runoff control of evolving regulations is possible through employment of systems and practices that use or mimic natural processes to; 1) infiltrate and recharge, 2) evapotranspire, and/or 3) harvest and use precipitation near to where it falls to earth. Best management practices (BMPs) that use low impact development (LID) techniques incorporated with GI are the most attractive control systems currently available for runoff control or treatment. Performance of LID/GI controls were demonstrated by several case studies and are reported elsewhere. The promise of runoff reduction is that the benefits go beyond water quality improvement.

New trends across the country, both at state and local community levels, for post development site design standards are requiring developers to retain the runoff volume at the site. Often these standards are implemented as a requirement to capture runoff resulting from a rainfall depth that is typically found at a frequency in their area i.e. events that occur 90% or 95% of the time, etc. Current Environmental Protection Agency (EPA) regulations require all new and re-development federal facilities to retain runoff volumes corresponding to rainfall events that occur 95% of the time. But in the case where the 95th percentile design is found not to provide sufficient protection to maintain or restore the pre-development site hydrology, site specific hydrology analysis needs to be conducted at federal facilities. Overall, the intent of the new approach for regulations in terms of runoff control is to maintain the pre-development hydrology at a development site to protect and preserve both the water resources onsite and those downstream. Figure 1 demonstrates the comparative site hydrology with runoff volume control requirements.

However, before any such new design standards are established for a community, as a first step, it is essential that long term representative rainfall data is reviewed and appropriate rainfall depth for site design standards be established that is both feasible for your area, for implementation, and is protective of public health and property. In this paper we have presented the approach recommended for analysis of rainfall data to determine percentile rainfall and the approach is demonstrated through analysis of long term rainfall data observed at Birmingham International Airport. There are also a number of computer modeling softwares which were developed for designing and evaluating LID/GI performance for a variety of site development scenarios. As part of this paper we have presented short descriptions of several common LID/GI techniques that are used for site hydrology control as well as presented basic information on the available LID/GI computers models.

VOLUME CONTROL APPROACH

Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act has recommended two approaches to meet requirements. The two approaches for meeting requirements are as follows: Option 1 is to retain the 95th percentile rainfall event; Option 2 is site-specific hydrologic analysis. When Option 1 is not protective enough to maintain or restore the predevelopment hydrology of the project (for example, in some headwater streams), Option 2 could be used to determine the types of stormwater practices necessary to preserve the predevelopment runoff conditions. Option 2 could also be used if predevelopment runoff conditions can be maintained by retaining less than the 95th percentile rainfall event. Because a performance based approach was selected in lieu of a prescriptive requirement in order to provide site designers maximum flexibility in selecting control practices appropriate for the site, Option 2 was provided in recognition that there are established methodologies that can be utilized to estimate the volume of infiltration and evapotranspiration based on site-specific hydrology and thus establish the predevelopment hydrology performance design objectives (ESA 2009).

Calculating the 95th Percentile Rainfall Event

Section E of the Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act contains information on how to calculate the 95th percentile rainfall event for a specific area. A long-term record of daily rainfall amounts (ideally, at least 30 years) is needed to calculate the 95th percentile rainfall.

Designers opting to use Option 1 need to do the following:

Step 1: Obtain a long-term rainfall record from a nearby weather station (daily precipitation is fine, but try to obtain at least 30 years of daily record). Long-term rainfall records can be obtained from many sources, including NOAA at the following link: http://cdo.ncdc.noaa.gov/

pls/plclimprod/poemain.accessrouter?datasetabbv=SOD&countryabbv=&georegionabbv.

Step 2: Remove data for small rainfall events that are 0.1 inches or less and snowfall events that do not immediately melt from the data set. These events should be deleted since they do not typically cause runoff and could potentially cause the analyses of the 95th percentile storm runoff volume to be inaccurate.

Step 3: Using a spreadsheet or simple statistical package, sort the rainfall events from highest to lowest. In the next column, calculate the percentage of rainfall events that are less than each ranked event (event number/total number of events). Use the rainfall event at 95% as the 95th percentile storm event.

Designers opting to use Option 2 need to do the following:

Option 2 requires the designer to conduct a site-specific hydrologic analysis to determine the pre-development runoff conditions instead of using the estimated volume approach of Option 1. Under Option 2, the pre-development hydrology would be determined based on site-specific conditions and local meteorology by using continuous simulation modeling techniques, published data, studies, or other established tools.

If the designer elects to use Option 2, the designer would then identify the pre-development condition of the site (example, undistributed open lot) and quantify the post-development runoff volume and peak flow discharges that are equivalent to pre-development conditions. The post-construction rate, volume, duration and temperature of runoff should not exceed the pre-development rates and the predevelopment hydrology should be replicated through site design and other appropriate practices to the maximum extent technically feasible (ESA 2009).

Birmingham, AL Rainfall Analysis

Data Source: As mentioned earlier, long term rainfall data, at least a 30 year period, is required for percentile rainfall analysis such that the long period of data can account for temporal changes that may have occurred over the time. A weather station located at Birmingham International Airport has the continuous period of monitored rainfall data longer period that is geographically representative of the City's watershed area. This particular rain gauge is located within the City of Birmingham and use of monitored data from the gauge is believed to be a good representation of weather conditions in the city. The weather station is maintained by National Weather Services (NWS) and its latitude and longitude are 33.5656 and -86.745, respectively. For the purpose of current analysis, monitored hourly rainfall data from the station for the period of June 1948 – December 2010, excluding data for October 1978 – July 1987, was obtained as a download from the Environmental Protection Agency's Better Assessment Science Integrating point & Non-point Source (BASINS) modeling tool. The hourly data was converted to daily data for analytical purposes.

Data Analysis: As described in the guidance document for federal facilities, a percentile rainfall event represents a precipitation amount which the given percent of all rainfall events for the period of record do not exceed. In more technical terms, the given percentile rainfall event is defined as the measured precipitation depth accumulated over a 24-hour period for the period of record that ranks as the given percentile rainfall depth based on the range of all daily event occurrences during this period. Percentile analysis presented in this memo determines a data value for a specified percentage. For example, if the 85th percentile rainfall depth is analyzed and a value of 1.00 inch is determined, 85 percent of all rainfall events produce 1.00 inch or less of precipitation. The analysis includes 24-hour periods with measurable rainfall and excludes all other 24-hour periods. In addition, Small rainfall events that are 0.1 of an inch or less are excluded from the percentile analysis because this rainfall generally does not result in any measureable runoff due to absorption, interception, and evaporation by permeable, impermeable, and vegetated surfaces. Also, for the purpose of analysis, the 24-hour period is typically defined as 12:00:00 am to 11:59:59 pm, hence the total rainfall occurring on a calendar day is considered as an event.

The compiled daily rainfall data was analyzed per the steps described in ESA 2009 for federal facilities. Results of analysis are illustrated in Figure 2 and data values for selected percentiles are presented in Table 1. The average 24-hour rainfall depth of the analyzed events was found to be 0.68 inches, which is equivalent to about the 64th percentile of the rainfall events for the area.

A time series plot of the rainfall data is illustrated in Figure 3. As expected and observed in the percentile rainfall depth analysis, most of the rain events had depth below average, which is also indicated by concentrated rainfall events close to the base in the Figure.

Overall, as expected most of the rainfall events had depths below average. It will be at the discretion of the regulators to choose the appropriate rainfall depth as their design standard for post-development site stormwater controls design such that post-development hydrology of the site is protected. At the same time the chosen rainfall depth should be such that the corresponding runoff will be technically feasible to control by established stormwater practices.

GI/LID TECHNIQUES

Previous methods for stormwater management have used methods that provide either costly BMPs such as large facilities located near the end of the drainage area, or “grey infrastructure” practices which show practically no stormwater control and include conventional stormwater piping networks that collect runoff from the impervious urban area and carry it into the local drainage basin or to a wastewater treatment plant. LIDs are practices used in the green infrastructure concept which can preserve or restore a watershed’s natural hydrologic conditions through fashioning a landscape that imitates natural hydrologic processes. GI/LID has become increasingly important as stormwater control requirements have been trending towards greater regulation on runoff volume control at a site to accomplish pollutant reduction and to maintain natural hydrologic conditions. GI/LID techniques manage rainwater through infiltration, evapotranspiration, and re-use while providing additional benefits such as improved aesthetics, improved habitats, and increases in property value and lifestyle quality. In short, GI/LID practices are believed to be the present and future of stormwater control and can help offset the adverse effects of urbanization on watersheds through cost effective and environmentally sustainable means. Some of the most common and effective LID techniques include bioretention, green roofs, vegetated swales, permeable pavements, disconnected downspouts, and rain barrels or cisterns. A brief explanation of each practice is provided below.

Bioretention

Bioretention areas, sometimes referred to as rain gardens, are stormwater management systems which provide on-site treatment of stormwater runoff using vegetation and modified topsoil. These areas are located at the lowest point of a small drainage area, such as a parking lot, and have a concave shape. Grass buffers can be used around the rain garden to help reduce runoff velocity and to act as a filter for larger particulates. The concave shape helps to collect the runoff as it settles through the engineered soil layers which filter it to remove pollutants. Plants and shrubs in the garden function as pollutant removers by removing nutrients from the soil as well as removing water through evapotranspiration. The filtered water that has passed through the soil can then be collected by a filter under drain which returns it to the storm drain system or in some cases can be used for groundwater recharge. While bioretention areas are not designed for flood control, but they can reroute initial runoff which can help to maintain predevelopment hydrology for smaller high frequency rain events. It is suggested that these areas should be individually designed as to optimize their performance however overall they have proven quite effective as on-site treatment facilities.

Green Roofs

Green roofs are a LID practice that uses a vegetated roof cover to reduce stormwater runoff from buildings. These roofs manage stormwater without the necessity of utilizing additional land, making them ideal for dense urban areas where they can significantly reduce the overall percentage of impervious area. Along with reducing runoff, green roofs can provide further benefits including increased insulation and energy efficiency, a reduction of urban heat island effects, and increased durability and lifespan compared to conventional roofs. Green roofs can be applied to new and existing buildings and often only require minor modifications when applied to existing structures. In general these roofs consist of a waterproofing layer, a soil layer, and a plant layer, and can be easily and effectively constructed on roofs with slopes up to twenty percent. For building design the loading of the roof under fully saturated conditions must be considered. Many European countries, especially Germany, and several cities in the United States have been using green roofs for a number of decades and find them a very cost effective method in alleviating the impacts of development with applicability in almost every climate.

Vegetated Swales

Vegetated swales provide a method of reducing runoff velocity as well as providing some filtration and infiltration of stormwater. Due to their linear form these swales are good for highway and residential street runoff treatment. Stormwater that enters these channels is slowed down by the vegetation which allows sedimentation to occur. Although sedimentation is the primary treatment provided, infiltration and adsorption by the sub-soils also occurs. These channels are often used as a link in a treatment train that conveys the water to a downstream unit such as a detention pond. The channels should be mild in slope as the effectiveness of the pollutant removal is based on the vegetation, soil adsorption, and velocity of the water. Obviously steeper slopes account for higher velocities which yield lower infiltration and sedimentation rates. The use of vegetated swales can reduce the need for traditional curb and gutter systems which feed into large storm drain pipe networks. Thus, not only does the use of these swales reduce runoff velocity, but they also can eliminate costs associated with piping systems, curb construction, and maintenance. Maintenance required for swales would include sediment removal when necessary, and mowing of grass. As always there are different options for swale design and each location would need a specific design for optimum functionality.

Permeable Pavements

Permeable pavement is an operational practice used to reduce the amount of impervious area and therefore reduce the total runoff volume from a precipitation event. Included in this category of permeable pavement are porous asphalt, porous concrete, permeable pavers, and open grid pavers. Permeable pavements allow for water to infiltrate through the pavement into the subsoil which then promotes pollutant removal and some groundwater recharge. They are often placed on a base layer of crushed stone or uniform aggregates that are conducive to infiltration as well. Porous asphalt and porous concrete are achieved by reducing the amount of sand or fine aggregates in the mix leaving air pockets which water can drain through. Permeable pavements are most well suited for use in low traffic areas such as sidewalks and parking lots, they are not recommended for use in high speed-high traffic areas.

Disconnected Downspouts

A large portion of stormwater runoff in urban areas comes from the roofs of buildings. Traditionally this water is collected in gutters whose downspouts discharge directly into storm drain pipe systems. To mitigate this problem gutter downspouts can be disconnected from the systems and water can be directly discharged into vegetated swales, bioretention cells, or even into rain barrels or cisterns.

Rain barrels and Cisterns
Rain barrels and cisterns are methods of collecting and storing rainwater for reuse later. These simple storage facilities can be connected directly to gutter downspouts to capture all runoff from roofs. The water can then be reused for irrigation purposes during drier time periods. This is a very basic yet effective way to not only reduce runoff volume but to also reduce water demand and alleviate stress on the water table due to irrigation.

As indicated by the previous descriptions, one of the keys to a successful BMP which can reduce the impact of developed conditions on the predevelopment hydrology is the reduction of impervious area. Multiple other practices can be used to further reduce the impervious to pervious ratio. For example: vegetated center islands can be used in traffic circles or cul-de-sacs, on street parking can be implemented instead of individual parking in residential districts, streets can be designed for minimum width requirements, and so on. Innovative thinking is the basis of fruitful GI/LID strategies and could take any form. For example: re-vegetation or reuse of abandoned lots for gardens or parks could further reduce impervious area and provide functionality for community usage, or, flood prone areas near stream channels could be converted into parks or playing fields which, although they may be flooded at times, could provide recreation during dry periods. In general, lessening the impact of development needs to be forefront on the minds of developers at all times in order to protect our environment and our most precious resource, water.

GI/LID MODELING SOFTWARE

With the emerging regulations and interest for GI/LIDs, there are several stormwater GI/LID design and assessment models that are emerging, which are upgrades of existing models or new models. These models can range from scoping level simple models such as National Green Values Calculator, CityGreen, GreenSave Calculator to the more complex SWMM, SUSTAIN, WinSLAMM hydrological and hydraulic models. Some of these models are free domain and function as web-based models. In this section some of the most commonly used models are briefly discussed. As described in the EPA supplement on GI/LID modeling tools, depending on their structure, modeling tools can be used to inform a variety of green infrastructure planning and design decisions: from setting a green infrastructure target for an entire watershed to designing a green infrastructure practice for a particular site. Outputs that are particularly important in informing green infrastructure planning and design include runoff volume, runoff rate, pollutant loading, cost, and other environmental benefits. Table 2 is adopted from EPA supplement 3 and provides links to a series of models that can be used to predict the performance and/or cost of green infrastructure approaches. The table also identifies the model owner, model price, and model outputs.

Green Values® National Stormwater Management Calculator
The Green Values® calculator is a tool that was developed to help engineers and developers make quick evaluations and comparisons on the performance, costs, and benefits of GI/LID stormwater management practices. It is a free, web enabled tool which can be used and accessed by anyone at http://greenvalues.cnt.org/national/calculator.php . This calculator will take the user through a step by step process in order to help them find a combination of GI BMPs that can meet the needs of that area in a cost effective way. The calculator makes a number of different assumptions in order to arrive at the calculation and therefore often the information entered or used is not very specific. This tool is very useful in finding a quick evaluation and estimate of what costs can be saved and what practices could be used. That being said, this tool should only be used for this and not for design purposes as it does not provide sufficient information for specific design.

Bioretention, Permeable Pavement, Green Roof, and Rainwater Harvesting Models
These models were created by a group of faculty, graduate students, associates, and “off-campus

Extension Faculty" at North Carolina State University to help in evaluation and with design for the different stormwater management practices. The tools are free for download at this link: http://www.bae.ncsu.edu/stormwater/downloads.htm . The models available include a bioretention hydrologic performance model for hydrologic and water quality prediction of bioretention cells, a bioretention design model, a bioretention thermal model for thermal impact evaluation, a green roof hydrologic simulation model which can simulate how a green roof will attenuate a specific rainfall event, and a rainwater harvester design model to simulate and assist designers in sizing rainwater cisterns.

Source Loading and Management Model (WinSLAMM)

WinSLAMM capable of simulating and predicting flow and pollutant discharges that can reflect a number of different development conditions and combinations of urban runoff control practices. Some of the control practices which can be evaluated by WinSLAMM include detention ponds, infiltration devices, street sweeping, porous pavements and catch basin cleaning. These controls can be evaluated in various combinations at various sources. The program can also predict the relative contribution of different source areas such as roofs, landscaped areas, parking lots, and streets. Normally the software is used to predict source area contributions and outfall discharges however, it is also often used by planners to effectively gain a better understanding of the success of different control practices. The WinSLAMM software is available for purchase from www.winslamm.com for $320.

Stormwater Management Model (SWMM)

This model developed by and freely available from the EPA is used for planning, design, and analysis stormwater runoff and drainage systems in urban areas. This software uses a dynamic rainfall-runoff simulation process which can simulate runoff quantity and quality from primarily urban areas. Originally this software could only evaluate pipe systems, channels, storage/treatment devices, pumps, and regulators, now however, the software can also explicitly model hydrologic performance of certain LIDs including: porous pavement, green roofs, rain gardens, rain barrels, infiltration trenches, and vegetated swales. This model can now accurately represent any combination of LID practices in an area. The model is available for free download from the EPA website at the following link: http://www.epa.gov/nrmrl/wswrd/wq/models/swmm/.

System for Urban Stormwater Treatment and Analysis IntegratioN Model (SUSTAIN)

SUSTAIN was developed to assist stormwater management professionals in developing plans for flow and pollution control, meeting water quality goals, and protecting source waters. It was also designed for simulating developing, evaluating, and selecting optimal BMP combinations for various watersheds based on cost effectiveness. The model is very successful in determining how effective BMPs are, how big they should be, and what the most cost-effective solutions are for meeting water quality and quantity goals. SUSTAIN currently supports evaluation of the following structural BMPs: bioretention, cisterns, constructed wetlands, dry ponds, grass swales, green roofs, infiltration basins, infiltration trenches, porous pavement, rain barrels, sand filters, vegetated filter strips, and wet ponds. This module is free and available for download from the EPA website at the following link: http://www.epa.gov/nrmrl/wswrd/wq/models/sustain/ .

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Table 1. Observed Percentile Rainfall Depth for City of Birmingham.

Percentile	50	60	70	80	85	90	95	99
Rainfall Depth (inches)	0.48	0.6	0.8	1.03	1.2	1.44	1.9	3.14

Table 2. LID/GI Designing and Evaluation Modeling Tools (adopted from EPA Supplement 3)

Model/ Calculator	**Owner**	**Freely Avail-able?**	**Runoff Volume**	**Runoff Rate**	**Cost**	**Pollutant Loading**	**Environmental Benefits**	**More Information**
Bioretention, Permeable pavement, Green Roof, and Rainwater Harvesting	NC State Coop-erative Extension	Yes, down-loadable	x					http://www.bae.ncsu.edu/stormwater/downloads.htm
Delaware Urban Run-off Management Model (DURMM)	Delaware De-partment of Nat-ural Resources & Environmental Control	Yes, down-loadable	x	x		x		http://www.dnrec.state.de.us/dnrec2000/Divisions/Soil/Storm-water/New/DURMM%20Re-lease%201.0.xls (Spreadsheet) http://www.dnrec.state.de.us/dnrec2000/Divisions/Soil/Storm-water/New/DURMM_UsersMan-ual_01-04.pdf (User's Manual)
Green LTCP-EZ	EPA	Yes, down-loadable	x	x	x			http://www.epa.gov/npdes/pubs/final_form_green_ltcpez.xls (Spreadsheet) http://www.epa.gov/npdes/pubs/final_green_ltcpez_instructionswith-poecacomments.pdf (Manual)
Green Save Calculator	Green Roofs for Healthy Cities	No, members only	x		x		x	http://lcc.greenroofs.org/index.php?option=com_content&task=view&id=626&Itemid=116
Green Values National Stormwater Management Calculator	Center for Neighborhood Technology	Yes, web enabled	x		x		x	http://greenvalues.cnt.org/na-tional/calculator.php
Hydrologic Modeling Sys-tem (HEC-HMS)	US ACE	Yes, down-loadable	x					http://www.hec.usace.army.mil/software/hec-hms/

Table 2. LID/GI Designing and Evaluation Modeling Tools (adopted from EPA Supplement 3) (continued).

Model/ Calculator	Owner	Freely Avail-able?	Runoff Volume	Runoff Rate	Cost	Pollutant Loading	Environmental Benefits	More Information
Hydrological Simulation Program – Fortran (HSPF)	USGS	Yes, down-loadable	x			x		http://water.usgs.gov/soft-ware/HSPF/
i-Tree	USDA Forest Service	Yes, down-loadable			x			http://www.itreetools.org/in-dex.php
LID Quicksheet	Milwaukee Met-ropolitan Sewer-age District	No, avail-able on a CD for $25 fee	x					http://v2.mmsd.com/AssetsCli-ent/Documents/stormwater-web/PDFs/Appendix_L.pdf
Long-Term Hydrologic Im-pact Assessment Model	Local Govern-ment Environ-mental Assis-tance Network	Yes, down-loadable	x			x		http://www.ecn.purdue.edu/runoff/lthia/lthia_index.htm
Program for Predicting Polluting Particle Passage through Pits, Puddles, and Ponds (P8)	William Walker	Yes, down-loadable	x			x	x	http://wwwalker.net/p8/
RECARGA	University of Wis-consin – Madi-son, CEE Dept.	Yes, down-loadable	x					http://dnr.wi.gov/topic/storm-water/standards/
Site Evaluation Tool (SET)	Tetra Tech	Yes, down-loadable	x		x	x		http://www.unrba.org/set/in-dex.shtml
Source Loading and Man-agement Model (Win-SLAMM)	PV & Associates	No, avail-able for $320	x			x		http://www.winslamm.com/winslamm_overview.html
Stormulator	State Water Re-sources Control Board, UC Davis Extension, and the California Sea Grant Pro-gram	Yes, down-loadable	x					http://www.stormulator.com/StormUlator/Welcome.html

Table 2. LID/GI Designing and Evaluation Modeling Tools (adopted from EPA Supplement 3) (continued).

Model/ Calculator	Owner	Freely Available?	Runoff Volume	Runoff Rate	Cost	Pollutant Loading	Environmental Benefits	More Information
Stormwater Management Model (SWMM)	EPA	Yes, downloadable	x	x				http://www.epa.gov/nrmrl/wswrd/wq/models/swmm/index.htm
Watershed Treatment Model	Center for Watershed Protection	Yes, downloadable	x			x		http://www.cwp.org/documents/cat_view/83-watershed-treatment-model.html
WinTR-55	Natural Resources Conservation Service	Yes, downloadable	x	x				http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/alphabetical/water/hydrology/?&cid=stelprdb1042901

Figure1. Site Hydrology Scenarios for pre- and post-development conditions.

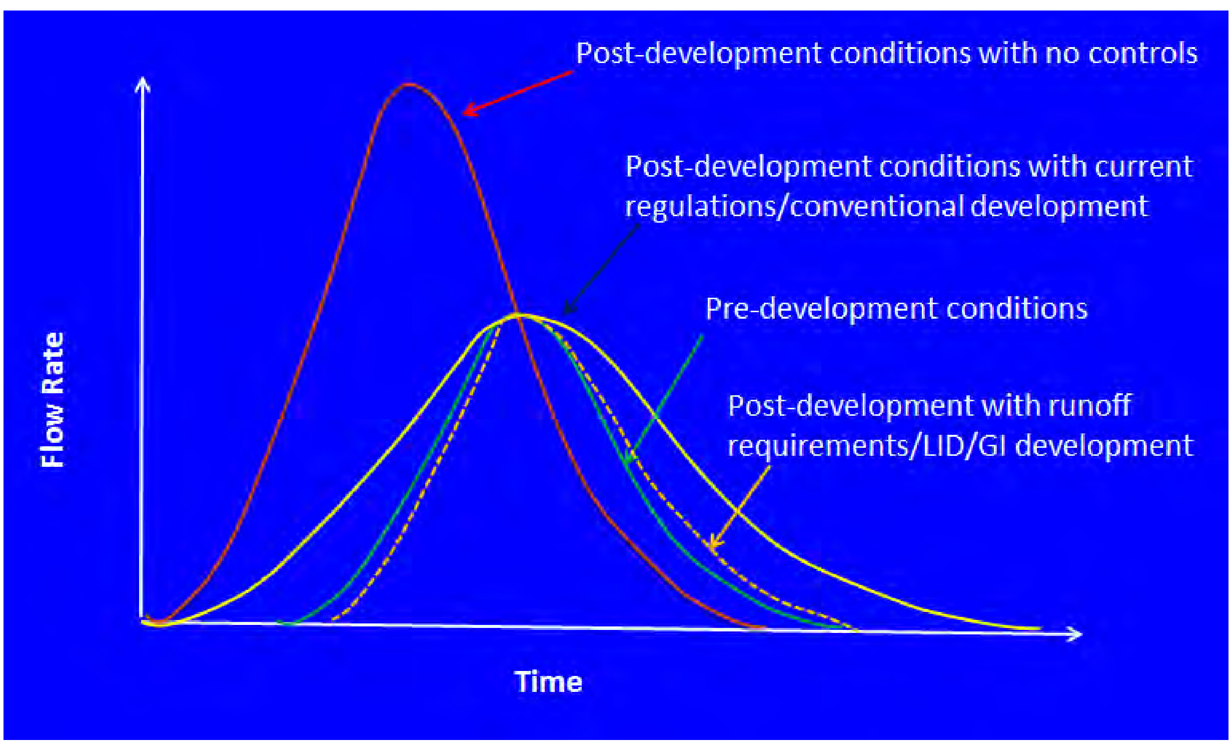


Figure 2. Rainfall Frequency Spectrum Rainfall Percentile and Corresponding Depths.

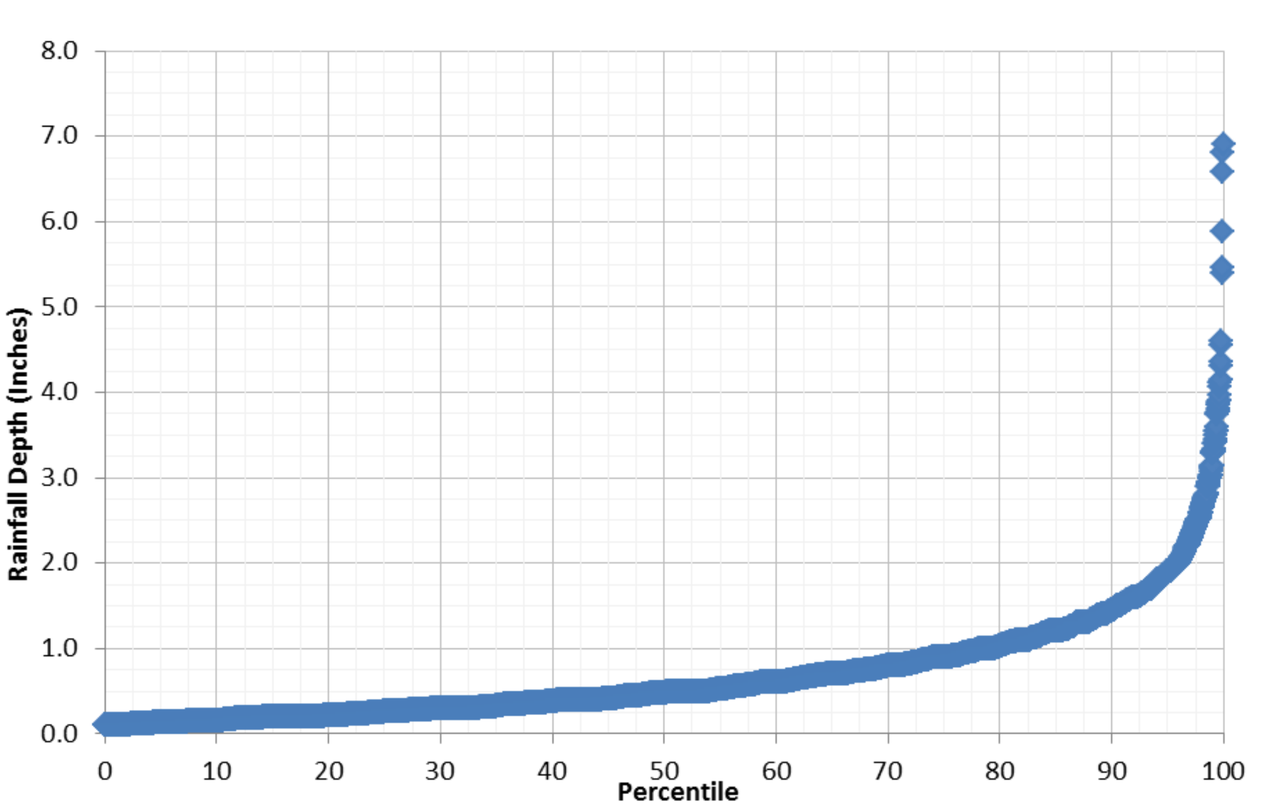
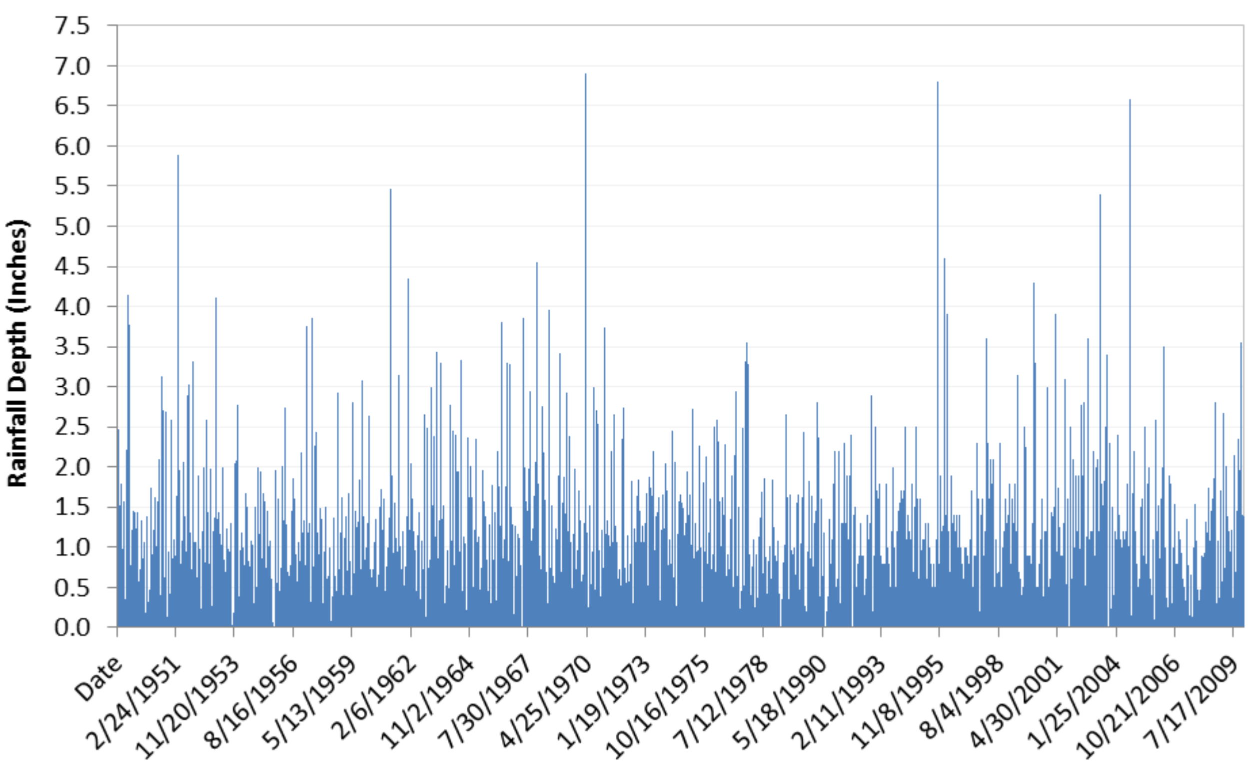


Figure 3. Time Series of Observed Daily Rainfall Data at Birmingham International Airport



Implementing Green Infrastructure through new Policies and Tools

Gallo, W.; Overbey, E.

The underlying theory behind green infrastructure or sustainable stormwater design is that the cumulative impact of many small facilities is greater than that of a few large facilities. This concept depends on the design, installation and management of many more facilities than a traditional pipe and detain ordinance would have created. Instead, a collection of small-scale, vegetated, best management practices are designed to fit seamlessly into the urban fabric to manage smaller storm events close to the source, mitigate nearly every new impervious area, and promote as much infiltration or bio-retention as possible.

For a municipality to move toward a green infrastructure approach requires major changes to how their stormwater ordinance is organized and administered. More facilities, potentially means more submittals, more calculations to check, and more designs to approve. A few municipalities have been grappling with this paradigm shift for the last decade. Their experience indicates that the shift toward green infrastructure requires new tools, which simplify the administrative and design process, and new policies, which ensure the goals of green infrastructure are implemented effectively.

This presentation will explore a few of the specific policies and tools, which have been developed to implement green infrastructure including:

- a pre-development definition which ensures policies will improve watershed protection over time;
- a low application trigger which is central to the concept of managing stormwater at the source;
- a detention requirement, which when combined with a low application trigger, does not impede urban development and also provides a high level of overall flood protection;
- an almost wholesale embrace of small-scale vegetated best management practices (BMPs), which focus on infiltration; and
- a collection of tools specifically designed to facilitate the design, approval, and implementation of small-scale BMPs.

Numerical Modeling of Sediment-Associated Water Quality Processes in Natural Lakes

Chao, X.; Jia, Y.; Shields Jr., F.

Sediment is a major nonpoint source pollutant. It may be transported into surface water bodies from agricultural lands and watersheds through runoff. These sediments could be associated with nutrients, pesticides, and other pollutants, and greatly affect the surface water qualities. Therefore, sediment has been listed as the most common pollutant in rivers, streams, lakes, and reservoirs by the US Environmental Protection Agency (USEPA).

This paper presents the development and application of a three-dimensional water quality model for predicting the distributions of nutrients, phytoplankton, dissolved oxygen, etc., in natural lakes. Three major sediment-associated water quality processes were simulated, including the effect of sediment on the light intensity for the growth of phytoplankton, the adsorption-desorption of nutrients by sediment and the release of nutrients from bed sediment layer. This model was first verified using analytical solutions for the transport of non-conservative substances in open channel flow, and then calibrated and validated by the field measurements conducted in a natural oxbow lake in Mississippi. The simulated concentrations of water quality constituents were generally in good agreement with field observations. This study shows that there are strong interactions between sediment and water quality constituents.

Aquatic Ecosystems

Aquatic Ecosystems

Daniel Goetz *(Mississippi State University)*	Effects of a native rough fish on water quality
James Feaga *(Mississippi State University)*	The effects of weirs on macroinvertebrate communities in agricultural drainage ditches of the Mississippi Delta
Clay Shipes *(Mississippi State University)*	The effects of weirs on vegetation communities in agricultural drainage ditches of the Mississippi Alluvial Delta
Robert Brzuszek *(Mississippi State University)*	Teaching how water works: Informal science education through exhibit design

Effects of a native rough fish on water quality

Goetz, D.; Kröger, R.; Miranda, L.

The smallmouth buffalo (SMB) (Ictiobus bubalus), a large bodied benthivore commonly considered a rough fish, is native to Mississippi. Smallmouth buffalos frequently access floodplain lakes during periods of high water level, and remain isolated within them for extended periods of time after the water recedes. Based on evidence from other benthivore studies we hypothesized that high densities of SMB may contribute to poor water quality conditions. We tested this hypothesis in 0.05 hectare, shallow (<1.5 m) earthen ponds at three stocking densities. Nine ponds were randomly stocked with either a low (15 kg/ha), moderate 85 (kg/ha), and high (315 kg/ha) density and measured for water quality parameters over a ten-week period during the summer of 2012. Results from repeated measures ANOVA suggest SMB at high and moderate densities significantly ($p < 0.05$) increased chlorophyll, turbidity, total suspended solids, volatile suspended solids, temperature, total inorganic phosphorus, while decreasing dissolved oxygen, and Secchi depth, both through time and across treatments. Several previous studies also attribute high benthivorous fish density to enhanced productivity through feedback mechanisms that keep nutrients and sediments in constant suspension. However, most studies have looked at densities much greater than 315 kg/ha (500 +kg/ha). Our results suggest that effects of SMB even at moderate densities may contribute to degraded water quality conditions in natural habitats such as shallow floodplain lakes.

The Effects of Weirs on Macroinvertebrate Communities in Agricultural Drainage Ditches of the Mississippi Delta

Feaga, J.; Kröger, R.

Drainage ditches are an essential part to effective agricultural production by regulating water levels to control the inundation of production acreage. Drainage ditch construction in the Mississippi Delta, was merely a response to the need for access to more fertile soils, which previously was dominated by bottomland hardwood forests, oxbow lakes, and cypress swamps. Various ditches within the Mississippi Delta system contain weirs, which function to limit nutrient export into downstream habitats by reducing flow of water and increasing residence time. Until relatively recently, the biological significance of these agricultural structures to macroinvertebrate communities was not entirely understood. We investigated patterns of communal macroinvertebrate composition within seven agricultural drainage ditches with weirs near Belzoni, Mississippi. We examined macroinvertebrate abundance responses to weir age and distribution patterns with respect to distance from weirs. We then compared these results to results observed in 3 control ditches without weirs. Macroinvertebrates sampled from 7 ditch sites represented 11 distinct taxa with a total abundance of 3,948 individuals. The main contributors to total abundances were Chironomidae (48%), Physidae (30%), and Oligochaeta (20%) with Physidae (43%, n = 876) and Chironomidae (66%, n = 1905) representing the largest relative abundances in treatment and control ditches, respectively. Simple correlation tests showed macroinvertebrate abundances are not significantly influenced by either weir age or distance from weir. Our study suggests further investigation is needed to accurately assess the functional response of macroinvertebrate community composition to weirs. Our study was limited in both sample size and time. These limitations prohibited us from making significant conclusions about our results. We suggest a longitudinal study with a larger sample size across a wider pool of age classes may produce statistically significant results.

The Effects of Weirs on Vegetation Communities in Agricultural Drainage Ditches of the Mississippi Alluvial Delta

Shipes, C.; Kröger, R.

Drainage ditches in the Mississippi Alluvial Delta are an essential part of the agricultural landscape of this region. These ditches vary greatly in size, location, and shape, but can aid in mitigation of contaminants from agricultural fields. Historically controlled drainage in the form of slotted or drop pipes, flash board risers, and vegetated drainage ditches have been used to effectively manage nutrients. More recently low-grade weirs have been used as an alternative to traditional controlled drainage structures. Low- grade weirs act to slow water flow, increase residence time, and allow sedimentation. Until recently the relationship between low-grade weirs and the vegetation communities present has not been evaluated. We selected 13 agricultural drainage ditches with weirs present in the Mississippi Alluvial Valley and investigated the vegetation community responses to weirs and weir age. We also selected 4 control ditches with no weirs present to compare our results. Vegetation assessment yielded 41 plant species ranging from obligate wetland plants to facultative upland plants. Simple correlation tests showed a strong positive relationship between weir age and species diversity, and also a positive correlation between total percent vegetative coverage and weir age. Linear regression also showed a positive relationship between weir age and the presence of facultative upland plants and a negative relationship between weir age and the presence of obligate wetland plants. This study shows some interesting trends, but we were limited in our sample size. Future studies should focus on a larger sample size with a wider range of age classes and should take other variables into account such as; vegetation communities upstream, slope of individual ditches, the spatial arrangement of weirs within the ditch system, and association with other weirs within the same ditch system.

Teaching How Water Works: Informal Science Education through Exhibit Design

Brzuszek, R.

The mission of the Crosby Arboretum, Mississippi State University Extension (located in Picayune, Miss.), is to preserve, protect and display plants and their communities native to the Pearl River Drainage Basin. The Crosby Arboretum's nationally award-winning master plan has designated a portion of its facility for the creation of a small stream swamp forest educational exhibit. Small stream swamp forests are wetlands situated on bottomlands of small streams that are predominated in species type and frequency by black gum (*Nyssa biflora*) and sweet bay magnolia (*Magnolia virginiana*). As specified in Mississippi's Comprehensive Wildlife Conservation Strategy by the Mississippi Department of Wildlife and Fisheries (MDWF), small stream swamp forests are considered vulnerable in the state of Mississippi. The proposed swamp forest exhibit will address MDWF priorities through the construction and management of the habitat type, as well as providing a venue for public education and experience in this vulnerable forest.

The Crosby Arboretum Foundation was awarded a grant to create a small stream forest educational exhibit. Graduate students in the Department of Landscape Architecture at Mississippi State University utilized a semester-long class project in spring 2011 to research and design the proposed exhibit. Students conducted a literature search on small streams and related wetlands and visited several in situ small stream swamps in Mississippi. Students recorded environmental data at the natural wetlands to inform the restoration design. Students also conducted an environmental inventory and analysis at the proposed exhibit site that recorded the site's hydrology patterns, plant species, soils and other data. A design charrette, or a collaborative session to determine solution to the design problem, was conducted with wetland specialists and landscape architects to develop the preliminary design. This paper will discuss the method used to develop the exhibit design and will exhibit the drawings for the proposed stream and associated wetland types. Long-term vegetation monitoring will be initiated after construction.

INTRODUCTION

Ecological restoration is defined as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (Society for Ecological Restoration, 2013). Restoration ecology, or the study of the restorative process, was defined in the late 1980's at the University of Wisconsin-Madison (Jordan, Guilpin, Aber 1987). Ecological restoration strives to return a landscape as close as possible to its original undisturbed state, prior to human disturbance (NRC 1992). It incorporates advanced techniques of estimating abundance, estimating spatial patterns and dispersion, and experimental designs (Krebs 1998). The challenges to this goal include that the conditions of this pristine condition may not be known (Hobbs and Norton 1996), or that the original state may no longer be attainable due to recent environmental changes (Waal et. al 1998). Nassauer and Opdam (2007) note one other important challenge: That even though science has made great strides in understanding natural process for a variety of landscapes and their resulting patterns, there has been one obvious flaw: this increased understanding has made little inroads into the public decision-making process (Nassauer and Opdam 2007). Instead, they argue, that science must incorporate design to result in patterns that are valued by society. Current ecological design methods are science-based and often center upon solving the hydrological functions in restoration projects. But in public landscapes, particularly in a today's pluralistic society, solving hydrological functions is often not enough. Eric Higgs noted in his 1997 article in Conservation Biology that ecological restoration "requires an expanded view that includes historical, social, cultural, political, aesthetic, and moral aspects." In 1994, a group of experts from the National Renewable Energy Laboratory developed the Sanborn Principles of Sustainability which adds one more important quality, that ecological design should be "beautiful." (Harwood et al 1994).

The landscape architecture firm of Andropogon Associates, located in Philadelphia, Pennsylvania, Ltd. is a noted firm for their merging of natural process and designed patterns. Founded in 1982 by a team of landscape architects, biologists, and engineers, the firm studied natural plant communities for their abstraction into designed landscapes for a variety of land use applications. In order to assess the spatial qualities of natural forested landscapes, the author tested a methodology in 1990 that combined the landscape determinants utilized by several landscape architects that were working on the Crosby Arboretum Master Plan, including Andropogon Associates, and Mississippi landscape architects Robert Poore, and Edward Blake, Jr. This method combines the understanding of the physical process of a landscape with the spatial patterns that occur (Brzuszek 1990).

The process and patterns elements include:

1. Process. This assesses how the natural area may have been formed through physical, biological and cultural effects.
   a. The physical environment concerns the geology, soils, hydrology, and climate.
   b. The biological focuses on vegetative and faunal species present and stages of plant succession.
   c. Cultural effects concern the impact of the natural area by human disturbance including pollution, recreational activities, and ownership.
2. Spatial patterns. The study of spatial patterns determines the mass and void of the environment and the elements that occur within those spaces.
   a. The spaces are analyzed by determining the vertical layers of the forest (canopy, understory, shrubs and groundlayer), and the horizontal layout (degree of openness or enclosure along a transect).
   b. The elements refers to the design principles and elements that are typically experienced within the given plant community. Artistic design principles include balance, proportion, rhythm, emphasis, scale and unity. Design elements include point; line; form, shape and space; movement; color; pattern; and texture (Jirousek 1995).
   c. Personal interpretation is a subjective assessment that identifies the intuitive feelings that are experienced within a natural area.
   d. Edges or ecotones. The transition from one plant community to another (road edge, inner edges, etc.).

In this paper, I will discuss how we applied specific design principles and elements as part of a methodology that also integrates site physical and biological research. While this paper does not comprehensively assess all of the landscape and spatial processes as mentioned in the above mentioned method, it does make a place for accepted design criteria to be included alongside the research process. This paper will explore these concepts through a case study for the Forested Stream Exhibit at the Crosby Arboretum.

THE CROSBY ARBORETUM

The Crosby Arboretum, located in Picayune, Mississippi, began in 1980 with a mission of "preserving, protecting, and displaying the native plants and their communities of the Pearl River Drainage System" The Pearl River is a 444-mile long major watershed in western Mississippi that encompasses the lands of the Crosby Arboretum. The Crosby Arboretum was established as a living memorial to South Mississippi timber pioneer and philanthropist L.O. Crosby, Jr. In addition to its 64-acre public Interpretive site named Pinecote, the Crosby Arboretum would research and manage seven different natural areas comprised of approximately 700 acres. The natural areas fulfills the Arboretum's mission of preserving and protecting local plant communities and also served as inspiration in order to create Pinecote's plant community exhibits. These lands provide habitats for 300 native plant species and animals, some of which are endangered or threatened.

After being logged of its virgin timber sometime prior to 1930, Pinecote was a working strawberry farm that once encompassed one section of land (640 acres). A few years after being farmed, the land was replanted in pine trees and became one of the state's first reforestation efforts. The land was maintained as a pine plantation (which uses prescribed fire to control woody undergrowth) into the 1980s, until it was designated as Pinecote, the Crosby Arboretum Interpretive Center. In its early years the entire Arboretum site continued to be managed as a pine savanna landscape, with slash pine (*Pinus elliotti*), loblolly pine (*Pinus taeda*), and longleaf pine (*Pinus palustris*) as the dominant tree species, with an understory of grasses and wildflowers.

Andropogon Associates and Edward L. Blake, Jr. devised the conceptual designs that led to Pinecote's master plan, which received a national ASLA Honor Award in 1991 (ASLA 1991). The master plan for the Crosby Arboretum incorporates and improves the pre-existing savanna exhibit already occurring at the Interpretive Center site, but reduced the Savanna Exhibit acreage from 64 acres to 20 acres (Figure 1). Approximately 40 acres were dedicated to allow the savanna landscape to utilize natural vegetation succession to form the Woodland Exhibit, and approximately 4 acres to form the Aquatic Exhibits.

THE FORESTED STREAM EXHIBIT AT CROSBY ARBORETUM

The Crosby Arboretum Master Plan highlights water as an important educational feature to its visitors. The Master Plan identifies the construction of four main wetland exhibits that are based upon regional water features. These include a two-acre Beaver Pond Exhibit that abstracts the form and function of locally-occurring beaver ponds; a half-acre Slough Exhibit based upon local bayous; a one acre Gum Pond exhibit that features a Gulf Coast waterbody primarily composed of tupelo gum trees (*Nyssa sylvatica var. biflora*), and a 970' small stream corridor entitled the Forested Stream Exihibit (Figure 2). The Piney Woods Lake, Slough, and Gum Pond Exhibits have already been constructed prior to 2011, and this paper concerns the design and construction using ecological principles for the Forested Stream Exhibit (previously identified on the plan as the Wetland Edge).

Small forested streams are common wetland features in the Piney Woods landscape. These narrow first-order waterways collect water and distribute them to larger creeks and streams and play an important role in the health of local watersheds. Some of the associated features along small forested streams are important, such as the lowland depressions that occur adjacent to these creeks. Prior to being farmed in the 1930s, botanist Dr. McDaniel classified the exhibit area as a wet pine flatwood. Pine flatwoods range from Florida to Louisiana and are common landscape features along the Gulf Coast. More accurately known as the East Gulf Coastal Plain near-coast pine flatwood, these landscapes have low, flat land and poorly drained soils. The Forested Stream Exhibit is designed to occur within approximately four acres of a current wooded exhibit (approximately 30 years of successional growth), and will connect the Gum Pond Exhibit in the northern part of the site to the Slough and Beaver Pond to the south. This wetland exhibit will create habitat for fish, amphibians, reptiles, and birds that are indigenous to the Pearl River Drainage Basin, and will offer an opportunity to teach visitors about the importance of forested wetlands by demonstrating the value of its functions.

APPROACH

In spring 2011, a graduate class in the department of landscape architecture at Mississippi State University, was assigned by the author the task of conducting the research and to develop the conceptual designs for the Forested Stream Exhibit. The semester-long project consisted of studying the research literature for small streams and stream restoration; site visits to small streams near the Arboretum site to measure and map their wetland configurations; study the plant species and spatial configurations of small stream corridors; to host a design charrette (which was facilitated by Duane Dietz and Karen Smith from Jones and Jones, Seattle, WA) to consider possible conceptual designs; and the resolution of conceptual ideas into a proposed exhibit design. To fund the exhibit construction, a federal grant was applied for and awarded through the National Fish and Wildlife Foundation's 5-Star Grant. The grant awarded $38,870 with a complementary match by the Crosby Arboretum and its partners, and the period required construction of the exhibit to be completed by June 2013.

RESULTS

Hydrology

The Forested Stream Exhibit area has traditionally served as a drainage corridor for the surrounding landscape. It is the valley between two sand ridges that occur to the east and west and has historically served as a first-order stream corridor. After the site was farmed in the 1930s, the land was ditched to allow the land to be more productive, and a small farm road was built through the exhibit site. Remnants of the old farm ditches are still present on the site and serve as the area's primary drainage channels. Students that visited the site after a rain event had noted the hydrological flow as: "After a significant rain event, it is observed the route of water flow on the site from the newly constructed gum-pond to the north to the beginning of the slough to the south" (Figure 3 Lackey and English 2011).

Design Spatial Patterns

Art elements and principles can be interpreted by designers near natural small streams. While there is some degree of presence of all design principles (balance, proportion, rhythm, emphasis, and unity) and elements (point, line, form, shape and space, movement, color, pattern, and texture) found within areas of small streams studied, the artistic elements such as line and rhythm were found to dominate the Small Forested Stream landscape type more strongly than others.

Line. Line is one of the more apparent design elements of a channelized water system. Most small streams have a clearly defined bank edge where the water travels, except in the occasional times when it overflows its edges (Figure 4). While the water level to a small stream varies widely in depth throughout the year, there is often an average water level. When a stream overflows its banks and begins to flood its surrounding area it is termed 'bankfull' (Dunne and Leopold 1978). An established stream has a defined bank edge that is apparent even when it is dry (Figure 5). Stream lines are horizontal features on the ground plane that contrast or complement other lines in the landscape. These include the strongly vertical lines of adjacent mature trees.

Local geology, topography, and the age of the stream can determine the form of the line. Steep mountain valleys feature streams and creeks with straight runs; while those in fairly flat floodplains meander through the landscape. The age of the stream can also determine the form of the waterway. Small water courses that recently formed can resemble a more channelized pattern, while those that are older have meanders and curves. Each of these line forms create a different emotional experience for the viewer, as straight streams provide a distant vanishing point and meandering streams create a sense of mystery as to what is around the next bend.

Rhythm. Rhythm is a design principle that reflects organized movement within a composition. Many natural features create a sense of rhythm, including tree trunks in a dense forest. Tree trunks without shrub layers allow an open vista that reveals a repetitive element in a scene. These components can vary widely in material and form, and can include mass flowering and other vegetation, water, ant hills, and even rocks or snow patterns. Rhythm carries the eye across the landscape scene, and can help to unify a landscape of many diverse materials and forms. In a forested system, a creek becomes a contrast as it is a different material from the surrounding vegetation, rocks or soil. But it also serves importantly as a rhythmic item which literally flows from one part of the landscape scene to the next. Thus the eye winds along the channel and serves as the primary focal point to the surrounding matrix.

Scale. The size of a landscape element in proportion to its surrounding features is an important principle of design. Small creek systems not only need to serve their hydrological role, but also serve their aesthetic parameters. The in situ small streams in south Mississippi that served as reference sites for the exhibit ranged from 3 feet in width of the stream channel to a maximum of 8 feet. Streams and creeks in excess of 8 feet wide often changed to a second-order stream type. Similarly, the most shallow stream depth encountered was 6 inches and a maximum of 3 feet. These stream sizes are determined by the volume of water handled (size of watershed and local precipitation amounts), and the maximal flow rates. Local geologic changes, erosion, or shifts in soil type can create changes in stream channel depth, and can widely vary along stream channels. Importantly, the size of the first-order stream channel should not dominate or overwhelm the landscape; but instead act as a smaller thread that is subordinate to the greater landscape features.

SUMMARY OF RESULTS

Steps in the traditional ecological restoration process were used in the design of this project, yet the additional study of spatial considerations and design elements and principles in natural small order streams was useful to result in better exhibit aesthetics. Line, rhythm and scale are by far the strongest design elements and principles encountered along natural stream channels in south Mississippi. Line, or the defined channel of the stream corridor, is a dominant landscape feature whether the channel is full or water or dry. The channel creates a topographic change in a relatively flat landscape that is in its own way—dramatic. The implementation of a line in the landscape creates a contrast to the surrounding matrix. Line creates a rhythmic element in the landscape, especially when it encompasses nearly 1,000 linear feet of exhibit area. Here the visitor will encounter the stream channel repeatedly throughout the space, and becomes one of the few consistent repetitive patterns in a very divergent vegetation type. The form of the lines studied in natural streams gives an overall idea of stream exhibit pattern. While the natural stream shapes will not be literally transcribed onto the Arboretum site, it does give a better definition to stream form. Similarly, understanding the scale parameters for the stream exhibit allows a better comprehension of stream size. Documenting the ranges of stream widths and depths gives the designer the latitudes in which to work to determine exhibit channel sizes for specific locations.

EXHIBIT LAYOUT AND CONSTRUCTION

With the conclusion of the class project in May 2011, which established the conceptual ideas for the Forested Stream Exhibit design, the author then further developed the site design details and construction documents. Since there already were mature trees located within the proposed stream corridor design, the centerline of the stream was studied and adjusted to minimize the removal of large pines and hardwoods. While the re-design still follows the general hydrological route of the major drainage corridor, it was then manipulated to weave around the large trees and other plant features. The proposed stream edges were then staked to mark their locations and then evaluated over a period of time for adjustments.

With the stream layout established, the next phase was to develop the widths and depths of the corridor itself. These were determined by looking at depths and widths of similarly sized streams in nature and to integrate into the scale of the exhibit environment. The stream edge stakes were adjusted to reflect the final stream widths. The stream widths were also determined by the width of the construction equipment that will be used in constructing the stream exhibit. To minimize construction impacts to the surrounding environment the stream excavation and haul routes were required to stay within the stream corridor banks itself.

It is at this level of site design where the design elements and principles can be utilized by the designer. For example, small streams primarily utilize the design element of line. The construction of a stream creates a new horizontal line in the site. Placement of the line must work with other elements in the area, including the vertical lines of trees or vines (Figure 6). Design of the stream channel takes into account a multitude of attributes that affect the experience of the future visitor, including changes in canopy tree light levels, bringing the visitor to experience interesting trees and other existing natural phenomena, and pathway connections to other exhibits.

CONSTRUCTION

After a review of the project proposal by the U.S. Army Corps of Engineers, construction for the exhibit began in October 2012. The few small trees that required removal from the stream corridor were cut and stream excavation began. The majority of the stream channel was dug by mid-November (Figure 7). By November 15, substantial rains occurred at the exhibit site and prevented exhibit completion until Spring 2013 when the soils were once again conducive to excavation.

Future design work will include the layout and construction of exhibit trails, and the architectural elements of all bridges, pavilions, seating areas, interpretive signs, and gather spaces. Designs for these elements are scheduled to be completed in Spring 2013.

DISCUSSION

This paper describes an approach to wetland exhibit design at an established ecologically-designed arboretum in the southern United States. The methodology used to develop the exhibit combined ecological studies of natural reference sites to inform the design, but also allowed for a study and interpretation of design attributes. This combination of science and art can inform ecologically-designed landscapes to best function, hydrologically and for successful vegetative species placement, but also aesthetically to dramatically heighten the exhibit experience for the visitor. In this study, the design principles of rhythm and scale, and the design element of line were found to most dramatically impact the design and layout attributes of the Forested Stream Exhibit. By utilizing and applying these design tools, as inspired by natural landscapes, designers can bring heightened drama to constructed waterways and stream channels.

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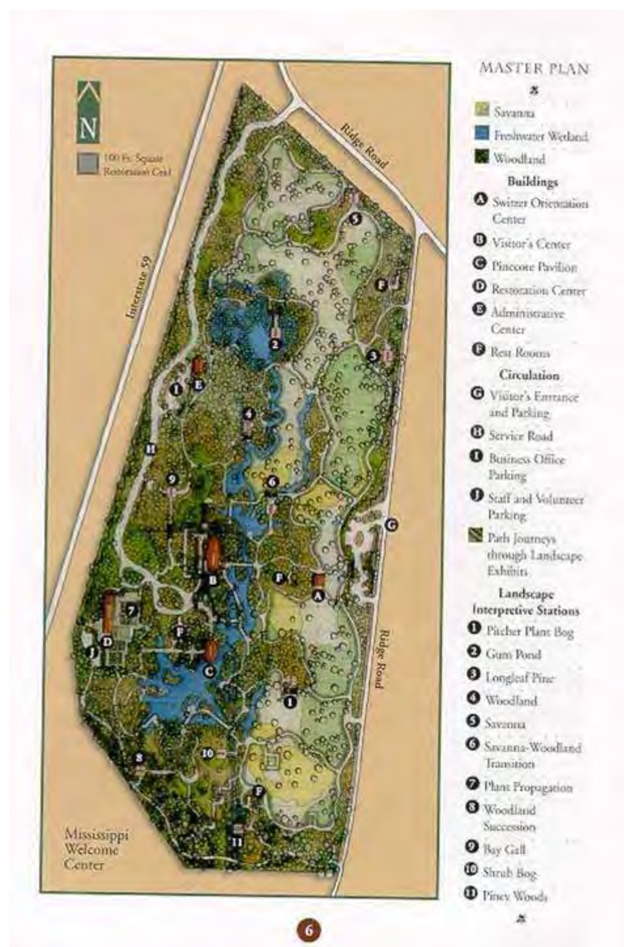

Figure 1: The Crosby Arboretum Master Plan (1994) shows the Arboretum's created plant community exhibits for savannas (20 acres), woodland (40 acres), and wetlands (4 acres).

Figure 2: The new Forested Stream Exhibit area incorporates a 970 linear feet constructed ephemeral stream.

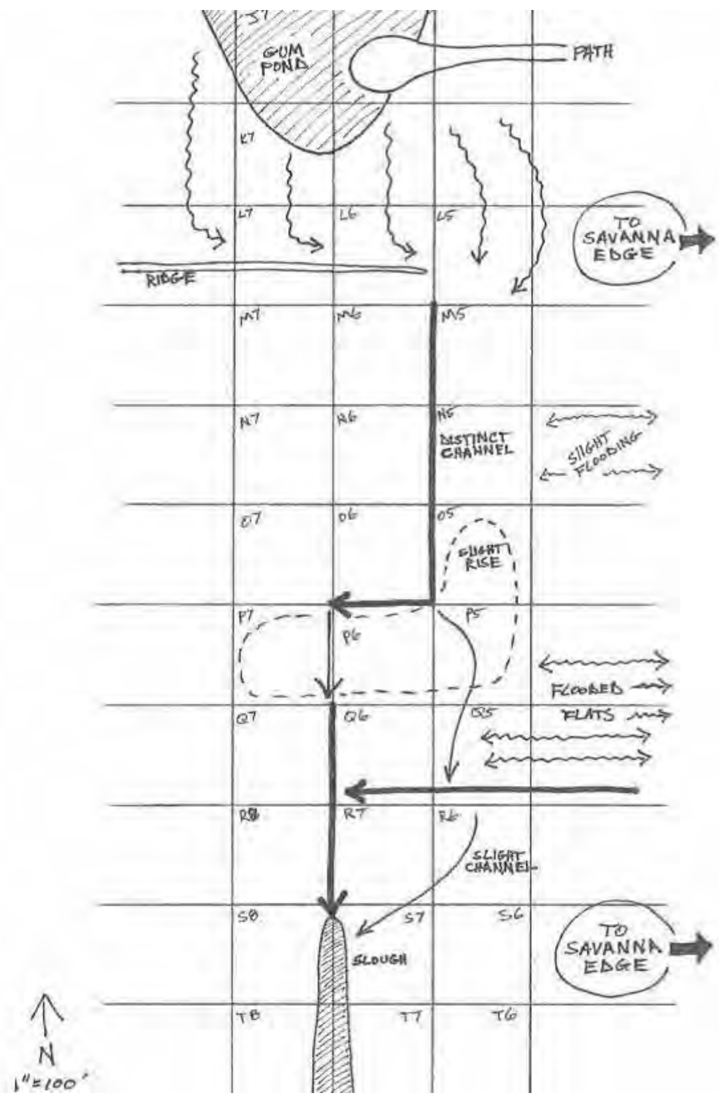

Figure 3: Students mapped the existing drainage patterns for the exhibit site.

Figure 4 (right). Studies of nearby streams provided the design elements inherent in natural waterbodies, such as the strong linear channels of bank edges.

Figure 5 (below). Stream bank widths and depths of small natural first-order channels informed the design of the exhibit.

Figure 6. This sketch by the author shows how the stream channel placement maximized the design composition and aesthetic potential for the constructed stream.

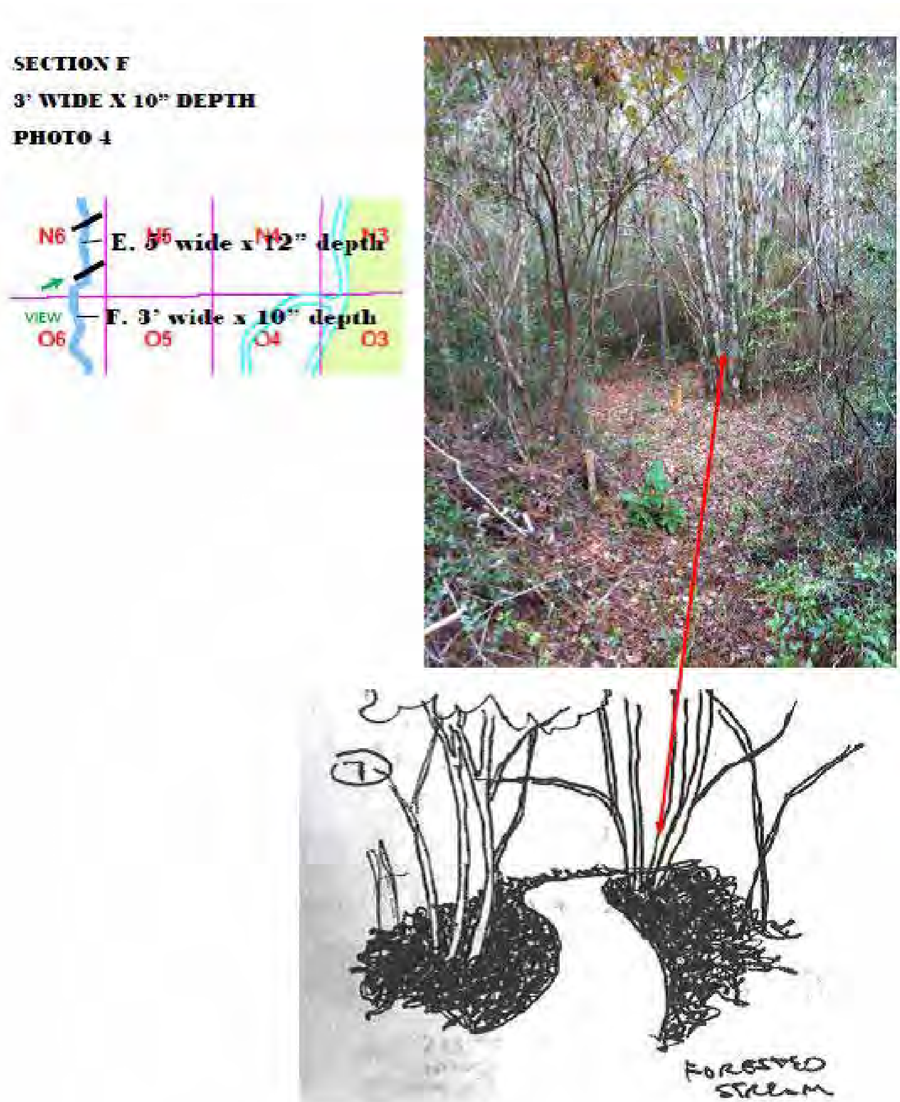

Figure 7. The first rain following channel construction displays the sinuous nature of the constructed stream exhibit.

Delta Hydrology

Jamie Dyer *(Mississippi State University)*	Influence of spatial precipitation patterns on seasonal recharge in the lower Mississippi River alluvial aquifer
Pat Mason *(Mississippi Department of Environmental Quality)*	Surficial geology and soils in the Mississippi Delta: In search of infiltration data
David R. Johnson *(US Army Corp of Engineers)*	Low flow, how low should we go?

Delta Hydrology

Influence of Spatial Precipitation Patterns on Seasonal Recharge in the lower Mississippi River Alluvial Aquifer

Dyer, J.; Mercer, A.

Water resources in the lower Mississippi River alluvial valley play a critical role in agricultural productivity due to the widespread use of irrigation during the growing season. Although the region receives abundant precipitation throughout the year, the unknown specifics of meteorological modifications in the region, along with continually changing anthropogenic needs on the groundwater system, makes it difficult for water resource managers to make sound decisions for future water sustainability. Additionally, agriculture in this region is under considerable strain due to diminishing groundwater availability and the non-sustainable trend in irrigation draws from the alluvial aquifer. As a result, it is crucial to correlate local rainfall patterns with aquifer water levels to better determine the spatial and temporal influence of precipitation on regional groundwater levels. This project will address water availability in the lower Mississippi River alluvial aquifer (LMRAA) over northwest Mississippi through an assessment of historical precipitation variability using high-resolution radar-derived precipitation estimates. This information will be used to estimate current and future precipitation availability over the region, which will be compared with regional groundwater observations to determine the level of interaction between rainfall and sub-surface water levels. Results of this project will aid in determining the natural limits to water resource availability, as well as the relationship between regional precipitation and groundwater variability.

Surficial Geology and Soils in the Mississippi Delta: In Search of Infiltration Data

Mason, P.; Thompson, D.

The water-bearing sands and gravels of the Mississippi River Valley alluvial aquifer (MRVA) underlying Mississippi's Delta region are very prolific and are important to agricultural interests. Significantly, the aquifer's overlying capping layer, or topstratum, is important in understanding the sustainability of this resource. This relatively thin topstratum is a primary controlling factor in determining how much direct recharge from precipitation passes from the surface to the aquifer. This process ultimately plays an important role in recharging this increasingly stressed and heavily utilized aquifer. Concepts and historical research vary regarding the permeability and character of the topstratum. Fisk (1944) described the topstratum as "various combinations of sand, silts, and clays" comprising a "relatively impervious topstratum". Little is known about specific locations in the Delta where direct recharge through the topstratum might be enhanced, restricted, or absent. As a result, previous efforts to simulate the groundwater flow system have postulated various schemes for assigning infiltration. These have included: 1) one uniform infiltration rate, 2) low rates in most areas with moderately low rates in zones controlled by topstratum geology, and 3) moderate to high rates in well-drained soils zones with no infiltration elsewhere. In an effort to clarify and illuminate the level of knowledge regarding this capping interval, systematic research and review of existing literature, surface geological mapping, soils mapping, and pertinent data sets is being undertaken. Some of the available data may be reprocessed or enhanced in order to better identify the various soil parameters, geomorphologic features, and depositional units which are thought to be useful tools in predicting and developing infiltration rates for the MRVA.

Low flow, how low should we go?

Johnson, D.

The determination of the minimum flow needed to support aquatic life and meet the needs of the Clean Water Act is a complex issue that has generally been answered with quick and meaningless statistical flows. This paper will examine a number of different methods used to establish low flow, and will compare them to observed flows several rivers in the Mississippi Delta.

Monitoring and Modeling: Pearl River Basin

Pearl River Basin

Monitoring and Modeling: Pearl River Basin

Abdullah O. Dakhlalla *(Mississippi State University)*	Assessing the impacts of future climate change on peak flows in a forested watershed
Priyantha Jayakody *(Mississippi State University)*	Spatial distribution of sediment and nutrient loadings from Upper Pearl River watershed (UPRW)
Prem B. Parajuli *(Mississippi State University)*	Monitoring and modeling of fecal coliform bacteria loads in the Upper Pearl River watershed

Assessing the Impacts of Future Climate Change on Peak Flows in a Forested Watershed

Dakhlalla, A.; Parajuli, P.

Future climate changes, such as precipitation, temperature, and carbon dioxide (CO2) can have dramatic impacts on the hydrological cycle. These climatic changes can also increase the intensity and occurrence of peak flow events, which cause significant damage to agriculture and infrastructure. This study was conducted in the Lower Pearl River Watershed (LPRW) in southern Mississippi, which is dominated by forests and is characterized by its high peak flows. The Soil and Water Assessment Tool (SWAT) was utilized to assess the impact of future climate change scenarios on peak flow frequency and magnitude.

The SWAT model was calibrated and validated for streamflow at five United States Geological Survey (USGS) gage stations (Bogalusa, Columbia, Monticello, Hanging Moss Creek, and Jackson) with good model performance based on the coefficient of determination, Nash-Sutcliffe Efficiency index, and root mean square error statistics. Future climate change scenarios were based on adjusting precipitation, temperature, and CO2 values. Observed daily precipitation and temperature data for the years 1981 to 2010 were used as inputs in a stochastic weather generator model to generate future climate data with the same statistical characteristics as the observed data. The occurrences and magnitudes of extreme peak flow events in the LPRW were analyzed under each climate scenario by developing flood hydrographs. Employing climate scenarios will aid in determining which climatic parameters have the most and least influence on peak flow magnitude and frequency. This study is expected to help in implementing best management practices (BMPs) more effectively in the LPRW that serve to attenuate peak flows.

Spatial distribution of Sediment and Nutrient Loadings from Upper Pearl River Watershed (UPRW)

Jayakody, P.; Parajuli, P.; Cathcart, T.

Deterioration of surface water quality is one of the most concern issues in the U.S. The knowledge of spatial and temporal variability of water quality parameters may help to formulate mitigation plans to improve water quality. This study was designed to investigate temporal and spatial variability of sediment, total nitrogen (TN), and total phosphate (TP) loadings to the surface water through a modeling approach. The Soil and Water Assessment Tool (SWAT) was applied for Upper Pearl River Watershed (UPRW) in central Mississippi. Water samples were collected from Burnside and Lena USGS gauging stations. The SWAT model was calibrated and validated for daily time steps using manual and automatic (SUFI-2) methods from Feb 2010 to May 2011. Preliminary results showed good to very good model performances with the coefficient of determination (R2) and Nash-Sutcliff Efficiency Index (NSE) from 0.6 to 0.8 (flow), 0.3 to 0.6 (sediment), 0.6 to 0.7 (TN), and 0.5 to 0.6 (TP) during both hydrologic and water quality model calibration and validation. Sub-watersheds were ranked based on water quality pollutants loading to prioritize land areas for watershed management operations.

Monitoring and Modeling of Fecal Coliform Bacteria Loads in the Upper Pearl River Watershed

Parajuli, P.; Jayakody, P.; Brooks, J.

Pathogens loading from the non-point sources of agricultural and non-agricultural activities contribute to water quality degradation. Developing Total Maximum Daily Loads (TMDLs) for the pathogens (e.g. fecal coliform bacteria, E. coli) require quantifying bacterial load contribution from potential sources. Quantifying bacterial loads from each source will help in developing pathogenic load reduction strategies to meet applicable water quality standards.

The objective of this research was to monitor fecal coliform bacteria concentrations and quantify bacteria loads from the Upper Pearl River Watershed (UPRW-7,885 km2) in the east-central Mississippi. Analysis of observed fecal coliform bacteria concentrations with stream flows from the watershed will be presented. Preliminary results from the model simulations with seasonal variability of bacteria concentrations will also be presented using appropriate statistics.

Surface Water Assessment and Monitoring

Surface Water Assessment and Monitoring

Zhangping Wei *(University of Mississippi)*	A shallow-water equation based one-dimensional dynamic wave model with non-hydrostatic pressure
Rick Kaminski *(Mississippi State University)*	Ecological assessment of NRCS's Migratory Bird Habitat Initiative in response to BP's Gulf Oil Spill
Jairo Diaz *(Alcorn State University)*	Modeling sediment and phosphorus yields using the HSPF model in the deep hollow watershed, Mississippi

A shallow-water equation based one-dimensional dynamic wave model with non-hydrostatic pressure

Wei, Z.; Jia, Y.

Coastal wave is one of major forces that dominate coastal hydronydamics, sediment transport, morphology and threaten coastal infrastructures. In recent years, the non-hydrostatic technique for solving Reynolds-averaged Navier-Stokes equations has been developed for wave propagation study. It has been shown that this method has a comparable accuracy for wave simulation to Boussinesq-type approaches and a better computing efficiency.

In this paper, a one-dimensional depth-integrated non-hydrostatic pressure wave model for wave propagation, breaking and run-up is developed based on the numerical method proposed by Stelling and Duinmeijer. In this numerical method, the non-conservative form of Navier-Stokes equation is solved for either momentum conservation or energy head conservation by applying different advection approximation methods. The method is, therefore, able to handle rapidly varied water flows (such as wave breaking) in wide range of Froude numbers. When wave run-up is concerned, wetting and drying treatment plays a key role for many numerical models. The wet & dry handling approach in the method is simple, efficient and capable of reserving positive water depth.

In this non-hydrostatic wave model development, the fractional time step method is adopted. The shallow water equations without non-hydrostatic pressure terms are solved for approximation of velocity; a tri-diagonal equation for non-hydrostatic pressure terms is then solved, and the approximate velocity is corrected by non-hydrostatic pressure terms. The free surface elevation is calculated by the depth-averaged continuity equation to satisfy global mass conservation. This model will be validated by an analytical solution and several benchmark wave dynamics test cases; it is anticipated the model can predict wave breaking and run-up processes effectively.

INTRODUCTION

In recent years, numerical simulations of wave motions using the non-hydrostatic pressure methods (Casulli and Stelling, 1998; Stansby and Zhou, 1998) have advanced a lot. Stelling and Zijlema (2003) improved the efficiency and accuracy of non-hydrostatic method by utilizing an edge-based compact difference scheme for the approximation of vertical gradient of the non-hydrostatic pressure located at the interface between vertical layers, with correct implementation of zero pressure boundary at the water surface, their model obtained good agreements with the linear dispersion relation with only two layers. Subsequent efforts were made to improve the model's efficiency, stability, and capability of handling wave breaking and run-up (Zijlema and Stelling, 2005, 2008); recently, an operational public domain code: SWASH was released (Zijlema et al., 2011). Following them, several non-hydrostatic models, for example, depth-averaged models (Walters, 2005; Yamazaki et al., 2008; Cui et al., 2012), two-layer models (Bai and Cheung, 2011, 2012) and multi-layer models (Ai et al., 2011; Ai and Jin, 2012; Ma et al., 2012) have been developed.

In order to properly simulate discontinuous flows, such as hydraulic jump and wave breaking, the numerical models should conserve the momentum

(Stelling and Duinmeijer, 2003). In general, two strategies have been used to achieve momentum conservation in the numerical formulation. In case that the non-conservative form of governing equations is under consideration, a momentum conservation scheme proposed by Stelling and Duinmeijer (2003) can be used to handle wave breaking (Yamazaki et al., 2008; Zijlema et al., 2011). The other way is to solve the conservation form of governing equations directly, since the momentum conservation is automatically considered, this method has also been widely used for wave breaking simulation (Zijlema and Stelling, 2008; Ai and Jin, 2012; Ma et al., 2012).

After a wave breaks, a portion of the remaining energy will energize a bore that will run up the face of a beach or sloped shore structure (Sorensen, 2006). In the numerical model, use of a moving boundary condition is required for the calculation of wave run-up and run-down. The detailed reviews on wetting and drying algorithms for coastal waves run-up modeling can be found at Zijlema and Stelling (2008).

In this paper, a one-dimensional depth-integrated non-hydrostatic wave model for wave propagation, breaking and run-up is developed. Non-hydrostatic approach is introduced into an existing shallow water model (Stelling and Duinmeijer, 2003), which solves the non-conservation form of shallow water equations with a momentum conservation scheme for handling hydraulic jumps and uses a simple wetting and drying algorithm for simulating the moving boundary. The newly developed non-hydrostatic model is able to simulate wave propagation, breaking and run-up. The paper is organized as follows. The governing equations and associated boundary conditions are introduced in Section 2. Section 3 describes the numerical solution. Section 4 presents an analytical solution and several benchmark cases for model verification and validation. Finally, conclusions are drawn in Section 5.

MATHEMATICAL FORMULATION

Governing equations

The three-dimensional Reynolds-averaged Navier-Stokes equations are given by

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (1)$$

$$\frac{\partial u}{\partial t}+\frac{\partial (uu)}{\partial x}+\frac{\partial (uv)}{\partial y}+\frac{\partial (uw)}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\frac{1}{\rho}\frac{\partial \tau_{xx}}{\partial x}+\frac{1}{\rho}\frac{\partial \tau_{xy}}{\partial y}+\frac{1}{\rho}\frac{\partial \tau_{xz}}{\partial z} \quad (2)$$

$$\frac{\partial v}{\partial t}+\frac{\partial (vu)}{\partial x}+\frac{\partial (vv)}{\partial y}+\frac{\partial (vw)}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+\frac{1}{\rho}\frac{\partial \tau_{yx}}{\partial x}+\frac{1}{\rho}\frac{\partial \tau_{yy}}{\partial y}+\frac{1}{\rho}\frac{\partial \tau_{yz}}{\partial z} \quad (3)$$

$$\frac{\partial w}{\partial t}+\frac{\partial (wu)}{\partial x}+\frac{\partial (wv)}{\partial y}+\frac{\partial (ww)}{\partial z}=-g-\frac{1}{\rho}\frac{\partial p}{\partial z}+\frac{1}{\rho}\frac{\partial \tau_{zx}}{\partial x}+\frac{1}{\rho}\frac{\partial \tau_{zy}}{\partial y}+\frac{1}{\rho}\frac{\partial \tau_{zz}}{\partial z} \quad (4)$$

where *u, v, w* are flow velocities in *x, y, z* directions, respectively; *t* is time, ρ is water density; *p* is the pressure; *g* is the gravitational acceleration, τ_{xx}, τ_{xy}, ..., and τ_{zz} are the stresses (including both molecular and turbulent effects).

Following Casulli and Stelling (1998) and Stelling and Zijlema (2003), the total pressure is split into hydrostatic and non-hydrostatic parts as

$$p=\rho g(\eta-z)+\hat{q} \quad (5)$$

where $\eta(x, y, t)$ is the free surface elevation, $\zeta(x,y)$ is the bed elevation, and the total water depth is $H=(\eta(x,y,t)-\zeta(x,y))$. The vertical datum is arbitrary, but it is usually set equal to the still water level (sea level) for coastal and oceanographic researches as shown in Figure 1.

The free surface and bottom kinematic boundary conditions are

$$w_\eta=\frac{D\eta}{Dt}=\frac{\partial \eta}{\partial t}+u_\eta\frac{\partial \eta}{\partial x}+v_\eta\frac{\partial \eta}{\partial y} \qquad \text{at } z=\eta \quad (6)$$

$$w_\zeta=\frac{D\zeta}{Dt}=u_\zeta\frac{\partial \zeta}{\partial x}+v_\zeta\frac{\partial \zeta}{\partial y} \qquad \text{at } z=\zeta \quad (7)$$

Depth integration of Equations (1)-(4) from to by taking into account the pressure in Equation (5) and the boundary conditions of Equations (7) and (8), ignoring the viscosity term, and following the non-hydrostatic pressure term treatments of Stelling and Zijlema (2003) and Walters (2005). The governing equations in Cartesian coordinate system are derived as

$$\frac{\partial \eta}{\partial t}+\frac{\partial (HU)}{\partial x}=0 \quad (8)$$

$$\frac{\partial U}{\partial t}+U\frac{\partial U}{\partial x}=-g\frac{\partial \eta}{\partial x}-\frac{gn^2U|U|}{H^{4/3}}-\frac{1}{2\rho H}(H\frac{\partial q}{\partial x}+q(\frac{\partial \eta}{\partial x}+\frac{\partial \zeta}{\partial x})) \quad (9)$$

$$\frac{\partial W}{\partial t}=\frac{q}{\rho H} \quad (10)$$

where *U*, *W* are depth-integrated velocities in horizontal and vertical directions, respectively; *q* is the non-hydrostatic pressure at the bottom and n is the Manning coefficient. As the distribution of vertical velocity is unknown, it is approximated by $W = (w_\zeta + w_\eta) / 2$. Due to introduction of the non-hydrostatic pressure and incompressibility (Casulli and Stelling, 1998; Stelling and Zijlema, 2003), the above equations are solved together with the two-dimensional vertical form of continuity equation (1):

$$\frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} = 0 \qquad (11)$$

Boundary conditions

To obtain a unique solution, boundary conditions are required at all the boundaries of the physical domain considered. At the free surface, since the current model doesn't consider the wind stress and surface tension, the atmospheric pressure boundary condition is used.

At the bottom, Manning equation is used to approximate the bed friction, and the vertical velocity at the bed surface is prescribed by the bottom kinematic boundary condition (7).

At the inlet, an incident normal velocity is given based on the linear wave theory as

$$u_I = \frac{\omega f_r}{k(\eta_I - \zeta)} \eta_I \qquad (12)$$

where $\omega = 2\pi/L$ is the angular frequency of wave with *T* the wave period; $\kappa = 2\pi/L$ is the wave number with *L* the wave length; η_1 is the incident wave surface elevation, for a regular wave, it is usually specified as a sinusoidal or monochromatic wave; f_1 is a ramp function used to prevent initially short waves with relatively large amplitudes (Stelling and Zijlema, 2003) and it is defined as

$$f_r(t) = \frac{1}{2}\left(1 + \tanh\frac{t - 3T}{T}\right) \qquad (13)$$

The non-hydrostatic pressure is implicitly assumed as zero at inlet.

At the outlet and both ends of solitary wave cases, the flow is assumed hydrostatic. To allow the waves to cross the outflow boundary without reflections, Sommerfeld's radiation boundary condition is applied:

$$\frac{\partial f}{\partial x} + c\frac{\partial f}{\partial x} = 0 \qquad (14)$$

where *f* can be water surface elevation and velocity, *c* is the phase velocity defined as $c = \sqrt{gH}$.

Numerical Formulation

In this research, the governing equations are discretized based on a one-dimensional grid $\{x_{i-1/2} \,|\, x_{i+1/2} = i\Delta x,\ i=0, \ldots, M\}$ with *M* the number of grid cells and Δx the length of the grid cell. The location of the cell center is given by $x_i = (x_{i-1/2} + x_{i+1/2}) / 2$. A staggered grid convention is used in which velocity *U* is located at $x_{i+1/2}$ on the other hand, free surface elevation η and the other variables ζ, w_η, $w\zeta$ and *H* are located at x_i.

The governing equations are solved semi-implicitly with several steps. In the first step, the momentum equation without non-hydrostatic pressure terms is explicitly solved for the provisional velocity; in the second step, a tri-diagonal equation for non-hydrostatic pressure is constructed using the continuity equation (11) and implicitly solved, and then the provisional velocity is updated; finally, the water depth is updated by solving the depth-integrated continuity equation to ensure global mass conservation.

First step

In this step, the provisional velocity is calculated by the momentum equation (9) without the non-hydrostatic pressure terms as

$$\frac{\partial U}{\partial t} + U\frac{\partial U}{\partial x} + g\frac{\partial \eta}{\partial x} + \frac{gn^2 U|U|}{H^{4/3}} = 0 \qquad (15)$$

and it is discretized as

$$\frac{\tilde{U}^{n+1}_{i+1/2} - U^n_{i+1/2}}{\Delta t} + ADV + g\frac{\eta^n_{i+1} - \eta^n_i}{\Delta x} + \frac{n^2 g \tilde{U}^{n+1}_{i+1/2}\left|U^n_{i+1/2}\right|}{(\bar{H}^{4/3}_{i+1/2})^n} = 0 \qquad (16)$$

where $U^n_{i+1/2}$ is the horizontal velocity at previous time level, $\bar{H}^n_{i+1/2}$, the water depth at a velocity point, is averaged from the neighboring water depths at surface points. *ADV* is the discretization of the advective term, and it is approximated by a momentum conservation scheme proposed by Stelling and Duinmeijer (2003) as

$$ADV = \left(u\frac{\partial u}{\partial x}\right)^n_{i+1/2} = \max(u_{\rightarrow},0)\left(\frac{u^n_{i+1/2}-u^n_{i-1/2}}{\Delta x}\right)+\min(u_{\leftarrow},0)\left(\frac{u^n_{i+3/2}-u^n_{i+1/2}}{\Delta x}\right) \quad (17)$$

with

$u_{\rightarrow} = \frac{\bar{q}^n_i}{\bar{H}^n_{i+1/2}}$, $u_{\leftarrow} = \frac{\bar{q}^n_{i+1}}{\bar{H}^n_{i+1/2}}$, $\bar{q}^n_i = \frac{q^n_{i+3/2}+q^n_{i+1/2}}{2}$ and $q^n_{i+1/2} = \hat{H}^n_{i+1/2}U^n_{i+1/2}$.

The water depth at a velocity point $\hat{H}^n_{i+1/2}$ is simply calculated by a first-order upwind scheme as follows:

$$\hat{H}^n_{i+1/2} = \begin{cases} H^n_i, & \text{if } U^n_{i+1/2} > 0 \\ H^n_{i+1}, & \text{if } U^n_{i+1/2} < 0 \\ \max(\eta^n_i,\eta^n_{i+1}) - \max(\varsigma^n_i,\varsigma^n_{i+1}), & \text{if } U^n_{i+1/2} = 0 \end{cases} \quad (18)$$

Second step

In the second step, to achieve a divergence-free velocity field, a tri-diagonal equation is formulated using continuity equation, the momentum equation and bottom kinematic boundary condition and it is implicitly solved for non-hydrostatic pressure. And then the provisional velocity field is corrected by non-hydrostatic pressure.

The vertical velocity at the bottom is calculated by Equation (6) as

$$w_{\zeta i}^{n+1} = \bar{\tilde{U}}^n_i \frac{\zeta_{i+3/2}-\zeta_{i+1/2}}{\Delta x} \quad (19)$$

where $\bar{\tilde{U}}^n_i$, the horizontal velocity at surface points, is calculated by $\bar{\tilde{U}}^n_i = (\tilde{U}^n_{i-1/2}+\tilde{U}^n_{i+1/2})/2$.

The vertical velocity at the free surface is calculated by vertical momentum equation (10) with the approximation $W = (w_\zeta + w_\eta)/2$ and therefore,

$$w_{\eta i}^{n+1} = w_{\eta i}^{n} - w_{\zeta i}^{n+1} + w_{\zeta i}^{n} + \frac{2\Delta t q_i^{n+1}}{\rho H_i^n} \quad (20)$$

Comparing Equation (15) with Equation (9), it is seen that the final horizontal velocity influenced by the non-hydrostatic pressure can be written as

$$\frac{U^{n+1}_{i+1/2}-\tilde{U}^{n+1}_{i+1/2}}{\Delta t}+\frac{1}{2\rho}\frac{q^{n+1}_{i+1}-q^{n+1}_i}{\Delta x}+\frac{1}{2}\frac{\bar{q}^{n+1}_{i+1/2}}{\rho \bar{H}^n_{i+1/2}}\frac{(\eta^n_{i+1}+\zeta_{i+1})-(\eta^n_i+\zeta_i)}{\Delta x}=0 \quad (21)$$

The non-hydrostatic pressure is calculated using the discretized continuity equation (11) as follows

$$\frac{U^{n+1}_{i+1/2}-U^{n+1}_{i-1/2}}{\Delta x}+\frac{w_{\eta i}^{n+1}-w_{\zeta i}^{n+1}}{H^n_i}=0 \quad (22)$$

Substituting Equations (19), (20) and (21) into Equation (22), a tri-diagonal equation for non-hydrostatic pressure is obtained:

$$A_W q^{n+1}_{i-1} + A_P q^{n+1}_i + A_E q^{n+1}_{i+1} = S \quad (23)$$

where

$$A_W = \frac{\Delta t}{4\rho}\frac{((\eta^n_i+\zeta_i)-(\eta^n_{i-1}+\zeta_{i-1}))}{\bar{H}^n_{i-1/2}\Delta x^2}-\frac{\Delta t}{2\rho\Delta x^2}$$

$$A_P = \frac{\Delta t}{\rho\Delta x^2}+\frac{2\Delta t}{\rho(H^n_i)^2}+\frac{\Delta t}{4\rho}\frac{((\eta^n_i+\zeta_i)-(\eta^n_{i-1}+\zeta_{i-1}))}{\bar{H}^n_{i-1/2}\Delta x^2}-\frac{\Delta t}{4\rho}\frac{((\eta^n_{i+1}+\zeta_{i+1})-(\eta^n_i+\zeta_i))}{\bar{H}^n_{i+1/2}\Delta x^2}$$

$$A_E = -\frac{\Delta t}{4\rho}\frac{((\eta^n_{i+1}+\zeta_{i+1})-(\eta^n_i+\zeta_i))}{\bar{H}^n_{i+1/2}\Delta x^2}-\frac{\Delta t}{2\rho\Delta x^2}$$

$$S = 2\bar{U}^n_i\frac{\zeta_{i+3/2}-\zeta_{i+1/2}}{H^n_i\Delta x}-\frac{\tilde{U}^{n+1}_{i+1/2}-\tilde{U}^{n+1}_{i-1/2}}{\Delta x}-\frac{w_{\eta i}^{n}+w_{\zeta i}^{n}}{H^n_i}$$

Equation (23) can be efficiently solved by a tri-diagonal solver (e.g. TDMA). Once the non-hydrostatic pressure is obtained, the horizontal velocity is corrected by Equation (21), and the vertical velocity at the free surface is updated by Equation (20).

Third step

In the last step, the depth-integrated continuity equation (8) is solved for the water depth using the corrected horizontal velocity as

$$\frac{\eta^{n+1}_i-\eta^n_i}{\Delta t}+\frac{\hat{H}^n_{i+1/2}U^{n+1}_{i+1/2}-\hat{H}^n_{i-1/2}U^{n+1}_{i-1/2}}{\Delta x}=0 \quad (24)$$

In case that the bed is fixed, Equation (24) can be rewritten as

$$\frac{H^{n+1}_i-H^n_i}{\Delta t}+\frac{\hat{H}^n_{i+1/2}U^{n+1}_{i+1/2}-\hat{H}^n_{i-1/2}U^{n+1}_{i-1/2}}{\Delta x}=0 \quad (25)$$

In Stelling and Duinmeijer (2003), a simple and efficient wetting and drying algorithm was proposed to obtain the non-negative depth with a semi-implicit formulation, and their algorithm is adopted for explicit time integration in this study. It is assumed that the velocity is positive, with the water depth at a velocity point $\hat{H}^n_{i+1/2}$ defined in Equation (17), Equation (25) is rearranged to be

$$H^{n+1}_i = H^n_i\left(1-\frac{\Delta t}{\Delta x}U^n_{i+1/2}\right)+H^n_{i-1}U^n_{i-1/2} \quad (26)$$

and therefore, the total water depth is ensured to be positive if . Similar requirement can be derived for a negative flow velocity.

MODEL VERIFICATION AND VALIDATION

In this section, the developed one-dimensional dynamic wave model is verified by an analytical solution and validated by three benchmark cases for nearshore phenomena simulation.

Solitary wave propagation along a constant water depth channel

The solitary wave is a nonlinear wave with finite amplitude, which is not a solution of the hydrostatic shallow water equations, and therefore it is first used to verify the correctness of the non-hydrostatic model. If the fluid is inviscid and the horizontal bottom is frictionless, the wave should maintain the shape and velocity during the propagation process. This case has been used in several non-hydrostatic model verifications (Stelling and Zijlema, 2003; Zijlema and Stelling, 2005; Walters, 2005; and Yamazaki et al., 2008). In this numerical test, a 1000 m long and 10 m deep frictionless channel with radiation boundary condition imposed at both ends is considered. The initial solitary wave is located at x_0=100 m and its initial height is A=2m. The mesh size is Δx=0.5 m, the time step is Δt=0.025 s, and the Courant number in terms of wave celerity is Cr = $= \Delta t\sqrt{gH} / \Delta x \approx 0.5$.

Figure 2 shows the initial solitary wave and simulated wave along the channel at 20, 40 and 60 s. There is a slight reduction of wave height at the beginning of simulation due to the initial condition approximated by the analytical solution, similar observations were reported by Walters (2005) and Yamazaki et al. (2008). It can be seen that the shape and amplitude are conserved well during the simulation, this is attributed to the non-hydrostatic pressure terms in the formulation.

Regular waves propagation over a submerged bar

The second numerical test investigates the wave model's capability to handle nonlinear dispersive waves propagation. Beji and Battjes (1993) and Luth et al. (1994) conducted physical experiments of regular waves propagation over a submerged trapezoidal bar in a 37.7 m long, 0.8 m wide and 0.75 m high wave flume. Figure 3 shows the numerical setup of the experiment, the still water depth is 0.4 m, a 0.3 m bar with offshore slope 1:20 and shoreward slope 1:10 is set between 6.0 m and 17.0 m in the flume. The incident sinusoidal waves with amplitude 1.0 cm and wave period 2.02 s, corresponding to the wave depth parameter $kH \approx 0.67$, are generated at left side. The wave absorber of the experiment, a 1:25 plane beach with coarse material at the right side, is modeled by an open flow area with the radiation boundary condition imposed (Stelling and Zijlema, 2003; Yamazaki et al., 2008). Surface elevations were measured with wave gauges at several locations. In the simulation, the 35 m long computational domain is discretized with Δx = 1.25 cm, and time step Δt = 0.0025 s.

Comparison of simulated and measured free surface elevations is shown in Figure 4. It is seen that the wave shoaling process on the offshore side of bar (Gauges 4 and 5) and wave transformation from a low frequency dispersion zone (Gauge 6) to a high frequency dispersion zone (Gauge 8) are well predicted by this depth-integrated non-hydrostatic model. However, obvious discrepancies appear between simulated and measured water surface elevations over the flat bottom behind the bar, in this area, the highly dispersive waves with water depth parameters range from 6 to 10 in this zone (Roeber et al., 2010), are out of the applicable range of depth-integrated model. However, these high dispersive waves have been simulated very well by a multi-layer non-hydrostatic model (Stelling and Zijlema, 2003).

Solitary wave run-up along a plane beach

The third numerical test examines the model's capability to handle wave breaking and wave run-up. Titov and Synolakis (1995) presented a solitary wave with wave height A/h = 0.3 (h is the still water depth) ran up a beach with slope 1:19.85. In the numerical model setup, the grid size is $\Delta x/h$=0.125, Manning coefficient n = 0.01 is used to define the surface roughness, and the initial solitary wave is at 20h from the beach toe. Figure 5 compares the simulated surface profiles with the measurement. As the wave propagates over the sloped beach, the wave front starts to skew, and eventually the wave breaks between $t\sqrt{g/h}$=20 and $t\sqrt{g/h}$=25, the numerical model successfully simulates the wave breaking process without any stability issues. And then the breaking water surges over the beach and a hydraulic jump forms around $t\sqrt{g/h}=50$. Overall, the numerical model reasonably predicts the wave run-up, a minor discrepancy is observed for the location of the return flow around $t\sqrt{g/h}=55$ this was also reported in other numerical test (Yamazaki et al., 2008; Roeber et al., 2010).

Solitary wave propagation over a fringing reef
The last case is a solitary wave transformation over an idealized fringing reef, validating the model's capability in handling nonlinear dispersive waves and wave bore propagation. Two series of laboratory experiments on solitary waves transformation over idealized fringing reefs at the O.H. Hinsdale Wave Research Laboratory of Oregon State University were reported by Roeber et al. (2010). In this study, the considered test involves a solitary wave of wave height A = 0.5 m in a 48.8 m flume and a still water depth of h = 1.0 m, a 1:5 fore reef and a dry reef flat, a Manning coefficient n = 0.012 is used to approximate the surface roughness. In the experiment, the wave starts to skew to the front as it propagates across the toe of the slope at x = 17 m, and gradually the wave surges over the flat reef undergoing a transition from subcritical flow to supercritical flow around $t\sqrt{g/h}=56$ after the wave surges onto the dry reef, it forms as sheet flow, meanwhile, the reef edge exposed because the rarefaction falls below the initial water level (Roeber et al., 2010). Figure 6 shows the comparison between the measured and simulated wave profiles as the solitary wave propagates across the flume, it can be seen that the numerical model correctly predict the wave surge, flow transition process, sheet flow, wave front and even the offshore rarefaction.

CONCLUSIONS

In this paper, a one-dimensional non-hydrostatic wave model for wave propagation, breaking and run-up has been developed based on the work of Stelling and Duinmeijer (2003). The model solves the depth-integrated, non-conservation form of shallow water equations with extra non-hydrostatic pressure terms. As the existing formulation can properly simulate hydraulic jump with a conservation scheme and handle the moving boundary with a simple and efficient wetting and drying algorithm, the newly developed non-hydrostatic module enables the model for dynamic wave motion simulation. Analytical solution and experimental data have been used to verify and validate the model, the results show that the developed wave model is suitable for nearshore phenomena simulation, and it is able to handle nonlinear dispersive waves propagation, wave shoaling, breaking and run-up to a certain degree.

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Figure 1. Computational domain with free surface and bed elevation.

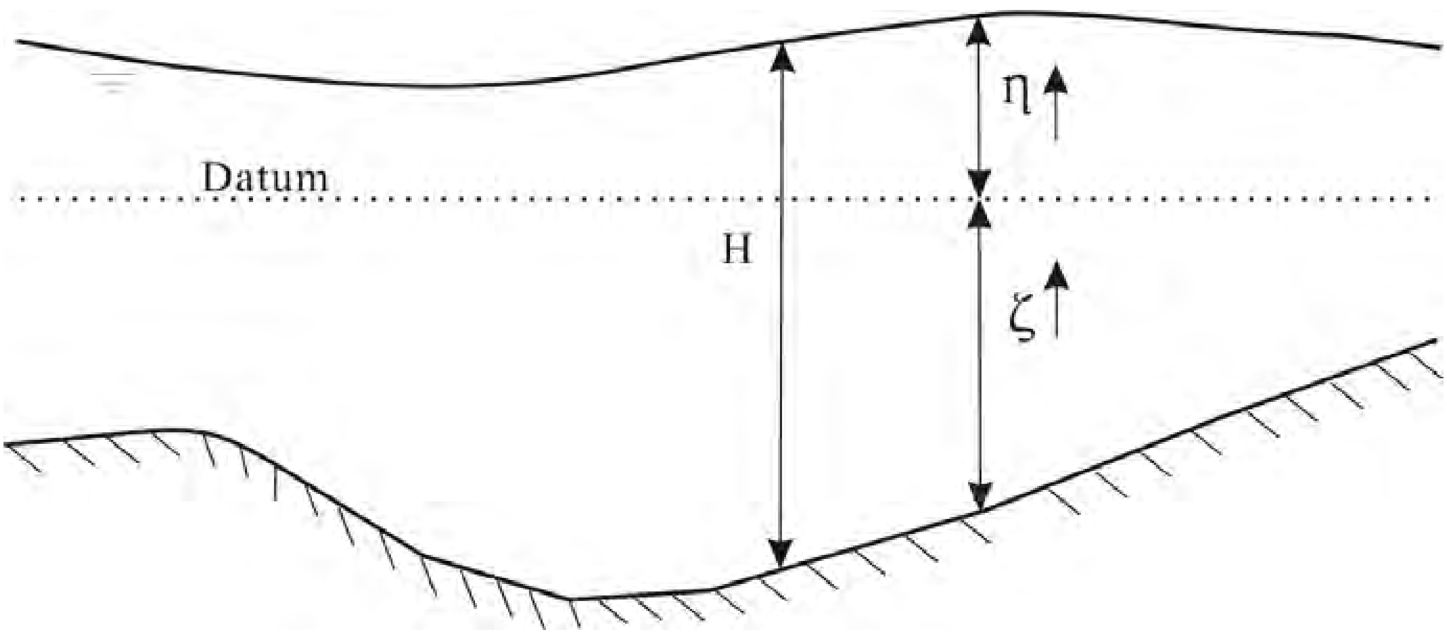


Figure 2. Solitary wave propagation along a channel at different time steps.

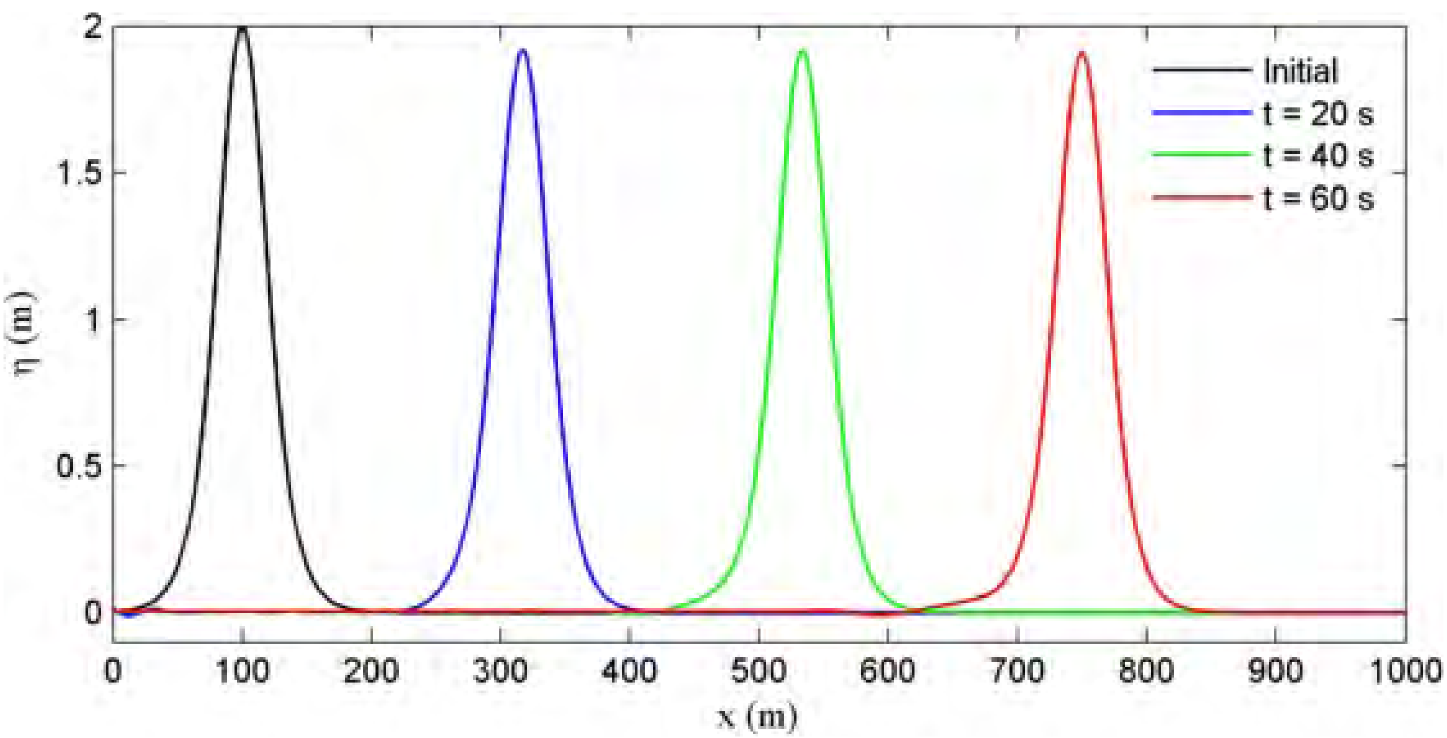


Figure 3. Numerical model setup of waves propagation over a submerged bar.

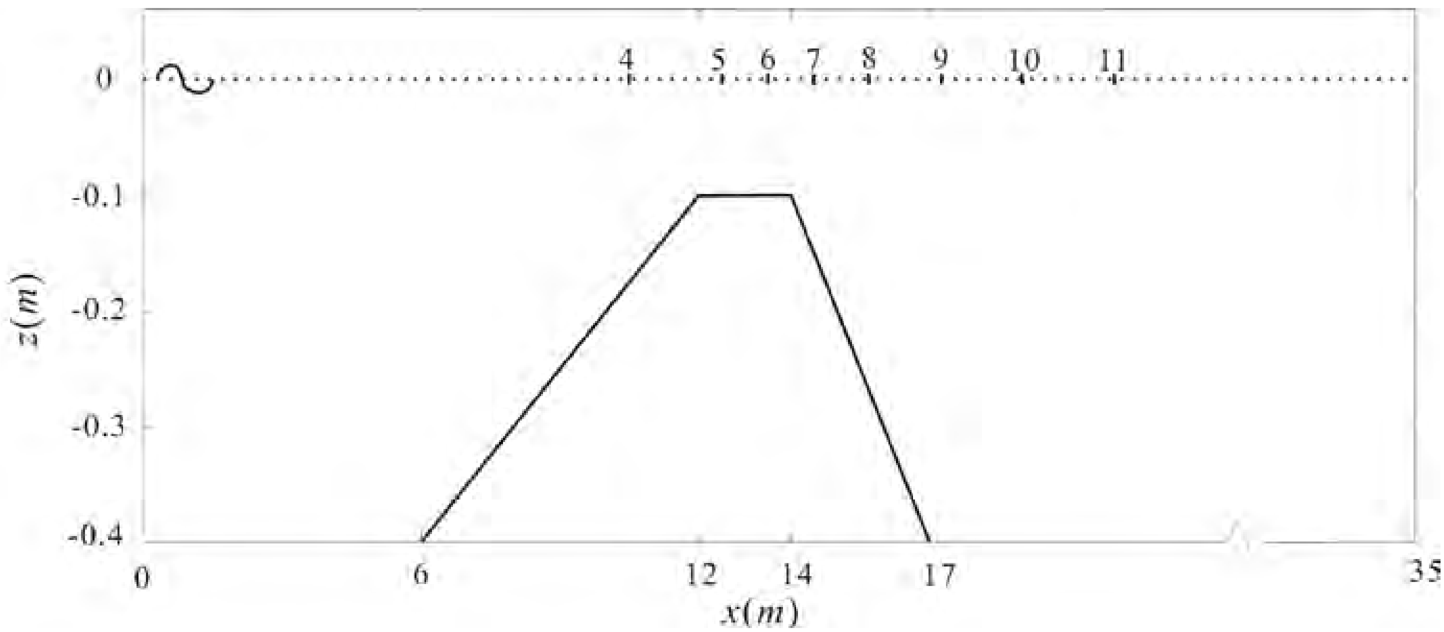


Figure 4. Comparison of simulated and measured free surface elevations at several wave gauges. Numerical results (solid lines), experimental data (circles).

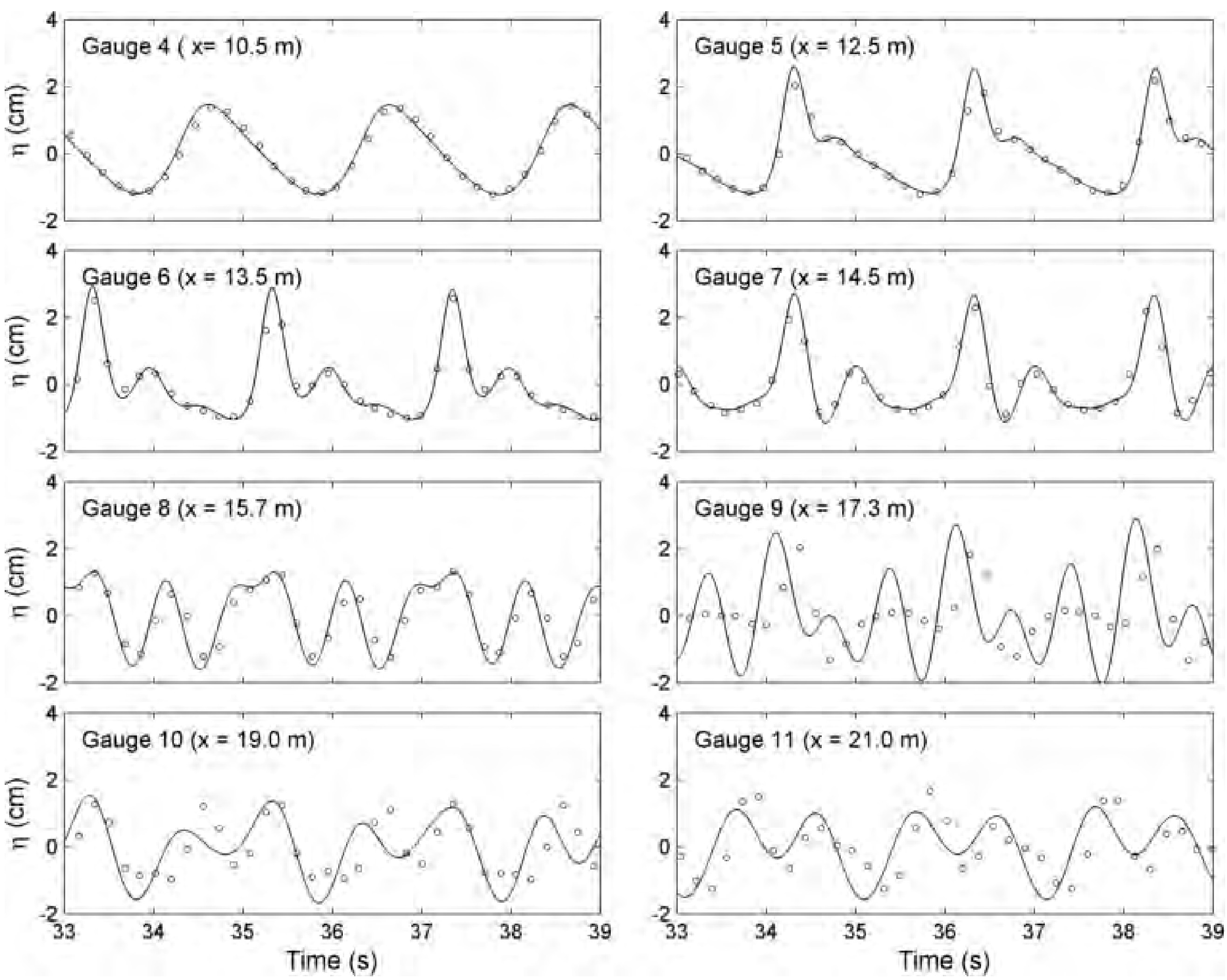


Figure 5. Surface profiles of a solitary wave run-up on a 1:19:85 plane beach. Numerical results (solid lines), experimental data (circles).

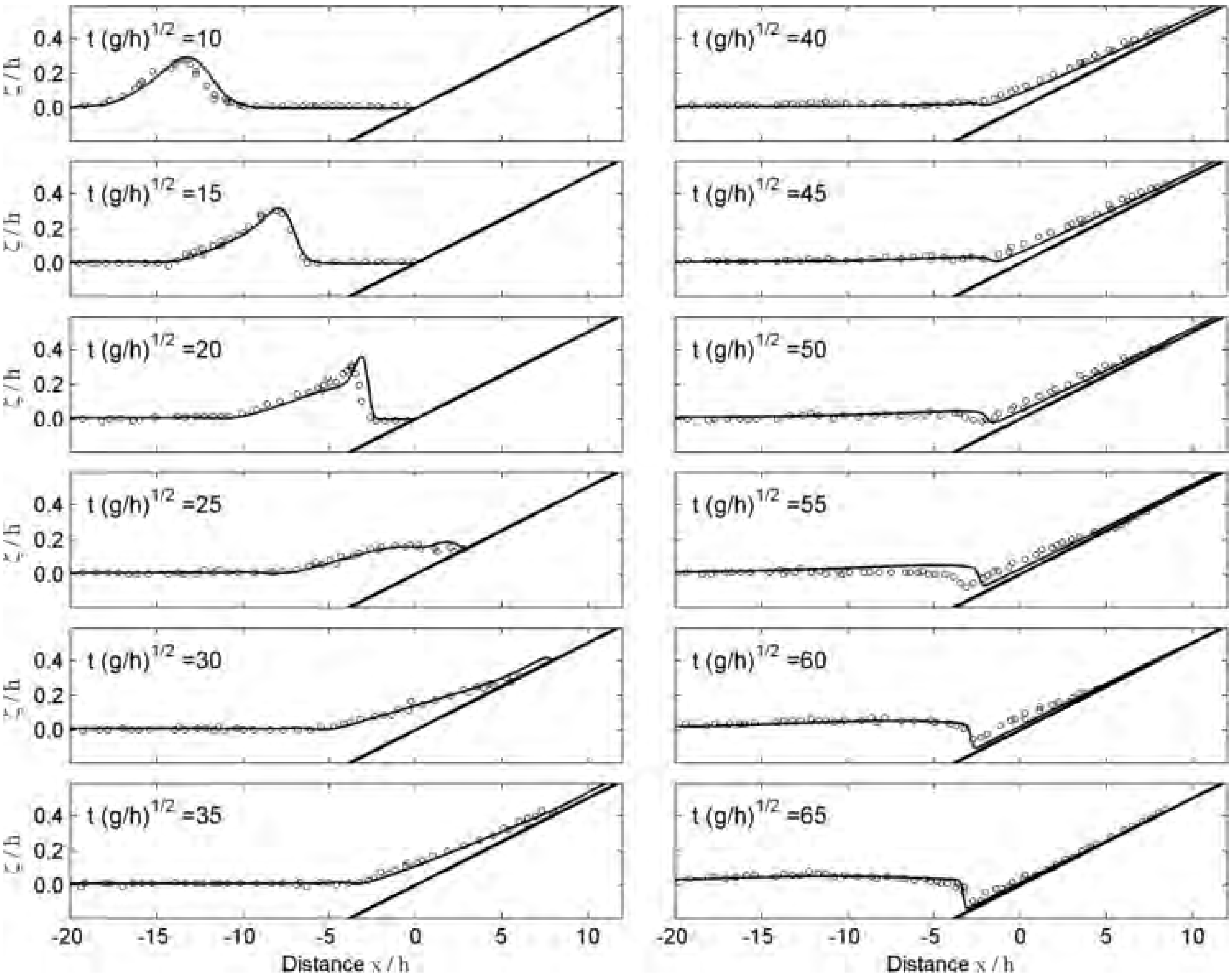
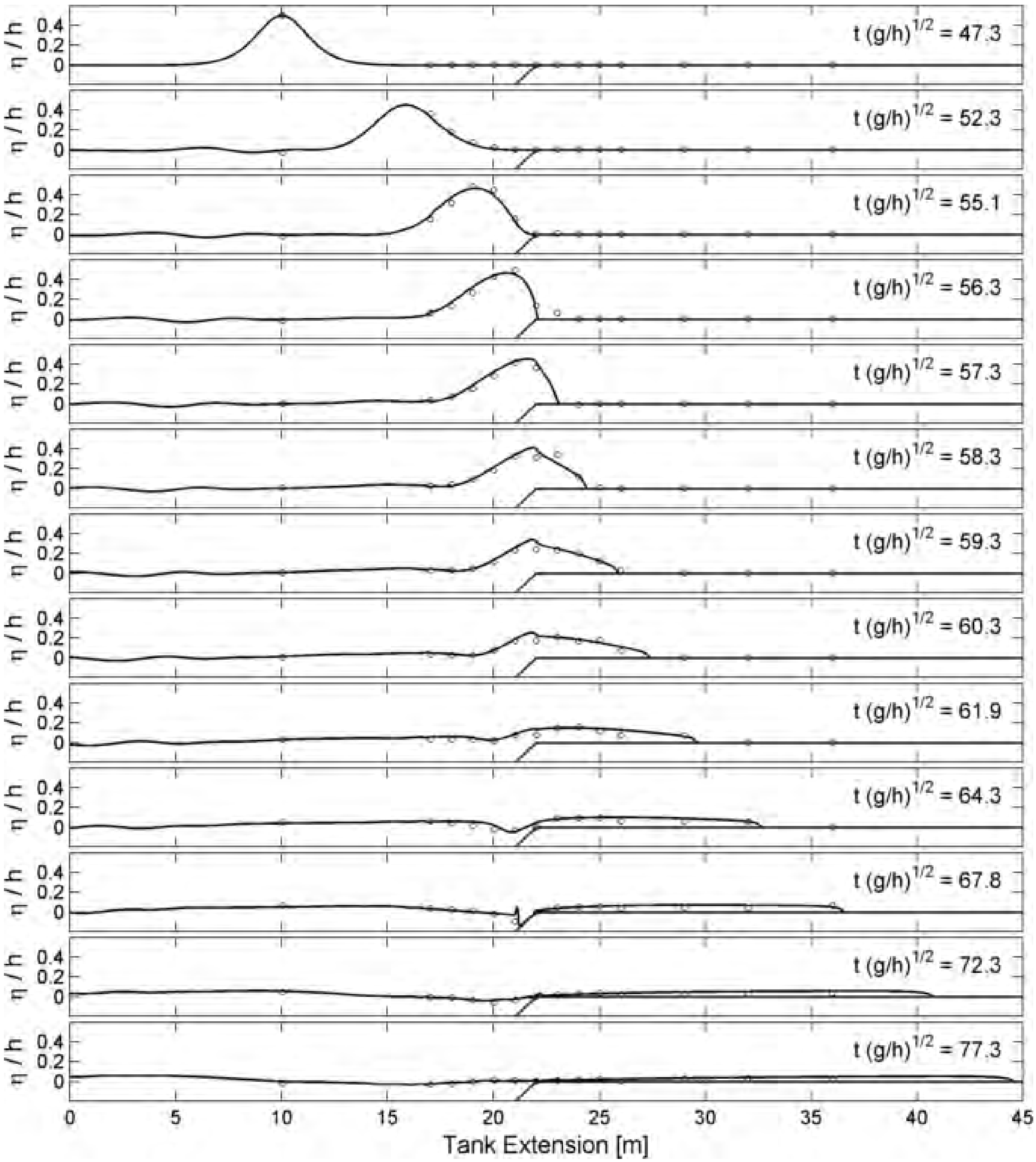


Figure 6. Surface profiles of a solitary wave propagation over a fringing reef. Numerical results (solid lines), experimental data (circles).



Ecological Assessment of NRCS's Migratory Bird Habitat Initiative in Reponse to BP's Gulf Oil Spill

Kaminski, R.

Science should guide conservation of natural resources to promote effectiveness, efficiency, and economy of management actions and policy development. Following the Deepwater Horizon Oil Spill in the Gulf of Mexico in April 2010, the Natural Resources Conservation Service (NRCS) established the Migratory Bird Habitat Initiative (MBHI). Working with owners and managers of private croplands, aquaculture ponds, and Wetland Reserve Program easements, NRCS and conservation partners managed thousands of acres of wetlands and agricultural lands in the Mississippi Alluvial Valley (MAV) and Gulf Coast regions to provide wetland and upland habitat inland from potentially oil-impacted coastal wetlands. In fall 2010, scientists and graduate students from Mississippi State University, Arkansas Tech University, and University of Missouri began designing and implementing local and landscape scale surveys to (1) estimate use of MBHI managed wetlands and comparable non-MBHI wetlands by shorebirds, waterfowl, and other waterbirds, and (2) assess relative effectiveness of different MBHI practices for providing habitat and food resources for migrating, resident, and wintering waterbirds. Currently, researchers are working in the MAV in Arkansas, Louisiana, Mississippi, and Missouri and the Gulf Coast Prairies in Louisiana and Texas. Our presentation will summarize estimated bird use and food abundance on MBHI and compared study areas and report future directions for completing the MBHI assessment by 2013. Generally, avian abundance and diversity have been greater on MBHI-managed than other areas, although complexes of managed and other wetlands are providing wetland habitat for waterbirds among seasons. For example, when managed wetlands are dewatered in spring-summer to promote emergent vegetation, wetlands lacking such hydrological management provide habitat for waterbirds. Our study will aid future habitat conservation and adaptive management on private and public lands inland from the Gulf, which is a proactive need considering continued decline of continentally important coastal wetlands.

Modeling Sediment and Phosphorus Yields Using the HSPF Model in the Deep Hollow Watershed, Mississippi

Diaz-Ramirez, J.; Martin, J.; McAnally, W.; Rebich, R.

The impact of excess nutrient loads on eutrophication of waterbodies, including the increasingly frequent occurrences of harmful algal blooms and hypoxia, is well known and well documented. The Mississippi River/Gulf of Mexico Hypoxia is also a major environmental issue, and a key component of the Gulf Hypoxia Action Plan is the development and implementation of state nutrient reduction strategies. Effective implementation of nutrient load reductions requires that analytical tools be available to accurately estimate loads from watersheds and waterbodies as a function of hydrologic conditions. Hydrologic models have widely been used to accurately estimate outflows from watersheds, and to a lesser degree sediment and nutrient loads. Factors impacting runoff of nutrients are not well understood and as a consequence predictions of nutrient loads are highly uncertain. This research evaluated the ability of the Hydrological Simulation Program—FORTRAN (HSPF) to simulate storm, seasonal, and long-term runoff, sediment, and phosphorus transport at the farm scale in the Deep Hollow drainage area, Mississippi. The main goal was to demonstrate the usefulness of HSPF as a computer tool for future environmental management and planning in the Mississippi Delta region. When analyzing the datasets developed by U.S. Geological Survey, 69 events were selected to setup and evaluate the HSPF model. Model evaluation consisted in splitting the available data in two different time periods, calibration from 1997 to 1998 and validation in 1999. Runoff processes were evaluated using 45 events for calibration and 24 events for validation. In evaluating sediment export processes, 29 and 11 storm events were utilized in calibration and validation periods, respectively. Phosphorus simulations (dissolved and total) were evaluated using 19 and four storm events in calibration and validation periods, respectively. The HSPF model was setup to evaluate runoff, soil erosion, dissolved & total phosphorus to storm, monthly, and annual time scales.

This study concluded that the HSPF runoff model's simulations of storm-by-storm, long term monthly, and annual intervals were very good. In simulating suspended sediment loads, HSPF performance was poor for storm-by-storm analysis. However, long term monthly, and annual suspended sediment load simulations were tracked fair and good, respectively. Simulations of dissolved phosphorus of storm-by-storm and long term monthly intervals were good. Simulated annual dissolved phosphorus loads correlated very good with observed data. Similarly, HSPF performed good in simulating long term monthly total phosphorus loads and showed very good results in modeling annual total phosphorus loads exported from Deep Hollow drainage area.

Irrigation Practices and Management

Management

Irrigation Practices and Management

Robert F. Thornton *(Mississippi State University)*	Can National Weather Service spatially gridded radar precipitation estimates be used to overcome spatial variability in Mississippi precipitation measurements?
Gretchen F. Sassenrath *(USDA Agricultural Research Service)*	Development of the Mississippi Irrigation Scheduling Tool-MIST
Brandon Rice *(Mississippi State University)*	Implementation of the Mississippi Irrigation Scheduling Tool in a dynamic web-based format
Rajkumar Prabhu *(Mississippi State University)*	Uncertainty, calibration and validation of the Mississippi Irrigation Scheduling Tool model

Can National Weather Service Spatially Gridded Radar Precipitation Estimates be Used to Overcome Spatial Variability in Mississippi Precipitation Measurements?

Thornton, R.; Sassenrath, G.; Schneider, J.; Corbitt, J.; Schmidt, A.; Crumpton, J.; Rice, B.; van Riessen, H.; Prabhu, R.

The goal of this research is to determine how reliable National Weather Service (NWS) spatially gridded radar precipitation estimates are in Mississippi. If results are good, the plan is to incorporate this source of rainfall information into the Mississippi Irrigation Scheduling Tool (MIST). Several rain gauge sources are included in the analysis in order to increase the spatial resolution of precipitation across the state of Mississippi. These sources include The Community Collaborative Rain, Snow and Hail Network (CoCoRahs), National Weather Service Cooperative Observers (COOP) and one DREC station. These rain gauge values were obtained for July 1-31 2012. Each rain gauge location is referenced by latitude and longitude, so it can be compared to NWS radar precipitation estimates at the same coordinates.

Summertime precipitation in Mississippi demonstrates a high degree of spatial variability through pop-up afternoon showers and thunderstorms. This research will determine the usefulness of radar-estimated precipitation, the spatial context of which could eliminate the variability problem inherit in point-source measurements. Actual rain gauge values are compared to radar-estimated values through the use of ARCGIS. If it is determined that radar-estimated precipitation is comparable to actual rain gauge data, then this will be incorporated into a tool to aid the Mississippi agricultural community in knowing when to most efficiently irrigate. The analysis will also attempt to find any spatial bias present between the two measurements, resulting in the discovery of any consistent correction coefficients. This, along with other conservation efforts already in place, will potentially help Mississippi farmers to conserve groundwater by supporting recharge of the Mississippi River Shallow Alluvial Aquifer over time.

Development of the Mississippi Irrigation Scheduling Tool-MIST

Sassenrath, G.; Schmidt, A.; Schneider, J.; Tagert, M.L.; van Riessen, H.; Corbitt, J.Q.; Rice, B.; Thornton, R.; Prabhu, R.; Pote, J.; Wax, C.

Increasingly variable and uncertain rainfall patterns together with higher production input costs have led farmers to rely on supplemental irrigation to enhance production. While many irrigation methods have been developed for dry climates, few tools are available for humid, high rainfall areas. Moreover, most scheduling tools require extensive data collection, entry and simulation runs, limiting their practical utility during the production season. We have designed the Mississippi Irrigation Scheduling Tool (MIST) as a web-based, easy to use management tool for crop producers. An estimate of crop water use is made using the modified Penman Monteith to calculate daily evapotranspiration. The "checkbook" water balance method sums the water balance of the soil, plus water from rainfall or irrigation, minus water used by the crop or evaporated from the soil. This method indicates the need for irrigation when the soil water available to the plant falls below that which is readily available for crop growth. To enhance utility, the MIST has been implemented in a web interface, allowing producers to access the information from anywhere through tablet computers or smart phones. To reduce the data entry requirements, the system relies on national databases for automated integration with a water balance model. The system was tested at multiple production sites during the 2011, and 2012 growing seasons. This presentation will give details on the development of input parameters for the water balance calculation, including crop water use and soil moisture, and water balance during the growing season for corn and soybeans. Additional presentations in this session will describe the implementation of the user interface (Rice et al.), calibration and validation of the model (Prabhu et al.), and spatial accuracy of national databases (Thornton et al.). The MIST will provide producers, consultants and other professional colleagues with a reliable, accurate, and easy to use tool for improved water management.

INTRODUCTION

Unlike other areas of the South, Mississippi has enjoyed plentiful ground water resources and rainfall in excess of 40" per year. However, decreasing groundwater levels in the Alluvial Aquifer are a growing concern in certain areas of the Mississippi Delta. In neighboring states, serious groundwater depletion threatens future cropping options (Bennett, 2002). The challenge for Mississippi is to manage water resources appropriately, and provide sufficient water for crop production through droughty periods that occur during the growing season. Increasing volatility in recent weather patterns has resulted in no change in overall rainfall amounts but a decrease in the number of events and a concomitant increase in intensity (SWCS Climate Change, 2003). These changes in rainfall patterns decrease the usable rain that enters the soil profile. Moreover, the uncertainty of amount and timing of rainfall makes irrigation scheduling a particular challenge, as a high rainfall event immediately following an irrigation can result in water logging of the soils and impede crop growth.

Yields and profits from non-irrigated crops are typically lower than for irrigated fields, resulting in greater use of ground water (Evett et al., 2003). The increased pumping has resulted in an average decline from the alluvial aquifer of 300,000 acre feet of water per year for the past 10 years (Powers, 2007). However, the most commonly used method of scheduling irrigation is based on the "feel-of-the-soil", with no quantitative measure of crop or soil water status used (NASS, 2007). While less efficient than sprinkler application, surface (furrow) irrigation accounts for nearly 70% of the irrigated acres in the Delta (NASS, 2007).

Implementing timely and accurate irrigation scheduling on all soybean acres could yield a net increase of 52M bushels of soybeans produced in Mississippi. Similarly, Mississippi corn acreage has more than tripled to just under a million acres per year (NASS, 2013). Again, yield has increased steadily but the state's average corn yield per acre over the preceding twenty years (110 bu/ac) is 28 bu/ac below the US average. Although corn yield can be substantially increased with irrigation, much of Mississippi corn acreage remains non-irrigated. Implementing timely and accurate irrigation scheduling on all corn acres could yield a net increase of 30M bushels of corn produced in Mississippi. If an irrigation scheduling tool reduces the volume of irrigation water pumped, farmers will also realize a reduction in fuel expenses for operating pumping equipment. Further, new state water permits require implementation of water conservation measures; an irrigation scheduling tool, developed for state-specific soils and climate, is an accepted conservation method. Particularly critical to the continued success of agriculture in the Delta is development of accurate, easy to use guidelines for irrigation scheduling and application.

Our goal is to develop and deliver to producers an accurate, easy-to-use system for water management in crop production. The Mississippi Irrigation Scheduling Tool, MIST, is designed using the latest information of crop water use and irrigation scheduling, and implemented in a web-based format for continual access anywhere. To test and parameterize the system for Mississippi, we conducted on-farm experiments in 2011-2013, collecting information on crop growth, plant stage, and soil water. As the decision support tool is validated and delivered, water use and irrigation cost information will be collected and used to develop economic tools for future inclusion in the scheduler.

METHODS

The sole standard equation accepted for calculating evapotranspiration is the Penman-Monteith (Allen et al., 1998). As used in a daily scheduling tool, this equation requires daily measurements of maximum and minimum temperature and relative humidity, and total solar radiation and wind speed, to calculate a reference evapotranspiration (ET_o). Uncertainty in the accuracy of any measured parameter required for the calculation can exacerbate the influence of a given meteorological parameter on the calculation of ET_o (Sassenrath et al., 2012). Daily measured maximum and minimum temperature, maximum and minimum relative humidity, total wind run, and total insolation data were downloaded from the Delta Research and Extension Center Weather Center (DREC, 2013), tested for errors or missing data (Sassenrath et al., 2012), and used as inputs to calculate total daily evapotranspiration (ET_o) using the modified Penman-Monteith (Allen et al., 1998). Erroneous weather data were removed, and missing data were estimated by averaging readings from previous days.

In addition to determining a reference evapotranspiration, calculation of the soil water balance requires calculation of the daily crop evapotranspiration, calculated by multiplying ET_o by a crop-specific coefficient (Allen et al., 1998). The crop coefficient is an expression of the evapotranspiration of the crop in relation to that of a reference crop, usually grass or alfalfa. Crop coefficients can be estimated using in situ measurements of crop growth (Allen et al., 1998). For real time irrigation scheduling using surface or sprinkler irrigation systems, Allen et al. (1998) suggest the use of a single crop coefficient, in which the evaporation from the soil surface and transpiration from the plant canopy are combined. Alternatively, a dual crop coefficient can be developed that separates the evaporation and transpiration components of the coefficient (Allen et al., 1998). For the MIST, we calculate crop water use using a single crop coefficient developed from crop growth measurements.

Measurement of daily total rainfall and irrigation water added to the field are also needed to determine the daily soil water balance. Erroneous specification of any of these factors contributes to errors in the calculation of plant-available soil water (Prabhu et al., 2013). Soil water balance, the water available in the soil for plant uptake, can be calculated over the growing season as:

$WB_t = WB_y - ET_c + Rain_U + Irr$

where WB_y = soil water balance yesterday; less the water used by the crop, $ET_c = ET_o \times K_c$ = daily crop evapotranspiration, calculated by multiplying reference evapotranspiration, ET_o, by a crop coefficient, K_c; plus $Rain_U$ = usable rainfall; and Irr = amount of irrigation applied. The irrigation decision is based on the calculated soil water balance (WB_t) and the soil available water capacity. When the soil water balance falls below that needed to maintain good crop growth, as established by Mississippi State Extension recommendations, an irrigation is indicated.

The MIST is implemented in a web-based format to enhance access and ease of use. Details on the implementation are given in this volume by Rice et al. (2013).

RESULTS AND DISCUSSION

Soybean planting in Mississippi can occur over a very long window of time, beginning in March and continuing through June. Soybean production is also sensitive to available water, especially for early planting dates (Table 1). The challenge in developing the irrigation scheduling tool is to have crop coefficients for the many maturity groups, cultivars, and production systems commonly used in Mississippi. To this end, we measured plant growth in production fields under a variety of production settings.

Plant growth measurements taken throughout the growing season showed the expected rapid growth period until a plateau was reached near canopy closure, followed by a slow decline as the crop matured (Figure 1). The percent light intercepted gave a better and more consistent curve for various planting dates, cultivars, and production systems than did plant height measurements. The published crop coefficients (Allen et al., 1998) were modified based on rates and timing of measured changes in light interception over the growing season to develop crop coefficients for the Mississippi Delta. Crop coefficients adjust throughout the growing season to reflect changing plant ET_c rates with crop growth and maturation (Figure 1). Surprisingly little difference occurred between the different cultivars and planting dates for both corn and soybeans, indicating single crop coefficients for each crop will suffice (data not shown).

Water tension in the soil was measured throughout the growing season using Watermark soil moisture sensors placed at 6” increments to a depth of 36” in the production and research fields at each location. The water tension in the soil increases as the plant roots remove water from the soil (Figure 2). These measurements were compared to calculated measurements of plant ET to determine how well the MIST tracked soil water balance. The MIST tracked soil water balance, as indicated by measured changes in soil water tension. Further validation of the MIST output will be performed to determine the accuracy of the model prediction.

CONCLUSIONS

The primary beneficiaries of this research are Mississippi corn and soybean producers. Understanding soil and crop water relations, irrigation scheduling, and crop water management will enable crop producers to make water use decisions based on crop needs. Water management tools and the web-based irrigation scheduler will improve the cost effectiveness of water applications, improve crop yield and quality, and reduce excess water use in crop production. Knowledge of agricultural water needs will be beneficial in developing water management policies that are economically realistic and environmentally sustainable. All Mississippians will benefit from this research through the improved management of our water resources.

DISCLAIMER

Mention of a trade name or proprietary product does not constitute an endorsement. Details of specific products are provided for information only and do not imply approval of a product to the exclusion of others that may be available.

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Thornton, R., Sassenrath, G.F., Schmidt, A.M., Corbitt, J.Q., Tagert, M.L., Prabhu, R., Pote, J., Wax, C. 2013. Determining the accuracy of National Weather Service spatially gridded radar precipitation estimates for determining field-level rainfall amounts. Mississippi Water Resources Conference, Jackson, MS.

Table 1. Impact of irrigation on yield of soybean with planting date.

Planting date	Yield, bu/ac		Increase with irrigation (bu/ac)	% loss without irrigation
	irrigated	non-irrigated		
4/14/2011	64.5	34.8	29.7	46.01
5/9/2011	58.8	36.5	22.3	37.90
6/20/2011	43.3	28.8	14.5	33.54

Figure 1. Development of a crop coefficient curve, based on published values and adjusted for Mississippi growing conditions using crop growth measurements from various production systems.

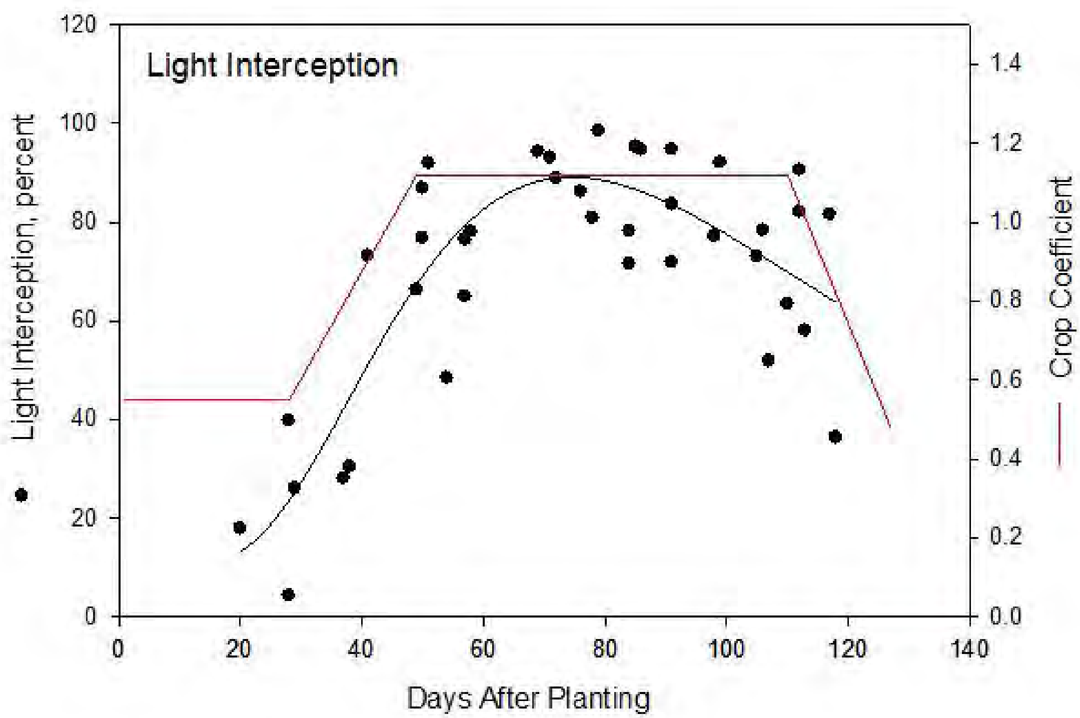
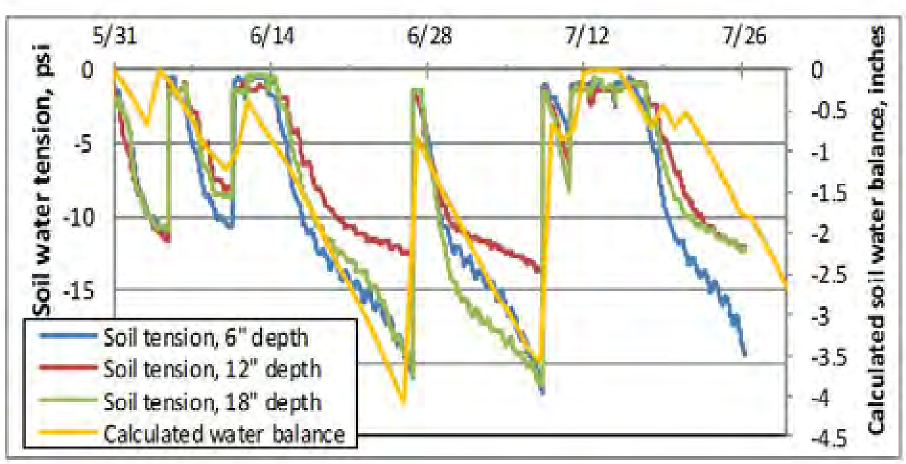


Figure 2. Comparison of changes in measured soil available water (soil water tension, psi) at 6, 12 and 18" depths in the soil with soil water balance calculated with the Mississippi Irrigation Scheduling Tool, through the growing season.



Implementation of the Mississippi Irrigation Scheduling Tool in a dynamic web-based format

Rice, B.; Sassenrath, G.F.; van Riessen, H.; Schmidt, A.M.; Tagert, M.L.

The Mississippi Irrigation Scheduling Tool (MIST) has been developed to provide a daily calculation of water balance for row crop production. This daily calculation incorporates field specific data on soil type, tillage depth, row spacing, and crop type to make a recommendation on crop water needs. Weather data is automatically downloaded from national and regional databases and used to calculate daily evapotranspiration rate using the Modified Penman-Monteith equations. The first goal of MIST was to make it more accessible to the users. To do this, MIST was implemented as a web application, developed with Java and HTML. Using a web application eliminates the need for the user to download, install and update software. The main difficulty with a web application is making sure that every browser is displaying the web pages correctly since each web browser can interpret code differently. Incompatibilities between web browsers were observed a few times; one of these occurrences was with the font that was being used. Potential incompatibilities are determined by testing the system on multiple web browsers and platforms, though updates in these systems may present problems in the future. All the data is stored within a MySQL database, which currently contains twenty tables each having between three to twenty data columns depending on the data stored. Database security is maintained by restricting server connections to local only. One of the more common SQL attacks is done through SQL injection. Prepared statements are used to prevent these types of attacks. Most of the data are stored in plain English text with a table's data column. Passwords are converted to a MD5 checksum. MD5 checksum is a cryptography based algorithm that allows the storage of data without knowing what the data actually is. This provides security in the event someone is able to obtain access to the database—sensitive information will not be accessible. There are a few different types of user ranks within the interface: admin, manager, consultant, company, and farmer, with each user rank assigned different permissions. To assist in the tedious task of setting up each field within the farm, farmers are allowed to select the border of their field with Google maps. Implementing MIST has been full of challenges and decisions that will be discussed in this paper. Given the widespread adoption of tablets and smartphones, a web application provides equal access to any device that has access to a web browser.

INTRODUCTION

Expanding reliance of crop producers on ground water for irrigation has begun to deplete the alluvial aquifer in Mississippi (Powers, 2007). Additionally, the water resource needs of crop production in the humid mid-South are not known. Accurate, easy to use tools, developed and calibrated for the humid, high rainfall environment are needed that allow crop producers to schedule irrigation based on crop need. Knowledge on crop water requirements and water resources is critical to develop practical, efficient water management guidelines for crop production. Moreover, information on agricultural water use and requirements is needed to develop scientifically sound water management policies within the region and the state.

Irrigation scheduling tools have been successfully developed and delivered to producers in many states. The success of online irrigation scheduling tools has advanced the access and use of web-based systems, and demonstrated their usefulness in crop management (Hess, 1996; Scherer and Morlock, 2008). Advantages of web-based decision support tools include: independence from operating systems; no need to install software; and accessibility on a wide range of mobile devices (including mobile phones). Challenges to implementing these tools include the need to address browser compatibility, with each browser interpreting code slightly differently; differences in features supported by different browsers; and compatibility issues even between browser versions. Many different browsers and mobile devices, and the continued development and modification of current systems, means web-based code must respond and adapt to remain viable. However, the increasing use and ease of use of these mobile devices offers a great opportunity to increase the access and use of decision support tools for crop production.

The Mississippi Irrigation Scheduling Tool (MIST) is designed to be an on-farm decision support tool to assist farmers in knowing when and how much to irrigate using a water balance approach (Bronner, 1992; Sassenrath et al., 2013). Water balance models used for scheduling irrigation calculate the soil water balance by summing the previous day's soil water, less crop water use, plus rainfall or irrigation. The MIST implements the latest knowledge of crop water management into a user-friendly, readily accessible web-based interface.

METHODS

Java is the main coding language used to implement the MIST. HTML is used to develop the user interface. Cascading style sheets (CSS) are used with HTML to change how the page is displayed to the user. JavaServer Pages (JSPs) are used for the website integration of HTML and Java. MySQL is used as the database to store the input data and calculations. Currently, 21 tables are used to hold the data and calculations. Additional tables can be added to accommodate increasing data or computational requirements.

The inputs to the system include weather data (sunlight, temperature, relative humidity, and wind speed), soil data (available water holding capacity and textural characteristics), rainfall, and data input by the end-user (Figure 1). The data required from the user includes field-specific information such as field boundary, crop type, planting date, and irrigation water applied.

The automated data and user-level input data are used to parameterize the system on the main server. The user accesses the system through a desktop or mobile device. Daily evapotranspiration rates are calculated, and daily soil water balance information is determined to decide irrigation needs.

RESULTS AND DISCUSSION

While making MIST a web application allows it to be easily accessed on multiple devices, extensive testing is needed to make sure the site appearance is consistent for each device/browser. Each browser – such as Internet Explorer, Chrome, or Firefox – has its own rules on how code is interpreted. This means that a table being displayed properly in Chrome might not even look like a table in Internet Explorer. The design of each page must be tested thoroughly on each browser and device to verify an equal experience upon each browser and device. Additional concerns that were addressed in the design and implementation of the user interface include security and protection of sensitive information. Passwords are generated using an MD5 HASH procedure.

After login, the user establishes individual fields. Fields are selected by highlighting an area on a map (Figure 2). A name is given for the field, and field information such as crop type, tillage, and planting date are entered. Initial information on soil type is chosen by the user. Alternatively, field boundaries can be imported as shape files in a predefined format.

Once the user inputs field, crop and soils information on the input pages, and the weather information is updated, the soil water balance is calculated and soil water deficit presented on the calendar page. Notifications and warnings of soil water deficit and field conditions are given in both symbol and color images for clarity (Figure 3). The information on individual field irrigation needs is displayed in a calendar format, with colored icons assigned to each field to indicate water deficit status.

After picking a field, the user will see the current month and the water deficit status for each day of the current month. The month and year that the calendar is displaying can be changed at the top of the page. By hovering over or clicking a specific day, the user can view the current water balance of the select field as well as the amount of rainfall and irrigation applied, if any. The user can adjust the rainfall or irrigation amount by clicking on the date of application. These changes will be considered on the next recalculation of soil water deficit. Three colors are used in the date blocks of the calendar to quickly give the user an idea of the water deficit status. A slightly darker tan than the calendar's background indicates future days during which soil moisture has not yet been calculated. A blue color indicates the water deficit in the field is within the acceptable boundaries. A red color is used to indicate field soil moisture has fallen below the established Maximum Allowable Depletion (MAD).

CONCLUSION

The decision support tool developed in this research project will help growers manage water resources. The system is intuitive, easy to use, accessible on a wide range of commonly used mobile devices, and requires minimal time to set up and run. By delivering the system through the web, the end-user will not need to install and upgrade the decision support tool. The utility of irrigation scheduling tools can be further enhanced by integrating them with other management systems, such as online pivot monitoring systems (WagNet, AgSense, LLC).

ACKNOWLEDGEMENT

The authors would like to acknowledge the generous support of this research by the Mississippi Soybean Promotion Board and the Mississippi Corn Promotion Board.

DISCLAIMER

Mention of a trade name or proprietary product does not constitute an endorsement. Details of specific products are provided for information only, and do not imply approval of a product to the exclusion of others that may be available.

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Figure 1. Implementation design of the Mississippi Irrigation Scheduling Tool - MIST.

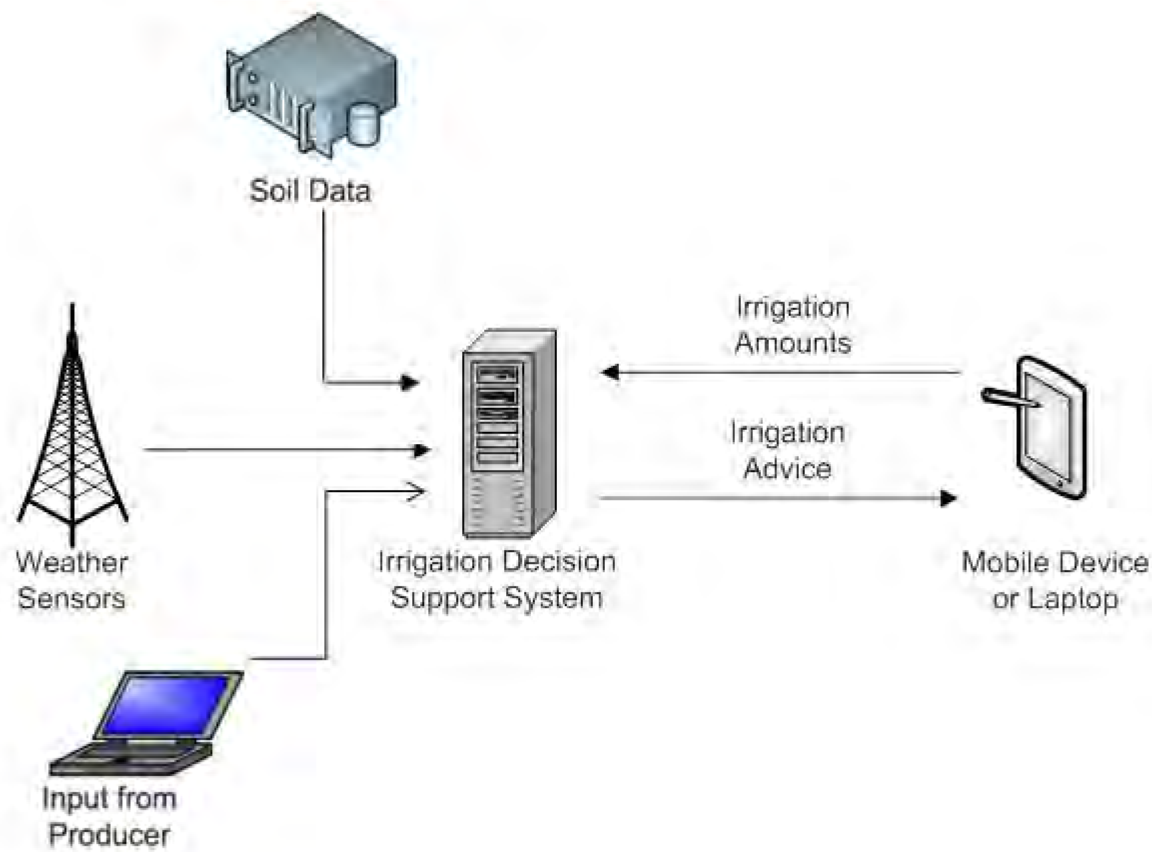


Figure 2. Setup of fields and initial data input in the Mississippi Irrigation Scheduling Tool - MIST.

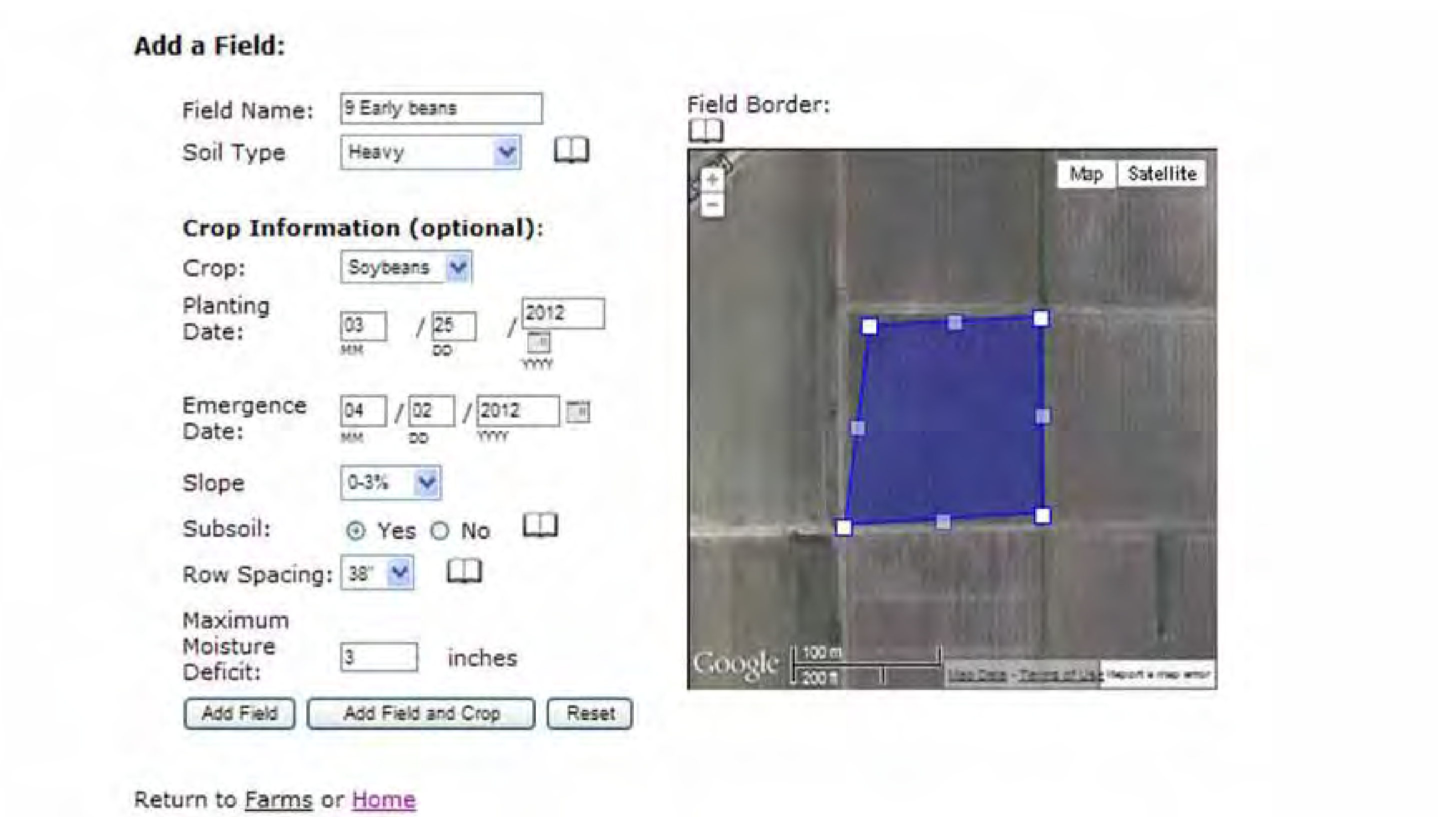
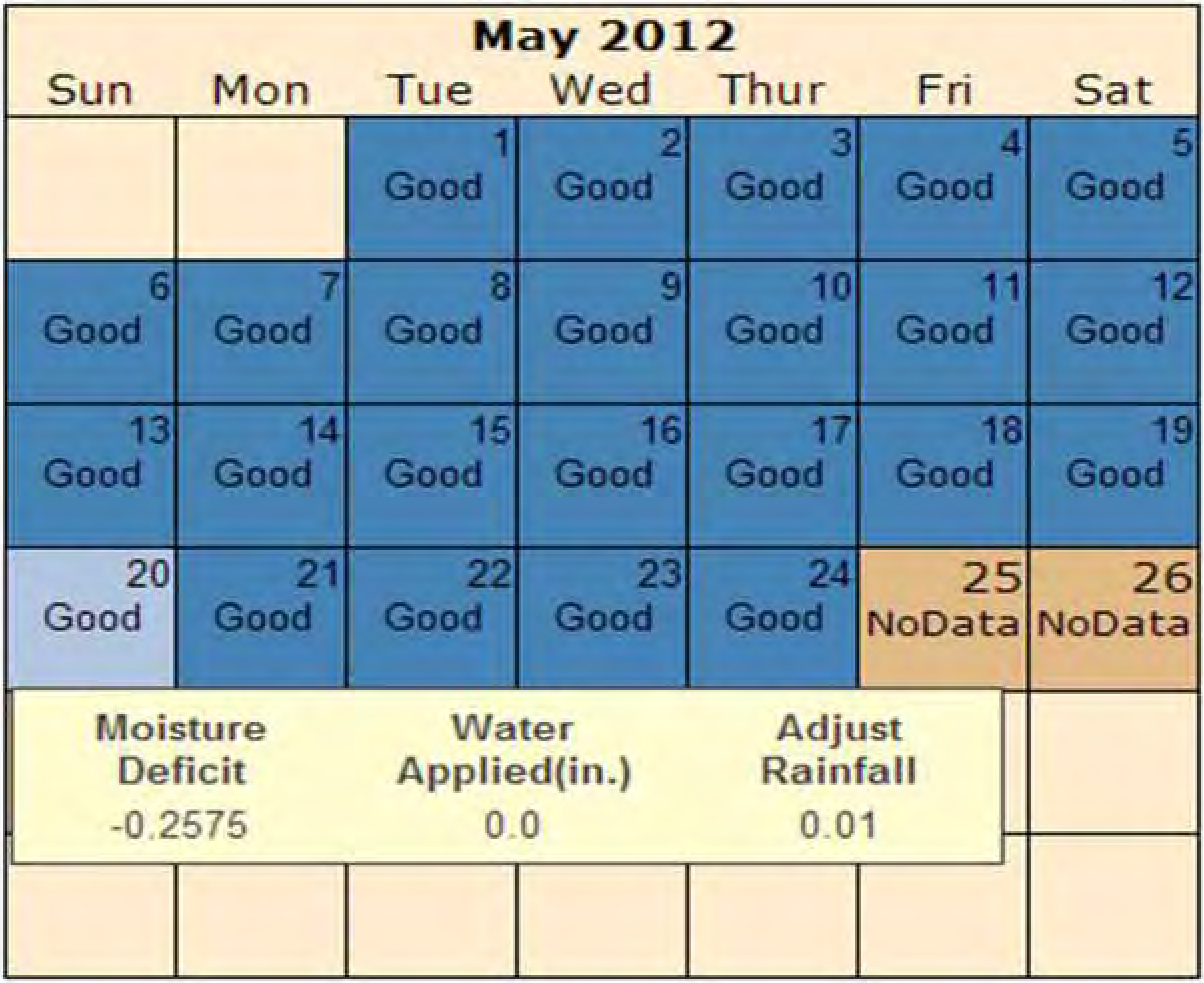


Figure 3. Information on soil water deficit for May 20 is displayed in a calendar view in the Mississippi Irrigation Scheduling Tool. Selecting a specific date gives detailed information on the soil conditions, allowing the end-user to update information on rainfall received or irrigation water applied. The color of the date in the calendar block indicates where soil water deficit is good, or has exceed the Maximal Allowable Depletion (MAD).



Uncertainty, calibration and validation of the Mississippi Irrigation Scheduling Tool model

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Implementation and use of a model requires an estimate of its accuracy. The Mississippi Irrigation Scheduling Tool (MIST) is an on-farm decision support tool to assist farmers in irrigating. The accuracy of the model is critical in designing good water management protocols. This research presents the results of the uncertainty analysis of the MIST model, showing the margin of error (uncertainty) of the irrigation advice. The basis for the verification and validation of the model is also given. The MIST calculates the daily soil water balance in a crop field from daily weather measurements, irrigation, and rainfall, accounting for crop type, planting date, soil type, tillage, and other field-specific information. The model output informs farmers of when irrigation is needed. The uncertainty analysis determines the margin of error in the irrigation decision and gives a range within which irrigation is feasible. The current uncertainty analysis also gives essential information on the influence of input parameters on the final irrigation recommendation calculated by the water balance.

The uncertainty calculations were based on Taylor's Series Method for the calculation of the total systematic uncertainty arising from measurement error of variables in the water balance calculation. The errors in measurement were one standard deviation in range, equivalent to an uncertainty with a confidence level of 68.2%. Because the current day's soil water balance depends on the previous day's water balance, the computations are iterative. As equations cascade to calculate the daily water balance, the uncertainties also propagate through the equations. Initially, uncertainty quantifications were performed for two sets of water balance calculations using local weather data. The final uncertainties for the water balance were of the order 3-6%, which is within the acceptable range for error.

The MIST water balance calculations were validated using local weather data consisting of rain days, and significant changes in the solar radiation, relative humidity and wind speed. The final water balance results showed values within acceptable ranges and comparable to in situ measurements of soil moisture. The final relative uncertainty in the water balance value was around 9%, which is in the normal range of margin of error. The current MIST web-based application and uncertainty quantification have been verified and validated for current parameters. The accuracy of the model was shown to be suitable for use by farmers in the Mississippi Delta area, and will help improve water management in crop production systems.

INTRODUCTION

Experimentation has been an essential attribute of humankind. We are all familiar with iconic lab coat-clad scientists in television advertisements presenting results that seem accurate and convincing to the audience, who are drawn to buy a commodity. The accuracy and degree of goodness of such data is occasionally questioned and seldom investigated. As an engineer or scientist, one realizes that all experimental data are subject to interpretation and include a certain amount of inaccuracy or uncertainty. To improve confidence in the accuracy of measured or estimated data to the true value, researchers have been driven to seek methodologies to quantify the errors. Quantification of uncertainties sheds light on the validity and limitation of the data. Therefore, uncertainty analysis of experimentally measured data and modeled results presents a formal methodology to quantify the errors arising from measuring and interpreting data.

In the late 1970's, the lack of international consensus among various scientific societies and authorities on uncertainty in experimental and computational measurements prompted Comite International des Poidset Mesures (CIPM) to establish international guidelines for the methodology of uncertainty analysis. This led to the International Organization for Standardization (ISO) setting up a task force to develop a guideline document. The product of the ISO task force was the "Guide to the Expression of Uncertainty in Measurement", also known as GUM (Bipm et al. 1993), which is now the international standard for the expression of uncertainty in measurements. Later, the North Atlantic Treaty Organization (NATO) Advisory Group for Aerospace Research and Development (AGARD) came up with a quality assessment methodology, through uncertainty analysis, for wind tunnel testing data (AGARD D-AR-304, 1994). With minor revisions in AGARD D-AR-304 (1994), American Institute of Aeronautics and Astronautics (AIAA) published its report on uncertainty analysis (AIAA Standard, 1995). The above mentioned reports comprise the set of standards for uncertainty analysis in engineering. Based on the recommendations of GUM and AIAA Standard S-071-1995 (1995), Coleman and Steele (1995) developed a less complex "large sample" uncertainty methodology. Coleman and Steele (1995) were able to show that their assumptions were less restrictive in the formulation of uncertainty propagation. GUM (1993) and Coleman and Steele (1995; 2009) encouraged researchers to distinguish uncertainties into those that are caused by variability and those that are not, which can be broadly distinguished as random and systematic uncertainty.

The recent development in uncertainty analysis in the engineering field has enabled scientists and engineers to combine and propagate uncertainties from experiments into the modeling stage. To improve its applicability to crop production, the implementation of the Mississippi Irrigation Scheduling Tool (MIST) and use of the web-based model requires an estimate of the accuracy of the simulation results. The following sections describe the uncertainty analysis methodology and the results and discussion deduced from the uncertainty analysis of the MIST web-based application.

UNCERTAINTY METHODOLOGY

Uncertainties arise in a measured variable through a vast number of sources such as an imperfect instrument calibration process, standards used for calibration, influence on the measured variable due to inconsistencies in ambient temperature, pressure, humidity and vibrations. Furthermore, uncertainties are also results of unsteadiness in a "steady-state" process being measured and undesirable interactions between the transducers and environment. In essence, the uncertainty that arises due to variability or randomness of a measured quantity (in this case, soil water balance on a given day: w_t) is referred to as random standard uncertainty (s_{w_t}) and uncertainties that do not arise from variability, but are calculated either through TSM or Monte-Carlo Method (MCM), are called systematic standard uncertainty (b_{w_t}). The total experimental uncertainty (U_{w_t}) is then calculated through a root sum square method specified by the following equation:

$$U_{w_t} = \sqrt{{s_{w_t}}^2 + {b_{w_t}}^2} \qquad (1)$$

The level of confidence of the uncertainty is 68%, meaning that the true value of w_t, at a given time, is expected to lie within the bounds of $\pm U_{w_t}$ 68% of the time.

The uncertainty in the result is given by the following expression:

$$U_r^2 = \left(\frac{\partial r}{\partial X_i}\right)^2 U_{X_1}^2 + \left(\frac{\partial r}{\partial X_2}\right)^2 U_{X_2}^2 + \cdots \left(\frac{\partial r}{\partial X_J}\right)^2 U_{X_J}^2 \qquad (2)$$

where U_x are the uncertainties in the measured variables X_i. The measured values of X_i are independent of another, and the uncertainties in the measured variables are also independent.

By dividing each term in the equation by r^2, the following equation is obtained from Eq. (2).

$$\frac{U_r^2}{r^2} = \left(\frac{X_1}{r}\frac{\partial r}{\partial X_1}\right)^2\left(\frac{U_{X_1}}{X_1}\right)^2 + \left(\frac{X_2}{r}\frac{\partial r}{\partial X_2}\right)^2\left(\frac{U_{X_2}}{X_2}\right)^2 + \cdots \left(\frac{X_J}{r}\frac{\partial r}{\partial X_J}\right)^2\left(\frac{U_{X_J}}{X_J}\right)^2 \quad (3)$$

where $\frac{U_r}{r}$ the relative uncertainty, and the factors $\frac{U_x}{xi}$ are the relative uncertainties for each variable. The factors which multiply the relative uncertainties of the variables are uncertainty magnification factors (UMF), and defined as:

$$UMF_i = \frac{X_i}{r}\frac{\partial r}{\partial X_i} \quad (4)$$

The relative uncertainty is increased by a UMF less than 1, and the relative uncertainty is decreased if the value of the UMF is greater than 1.

RANDOM UNCERTAINTY

Random uncertainties occur as a result of precision limitations and the inability to replicate data from test to test. Randomness of experimental data is noticed by its scatter or spread in relation to the measured variable. Standard deviation (σ) of data gives an estimate of the extent of the spread. Although there are many key factors that help determine the random uncertainty, repetitive temperature and water balance measurements on the field are the prime reasons of limitations when attempting experimental duplication. The value for σ is calculated from the following expression:

$$\sigma = \sum_{i=1}^{N}\sqrt{\frac{1}{N-1}(x_i - \bar{x})^2} = 0.5 \cdot s_{\sigma_t} \quad (5)$$

where $\bar{x}$ is the arithmetic mean of N tests and x_i is the test data for the ith repetition. The resulting bounds of the random uncertainty bands give a 68% confidence interval. The assessment of the random uncertainty requires substantial experimentation, and as such will be part of the analysis in the next stage of the project.

SYSTEMATIC UNCERTAINTY

The systematic uncertainty can include calibration, data acquisition, data reduction, or conceptual errors. But unlike random error, systematic error is based solely upon inaccuracies in measurement. These measurements have an associated offset, such that each measurement provided by the system contains a degree of inaccuracy. Therefore upon calculation, the systematic error is determined to be a quantity or component of the total error that remains constant at any given time. The systematic uncertainty in the MIST modeling procedure is due to the margin of error in data measurement (strain gage, digital calipers and digital weighing scale). The propagation of systematic error in measuring the water balance through Equation 1 is given by:

$$b_{w_t} = \left\{\left(\frac{\partial w_t(t)}{\partial w_{t-1}}\right)^2 \cdot b_{w_{t-1}}^2 + \left(\frac{\partial w_t(t)}{\partial ET_t(t)}\right)^2 \cdot b_{ET_t(t)}^2 + \left(\frac{\partial w_t(t)}{\partial K_c}\right)^2 \cdot b_{K_c}^2 + \left(\frac{\partial w_t(t)}{\partial RO(t)}\right)^2 \cdot b_{RO(t)}^2\right\}^{1/2} \quad (6)$$

where b_{w_t} is the systematic uncertainty of the final water balance that has to be calculated; $b_{w_{t-1}}$ and $b_{ET_t}(t)$ are the systematic errors in the measurement of the previous day's water balance and evapotranspiration equation respectively; b_{K_c} and $b_{RO(t)}$ are the uncertainty in the calculation of the crop coefficient and runoff respectively (which are essentially the same). The list of the Uncertainty Magnification Factors (UMFs) associated with each parameter of the MIST tool are given in Table 1.

RESULTS AND DISCUSSION

The uncertainty calculations were based on Taylor's Series Method (TSM) for the calculation of the total systematic uncertainty arising from error in the measurement of each variable associated with the water balance calculation. The errors in measurement were one standard deviation in range, which amounts to an uncertainty with a confidence level or accuracy of 68.2%. During the course of calculation the systematic uncertainty of a measured variable does not change. For instance, the temperature measured in the field may have an error of ±0.5 °F, which normally amounts to 0.5-2% relative error; this will remain a consistent error throughout the calculations. This relative error then becomes the relative systematic uncertainty that was used in the uncertainty quantification of the MIST web-based application. Because the current day's soil water balance depends on the previous day's water balance, the computations are iterative. As equations were cascaded to calculate the daily water balance, the uncertainties were also propagated through the same set of equations. Initially, uncertainty quantifications were performed for two sets of water balance calculations based on local weather data obtained from the Mississippi Delta, spanning separate 7-day periods. The final uncertainties for the water balance were of the order 3-6%, which is within the acceptable range for error involved in such calculations. These test cases then become the verification process for the MIST web-application implementation and its uncertainty quantification.

The MIST water balance calculations were validated using the local weather data that consisted of a few days of rain, and significant changes in the solar radiation, relative humidity and wind speed. The result of the analysis on the verification of the MIST tool showed that the relative uncertainty of the water balance varies from -4.5 % to 4.5 % (Figure 1). Further, the rainfall affects the uncertainties significantly for the day having rainfall and the day after rainfall.

CONCLUSIONS

The final water balance results showed values within acceptable ranges and comparable to in situ measurements of soil moisture. The final relative uncertainty in the water balance value was around 9%, which is in the normal range of the margin of error. The current MIST web-based application and uncertainty quantification have been verified and validated with limited preliminary data. Further verification and validation is needed for the entire range of Mississippi weather and irrigation.

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Table 1. The UMFS and corresponding mathematical expressions.

No.	From which eqn.	UMF Mathematical Term
UMF1	$\frac{b_{R_{NS}}}{R_{NS}}$	1
UMF2	$\frac{b_{R_N}}{R_N}$	$\frac{R_{NS}}{R_{NS} - R_{NL}}$
UMF3	$\frac{b_{R_N}}{R_N}$	$-\frac{R_{NL}}{R_{NS} - R_{NL}}$
UMF4	$\frac{b_{R_{NL}}}{R_{NL}}$	$\frac{4T_{max}^4 + T_{min}^4 T_{max}}{T_{max}^4 + T_{min}^4}$
UMF5	$\frac{b_{R_{NL}}}{R_{NL}}$	$\frac{4T_{max}^4 + T_{min}^4 T_{max}}{T_{max}^4 + T_{min}^4}$
UMF6	$\frac{b_{R_{NL}}}{R_{NL}}$	$\frac{0.34 - \frac{0.14}{2\sqrt{e_a}}}{0.34 - 0.14\sqrt{e_a}} e_a$
UMF7	$\frac{b_{R_{NL}}}{R_{NL}}$	$\frac{1.35R_s}{1.35R_s - 0.35R_{so}}$
UMF8	$\frac{b_{R_{NL}}}{R_{NL}}$	$-\frac{1.35R_s}{(1.35R_s - 0.35R_{so})}$
UMF9	$\frac{b_{ET}}{ET}$	$\frac{0.408\Delta R_n}{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}$
UMF10	$\frac{b_{ET}}{ET}$	$\frac{0.408\Delta R_n}{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}$
UMF11	$\frac{b_{ET}}{ET}$	$\frac{0.408\Delta R_n}{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}$
UMF12	$\frac{b_{ET}}{ET}$	$\frac{0.408\Delta R_n}{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}$
UMF13	$\frac{b_{ET}}{ET}$	$\frac{\frac{u_2 900\gamma e_s}{T+273}}{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}$
UMF14	$\frac{b_{ET}}{ET}$	$\frac{-\frac{u_2 900\gamma e_a}{T+273}}{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}$
UMF15	$\frac{b_{ET}}{ET}$	$\frac{\Delta 0.408(R_n - G)(\Delta + \gamma(1 + 0.34u_2)) + [(0.408\Delta(R_n - G) + \frac{u_2 900\gamma(e_s - e_a)}{T+273}}{(\Delta + \gamma(1 + 0.34u_2))\{0.408(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)\}}$
UMF16	$\frac{b_{u_2}}{u_2}$	1
UMF17	$\frac{b_{u_2}}{u_2}$	$\frac{67.8Z}{\ln(67.8Z - 5.42)(67.8Z - 5.42}$
UMF18	$\frac{b_{e_s}}{e_s}$	$\frac{e^0(T_{max})^2}{2(e_s)}$
UMF19	$\frac{b_{e_s}}{e_s}$	$\frac{e^0(T_{max})^2}{2(e_s)}$
UMF20	$\frac{b_{e^0(T)}}{e^0(T)}$	$\frac{T(17.27 - 17.27T)}{(T + 237.3)^2}$
UMF21	$\frac{b_{e_a}}{e_a}$	1
UMF22	$\frac{b_{e_s}}{e_s}$	1
UMF23	$\frac{b_{e^0(T)}}{e^0(T)}$	$\frac{e^0(T)}{RH}$
UMF24	$\frac{b_{\Delta}}{\Delta}$	$\frac{(17.27 - 17.27T - 2(T + 237.3)^3)T}{(T + 237.3)^4}$
UMF25	$\frac{b_{R_{So}}}{R_{so}}$	$\frac{R_a 2 \times 10^{-5} \times Station\ elevation}{R_{so}}$
UMF26	$\frac{b_{R_{So}}}{R_{so}}$	$\frac{R_a 2 \times 10^{-5} \times Station\ elevation}{R_{so}}$

Figure 1. The relative uncertainty of water balance during a week from 3/23/2012 to 3/29/2012.