Missouri Water Resources Research Center Annual Technical Report FY 2005

Introduction

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WATER PROBLEMS AND ISSUES OF MISSOURI

The water problems and issues in the State of Missouri can be separated into three general areas: 1) water quality, 2) water quantity, and 3) water policy. Each of Missouris specific problems usually requires knowledge in these three areas.

Water Quality: New media attention to the occurrence of pesticides in drinking water in the Midwest has raised a serious public concern over the quality of Missouri drinking water and how it can be protected. With the large agricultural activity in the state, non-point source pollution is of major interest. Because of several hazardous waste super-fund sites, hazardous waste is still of a concern to the public. The Centers research has been to evaluate the quality of current waste sources and improve the methods to protect them. Areas of research for the past ten years have included (but are not limited to): erosion, non-point pollution reclamation of strip mine areas, hazardous waste disposal, acid precipitation, anthropogenic effects on aquatic ecosystems and wetlands.

Water Quantity : Missouri has a history of either inadequate amounts of rainfall, or spring floods. Because of the 1987-1989 drought years, and the flood of 93 and 95, water quantity has become a major topic of concern. Research is needed to better understand droughts and flood conditions.

Water Policy: Policies and programs need to be formulated that will ensure continued availability of water, as new demands are placed on Missouri water. The social and economic costs may no longer be held at acceptable levels if water becomes a major issue in cities and rural areas. Past droughts and the possible lowering of the Missouri River have raised serious questions over states rights to water and priority uses. Research areas in this program have included drought planning, legal aspects, perception and values, economic analysis, recreation, land/water use policy and legislation, and long-term effects of policy decision.

SUMMARY OF ADVISORY COMMITTEE ACTIVITIES

The following individuals have participated in the selection and development of our 2005 research program.

UNIVERSITY OF MISSOURI FACULTY ADVISORY COMMITTEE

1. Steven Anderson, University of Missouri-Columbia, 302 Abnr Bldg-Soil Sci, Columbia, MO. 2. Dr. Patrick Osbourne, University of Missouri-St. Louis, 224, Research Building, St. Louis, MO 63121.

STATE OF MISSOURI ADVISORY COMMITTEE MEMBERS

1. Dr. John Madras, Department of Natural Resources, Water and Pollution Control, PO Box 176, Jefferson City, MO 65102. 2. John Schumacher,U.S. Geological Survey, 1400, Independence Road, Rolla MO 65401 3. Dr. Steve McIntosh, Water Resources Program, Department of natural Resources, PO Box 176, Jefferson City, MO. 4. Jim Czarneszki, Fisheries & Wildlife, Department of Conservation, 1110 South College Avenue, Columbia, MO 65201. 5. Becky Shannon, Missouri Departmental of Natural Resources, PO Box 176, Jefferson City, MO 65102.

Research Program

Research Program

PROGRAM GOALS AND PRIORITIES

The Missouri Water Resources Research Centers goals are 1) establish active research programs to aid in understanding and solving Missouris and the nations water problems; 2) provide educational opportunities in research for students with an interest in water resources and related fields; and 3) be actively dedicated to the dissemination of water related information, using all aspects of the media.

With these goals, the Center is able to mobilize the best faculty expertise in the state to examine specific water resources problems. The Center is familiar with research needs and activities, and its goals are to help researchers avoid duplicate efforts and to serve as a link between the research community and potential users of research results such as industries, planning commissions, and state agencies.

Because Missouris economy revolves around its water resources, the director and principal investigators have worked closely with the state in addressing their problems by providing research data which are necessary in order to solve present and future water problems. Each of the research projects forwarded for regional competition has undergone a thorough evaluation process by the Water Centers Advisory Committee to determine its importance in solving Missouris and the nations water problems.

Improved Modeling for Runoff and Soil from Natural Events

Basic Information

Title:	Improved Modeling for Runoff and Soil from Natural Events
Project Number:	2005MO47B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	9th
Research Category:	Ground-water Flow and Transport
Focus Category:	Climatological Processes, Models, Water Quality
Descriptors:	
Principal Investigators:	Allen L. Thompson

Publication

1. Mattingly, Christina A. 2004. Influence Of Raindrop Energy On Polyacrylamide Effectiveness. MS Thesis. University of Missouri-Columbia, Columbia, MO.

Missouri Water Resources Research Center

Title: Soil Erosion and Runoff Reduction Using Three Methods of Polyacrylamide Application.

Name: C.J. Gantzer, S.H. Anderson, and A.L. Thompson

Nature, Scope and Objectives of Research:

This project is studying of the longevity of protection from application methods of Polyacrylamide Monomer **(**PAM) to protect soil from surface sealing and erosion. The research objective is to determine the amount of rainfall PAM-treated soil can withstand before erosion returns to untreated rates of detachment. The goal of this work is to develop improved guidelines for use of PAM to reduce soil erosion on bare soil until protective vegetative cover is established.

Progress:

A gravity-fed rainfall simulator at 6.4 cm h^{-1} was used for initial testing (Regmi and Thompson, 2000). Polyacrylamide influenced cumulative surface runoff depth and cumulative sediment loss. It was determined that applying PAM at 40 kg ha^{-1} was not significantly different than the application of 20 kg ha^{-1} PAM during a period of an hour. Separate trends were distinguished between application of 0, 20, and 40 kg ha^{-1} PAM. Measured interrill erosion rates were compared to predicted interrill erosion rates for 3 treatments of PAM at 3 rainfall rates (6.4, 9.6, and 12.8 cm hr^{-1}) for two fall heights (0.8 and 13.8 m). Linear regression equations were fitted to the three PAM treatments for during the 1 hr sampling time to account for the breakdown of PAM by droplet energy. A soil stabilizer factor, *P*, was calculated based on these regressions. The addition of a soil stabilizer factor to the modified interrill erosion prediction equation improved the percent of variation explained from 0.75 to 0.93.

The laboratory study used a rainfall simulator (Miller, 1987) that produced a constant intensity of 80 mm/hr with rainfall energy of 25 J m^{-2} m^{-1}. Cumulative studies of 3 one-hour duration events hours (a total rainfall 240 mm) for each test bed were done on bare soil beds of 1 by 0.3 by 0.3m in size on a 5% slope. Mexico silt loam soil (fine, smectitic, mesic Aeric Vertic Epiaqualf) were collected from Bradford Research Center. Disturbed soils were collected and air-dried, and sieved to pass a 4 mm sieve and packed into soil beds to a bulk density of ~1.3 g cm^{-3}. Rainfall and runoff was monitored throughout the tests. Treatments include four levels of solution application of PAM (20, 40, 60, and 80, kg $ha^{-1)}$ in single and split applications. Ultra high resolution x-ray CT of soil surface seals formed from raindrop impact were used to create *3-D* volume rendered images to characterize the surface seal macropore volume, number, size-distribution, perimeter, circularity, topological dimension, and pore-connectivity, tortuosity, volume and width using the 3-D medial axis software package written by Lindquist. Results are in given in detail in the below student thesis that is available on request.

Publications: Mattingly, Christina A. 2004. Influence Of Raindrop Energy On Polyacrylamide Effectiveness. MS Thesis. University of Missouri-Columbia, Columbia, MO.

Characterization and Biological Effect Study of Endocrine Disruptors in Indian Creek, Newton, County, Missouri

Basic Information

Title:	Characterization and Biological Effect Study of Endocrine Disruptors in Indian Creek, Newton, County, Missouri
Project Number:	2005MO51B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	9th
Research Category:	Biological Sciences
Focus Category:	Water Quality, Toxic Substances, Nitrate Contamination
Descriptors:	
Principal Investigators:	Yue-wern Huang, Paul Nam

Publication

Title: Characterization and Biological Effect Study of Endocrine Disruptors in Indian Creek, Newton County, Missouri

Names: Drs. Yue-wern Huang and Paul Nam

Research Objectives

Many environmental substances possess estrogenic activity. Studies have shown that exposure to these chemicals can cause abnormality and failure in reproduction. Indian Creek in the Elk River Basin in southwest Missouri has a large aggregate of poultry and turkey farming operations. Animal waste which contains steroid metabolites is applied to crop lands. Corn and soybean croplands use herbicides such as atrazine which has been shown to be estrogenic to wildlife. Up to date, there is no study on potential runoff of these chemicals and their biological impacts in Indian Creek in Newton County, Missouri. The original objective of this project is to identify putative estrogenic chemicals in Indian Creek. Upon discussions with USGS at Rolla, we analyzed samples from their four gauging stations in the Elk River basin in McDonald County. The PI also collected water samples from tributaries of Shoal creek. We did not conduct biological effect studies due to limited resources.

Methods, Procedures and Objectives of Research

Water Sample Collection and Chemical Analyses

Eight liters of grab samples were taken from site with an automatic, time-proportioned sampling device (Isco 3710, Lincoln, NE, USA). Samples were placed in pre-cleaned glass bottles which were immediately transported to the UMR Toxicology Laboratory in an ice-cooled container once sampling concludes. We focused on identifying E2, estrone, estriol, 17α-ethynylestradiol, atrazine, metolachlor, tebuthiuron, plasticizers, and chemicals commonly found in streams in the USA.

Solid Phase Extraction

As soon as the samples arrive at UMR, organic materials were recovered from the water sample by a solid phase extraction (SPE). A specific amount of surrogate compounds such as d_5-atrazine and d_5-estradiol were added to each water sample to monitor the recovery of analytes through the analysis. Suspended solids in the sample were first removed with 2.7 μm pore size glass fiber filters. The filtered water sample were pulled through a 1g reversed phase octadecylsilane (C_{18}) SPE cartridge (Alltech Associates, Inc., Deerfield, IL) at a flow rate of 10-15 mL/min by applying a vacuum. Each SPE cartridges used in this study were preconditioned by eluting 10mL each of acetone, methanol, and nanopure water. After the sample was passed through, the SPE cartridge was washed with 6mL of nanopure water and vacuum-dried until all of the water was removed. The dried SPE cartridge was connected in series to a glass column filled with anhydrous granular sodium sulfate. The organic materials in the SPE cartridge were eluted into a graduated test tube by passing 3 mL of acetone twice. The extract was then concentrated to 1mL under gentle stream of nitrogen, and subsequently stored in the freezer until further chemical analysis. For the analytical quality control purpose, a fortified laboratory spike and a blank were be analyzed with each set of water samples.

Derivatization

For the GC/MS analysis, the extract from SPE was be derivatized to improve the stability and sensitivity of the analytes. Fifty µL of Sylon BFT (99:1 mixture of BSTFA + TMCS, Supelco, Bellefonte, PA) was added to the extract after evaporating to dryness. After reacting for 30 min at 60 ºC, the derivatized extract was evaporated to dryness under gentle stream of nitrogen and reconstituted with 100 µL of hexane. A specific amount of internal standard was be added to the final sample prior to GC/MS analysis.

GC/MS Analysis

Gas chromatography-mass spectrometry analysis was performed with a Varian Saturn 2000 GC/MS utilizing a DB-5M capillary column (30 m X 0.32 mm i.d. with 0.25 µm film, Agilent Technologies, Wilmington, DE). The GC carrier gas was helium and the following temperature condition was used; initial 1 min held at 120 °C and increased to 190 °C in 8 min, and held at final temperature of 290°C. Injection was splitless with temperature set at 280 °C. Mass spectrometer was operated with electron impact at 70 eV and scan 45-500 amu. The accurate quantitation of low level analytes was achieved via the selected ion monitoring (SIM) mode and MS/MS.

Results and Discussions

Table 1 summarized the chemicals found in the USGS gauging station. Atrazine was detected in May 2005 in three of the four USGS gauging stations, ranging between 4865 ng/L water and 599.38 ng/L water. Metolachlor was identified in all four USGS stations, ranging between 5.29 ng/L water to 33.74 ng/L water. The existence of these two chemicals corresponds with the crops seasons.

Several phenols and plasticizers were found in all stations most of the time. They include 4-tert-octyl phenol, 4-octylphenol, nonylphenols, benzyl butyl phthalate, dibutyl phthalate. The concentrations were within the ranges found in other streams in the USA. We are currently compiling information for comparison purpose.

Estrogenic chemicals were identified in the water samples. Estrone, 17α-estradiol, 17β-estradiol, 17α-estradiol, and estriol ranged between 16.37 ng/L water and 63.01 ng/L water. Anti-estrogen, tamoxifen, was found in two stations in May 2005.

Table 2 summarized the chemicals found in the sites we selected in the tributary of Shoal Creek. Atrazine was not found in the two selected site, FR1060 and FR1090, in May, July, and September, 2005. Metolachlor was only found twice at less than 10 ug/L water. Phenols and plasticizers were found less frequent but the concentrations were similar to those found in the USGS gauging stations. Estrone, 17α-estradiol, 17β-estradiol, 17α-estradiol, estriol, and tamoxifen.

The PI is currently requesting USGS to provide other important hydrological data to correlate our water chemistry data.

Education

This project supported two undergraduate students and one master degree student. They have learned a great deal of knowledge in the area of endocrine disruption in the environment. The master degree student is currently enrolled in the Ph.D. program of Arkansas State University at Jonesborough. The undergraduate student is currently a master degree student at the Department of Biological Sciences.

Perspectives

This is the first attempt to collect water chemistry information using GS/MS in this southwestern area of Missouri. The biological and ecological effects of these chemicals identified were not known and warrant further investigation.

Table 1. Water chemistry data of the USGS gauging stations in the Elk River basin in McDonald County, MO

	GC/MS Parameter		Concentration (ng/L water)								
Compound	Ret. Time (Minute)	Quant Ion (m/z)	8653 May '05	8653 Aug '05	8838 May '05	8838 Aug '05	8885 May '05	8885 Aug '05	9000 May '05	9000 Aug '05	9100 Aug '05
Atrazine	9.55	200	<DL	<DL	48.65	<DL	402.56	<DL	599.38	<DL	<DL
Simazine	9.44	201	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
Tebuthiuron	6.66	156	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
Metolachlor	12.64	162	7.89	<DL	5.29	<DL	33.74	<DL	5.73	<DL	<DL
p,p'-DDE	15.52	318	7.48	<DL	<DL	<DL	1.11	<DL	<DL	<DL	<DL
4-tert-octyl phenol	8.06	207	2.95	<DL	2.66	<DL	<DL	<DL	<DL	<DL	<DL
4-octyl phenol	9.90	207	14.91	139.52	28.35	19.72	13.61	522.76	30.12	<DL	<DL
Nonyl phenol	9.42	207	47.41	97.49	72.81	<DL	44.50	307.33	18.88	<DL	<DL
Benzyl butyl phthalate	18.10	149	56.56	48.52	35.46	<DL	38.17	118.64	29.67	<DL	<DL
Dibutyl phthalate	12.25	149	28.21	32.46	17.30	28.21	35.63	66.79	21.39	37.04	15.32
Bisphenol A	16.35	358	62.37	105.49	52.00	<DL	7.93	220.97	62.62	<DL	<DL
Bioallethrin	14.13	123	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
Permethrin	23.64	183	83.80	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
Di-p-tolyl sulfone	15.72	246	14.58	<DL	5.04	<DL	8.43	<DL	2.06	<DL	<DL
Diethylstilbestrol	18.48	412	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
Estrone	22.38	342	29.31	33.51	27.67	<DL	16.37	63.01	20.49	<DL	<DL
17a-estradiol	22.60	416	20.47	19.95	17.95	<DL	<DL	<DL	15.93	<DL	<DL
17b-estradiol	23.31	416	23.58	24.49	19.18	<DL	<DL	<DL	17.87	<DL	<DL
17a-ethinyl estradiol	24.82	425	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
Estriol	26.53	386	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
Tamoxifen	23.65	368	107.39	<DL	108.28	<DL	<DL	<DL	<DL	<DL	<DL
b-Sitosterol	31.90	357	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
Atrazine-d5 ^	9.45	205	-	-	-	-	-	-	-	-	-
Anthracene-d10 *	10.08	188	-	-	-	-	-	-	-	-	-
Cholestane **	25.37	217	-	-	-	-	-	-	-	-	-
Estradiol-d5 ^^	23.25	421	-	-	-	-	-	-	-	-	-

* Internal standard #1
** Internal standard #2
^ Surrogate #1
^^ Surrogate #2

Table 2. Water chemistry in the two sites of the tributary of Shoal Creek in McDonald County, MO

	GC/MS Parameter		Concentration (ng/L water)					
Compound	Ret. Time (Minute)	Quant Ion (m/z)	FR1060 May '05	FR1060 July '05	FR1060 Sept '05	FR1090 May '05	FR1090 July '05	FR1090 Sept '05
Atrazine	9.55	200	<DL	<DL	<DL	<DL	<DL	<DL
Simazine	9.44	201	<DL	<DL	<DL	<DL	<DL	<DL
Tebuthiuron	6.66	156	<DL	<DL	<DL	<DL	<DL	<DL
Metolachlor	12.64	162	<DL	1.87	<DL	<DL	9.86	<DL
p,p'-DDE	15.52	318	<DL	<DL	<DL	<DL	4.10	<DL
4-tert-octyl phenol	8.06	207	<DL	<DL	<DL	<DL	<DL	<DL
4-octyl phenol	9.90	207	<DL	492.02	<DL	<DL	288.24	<DL
Nonyl phenol	9.42	207	<DL	390.91	<DL	<DL	210.11	<DL
Benzyl butyl phthalate	18.10	149	<DL	<DL	<DL	<DL	71.67	<DL
Dibutyl phthalate	12.25	149	9.77	18.83	332.78	58.59	25.23	92.94
Bisphenol A	16.35	358	<DL	<DL	<DL	<DL	<DL	<DL
Bioallethrin	14.13	123	<DL	<DL	<DL	<DL	<DL	<DL
Permethrin	23.64	183	<DL	<DL	<DL	<DL	<DL	<DL
Di-p-tolyl sulfone	15.72	246	<DL	16.26	<DL	104.22	15.52	23.85
Diethylstilbestrol	18.48	412	<DL	<DL	<DL	<DL	<DL	<DL
Estrone	22.38	342	<DL	<DL	<DL	<DL	<DL	<DL
17a-estradiol	22.60	416	<DL	<DL	<DL	<DL	<DL	<DL
17b-estradiol	23.31	416	<DL	<DL	<DL	<DL	<DL	<DL
17a-ethinyl estradiol	24.82	425	<DL	<DL	<DL	<DL	<DL	<DL
Estriol	26.53	386	<DL	<DL	<DL	<DL	<DL	<DL
Tamoxifen	23.65	368	<DL	<DL	<DL	<DL	<DL	<DL
b-sitosterol	31.90	357	<DL	<DL	<DL	<DL	<DL	<DL
Atrazine-d5 ^	9.45	205	-	-	-	-	-	-
Anthracene-d10 *	10.08	188	-	-	-	-	-	-
Cholestane **	25.37	217	-	-	-	-	-	-
Estradiol-d5 ^^	23.25	421	-	-	-	-	-	-

* Internal standard #1
** Internal standard #2
^ Surrogate #1
^^ Surrogate #2

Fate and Transport of Heavy Metals in Artificial Soil

Basic Information

Title:	Fate and Transport of Heavy Metals in Artificial Soil
Project Number:	2005MO53B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	9th
Research Category:	Ground-water Flow and Transport
Focus Category:	Geochemical Processes, Models, Solute Transport
Descriptors:	
Principal Investigators:	William J. Likos, John J. Bowders, R. David Hammer

Publication

1. Masters Thesis: Bergsten, J., 2006, Sorption and transport of heavy metals in artificial soil, M.S. Thesis, University of Missouri Fall 2006.
2. Conference Proceedings: Wayllace, A., and Likos, W.J., 2006, Numerical modeling of artificial soil as an evapotranspirative cover, Proceedings of 4th International Conference on Unsaturated Soils, Carefree, AZ, April 2006.

FATE AND TRANSPORT OF HEAVY METALS IN ARTIFICIAL SOIL

Objectives, Methodology, and Results

The objective of this research is to assess the short- and long-term fate of metals in "artificial soil" produced by blending yard waste, biosolids, cement kiln dust (CKD) and coal ash and use for land reclamation applications. Field sampling has been conducted within relatively recently placed (< 6 months) and relatively mature placements of artificial soil at a pilot site in Hannibal, MO. Materials were analyzed for pH, organics, carbonate content, cation exchange capacity, metals concentrations as a function of depth from the surface to assess in-situ transport. Batch sorption tests were conducted to quantify sorption parameters (e.g., Figure 1). Column leaching tests using distilled water and a pH-buffered solution (4.5 – 5.3) were conducted to quantify metals transport behavior. Concentrations of metals in the leachate (Cd, Zn, Pb) were below detection limits (>1ppm) after approximately 20-30 pore volumes of flow. A finite-difference based model for variably saturated fluid transport has been developed to model the liquid transport at the field site. Wetting front propagation was simulated under a series of sustained and short-term precipitation events and compared with actual infiltration data obtained from the Hannibal site. The predicted depth of the wetting front is 250 cm, which compares reasonably well with moisture data obtained from the field site and is less than the total thickness of the cover (425 cm). The artificial soil acts as an effective evapotranspirative cover system by restricting wetting front propagation and causing water to either evaporate or flow laterally. Results provide initial quantitative data to support the beneficial reuse of select waste materials in land reclamation applications.

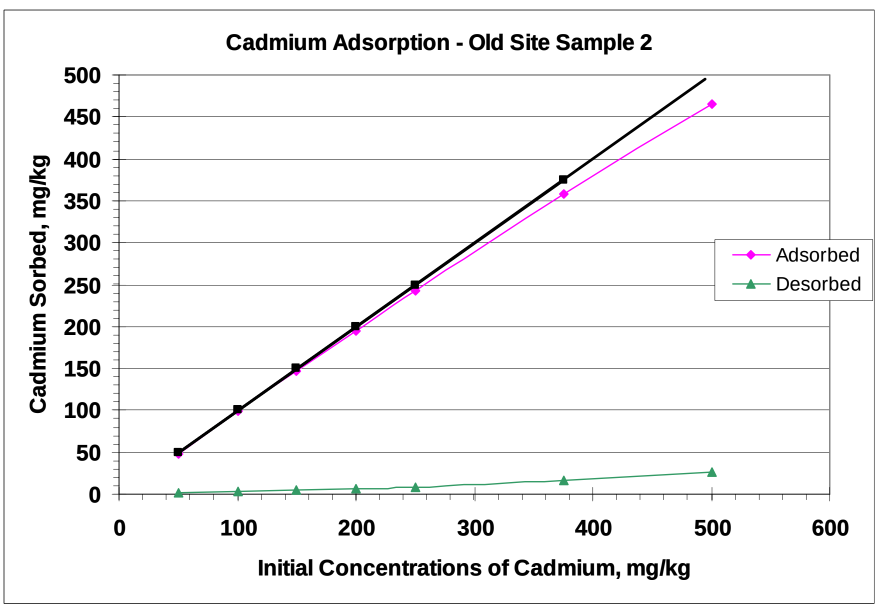

Figure 1. Batch sorption results: Cd, Mature site, Sample 2.

Students Directly Supported

Joshua Bergsten, Graduate Student (M.S.), completion date = Fall 2006

Publications

Bergsten, J., 2006, "Sorption and transport of heavy metals in artificial soil," M.S. Thesis, University of Missouri – Fall 2006.

Wayllace, A., and Likos, W.J., 2006, "Numerical modeling of artificial soil as an evapotranspirative cover," *Proceedings of 4th International Conference on Unsaturated Soils*, Carefree, AZ, April 2006.

Supplemental Grants Obtained

Portland Cement Association (PCA) Education Foundation Fellowship Award – $20,000 fellowship awarded to Alexandra Wayllace (UMC Graduate Student).

Geographic Information Systems for Tracking Vessels on the Inland Waterways

Basic Information

Title:	Geographic Information Systems for Tracking Vessels on the Inland Waterways
Project Number:	2004MO59S
Start Date:	7/15/2004
End Date:	7/14/2005
Funding Source:	Supplemental
Congressional District:	9th
Research Category:	Ground-water Flow and Transport
Focus Category:	Methods, Solute Transport, None
Descriptors:	GIS Tracking, Inland Waterway Transport, Tracking Systems
Principal Investigators:	, Ray Mundy

Publication

Geographic Information Systems for Tracking Vessels on the Inland Waterways
USGS award No. 04HQGR0145 REVISED
Status Report – May 25, 2005

Ray Mundy and James F. Campbell
College of Business Administration &
Center for Transportation Studies
University of Missouri – St. Louis
One University Boulevard
St. Louis, MO 63121 USA

This note summarizes the status for the project "Geographic Information Systems for Tracking Vessels on the Inland Waterways" (USGS award No. 04HQGR0145 REVISED). The major activities of the project are:

- Survey geographic information systems (GIS) and automatic tracking applications for inland waterway transport on the Upper Mississippi River (UMR) system.
- Develop a prototype GIS to display dynamic vessel locations, lock locations and operating conditions, river features, and important shore elements, with relevant attribute data.
- Document appropriate technologies necessary to implement the tracking system.
- Conduct a peer review of the GIS system from both academic and practitioner viewpoints.

Each of these activities is addressed in the remainder of this document, preceded by a brief introduction.

Introduction

Inland waterways in the United States carry over 600 million tons of commerce per year. This accounts for about 300,000 million ton-miles or approximately 8% of the total freight traffic in the U.S. The Mississippi River system is the most important component of the inland waterway system, accounting for about 65% of the total domestic inland waterway tonnage. A system of 29 locks and dams has been constructed along the Upper Mississippi River (UMR) to facilitate the transportation of bulk commodities vital to the United States economy. Tows (tow boats pushing groups of barges) traveling up and down the UMR may experience congestion at the locks which creates unproductive waiting time while other vessels utilize the lock chamber.

Many transportation systems rely on vehicle or vessel tracking with geographic positioning systems to improve operations, environmental protection, safety, and security. Vessel tracking technologies allow real or near-real time tracking of watercraft at remote locations. Geographic information systems (GIS) provide a visual display of location-based data integrated with descriptive attribute information. Integrating vessel tracking with GIS can help improve transportation system operations by visually presenting vessel positions and movements on electronic maps that display infrastructure and other relevant features, along with associated static and dynamic descriptive information. Current technologies for finding real-time locations and for mobile communications allow data to be collected and displayed efficiently in real or near-real time. This enhanced visibility and knowledge can lead to better management of limited transportation resources and constrained infrastructures. This project investigates the feasibility of vessel tracking for better managing lockages, thereby improving traffic flow on the inland waterways, and develops a prototype GIS-based vessel tracking system for monitoring vessels on the UMR.

This project compliments a companion project underway at the Center for Transportation Studies (CTS) at the University of Missouri – St. Louis entitled "Appointment Systems for Inland Waterway Traffic Control". The Appointment Systems project investigates how an intelligent appointment or scheduling system that better manages tows and barges for passage through the locks on the UMR might reduce congestion at the locks. A GIS-based vessel tracking system could support more effective and more efficient lockages and river traffic management by providing relevant individuals (e.g., a river "traffic manager") with a single information source including dynamic display of vessel locations and attribute information. Collateral benefits could accrue to inland waterway shippers and carriers through decreased costs and increased reliability from more efficient lock operations. A vessel tracking system on the UMR could also provide benefits in other areas, including homeland security, by providing information on where individual barges are located within the waterway system, as well as to whom they belong, their contents and their precise position in regard to various structures within and along the waterway.

The Upper Mississippi River (UMR) is an integral part of a national inland water transportation network. The UMR river navigation system provides an important transportation link into and out of America's Midwest. The UMR navigation system extends approximately 663 miles north from the confluence of the Mississippi and Missouri Rivers (just north of St. Louis, Missouri) to just beyond Minneapolis, Minnesota. There are more than one hundred terminals along the UMR that ship and receive commodities. Agricultural products are the primary commodities transported on the UMR; other common bulk commodities include chemical products, coal, cement, and petroleum products.

Safe and reliable navigation on the UMR from St. Louis to Minneapolis is created by a series of 29 lock and dam facilities that are designed to produce a minimum channel depth of nine feet for the entire length of the navigable system. Figure 1 presents a map of the UMR portion of the inland navigation system. The dams on the UMR create a sequence of connected pools that maintain the depth necessary for navigation of commercial tows, as well as other vessels. Lock chambers at each dam permit traffic to traverse up and down the river system. Figure 2 presents a schematic view of the UMR pool system.

Traffic congestion arises on the UMR at the locks when demand for lockages exceeds the throughput capacity. This may be due to heavy levels of traffic or to a decrease in capacity at the lock (for example, due to lock maintenance or closure). Unusual events such as lock malfunctions, tow pilot errors, and adverse vessel or lock operating conditions also contribute to delays at these locks. The time for a lockage depends on a range of factors including the structural design of the lock itself, the size and characteristics of the tow, the equipment on the barges and at the lock, the experience of the crew, flow conditions, weather, and the previous lockage. Also, significant use of the locks by non-commercial vessels, such as privately owned recreation craft, can contribute to congestion and lockage delays in the UMR system.

The original locks on the UMR were constructed in the 1930's with main chambers 600 feet in length and 110 feet in width. These locks were originally designed at 600 feet long to accommodate the largest commercial tows at that time. Since then towboats on the UMR have become significantly larger to take advantage of the strong economies of scale in river transportation. Large tows on the UMR now measure almost 1200 feet in length and are often comprised of 15 barges (each approximately 200 feet long) arrayed in five rows of three barges each, pushed by a single towboat. Movement of a tow longer than 600 feet through a 600 foot long lock chamber requires two passes or "cuts". To accomplish this passage, the tow enters into the chamber, decouples from a set of barges (less than 600 feet long), then backs out of the chamber. The chamber is then raised or lowered as desired and the barges in the chamber are then moved out of the chamber (e.g., using winches at the lock) and tied along a wall just outside the chamber. The chamber is then returned to the original level to take the remaining barges and towboat. These enter the chamber and are raised or lowered as a unit. Then the tow must be re-coupled by joining the two segments, before proceeding on its way. These "double lockages" require a relatively lengthy processing time: the mean lockage time for a two-cut tow is two to three times larger than the mean lockage time for a single cut tow on the locks of interest on the UMR.

Three locks on the UMR have been extended or replaced to now measure 1200 feet in length (locks 19, 26, and 27) and these locks experience relatively little congestion since their length precludes double lockages. The lower (southernmost) five 600 foot long locks of the UMR navigation system, Locks 20, 21, 22, 24 and 25 (there is no Lock 23) are the most heavily utilized 600 foot long locks, and are among the most congested of all locks in the inland navigation system. These locks have been selected as the study site for the companion project "Appointment Systems for Inland Waterway Traffic Control". These five locks experience periodic traffic congestion and strong seasonal variation in demands for service. They also tend to operate as a system in that they share a large amount of common interrelated commercial tow traffic. The prototype GIS-based vessel tracking system is developed for the portion of the UMR covering these five locks.

Congestion at the locks produces waiting times for the tows that arrive while the lock chamber is occupied. For the five locks in the study area, the U.S. Army Corps of Engineers OMNI lock data for 2000 through 2003 indicates that the average number of lockages per lock per year was 3,509 and vessels waited an average of 2.4 hours per lockage before beginning processing at a lock. Of these lockages, 84% were for commercial tows and the average wait per commercial tow was 2.8 hours per lockage. (The greater mean waiting time for commercial tows - 2.8 hours vs. 2.4 hours for all vessels - reflects the priority given to non-commercial recreation craft.) There was also relatively large variability in the distribution of the waiting times throughout the entire four-year period.

To familiarize ourselves with the operating environment we have made site visits to all five Lock and Dam facilities in the study region (Lock & Dam 20, 21, 22, 24 and 25). We have also visited the Volpe National Transportation Center in Cambridge, Massachusetts to learn of their experiences with vessel tracking and GIS/GPS. We have also met with barge industry representatives, U.S. Coast Guard personnel, GIS managers with the Corps, and inland waterway researchers to collect relevant information for our study.

GIS and Vessel Tracking Applications

Vessel and vehicle tracking technologies are well developed for a wide variety of transportation applications, in both the public and private sector. For example, air traffic control systems have long been used to manage air transportation, primarily for reasons of safety (though security concerns have become prominent more recently). Public transit and public works agencies often track vehicles to improve operations. Private sector firms in the rail and motor carrier industry also track vehicles – and have developed extensive information and decision support systems based on dynamic real and near-real time locational data. Vessel tracking systems have also been implemented in a variety of applications worldwide for both maritime (deep-sea) and inland water transportation.

Vessel tracking systems require determining the location of the vessel and communicating that information (along with other relevant information) to a central location capable of receiving and managing the locational information. Vessel tracking applications generally have one of the following primary motivations: safety and security, compliance, and operational improvements/traffic management. However, there is often some overlap between these categories, and technologies implemented for one purpose (e.g., safety) may have applications in other areas (e.g., traffic management).

The larger barge companies operating on the UMR have implemented real or near-real time tracking for their own fleets of towboats on the UMR and other inland waterways. This information can be used for a variety of strategic and operational purposes within the firm. The U.S. Coast Guard has recently instituted tracking barges carrying of hazardous cargos on a portion of the UMR. However, the U.S. Army Corps of Engineers is not currently tracking tows on the UMR (or elsewhere), and neither the individual operators nor the Coast Guard share their data with the Corps. The closest the Corps comes to vessel tracking is in creating a database of the lockages for each lock, in which a variety of information is recorded for every commercial tow that passes through a lock. In the pools between the locks, the Corps is generally unaware of the exact location of the tow, though they may estimate its position based on the elapsed time from the last lockage and any communications with tow itself.

We are currently preparing a report to document the use of GIS and vessel tracking in applications from around the world relevant to the inland waterways. This report will include the following:

- Automatic Identification Systems (AIS) and its use on the St. Lawrence Seaway and in vessel traffic services (VTS) areas managed by the U.S. Coast Guard,
- The Inland Rivers Vessel Movement Center (IRVMC) in St. Louis that tracks transportation of certain dangerous cargoes (CDCs) on the UMR,

- The Vessel Identification and Positioning System (VIPS) system developed by the Volpe National Transportation Center and implemented in a variety of locations for safety, security and environmental compliance,
- Vessel Monitoring Systems (VMS) required by the National Marine Fisheries Service (NMFS) for compliance purposes,
- Commercial barge tracking systems in use on the UMR, such as BOATRACS,
- The SMARTLOCK project using differential GPS at the Port of Pittsburgh,
- The Communications Tracking and Navigation (CTAN) system at the Panama Canal,
- The development of the comprehensive river information system (RIS) concept in the European Union, and
- Relevant geographic information systems application for the inland waterways.

Prototype Vessel Tracking GIS

We have developed a prototype geographic information system (GIS) to display dynamic vessel locations, lock locations and operating conditions, river features, and important shore elements, with relevant attribute data. This is built using the ArcGIS 9 geographic information system with the Tracking Analyst extension for managing the dynamic tow locations (both are software products of ESRI, Inc.). Creation of the electronic base maps of the study area required collecting and cleaning a variety of spatial data sets for the river and shore features, as well as the lock and dam infrastructure, and developing the associated attribute information. To demonstrate the vessel tracking capabilities we created input files for dynamic display of tow locations for a set of sample voyages along the UMR derived from actual tows trips as represented in the OMNI database.

The prototype vessel tracking GIS provides sample displays and vessel tracking to demonstrate the type of functionality possible. Static map views demonstrate the capabilities to display geographic (map) and attribute (tabular) data that would be of use to a traffic manager responsible for lockages in the study area. Dynamic views are used to show tows moving on the UMR through the study region. Figure 3 is a screen capture from the prototype vessel tracking GIS display with 12 tows in the study area between Lock and Dam 20 (near the top) and Lock and Dam 25 (near the bottom). The small numbers along the river from 210 to 350 are the river miles as measured upstream from the mouth of the Ohio River. Figure 4 shows the prototype vessel tracking GIS display of Lock and Dam 24. This figure shows one tow in the lock chamber, three tows in queue (nosed into the shore) upstream of lock (between river miles 274 and 275) and one tow in queue downstream of the lock (between river miles 272 and 273). The five oval icons above and to the right of the lock provide relevant attribute (tabular) data for the upstream and downstream pools, Pool 24 and Pool 25 respectively, (P24 or P25), the lock (L) and the tows and recreational vessels in the lock queue (QT and QR, respectively). Figure 5 shows the same view with the accompanying attribute information for the queue of commercial tows (from the QT icon) at lock 24. The information to display with the prototype GIS depends on the needs of the “traffic manager” and the traffic management alternative, as identified in the companion project “Appointment Systems for Inland Waterway Traffic Control”.

Technologies to implement vessel tracking on the UMR

Tows on the UMR can be tracked in real or near-real time with a variety of different methods and technologies. Most large tow operators track their tows with commercial or proprietary systems. Popular satellite-based systems, such as BOATRACS (an extension of the OMNITRACS system for vehicle tracking on land), provide tow locations, and other information, automatically at regular intervals (e.g., hourly) and every time a message is sent. The U.S. Coast Guard tracks tows with hazardous cargoes by requiring the tow operators to report their position and some associated information at various locations along the river and when specified activities occur. This information may be provided electronically from the tow operator's traffic management center, or by the individual tow pilot using email, fax or phone.

The key components of a vessel tracking system for lockage (or traffic) management are: (1) finding the tow's geographic position, (2) communicating the tow position to a shore station, and (3) integrating the information for managing lockages. The geographic position of a tow can be readily and economically determined by equipment onboard the tow using standard GPS technologies or via triangulation with satellites or shore-based antenna. The tow position could also be determined by remote sensing technologies such as radar. However, remote sensing technologies require additional communications to identify the vessel and link to relevant data. Communication of tow locations from the tow to shore stations relies on standard communication channels and technologies via satellite or radio (VHF) (e.g., AIS). These transmissions may be secure or non-secure (as with AIS). Integrating tow locations into a lockage management decision support system requires collection of the relevant tow and lock data in real (or near-real) time, verification of the data, integration of data from numerous tows and other inputs, including the lock, for input to the lock management algorithm, and creation of the outputs (e.g., suggested lockage sequences or lockage appointment times).

We are currently preparing a report to document the technologies to implement vessel tracking on the UMR. This will focus on relevant methods for (1) acquiring dynamic location and attribute data of vessels, and (2) communicating the real-time information to the lock management system. The report will include the following:

- Vessel location technologies including GPS and DGPS (differential GPS),
- Other satellite systems for geographic positioning,
- Discussion of extending AIS to the UMR as a data source for managing lockages,
- Commercial vessel tracking systems, especially those that have been applied on the UMR,
- Communication options from ship-to-shore and on to the "traffic manager",
- Identification of key issues in position reporting and communications,
- Identification of key data elements specific to the tow and the voyage needed for managing lockages, and
- Discussion of key organizational issues, including responsibility and authority, associated with vessel tracking on the UMR.

Remaining Activities

The activities remaining for completion of the project include:

- Peer review of the prototype vessel tracking GIS from both academic and practitioner viewpoints,
- Visit to the St. Lawrence Seaway traffic control center (May 26, 2005),
- Refinement of the prototype GIS-based vessel tracking systems,
- Documentation of the development and the system requirements of the prototype vessel tracking GIS,
- Documentation of possible extensions of the prototype, and
- Finalizing all reports.

We are scheduling a conference with representatives of the Army Corps of Engineers, the Coast Guard, and the barge industry on June 15, 2005, to present preliminary results and obtain their feedback. We anticipate completion of the project in July 2005.

Figure 1. Map of the Upper Mississippi River (UMR) Navigation System
Source: U.S. Army Corps of Engineers

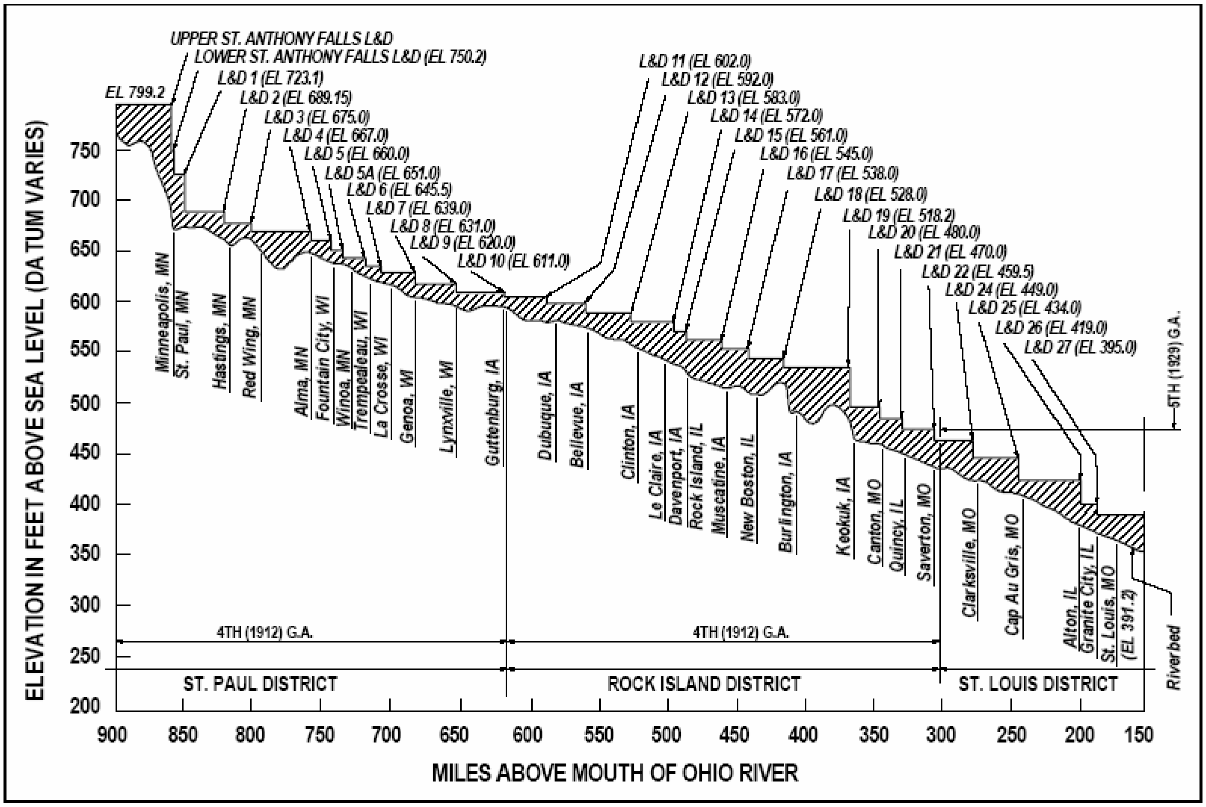

Figure 2. Schematic View of the Upper Mississippi River Pool System
Source: U.S. Army Corps of Engineers

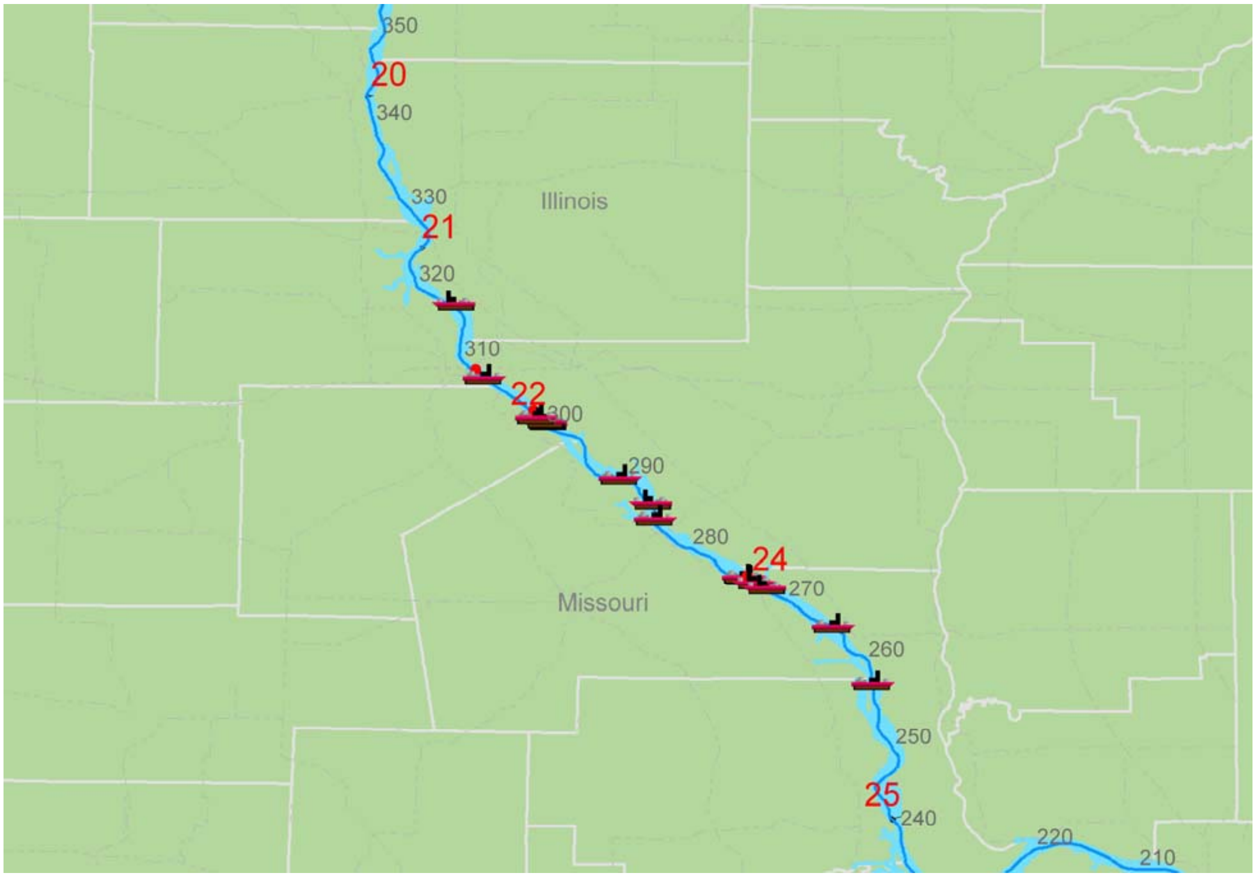

Figure 3. Prototype Vessel Tracking GIS Screenshot of the Study Area

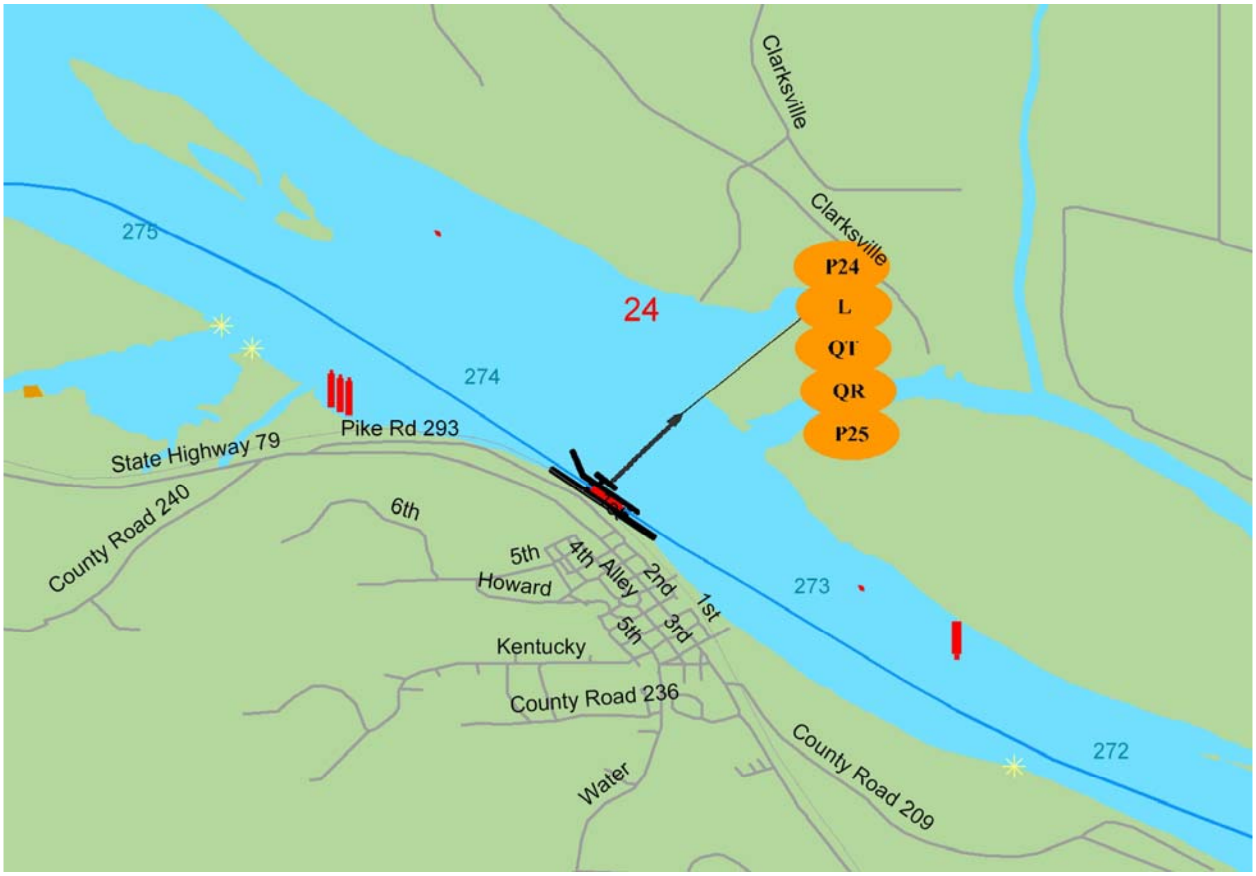

Figure 4. Prototype Vessel Tracking GIS Screenshot of Lock and Dam 24

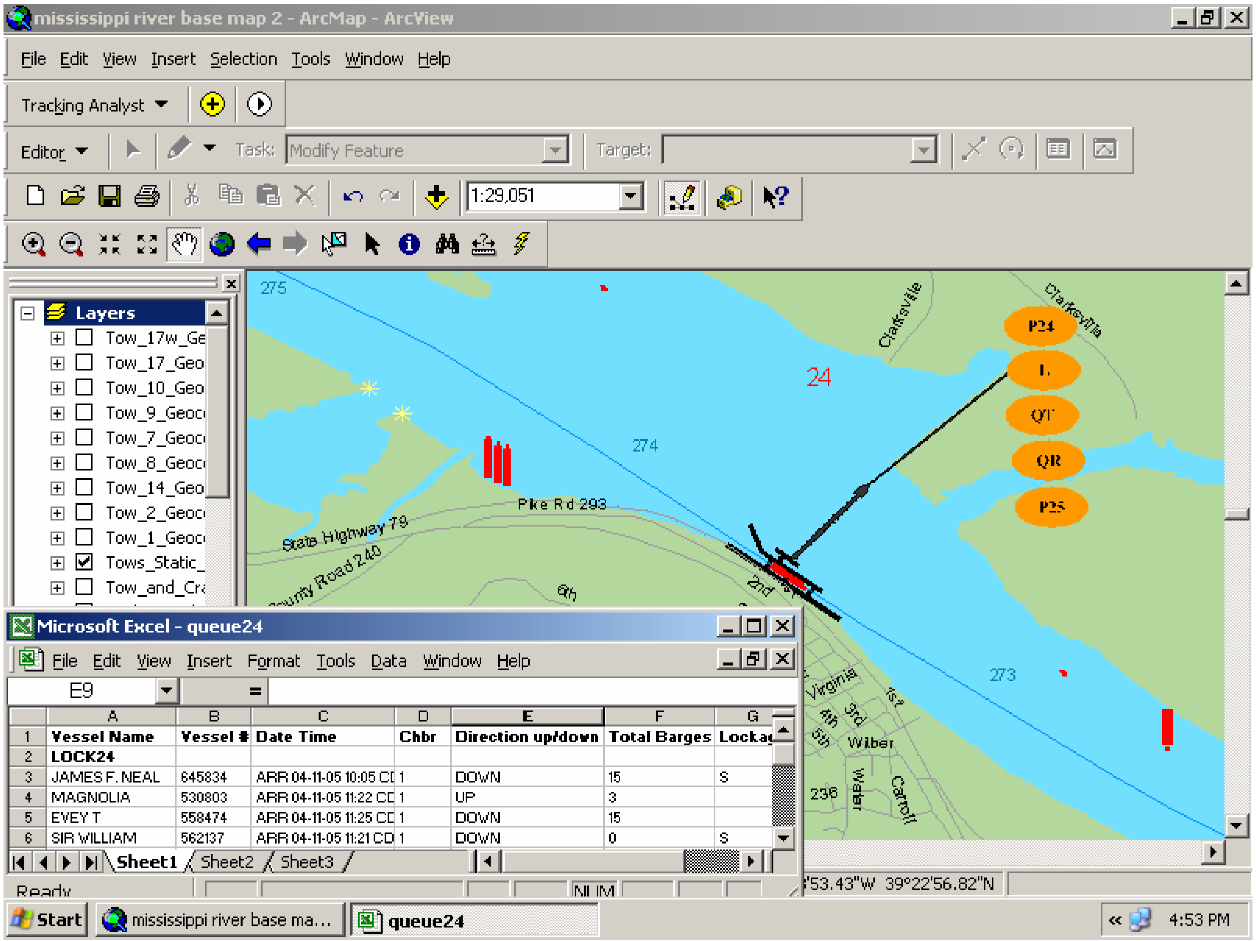

Figure 5. Prototype Vessel Tracking GIS Screenshot of Lock and Dan 24 with Lock Queue Data

Information Transfer Program

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	3	0	0	0	3
Masters	4	0	0	0	4
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	7	0	0	0	7

Notable Awards and Achievements

Supplemental Grants Obtained:

Portland Cement Association (PCA) Education Foundation Fellowship Award $20,000 fellowship awarded to Alexandra Wayllace (UMC Graduate Student).

Publications from Prior Projects

1. 2004MO31B ("Use of Excitation/Emission Matrix Fluorescence") - Conference Proceedings - Conference Proceedings: B. Hua and B. Deng. Water source characterization and classification with fluorescence EEM spectroscopy: PARAFAC analysis. 34th Annual waste management conference, Missouri Waste Control Coalition, Lake Ozark, MO, June 25-27, 2006.
2. 2004MO31B ("Use of Excitation/Emission Matrix Fluorescence") - Other Publications - Masters Thesis: Koirala, Amod; "Use of Fluorescence Excitation Emission Matrix Spectroscopy for Water and Waste Water Characterization."