Oklahoma Water Resources Research Institute
Annual Technical Report
FY 2006

Introduction

The Environmental Institute (EI) at Oklahoma State University promotes interdisciplinary environmental research, graduate education, and public outreach leading to better understanding, protecting, and sustainably developing the natural environment. The Oklahoma Water Resources Research Institute (OWRRI), located within the EI, is responsible for developing and coordinating water research funding to address the needs of Oklahoma. To guide it in meeting this objective, the OWRRI has assembled a board of state regulators, policymakers, and other water resource professionals. This board is known as the Water Research Advisory Board (WRAB).

Research Program

In 2006, proposals were solicited from all comprehensive universities in Oklahoma. Proposals were received from three of these institutions: Oklahoma State University, University of Oklahoma, and the University of Tulsa. Eight proposals were submitted and from these four projects were selected for funding for one year each.

Retrospective Ecosystem Analysis of the Eucha-Spavinaw Watershed is an evaluation of environmental changes to this watershed in Eastern Oklahoma and Western Arkansas using geochronological and geochemical analysis of undisturbed sediment cores. Science, Development and Public Opinion: The Adjudication of Groundwater Policy for the Arbuckle-Simpson Aquifer is a multi-year investigation that assessed the impact on public opinion and water policy of another scientific study conducted by the Oklahoma Water Resources Board. Decision Support System for Long Term Planning of Rural and Urban Water Supply Systems Cost in Oklahoma developed a economic model for evaluating the costs of expanding, upgrading, and/or regionalizing drinking water treatment plants. Occurrence of Pharmaceuticals, Hormones, and other Organic Wastewater Contaminants in Cave Water within the Lower Neosho and Illinois River Basins, Oklahoma studied the prevalence of these contaminants in caves known to house the Ozark cavefish (a threatened species).

Science, Development & Public Opinion: The Adjudication of Groundwater Policy for the Arbuckle-Simpson Aquifer

Basic Information

Title:	Science, Development & Public Opinion: The Adjudication of Groundwater Policy for the Arbuckle-Simpson Aquifer
Project Number:	2005OK45B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	2, 4
Research Category:	Social Sciences
Focus Category:	Groundwater, Law, Institutions, and Policy, Education
Descriptors:	None
Principal Investigators:	Beth Caniglia

Publication

Title: Science, Development & Public Opinion: The Adjudication of Groundwater Policy for the Arbuckle-Simpson Aquifer

Start Date: 03/01/06

End Date: 2/28/07

Congressional District: 3rd

Focus Categories: GW, LIP, EDU

Descriptors: Arbuckle-Simpson Aquifer, Oklahoma Water Resources Board, Science, Stakeholders, Environmental Sociology

Principal Investigators:

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Problem and Research Objectives:

Purpose

- To collect benchmark public opinion data from relevant representatives of citizen groups, public agencies and legislators toward: development trajectories of the Arbuckle-Simpson aquifer, the present moratorium on permits for extra-county use of Arbuckle-Simpson groundwater resources (Senate Bill 288); and the Arbuckle-Simpson Aquifer Hydrogeology Study being conducted by the Oklahoma Water Resources Board
- To systematically assess over time the impact of the Arbuckle-Simpson Aquifer Hydrogeology Study on public opinion in the above mentioned areas
- To assess the ultimate impact of the Arbuckle-Simpson Aquifer Hydrogeology Study on groundwater law in the State of Oklahoma

Project Description

In May 2004, the Oklahoma State Legislature passed Senate Bill 288, which places a moratorium on the issuance of temporary permits that would result in the usage of water from a “sensitive sole source” aquifer outside of its home county, until a scientific study is conducted by the Oklahoma Water Resources Board (OWRB). The purpose of the OWRB study is to approve “a maximum annual yield that will ensure that any permit for the removal of water from a sensitive sole source groundwater basin or subbasin will not reduce the natural flow of water from springs or streams emanating from said basin or subbasin” (ENR. S. B. NO. 288). Senate Bill 288 may add a new provision to Oklahoma’s water law, and that possibility has motivated unprecedented activist engagement targeted at OWRB. Literally thousands of public comment letters have poured into OWRB offices. One lawsuit, which was filed just hours after passage of the Bill, resulted in a ruling that the Bill is constitutional, and the appeal filed with the Oklahoma Supreme Court reiterated the original ruling. Therefore, the adjudication of cross-county water transfer permits hinges upon science.

Following the impact of this hydrological study is of intellectual import. Environmental policy is frequently based upon natural science. While natural science is often billed as the central determinant in environmental policy decision-making, sociologists argue that the impact of policy science studies varies based on several factors including: the extent to which findings and predictions are certain, the extent to which the scientific processes and findings are clearly communicated to various publics, and the extent to which relevant authorities possess political capacity and will to enact the recommendations of scientists. To date, we have been unable to find extant systematic studies within the sociology of science, technology and environment that empirically measure the impact of policy science from its inception to its policy conclusions. The current study is designed to fill this gap. By systematically examining the impact of information related to the OWRB study on public opinion and legislative decisions, our research will provide an empirically informed model of the role of science in the formation of environmental policy in the Arbuckle-Simpson case.

Methodology:

This longitudinal study follows the impact of a scientific study being conducted by the Oklahoma Water Resources Board until its completion. Phase I of the project, which was funded by a previous OWRRI grant, assembled baseline public opinion data from newspaper articles, public comment letters and in-depth semi-structured interviews (see 2006 report for more details). The current grant funded Phase II of the project, which consisted of two data collection strategies. First, we continued to update the newspaper and newsletter archive related to the Arbuckle-Simpson aquifer, expanding its coverage to include a census of articles May 2001 – August 2006. Second, we conducted in-depth interviews in order to compare benchmark public opinion to current views toward the study and development of the aquifer.

A total of fifteen (15) in-depth interviews were conducted with members of most target publics (or stakeholder groups) indicated in the OWRB public participation plan (see attached questionnaire). The interviews followed an open-ended format, where respondents were encouraged through probes and follow-up questions to elaborate answers to a set of ten questions. Twelve of the interviews were conducted face-to-face, while the remaining three were telephone interviews that ranged between fifteen minutes and one hour. We were able to interview many participants from the benchmark study and added new respondents who fit appropriate profiles. The interviews were transcribed by the social science research bureau at Oklahoma State University, and the transcripts were uploaded into a qualitative software package for systematic analysis.

These data will be triangulated with the benchmark data collected in 2005 to make comparisons between public opinion toward the Arbuckle-Simpson aquifer prior to the release of significant scientific findings from the Oklahoma Water Resources Board and opinions after examination of study findings. While full analyses of the data have not been conducted, some cursory findings can be inferred.

Principal Findings and Significance:

The principal findings from this phase of the research are two-fold. First, very little change in opinion is expressed by these respondents. Even though we conducted fewer interviews than we hoped, we heard repeatedly the same themes, giving us confidence in the inferences drawn from these data. The second very important finding suggests that the trends observed may not be transferable to similar conflicts in large metropolitan areas. I will discuss each of these in turn.

One of the central questions of this longitudinal research is: will public opinion toward the study and development of the aquifer change as a function of study findings reported by the Oklahoma Water Resources Board. Interviews conducted during Phase I indicated that our respondents were scientifically literate. Most claim to have read earlier studies of the Arbuckle-Simpson aquifer, and most stated that they intended to keep up with the current OWRB study. In order to answer our question regarding change over time, it was necessary to determine first whether our respondents were up-to-date on the OWRB study findings. Every respondent claimed to regularly consult the OWRB study website, and they all claimed that this website and OWRB personnel were their primary sources of information regarding study findings. Therefore, I would conclude that most target publics are staying informed regarding the OWRB study as findings are released.

The second requirement was to determine whether our respondents had changed their views toward the study and/or development of the aquifer as a result of the study findings. With only one exception, none of our respondents have revised their views. Instead, they are largely satisfied that the study appears to support their original views. This finding should not be overstated, however, because most respondents also admitted to being in a holding pattern while waiting for the final recommendations to be put forth by OWRB. Most felt that a new round of controversy will be centered around those final recommendations.

Comments from the most recent round of interviews suggest very important considerations regarding the rural, smaller town communities who are engaged in the fight over Arbuckle-Simpson aquifer water. Two interviews with landowners who hope to sell their permitted groundwater for profit highlight difficult personal circumstances they have encountered. One landowner, for example, stated:

"…I would like if there's a new water law, I'd like to see it handled through the Oklahoma Water Resource Board. I do not want to see this resolved in [the] legislature because you know, the big cities are going to fight for my water, ok, but the local people here are all going to hate me, you understand? And I don't want to live in an area where people don't like me."

When asked what he planned to do now that the lawsuit was over, the second landowner stated:

"I received eleven thousand, literally eleven thousand protests to me trying to sell my water and when eleven thousand of your neighbors send you a letter and tell you that you're doing the wrong thing, you know, it just, it wears on you. You know, we've been called in the papers and everywhere, we've been called greedy. We've been called scrooge. We've been called thieves, all kinds of things of which none of those are true, but even though you know in your heart that that's not right it still hurts and you hate to be called that."

These comments and others highlight the very personal nature of small town disputes. As a result, the next theoretical turn in my study will focus on rural sociology and small group interactions as lenses from which to infer the extent to which this study can be generalized to metropolitan resource disputes. The next stage of data collection will commence with the release of the OWRB recommendations to the legislature, which is currently scheduled for late spring 2008.

Student Support: A summary of the number of students, their degree level and discipline supported by the project in the following table:

Student Status	Number	Disciplines
Undergraduate		
M.S.		
Ph.D.	1	Sociology
Post Doc		
Total	1	

Science, Development & Public Opinion: The Adjudication of Groundwater Policy for the Oklahoma Arbuckle-Simpson Aquifer

Phase II Interview Main Questions[1]

Introduction:

[1] Additional questions may emanate from respondents' answers.

Read Consent form:

Consent to tape record:

1. Can you give me a general idea of how you keep abreast of the OWRB hydrology study of the Arbuckle-Simpson Aquifer?

2. Can you list for me all of the sources you are aware of that provide information on the OWRB hydrology study of the Arbuckle-Simpson Aquifer (prompts are fine – e.g. newspapers, web sites, newsletters, etc.)?

3. Of those you listed, which do you find the most useful in your own research related to the study?

4. In your opinion, what have been the most useful pieces of information to come out of the study so far?

5. What, if any, have been your frustrations with the study?

6. In general, do you feel the OWRB study will be helpful in determining how best to manage the aquifer resources?
7. Have any of the study findings affected your views regarding how the Arbuckle-Simpson Aquifer resources should be managed or allocated? Please be as specific as possible regarding your original views and how those have changed as a result of the study findings. (If no change, "In that case, can you please share with me your general views regarding the development, management and allocation of the Arbuckle-Simpson Aquifer)?

8. In general, do you feel you have access to sufficient information regarding the Arbuckle-Simpson Aquifer study?

9. Are there additional pieces of information that would benefit you? Please be specific.

10. Are there other comments you would like to share with us regarding the aquifer, the OWRB study or the current moratorium on cross-county transfer of the aquifer resources?

Thank you for your participation in our study!
Have a nice day.

Occurrence of Pharmaceuticals, Hormones, and other Organic Wastewater Contaminants in Cave Water within the Lower Neosho and Illinois River Basins, Oklahoma

Basic Information

Title:	Occurrence of Pharmaceuticals, Hormones, and other Organic Wastewater Contaminants in Cave Water within the Lower Neosho and Illinois River Basins, Oklahoma
Project Number:	2006OK60B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Toxic Substances, Groundwater
Descriptors:	None
Principal Investigators:	Joseph R. Bidwell

Publication

Title: Occurrence of Pharmaceuticals, Hormones, and other Organic Wastewater Contaminants in Cave Water within the Lower Neosho and Illinois River Basins, Oklahoma

Start Date: 3/1/2006

End Date: 2/28/2007

Congressional District: District 3 (University), District 2 (Field Sites)

Focus Category: GW, NPP, WQL

Descriptors: Organic wastewater contaminants, cave streams, passive sampler

Principal Investigators: Joseph R. Bidwell, Department of Zoology, Oklahoma State University

Publications: A manuscript that will be submitted to a peer-reviewed publication is currently in preparation.

Problem and Research Objectives: The headwaters and upper basins of the Illinois River and the eastern part of the Lower Neosho River are located in northwestern Arkansas and northeastern Oklahoma. In Arkansas, this area is experiencing significant urban development and is one of the most productive poultry producing regions in the United States (Galloway et al. 2004). While there has been widespread concern about the health and continued aesthetic quality of these systems due to nutrient input and associated water quality effects, effluent and/or runoff from livestock production facilities and municipal wastewater treatment plants may contain a number of organic wastewater contaminants (OWCs) such as antibiotics, hormone residues, various pharmaceutical compounds, and other trace organics that are ultimately transferred to aquatic habitats. The frequency with which these contaminants occur in U.S. surface waters was clearly indicated by a U.S. Geological Survey (USGS) study that found 80% of the 139 streams sampled contained detectable levels of OWCs (Kolpin et al. 2002). Another recent USGS study (Galloway et al. 2004) sampled surface water in Benton and Washington counties, Arkansas, and similarly reported the presence of selected OWCs in some streams receiving input from municipal wastewater treatment plants.

In addition to the land use characteristics stated above, the basins of the Illinois and Lower Neosho Rivers are situated within the Ozark Plateau, an uplifted region with a karst topography that is characterized by sinkholes, disappearing springs, and caves. As a result of these features, surface water contaminants may enter the groundwater and associated cave ecosystems. The presence of contaminants in water flowing through caves is a concern since these habitats often support a highly specialized assemblage of organisms which may be particularly susceptible to water-quality impacts due to their generally low population densities and unique life history requirements (Graening and Brown, 2003). Several aquatic species that are federally-listed or considered species of special concern are known to use caves in the Ozark Plateau of Oklahoma. These species include the Ozark cavefish, *Amblyopsis rosae*, federally- and state-listed as threatened, and the Oklahoma cave crayfish, *Cambarus tartraus*, state-listed as endangered. An unnamed cave crayfish, *C. subterraneus*, and the Ozark cave amphipod, *Stygobromus ozarkensis,* both considered critically imperiled by the Oklahoma Natural Heritage Inventory, also occur in caves of this region (NatureServe, 2005). Environmental contamination has been identified as one of the most significant threats to cave-dwelling fishes (Proudlove, 2001), and chemical and septic system pollution has been implicated in the loss of both invertebrate and vertebrate taxa from cave ecosystems (Aley, 1976; Crunkilton, 1984; Simon and Buikema, 1997).

The prevalence and potential impacts of pharmaceuticals, hormones, and other OWCs in the Ozark cave habitats of Oklahoma are currently unknown. However, given the agricultural activities, wastewater discharges, and urban development that are occurring in the Lower Neosho and Illinois River basins, the karstic nature of these basins, and the recent detection of OWCs in streams within them (Galloway et al. 2004), contamination of ground water and associated cave habitats may be occurring. The presence of OWCs and related compounds could have significant implications for the long-term management of cave habitats since the potential for effects due to exposure to these contaminants may result in the need to relocate populations of some organisms and make it necessary to revise recovery plans for those groups listed as threatened or endangered. By determining the extent to which OWC residues are present in caves, this project will provide an important first step toward understanding the risk these chemicals pose to these sensitive habitats.

The objectives of this study were to 1) determine the presence of selected lipid soluble and water soluble pharmaceuticals, hormones, and other organic wastewater contaminants at two surface-water sites and in ground water in six caves in northeastern Oklahoma and western Arkansas using Semi Permeable Membrane Devices (SPMD) and Polar Organic Chemical Integrated Samplers (POCIS), and 2) evaluate the potential for sub-lethal effects associated with exposure to water from the sampling sites through 7-day bioassays with the fathead minnow, *Pimephales promelas*, a standard US EPA test organism.

Methodology: *Site selection*: Caves were selected in the Illinois and Lower Neosho River basins with the guidance of Mr. Steve Hensley and Mr. Richard Stark, US Fish and Wildlife Service, Tulsa Field Office, and were restricted to sites in which populations of Ozark cavefish, *A. rosae*, were known to have occurred. The caves evaluated included four systems (Twin, Starr, Mgee and Long, and January-Stansbury) in Delaware County, OK, and two systems (Logan and Cave Springs) in Benton County, AK. In addition, sampling devices were deployed at one surface water site in Oklahoma and one in Arkansas. The Oklahoma site (designated OK-Surface) was located in an unnamed creek near the town of Jay, OK, with the sampler deployed approximately 250 m downstream from the outfall of a municipal wastewater treatment plant. A previous study indicated a link between water in this stream and that occurring in Star Cave (Aley, 2005). The Arkansas surface water site was located in Little Osage Creek (designated AK-Surface) near Osage Mills, AK.

Passive sampler deployment: The cave and surface-water sites were sampled using two types of passive, *in situ*, samplers; the polar organic chemical integrative sampler or POCIS and the semi-permeable membrane device or SPMD. The POCIS is designed to sample transient water-soluble (polar or hydrophilic) organic chemicals from aquatic environments (USGS, 2004), while SPMDs passively accumulate transient hydrophobic organic compounds, such as PCBs, PAHs, and organochlorine pesticides (Huff, 2005). Both of these samplers have been successfully used to monitor OWCs in surface and groundwater (Jones-Lepp et al. 2004; Vrana et al. 2005). The POCIS and SPMDs were purchased from Environmental Sampling Technologies (EST), St. Joseph, MO, and were sent to Oklahoma State University under argon gas in sealed metal cans. The sampling membranes were held on stainless steel racks and deployed in stainless steel canisters (also obtained from EST, Figure 1 & 2). Each canister included three POCIS and three SPMD samplers, with a single canister placed at each site. During deployment, the samplers were removed from their original metal cans and placed in the deployment canisters as quickly as possible to minimize air exposure. In the caves, the cages were tied off to some object on the shoreline with a length of nylon rope (Figure 2). At the surface water sites, the racks were affixed to a concrete block with lengths of stainless steel cable and submerged. The time taken to transfer the sampler to the cage and then to submerge the cage in water was recorded during each deployment. A set of six trip blanks consisting of metal cans that contained either one of three POSIS or SPMD membranes were opened and exposed to air during the time the water samplers were being deployed as well.

The samplers were left on site for approximately 30 days (exact duration is presented in results). During retrieval, the stainless steel canisters were first moved from the water to the shoreline where they were opened. The racks holding the sampling membranes were removed and placed in the original metal cans. As for deployment, trip blanks for both membrane types were exposed to the air from the time the samplers were first removed from the stainless steel canisters until they were placed in the holding cans and the cans sealed by gently tapping their metal lids into place. The sealed cans were placed on ice as soon as possible and transported back to Oklahoma State University where they were held at -20°C until being shipped overnight to Environmental Sampling Technologies (also on ice) for extraction.

The membrane extraction procedures followed standard protocols used by Environmental Sampling Technologies for the POCIS and SPMD. The final extract from each sampling cage was a composite of either the three POCIS or SPMD membranes. Similarly, the replicate trip blanks were composited into one extract. The final combined extracts were transferred to 2 ml amber ampules and the ampules sealed in preparation for analyses. In total, the samples were analyzed for 159 different compounds, including 68 common wastewater organics (USGS Schedule 1433), 33 antibiotic and pharmaceutical compounds and 58 additional organics including a number of halogenated forms (Tables 1-3). The analyses were conducted using liquid chromatography-mass spectroscopy (LC-MS) and gas chromatography-mass spectroscopy (GC-MS) at the USGS National Water Quality Laboratory, Denver, Colorado, under the direction of Dr. Steven Zaugg (analytes listed in Table 1 & 3) and at the Organic Geochemistry Laboratory, USGS Kansas Water Science Center, Lawrence, Kansas, under the direction of Dr. Michael Meyer (antibiotics listed in Table 2). As indicated in Tables 1-3, some of these analyses were conducted on extracts from both samplers, while others were restricted to a particular membrane type. The methods used for analyses of the OWCs and antibiotics listed in Tables 1 &2 followed established protocols (Zaugg et al. 2001; Alvarez et al. 2005) that allowed detection at the microgram (1×10^{-6}g) level. The 58 organic compounds listed in Table 3 were quantified at the nanogram (1×10^{-9}g) level by a technique that is currently under development and is not yet published (S. Zaugg, USGS, personal communication). The results of chemical analyses are qualitative (presence/absence) or semi-quantitative (relative concentrations) since calculations of water concentrations based on levels sequestered in the sampling devices requires an *in situ* sampling rate for each chemical and this value is not known for all analytes (Alvarez et al. 2005).

Field water chemistry and fathead minnow bioassays: Basic water chemistry parameters including specific conductance, pH, temperature and dissolved oxygen were measured at cave and surface-water sites when samplers were deployed and collected using a YSI XL-600 multimeter. These same parameters and alkalinity and hardness were determined for each of the water samples collected for the fathead minnow bioassays. Water for these bioassays was collected in acid-washed, 3-liter plastic containers at each cave and surface water site and placed on ice as soon as possible for transport back to the University. Fathead minnow bioassays were conducted at the Ecotoxicology and Water Quality Research Laboratory, Oklahoma State University. General test protocols (test chamber size, loading rate, water renewal, feeding, etc.) followed methods described in US EPA (2002). Briefly, larval fish (<24 h) were exposed to sample water for 7 days and their survival and growth (as dry weight) were compared to that of fish maintained in laboratory water formulated to have similar hardness as the site water (US EPA 2002). Statistical analyses of growth and survival data were conducted using the Comprehensive Environmental Toxicity Information System (CETIS ver 1.1.1, Tidepool Scientific Software, McKinleyville, CA) and followed the standard US EPA decision tree for chronic toxicity data (US EPA 2002). In cases where a significant difference in growth and/or survival was observed between laboratory reference and field samples, the site was re-sampled and a dilution series of the site water was prepared (using laboratory water as the diluent) to determine if a dose response could be generated.

Figure 1. POCIS (left) and SPMD (right) sampling membranes deployed at the cave and surface water sites.

Figure 2. Deployment of a stainless steel canister in a cave (left) and at one of the surface sites (right).

Table 1. Organic wastewater compounds that were targeted in analyses of the extracts from both the POCIS and SPMD passive sampling devices. Descriptions of chemicals and associated laboratory reporting levels were taken from Galloway et al. (2004) and Alvarez et al. (2005). *-Compound analyzed in extracts from SPMD only

Compound	Description	Laboratory Reporting Level (µg/L)
1,4-Dichlorobenzene	Moth repellant, fumigant, deodorant	0.5
1-Methylnapthalene	Component of gasoline/diesel/crude oil	0.5
2,6-Dimethylnapthalene	Component of diesel and kerosene	0.5
2-Methylnapthalene	Component of gasoline/diesel/crude oil	0.5
3,4-Dichlorophenylisocyanate	Herbicide intermediate	
3-beta-Coprostanol	Carnivore fecal indicator	2.0
4-Cumylphenol	Nonionic detergent metabolite	1.0
17-beta-Estradiol*	Estrogen replacement therapy and metabolite	5.0
4-n-Octylphenol	Nonionic detergent metabolite	1.0
4-tert-Octylphenol	Nonionic detergent metabolite	1.0
5-methyl-1H-Benzotriazle	Antifreeze component, deicer	2.0
2,2',4,4'-tetrabromodiphenylether*	Flame retardant	
Acetophenone*	Fragrance in soap, detergent, tobacco; flavor in beverages	0.5
Anthracene	Wood preservative, component of tar/diesel/crude	0.5
Anthraquinone	Used in Manufacture of dye/textiles	0.5
Atrazine	Herbicide	
Benzo(a)pyrene	Polyaromatic hydrocarbon, by-product of combustion	0.5
Benzophenone	Fixative for perfumes and soaps	0.5
Beta-sitosterol	Generally a plant sterol	2.0
BisphenolA	Manufacture of resins; antioxidant	1.0
Bromacil	Herbicide- non-crop grass/brush control	0.5
Bromoform	By-product of wastewater ozination	0.5
Caffeine	Stimulant	0.5
Camphor	Flavor, odorant, in ointments	0.5

Table 1. Continued

Compound	Description	Laboratory Reporting Level (µg/L)
Carbazole	Manufacture of dyes, explosives, and lubricants	0.5
Chlorpyrifos*	Organophosphorous insecticide	0.5
Cholesterol	Fecal indicator, also a plant sterol	2.0
Cotinine	Primary nicotine metabolite	1.0
Cumene	Manuf phenol/acetone; component of fuels/paint thinner	0.5
Diazinon	Organophosphorous insecticide	0.5
Dichlorvos	Organophosphorous insecticide	1.0
Diethylhexylphthalate	Plasticizer	0.5
Diethylphthalate	Plasticizer	0.5
d-Limonene	Antimicrobial antiviral; fragrance in aerosols	0.5
Estrone*	Hormone	5.0
Ethanol,2-butoxy-,phosphate	Flame retardant	0.5
Ethylcitrate	Cosmetic component	0.5
Fluoranthene	Component of coal tar/asphalt	0.5
Galaxolide (HHCB)*	Musk fragrance	0.5
Indole	Fragrance	0.5
Isoborneol	Fragrance	0.5
Isophorone	Solvent for lacquers, plastics, oils, silicon, resins	0.5
Isoquinoline	Manuf phenol/acetone; component of fuels/paint thinner	0.5
Menthol	Cigarettes, cough drops, liniment, mouthwash	0.5
Metalaxyl	Fungicide	0.5
Methylsalicylate	Liniment, food, beverage, UV-absorbing lotions	0.5
Metolachlor	Herbicide	0.5
N,N-diethyltoluamide (DEET)	Insect repellant	0.5
Naphthalene	Fumigant	0.5
Nonylphenol di-ethoxylates (total)	Nonionic detergent metabolite	5.0
Octylphenol di-ethoxylates (total)	Nonionic detergent metabolite	1.0
Octylphenol monoethoxylates (total)	Nonionic detergent metabolite termite control	1.0
Para-cresol*	Wood preservative	1.0

Table 1. Continued		
Compound	**Description**	**Laboratory Reporting Level (µg/L)**
Para-nonylphenol (total)	Nonionic detergent metabolite	5.0
Pentachlorophenol	Insecticide	2.0
Phenanthrene	Component of tar/diesel/crude	0.5
Phenol*	Disinfectant	0.5
Prometon	Herbicide	0.5
Pyrene	common in coal tar/asphalt	0.5
s3-Methyl-1(H)-indole (skatol)	Odor in feces and coal tar	1.0
Stigmastanol	Generally a plant sterol	2.0
Tetrachloroethylene	Solvent, degreaser; Veterinary: anthelminic	0.5
Tonalide (AHTN)*	Musk fragrance	0.5
Triclosan*	Antimicrobial in soaps	1.0
tri(2-Chloroethyl)phosphate	Plasticizer and flame retardant	0.5
tri(Dichlorisopropyl)phosphate	Flame retardant	0.5
Tributylphosphate	Antifoaming agent and flame retardant	0.5
Triphenylphosphate	Plasticizer, resins, waxes, finishes, roofing paper, Flame retardant	0.5

Table 2. Antibiotics and other pharmaceutical compounds that were additionally targeted in analyses of the extracts from the POCIS samplers.

Compound	Description	Laboratory Reporting Level (µg/L)
Azithromycin	Antibiotic	0.005
Carbamazapine	Anticonvulsant	0.005
Chloramphenicol	Antibiotic	0.020
Chlorotetracycline	Antibiotic	0.01
Ciproflaxacin	Antibiotic	0.005
Doxycycline	Antibiotic	0.01
Enrofloxacin	Antibiotic	0.005
Epi-chlorotetracycline	Antibiotic	0.01
Epi-iso-chlorotetracycline	Antibiotic	0.010
Epi-oxytetracycline	Antibiotic	0.010
Epi-tetracycline	Antibiotic	0.010
Erythromycin	Antibiotic	0.005
Erythromycin-H2O	Antibiotic	0.005
Ibuprofen	Analgesic	0.020

Table 2. Continued

Compound	Description	Laboratory Reporting Level (µg/L)
Iso-chlorotetracycline	Antibiotic	0.010
Lincomycin	Antibiotic	0.005
Lomefloxacin	Antibiotic	0.005
Norfloxacin	Antibiotic	0.005
Ofloxacin	Antibiotic	0.005
Ormetoprim	Antibiotic	0.005
Oxytetracycline	Antibiotic	0.010
Roxithromycin	Antibiotic	0.005
Sarafloxacin	Antibiotic	0.005
Sulfachloropyridazine	Antibiotic	0.005
Sulfadiazine	Antibiotic	0.005
Sulfadimethoxine	Antibiotic	0.005
Sulfamethazine	Antibiotic	0.005
Sulfamethoxazole	Antibiotic	0.005
Sulfathiazole	Antibiotic	0.005
Tetracycline	Antibiotic	0.010
Trimethoprim	Antibiotic	0.005
Tylosin	Antibiotic	0.005
Virginiamycin	Antibiotic	0.005

Table 3. Additional organic compounds that were targeted in analyses of the extracts from the SPMD samplers only. Analyses were conducted with a method that allowed lower detection limits.

Compound	Description	Laboratory Reporting Level (ng/L)
BDE100 (Brominated di-phenyl ether)	Flame Retardant	0.2
BDE138	Flame Retardant	0.5
BDE153	Flame Retardant	0.5
BDE154	Flame Retardant	0.5
BDE183	Flame Retardant	0.5
BDE47	Flame Retardant	0.5
BDE66	Flame Retardant	0.5
BDE71	Flame Retardant	0.5
BDE85	Flame Retardant	0.2
BDE99	Flame Retardant	0.2
Chlorpyrifos	Organophosphorous insecticide	0.5

Table 3. Continued

Compound	Description	Laboratory Reporting Level (ng/L)
Chlorthalonil	Organochlirine, Fungicide	10
cis-Chlordane	Organochlorine, Insecticide	0.2
cis-Nonachlor	Organochlorine, Insecticide	0.2
Cyfluthrin	Pyrethroid insecticide	0.5
Cyhalothrin	Pyrethroid insecticide	0.5
DCPA	Phthalate/herbicide	0.2
desulfnylFipronil	Organochlorine, Insecticide	0.2
Dieldrin	Organochlorine, Insecticide	0.2
Endosulfan I	Organochlorine, Insecticide	0.2
Fipronil	Organochlorine, Insecticide	0.2
FipronilSulfide	Organochlorine, Insecticide	0.2
Firemaster	Flame Retardant	0.5
HCB	Organochlorine, Fungicide	0.2
Octachlorostyrene	Organochlorine biproduct	1
Oxychlordane	Organochlorine breakdown product	1
Oxyfluorfen	Herbicide	10
p,p-DDT	Organochlorine, Insecticide	5
p,p'-DDE	DDT metabolite	1
p,p'-DDD	DDT metabolite	2
PCA (p-chloroaniline)	Dye intermediates, agricultural chemicals and pharmaceuticals	0.2
PCB101 (Polychlorinated biphenyl)	Organochlorine, formerly used in hydraulic oils and some other industrial applications	2
PCB110		1
PCB118		0.5
PCB138		0.5
PCB146		0.5
PCB149		1
PCB151		1
PCB170		0.5
PCB174		0.5
PCB177		0.5
PCB180		0.5
PCB183		0.5

Table 3. Continued		
Compound	**Description**	**Laboratory Reporting Level (ng/L)**
PCB187		0.5
PCB194		0.5
PCB206		0.5
PCB44		5
PCB49		5
PCB52		5
PCB70		2
Pendimethalin	Herbicide	5
Pentabromotoluene	Flame Retardant	1
Pentachloronitrobenzene	Water treatment/fungicide	0.2
Tefluthrin	Pyrethroid insecticide	0.2
Tetradifon	Acaricide	0.5
trans-Chlordane	Organochlorine, Insecticide	0.2
trans-Nonachlor	Organochlorine, Insecticide	0.2
Triclosan	Antimicrobial in soaps	10
Methoxytriclosan	Antiseptic, metabolite of Triclosan	2
Trifluralin	Herbicide	0.2

Principal Findings and Significance: The deployment time for the samplers ranged from 28 to 35 days (Table 4). The first deployment at Star Cave in May – June 2006 failed because the cave stream went dry before the end of the exposure time. A second successful deployment was conducted in June –August 2006 in which the sampler was placed in more permanent water farther into the cave. Due to the possible connection between the OK surface water site and this cave, a second sampler was deployed at the OK surface site in conjunction with the second deployment at Star Cave.

Table 4. Deployment and retrieval dates and durations of exposure for the POCIS and SPMD samplers at each cave and surface water site.

Site	Deploy date	Retrieve date	Exposure time (Days)
AK-Surface	8 May 2006	5 June 2006	28
OK-Surface-1st Deployment*	8 May 2006	7 June 2006	30
OK-Surface-2nd Deployment*	27 June 2006	1 August 2006	35
Cave Springs (AK)	2 May 2006	5 June 2006	34
January-Stansbury (OK)	1 May 2006	1 June 2006	31
Logan (AK)	2 May 2006	5 June 2006	34
Mgee and Long (OK)	1 May 2006	1 June 2006	31
Star (OK)- 1st Deployment*	8 May 2006	7 June 2006	30
Star – 2nd Deployment*	27 June 2006	1 August 2006	35
Twin (OK)	6 May 2006	6 June 2006	31

*= The stream in Star Cave went dry during the first deployment and a new sampler had to be redeployed. A second sampler was also placed at the OK-Surface because of the potential link between it and Star Cave.

On-site water chemistry: The water chemistry values measured at each of the sites are presented in Table 5. Due to instrument malfunctions, values were not available for all sites on all visits. The measured temperature at the cave sites ranged from 13-15 °C, pH was near neutral and dissolved oxygen was near saturation. Conductivity levels for the Oklahoma caves were higher than those for the Arkansas caves. The temperature values at the Oklahoma surface water site were approximately 10°C higher than that in the caves, and dissolved oxygen was below saturation.

Table 5. Water chemistry values at surface water and cave sites during deployment/retrieval of the samplers. Due to instrument malfunctions, data for some of the sites were not available (NA).

	AK-Surface	OK-Surface	Cave Springs	January-Stansbury	Logan	Mgee and Long	Star	Twin
Temperature (°C)	NA	21.6[1]/23.5[2]	14.9/NA	13.5/14.2	14.3/NA	13.8/15.0	15.8[3]/NA	15.7[4]
Dissolved Oxygen (mg/L)	NA	7.2[1]/5.6[2]	8.8/NA	10.2/10.1	9.3/NA	9.2/7.6	6.2[3]/NA	8.5[4]
pH	NA	6.9[1]/6.5[2]	6.9/NA	7.0/7.0	7.1/NA	6.8/6.8	6.4[3]/NA	7.6[4]
Conductivity (uS/cm)	NA	494[1]/602[2]	269/NA	207/293	293/NA	NA/258	456[3]/NA	398[4]

1-Value from 7 June 2006 retrieval of sampler

2-Value from 27 June 2006 deployment of sampler

3-Value from 27 June 2006 deployment of sampler

4-Value from 3 December 2005 reconnaissance of site

Detection of target compounds in passive sampler extracts: Lists of the compounds detected in the extracts from the POCIS and SPMD samplers are presented in Tables 6-9. These tables are differentiated based on analytical technique used and compounds analyzed. The data presented in Tables 6 & 7 were derived from the analyses for standard wastewater compounds (e.g. Zaugg et al. 2001), the data in Table 8 summarizes the antibiotic residues detected, while that in Table 9 summarizes the results of analyses for chlorinated and other organics using the experimental, unpublished analytical technique which provides lower detection limits. An additional summary of all detections is presented in Figure 3. Regardless of the analytical technique used, more compounds were detected in the surface water sites than in caves and more were detected in the OK-Surface site than in the AK-Surface site. This is not a surprising result given that the OK samplers were placed directly downstream from the outfall of a municipal wastewater treatment plant.

A total of 27 different organic wastewater compounds were detected in the POCIS and SPMD extracts from the surface water and cave sites, with the majority of these found in the extracts from the POCIS samplers (Tables 6 & 7). Of these 27 compounds, 11 OWCs were detected in the caves, and Star Cave had the greatest number of detects, followed by Cave Springs Cave. Cholesterol and diethylexylphthalate were the most commonly detected compounds in the POCIS extracts, while no consistent trend in compound detection was apparent for the SPMD extracts.

Measurable levels of antibiotics/pharmaceuticals were only found in the extracts from samplers at the OK surface water site and in Star Cave, with 8 compounds detected in the surface water and 2, carbamazapine and sulfamethoxazole, detected in the cave (Table 8). In most cases, the level of antibiotic measured in these extracts was 5 times the detection limit or higher.

As would be expected, the majority of compound detections were observed in the SPMD extracts that were analyzed with the experimental method allowing for lower detection limits (Table 9). A total of 44 compounds were measured using this method, with this number including those with estimated levels below the laboratory reporting limit (LRL). Since this analytical technique is still being developed, a more conservative approach was taken when interpreting the data. Specifically, a “detect” was considered to have occurred only if the level of compound in the extract was at least 2X the LRL or level measured in the blanks. With this approach, 32 detections were observed, with 23 of these occurring in extracts from the cave samplers. In the OK surface site, the most commonly encountered residues were selected BDE and PCB congeners, organochlorine pesticides, and the common wastewater contaminants triclosan and methoxytriclosan. For the caves, the most common residues were BDEs and other selected flame retardants, organochlorine pesticides and triclosan and methoxytriclosan. Most of these residues were observed in the samples from January-Stansbury and Logan caves, although Star cave also had a number of detects at lower (<2X LRL) levels. The compounds triclosan and chlorpyrifos were also targeted as part of the OWC analyses (Table 1), although chlorpyrifos was only measured using the method with nanogram detection and triclosan was detected at more sites using this more sensitive method (Table 9).

Table 6. Compounds detected in extracts from the POCIS samplers. *(D)*=Detection at less than the laboratory reporting limit (LRL); D=Detection above, but less than 2X, LRL or average blank concentration; D-2X=Detection at or above 2X, but less than 5X, LRL or average blank concentration, D-5X=Detection at or above 5X LRL or average blank concentration.

	AK-Surface	OK-Surface	Cave Springs Cave	January-Stansbury Cave	Logan Cave	Mgee and Long Cave	Star Cave	Twin Cave
4-tert-octylphenol	ND	***(D)***	***(D)***	ND	ND	ND	ND	ND
Anthracene	ND	***(D)***	ND	ND	ND	ND	ND	ND
Atrazine	***(D)***	ND	ND	ND	ND	ND	ND	ND
Benzophenone	ND	***(D)***	ND	ND	ND	ND	**D**	ND
beta-Sitosterol	***(D)***	**D-2X**	ND	ND	ND	ND	ND	ND
Bromacil	ND	**D-5X**	ND	ND	ND	ND	ND	ND
Caffeine	***(D)***	**D**	ND	ND	ND	ND	ND	ND
Cholesterol	**D**	**D-5X**	**D-2X**	**D-2X**	**D**	**D-2X**	**D**	**D-5X**
Diethylhexylphthalate	**D**	**D-5X**	***(D)***	ND	***(D)***	***(D)***	**D-5X**	**D-2X**
Diethylphthalate	ND	**D**	ND	ND	ND	ND	**D-5X**	ND
d-Limonene	ND	ND	**D-5X**	ND	ND	ND	ND	ND
Ethanol,2-butoxy-,phosphate	ND	**D-5X**	ND	ND	ND	ND	ND	ND
Indole	ND	**D-5X**	ND	ND	ND	ND	ND	ND
Methylsalicylate	ND	***(D)***	ND	ND	ND	**D-5X**	ND	ND
N,N-diethyltoluamide(DEET)	***(D)***	**D-2X**	***(D)***	ND	ND	ND	***D***	ND
Naphthalene	ND	***(D)***	ND	ND	ND	ND	ND	ND
Octylphenol monoethoxylates (total)	ND	***(D)***	ND	ND	ND	ND	***D***	ND
Prometon	***(D)***	ND	ND	ND	ND	ND	***D***	ND
Skatol	ND	***(D)***	ND	ND	ND	ND	ND	ND
tri(2-Chloroethyl)phosphate	ND	**D**	ND	ND	ND	ND	ND	ND
tri(Dichlorisopropyl)phosphate	ND	***(D)***	ND	ND	ND	ND	ND	ND
Number of Detections	**7**	**18**	**5**	**1**	**2**	**3**	**7**	**2**

Table 7. Compounds detected in extracts from the SPMD samplers. *(D)*=Detection at less than the laboratory reporting limit (LRL); D=Detection above, but less than 2X, LRL or average blank concentration; D-2X=Detection at or above 2X, but less than 5X, LRL or average blank concentration, D-5X=Detection at or above 5X LRL or average blank concentration.

Compound	AK-Surface	OK-Surface	Cave Springs Cave	January-Stansbury Cave	Logan Cave	Mgee and Long Cave	Star Cave	Twin Cave
2,2',4,4'-Tetrabromodiphenylether	ND	D	ND	ND	ND	ND	ND	ND
Diethylhexylphthalate	ND	ND	ND	ND	ND	ND	ND	ND
Diethylphthalate	**D-5X**	D	ND	ND	ND	ND	ND	ND
Fluoranthene	ND	D	ND	ND	ND	ND	ND	ND
Pyrene	ND	D	ND	ND	ND	ND	ND	ND
Tetrachloroethylene	ND	ND	ND	***(D)***	ND	ND	ND	ND
Tonalide (AHTN)	ND	**D-5X**	ND	ND	ND	ND	ND	ND
Triclosan	ND	**D-5X**	ND	ND	ND	ND	ND	ND
Number of Detections	**1**	**2**	**0**	**1**	**0**	**0**	**0**	**0**

Table 8. Antibiotic and other pharmaceutical compounds detected in extracts from the POCIS samplers. *(D)*=Detection at less than the laboratory reporting limit (LRL); D=Detection above, but less than 2X, LRL or average blank concentration; D-2X=Detection at or above 2X, but less than 5X, LRL or average blank concentration, D-5X=Detection at or above 5X LRL or average blank concentration.

Compound	AK-Surface	OK-Surface	Cave Springs Cave	January-Stansbury Cave	Logan Cave	Mgee and Long Cave	Star Cave	Twin Cave
Azithromycin	ND	D-5X	ND	ND	ND	ND	ND	ND
Carbamazapine	ND	D-5X	ND	ND	ND	ND	D-5X	ND
Erythromycin-H2O	ND	D-2X	ND	ND	ND	ND	ND	ND
Ibuprofen	ND	D-5X	ND	ND	ND	ND	ND	ND
Lincomycin	ND	D-5X	ND	ND	ND	ND	ND	ND
Sulfamethoxazole	ND	D-5X	ND	ND	ND	ND	D-5X	ND
Trimethoprim	ND	D-5X	ND	ND	ND	ND	ND	ND
Tylosin	ND	D-5X	ND	ND	ND	ND	ND	ND
Number of Detections	**0**	**8**	**0**	**0**	**0**	**0**	**2**	**0**

Table 9. Chlorinated and other compounds detected in extracts from the SPMD samplers using the experimental analytical method with lower detection limits. *(D)*=Detection at less than the laboratory reporting limit (LRL); D=Detection above, but less than 2X, LRL or average blank concentration; D-2X=Detection at or above 2X, but less than 5X, LRL or average blank concentration, D-5X=Detection at or above 5X LRL or average blank concentration.

Compound	AK-Surface	OK-Surface	Cave Springs Cave	January-Stansbury Cave	Logan Cave	Mgee and Long Cave	Star Cave	Twin Cave
BDE100	**D-2X**	**D-5X**	**D-2X**	**D-2X**	**D-2X**	**D**	**D**	**D**
BDE153	ND	**D-5X**	**D-2X**	**D-2X**	**D-2X**	**D-2X**	ND	**D**
BDE154	**D**	**D-5X**	*(D)*	**D-2X**	**D-2X**	**D-2X**	**D**	**D**
BDE183	ND	**D-2X**	**D-2X**	ND	**D-5X**	ND	ND	**D-2X**
BDE47	**D**	**D-5X**	**D-2X**	**D-2X**	**D-2X**	**D-2X**	**D**	**D**
BDE66	ND	**D-5X**	ND	ND	ND	ND	ND	ND
BDE71	**D-5X**	ND	ND	ND	ND	ND	ND	ND
BDE85	ND	**D-5X**	ND	**D-2X**	**D-2X**	**D**	**D**	ND
BDE99	**D**	**D-5X**	**D**	**D-2X**	**D-2X**	**D-2X**	**D**	**D**
Chlorpyrifos	**D-2X**	**D-5X**	ND	ND	ND	ND	**D**	ND
cis-Chlordane	**D-2X**	**D-5X**	**D-5X**	**D-2X**	**D-2X**	**D**	**D**	**D-2X**
cis-Nonachlor	**D-5X**	**D-5X**	**D-5X**	**D-2X**	**D-2X**	ND	**D-2X**	**D**
desulfnylFipronil	ND	ND	ND	**D-2X**	ND	ND	ND	ND
DCPA	ND	*(D)*	ND	ND	ND	ND	ND	ND
Dieldrin	**D-2X**	**D-5X**	**D-2X**	ND	ND	ND	**D-2X**	ND
Fipronil	ND	ND	ND	**D-2X**	ND	ND	ND	ND
FipronilSulfide	ND	ND	ND	**D-2X**	ND	ND	ND	ND
Firemaster	ND	**D-5X**	ND	**D-2X**	**D-2X**	ND	ND	ND
HCB	**D-5X**	**D-5X**	ND	**D-2X**	**D-2X**	ND	**D**	ND
Oxychlordane	**D**	**D-5X**	**D**	ND	ND	ND	ND	ND
p,p'-DDD	ND	**D-5X**	ND	ND	ND	ND	ND	ND
p,p'-DDE	**D-2X**	**D-5X**	**D-2X**	ND	**D-2X**	ND	**D**	**D-2X**
p,p-DDT	ND	**D-5X**	ND	ND	ND	ND	ND	ND
PCA	**D-5X**	**D-5X**	**D-2X**	ND	ND	ND	**D**	ND
PCB110	ND	**D-2X**	ND	ND	ND	ND	ND	ND
PCB118	ND	**D-5X**	**D**	**D-2X**	ND	ND	**D**	**D**
PCB146	ND	**D-2X**	**D**	**D**	**D**	**D**	ND	ND

Table 9. Continued

Compound	AK-Surface	OK-Surface	Cave Springs Cave	January-Stansbury Cave	Logan Cave	Mgee and Long Cave	Star Cave	Twin Cave
PCB149	ND	**D**	ND	ND	ND	ND	ND	ND
PCB151	ND	**D**	ND	ND	ND	ND	ND	ND
PCB170	ND	ND	ND	ND	***(D)***	ND	ND	ND
PCB174	ND	**D**	ND	**D**	***(D)***	ND	ND	ND
PCB180	ND	**D-2X**	**D**	**D-2X**	**D**	ND	ND	ND
PCB183	ND	ND	ND	**D**	ND	ND	ND	***(D)***
PCB187	ND	**D-2X**	ND	**D**	***(D)***	ND	ND	**D**
PCB194	ND	ND	ND	**D**	ND	ND	ND	ND
PCB206	ND	ND	ND	**D**	ND	ND	ND	ND
PCB44	ND	**D**	ND	ND	ND	ND	ND	ND
PCB52	ND	ND	ND	ND	ND	ND	**D**	ND
Pendimethalin	**D-2X**	ND	ND	ND	ND	ND	ND	ND
Pentachloronitrobenzene	ND	**D-2X**	ND	**D-2X**	ND	**D-2X**	**D-2X**	**D-2X**
trans-Chlordane	**D-2X**	**D-5X**	**D-5X**	**D-2X**	**D-2X**	**D-2X**	**D-2X**	**D-2X**
trans-Nonachlor	**D-5X**	**D-5X**	**D-5X**	**D-2X**	**D-5X**	**D-2X**	**D-2X**	**D-2X**
Triclosan	***(D)***	**D-5X**	ND	**D-5X**	**D-2X**	**D**	**D-2X**	**D-2X**
Methoxytriclosan	**D-5X**	**D-5X**	ND	**D-5X**	**D-5X**	**D-5X**	**D-5X**	**D-5X**
Number of Detections								
(D)	**1**	**1**	**1**	**0**	**3**	**0**	**0**	**1**
D	**4**	**4**	**5**	**6**	**2**	**5**	**12**	**8**
D-2X	**7**	**6**	**7**	**18**	**13**	**7**	**6**	**7**
D-5X	**6**	**23**	**4**	**2**	**3**	**1**	**1**	**1**

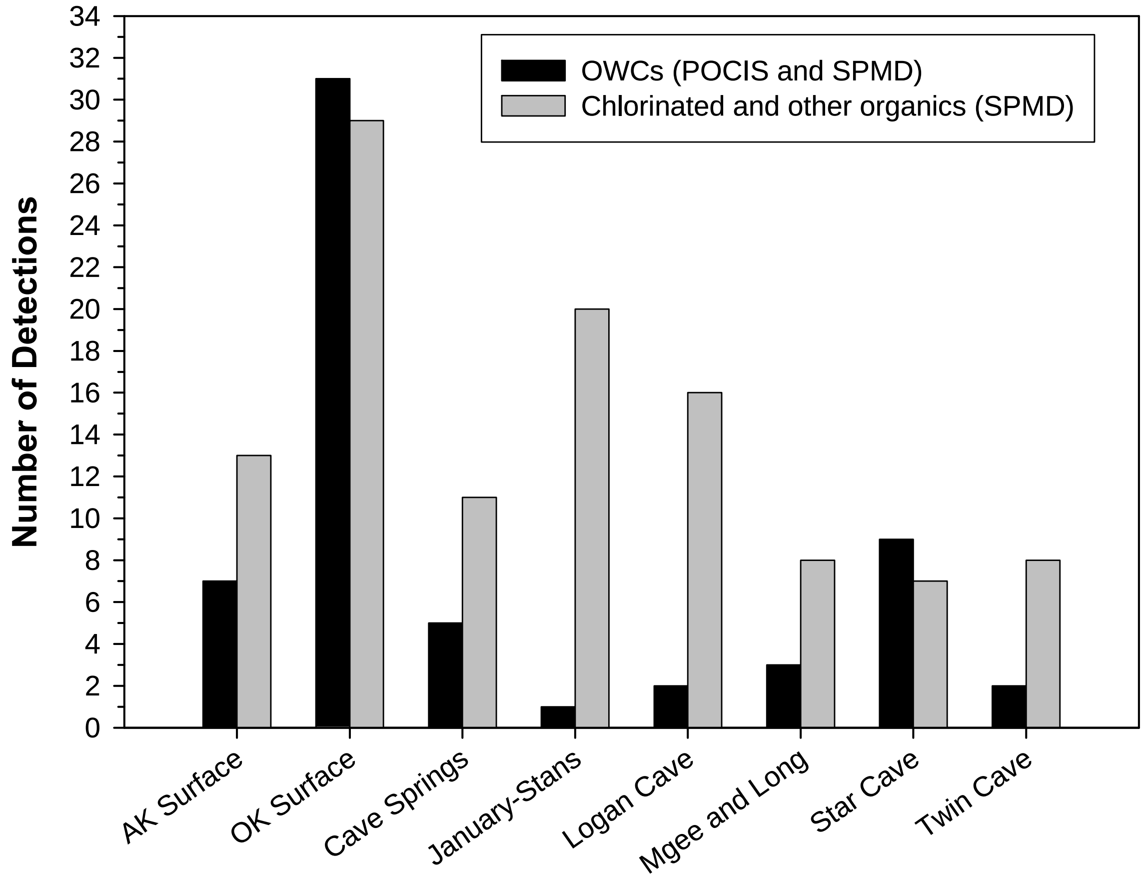

Figure 3. Summary of compound detections in extracts from the POCIS and SPMD samplers. OWCs (including antibiotics) were analyzed in the µg range while the chlorinated and other organics were analyzed in the ηg range using an experimental method that is under development.

Fathead minnow bioassay results: The water chemistry results derived from the fathead minnow bioassays were consistent with the data that were available from the field sampling (Table 5 & Table 10). The hardness of the water from the sites ranged between 76-190 mg/L as $CaCO_3$, and a moderately hard laboratory water (80 -100 mg/L as $CaCO_3$, USEPA 2002) was used as the reference water for the bioassays. For the majority of tests conducted, there were no significant differences between survival and growth of fish in laboratory versus cave water (Table 11). In Test 1 (3 May 2006), survival of fish exposed to water from Cave Springs Cave was reduced, although the difference was not statistically significant from that in the laboratory reference water. A follow-up bioassay with diluted Cave Springs water was conducted (Test 4, 7 June), with no effects observed. Similarly in Test 5 (9 June), a significant reduction in survival of fish exposed to Logan Cave water was observed, but a follow-up bioassay (Test 6, 20 June) indicated no effects. These data may suggest the presence of transitory stressors in the cave water that may be associated with run off events (Cave Springs Cave water was turbid with high flow on the day the sample was collected for Test 1), but consistent chronic effects were not indicated by the limited number of bioassays that were conducted for this study.

Table 10. Water chemistry ranges for all fathead minnow bioassays conducted with the surface and cave water samples.

	AK-Surface	OK-Surface	Cave Springs	January-Stansbury	Logan	Mgee and Long	Star	Twin
pH	6.8-7.1	6.8-7.5	6.4-7.3	6.4-7.3	6.5-7.0	6.7-7.2	6.3-7.0	6.7-7.2
Conductivity (uS/cm)	375-379	472-549	274-357	209-280	272-393	227-303	335-436	343-363
Dissolved Oxygen (mg/L)	8.3-9.0	7.1-7.9	8.0-8.7	8.5-10.0	8.4-9.7	8.0-8.9	8.2-8.3	8.5-8.6
Alkalinity (mg/L $CaCO_3$)	110-124	64-92	110-140	72-120	114-140	102-118	74-106	78-96
Hardness (mg/L $CaCO_3$)	120-146	104-114	120-190	76-116	132-154	106-132	90-156	96-122

Table 11. Results from bioassays with fathead minnows (*Pimephales promelas*) exposed to water from the caves and surface water sites evaluated in the study.

Test 1, Date: 3 May 2006-10 May 2006

Site	% Survival	Av. Dry Biomass (mg)	Range (mg)
Laboratory water	90	0.292	0.232-0.430
Cave Springs Cave	66	0.230	0.192-0.275
January-Stansbury Cave	92	0.277	0.226-0.324
Logan Cave	86	0.297	0.211-0.392
Mgee and Long Cave	90	0.320	0.225-0.476

Test 2, Date: 9 May -16 May 2006.

Site	% Survival	Av. Dry Biomass (mg)	Range (mg)
Laboratory water	100	0.463	0.398-0.559
AK-Surface	98	0.436	0.402-0.483
OK-Surface	94	0.439	0.392-0.490
Star Cave	96	0.460	0.395-0.494
Twin Cave	98	0.466	0.446-0.492

Test 3, Date: 2 June 2006-9 June 2006.

Site	% Survival	Av. Dry Biomass (mg)	Range (mg)
Laboratory water	100	0.291	0.222-0.370
January-Stansbury Cave	100	0.328	0.306-0.351
Mgee and Long Cave	96	0.290	0.249-0.333

Test 4, Date: 7 June 2006-14 June 2006. Results of bioassays with fathead minnows exposed to water from Cave Spring Cave.

Site	% Survival	Av. Dry Biomass (mg)	Range (mg)
Laboratory water	100	0.185	0.163-0.207
32% Cave water	94	0.213	0.198-0.219
42% Cave water	88	0.400	0.187-1.172
56% Cave water	92	0.231	0.176-0.285
75% Cave water	90	0.248	0.186-0.309
100% Cave water	92	0.249	0.226-0.265

Test 5, Date: 9 June 2006-16 June 2006. *- Survival significantly different from that in laboratory water at α=0.05.

Site	% Survival	Av. Dry Biomass (mg)	Range (mg)
Laboratory water	100	0.364	0.337-0.409
Logan Cave	72*	0.337	0.229-0.420
AK Surface	82	0.421	0.315-0.484
OK Surface	88	0.413	0.351-0.470
Twin Cave	86	0.375	0.339-0.410

Table 11. Continued.

Test 6, Date: 20 June 2006-27 June 2006. Results of bioassays with fathead minnows exposed to water from Logan Cave.

Site	% Survival	Av. Dry Biomass (mg)	Range (mg)
Laboratory water	100	0.502	0.388-0.698
12.5% Cave water	100	0.495	0.380-0.643
25% Cave water	100	0.563	0.444-0.720
50% Cave water	100	0.422	0.304-0.523
100% Cave water	100	0.461	0.347-0.559

Test 7, Date: 29 June 2006-6 July 2006.

Site	% Survival	Av. Dry Biomass (mg)	Range (mg)
Laboratory water	96	0.366	0.331-0.391
Star Cave	88	0.425	0.361-0.478
OK Surface	96	0.373	0.139-0.649

Test 8, Date: 2 August 2006-9 August 2006.

Site	% Survival	Av. Dry Biomass (mg)	Range (mg)
Laboratory water	92	0.405	0.274-0.558
Star Cave	96	0.445	0.348-0.523
OK Surface	98	0.474	0.442-0.537

Test 9, Date: 27 October 2006-3 November 2006.

Site	% Survival	Av. Dry Biomass (mg)	Range (mg)
Laboratory water	100	0.518	0.234-0.648
January-Stansbury Cave	92	0.535	0.502-0.580
Logan Cave	90	0.525	0.313-0.646
Mgee and Long Cave	96	0.622	0.497-0.680

Signiicance of Results: Links between land use activities and residues in surface water and cave sites: A key objective in the management of both surface and cave water habitats is to understand the linkage between land use activities and water quality. In this study, a greater number of analytes were measured in the surface waters than in caves which is expected given the potential for aerial deposition and the larger drainage area available to influence surface water quality. As previously mentioned, the higher number of detections at the Oklahoma surface water site was expected given the proximity to a wastewater treatment outfall, and the number of detections is consistent with previous studies that analyzed either water samples or used passive sampling devices to evaluate the presence of OWCs downstream from WWTP outfalls (Galloway et al. 2004; Alvarez et al. 2005). Given the preliminary nature of this study, it is not possible to make any definitive conclusions regarding land use activities and the compounds that were detected in the caves, although some of the results are compelling. For example, antibiotic residues were only found at the OK surface site and Star Cave, the two sites known to have a hydrologic link (Aley 2005). Star Cave also ranked higher than others in the number of organic wastewater contaminants that were detected in the sampler extracts from that site. The presence of the antibacterial compounds triclosan and methoxytriclosan at most of the cave sites may suggest a wastewater influence at these sites as well.

The higher number of chlorinated organic residues that were detected at January-Stansbury, Logan, and to some extent Cave Springs caves is also intriguing. Both Logan and Cave Springs caves occur in drainage areas where there is increasing urban development, but January-Stansbury Cave is in a relatively undeveloped area. One common attribute of these sites is that the sampling canisters were placed relatively close to the cave entrance (versus Star and Twin caves in which a significant penetration of the system was required to reach permanent water). The water at these sites may therefore be more influenced by aerial deposition of dusts that contain these persistent organochlorine residues.

The significance of this study is that it did indicate the presence of a range of organic wastewater contaminants and other organic compounds in water of the caves examined. While the levels of these compounds are quite low (mostly in the 1×10^{-9}g range), their presence in these systems is a concern since so little is known about how contaminants may influence cave stream fauna. Additional studies that further quantify OWC levels in these habitats and investigate links between land use activities and cave water quality are critical to understand the risk these chemicals pose to cave habitats.

Acknowledgement
This study would not have been possible if not for the efforts of a number of individuals who gave their time and input toward project design and deploying the sampling devices. Carol Becker of the USGS Oklahoma Water Science Center was instrumental in the inception of the project and assisting with sampling. Steve Hensley and Richard Stark of the US Fish and Wildlife Service, Tulsa Field Office, arranged access to the caves and also helped with sample collection. Dr. Steven Zaugg of the USGS National Water Quality Laboratory, Denver, Colorado, and Dr. Michael Meyer of the Organic Geochemistry Laboratory, USGS Kansas Water Science Center analyzed the extracts from the passive samplers for the target compounds.

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Notable Achievements and Awards: The notable achievement is the detection of these compounds in the cave water. This establishes the basis/need for additional study of these cave systems.

Student Support: A summary of the number of students, their degree level and discipline supported by the project in the following table:

Student Status	**Number**	**Disciplines**
Undergraduate	1	Zoology
M.S.	1	Zoology
Ph.D.	1	Zoology
Post Doc		
Total	3	

Decision Support System for Long Term Planning of Rural and Urban Water Supply System Costs in Oklahoma

Basic Information

Title:	Decision Support System for Long Term Planning of Rural and Urban Water Supply System Costs in Oklahoma
Project Number:	2006OK64B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	1, 2
Research Category:	Not Applicable
Focus Category:	Water Supply, Management and Planning, Methods
Descriptors:	None
Principal Investigators:	Arthur Stoecker

Publication

Decision Support System for Long Term Planning of Rural and Urban Water Supply Systems Cost in Oklahoma

Final Report

Submitted to:

Oklahoma State University Environmental Institute
United States Geological Survey

Authored by:
Arthur L. Stoecker, Associate Professor
Anna Childers, Ph.D. Student

Oklahoma State University
Department of Agricultural Economics
Stillwater, Oklahoma State University

May 31, 2007

SYNOPSIS

Title: Decision Support System for Long Term Planning of Rural and Urban Water Supply Systems Cost in Oklahoma

Investigators:

Dr. Arthur L. Stoecker, Principal Investigator
Anna Childers, Ph.D. Student, Graduate Research Assistant

Oklahoma State University, Stillwater, OK

Congressional District: Oklahoma, Third.

Descriptors: Rural Water Systems, Decision Support System, Regionalization, Investment Planning

Problem and Research Objectives:

The state of Oklahoma has embarked on a five year process to develop a state water plan. One aspect of the overall plan deals with infrastructure issues where urban areas are rapidly expanding into areas currently served by rural water systems. There are over one thousand Rural Water Districts (RWD) in Oklahoma, serving at least 10,000 rural Oklahoma residents. Oklahoma Water Resources Board (OWRB) permits RWDs based on OWRB guidelines. Oklahoma Department of Environmental Quality (ODEQ) monitors the water quality standards. Most RWDs belong to the Oklahoma Rural Water Association (ORWA) and have their guidelines for operation. The basic economic problem for Oklahoma rural communities is the lack of available funds to absorb the initial capital costs of water systems, and the potential difficulty in covering sustaining costs such as operation and maintenance. Furthermore, there is a potential fear in not being able to meet the projected increasing future demands of water supply with the existing water treatment and/or distribution capacities.

The purpose of this research project is to develop an economic Decision Support System (DSS) to be used as a management and planning tool by regional and local water planners for the sequential expansion, upgrading, and regionalization of drinking water treatment plants at a minimum total discounted future cost. The DSS will aid water resource managers to make cost minimizing investments and provide investment options on existing and future water treatment plants and to evaluate efficient supply, transmission, treatment, staging, and distribution of high quality drinking water to Oklahoma residents. The DSS will provide water managers with information on the optimal number, location, and size of drinking water treatment plants and distribution lines per county/per drinking water source in Oklahoma within existing and predicted future constraints, based on a 50 year planning horizon.

Methodology:

The first step was to meet with managers of RWDs in Northeastern Oklahoma to determine stakeholder interest in long-term planning and the current status of long term plans for each of the RWDs. The methodology has been to develop a working relationship with RWDs in the study area to explore long-term needs.

Several hydrological planning models such as EPANET, KYPIPES, and WaterCAD were evaluated. The WaterCAD program was selected because of its capacity to handle a large number of spatially separated users, graphical user interface, and flexibility in planning purposes. The shape files of the existing pipe line maps for each district were available from the Oklahoma Water Resources Board (OWRB). The data base files associated with the maps were converted to a form useable by WaterCAD so the existing water system could be simulated. Where possible the simulations were checked against known system parameters.

A critical problem faced by RWDs and by the state as a whole is how to serve the urban population that is increasing in areas served by RWDs. Each RWD could develop investment plans to meet this rapidly increasing demand on its own, it could allow the nearby urban city to serve the development, or partner with other RWDs or urban areas to meet expected future demands.

The Oklahoma Department of Commerce made population projections through the year 2060 for each county, delineated by each city in each county and the rest of the county. Water demands for the same geographic distribution were projected through 2030. It quickly became apparent that a method of projecting the location of the "rest of county population growth" more precisely within each county was required if any meaningful assessment of the adequacy of the future needs of local water infrastructure were to be made.

The proposed systems to be included in the DSS system were:

1. ArcView GIS datasets: These data sets include 30 meter land use-land cover data, existing infrastructure including highways, existing waterlines, block census data from 2000 and 1990, census tract information through 2006. The block census data included population, single and multiple family housing units, age of housing, occupation, and commuting time.
2. UrbanSim. This unit was added to test its ability to utilize information in part 1 to predict the probability that a given sub-geographical area would be developed given existing development plans, the development in surrounding areas and access to infrastructure such as highways and schools. The logit regression package within UrbanSim is being tested for ease of use relative to other packages such as SAS. The objective of UrbanSim is to develop alternative spatial distributions of the projected "rest of county population growth".
3. IWR-MAIN. This program is used by groups such as the U.S. Army Corps of Engineers to estimate water demands by geographic area. The spatially,

sectorally, and temporally distributed population data from step 2 will be input into this program. These data include population numbers, income levels, and within-area employment.

4. WaterCAD/WaterGEMS: The first three steps above provide estimates of spatial temporal water demands. The WaterCAD/WaterGEMS hydraulic simulation program is then used to assess the adequacy of the existing water system infrastructure (supply sources, treatment facilities, pipelines, and pumping systems to meet the spatially and temporally distributed water demands.

The project is not finished at the time of this report but the work is being continued under other funding. It is anticipated the major portion of the dissertation research will be completed December 2007.

Publications:

Conference Presentations:

Childers, A.:

OWRRI Oklahoma Water Conference 2007, Oklahoma City, October 2006. Poster presentation: “Planning for Rural Water Systems to Meet Future Drinking Water Demands in Oklahoma.”

USDA-CSREES National Water Conference, Savannah, GA, February 2007. Poster presentation: “Planning for Rural Water Systems to Meet Future Drinking Water Demands in Oklahoma.”

OSU Graduate Research Symposium, Oklahoma State University, February, 2007. Paper presentation: “Planning for Rural Water Systems to Meet Future Drinking Water Demands in Oklahoma.”

Winner of Environmental Science Program’s Outstanding Research Student Award, March 2007.
Winner of the OSU Women’s Faculty Council-2007 Award for an Outstanding Research Project, March 2007.

Students Supported By Project:

Type	Number	Discipline
Undergraduate	1	Agricultural Economics
Masters	1	Environmental Science
Ph.D.	1	Environmental Science
PostDoc	0	
Total	3	

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Acknowledgements

We would like to thank Oklahoma State University's Oklahoma Water Resources Research Institute (OWRRI) for their funding of this project in 2006-2007. We are also thankful for various individuals in Federal, State, and local agencies. Without their help, ideas, and resources, the initiation and completion of this project would have not been possible. We specifically would like to thank Mr. Gene Whatley and Mr. Jerry Gammill of Oklahoma Rural Water Association (RWA) who "led" us toward the topic of this project. We would like to thank Mr. Mike Langston of OSU/OWRRI for providing his knowledge of the professionals in the field of water planning and management, and introducing us to those water planners in Oklahoma Water Resources (OWRB) and RWA. Mr. Mike Mathis of C.H. Guernsey (with OWRB until October 2006) and Ms. Terry Sparks of OWRB have been very generous of their time and sharing their vast experience in Oklahoma's water issues. Dr. Ed Rossman and Ms. Liz Beshaw of the U.S. Army Corps of Engineers (USACE), Tulsa District, have given their time and resources within USACE to benefit this project tremendously. Their generosity to provide Anna Childers access to learn and utilize IWR-MAIN software in their district office in Tulsa to forecast water demands is immeasurable. Several individuals deserve our thanks in assisting with data collection, specifically: Dr. Kit Wagner with the Atmospheric Information Systems in Norman, Mr. Gaylon Pinc, until 2007 with Indian Nations Council of Governments (INCOG), Tulsa, Mr. Arvil Morgan, Rural Water District (RWD) 5 and Mr. Bill Giles, RWD 4 in Wagoner County, and Mr. Rick Stull, RWD 3 and Mr. Steve Dunavant, RWD 5 in Rogers County.

1.0 Introduction

1.1 Scope of the Project

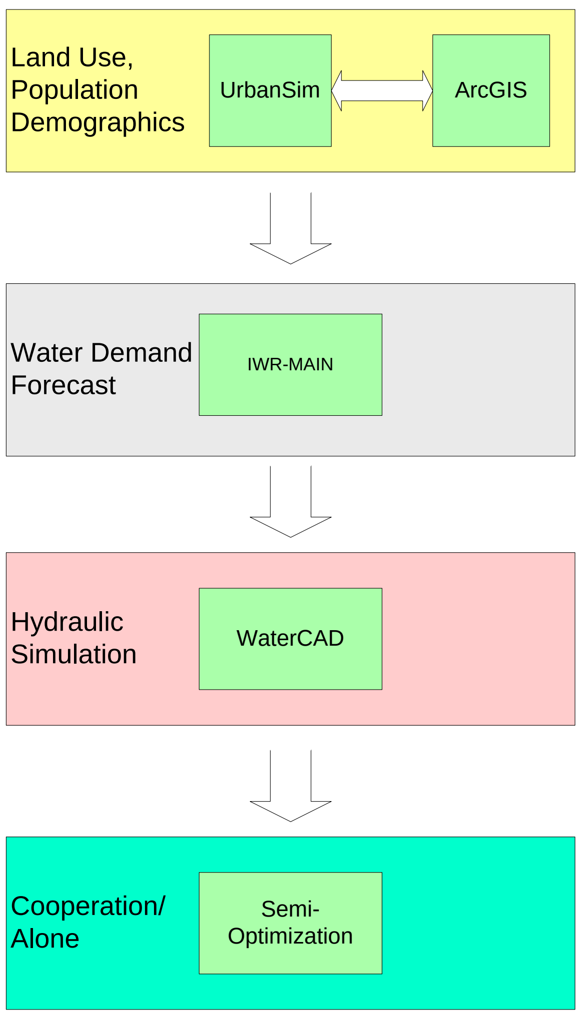
The general objective of this project is to demonstrate a method to develop a Decision Support System (DSS) to addresses how to optimally (least cost) meet the increasing demands of drinking water in selected areas, and thus the anticipated water supply infrastructural needs of small (rural) water systems. This project takes a demonstration approach to facilitate planning for future infrastructural needs of small drinking water systems in Northeastern Oklahoma. In particular, the planning process aims to provide sufficient and accurate information about the sequence of the events that triggers increased disaggregated drinking water demands which in turn trigger performance requirements on the existing water infrastructures of small water systems. In this study, the planning approach is done in four separate stages by incorporating data into four different software applications. The end-goal of the planning process is an economic performance evaluation of the four small water systems in Wagoner and Rogers Counties under the increased infrastructure needs. Based on those results, a decision-maker can further investigate the feasibility of structural regionalization of two or more small water systems to meet the increased demands together. We demonstrate how the end-goal of the planning is achieved by taking multiple intermediate steps that produce crucial data that feed into the further stages of the future drinking water infrastructure planning process.

Much of wording and ideas of this project came from the future Ph.D. dissertation of Anna Childers, who worked as a graduate student in this project. The final DSS model and the application of it are being utilized in Ms. Childers' Ph.D. dissertation at Oklahoma State University, Environmental Science Graduate Program, Stillwater, OK. The preliminary results of the DSS model will be available in the fall of 2007.

The capital stock of a drinking water system can be divided into four principal components: source water, treatment, storage, and transmission and distribution. In this project we use interchangeably the concepts of "water infrastructure" and "water systems". Both of these concepts include the four principal components. DSS are intended to help decision makers to use models to identify and solve problems, complete decision process tasks, and make decisions. DSS are a general term for any computer application that assists a person or group's ability to make decisions. In general, DSS are a class of computerized information system that supports decision-making activities. There is variety of DSS classes depending on the purpose of the DSS. In this project the focus is on the assembly of a model driven DSS. This type of DSS emphasizes manipulation of a model. Depending on the complexity of the problem setting and situation in question, a model driven DSS can become fairly data-intensive.

In this project we will demonstrate how DSS structure can be assembled, and what software applications and data can be incorporated. The assembly of the DSS of this project incorporates three major components: 1) water demand forecast model incorporating land-use development; 2) hydraulic model for simulation experiment, and; 3) economic model for semi-optimization. The water demand forecast model includes multiple data entries including identification of the fastest growing areas and the projections of future drinking water demands based on population growth, population densities, land-use profiles, and probability of land-development. The hydraulic simulation model includes water system simulations under different growth scenarios and the associated cost estimates. The economic model is a semi-optimization of potential cooperative arrangements of two water systems. The end-result of this project is a demonstration model that presents how to assemble a holistic model that incorporates population demographics and land-development, hydraulic simulations and economic feasibilities of cooperative solutions of water distribution.

Figure 1-1: Flow Chart



1.2 Structure of this Report

This project is divided into nine sections. The structure of this project is as follows. In section one, we describe the reasoning to undertake the study. We look at the different components that constitute the relevance of this study and evaluate what has been done before. In section two, we will first address the components that are the triggers behind water demand analysis, including the analysis of population demographics and land-use of the planning area. This is an important intermediate step in understanding these explanatory variables and their impact on water demands, as it further aids in selecting forecast models and selection of forecast variables of land-use in the study area. In section three, we will introduce the methods of water use forecasting and make a selection to forecast water demands in spatial, sectoral, and temporal manners in IWR-MAIN software. Section four is a detailed presentation of the elements involved in disaggregated water demand forecasting, wherein we demonstrate the interconnection of the three different software applications that are needed to yield water demand forecasts, which are later input into the hydraulic simulation model. The selection of model parameters for IWR-MAIN and UrbanSim are explained in detail. Section five explains the procedural steps to the planning area's water use forecasting. In section six we input water demand forecast variables into WaterGEMS software. Section seven discusses physical consolidation of water infrastructures and the economic theories behind it. Section eight summarizes conclusions the benefits of the proposed DSS. Section nine presents the caveats and recommendations for the future research.

1.3 Justification of the Study

When water systems infrastructure fails, communities look for financing to repair, upgrade or replace it. If the communities are unable to fund the infrastructure projects themselves they will seek financial assistance in the form of grants and loans from state and federal agencies. Many times the state and federal loans and grants are not sufficient and the resultant wait can be several years. Without funding to fill the financing gap, end-users of water may face increased monthly water bills. The prevailing approach in water infrastructure planning is water supply infrastructure assessment. The infrastructure assessment approach identifies the state of the existing infrastructure in water systems, but it falls short in projecting the needs for infrastructure replacement and expansion under specified conditions. The existing water system infrastructure research highlights the “gaps” in water systems infrastructures where the results are based on questionnaires completed by water system operators. This approach works for current assessment of water infrastructure needs. However, projection of infrastructure needs is a complex undertaking that requires an understanding all the impacting variables impacting water demand and their potential influence on water distribution infrastructure. Thus, the projections require exhaustive data and simulations.

When the Safe Drinking Water Act (SDWA) was passed in 1974, many in U.S. Congress had anticipated that many small systems (serving less than 3,300 persons) would consolidate and form more cost-effective regional systems. However, the number of small systems has continued to increase. The U.S. Congress recognized the infrastructure problems facing small water systems in the mid-1980s, and in 1987 authorized the U.S. Environmental Protection Agency (EPA) to provide greater technical assistance to small public water systems to help them meet the federal drinking water requirements. Since its enactment, the Clean Water State Revolving Fund (CWSRF) has provided states with a continuous source of funding to address water projects. Similarly, in 1996, the Congress created the Drinking Water State Revolving Fund (DWSRF) to provide States funding to support sustainability in drinking water infrastructure. Combined, the two programs represent EPA's largest single program accounting for half of the EPA's assistance award funds. States must provide matching funds equal to twenty percent of the grants. States can also loan additional funds to communities to finance water projects. EPA estimates that by 2020 there will be $263 billion funding gap in water infrastructure (total of capital and operations and management) using the current level of investment.[1]

The U.S. Conference of Mayors' Urban Water Council (UWC) conducted a survey of 414 principal cities (population 30,000 or greater) to examine water resources priorities. The study was conducted in 2005 and the respondents were asked to evaluate water resources capital investment needs during the past five years (2000-2004) and predict the next five years (2005-2009). Three priorities were identified by the respondents: first, chronic "every-day" problems; second, the potential of catastrophic events, and; third, concerns of water supplies. The chronic "every-day" problems included priority of

[1] EPA's Local Government Advisory Committee (LGAC) DVD released March 30th, 2007.

aging infrastructure, identified by over sixty percent of the respondents.[2] The water distribution system infrastructure category had the highest actual and planned investment needs across all three city classes (small, medium and large). According to the survey, small cities (population less than 50,000) were less likely to invest on future water infrastructure (all infrastructure categories) than the large ones (population greater than 100,000). However, a larger percentage of small cities (over 40 percent) prioritized the aging infrastructure needs compared to the large cities (26 percent). The survey also looked at how the cities have financed and intended to finance the capital improvements of water systems. In both cases, over 50 percent of respondents relied or intended to rely on a single source of financing for their major capital investments in water infrastructure, and over 20 percent of those identified the type of financing as “other”. This category of financing includes capital reserves from user charges, increased user rates, and transfers from general funds. These are generally referred to as “pay-as-you–go” approaches of financing. State revolving funds (SRF) were identified 38 percent of the time as a source for financing capital improvement projects in water infrastructure. SRF loan programs appeared to be a more important source of financing for smaller cities than larger ones.

Condition and status of community infrastructure, especially drinking water infrastructure, has gained national, regional and local attention for years. Despite the attention and need for recognition, no regional, state, or federal source collects or maintains information on the status or scale of these infrastructure needs. Although, the 1999 EPA’s report addressed the community water system needs, there is no study

[2] U.S. Conference of Mayors’ Urban Water Council (UWC), National City Water Survey 2005, Washington, DC.

available that directly addresses the capital make-up of drinking water systems.[3] Despite the federal, state, and municipal efforts to address the infrastructure needs, the current level of information of the future infrastructural and investment needs of rural water systems in Oklahoma is unclear to the state's water planners. Many of the water supply infrastructure concerns have concentrated on the needs of the very smallest systems (serving less than 3,300 persons). The infrastructure concerns cannot be linked too tightly to the current size of water systems, but should be expanded to include systems that are experiencing growth now or are projected to experience growth in the adjacent areas. The quality and deterioration of the system infrastructure components are not the only areas of concern, but also the future infrastructure expansion needs. In order to address that concern, one needs to be able to extrapolate where this expansion is going to take place and when. By knowing the future demand increases of an area, local planners and water system managers can start identifying the water system expansion needs, budget for the capital and O&M needs, and thereby, apply for appropriate funding on time. By a proactively planning water infrastructure needs, the water planners can avoid management by crisis.

Drinking water infrastructure needs are local and are, thus best understood by local water planners. EPA conducts Drinking Water Infrastructure Needs Survey and Assessment (DWINSA or Assessment) every four years for the purposes of DWSRF as mandated by SDWA. The Assessment develops a cost model which is compiled from cost data submitted by different size systems nation-wide and from modeled costs as calculated by EPA. The sets of data items collected in the Assessment to model the

[3] U.S. Environmental Protection Agency (EPA), 1999, Drinking Water Infrastructure Needs Survey. Office of Water: Washington, DC.

cost of infrastructure are the same data items that need to be collected in this DSS to model the infrastructure needs in the planning area. Thus, the Assessment is an important guide for identifying project components. However, the infrastructure components must be localized and calibrated to respond to future infrastructure needs so that cost estimating is accurate.

A planning approach assessing how to project water supply infrastructure needs of rural water systems in Northeastern Oklahoma, and the costs associated with different supply system scenarios, has not been previously addressed in a comprehensive study. Most studies in the field of water infrastructure assessment in Northeastern Oklahoma have either an engineering or a water demand emphasis. These two have not been combined in a holistic model that also addresses the concept of structural consolidation of water systems. More technologically advanced and wealthier rural water systems have hydraulic studies of their systems, but these studies have not incorporated sophisticated water demand projections of the area. Nor is there a uniform methodology or standard on how these single system based-studies were done. Nor is there a system in place in Oklahoma to advance this engineering focused information to the state's planning agents.

This project is limited to four rural water systems in Northeastern Oklahoma in Wagoner and Rogers Counties. The problem statement and the methods are limited to those specific systems in this area. The water use evaluated is residential and non-residential surface water but does not include water uses for agriculture or mining. Population projection factors and hence water demand factors vary within the region. Costs are dependent on the location and always need to be normalized using a location factor. Similarly, cost of water treatment varies greatly depending on the source water quality, the treatment plants configuration, and local conditions. Furthermore, the cost estimates need to be adjusted to the time period in question.

2.0 Spatial, Sectoral, and Temporal Drinking Water Demands

Rural water systems adjacent to growing urban areas in Northeastern Oklahoma, in Wagoner and Rogers Counties, are expected to face challenges in the future concerning the optimal management of their water supplies, treatment as well as the optimal rate of construction of new distribution systems. As Figures 2-1 and 2-2 illustrate, these rural water systems will experience increased drinking water demands and changing water demand profiles due to urban/rural interface caused by actual population growth, annexation, and housing and commercial developments in the adjacent rural water service areas.

An important element in the accuracy of water distribution simulations is the accuracy of the associated water demand estimates and projections. Temporal, sectoral, and spatial characteristics of drinking water demands and allocations are dependent on a wide range of explanatory variables describing the demographic, cultural, economic, and legal structures of the community, as well environmental conditions such as temperature and precipitation. The steady increases in population and expansive land-use plans translate into increased drinking water demands. Increased demands translate into performance requirements on existing drinking water treatment, storage and distribution infrastructures, and demands of future water supplies. The past studies have projected future drinking water demands based on county-wide flat data. Total county projections give a good estimate for the total volume of drinking water demands, but they are not spatially distributed (disaggregated) to small areas. Cross-sectional forecasts do not necessarily give a true representation of a small area, as small area forecasts cannot be aggregated to cross-sectional elements. Small area population forecasts and land-use plans focus on areas that are smaller than a county, generally the size of a city, census tract or group, or traffic analysis zone. Therefore, it is important to specify the model to incorporate small-scale spatially distributed disaggregated population projections and land-use plans in order to provide more defined needs for water system expansions and additions to the water infrastructure.

In order to model the relationships among water demand growths and required water infrastructure needs, the elements contributing to the water demands need to be evaluated. The water demands need to be coupled with land-use forecasting and population demographics. Also, explanatory variables need to be assessed in both residential and non-residential water demand projections.

To accomplish these objectives, we need to develop methodologies to disaggregate water demands and forecast those disaggregated demands into the future. Thus, the first task in planning process is to select and forecast the set of explanatory variables that impact water demands. The two broad categories of water demand forecasting are population demographics and land-use. Population demographics are projected by the Oklahoma Department of Commerce (ODC) up to 2030. However, land-use choices and development potentials have not been previously projected to the planning area. The results of the simulation and forecasting of land-use feed directly into IWR-MAIN water demand forecasting software and the projection of explanatory variables of water demand within the Forecast Manager of IWR-MAIN.

The data for spatial, sectoral, and temporal water use forecasting comes from many sources. The base line conditions for water use are fairly straightforward even in a disaggregated studies, but establishing forecast values in a disaggregated manner is more demanding.

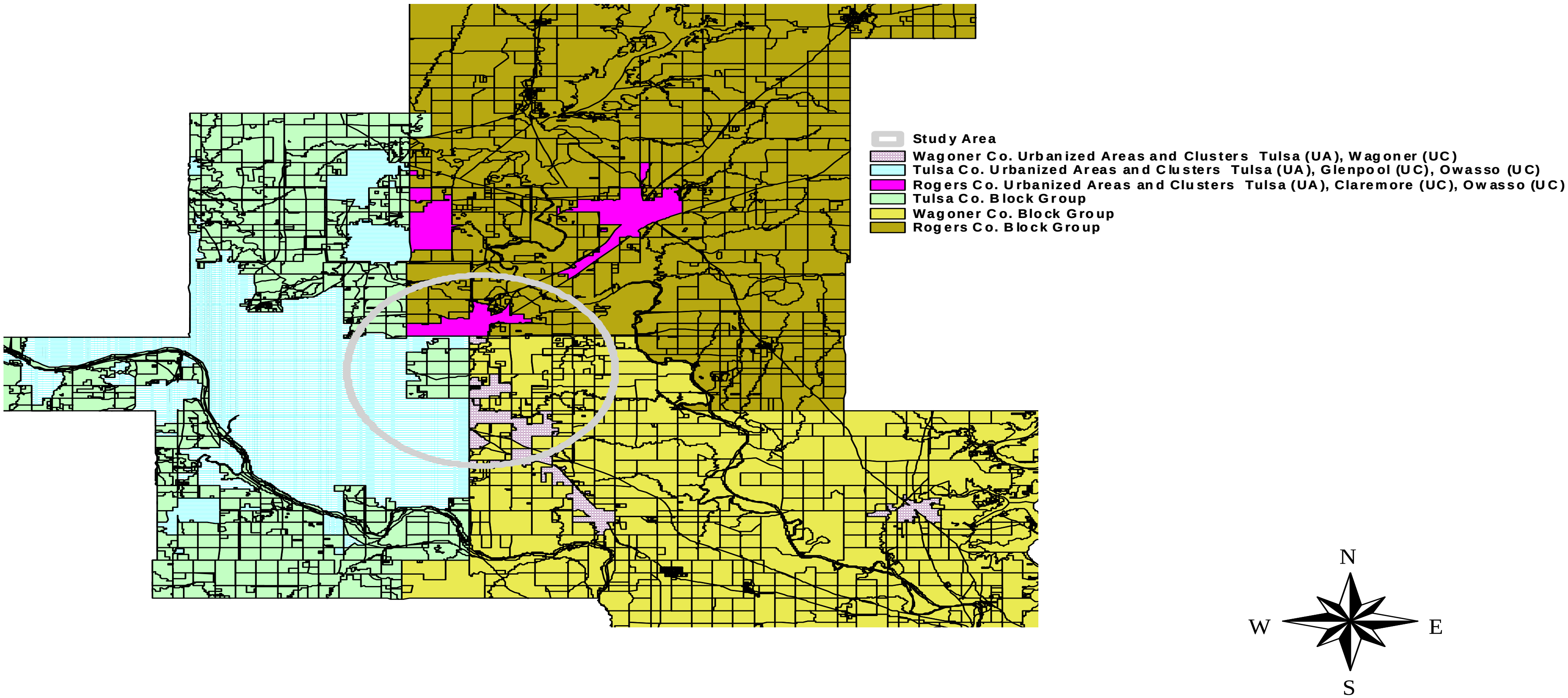


Figure 2-1: Planning Area Representing Urbanized Areas and Urban Clusters in Wagoner, Rogers, and Tulsa Counties in Northeastern Oklahoma

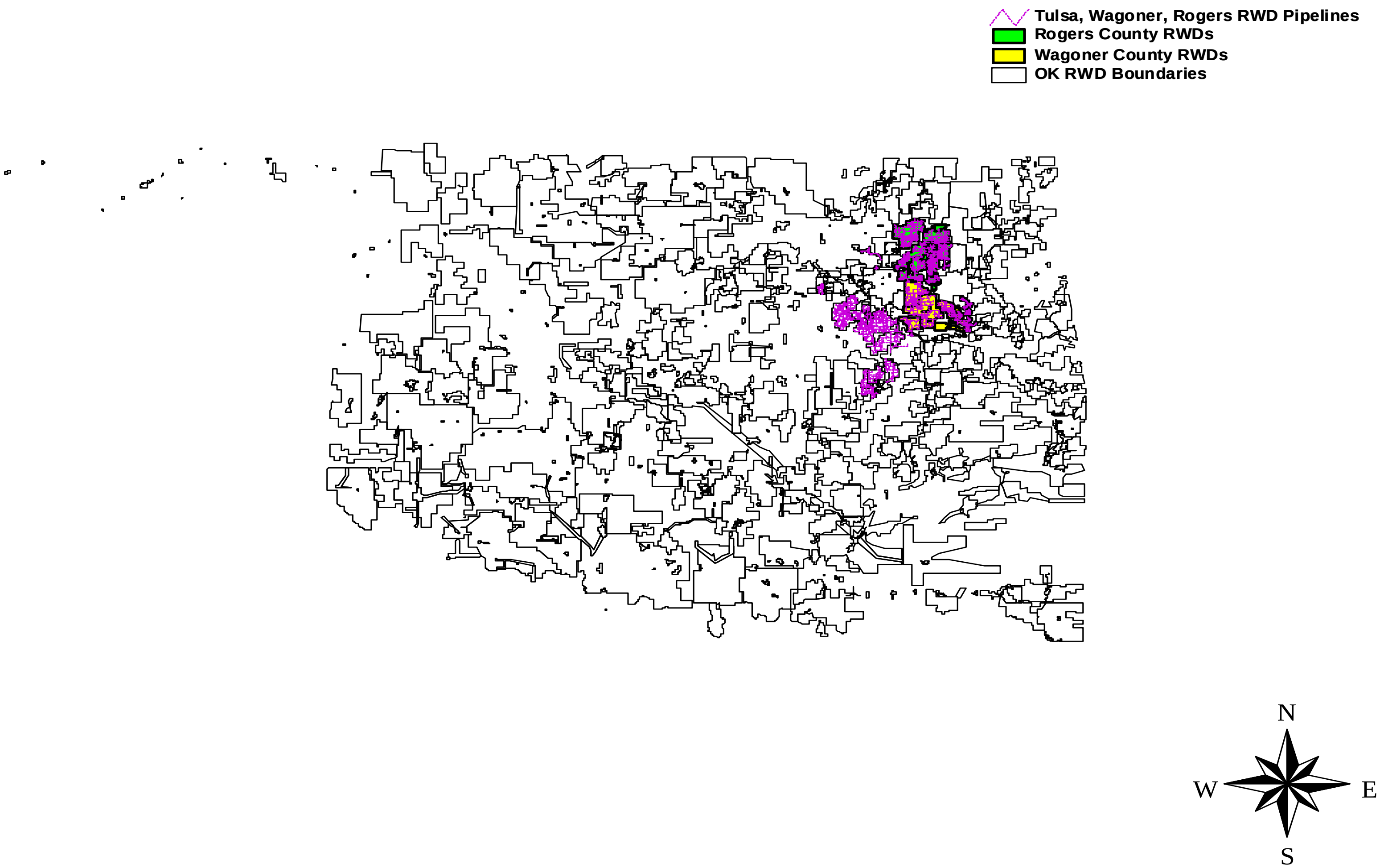


Figure 2-2: Planning Area Representing Oklahoma's' RWD Boundaries, Wagoner and Rogers County RWD Boundaries and Pipelines

2.1 Population Demographics

The population in those parts of Wagoner and Rogers Counties that are closest to urban areas (i.e. Tulsa, Broken Arrow, and Owasso) is projected to increase by more than 50 percent between 2007 and 2030. The national data generally indicate that many rural areas suffered significant economic and population declines in the 1970s and 1980s, while Wagoner and Rogers Counties experienced rapid growth in the 1990s. This national population growth pattern is somewhat different for Wagoner and Rogers Counties due to the fact that those numbers are applicable to rural farm people, and not to rural non-farm people. According to historical censuses, there was no population decline in Wagoner and Rogers Counties in the 1970s. To the contrary, there was an average annual population increase between 1970 and 1980 of 6.6 percent in Wagoner County and 5 percent in Rogers County. There was a population growth slow-down in the 1980s in the two counties, as the annual average increases in the 1980s were only 1.4 percent and 1.8 percent respectively. In the 1990s these rural county areas continued to grow with an annual average growth of 1.8 percent in Wagoner County and 2.8 percent in Rogers County. However, closer examination of the 1990 U.S. Census sub-county or census tract population (1990-1999) for these counties reveals that the population growth occurred in concentrated pockets in the cities and in the areas. The highest growth occurred in places such as Bixby and Broken Arrow (Wagoner and Tulsa Counties), Coweta (Wagoner County), Owasso (Rogers and Tulsa Counties), and Catoosa and Claremore (Rogers County). The same trend is observable in 2000-2006 estimates. The city of Bixby experienced 6.6 percent annual average population increase, Broken Arrow 1.4 percent, Coweta 2 percent, Owasso 4.8 percent, Catoosa 3.6 percent, and Claremore 1.5 percent. Throughout the 1970s, 1980s and 1990s, all of Tulsa County was experiencing an average of one percent annual population growth indicating that the “bedroom” communities have been more attractive as well as more available for development purposes. The 2000-2005 estimates indicated negative population growth in the city of Tulsa. However, the county of Tulsa experienced an average annual growth of 3.3 percent during the same time period. The biggest contributors for the county wide population increase were non-metropolitan cities within the Tulsa County: Bixby, Broken Arrow, and Owasso. According to 2000-2005 Census data, Rogers County was the fastest growing county in Oklahoma; it grew by 16.7 percent from April 2000 to July 2006.

2.2 Land-Use

Oklahoma Department of Commerce (ODOC) made population projections for Oklahoma Water Resources Board (OWRB) through 2030. The projections are for the entire county, cities in each county, and the rest of the county. In order to utilize these projections in this study, they need to be assigned in part to the planning area in question. Population growth and land-development affect where and how people live. Also, land-development determines where businesses will locate. Therefore, probability of land-development must be estimated. The term "land-development" refers to the conversion of land for the purposes of residential, commercial, industrial, or other activities. Land-development can be described by the amount of land by type of use in an area, as well as the characteristics of the development (e.g. residential density). Typical land-use types adopted in this study are low- and high-density residential, commercial, light and heavy industrial, parks and open areas, public areas (schools, hospitals, and government buildings), lots, and transportation areas. Land-development has an intermediate impact that results in a variety of other impacts on the physical environment such as an increased drinking water demand.

Seven primary factors drive the probability of land development:

1) Land use policies, such as zoning codes and taxation regulations, which may provide incentives or constraints for different types of development.
2) Accessibility, which is determined by the characteristics and performance of transportation system, in conjunction with the spatial patterns of existing development in the area, such as existing highways and roads, and areas connected with bridges.
3) Ownership of land, primarily referring to the Native American lands.
4) Physical characteristics of the area, such as topography, soils, and natural features, which can provide incentives or constraints for different types of development.
5) Economic forces.
6) The presence of institutional groups, such as military bases, hospitals, or prisons.
7) Proximity to existing development, such as urban areas.

There are many methods for forecasting land development. However, safe generalizations can be made about future trends in land development. These trend indicators can be derived from changes in median house sizes and desired living locations over a period of time. The national trend shows that median house size has increased from 1,525 square feet to 2,227 square feet from 1973 to 2000.[4] According to the 2004 survey by the National Association of Realtors and Smart Growth America, 13 percent of Americans want to live in a city, 51 percent in a suburb, and 35 percent in a rural community.[5] The Survey data indicate that even historic cities such as Boston, San Francisco and Minneapolis are losing population. The primary reasons for the exodus to suburban areas are the affordability of land and the freedom to build larger homes. Ninety percent of the U.S. metropolitan growth has occurred in suburbs since the 1950s. The 2004 Survey proves that the population growth is in the fringes of the cities.

An area's geographic context has a significant effect on its development. Economic opportunities accrue to an area by virtue of population size, physical size and access to larger economies. In 2003, the U.S. Office of Budget and Management (OBM) released the Census 2000 version of metropolitan (metro) and nonmetropolitan (nonmetro) areas, new classification system often used to define urban and rural America. The metro counties are defined for all urbanized areas regardless of total area population. They are distinguished by the population size of the Metropolitan Statistical Area of which they are part. The 2003 OBM classification subdivided previously undifferentiated nonmetro territory into two distinct types of geographical entities:

[4] U.S. Census Bureau, 2000, U.S. Department of Commerce, Economics and Statistics Administration.

[5] National Community Preference Survey Conducted for Smart Growth America and National Association for Realtors, 2004.

Micropolitan (micro) and noncore. The micropolitan areas can also be called edge cities, galactic cities, or technoburbs. These places are largely self-contained, with many jobs for local residents, most of whom would not have to commute long distances. Micropolitans sit outside of the metropolitan areas. The OBM used the following definition of micropolitans: "At least one urban cluster of at least 10,000 but less than 50,000 in population."[6] While micropolitans lack a large central city of over 50,000 residents, they often contain central cities akin to modest-sized towns, according to census analysis of 567 micropolitans in the continental U.S. published by Robert Lang and Dawn Dhavale.[7]

The above definitions of micropolitans do not fit directly to the planning area of this project. This is due to the facts that when looking at the weighted averages of time to commute to work and population estimates, the areas in this study currently act as bed-room communities to the larger metropolitan areas. Also, according to the 2003 OBM definition, metropolitan areas are: 1) Central counties with one or more urbanized areas, and 2) outlying counties that are economically tied to the core counties as measured by commuting to work. Therefore, these areas in the study are metropolitan areas and more specifically can be called exurbs - suburbs at the fringes of metropolitan areas. According to the National Brookings 2006 Report, exurbs are communities located on the urban fringe that have at least 20 percent of their workers commuting to jobs in an urbanized area, exhibit low housing density, and have relatively high population

[6] OBM BULLETIN NO. 03-04, June 6, 2003.
[7] Lang, Robert and Dawn Dhavale, 2004, Micro-Politan America: A Brand New Geography. Metropolitan Institute at Virginia Tech Census Note 05:01.

growth.[8] People living in exurbs tend to commute to the core city. Exurbs are a subset of the suburbs, but are still part of the metropolitan community and economy. They are located on the furthest ring of a metropolitan area, are mostly residential, and the residents commute to work to metropolitan areas. According to Census data and the Urban Land Institute, these areas are growing faster than any other kind of community.[9] Exurbs are experiencing growth to which they are not accustomed, and thus do not have the infrastructure or experience to deal with the growth. The National Brookings Report ranks Oklahoma 16th nationally with 8.9 percent of the total population being exurban. According to the same study, Tulsa Metropolitan Area (MA) ranks 13th nationally with 16.9 percent of the total population being exurban and Oklahoma City MA ranks 17th with 14.8 percent of total population being exurban. There are six counties that contribute to Tulsa MA rankings: Rogers, Wagoner, Okmulgee, Osage, Creek, and Pawnee. Rogers County's total population is 69 percent exurban; the percentage for Wagoner County is 35 percent. The increase in five year period (2000-2005) was 13.1 percent for Rogers County, and 11.2 percent for Wagoner County.

The planning approach to meet the increased drinking water demands in exurbia must be viable in that the small system costs are reduced. The trickle-down benefits of implementing a viable economic plan to small and medium systems can be experienced at many levels. First, the end-users benefit from economic feasibility of water systems in a form of a cheaper price for drinking water. Second, the system itself as well as

[8] The Brookings Institution Report, 2006, Prepared by Alan Berube, Audrey Singer, Jill H. Wilson, and William H. Frey. Finding Exurbia: America's Fast-Growing Communities at the Metropolitan Fringe. Living Cities Census Series.

[9] Urban Land Institute (ULI) Report/Joseph Z Canizaro Public Officials' Forum, 2004, Smart Growth in the Fringe, Prepared by Victoria R. Wilbur.

surrounding systems within the distribution area can adjust their plans based on the anticipated future infrastructural needs caused by increased demands.

3.0 Forecasting Water Use

The needs for water use forecasts are many depending on the water planning approach. In general they can be divided into short- and long-term planning approaches. Short-term planning involves usually seasonal demand forecasting, whereas long-term planning can involve many aspects of water demand forecasting. Long-term water demand forecast models can be utilized in evaluating water quality and quantity available in the future. They can also be utilized for financial planning purposes. Long-term forecasting deals with population growth, household compositions, land-development, conservation patterns, and housing mix patterns. In this study we take a long-term planning approach of forecasting water demands spatially, sectorally, and temporally in a small segment of an area so that the future financial needs of infrastructural expansion and updates of water distribution can be identified for specific systems.

3.1 Methods of Forecasting Water Use

There are many methods of forecasting water demand (Pradham, 2003, Bauman et al., 1997). Most methods have evolved from extrapolating the past water use to including more complex explanatory variables. Some simpler versions of water demand forecast models have been used due to lack of access to more complex computerized models and inability to handle large quantities of data. Hence, for example, a multivariate coefficient demand model has been used by some modelers.

3.1.1 Time Extrapolation

Time extrapolation method's basic assumption is that the water usage in the future is explained by the past trends. The past observations of water use are fitted to a smooth curve mathematically. This method is highly subjective and more applicable to aggregate (versus disaggregate) water consumption forecasting. Also, the time extrapolation method is very limited in forecasting since time is the only explanatory variable.

3.1.2 Bivariate Models

In bivariate methods of forecasting water use, a single explanatory variable is used, which usually is population. This method is also known as per capita method. A water use forecasting in a linear form can be written as:

$$Q = a + b \cdot X \qquad (1)$$

Where:

Q = water use per unit of time

X = explanatory variable

a, b = coefficients

A multivariate model can be applied to disaggregated water use forecasting, however, the use of explanatory variables is limited to one: population. The same shortcoming is in an extension of bivariate method, per capita method of water use forecasting where the only explanatory variable is the population:

$$Q = b \cdot P \qquad (2)$$

Where:

Q = average daily total water use

P = population in service area

b = per capita water use

Bivariate methods of water use forecasting are simple because they require a limited number of data: water use and population. The assumption of population correlating with water use may hold true with residential water use, but that assumption cannot be extended to non-residential water-use. Non-residential water use consists of various different types of sectors that correspond to different set of explanatory variables that need to be built into the model.

3.1.3 Multivariate Models

Multivariate methods of water use forecasting are utilized in today's water use forecasting models. These models are more robust because they incorporate several explanatory variables of water use. Residential and non-residential water demand is a complex function of socio-economic characteristics, climatic factors and public water policies and strategies. When different explanatory variables affect the water use of different sectors differently, the relationship is additive and the model can take the form of:

$$Q = a + b_1 \cdot X_1 + b_2 \cdot X_2 + ... + b_n \cdot X_n \qquad (3)$$

Where:

Q = water use

X_1 = explanatory variable *i*

a,b₁, b₂, ...bₙ, = coefficients

When several of the explanatory variables explain the same kind of water use, the lnlog form of equation (3) in log–linear form can be written as:

$$Q = \alpha \cdot X_1^{\beta} \cdot X_2^{\gamma} \cdot X_n^{\delta} ... \qquad (4)$$

Where: $\alpha, \beta, \gamma, \delta$ = coefficients

The main disadvantage of this approach of multivariate form of modeling water demand is that the model tends to highlight the correlation of explanatory variables into water demand rather than the causation.

3.1.4 Disaggregated Water Demand Models

An extension of a multivariate model is an econometric approach which considers a variety of parameters to forecast and manage sectoral (residential and non-residential), spatial and temporal water demands. An example of an econometric water demand model is a propriatery IWR-MAIN (Institute for Water Resources – Municipal and Industrial Needs) Water Demand Analysis Software. The original version of the model was developed by Hittman and Associates, Inc. (1969). Later, the U.S. Army Corps of Engineers (USACE) obtained the model and improved many of its features. Today, the software is owned by Planning and Management Consultants, Ltd. (PMCL).

4.0 Spatial, Sectoral, and Temporal Water Demand Forecasting

This section provides an overview of the methods needed to obtain water demand forecast for the desired planning area. Disaggregated water demand projections are crucial for providing valid inputs for water system infrastructure analysis. The modeler needs to make a decision how to disaggregate the data. Most water demand data is tabulated at the county level and it needs to be disaggregated to correspond the planning area geography. Water demand analysis is not an exact science but more of an interpretive one, as a complex set of explanatory variables affects water use. Depending on the model preferences, and the set of explanatory variables and their projection, the output of a forecast can vary greatly. In this project we expand the traditional approach of keeping the set of explanatory variables constant, by incorporating innovative methods of forecasting and scenario-modeling of the required explanatory variables.

The figure 4-1 on the following page (p.26) illustrates the approach that we recommend in disaggregated water demand forecasting. It requires the use of three different software applications to forecast or create scenarios for water demand. The use of the three softwares will yield outputs that provide input data for the next stage. (More of the procedural stages are discussed in Section 5).

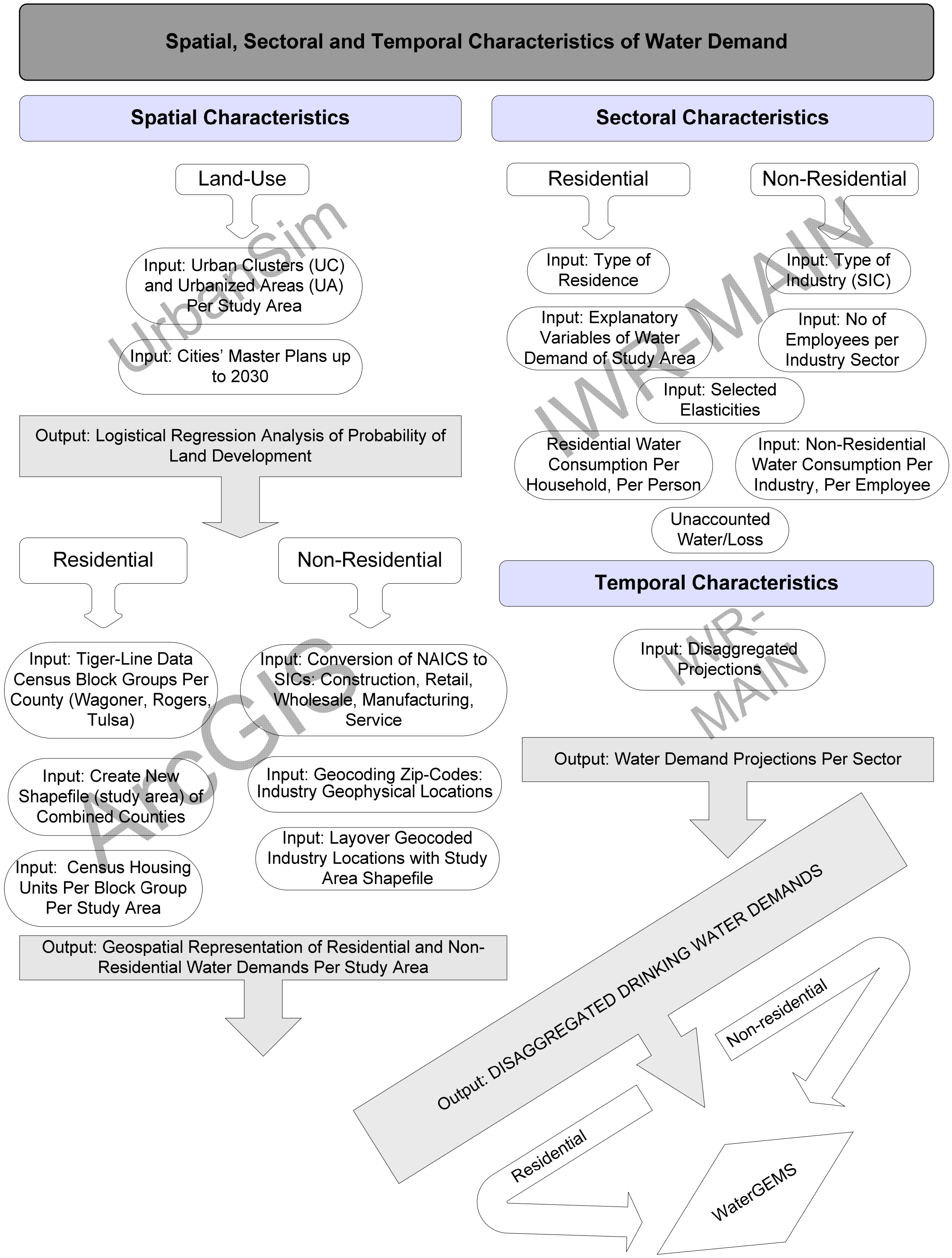


Figure 4-1: Spatial, Sectoral, and Temporal Characteristics of Water Demand

The IWR-MAIN water demand model cannot be used before ArcView GIS and UrbanSim have been used. ArcGIS maps the planning area and links census attributes to the corresponding area. This is done in Census block group level. UrbanSim is utilized to analyze land-use planning choices in ten year time-steps up to 2030. UrbanSim is constructed using logistical regression, also known as “logit” and discreet choice model. Model parameters on land-development are estimated using maximum-likelihood procedure. Also, spatial autocorrelation method is utilized. The results of UrbanSim are extrapolated to forecast scenarios of potential land-use development, which is turn aids in forecasting land-use dependent explanatory variable of water-use in IWR-MAIN.

4.1 IWR-MAIN

The theoretical basis of IWR-MAIN is to forecast water demand. Structurally, IWR-MAIN consists of three parts: The “Forecast Manager” for water demand forecasting, the “Conservation Manager” for analyzing the demand-side water use conservations options, and the “Benefit-Cost Tool” within the Conservation Manager for estimating the costs and benefits associated with implementation of water use conservation programs. The “Forecast Manager” is used to estimate future water uses sectorally, temporally, and spatially. Water use can be forecasted on a daily basis by month or total demand by month. The total demand forecast is generated adding the different time-periods together.

In this project, we recommend the use of Forecast Manager within IWR-MAIN. The Forecast Manager has an ability to consider multiple factors and project water use drivers, a flexibility to allow user to define coefficients, availability of different types of models, such as linear and multiplicative, and ability to perform sensitivity analysis. The Forecast Manager projects water use by customer type (sector): residential and non-residential. The modeler is able to define the planning area spatially. This feature allows the planner to account for regional population growths, as well as variances in socioeconomic attributes and seasonal variations in economic and climatic conditions. The disaggregated water use per space allows more accurate observation of the potential changes in water demands in specified areas. Also, the modeler is able to forecast the planning area’s water demands temporally. Temporal data disaggregation enables modeler to observe variations in water demand per time change, e.g. season, time of day, and annual water demands. The sectoral water demand forecasting element of IWR-MAIN can identify major sectors of water users. These include residential, non-residential, public, and other. Residential sector can be further disaggregated into single-family and multi-family uses. Non-residential water uses can be further disaggregated into the North American Industry Classification System Codes (NAICS), or Standard Industrial Classification Codes (SICs). The IWR-MAIN model provides the modeler with the ability to study different scenarios by making changes in the explanatory variables of water demand and to analyze the impacts of these variables in a long-term water demand scenarios.

The basic structure of the IWR-MAIN model is:

$$Q_{t,d,s,i} = f(P, H, W, C, N, E) \qquad (5)$$

Where: $Q_{t,d,s,i} =$ average daily water use in year *t* with a temporal element of *d* (e.g. season) in user sector *i* (multifamily residential); with a sample set of explanatory variables of: P=marginal price of water; W=climate (residential); C=conservation programs; N=number of users; and E=number of employees (non-residential sector). Once the water demand forecast is calculated per sector, the total municipal water use can be calculated:

$$Q_{t,d} = \sum_{s=1}^{k}\sum_{i=1}^{n} Q_{t,d,s,i} \qquad (6)$$

Where: *n* and *k* represent the number of categories and water user sectors in the forecast. In this study, residential water use is estimated in IWR-MAIN by an existing set of equations. However, the IWR-MAIN equations and coefficients may be reviewed and edited based on existing literature and empirical studies of residential water use. Non-residential uses are sectorally disaggregated into hundreds of industry categories.

4.1.1 IWR-MAIN Parameters

The IWR-MAIN Forecast Manager generates a forecast for water-use as function of a base year. Thus the inputs in the software must reflect these two aspects: Base year and forecast year(s). The Forecast Manager suite has in-built algorithms to construct these models. The algorithms are easy to adjust. For each sector and sub-sector, the modeler selects one of the forecasting methods of Forecast Manager. Constant Use

Rate Method calculates the base year per unit water use rate times the number of counting units for each sub-sector. In the Multiplicative Method, the modeler must develop a multiplicative predictive model prior to using the software. In the Linear Model, the modeler must develop a linear predictive model prior to using the software. The Build Forecasting Model allows the modeler to adjust the per unit usage rate with information about the selected variables. Build Forecasting Model is the recommended primary method to use to forecast the water demand in this planning area. Each of the above mentioned methodologies follows the approach:

$$Q_{c,m,y} = q_{c,m,y} \cdot N_{y,c} \qquad (7)$$

Where:

$Q =$ water use

$q =$ per unit use

$c =$ customer class (sector)

$m =$ month

$y =$ year

Thus, the projected number of units multiplied with the estimated water use per unit use yields the estimate of water use for the given sector (customer class). The number of units (N) is the planning area. Per unit use (q) can be estimated by average rate of use, disaggregate factor forecast, or by functional per unit use models. We recommend using the disaggregate factor forecast method. It follows the general form:

$$Q = N \cdot q \qquad (8)$$

Where:

$$Q_{c,m,y} = (Q_b / N_b)_{c,m} (X_{1f} / X_{1b})^{\beta_1}{}_{c,m} (X_{2f} / X_{2b})^{\beta_2}{}_{c,m} \ldots (X_{n,f} / X_{nb})^{\beta_n}{}_{c,m}$$

And:

$q =$ adjusted per unit use

$c =$ customer class (sector)

$m =$ monthly use

$y =$ year (b=base year; f=future years)

$Q_b =$ base year unit use

$N_b =$ counting unit (e.g. residential: housing units; non-residential: employee counts per sub-sector)

$X_b =$ base year factor variable

$X_f =$ projected factor variable

$\beta =$ elasticity

Factor variables are not determined by regression analysis in the disaggregate factor forecast method. The factor forecast can be developed from base year values of water use (Q and N) and base year and future values for the factor variables. The factor variables recommended for this project will be discussed later. The factor variables; explanatory variables, are selected for each sector (residential and non-residential). The modeler is required to develop projected values for each explanatory variable. Also, projected values for number of counting units (N) are required. The projection of explanatory variables and number of counting units is the most challenging part of the water demand forecasting. The modeler also needs to remember that the counting unit data must be defined in the same units as the customer class (sector). For example, if per unit use is defined as water use per demographic unit (population, housing units, and employment), the customer class (sector) unit (N) needs to be defined as the same unit (single- or multi-family classes, non-residential class). Also, customer class (N) must have projected values of the explanatory variables. Projected values are many times in county level rather than in exact planning area level. There are two methods that should be considered to disaggregate the county level estimates: 1) estimate the demand at a county level and then allocate the demand to planning area demand, or 2) allocate county level data to planning area units and then estimate the planning area demand.

The elasticities for the factor variables may be selected from the literature. There is extensive research available on water demand parameter estimation on both residential and non-residential sectors. The existing extensive literature on the subject should be utilized as it is beyond the scope of this project to develop methods of estimating water use coefficients and elasticities. Depending on the choice of explanatory variables, the corresponding elasticitites need to be utilized. The modeler should be aware of the appropriate elasticity factors based on the water users' long- or short-term response time frame. Elasticity is a measure of the responsiveness of one variable (water demand) to changes in explanatory variables (water price, household size, and income). For example, if the marginal price of water is doubled and as a consequence water demand dropped 30 percent, then the price elasticity is -0.3. Alternatively, an elasticity of +0.4 on income in water demand equation indicates that a one percent increase in income will cause a 0.4 percent increase in water use. (PMCL, 1996). One of the expressions for price elasticity is:

$$E = (dq/dp) \cdot p(i)/q(i) \qquad (7)$$

Where:

$E =$ elasticity

$dq =$ change in water quantity demanded

$dp =$ change in price

$dq/dp =$ regression coefficient of price (slope of quantity demanded and price)

$p(i) =$ price at some point on the curve (average price)

$q(i) =$ quantity demanded at some point on the curve (average quantity)

Elasticities of different explanatory variables for residential and non-residential water demands are built into the model but can be adjusted to better estimate these sectors' water demand coefficients. It is appropriate, in our opinion, to use the combination of built-in and observed averages of different elasticities based on past research and literature. The modeler needs to separate the water use sectors in estimating the elasticities. For example, in single-family residential sector, the average price elasticity of water is -0.20.[10] This suggests that ten percent increase in water rates might reduce water demand by two percent. The range of the calculated price elastics is: -0.09 to -0.28 in single-family sector. In multi-family sector the observed average is -0.10 and the range of the values is: -0.08 to -0.16.[11] In the commercial, industrial and institutional

[10].Weber, Jack A., 1989, Forecasting Demand and Measuring Price Elasticity, Journal of American Water Works Association (AWWA), 81(5), 57-65.
[11] Gleick, Peter H., Heather Cooley, and Groves David, 2005, California Water 2030: An Efficient Future, Pacific Institute, 1-43.

sectors, the average observed price elasticity is -0.25, the range being -0.08 to -0.55.[12] Income and household elasticities for residential and non-residential of water demand have also been estimated. These values are readily available in IWR-MAIN or can be modified based on modeler's discretion. In single-family sector, the commonly used values are 0.4 in both cases. In non-residential sector these values have been estimated to be 0.45 and 0.5.[13] It is wise to use any elasticities for the purposes of observing the order of magnitude impacts rather than for obtaining precise responses.

4.1.2 Selection and Generation of Model Variables

The selection and generation of model variables are described in Table 4-1 and the variable data availability is described in Table 4-2. The chosen explanatory variables are calculated for both base year and forecast years. The sectoral separation of water use mandates the use of different set of explanatory variables as discussed earlier. Using the disaggregate factor forecast method to estimate the per unit use value of (q), significant explanatory variables are not determined by regression analysis or kept constant. The explanatory variables are developed from base year values of water use data. Using the disaggregate factor forecast model, the residential water demand forecasting factor variables include median household income, housing density, persons per household, marginal price, temperature, and precipitation.

[12] *Ibid.*
[13] *Ibid.*

Table 4-1
Selection and Generation of Model Variables

PROCEDURE	UrbanSim	ArcGIS	DATA SOURCE	IWR-MAIN	DATA SOURCE
Define Planning Area: RESIDENTIAL		Wagoner, Rogers, and Tulsa Counties Urban clusters, urbanized areas Block groups No. of households	U.S. Census 2000 Tiger-Line Data		
Spatial Disaggregation: RESIDENTIAL	Population	New shapefile of planning area	U.S. Census 2000 Tiger-Line Data	*Explanatory variables: Model parameters*	
	Land-Use Plans			**Socioeconomic**: Persons per household Housing units Housing density Industrial employment Residential water price Household income	U.S. Census 2000
		Add population projections to attributes up to 2030 per block group	OK Department of Commerce	**Climate/Weather:** Precipitation Cooling degree days Av. daily max. temp.	USGS OK Climatological Survey U.S. FedStats
Define Planning Area: NON-RESIDENTIAL		Wagoner, Rogers, and Tulsa Counties	U.S. Census 2000 Tiger-Line Data Land-use master plans: county business patterns Binomial logit analysis: probability of land-development		
Spatial Disaggregation: NON-RESIDENTIAL	Regional Economic Forecasts	Basemap: Residential shapefile	Planning area residential basemap	Construction, retail, wholesale, manufacturing, service: Establishments, employees	SIC (NAICS)
	Land-Use Plans Employment Estimates	Geocoding zip codes	U.S. Census zip codes		OK County Business Patterns
Water Use Coefficients				No of accounts per type Water use per customer sector: • Single family • Multiple family • Construction • Retail • Wholesale • Manufacturing • Service	
Model Parameters				Elasticities: • Median household income • Housing density • Persons per household (pph) • Marginal water price • Av. daily maximum temperature • Total precipitation • Cooling degree days	IWR-MAIN library Literature
Forecasting Model Type				Build forecasting model	
Define Forecast Years				10 year increments: 2010, 2020, 2030,	

Table 4-2
Variable Data Availability

VARIABLE	SUBJECT	GEOGRAPHY	DATA SOURCE*
Population	Total Population	Wagoner, Rogers, and Tulsa Counties Block Groups	U.S. Census 2000: Total population per block group
	Urban clusters, urbanized areas	Wagoner, Rogers, and Tulsa Counties	U.S. Census 2000: UCs and UAs per county
	No of Households	Block groups/water service area	U.S. Census 2000: No. of households per block group OK Water Resources Board: Small system service area
	Persons per Household	Block groups/water service area	U.S. Census 2000: Total persons per household per block group OK Water Resources Board: Small system service area
	Projection	Block groups/water service area	OK Department of Commerce: Sub-County Population Projections
Housing	Housing Units	Block group/ water service area	U.S. Census 2000: 108th Congressional District summary files: Total housing units per block group
	Density (units per acre)	Block groups/water service area	U.S. Census 2000: 108th Congressional District summary files
	Units in Structure	Block groups/water service area	U.S. Census 2000: Units in structure: Residential: Single, multiple, occupied, vacant
	Projection	Block groups/water service area	Binomial logit model
Income	Median Income	Block groups/water service area	U.S. Census 2000 FactFinder
	Projection	Block groups/water service area	REMI: Economic Forecast Series
Employment	Employment	Block groups/water service area	Geocoded Zipcodes Labor force participation (LFP) rate County Business Patterns (CBP)
	Projection	Block groups/water service area	Land-use master plans: Binomial logit model: Probability of land-development: UrbanSim. REMI: Economic Forecast Series
Climate	Average Daily Max Temperature (normal and actual)	Block groups/water service area	OK Climatological Survey: Historical Data: Monthly Average Maximum Temperature
	Precipitation (normal and actual)	Block groups/water service area	OK Climatological Survey: Historical Data: Monthly Total Precipitation
	Cooling Degree Days (normal and actual)	Block groups/water service area	OK Climatological Survey: Historical Data: Monthly Cooling Degree Days for Each Year

*data may or may not be available “as is” basis. Modeler may need to extrapolate and calculate the data to fit particular forecasting in question.

In the non-residential sector these include cooling degree days, marginal price, and employment per industry (establishment). In order to validate the elasticity coefficients available in IWR-MAIN library, the modeler has to localize the modeling effort in the elasticity selection. For example, in a water demand forecasting effort of the Twin Cities Metropolitan Area in Minnesota in 2001, it was observed that historical household water consumption was not sensitive to average household income.[14] Those cities with the highest average household income did not have the highest per capita residential water demand. However, IWR-MAIN has positive (0.4) elasticity, indicating that as median household income increases, the water consumption also increases. Some modeling efforts have thus held the income constant, assuming that there is no change in water demand due to median household income. The base year forecast for income is estimated by using the U.S. Census American FactFinder web-site. The projected median household incomes for the planning area need to be extrapolated and adjust for inflation. Income can be reported in current dollars. The modeler needs to be careful not to factor aggregate and flat data of household income. State and even county median household incomes may not be the best fit with the model. Southwestern Oklahoma Sate University Center for Economic and Business Development (CEBD) has developed a forecast up to 2010 of the real disposable income for the planning area. See more about the CEBD forecast method in the context of employment variables. The real disposable income can be extrapolated per capita basis.

The base year estimates for housing data can be obtained from U.S. Census Bureau's 108th Congressional District File, which contains population, housing units,

[14] Metropolitan Council, 2001, Regional Report Projected Water Demand for the Twin Cities Metropolitan Area, Publication No. 32-01-010, 1-56.

area, and housing densities for the year 2000. For forecasting purposes, median housing density calculations (units/acre) can be somewhat speculative. In order to forecast the change in housing densities, the modeler needs to estimate this for the forecast years. In this report, we recommend utilizing the land-use development model in combination with UrbanSim simulation method to better understand the potential changes in land-use patterns. Both of these methods are discussed later on this report. Most water demand forecasting efforts have opted to hold household density variable constant for forecast years. Although land-use forecasting may be speculative, in our opinion it is more important to try to factor the probability of land-development into the model than to hold the land-development variable constant. If it is held constant, then the modeler assumes there is no effect of land-development on water demand forecasts. IWR-MAIN has an elasticity value of -0.3 indicating that if there was an increase in population density it would yield a decrease in water demand.

When forecasting future housing data explanatory variables as well as employment variables, the examination of land-use probability is needed. The dependent variable, land-use, is categorical rather than continuous, thus the land-use model can be estimated using logistical regression, also known as "logit" instead of linear regression method. Model parameters on land-development are estimated using maximum-likelihood procedure. The land-use variable can be given two categorical values (indicating land-use change or no land-use change). When there are two categorical values, binominal logit (logit-probit) is an appropriate model. The extension of binomial logit model applies to any explanatory variable of water demand that is affected by land-use changes. There are different assumptions that should be taken into account regarding discrete land-use choices.[15] The first assumption is that the land-development process must act independently of each other (homebuyers, builders, brokers etc.). The second assumption is there are neither non-profit-maximizing buyers nor utility-maximizing sellers. In the other words, the acting agents in the market are not known (buyers and sellers). This approach is also known as reduced-form model because the outcome of the transaction is known (buy/sell) but not the agents involved in the transaction.

The use of spatial autocorrelation is a useful tool of predicting land-use change. This method theorizes that an adjacent or nearby objects tend to influence each other. Spatial autocorrelation is very useful in the planning area in question, since the planning area rural water districts are located in the fringes of the urban clusters and areas that are spreading to rural water service districts. The selection of independent variables of land-use change depends on the modeler. There are multiple resources the modeler may select to establish the right combination of dependent variables. Two variables that we suggest using are “Development Potential” and “Adjacency and Neighborhood”. In the planning area, the major cities have developed Master Plans (Broken Arrow, Owasso, and Tulsa) that outline preferred development patterns of land-use, identify land-use development potential, and land-use characteristics.

As an example, Broken Arrow’s Future Development Guide of the Comprehensive Plan is a color-coded map of the city that outlines a preferred development pattern. The Comprehensive Plan utilizes Land-Use Intensity System (LUIS), which is based on the concept that certain land-uses have similarities in intensity of use and thus, compatible,

[15] McFadden, Daniel, M. Balch, and S. Wu (ed), 1974, Essays on Economic Behavior Under Uncertainty, North Holland: Amsterdam.

while other land-uses have different levels of intensity and may not be compatibility for land-use. The LUIS levels of intensity are tied together with the appropriate zoning classifications. The Comprehensive Plan includes a map called the Future Development Guide (FDG), which groups different zoning districts into seven different color-coded levels. The FDG contains a matrix that shows what zoning is allowed within each level. The colors represent different levels of intensity of land-use per square mile. These are rural residential (large residential lots), urban residential (standard single family lots), transition area (office uses, duplexes, townhomes, etc.), commercial and employment, downtown area, regional employment/commercial (major commercial centers oriented around highways, some light industrial), and major industrial (industrial parks, research parks, some commercial). Vacant land parcels based on the LUIS codes are calculated and incorporated into ArcGIS.

The baseline explanatory variable of persons per household (pph) can be calculated from total population and types of housing units for the planning area. U.S. Census American FactFinder and 108th Congressional District summary files have the current estimates available. Again, the dilemma arises from the projections of these values. The modeler has to decide whether to keep these values constant or project them exogenously. Oklahoma Department of Commerce has projected populations in a sub-county level up to 2030. IWR-MAIN's elasticity value for persons per household is 0.45 which indicates an increase in pph would increase water demand. Pph values can be derived from land-use forecasting results, which is discussed above.

Marginal water price should be calculated from each supplier. We recommend that modeler obtains marginal price of water in the planning area by averaging the price of different usage categories per supplier and then averaging that price with the other average prices of area suppliers. Projection of marginal water prices can be done by factoring in the planning area's annual average price increases. IWR-MAIN library has an elasticity value of -0.04 indicating that the model is not very sensitive to changes in marginal water price.

Environmental variables, precipitation, and maximum daily air temperature, can be obtained from state climatological service or national level services such as U.S. Geological Survey, (USGS) and U.S. FedStats.[16] In our project area, Oklahoma Climatological Survey has the relevant data. Climatological Survey's County Climate Summaries, Historical Monthly Average Maximum Temperatures, and Monthly Total Precipitation can be obtained directly from their web-site.[17] There are sources of this data that have the data averaged on time scales varying from one hour to 30 years.[18] Also, National Oceanic, and Atmospheric Administration (NOAA) and Oklahoma Mesonet provide climatolocial data of the area. Oklahoma Climatological Survey provides average and maximum monthly and annual temperatures and precipitation data since 1895. The projected area maximum temperatures and total precipitation data are based on historical averages. IWR-MAIN elasticity for maximum temperature is 0.5 and for total precipitation -0.02. The temperature elasticity indicates that an increase in temperature results in an increase in water demand. The rainfall elasticity indicates a decrease in water demand due to precipitation. Since forecasting weather is

[16] http://www.fedstats.gov/

[17] http://climate.ocs.ou.edu/

[18] Personal communication with Dr. Kit Wagner, Atmospheric Information Systems, May 2007.

problematic and beyond the skills of the authors and the scope of this report, we recommend using constant temperatures and precipitation values in the projection years. It would be very interesting to test variations in temperature and precipitation (draught, flooding) on water demand in both in short-run and long-run.

In both residential and non-residential sectors, the water use data is inputted by number of accounts per customer sector. The modeler enters base year water use in gallons for each month by each sub-sector. The water use data in this study can be obtained from each water system within the current service area. The data consists of number of connections, monthly production, and monthly metered production. The data is used to provide average water consumption per account by water use sector.

The selection and calculation of parameters in the non-residential sector is slightly less complex than in the residential sector. IWR-MAIN uses SIC (Standard Industrial Classification) codes. In 1997 the Office of Budget and Management (OBM), replaced SIC system with the North American Industry Classification System (NAICS). Both SIC and NAICS are hierarchical classification code systems that are used to identify the types of businesses in the planning area. The planning area NAICS codes can easily be converted into SIC codes. Average water demands in each SIC code are determined on the basis of water use per employee per day. IWR-MAIN comes with an extensive library of water use coefficients in different SIC codes. These coefficients are best validated by comparing them to the current literature of water use per industry sector. Most likely water consumption in different industries has diminished due to improved and more efficient technologies and conservation measures.

In order to forecast job projections in the planning area, population projections data of the area and Bureau of Labor Statistics projections of trends in labor force and job growth are needed. The Center for Economic and Business Development (CEBD) in Southwestern Oklahoma State University in Weatherford, Oklahoma, has used Regional Economic Models, Inc. (REMI), based in Amherst, MA.[19] REMI is a proprietary economic modeling software that enables modelers to answer "what if" questions about their respective economies. Each REMI model is tailored for specific geographic regions by using data, including employment, demographic, and industry data, unique to the modeled region. The CEBD uses the Oklahoma REMI model, which is a six region, 70 sector model, to forecast how a given economic activity or policy change occurring in one region would affect that region, a group of regions, and/or the state. The REMI simulation model uses hundreds of equations and thousands of variables to forecast the impact that an economic/policy change has upon an economy. The six regions used in Oklahoma REMI are: Northwest Oklahoma, Northeast Oklahoma, Southwest Oklahoma, Southeast Oklahoma, the Oklahoma City metro area, and the Tulsa metro area. The Oklahoma metro area and the Tulsa metro area correspond to the Metropolitan Statistical Areas (MSAs) defined by the Office of Budget and Management. The counties that comprise the Tulsa MSA are: Creek, Okmulgee, Osage, Pawnee, Rogers, Tulsa, and Wagoner. REMI generates a control forecast, which uses current data regarding the economy. The control forecast represents the projection of the economy into the future *ceteris paribus*. This approach is also commonly used, for example, in projecting population, employment, densities, and

[19] Regional Economic Models, Inc: http://www.remi.com/software/software.shtml Obtained May 20, 2007.

urban land shares. This approach generates separate sectoral in MSA or county-level forecasts and then aggregates them into single regional total. If the modeler wants to deviate from forecasting to scenario planning instead, then the use of past similar patterns of the observed variables may not be the only means of interpreting the future job growths.

USACE has projected the employers using labor force participation (LFP) rate (number of employed/population).[20] The modeler has to be careful not to use population projections by residence but by employment based pm location of work. However, some studies in California, in particular, presume that there is a relationship between the size of region population and employment base. This is due to the fact that there is a long-term spatial trend in California (and elsewhere) of jobs being located outside of the city centers. The modeler needs to be familiar with the planning area in question, and whether the national trend of job decentralization applies to it. As we demonstrated in Section 2.2, it is safe to state that the decentralization of jobs has not occurred in our planning area.

The County Business Patterns (CBP) reports employment by location of work, and this can be used for base year calculations. In order to forecast those numbers into the future, the modeler needs to make a choice whether to keep the numbers constant or try to project them. USACE Tulsa district performed a water demand study for the city of Bartlesville, and they kept LFP constant. The assumption keeps the study simple and may be safe because the literature suggests that the LFP national trend is in

[20] Personal communication with Dr. Edwin Rossman, USACE, Tulsa District, Planning Division, May 2007.

decline.[21] Keeping the LFP constant assumes the structure of the economy is unchanged. However, the study community may not always follow the national trend, and thus we propose that small area projections of economic forecasting may be possible by using land-use projections as discussed earlier. IWR-MAIN extracts water demands for non-residential sector by employers per establishment basis. This ratio indicates how water-intensive the industry in question is.

The other model variables chosen to forecast non-residential sector water demand are: the cooling degree days (CDD) and the marginal price of water. Cooling degree days are used to estimate how hot the climate is and how much energy may be needed to keep buildings cool. CDDs are calculated by subtracting a balance temperature from the mean daily temperature, and summing only positive values over an entire year. The balance temperature used can vary, but is usually set at 65°F (18°C), 68°F (20°C), or 70°F (21°F).[22] In general, it is a measure of the severity of the summer in a given locality: the more cooling degree days, the hotter the summers. OK Climatological Survey has monthly cooling degree days for each year. The marginal price of water for each industry sector is calculated in a similar fashion to residential price of water.

4.2 UrbanSim

UrbanSim models land development for land-use. The input variables selected for different models with UrbanSim need to be generated outside the model. As we

[21] Toossi, Mitra, 2002, A Century of Change: The U.S. Labor Force, 1950-2050, Monthly Labor Review, 15-28.

[22] U.S. EPA: http://www.epa.gov/heatisland/resources/glossary.html Obtained 04/20/2007.

discussed above, in the context of land-use planning and housing densities and job projections to generate input variables into IWR-MAIN, the same methodologies are used to generate input variables into UrbanSim. The input data needed in UrbanSim are: population and employment estimates, regional economic forecasts, and land-use plans. All these input data are disaggregated and thus the output of the model is disaggregated.

5.0 Procedures to Planning Area Water Use Forecasting

The flow chart 4-2 (p.26) presents part of the entire model driven DSS. This flow chart contains the first set of three procedures using three software applications to obtain the output of water demand forecast. The DSS modeling at the early stages are done by using ArcGIS/ArcView 9.2, UrbanSim and IWR-MAIN 6.1 softwares. The modeling capabilities and data requirements of IWR-MAIN and UrbanSim are discussed in Section 4.

ArcView 9.2 version of desktop GIS (Geographical Information Systems) is a mapping tool to map, visualize, and analyze data with geographical components. The software is an ESRI product. The starting point in building a basic model is to define the spatial element of the forecasting, i.e. the planning area. This is done by identifying the fastest growing areas (urban clusters and urbanized areas) in the study region and mapping them in ArcGIS. This spatial element is then correlated with the rural water district pipeline data. The next stage is to further refine the planning area by breaking up the physical planning area into U.S. Census Block Groups (BG). Now the physical base map represents geographical representation of water service boundaries. BGs do not contain any demographics data. Using a similar methodology to McPherson and Witowski (2005) and McPherson and Brown (2003), residential housing units data are spatially disaggregated to a raster representation of census blocks. This is done by adding housing units per BG and this becomes a new shapefile. The BG data and the occupied housing units per block group of each study county area and the geographical representation of these are obtained from U.S. Census. This procedure aids in calculating spatially distributed demands of residential drinking water. Block groups are clusters of census blocks and is the smallest geographic unit, containing from 600-3,000 people in each block. Many blocks correspond to individual city blocks bounded by streets, but blocks especially in rural areas may include many square miles and may have some boundaries that are not streets. The temporal/spatial element of residential water use forecast modeling is done by matching the physical planning area with the disaggregated Oklahoma Department of Commerce population projection data. This is done in 10-year time steps up to 2030.

In order to input demand forecast elements of non-residential water use, the base map is expanded to include the main classes of industry in the area. We have selected manufacturing, retail, construction, wholesale, and service sectors. Mapping of these sectors is done by incorporating Geoprocessing method in ArcView. This is done by using U.S. Census County Business Patterns data and identifying the zip codes of the industries located in the planning area. This aids in locating current non-residential water demand sectors in the planning area. ArcView is not forecasting software, but its ability to create spatial representation of the planning area as it currently exiists, helps us in extrapolating future water demands in the area. Also, linking current Census data with spatial data files gives a better understanding of the socio-economic characteristics of the planning area. We correlate the number of housing units, population, income, and population density with the physical BG. In the non-residential side of water demand, current location of businesses and industries are correlated with BGs. ArcView is also later linked with hydraulic modeling. In all the stages of DSS, ArcView functions not only as a mapping tool, but also compiles, stores, analyzes, and manages data and integrates database operations.

Once the spatial planning area is defined and the current values of the explanatory variables are added into the spatial elements, the UrbanSim land-use simulation should be started. This procedure is discussed in Section 4. The output of UrbanSim is inputted into IWR-MAIN. Also, the other exogenously extrapolated data are inputted in IWR-MAIN, as discussed above.

6.0 Hydraulic Network Simulation

WaterGEMS (proprietary) is not a single model. It is better considered as a geospatial hydrologic simulation system, consisting of software architecture for implementing different models and the interaction of the models within this environment. The models implemented in WaterGEMS employ a wide range techniques and approaches. The usability of WaterGEMS in this project stems from its ability to perform “what if?” scenarios of hydraulic systems (distribution networks). In this model a variety of alternatives (demand growth scenarios) can be employed in Extended

Period Simulations (EPS). WaterGEMS was designed, developed and programmed by Haestad Software and Civil Engineers. It consists of in-built algorithms of hydraulics. Based on the modeling desires, the appropriate in-built coefficients can be chosen to represent the hydraulic situation in question.

In essence, we are interested in finding out if and for how long the existing water distribution system can be expanded to new customers. Demand alternative of WaterGEMS allows the modeler to model the responses of the water system to different sets of demands now and, e.g. ten years later. This is done by modeling new piping that will become part of an existing system and that has a connection point that is not a tank or pump station. The new pipelines may need to be constructed for a new residential subdivision, industrial park, or mixed-use land development. The pipe sizing of the new system cannot be sized independently, since we intend to use the existing water system. Thus, the simulation process starts with constructing the base-line system of a distribution network. Each junction (node) in the network is assigned average conditions per time-frame with respective water flows, pressures, elevated storages, source reservoirs. Then the existing base model is calibrated to receive the new pipelines. Prior to simulation of the new system, the modeler must define the pressures and elevations, and all other hydraulic conditions.

The best way to model the extension of an existing system is to build the new pipes and customers into a calibrated model of the existing system. By doing this, the modeler detects the extended system's impacts on the existing one, and vice versa. Having a calibrated model of a system also allows a wide variety of situations to be simulated (e.g. modeling of different demand scenarios). The scenario management feature of WaterGEMS allows the modeler to build scenario cycles by altering the average conditions by, for example, increasing the water flow through the system. The anatomy in scenario management begins by identifying the attributes of elements in the hydraulic networks that may experience change due to a different scenario, such as an increased water demand that needs to piped though the existing pipelines.

The purpose of the earlier part of this project is to demonstrate how to forecast water demands and assign those into the planning area (into Block Groups, BGs). In WaterGEMS the water demands of the planning area are called “lump-sum area”. This represents total water use of the service areas based on the demand nodes (either meters or nodes of pipelines within block groups). Each service area polygon within the lump-sum area is assigned a single flow. The flow can be distributed equally among the service areas within the lump-sum area, or the flow can be distributed proportionally among the service area polygons within the lump-sum area. In order to simplify spatial and demand allocation, the proportional distribution option of lump-sump demand allocation per service area is recommended in this project. The greater the percentage of population in the service area, the greater the percentage of the total flow is assigned to that service area. The distribution networks are then simulated to meet the service area demands in the determined time-steps. The goal is to identify the point when the current system will no longer be able to meet the increased demands.

The costs of each type of element in water system stem from construction and non-construction costs. The Capital Cost Manager of WateGEMS needs to be utilized in order to encapsulate construction costs involved in different scenarios. It tracks costs associated with water distribution capital improvements. The modeler needs to supply this information to the software, as the costs are not built into the system. The cost calculations are thus calculated exogenously. The modeler needs to define the physical elements, demands or loads, baseline setting of the network, and then calculate the unit costs of those. In the distribution network capital cost estimating, the elements that need to be calculated are broadly categorized as pipeline and nodal element costs. Pipelines costs are: pipeline costs per unit length, number of service lines, and lengths of pipe segments. Nodal element costs are: number of valves, tanks, and pumps. The non-construction costs are assigned as a lump sum amount. Non-construction costs in general are indirect costs of construction, such as inspections, administration, and legal.

Once the physical elements have been identified and their associated costs calculated, these are entered into unit cost functions within WaterGEMS. The cost functions are in equation or tabular format. We suggest using several different equation cost formulas since pipelines have different costs associated with them depending on the soil types in question. The general form of the cost function is:

$$\$/ft = d + a(x-c)^b \qquad (8)$$

Where:

X = diameter of pipe

a,b,c,d = cost coefficients

Coefficient *b* is an exponent and indicates how sensitive the costs are the size of a pipe. Hence, if costs are less sensitive to the size, *b* is small. Coefficients *d* and *a* are independent of the size of the pipe, and associated with excavation and laying the pipelines.

When the baseline system is altered, the scenario construction costs are adjusted. This is done in WaterGEMS by building costs associated with each physical scenario. Each scenario is constructed by using physical alternatives (e.g. different pipe sizes) and then associating that scenario with matching cost alternatives (e.g. cost functions).

The other important element of cost analysis is energy costs. WaterGEMS has an Energy Cost Manager feature that allows the modeler to estimate energy costs of the water system. Energy cost manager, like capital cost manager, can be run independently or in conjunction with the simulated scenarios. Also, like capital costs, energy costs are obtained outside the software. The largest energy consumptions stem from pump operations.

The results of EPS of water system networks and the associated costs provide the final components to the assembly of the decision support system. The 10-year incremental demand simulations provide information to the decision makers about the costs and infrastructural capabilities of water supply systems.

7.0 Cooperation with Consolidation or Acting Alone

Regional consolidation, collaboration, restructuring, centralization, or regionalization of water systems, especially in rural areas, has been promoted by water planning and research agencies in state and federal levels as a solution to combat the consequences of increased drinking water demands. The main idea of regionalization is that it pools individual sources of two or more water systems to better meet the growing demands of water. In this project the final product of DSS will inform water planners and water system managers whether consolidation of physical assets in the planning area is needed at different time-periods so that costs are minimized. The structural consolidation includes any form of physical interconnectedness of two or more systems, whereas the non-structural form of consolidations emphasizes procedural changes in water system management and administration.

Table 7-1 presents the potential gains of both physical and non-physical forms of regionalization. The benefits of regionalization/consolidation are not straight-forward or unlimited. The optimal result of consolidation is decreased cost of treated water.

TABLE 7-1 Perspectives on Consolidation

Perspective	Key Reasons
Economic	Economies of scale and scope (lower unit costs)
Financing	Access to capital and lower cost of capital
Engineering	Operational efficiency and technological improvement
Natural resource	Resource management and watershed protection
Federal standards	Compliance with standards at lower cost, greater capacity development, and greater affordability of water service

SOURCE: Beecher (1996) [23]

The potential gains or losses of consolidation are derived from the theories of scale economies, size economies, and scope economies. These theories stem from the nature of production processes within firms.

The nature of returns to scale (constant, increasing, and decreasing,) refers to physical relationships between inputs and outputs. Returns to scale measures how

[23] Beecher, J. A., 1996, *Regionalization of Water Utilities: Perspectives, Issues, and Annotated Bibliography*, The National Regulatory Research Institute: Columbus, Ohio.

output reacts to either increases or decreases in inputs. The constant returns to scale indicate that if all inputs where doubled, the output doubled also. If the output more than doubled as a result of doubling the inputs, increasing returns to scale is present. If the output less than doubled as a consequence of increased inputs, decreasing returns to scale are present. Scale economies refer to the costs associated with the physical relationship of input(s) and output(s). Economies of scale indicate that the average unit cost of output is falling; economies of scale indicate that the average unit cost of output stays the same, and diseconomies of scale indicate that the average unit cost of output is increasing. Size economies differ from scale economies by allowing input proportions to alter when doubling of output is achieved for less than twice the cost. However, the distinction between scale and size economies is not important for many practical purposes. Thus, size and scale economies are used interchangeably. In the context of small water systems, scale economies and diseconomies have been widely applied in justifying water system consolidation.

Capital-intensive services usually yield significant economies of scale since the cost of fixed assets can be distributed across a larger number of customers. Thus, the economies of size are easy to realize with water treatment; Lower unit costs of water are obtained with treatment plant size increase. However, transmission and distribution costs of water depend on the service area (size, population density, topography, and soil type), and thus the economies of size may be offset due to diseconomies of distribution. The past literature suggests different results of the economies of scale associated with different water system components. Some studies show high economies of scale in water treatment. Other studies show more scale economies in water system administration than in water treatment. Also, some studies consider the possibility of economies of scale being offset due to diseconomies of distribution. In the drinking water industry the economies of scale and size can be achieved by nonstructural or structural forms of consolidation.

There is no theoretical relationship between scale/size economies and scope economies. Thus, the economies or diseconomies can be occurring independently from each other. Therefore, it is possible to achieve scale and size economies and suffer scope diseconomies simultaneously. The existing literature derives its economic reasoning of water systems consolidation from the concepts of economies of size and scope. The concept of scale economies have been applied in joint production framework but not in interactions between production processes.

The outputs of the modeling of land-use development, water demands, and simulation of distribution networks give cost estimates of different water pipeline and treatment infrastructure needs based on the simulation and modeling scenarios. These scenarios and associated costs are given in 10-year time increments up to 2030. Each one of the scenario, every ten years, is evaluated for its cost estimates. Each one of the scenario is then evaluated within the economic framework of consolidation as described above.

8.0 Conclusions

In this report we have established a basis for a comprehensive model-driven DSS of water system infrastructure planning that will enable the decision-maker to consider future growth factors in determining the optimal utilization of current and likely future water system infrastructure. The purpose of the DSS is to guide and to inform the decision-maker rather than make the decision on his/her behalf. The options analyzed will include the determination of suitability of existing infrastructure, the need for enhancement of existing pipelines, pumps, and/or distribution systems, or semi-optimization by consolidating with other water systems. The new element of this DSS is the ability to analyze water system infrastructure at he most basic (e.g. rural water district) level such that the decision maker can perform real-world concrete analysis of the infrastructure requirements to meet future growth demand in the most cost-effective manner.

9.0 Caveats and Recommendations

There are many challenges for development of a holistic model-driven DSS. These challenges stem from data availability and requirements, model formulations, and model solutions. Data requirements relate to the type of data needed, level of forecasting, and level of dissaggregation scales. Mixed types of data from various sources are used in interdisciplinary models with spatial, sectoral, and temporal dimensions. These data requirements and manipulation make the assembly of the models labor-intensive. The temporal scale of planning of infrastructure needs further complicates the assembly of the models. Continuous modeling techniques can not assume to generate solid, hard-core forecasts but take an approach of scenario modeling in both the input forecasting as well as in constructing the main models. The modeler has a responsibility to identify the potential short-comings in the scenario planning process and incorporate to the model in a best possible manner.

Many of the input parameters in water demand forecasting need to be calculated by the states' planning agencies, who may alternatively contract professionals in land-use planning and population forecasting to generate these data. Land-use planning and population forecasting are specific disciplines and require mastery of skills that many times are beyond the skills of an engineer or a water demand forecaster.

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Historical Ecological and Geochemical Analysis of Lakes Eucha and Spavinaw

Basic Information

Title:	Historical Ecological and Geochemical Analysis of Lakes Eucha and Spavinaw
Project Number:	2006OK67B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	2
Research Category:	Not Applicable
Focus Category:	Sediments, Agriculture, Non Point Pollution
Descriptors:	None
Principal Investigators:	J. Berton Fisher, Bill Potter, Ken Roberts, Bryan Tapp, Harrington Wells

Publication

Student Status	Number	Disciplines
Undergraduate	5	Biology, Geosciences
M.S.	1	Chemistry
Ph.D.		
Post Doc		
Total	6	

Title: Retrospective Ecosystem Analysis of the Eucha-Spavinaw Watershed

Start Date: 02/01/2005

End Date: 07/31/2007

Congressional District: University of Tulsa - Federal Congressional District 1; Eucha-Spavinaw Watershed Federal Congressional District 2

Focus Category: WQL, SED, M&P, GEOCHE, ECL, AG

Descriptors: Sediments, lake, reservoir, watershed, poultry, pollution, ecology, agriculture, phosphorous, arsenic, selenium

Principal Investigators: J. B. Fisher, University of Tulsa, Bryan Tapp, University of Tulsa, Ken Roberts, University of Tulsa, William Potter, University of Tulsa, Harrington Wells, University of Tulsa

Publications: Fisher, J. Berton. 2006. Secular Variation in Arsenic and Selenium Concentrations in Sediments from Lakes Eucha and Spavinaw and Spavinaw. Oral Presentation, Oklahoma Water 2006, October 5-6, Oklahoma City, OK.

Murdianti, Befrika, 2006. Eucha-Spavinaw Lake Sediments: A Poultry Production Fingerprint. Poster Presentation, Oklahoma Water 2006, October 5-6, Oklahoma City, OK.

Problem and Research Objectives: Just under than 50% of the drinking water used by approximately 500,000 persons in the City of Tulsa and surrounding communities comes from the Eucha-Spavinaw watershed, located in western Arkansas and eastern Oklahoma. This watershed covers roughly 415 mi^2 of largely agricultural land in Mayes County and Delaware County, Oklahoma, and Benton County, Arkansas. Lake Eucha and Lake Spavinaw impound water from Spavinaw Creek (the primary drainage channel). Water quality within the watershed has substantially changed from 1924 when the dam forming Lake Spavinaw was closed. The most notable biological change is the clear and profound increase in phytoplankton production in the lakes and an apparent change in the relative abundance of phytoplankton species. Water from the

Eucha-Spavinaw watershed could and was originally used by Tulsa with little or no treatment. In recent years, however, treatment costs have risen. Moreover, the frequency of taste and odor complaints has increased. Water quality monitoring data indicate that both Lake Eucha and Lake Spavinaw were originally oligotrophic, but are now both nutrient-enriched and display high or excessive levels of algal production. During much of the year, the phytoplankton community in both lakes is dominated by dominated by blue-green algae. Changes in composition and abundance of phytoplankton community in the lakes may be attributable to increases in nutrient levels in the lakes, and in the waters feeding the lakes. Unfortunately, detailed water quality studies of phosphorous loading to the watershed did not begin until 1997 when a Conservation Commission report indicated increasing phosphate content in Spavinaw Creek. It is reasonably probable that changes in land use and land cover (LULC) are likely the cause of increased nutrient loading to the watershed. In the 1930s, land usage within the watershed was focused on corn, wheat, and oat production in Oklahoma (Kesler, 1936), and on apple, peach and grape production in western Arkansas. Moreover, at that time, nearly 80% of the watershed was undeveloped scrub timber. Since the mid-1950s, and especially since about 1980, land usage within the watershed has changed to support ever-increasing levels of poultry (primarily broiler) production, and most agricultural land is now pastured for the production of beef cattle. At present, just over 50% of the land area of Delaware County, Oklahoma and Benton County, Arkansas is classified as “Land in Farms” (USDA, 1997). In particular, the shift to poultry production is likely highly significant in impacting nutrient loading to the Eucha-Spavinaw watershed. Historically, the phosphorus laden fecal wastes from poultry production have been spread as fertilizer on land within the watershed. In the recent past, the Eucha-Spavinaw watershed had the capacity to produce over 84 million chickens, along with some 1,500 tons of phosphorous rich waste per year (Tulsa Metropolitan Utility Authority, 2001). Phosphorous present in these wastes and excess phosphorous stored in soil may then be washed into streams as a non-point-source pollutant. Ultimately, this phosphorus reaches the water supply lakes and promotes excessive algal growth. Although poultry waste disposal on fields within the watershed is now largely governed by a court order (see Egan, 2004) that limits the land disposal of poultry wastes, some wastes continue to be spread, and soil levels of phosphorus remain high. As a consequence, agricultural runoff, and the resultant nutrient loading and eutrophication of Lake Eucha and Lake Spavinaw remains a source of significant controversy and friction between those who use water from the Eucha-Spavinaw Watershed and those who produce chickens within the watershed.

Methodology: This problem was address through review of historical records of poultry production, analysis of land use and land cover and geochronological and geochemical analysis of undisturbed sediment cores from Lake Eucha and Lake Spavinaw.

Principal Findings and Significance: Within the sediments of Lake Eucha and Lake Spavinaw, increases in the concentrations for arsenic, selenium, and molybdenum, beginning in the early 1980's, are coeval and consistent with the increased poultry production within the watershed.

ABSTRACT

Within the last twenty five years, the Eucha-Spavinaw drinking water watershed in Northeastern Oklahoma and Northwestern Arkansas has shown a large increase in commercial poultry production. Presently, the level of nutrients entering Lakes Eucha and Spavinaw has put both lakes under eutrophic and hypereutrophic conditions. This project evaluates the sedimentary history of the Lakes to evaluate if there is any correlation between the timing of the increased poultry production and any changes in sedimentary trace metals. The sedimentary chronology is determined by gamma spectrometry using standard ^{210}Pb and ^{137}Cs dating methods. The sediments are analyzed for metals using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). The data show increases in the concentrations for arsenic, selenium, and molybdenum beginning in the early 1980's, concurrent and consistent with the increased poultry production within the watershed.

Introduction

The Eucha-Spavinaw watershed has been used by the City of Tulsa as a source of its water supply since the early 1920's. The watershed covers roughly 415 square miles of agricultural land in Mayes County and Delaware County, Oklahoma, and Benton County, Arkansas.

The Eucha-Spavinaw watershed has a long history of agricultural activity. At present, the watershed supports a high level of poultry production. Recent water quality data for Lakes Eucha and Spavinaw indicate that higher levels of nutrients are now entering the watershed (OWRB 2002). Both lakes are presently classified as eutrophic or hypereutrophic. The lakes now show higher levels of algae production and the related taste and odor problems have increased the costs for water treatment by the City of Tulsa. The City of Tulsa is presently in litigation with the Poultry Integrators over the role of poultry production and poultry waste disposal within the watershed.

The poultry industry in the United States is the world's largest producer and exporter of poultry meat. Since the year 1980, the Eucha-Spavinaw watershed has supported a rapid increase in the commercial poultry industry, especially broilers (Figure 1). It is estimated that the watershed has the capacity to produce over 8 million chickens, along with some 1,500 ton of phosphorous per year.

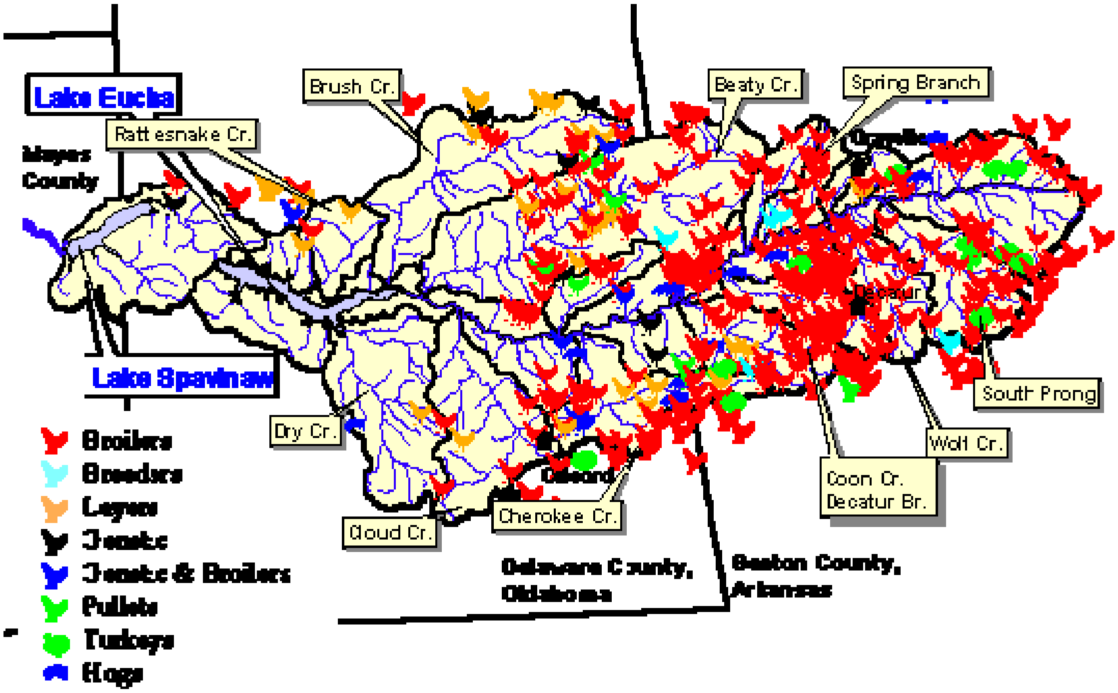

Figure 1. Map of Eucha-Spavinaw watershed with poultry farms, available online at http://www.tulsawater.com/eucha.html

According to the 2006 Poultry - Production and Value Report by the United States Department of Agriculture (USDA 2006), the total number of broilers produced in 2005 for Oklahoma and Arkansas were 0.25 billion and 1.21 billion, respectively (USDA 2006, 2002). The distribution of this poultry production within the Eucha-Spavinaw watershed for the last 50 years is presented in Table 1. As illustrated for yearly broiler sales in Figure 2, poultry production began to accelerate dramatically in the early 1980's.

In poultry feed, trace minerals are commonly used as additives. These feed additives can enhance immune function and disease resistance. In 1981, Underwood suggested that there were 22 minerals categorized as essential (Underwood and Suttle 1999) and include zinc, copper, manganese, molybdenum, selenium, and arsenic. As a result of these additions to poultry feeds, poultry waste normally contains higher concentrations of certain trace minerals.

Organoarsenicals, such as p-arsanilic acid and roxarsone (3-nitro-4-hydroxy-phenylarsonic acid), are commonly used as a growth stimulant antimicrobials to improve poultry production efficiency. Most of the arsenic fed to broilers is excreted (Laski, Sun et al. 2004).

The rapid growth of the poultry industry has produced a staggering amount of poultry waste. The most inexpensive way to treat poultry wastes with high nutrient content is through land disposal (Sims and Wolf 1994). Land disposal of poultry wastes may produce an accumulation of trace metals in soil and water system. Previous studies have raised concerns regarding application of poultry manure containing the organoarsenical feed additive roxarsone (Garbarino, Bednar et al. 2003; O'Connor, O'Connor et al. 2005; Cortinas, Field et al. 2006).

Table 1. Agricultural activity in the Eucha-Spavinaw watershed (estimated from USDA data)

Year	TOTAL Pasture (acres)	TOTAL Cropland (acres)	TOTAL Broiler Sales (birds)	TOTAL Cattle and Calves Sold (individuals)
2002	75,861	83,488	38,215,494	27,508
1997	80,970	87,360	34,003,897	24,701
1992	74,048	83,360	27,561,817	22,544
1987	85,299	82,953	18,928,529	23,255
1982	78,107	77,039	13,848,852	20,945
1978	87,082	77,856	10,049,832	25,678
1974	133,041	74,549	9,783,270	19,703
1969	134,188	85,962	10,344,923	21,601
1964	126,190	70,903	8,891,238	11,565
1959	156,503	79,871	5,788,672	13,230
1954	182,748	75,721	3,329,527	11,326

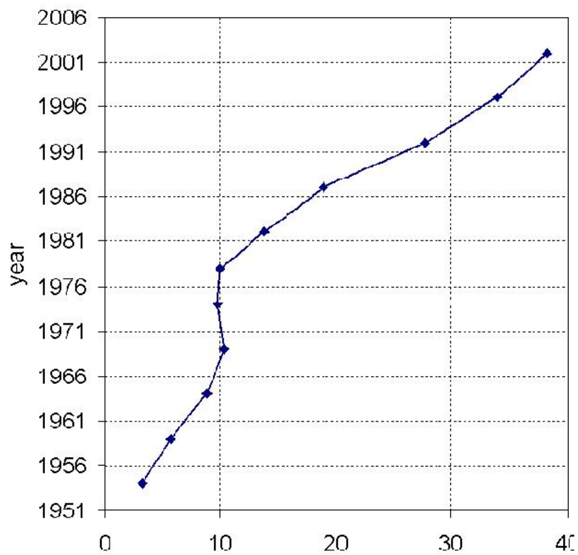

Fig. 2. Total broiler sales per year (in millions)

Nearly all the roxarsone used as an additive in chicken feed is excreted unchanged and is relatively stable in fresh dried poultry waste (Morrison 1969); however, during storage and land disposal (as fertilizer), arsenic species in poultry waste are degraded from roxarsone to arsenate, a more toxic inorganic species (Arai, Lanzirotti et al. 2003; Garbarino, Bednar et al. 2003; Jackson, Bertsch et al. 2003). Under anaerobic conditions, the degradation product of roxarsone and related N-substituted phenylarsenic acids is arsenite (Cortinas, Field et al. 2006).

This research examines the sedimentary history of Lakes Eucha and Spavinaw. The dates of sediment deposition were determined by using both ^{210}Pb and ^{137}Cs gamma spectrometric dating methods (Appleby and Oldfield 1992; Dabous 2002). Trace metals within the sediments were analyzed using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS).

Materials and Methods

Sediment cores were collected by SCUBA divers on June 2005 from Lakes Eucha and Spavinaw. Lake Eucha is located approximately 6 miles south the city of Jay, Delaware County, Oklahoma, USA, off SH-10 and US-59. Lake Spavinaw is located approximately 4 miles downstream of Lake Eucha. The Eucha-Spavinaw watershed is located on the border of Northeastern Oklahoma and Northwestern Arkansas. Coring of the sediments was done using clear polycarbonate core tubes with a 3-mm wall thickness. The inside diameter of the tubes was 5 cm. The tubes were sealed with plastic caps on top and on the bottom, in situ, until ready to be sectioned off. The cores were maintained vertically to avoid disturbances. After arriving on land, the cores were prepared to be sectioned. The water inside the tubes was siphoned slowly so that no sediment was lost, and the bottom cap was released while the tube was placed

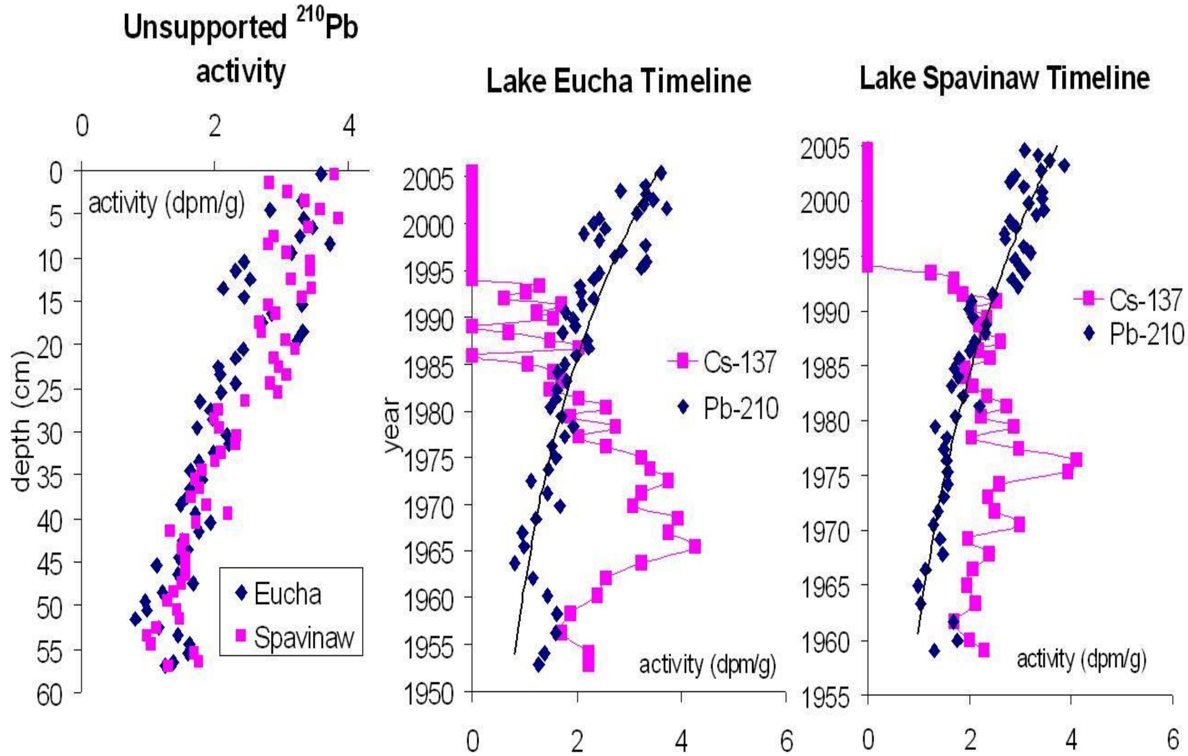

Fig. 3: Plot of unsupported ^{210}Pb with depth for Lakes Eucha and Spavinaw; ^{210}Pb and ^{137}Cs activity and time of deposition for Lakes Eucha and Spavinaw

onto a base plate with an incremental extrusion rod such that sections were sliced at 1 cm increments. The sectioned material was processed for water content by drying at 85^{o}C, and ground by hand using a mortar and pestle. Individual aliquots were taken for gamma spectrometry and trace metals analyses.

Gamma spectrometry was done using 4.0 gram samples in a sterile plastic petri dish (85mm x 15 mm) as a container. The petri dish was sealed by applying a thin layer of methylene chloride along the seam and samples were equilibrated for one month to allow for daughter product equilibration before gamma spectrometric analyses (24 hours, using a Low Energy Germanium (LEGe) detector model GL2020R from CANBERRA).

Acid digestion for trace metals analysis was performed using the EPA standard method 3050B which uses 1.0 gram of dry sample digested with repetitive addition of high purity nitric acid (HNO_3) and hydrogen peroxide (H_2O_2). ICP-MS analyses were performed using the ELAN® 6100 DRC II ICP-MS from PerkinElmer Instruments which uses ammonia with its dynamic reaction cell to eliminate interference for As, Fe, Cr and Se analytes. Combo multi- elements standard and internal standard solutions used were provided by PerkinElmer with catalog #N9301721 in 5% HNO_3 and #N9301722 in 2% HNO_3 respectively. For metal analyses with ICP-MS, 15-mL plastic tubes were used as sample containers. External standards with concentration of 1, 10 and 50 ppb were used for calibration. External standards were made of the multi-elements standard stock solution from PerkinElmer (catalog #N9301721 in 5% HNO_3). Nitric acid and water used for preparation of external standards were of high purity. Samples were diluted 10 times using 1% HNO_3 prior to analyses. Twenty ppb of internal standard (catalog #N9301722 in 2% HNO_3) were added to each external standards and samples prior to analyses. Calibrated micropipettes with sterile plastic tips were used for transferring internal standard solution to the samples and to the external standards.

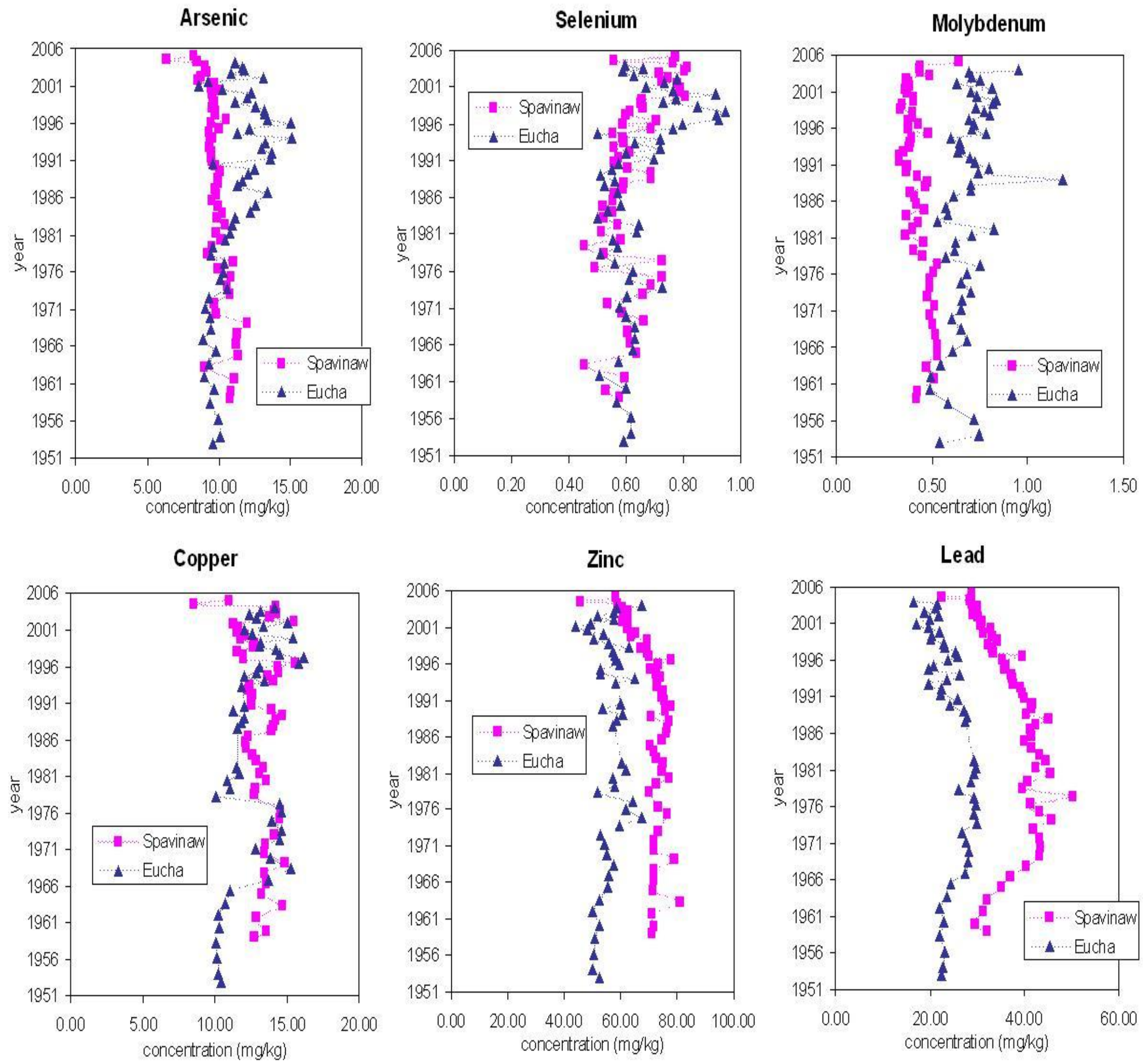

Figure 4. Plots of concentration of trace metals versus depositional year for Lakes Eucha and Spavinaw

Results and Discussion

Geochronology using ^{210}Pb and ^{137}Cs

The geochronology of the lakes sediments were determined using ^{137}Cs and ^{210}Pb dating (Figure 3). The year of deposition was calculated using a constant initial concentration model, which assumes that the initial activity of unsupported ^{210}Pb is the same at all depths. ^{210}Pb is a naturally occurring radioisotope in the ^{238}U decay series. Unsupported ^{210}Pb, that is the isotope derived from atmospheric deposition, was determined by difference between the total ^{210}Pb and supported ^{210}Pb (derived from decay of *in situ* ^{238}U). The sediment cores date to the 1950's.

The maximal ^{137}Cs activity, derived from atmospheric nuclear testing, is generally considered to have occurred in mid-1960. Sediments in Lakes Eucha and Spavinaw show maximal ^{137}Ca activity which corroborates the ^{210}Pb dating to the mid-1960's (Figure 3).

Trace metals analyses

Trace metal concentrations in Eucha and Spavinaw sediments are presented in Figure 4. Plots of arsenic, selenium, and molybdenum show increases beginning in the early - to mid-1980's, predominantly in Lake Eucha.

The increase of arsenic and selenium concentration in Lake Eucha began in the early 1980's. There is no significant change for arsenic concentration throughout the sediment profile in Lake Spavinaw. The increase of arsenic and selenium concentrations in Lake Eucha is time- correlative with the growth of poultry industry within the watershed.

Both arsenic and selenium are commonly used as additives in poultry feed. The changes of arsenic and selenium concentration in Lake Eucha suggest that Lake Eucha sediments are acting as a sink for arsenic and selenium released to the environment as a result of poultry waste application within the watershed.

Copper, zinc and lead concentrations show minor variability between Eucha and Spavinaw. The decreasing concentration of lead in both lakes shows a correlation with the ban of leaded gasoline usage in the United States beginning in 1970's. Copper increases slightly in the more recent sediments for both lakes, whereas zinc decreases showing a consistently higher level in Spavinaw.

Conclusions

Lake Eucha and Spavinaw sediments display changes over the last 50 years that are time-correlated with increased poultry production in the watershed.

Arsenic and selenium are commonly used additives in poultry feed. Both of these contaminants have increased in Lake Eucha beginning in the early to mid 1980's. At present, we do not know if molybdenum is added to poultry feed, but our data suggests that is has been. Independent studies on the trace metal contents in poultry feed are underway.

Finally, differences in arsenic concentration in Lake Eucha and Spavinaw sediments suggest selective bio-trapping in Lake Eucha.

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Information Transfer Program

Activities for the efficient transfer and retrieval of information are an important part of the OWRRI program mandate. The Institute maintains a website on the Internet at URL http://environ.okstate.edu/owrri that provides information on the OWRRI and supported research. The site provides links to information on publications of the Institute, grant opportunities and deadlines, and any upcoming events. Abstracts of technical reports and other publications generated by OWRRI projects are updated regularly and are accessible on the website.

The OWRRI produces a quarterly newsletter entitled "The Aquahoman" to disseminate research results and provide information on upcoming events and grant competitions.

The OWRRI sponsors a water research symposium in the fall of each year at which OWRRI sponsored projects are presented. In addition, to keep state water professionals apprised of our work, updates on current-year projects are presented at the OWRRI’s Water Research Advisory Board, which consists of representatives from 21 state and federal water agencies, and non-government organizations.

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	7	0	0	0	7
Masters	3	0	0	0	3
Ph.D.	3	0	0	0	3
Post-Doc.	0	0	0	0	0
Total	13	0	0	0	13

Notable Awards and Achievements

In 2006, OWRRI continued its emphasis on expanding its outreach efforts. This has taken several forms. The annual water conference was held in Oklahoma City and attended by over 100 researchers and agency personnel. This meeting provides a much-needed opportunity for professionals to learn about recent water research in the state.

In January, the second annual Water Research Advisory Board (WRAB) meeting was held. The WRAB brings together representatives of state and federal agencies and NGOs with an interest in water research to learn about current OWRRI research, set priorities for the following year’s competition, and recommend proposals for funding in the ensuing year. This meeting was a significant success. Several attendees mentioned that not only did they benefit from hearing the presentations but also from the opportunity to discuss issues with the other water agencies in the state.

Also in 2006, OWRRI culminated two years of discussions and planning with the Oklahoma Water Resources Board (OWRB) on the update of the state’s comprehensive water plan. As a result, the OWRB contracted with the OWRRI to conduct an extensive public input component for the update. This effort will involve holding 68 public meetings across the state over the next four years to gather, consolidate, and prioritize citizens’ concerns, and then, develop policy recommendations regarding state water issues. As part of this effort the OWRB has joined the OWRRI in funding research to address the state’s water planning needs by providing a match to the money provided by the US Geological Survey. In addition, the OWRB and the OWRRI agreed to hold their annual water conferences in conjunction this year in celebration of the fiftieth anniversary of the founding of the OWRB and to promote the revision of the comprehensive water plan.

Publications from Prior Projects

1. 2005OK42B ("Estimating the orientation and intensity of fractures in sedimentary rocks using multi-component 3-D ground-penetrating radar (GPR)") - Articles in Refereed Scientific Journals - This article will appear in a very widely-read publication of the Society of Exploration Geophysicists

in August 2007. The experimental results reported in this article are of considerable interest to the geophysical community studying seismic and radar resposes to fractures. Ramirez, David, Roger Young; 2007, Fracture Orientation Determination in Sedimentary Rocks Using Multicomponent Ground Penetrating Radar Measurements. The Leading Edge, vol 26 (8).

2. 1967OK011A ("Biological Fixation and Transformation of Nitrogen in Small Impoundments") - Articles in Refereed Scientific Journals - This project contributed to the publication "Nitrate in Ground and Surface Waters In the Vicinity of a Concentrated Animal Feeding Operation" in the journal "Archic fuer Hydrobiologie" May 2006, pp. 67-77. Non-point source pollution by Nitrates (NO3) from fertilizers and animal wastes has potential effects on human health and eutrophication of surface waters. Until now one problem in determining sources of NO3 has been the difficulty of identifying origin. Stable isotopes of nitrogen can be used as a signature of NO3 to identify origin from animal wastes. NO3 derived from animal waste has a [Delta raised to the 15th power]N signature of +10 +20%, which is uniquely high compared to [Delta raised to the 15th power]NO3 from other sources. The purpose of this research was to describe the distribution of [Delta raised to the 15th power]NO3, NO3, and Cl in wells, springs, seeps and lakes in the vicinity of a concentrated animal feeding operation (CAFO), which was the suspected source of contamination. Nitrate concentrations and [Delta raised to the 15th power]NO3 were higher in wells just below the waste spray area of the CFO than above it. Chloride ion concentrations in wells confirmed a contaminated area below the waste spray area. Surface water samples had a wide range of NO3 concentrations and were uncontaminated, except for samples from one seep and one spring. However, the mean [Delta raised to the 15th power]NO3 in samples from springs were +3.9 to +5.0%, values that are in a range reported for soil NO3. Thus, although data are not available on groundwater movement, both stable isotope signatures and chloride concentrations indicate that animal wastes were the source of NO3 contaminations.
3. 1972OK023A ("Nitrogen Turnover in Impoundments") - Articles in Refereed Scientific Journals - This project contributed to the publication "Nitrate in Ground and Surface Waters In the Vicinity of a Concentrated Animal Feeding Operation" in the journal "Archic fuer Hydrobiologie" May 2006, pp. 67-77. Non-point source pollution by Nitrates (NO3) from fertilizers and animal wastes has potential effects on human health and eutrophication of surface waters. Until now one problem in determining sources of NO3 has been the difficulty of identifying origin. Stable isotopes of nitrogen can be used as a signature of NO3 to identify origin from animal wastes. NO3 derived from animal waste has a [Delta raised to the 15th power]N signature of +10 +20%, which is uniquely high compared to [Delta raised to the 15th power]NO3 from other sources. The purpose of this research was to describe the distribution of [Delta raised to the 15th power]NO3, NO3, and Cl in wells, springs, seeps and lakes in the vicinity of a concentrated animal feeding operation (CAFO), which was the suspected source of contamination. Nitrate concentrations and [Delta raised to the 15th power]NO3 were higher in wells just below the waste spray area of the CFO than above it. Chloride ion concentrations in wells confirmed a contaminated area below the waste spray area. Surface water samples had a wide range of NO3 concentrations and were uncontaminated, except for samples from one seep and one spring. However, the mean [Delta raised to the 15th power]NO3 in samples from springs were +3.9 to +5.0%, values that are in a range reported for soil NO3. Thus, although data are not available on groundwater movement, both stable isotope signatures and chloride concentrations indicate that animal wastes were the source of NO3 contaminations.