Oklahoma Water Research Institute
Annual Technical Report
FY 2001

Introduction

The Environmental Institute at Oklahoma State University has as its mission to serve as a center for stimulation and promotion of interdisciplinary research, graduate education and public education relating to understanding, protecting, utilizing and sustaining the natural environment. The University Center for Water Research (UCWR) is an integral part of the Institute's research efforts and is responsible for developing and coordinating water research funded through two programs: Oklahoma Water Resources Research Institute (OWRRI)funded by the Department of Interior through the U.S. Geological Survey and the Water Research Center (WRC) funded by the State of Oklahoma. The primary objective of the UCWR is the promotion of research of water related issues that are not only of national and regional concern, but also address the needs of Oklahoma.

The federally supported Oklahoma Water Resources Research Institute is one of 54 Water Institutes created under Section 104 of the Water Resources Research Act. In Fiscal Year 2001, the $75,321 grant to the OWRRI was used to support three research projects and water research administration and development activities as well as the information transfer program. The three research projects supported by the OWRRI program are as follows:

Project OK4441 Springs in Peril: Have Changes in Groundwater Input Affected Oklahoma Springs?, assessed the status of Oklahoma springs with respect to groundwater input, and the effects of altered groundwater flow rates on spring biota.

Project OK4461 Enhanced Life Cycle Assessment (ECLA): Analysis to Guide Environmental Technology Implementation, develops an Enhanced Life Cycle Assessment (ECLA) framework for the integrated assessment of the implementation of environmental technologies.

Project OK4481 Resistance Tomographic Imaging, Digital Mapping and Immersion Visualization of Evaporite Karst in Western Oklahoma investigates a novel and innovative procedure that combines Electrical Resistivity Tomography (ERT), digital mapping and immersion visualization hardware and software to provide a digital image of subsurface conduit networks in a karst environment.

Research Program

Basic Information

Title:	Springs in Peril: Have Changes in Groundwater Input Affected Oklahoma Springs?
Project Number:	2001OK4441B
Start Date:	3/1/2001
End Date:	2/28/2003
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, None, None
Descriptors:	invertabrate fauna, biomonitoring, temporal change, dewatering, springs,groundwate-surface water interactions
Principal Investigators:	, Elizabeth A. Bergey

Publication

1. Bergey, E. 2002. OBS Research Projects: A Survey of Oklahoma Springs. Biosurvey News. Oklahoma Biological Survey. Spring Newsletter, pp 3-4.

Springs in Peril: Have Changes in Groundwater Input Affected Oklahoma Springs?

Problem and Research Objectives

Groundwater is an extremely important commodity to Oklahoma, with heavy use by agriculture, industry, municipalities, and private landowners. Groundwater is also critical for wildlife and for maintaining the high-quality outdoors environment of Oklahoma, especially through the influence of groundwater on springs and on stream flows.

Springs, by definition, are the areas where groundwaters emerge and become surface waters. As a habitat, springs share characteristics of both underground waters (nearly constant temperatures and water flow, and low oxygen concentration) and surface waters (light and algal growth, inputs of dead plant material, and the water-air interface which allows gas exchange and colonization by flying insects). Typically, springs have a characteristic fauna that may include certain fishes and a predominance of non-flying invertebrates, such as snails and flatworms.

The extensive use of groundwater in Oklahoma and surrounding states may reduce water levels in some Oklahoma aquifers, with consequent partial or complete dewatering of the associated springs. In fact, springs provide an excellent point to monitor quantitative and qualitative changes in groundwater resources (Williams and Danks, 1991). Such reduction in spring flows may adversely affect the plants and animals living in spring, especially those species that are spring specialists.

Objectives: The research will assess (1) the flow status of springs in Oklahoma, and (2) the effects of altered flow rates on spring biota. Discharge data and invertebrate surveys from 50 springs collected in 1981-1982 (existing data from a previous OWRRI project; Matthews et al.1983) and in 2001-2002 (this proposal) will be used to assess changes in groundwater discharge into springs and how these changes affect the invertebrate fauna of springs.

Specific objectives of the project are:

A. Estimate the extent of groundwater flow changes into springs throughout Oklahoma.
B. Determine if changes in spring conditions over the past 20 years have affected spring invertebrate communities.
C. Determine whether some types of springs are more susceptible to flow reduction than other types of springs.
D. Identify possible indicator species that either appear or disappear in flow-impacted springs.
E. Increase the knowledge base of the biodiversity and distribution of spring-dwelling invertebrates.
F. Train one graduate student to work on the springs of Oklahoma.
G. ‘Re-use’ data from the project by adding data to the OBS database, to be used, for example, in future research projects by external researchers.
H. Disseminate information and results in a final report, by developing a project website, presenting results at one or more meetings, and writing one manuscript.

Addition to objectives. In addition to sampling invertebrates at each spring, fish were collected, when present. Fish were collected in the 1981-1982 study and their inclusion in this study adds to the information gained about changes in the biota over the 20-year period. Fish were not included in the original proposal because there was insufficient time to obtain the required approval for research involving vertebrates by the University of Oklahoma. Approval has since been obtained (see copy of the letter in Appendix 1).

Methodology

The study hinges on the comparison of two datasets of spring surveys, one collected in 1981-1982 and the other collected in 2001. In order to have comparable surveys, the methods used in the 2001 springs survey closely followed those of the previous survey. Descriptions of the methods used in the 1981-1982 surveys are found in the final project report (Matthews et al. 1983), manuscripts (Matthew et al. 1985), and in the hardcopy files from the project.

Field sites. The 50 spring sites were originally selected because they had enough flow to be used as a water supply (with a few exceptions), were good sites for monitoring particular aquifers, and had landowner permission for privately owned sites. The 50 sites are located in 29 Oklahoma counties (Figure 1) and in 8 aquifers (Appendix 2).

The first step was to re-locate the 50 sites. Some sites were easily located; others were not. Difficult sites to find were not marked as springs on the 1:24,000 topographic maps and had known locations only to the section. Likely locations of springs were chosen from maps and county assessors kindly provided the names and addresses of potential landowners.

Each potential landowner was sent a letter explaining the project and asking permission to sample the spring. Also included was a questionnaire for owners to complete. The goal of the questionnaire was to get information on flow variability and flow trends over time, and land use changes that might not be apparent during one-time visits to the springs. A copy of the questionnaire is found in the Appendix 3A. Despite advance preparation, several sites were located by asking local residents.

As in the earlier survey, springs were surveyed during the summer. A standard data sheet was designed for the project, to ensure that complete set of data was collected at all sites. Data and samples collected at each spring included:

- A description of the spring site. This description included a diagram of the spring, directions to re-locate the site, GPS readings, and information on local land use, alterations to the spring, and the vegetation in and near the spring.
- Measurement of several physical and chemical parameters: including, pH; water temperature; conductivity; water widths, depths, and velocities. Discharge (the quantity of water flow per time, as liters per second) was calculated from the last three variables.

- Sampling for aquatic invertebrates. Qualitative sampling followed the 1981-1982 sampling protocol and included dip-netting, picking organisms off stones, and collecting leaf packs, which were preserved and later searched for invertebrates in the laboratory. Additionally, 3 to 6 core samples (diameter = 10.2 cm) were collected at each site. Invertebrate samples were preserved in 70% ethyl alcohol.
- Sampling for fish. Springs were seined with a fine-meshed (3 mm openings) seine and representatives of each species caught were preserved in 10% formaldehyde. The majority of captured fish were released.

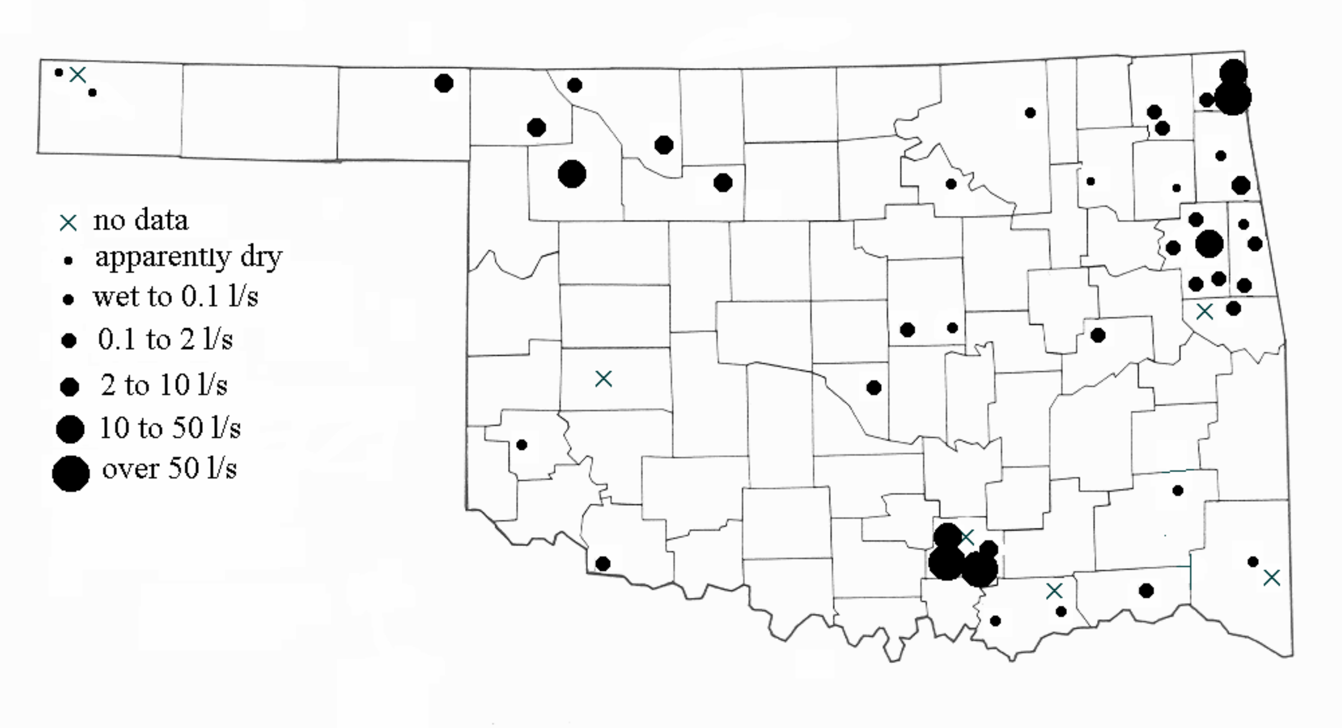


Figure 1. Location of the 50 springs sampled in 1981-82 and in 2001. The calculated discharge of each spring during the 2001 sampling is indicated by the symbol marking each spring (see legend).

Physical/chemical data (including water flows and habitat information)

Measurements for discharge were typically taken in the springbrook downstream of the springhead at a point were the water was relatively deep and there was an even bottom. In some cases, this was many meters below the springhead. Discharge was calculated by dividing the outflow stream into a transect of cells. The area of each cell was calculated as width x depth, and the cell-specific discharge was cell area x mean velocity of the cell. Velocities were measured with a Marsh-McBirney flow meter as feet/sec (to improve precision over a m/s reading). Depths were often very shallow (under 5 cm); but where deeper, velocities were read at 60% depth (the approximate mean velocity of the water column). At sites with an outflow through a pipe, discharge was measured as the time in seconds to nearly fill a one-gallon milk jug. All discharge measurements were converted to liters/second (= l/s).

Laboratory processing of biological samples. Fish samples were rinsed of formaldehyde, identified by Dr William Matthews (Curator of Fishes, Sam Noble Oklahoma Museum of Natural History, University of Oklahoma), and transferred to 70% ethyl alcohol. The fish samples will be curated (separated by species and appropriately labeled), and will be deposited in the fish collection at the SNOMNH.

Invertebrate collections are currently being processed. Most of the crayfish have been identified from 2001, and we are beginning to identify the crayfish from the earlier surveys (unfortunately, some of these samples were lost). Invertebrates in the qualitative (dipnet) and quantitative (core) samples are being separated from the detritus and substrate portions of each sample; a step that is necessary before invertebrates in the samples can be identified. Hence, the invertebrate data is not yet available for analysis.

Questionnaires. Questionnaires (see Appendix 3A) were completed for 39 of 50 sites. Landowners returned fewer than half of the questionnaires in the original mailing. Additional questionnaires were filled out by interviewing landowners during the fieldwork or during subsequent phone calls. Questionnaires were not completed where there was no identifiable ‘owner’ (especially sites on road easements) or owners who could not be contacted. Four questionnaires were ‘completed’ with no data because owners/managers were not very familiar with the springs. These four sites were the exception; most owners were very knowledgeable about their springs.

Summary of available data

- Site locations
- Discharge
- Questionnaire data
- Fish data
- Physical/chemical/habitat data

Site-specific locations. General location information for the 50 sites is found in Appendix 4. Most of the original sites were re-located exactly; exceptions are listed in Table 1. Access was denied at two sites; although partial information (and a completed questionnaire) was collected at one of these. One site (#40) was not a spring. This site was near a named spring (Gum Spring) and consisted of a hole that the landowner had dug with a backhoe next to the springbrook. I assume that the earlier field crew (which did not include the Principal Investigator) did not understand the nature of the ‘spring’. Some of the areas contained several springs and in four of these, the actual spring that was sampled was probably not the one sampled in 1981-2.

Table 1. Problematic sites in which, (1) the exact spring that was sampled in 1981-2 was probably not relocated in the 2001 survey, (2) field data is incomplete, or (3) the site is not a spring.

Spring	Site specific information
3	access denied by owner
5,8,22, & 27	a cluster of springs; the one sampled in 2001 may not have been the same one sampled in 1981-1982
12	can't tell if its the same location (major habitat alteration)
29	site was recorded wrong in 1981-82; no springs nearby
38	owner restricted data collection
40	site sampled was not a spring
48	missing, presumed dried; possibly covered by logging road (which had a wet spot)

Principle Findings and Significance.

Discharge. Spring discharge ranged from 0 to 236 liters/minute (=l/m) with an average of 16 l/m. Spring-specific discharges are shown graphically in Figure 1 and listed in Table 2. Several sites had no discharge, either because there was standing water but no outflow, or the spring was dry.

Discharge varied among aquifers (aquifers are shown in Appendix 2). The Simpson/Arbuckle Group (in the Arbuckle Mountains) had the highest average discharge of about 77 l/s. At the other extreme, three aquifers (the Trinity Group, Garber Sandstone, and Vamoosa Formations) had mean discharges of less than 1.0 l/s. The Ogallala Aquifer averaged 3.2 l/s, despite two of the three springs being dry. The third spring (# 27) is located near the division of the Ogallala Aquifer and the alluvial & terrace deposits near the Cimarron River; if the spring is actually has an alluvial / terrace origin, the mean flow for the measured Ogallala sites would be 0.0 l/s.

The flow 'health' of an aquifer may be indicated by a comparison between the mean spring discharge and the potential yield of the aquifer. The resulting percents of spring discharge to historic potential yield are shown in Table 3. Springs in the Keokuk & Reeds Springs Formations and the Simpson / Arbuckle have mean discharges exceeding the estimated maximum yields from the aquifers, indicating that these sets of springs have a 'healthy' discharge. In contrast, springs in the Trinity Group have discharges that are small relative to the historical potential yields, which may indicate reduced discharges since 1972 in these springs. Garber Sandstone and Vamoosa Formations likewise have relatively small average discharges, but the sample size of only two springs in each is too small to draw conclusions. The Ogallala Formation has a moderate percent discharge, but if spring # 27 is instead an alluvial / terrace spring, the percent discharge drops to zero (there is no flow).

Table 2. Site-specific discharge of the 50 springs, as measured in summer, 2001. Aquifers were designated as in 1981-2. For Discharge, 'NA' = not available, '0' = spring had standing water but no outflow, '0.0 (dry)' = spring was dry. Springs with fish are also indicated.

Spring number	Discharge (l/s)	Aquifer	Notes	Fish present?
1	7.2	Simpson	water is pumped for a fish farm	yes
2	NA	Simpson	spring is in a flow-through pond	yes
3	NA	Trinity	denied access by owner	
4	0	Trinity		
5	0.02	Trinity		
6	136.2	Simpson		yes
7	28.98	Simpson		yes
8	136	Simpson		
9	0.11	alluvial and terrace		
10	0.0 (dry)	alluvial and terrace		
11	0.33	Keokuk & Reed		
12	0	Keokuk & Reed		yes
13	9.84	Keokuk & Reed		
14	0.41	Keokuk & Reed		
15	0.09	Keokuk & Reed		
16	12.81	Keokuk & Reed		
17	1.87	Keokuk & Reed		yes
18	1.7	Keokuk & Reed		
19	1.76	Keokuk & Reed		yes
20	1.56	Keokuk & Reed		
21	1.1	alluvial and terrace		yes
22	2.6	alluvial and terrace		yes
23	4.31	alluvial and terrace		yes
24	0.67	alluvial and terrace	shoreline seeps not included	
25	3.83	alluvial and terrace		
26	12.67	alluvial and terrace		
27	9.67	Ogallala		yes
28	0.0 (dry)	Ogallala		
29	NA	Ogallala	site was not found	
30	0.0 (dry)	Ogallala		
31	0	Vamoosa		
32	0.02	Vamoosa		
33	0.0 (dry)	alluvial and terrace		
34	0.24	alluvial and terrace		
35	0.24	Keokuk & Reed		yes
36	0.11	Keokuk & Reed		
37	46.91	Keokuk & Reed		yes
38	236.14	Keokuk & Reed		yes
39	0.58	Keokuk & Reed		

Spring number	Discharge (l/s)	Aquifer	Notes	Fish present?
40	NA	alluvial and terrace	not a spring	
41	0.67	alluvial and terrace		
42	0	alluvial and terrace	some may be pumped by neighbor	
43	NA	Rush	inundated	yes
44	0.44	Garber Sandstone		
45	0.59	Garber Sandstone		
46	0.073	alluvial and terrace		yes
47	0	Trinity		
48	0	Trinity		
49	0	Trinity		yes
50	0.19	Trinity		

Table 3. Aquifer-specific discharge of the 50 springs in the study. SE = +/- 1 standard error from the mean.

Aquifer	Total no. of springs	No. of dry springs[1]	No. of springs used in calculation[1]	Mean discharge (l/s) (SE)	Maximum yield of aquifer[2] (l/s)	Mean as % of maximum yield
Keokuk & Reeds Springs Formations	15		15	21.0[3] (15.7)	3.2	665.6
alluvium & terrace deposits	14	2	12	2.2 (1.05)	31.6	7.0
Trinity Group (Antlers Sandstone)	7		6	0.04 (0.03)	63.1	0.06
Simpson / Arbuckle Groups	5		4	77.1 (34.4)	18.9 157.8	407.3 48.9
Ogallala Formation	4	2	3	3.2 (3.2)	63.1	5.1
Garber Sandstone / Wellington Formation	2		2	0.5 (0.1)	18.9	2.6
Vamoosa Formation	2		2	0.01 (0.01)	9.5	0.1
Rush Springs Sandstone	1		0		31.6	

[1] Not all possible springs were used in calculating aquifer-specific mean discharges or determining dry springs because some springs were not found and / or discharge could not be accurately measured.

[2] Data are modified by conversion of units from Johnson et al. 1972.

[3] If site #38 (a very high discharge site) is excluded, the mean drops to 5.6 l/s (SE = 3.3).

Other indicators of spring 'health'. Changes in the discharge of individual springs were assessed by (1) comparing velocity and discharge data among years and (2) examining the responses in the owner questionnaires. Unfortunately, the flow data from 1981 was not as detailed as expected and earlier discharges could not be calculated. The exception was site #

50, in which the water flowed out of a pipe, and timing the filling of a container gave a good discharge measurement. Additionally, velocities were listed as 'negligible' or 'unmeasurable' for 18 springs in 1981. Data from 1982 were scantier. Instead, velocity, depth and width (components of discharge) were compared among years, and changes in sketches of the sites were also noted. In the questionnaires, owners were specifically asked whether spring flow had changed during the last 20 years (see questionnaire form in Appendix 3A). Spring-specific results are shown in Appendix 5.

The questionnaire data, although incomplete, provide a clearer picture of temporal flow changes in the springs. Owner knowledge (as sampled by the questionnaire) is not hampered by comparisons between two different field teams that each used a different method to describe flows, or by the point measurements of flow 20 years apart (when flow is likely variable from year-to-year). Unfortunately, not all owners were familiar with their springs throughout the period, nor were questionnaires completed for all sites. Questionnaire data, supplemented and amended by field data, were used for temporal analysis.

Thirty-two (64 %) of springs were classified for relative change in discharge over the 20-year period (Appendix 5). Over one-half (63 %) of these springs showed no change in discharge over the interval.

Relative change in discharge differed among aquifers (Table 4). Of seven aquifers, only two, the Simpson/Arbuckle and Garber Sandstone, had springs that all remained relatively constant. Both of these aquifers also had two or fewer springs with data, so this pattern may not hold for the aquifers' springs, as a whole. Discharge in most Keokuk & Reed Formation springs remained unchanged, but 20 % of these springs showed a decrease in discharge. Alluvium and terrace springs are a group of springs from several rivers that span most of the state. Hence, it is not surprising that the terrace alluvial springs vary in their temporal change. Although flow in most alluvium and terrace springs did not change, one spring had reduced discharge and, more notably, two springs dried. The dried alluvial/terrace springs are located in NE Oklahoma in the Verdigris River watershed.

Table 4. Summary of relative temporal change on spring discharge between 1981-82 and 2001. Data are from the table in Appendix 5 and are derived primarily from landowner questionnaires. Data are listed as 'number of springs' and as percentages of the springs with data (in parentheses).

	Number of springs					
Aquifer	**Total**	**With data**	**No change**	**Decrease**	**Dry**	**Increase**
Keokuk & Reed	15	10	8 (80 %)	2 (20 %)		
alluvium & terrace	14	10	7 (70 %)	1 (10 %)	2 (20 %)	
Trinity	7	5	2 (40 %)	2 (40 %)		1 (20 %)*
Simpson/Arbuckle	5	2	2 (100 %)			
Ogallala	4	2			2 (100 %)	
Garber Sandstone	2	1	1 (100 %)			
Vamoosa	2	2		2 (100 %)		
Rush	1	0				

* = The increased discharge of one spring was probably the result of a new outflow pipe that was installed by the county the previous year.

Springs associated with three aquifers were characterized by reductions in discharge over the 20-year period. Forty percent of the springs in the Trinity aquifer and all springs in the Vamoosa aquifer had noticeably reduced discharge, and both Ogallala springs dried. Each of these aquifers had few springs with data and additional data is needed to substantiate these preliminary findings.

Fish. The fish data have only been partly analyzed.

A total of 26 species of fish were found in 21 springs over the course of the three surveys (Appendix 6). In any year, fish were found in 14 to 18 springs; thus, there is year-to-year variation in which springs have fish at the time of sampling. Most of the fish species found in the springs are also common in streams, and fish may move between springs and streams. Hence, the absence of a fish species in a spring during some years may result from fish movements, combined with a one-time sampling (that is, fish that may normally be present may not be caught during sampling).

Overall, the fish fauna differed among springs and was characterized by a large number of species that occurred infrequently. Five species were common, occurring in 25 % or more of samples; in contrast, 11 species were collected only once during the three years of sampling.

Plans for this year. The questionnaire has been revised (see Appendix 3B), with the hope of (1) getting more specific information from landowners and (2) adding a request for historical use of springs. About 100 questionnaires (along with information about the study) will be mailed to potential owners of springs by the end of March. Some of these springs will be sampled as part of this project.

This summer, I will extend the fieldwork to include 20 to 30 additional springs. Springs in sparsely sampled aquifers. Such aquifers include the Trinity / Antlers Sandstone Group in the southeast corner of Oklahoma, and the Ogallala aquifer in the northeast corner of the state.

References:

Johnson, K. S., C. C. Branson, N. M. Curtis, Jr., W. E. Ham, W. E. Harrison, M. V. Marcher, and J. F. Roberts. 1972. Geology and Earth Resources of Oklahoma: An Atlas of Maps and Cross Sections. Oklahoma Geological Survey. 8 pp.

Matthews, W. J., J. J. Hoover, and W. B. Milstead. 1983. The biota of Oklahoma springs: Natural biological monitoring of ground water quality. Misc. Publ. Oklahoma Water Research Institute, Oklahoma State University, Stillwater, Oklahoma. 64 pp.

Matthews, W. J., J. J. Hoover, and W. B. Milstead. 1985. Fishes of Oklahoma springs. Southwest Nat. 30:23-32.

Williams, D. D., and H. V. Danks.1995. Arthropods of springs: Introduction. Mem. Ent. Soc. Canada 155:3-5.

List of Appendices

Appendix 1. Copy of letter from OU's Animal Care and Use Committee for sampling spring fish.

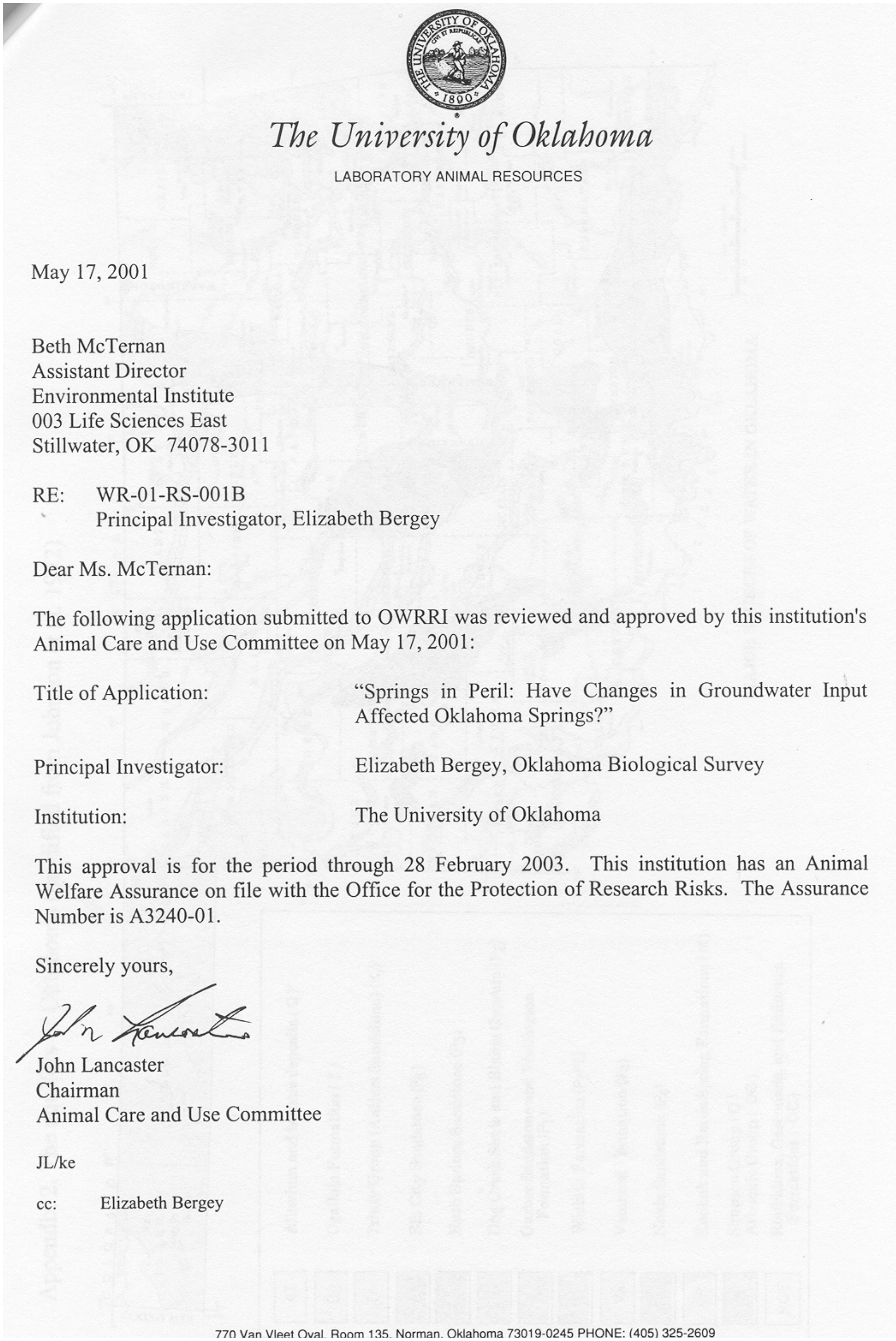
Appendix 2. Map of aquifers in Oklahoma.

Appendix 3. Questionnaires for the owners of springs (A) used in 2001 and (B) to be used in 2002.

Appendix 4. Spring location information.

Appendix 5. Spring discharge and questionnaire results.

Appendix 6. Fish data.



The University of Oklahoma
LABORATORY ANIMAL RESOURCES

May 17, 2001

Beth McTernan
Assistant Director
Environmental Institute
003 Life Sciences East
Stillwater, OK 74078-3011

RE: WR-01-RS-001B
Principal Investigator, Elizabeth Bergey

Dear Ms. McTernan:

The following application submitted to OWRRI was reviewed and approved by this institution's Animal Care and Use Committee on May 17, 2001:

Title of Application:	"Springs in Peril: Have Changes in Groundwater Input Affected Oklahoma Springs?"
Principal Investigator:	Elizabeth Bergey, Oklahoma Biological Survey
Institution:	The University of Oklahoma

This approval is for the period through 28 February 2003. This institution has an Animal Welfare Assurance on file with the Office for the Protection of Research Risks. The Assurance Number is A3240-01.

Sincerely yours,

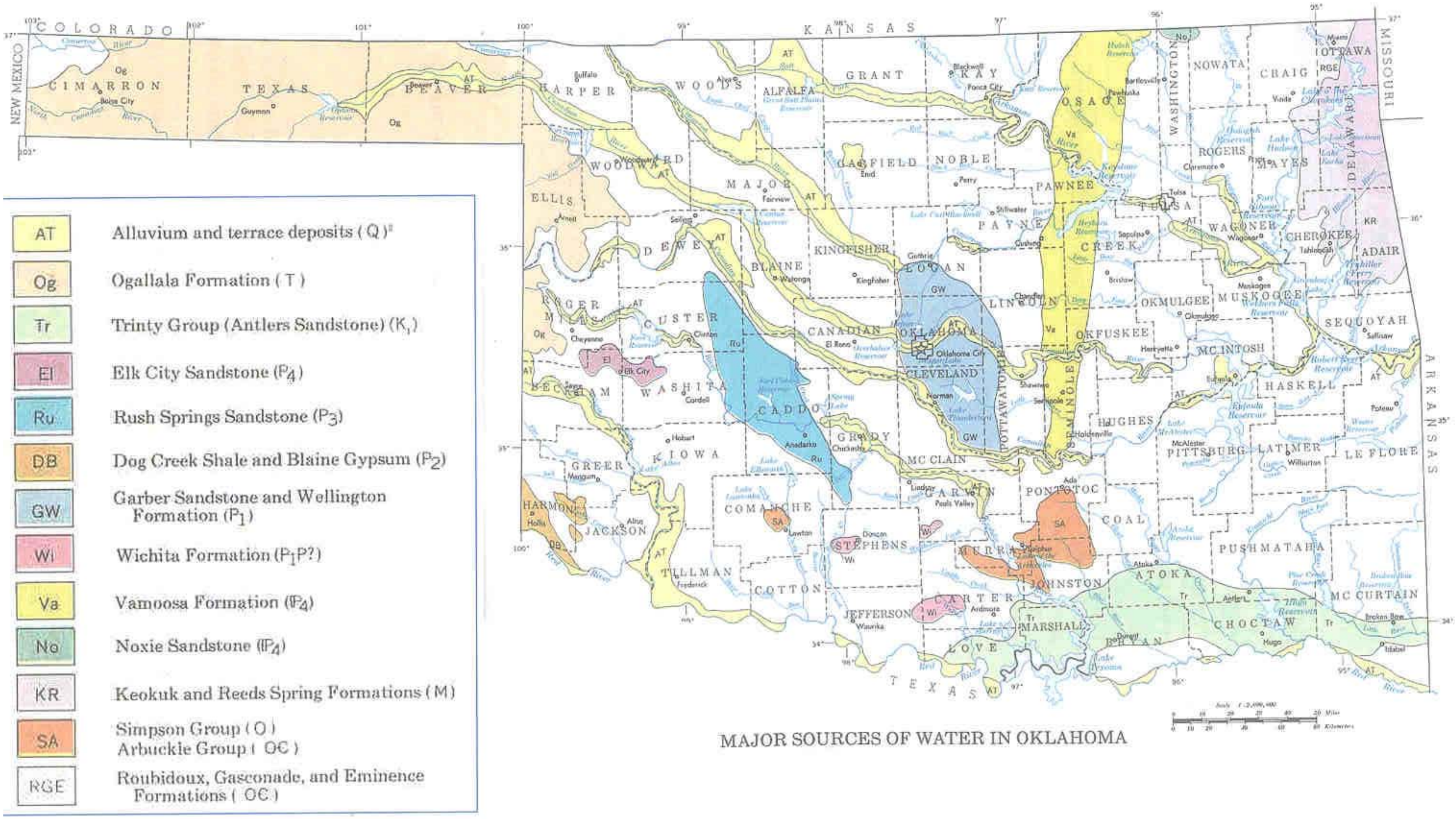
John Lancaster
Chairman
Animal Care and Use Committee

JL/ke

cc: Elizabeth Bergey

770 Van Vleet Oval, Room 135, Norman, Oklahoma 73019-0245 PHONE: (405) 325-2609

Appendix 2. The aquifers of Oklahoma (modified from Johnson et al. 1972)



Appendix 3A. Owner questionnaire used in 2001.

Spring name:
Spring location:
Owner:

1. Were you the property owner in 1981?
   If not, about how long have you owned the property? ________, and is there a person who might be more familiar with the spring over the last 20 years?

2. Does the spring ever dry completely? _______ Or dry only to an isolated pool? _______
   How often and how long?

3. Circle any of the recent summers in which the spring dried: 1997 1998 1999 2000

4. Is the flow steady during the year (for example is the flow the same in winter and summer)?

5. Does the water flow from the spring sometimes increase after rains?

6. Have you noticed that the water flow in the spring has shown a pattern of change over the years? _____. In particular, has the flow tended to (circle one)

increase a lot   increase slightly   not change   decrease slightly   decrease a lot

7. Do you know what may cause this water flow pattern? (if one was observed)

8. Have there been any land use changes in the vicinity of the spring or alterations to the spring in the past several years? (as examples, has grazing changed or has the spring been dammed?)

9. May I contact you for further information? _____ How may I contact you?
   ____

Appendix 3B. Questionnaire form for 2002 field season. (Spaces have been reduced.)

Spring name: Owner:
Spring location:

1. About how many years have you owned the property with the spring? _______
2. How familiar are you with your spring? (For example, do you see the spring frequently and would you notice year-to-year changes?) ________________________________
   (Note: if you know somebody who is more familiar with the spring, please give them this questionnaire or let me know, so that I can send them a questionnaire).
   ____
   ____

3. How has the spring been modified from the natural state (for example, does it have a spring box? has the springbrook been dammed to make a pond?) ___________________________________
   ____
   How is the spring used now? ____
   How has it been used in the past? ____
4. Check the description that matches your spring in the past few years (= Now) and in the past (=Past). This gives me an idea of what sorts of animals may live in your spring and whether the water flow I your spring is changing. Check all that apply.

Now	Past	
___	___	1. to my knowledge, the spring has never dried
___	___	2. runs well year-around in all years
___	___	3. runs year around in all years, but flow increases after rains
___	___	4. runs year around in all years, but flow decreases during dry weather
___	___	5. normally runs year around, but stops flowing (stays wet) in dry weather
___	___	6. normally runs year-around, but dries completely in very hot, dry weather
___	___	7. runs most of the year, but stops running (stays wet) when it's very dry
___	___	8. runs most of the year, but dries during the summer
___	___	9. is generally wet, but flows when there weather is wet
___	___	10. is generally wet year-around
___	___	11. is dry, but runs briefly after rains or wet weather
___	___	is dry and never runs

Comments, especially if the pattern of flow has changed or none of these fits your spring:

5. Has the area around the spring changed over the past several years? If so, How? (for example: no longer grazed; now dammed, springbox removed)

6. May I contact you for further information? __________ How may I contact you?
____

Appendix 4. Locations of the 50 springs that were sampled in 1981, 1982 and 2001. Locations are given to the nearest section to because most sites are privately owned and many owners did not want the exact locations disclosed. The date of the 2001 sampling is also listed.

Site	County	T/R/Sec	Date	Site	County	T/R/Sec	Date
1	Bryan	T1S R6E Sec.24	7/5/01	26	Woodward	T23N R20 Sec 23	6/19/01
2	Johnston	T1S R6E S12	9/25/01	27	Beaver	T5N R26E Sec 1	6/20/01
3	Bryan	T5S R12E S33	no access	28	Cimarron	T6N R50W Sec 31	6/20/01
4	Bryan	T6S R11E Sec 1	7/10/01	29	Cimarron	T6N R1E Sec 28?	not found
5	Bryan	T6S R7E Sec 24	7/10/01	30	Cimarron	T6N R4E Sec 10	6/20/01
6	Johnston	T1S R6E Sec 24	7/5/01	31	Pawnee	T22N R6E Sec 26	6/26/01
7	Johnston	T1S R6E Sec. 22	8/10/01	32	Osage	T25N R11E Sec 10	6/26/01
8	Johnston	T1S R6E Sec. 22	8/10/01	33	Rogers	T22N R15E Sec 10	6/26/01
9	McIntosh	T12N R15E Sec 5	7/13/01	34	Rogers	T24N R18E Sec 3	6/27/01
10	Mayes	T20N R20E Sec 4	7/28/01	35	Craig	T24N R21E Sec 11	10/4/01
11	Cherokee	T19N R21E Sec 35	7/17/01	36	Ottawa	T26N R24E Sec 8	6/27/01
12	Delaware	T22N R24E Sec 29	7/28/01	37	Ottawa	T27N R25E Sec 31	6/28/01
13	Delaware	T20N R25E Sec 36	7/17/01	38	Ottawa	T27N R25E Sec 31	6/28/01
14	Adair	T17N R26E Sec 9	7/19/01	39	Sequoyah	T13N R23E Sec 19	7/12/01
15	Adair	T18N R25E Sec 31	7/19/01	40	Sequoyah	T13N R21E Sec 8	7/12/01
16	Cherokee	T17N R22E Sec 33	7/18/01	41	Tillman	T4S R17W Sec 14	7/2/01
17	Cherokee	T17N R21E Sec 12	7/17/01	42	Greer	T6N R24W Sec 25	7/2/01
18	Cherokee	T15N R22E Sec 9	7/17/01	43	Washita	T10N R14W Sec 35	7/2/01
19	Cherokee	T15N R23E Sec 22	7/17/01	44	Cleveland	T10N R1W Sec 14	6/14/01
20	Adair	T14N R24E Sec 4	7/17/01	45	Lincoln	T12N R2E Sec 25	6/14/01
21	Garfield	T21N R8W Sec 26	6/22/01	46	Okfuskee	T12N R7E Sec 25	6/14/01
22	Major	T22N R10W Sec 27	6/22/01	47	McCurtain	T4S R24E Sec 27	7/11/01
23	Woods	T23N R15W Sec 13	6/21/01	48	McCurtain	T5S R25E Sec 1	7/12/01
24	Woods	T28N R18W Sec 2	6/21/01	49	Pushmataha	T1S R19E Sec 30	7/11/01
25	Harper	T26N R20W Sec 12	6/21/01	50	Choctaw	T6S R17E Sec 20	7/10/01

Appendix 5. Summary of results from field data and owner questionnaires on whether discharge in the 50 study springs has changed over the last 20 years. Because discharge was not measured in 1981-82, field data comparisons are limited to comparisons of water velocity and depth, spring width, and diagrams / measurements of each spring. Only data in the Questionnaire column was used for further analysis.

Spring number	**Field data: Change since 1981?**	**Field data: Notes**	**Questionnaire: Change since 1981?**
1	possibly reduced	lower velocity & depth	no
2	can't tell	habitat alterations	no
3		denied acess	
4	possibly reduced		decreased a lot
5	can't tell	not the same spot	no
6	can't tell	inadequate data	no
7	no evidence of change		unsure
8	can't tell	spring may have shifted	unsure
9	no evidence of change		no
10	apparently dry		[dry]*
11	can't tell	springbox had broken	no
12	can't tell	habitat alteration	no
13	possibly reduced	1 of 2 seeps was dry (or shifted)	no
14	can't tell	heavy siltation	no
15	possibly reduced	habitat alteration	no
16	can't tell	inadequate data	no
17	can't tell	habitat alteration	
18	possibly reduced	lower velocity & depth	
19	no evidence of change		
20	no evidence of change		decrease noticeably
21	possibly decreased	habitat alteration	no
22	no evidence of change		
23	no evidence of change		no
24	no evidence of change		no
25	no evidence of change		no
26	no evidence of change		decrease a bit
27	can't tell	same site?	seems deeper
28	dried		dried; decreased since 70's
29	can't tell	not found in 2001	
30	apparently dry		dried; ran in 1999 (wet yr)
31	apparently reduced	too low for a water supply	no [decrease]*
32	no evidence of change		decrease slightly
33	dried		[dry]*
34	no evidence of change		
35	possibly reduced	lower velocity; smaller pond	no
36	no evidence of change		
37	can't tell	spring shifted; slight increase?	decrease slightly
38	no evidence of change		no

39	possibly reduced	habitat altered; reduced vel. & width	
40	no evidence of change		no
41	no evidence of change		no
42	no evidence of change		no
43	can't tell	inundated; increase in adjacent stream	increase slightly [unsure]*
44	can't tell	overgrown with rushes	no
45	can't tell	inadequate data	
46	no evidence of change	pools appear bigger (erosion?)	
47	no evidence of change		decrease slightly
48	can't tell	possibly covered by logging road	
49	no evidence of change		
50	increased	greater discharge from new pipe	increase slightly

* Data in brackets was added from the field notes and consists of two dried springs (# 10 and # 33), a spring (# 31) that was used as a drinking water source in 1981-82, but did not flow in 2001, and a spring (# 43) was inundated by an impoundment and wasn't visible (the adjacent stream increased in flow as it was intermittent in 1981-82 and flowing in 2001).

Appendix 6. The occurrence of fish in the sampled springs. Data are from 1981,1982, and 2001. Fish were sampled qualitatively and data are in a presence (= 'x') / absence (= blank) format. A summary end of the table.

Spring number	1	1	1	2	2	2	6	6	6	7	7	7	8	12	12	16	17	17	17	18
Fish species **Year**	1981	1982	2001	1981	1982	2001	1981	1982	2001	1981	1982	2001	1982	1981	1982	1981	1981	1982	2001	1981
Ameiurus melas																				
Ameiurus natalis																				
Campostoma anomalum	x		x	x	x	x	x	x	x				x							
Cottus carolinae																				
Cyprinella lutrensis																				
Etheostoma cragini																				
Etheostoma microperca	x	x	x							x	x	x	x							
Etheostoma radiosum																				
Etheostoma spectabile	x	x	x	x	x	x	x	x	x		x	x			x		x	x	x	
Etheostoma whipplei																				
Fundulus notatus															x					
Fundulus zebrinus																				
Gambusia affinis	x	x	x	x	x	x	x	x		x		x	x	x	x					
Labidesthes sicculus															x					
Lepomis cyanellus			x		x			x						x	x					
Lepomis cyanellus ?																				
Lepomis humilus																				
Lepomis macrochirus															x					
Lepomis megalotis																				
Luxilus cardinalis																				
Luxilus chrysophelalus									x											
Micropterus salmoides																				
Notemigonus crysoleucas																				
Notropis stramineus																				
Phoxinus erythrogaster	x	x	x				x	x	x			x			x	x				x
Pimephales promelas																				
Semotilus atromaculatus															x					

Appendix 6. Continued.

Spring number	18	18	21	21	22	22	22	23	23	27	33	35	35	35	37	37	37	38	38	38	43
Fish species Year	1982	2001	1981	1982	1981	1982	2001	1981	2001	2001	1982	1981	1982	2001	1981	1982	2001	1981	1982	2001	1981
Ameiurus melas				X																	
Ameiurus natalis			X																		
Campostoma anomalum							X				X	X	X								
Cottus carolinae															X	X	X	X	X	X	
Cyprinella lutrensis			X	X	X	X	X														
Etheostoma cragini												X	X	X							
Etheostoma microperca																					
Etheostoma radiosum																					
Etheostoma spectabile													X	X							
Etheostoma whipplei																					
Fundulus notatus																					
Fundulus zebrinus			X		X	X	X														
Gambusia affinis										X		X	X	X							
Labidesthes sicculus																					
Lepomis cyanellus			X	X		X															
Lepomis cyanellus ?									X												
Lepomis humilus			X																		
Lepomis macrochirus																					
Lepomis megalotis			X	X		X															X
Luxilus cardinalis																X					
Luxilus chrysophelalus																					
Micropterus salmoides								X	X												
Notemigonus crysoleucas				X																	
Notropis stramineus					X	X	X														
Phoxinus erythrogaster	X	X														X					
Pimephales promelas			X	X							X										
Semotilus atromaculatus																					

Appendix 6. Continued

Spring number	43	44	46	46	46	49	49	49
Fish species **Year**	1982	1981	1981	1982	2001	1981	1982	2001
Ameiurus melas								
Ameiurus natalis								
Campostoma anomalum						x	x	x
Cottus carolinae								
Cyprinella lutrensis	x							
Etheostoma cragini								
Etheostoma microperca								
Etheostoma radiosum						x	x	x
Etheostoma spectabile								
Etheostoma whipplei					x			
Fundulus notatus								
Fundulus zebrinus								
Gambusia affinis		x	x	x				
Labidesthes sicculus								
Lepomis cyanellus			x	x	x		x	x
Lepomis cyanellus ?								
Lepomis humilus								
Lepomis macrochirus								
Lepomis megalotis	x							
Luxilus cardinalis								
Luxilus chrysophelalus								
Micropterus salmoides								
Notemigonus crysoleucas								
Notropis stramineus								
Phoxinus erythrogaster								
Pimephales promelas	x							
Semotilus atromaculatus								

	Number of springs			No. of
Fish species **Year**	1981	1982	2001	records
Ameiurus melas	0	1	0	1
Ameiurus natalis	1	0	0	1
Campostoma anomalum	5	6	5	16
Cottus carolinae	2	2	2	6
Cyprinella lutrensis	2	3	1	6
Etheostoma cragini	1	1	1	3
Etheostoma microperca	2	3	2	7
Etheostoma radiosum	1	1	1	3
Etheostoma spectabile	4	7	6	17
Etheostoma whipplei	0	0	1	1
Fundulus notatus	0	1	0	1
Fundulus zebrinus	2	1	1	4
Gambusia affinis	8	7	5	20
Labidesthes sicculus	0	1	0	1
Lepomis cyanellus	3	7	3	13
Lepomis cyanellus ?	0	0	1	1
Lepomis humilus	1	0	0	1
Lepomis macrochirus	0	1	0	1
Lepomis megalotis	2	3	0	5
Luxilus cardinalis	0	1	0	1
Luxilus chrysophelalus	0	0	1	1
Micropterus salmoides	1	0	1	2
Notemigonus crysoleucas	0	1	0	1
Notropis stramineus	1	1	1	3
Phoxinus erythrogaster	4	5	4	13
Pimephales promelas	1	3	0	4
Semotilus atromaculatus	0	1	0	1

Basic Information

Title:	Enhanced Life-Cycle Assessment (ELCA): Analysis to Guide Environmental Technology Implementation
Project Number:	2001OK4461B
Start Date:	3/1/2001
End Date:	2/28/2003
Research Category:	Social Sciences
Focus Category:	Law, Institutions, and Policy, Economics, None
Descriptors:	risk assessment, benefit cost analysis, life cycle assessment, stakeholder processes,integrated environmental decision-making
Principal Investigators:	Robert P Anex , Chad Settle

Publication

1. Focht,W. and J.G. Hull, 2002, "Framing policy solutions in a conflicted policy environment: An application of Q methodology to a superfund cleanup," in Proceedings of the Annual Meeting of the Western Political Science Association, March 22, 2002, Long Beach, CA.

Enhanced Life-Cycle Assessment (ELCA): Analysis to Guide Environmental Technology Implementation

Problem and Research Objectives:

The proposed research will develop an Enhanced Life-Cycle Assessment (ELCA) framework for the assessment of environmental technologies which will be demonstrated by assessing the life-cycle costs and benefits, risks, and stakeholder acceptability of using treatment wetlands for cleanup and restoration at the Tar Creek Superfund site.

Our overall objective is to develop a systematic process for environmental technology assessment that accounts explicitly for the interdependence among changes in releases of pollutants, human health risks, and economic impacts throughout the technology life cycle, and that is guided by stakeholder concerns and preferences regarding environmental management and pollution control. **Specific goals of the proposed research** include: i) development of methods of assessing stakeholder concerns and preferences suitable for guiding policy-relevant analyses; ii) to integrate risk assessment and benefit-cost analysis methods with life-cycle assessment techniques; iii) to demonstrate the ELCA framework by producing policy-relevant data regarding the costs, benefits, risks, and stakeholder acceptability of using treatment wetlands at the Tar Creek Superfund site; and iv) to identify priority information needs of the decision-making process to help guide future scientific research.

Methodology

The process of making environmental decisions involving health, societal, and economic issues is most commonly supported by three types of analysis: benefit-cost analysis (BCA), life-cycle assessment (LCA), and human health risk assessment. This project is advancing these analytic methods by integrating them into a coherent ELCA framework. The ELCA framework is both an integrated set of analysis tools that support the policymaking process as well as a procedure that involves stakeholders in defining the analysis process and therefore involves them in a critical part of policymaking. Involving stakeholders in the analysis process is important because stakeholders will not support a policy decision that they do not feel is fully legitimate.

The ELCA framework is being used to assess the technical effectiveness of the enhanced wetland technology in reducing human health risk through an integrated LCA and risk assessment process. The risk assessment process is guided by input from stakeholders gathered through survey and interviews. Benefit-Cost Analysis (BCA) is being used to assess the net benefit of the proposed use of treatment wetlands at the Tar Creek site. Incorporating BCA within the ELCA framework assures that the market and non-market site characteristics that are evaluated and included in the analysis are those that are important to the stakeholders and not simply those that an analyst thinks should be important. The BCA is also guided by the results of stakeholder interviews, Q sorts, and surveys. Stakeholder acceptability is being assessed from interviews with stakeholders residing or working near the proposed project site. Statements from these interviews are being Q sorted by stakeholders in a subsequent interview, and these Q sorts are being factor analyzed to reveal general perspectives on the technologies and to determine whether a conflict exists among these perspectives. Finally, the information regarding stakeholder concerns and preferences regarding the proposed remediation technology being developed from narrative analysis of the open-ended interview transcripts, Q methodology, and preference ranking are being used to develop a survey instrument. Survey responses are being analyzed using descriptive statistics and regression to determine stakeholders' concerns and judgments of the acceptability of the proposed remediation technology as well as their willingness to tradeoff benefits and costs to implement the technology. The information regarding stakeholder preferences and concerns is being fed back to guide and inform the three assessment processes (LCA, BCA and risk assessment).

Principal Findings and Significance

Of the three assessment exercises in this project (social impact assessment; economic impact assessment; environmental risk assessment), the social impact assessment effort needed to be completed first, since it is used to help frame the conduct of the other components. This assessment was conducted by interviewing selected stakeholders who are nearby residents, regulatory officials having responsibility for site remediation, experts who have or are conducting studies of the site, and representatives of various interest groups who perceive that they have a stake in site remediation. The social impact assessment was conducted via two rounds of face-to-face stakeholder interviews conducted in the Picher-Cardin-North Miami area surrounding the Tar Creek site.

During the second interview, stakeholders were asked to perform a Q sorting exercise. Each subject was asked to review and sort statements about Tar Creek concerns (sort #1) and remediation preferences (sort #2) by reading representative statements taken from the first round of interviews and then placing them on a Q sort formboard. Interpretation of the factors derived from the Q sorts provide insight into stakeholders' perspectives on their concerns and preferences, which are in-turn being used to both frame subsequent economic and risk assessments and in characterizing the nature of the conflict that exists among perspectives. Knowledge of these perspectives will also be valuable to policymakers as they deliberate about the future of the Tar Creek site.

Based on the results of the Q-sorts we concluded that the conflict at Tar Creek was contingent and that it is possible to conceive of a policy solution to the Tar Creek Superfund controversy that is super-optimal, that is, can satisfy all parties in dispute. In this case, we can conceive of a resolution to the conflict by creatively addressing the fundamental concerns manifest in the four orthogonal perspectives, which, by definition, are not in veridical conflict. In other words, what any one party wants is not really opposed by any other party – despite the rhetoric and reporting that has occurred over the last 20 years.

Based on review of the four identified perspectives regarding remediation preferences, we are able to make recommendations that may help reduce conflict. We recommend that the USEPA seek to improve the legitimacy of remediation decision-making by involving all stakeholders in helping to frame the analyses that should be conducted and in participating in deliberations about the remedies that should be implemented. Easily accessible information repositories should be located in the community, frequent meetings should be held to discuss proposals, and stakeholders' concerns and values should be incorporated into decision-making. A protocol for recursively integrating policy analysis with policy integration has been proposed by Stern and Fineberg (1996). This protocol suggests that deliberants should not only participate in making decisions but also in framing analyses that are designed to inform their deliberations.

The controversy over the remediation of the Tar Creek Superfund site has continued unabated for two decades with no end in sight. Distrust is growing, stakeholders are frustrated and angry, and hope is fading that any resolution that is satisfactory to residents will be found. We entered this investigation with profound respect for the difficulties that residents are facing and wondered whether we could discover possible solutions that could gain stakeholder support when so many others have failed. We conducted the Q methodological investigation with cautious hope and were pleased that we did not find bipolar factors – suggesting that the Tar Creek controversy represents a contingent conflict amenable to a super-optimum solution. We have suggested changed circumstances, particularly with respect to decision-making processes and remediation priorities, that we believe will find little opposition in the affected communities. Though the costs of implementing these measures are not trivial, they will likely pale in the face of the $50 million that has been spent so far in remediating residential yards and diverting recharge into the Boone Formation that has proven ineffective at addressing stakeholder concerns and controversial.

We have only now completed the Q analysis of stakeholder perspectives on remediation preferences in this case and thus have not yet had an opportunity to determine just how well these recommendations will be received by those holding the four perspectives. We will be contacting the participants again in the coming months. We remain optimistic.

The results of social impact assessment have been used to frame the economic and technological effectiveness assessments that are now underway.

Reference:

Stern, Paul C., and Harvey V. Fineberg, eds. 1996. *Understanding Risk: Informing Decisions in a Democratic Society.* Committee on Risk Characterization, Commission on Behavioral and Social Sciences and Education, National Research Council. Washington, DC: National Academy Press.

Basic Information

Title:	Resistance Tomographic Imaging, Digital Mapping, and Immersion Visualization of Evaporite Karst in Western Oklahoma
Project Number:	2001OK4481B
Start Date:	3/1/2001
End Date:	2/14/2003
Research Category:	
Focus Category:	Groundwater, Solute Transport, None
Descriptors:	digital mapping, visualization, evaporite karst, Oklahoma, contaminant transport,resistivity imaging, groundwater pollution
Principal Investigators:	Aondover Tarhule , Thomas Dewers , Rozemarijin Tarhule

Publication

1. Zume, Joseph, A. Tarhule, S. Christenson, 2002, Resistivity Conductivity Anomalies at the Norman Landfill Site, Annual Meeting of the Geological Society of America, Denver, CO.

Resistance Tomographic Imaging, Digital Mapping, and Immersion Visualization of Evaporite Karst in Western Oklahoma

Problem and Research Objectives

The objective of this proposal is to employ subsurface imaging techniques, specifically Electrical Resistivity Tomography (ERT) and immersion visualization software to provide a digital imagery of the subsurface conduit system in a karst environment. The research objective addresses the need to monitor contaminant flow in karst conduits, which is difficult to detect with discrete network of monitoring wells.

The product of the study will be a procedure for imaging hidden cavities in the karst aquifer system in Northeastern Oklahoma. The information is useful for directly monitoring contaminant occurrence and movement and for drilling targeted wells for groundwater monitoring and aquifer characterization.

Funding Arrangement

The total budget for the proposal was $50,000, over two years (March 2001-March 2003). Of this amount, the Oklahoma Water Resources Research Institute (OWRRI) provided $18,000 while the Oklahoma Department of Environmental Quality (ODEQ) decided to make up the balance ($32,000). However, delays related to the approval of the Quality Assurance Plan (QAP) held up the ODEQ portion of the funding until August 1, 2002 when it was finally approved.

This report describes how the funds received from OWRRI have been spent, with supporting comments to the research activities since the approval of the ODEQ portion.

Research Activities

The Department of Geography owned one AGI Sting Resistivity meter (R1-IP), which was operated in manual mode. During the summer of 2001, the funding provided by OWRRI enabled us to acquire a Swift converter, 28 smart electrodes and 150 m of cable for the Sting R1 earth meter. The new additions facilitate automatic resistivity surveys that were not possible in the manual mode. The total cost of the swift converter and cables came to $14, 230

Fig. 1. The Sting Swift System acquired with funding provided by OWRRI

Reconnaissance Surveys

As specified in the proposal, our goal is to evaluate the feasibility of using resistivity methods to detect groundwater contamination in karst aquifers. Because the conduits in which the groundwater travels are inaccessible it is critical to determine the detection accuracy of the proposed method and to develop confidence in its use. Consequently, we designed a three-phase evaluation procedure. Phase I consists of detecting large conduits with known locations and dimensions, which would serve as ground truth in evaluating the accuracy of resistivity models. Phase II will determine the detection capability of resistivity by establishing the depths and sizes of cavities that could be detected using array configurations. Finally, Phase III will involve imaging small inaccessible cavities, relying on experience gained from Phases I and II to interpret the modeled curves.

During the summer of 2001, several reconnaissance surveys were carried out to locate suitable sampling sites. With assistance provided by the Central Oklahoma Grotto, the Oklahoma Geological Survey and Scott Christensen of the USGS (Oklahoma City), we surveyed Nescatunga caves, The Corn Caves and Jester Caves.

Figure 2. One of the cave passages at Corn Caves near Weatherford, investigated during the reconnaissance survey.

Norman Landfill Study

To test the new equipment, preliminary investigations were carried out at the Norman Landfill site, in collaboration with Scott Christensen (USGS). The old Norman landfill, located on the floodplain of the Canadian River (Fig. 3), was the major repository for municipal waste between 1922-1985. During that time, it is estimated to have received approximately 1,128 tons of municipal waste per week. Leachate plume emanating from the landfill has contaminated a good portion of the underlying alluvial aquifer. The site is therefore ideal for testing the ability of resistivity methods for mapping groundwater contamination.

Our objectives were to

(i) Delineate the pathways through which the leachate flows out of the landfill, and

(ii) Determine the extent of the migration plume that results.

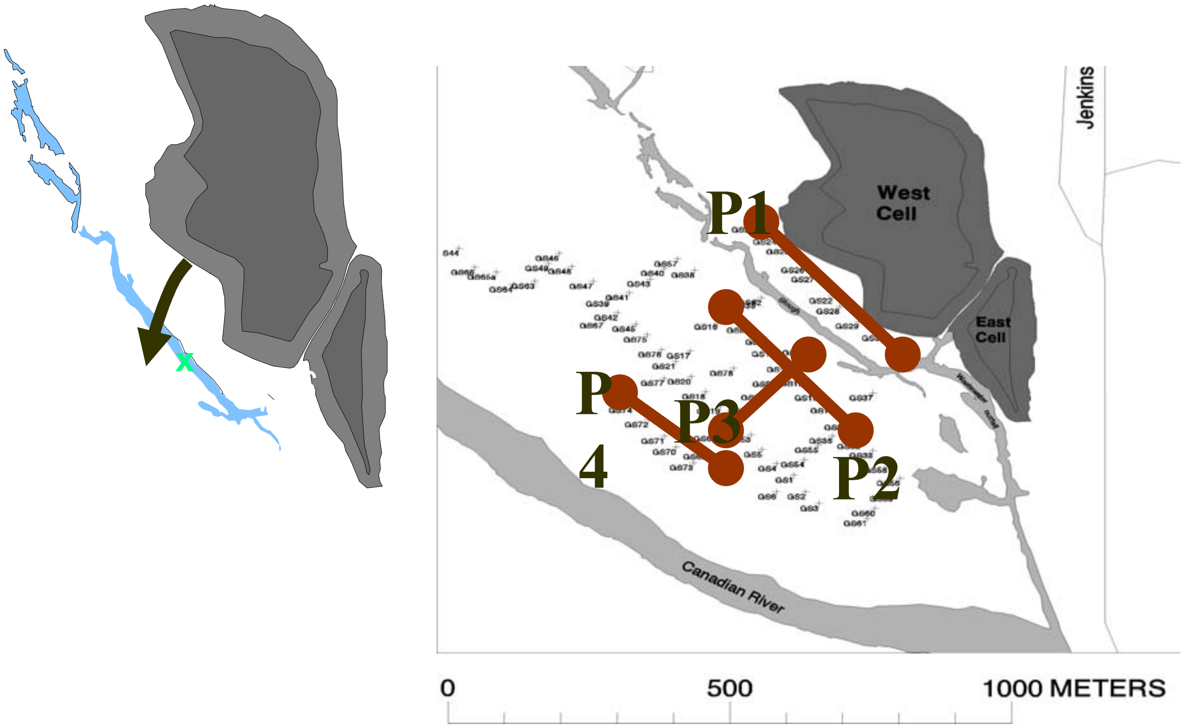


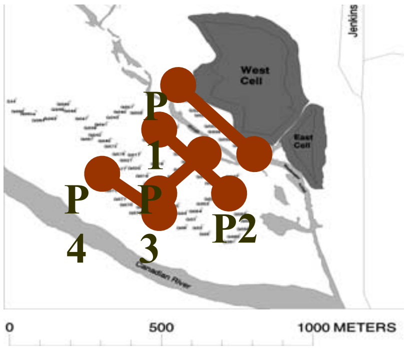
Fig 3. The old Norman Landfill site on the floodplain of the South Canadian River. Resistivity transect lines are shown in red. Conductivity points are shown as dots.

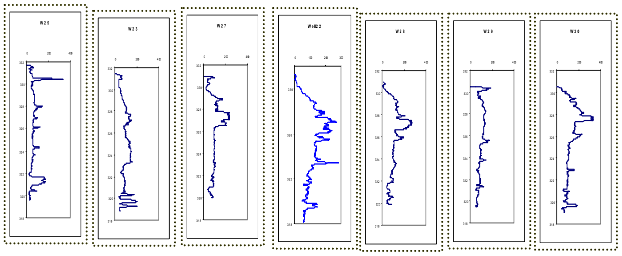
Methodology

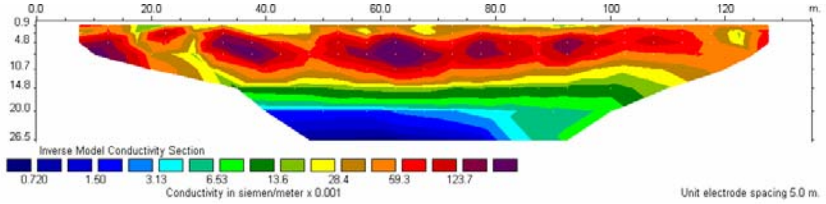
Electrical Resistivity methods including Wenner, Wenner-Schlumberger, and dipole-dipole array types were used at 5 m spacing. Four resistivity transects, each 135 m long were completed. For each transect, all three array types were used, resulting in a total of 12 surveys. 36 conductivity logs at 0.5 m depth intervals supplemented the data. Additionally, water chemistry and soil core data provided by the USGS facilitated ground truth and resistivity interpretation.

Principal Findings and Significance

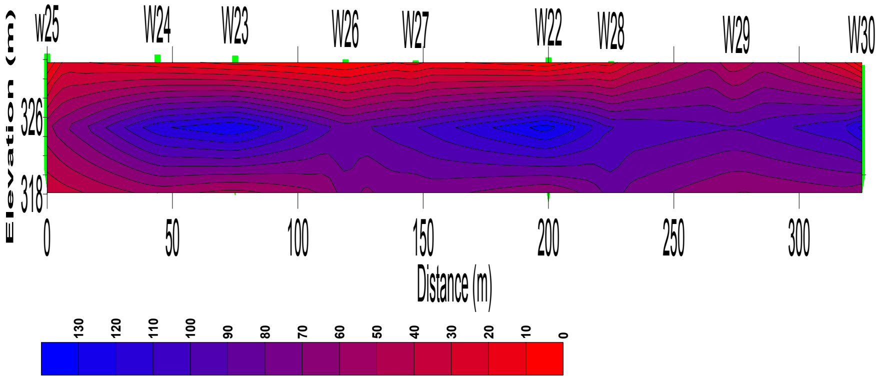
The results presented below integrate the information generated from soil water chemistry (i.e. conductivity in monitoring wells), 2D resistivity modeling plotted as conductivities and geoprobe conductivity logging.







Sting section



Geoprobe section

Figure 4. Results of water chemistry (i.e. conductivity analysis; top panel), 2D resistivity modeling (middle panel) and geoprobe section (bottom panel) for profile 1 (insert, top left). Dark red colors in the 2D resistivity profiles (middle panel) show areas of high conductivity (i.e. low resistivity) and blue colors are areas of high resistivity (low conductivity). The color bands are reversed in the bottom panel; blue colors are high conductivity areas and red colors are low conductivity areas.

The three methods utilized reproduce the subsurface conductivity profile in different ways. Measurements of conductivity in monitoring wells provide only the conductivity of the liquid water. The resistivity approach provides an average of the soil resistiviy (or conductivity) along a half space under the four electrodes in the horizontal dimension. Finally, the SC400 soil conductivity meter is a four-pole "Wenner" array type probe: it provides an average of the soil conductivity matrix between the four electrodes in the vertical dimension. The major difference between the methods therefore is that both the water chemistry and geobrobe measurements are site specific whereas the resistivity methods integrates values for a larger area.

Despite such differences, there is good agreement between the methods. In particular, the 2D resistivity (dipole-dipole) and geoprobe profiles for P1 (10 m away from the landfill) show striking similarities: the areas of high conductivity agree quite well both in terms of depth and horizontal position. The dipole-dipole method consistently provided superior image resolution relative to the array types. Results of water chemistry analysis (top panel) suggest that these areas of high conductivity represent the pollutant plume migrating from the landfill.

To test this hypothesis, surveys were conducted along parallel transects P1, P2, and P4, located respectively at 10, 180 and 460 m away from the landfill towards the river channel. Our goal was to image the pollutant profile along each transect and to track its migration towards the river. Finally, transect P3 was oriented concordantly between the landfill and the river channel in the expectation that the leading edge of the contaminant plume could be detected. Figures 5 – 7 show the results.

Figure 5 (P2) detected two areas of pollutant concentration compared to the several blotches or fingers of pollutant plume seen in P1, consistent with the result of water chemistry analysis. Transect P4, near the river channel detected no evidence of the contaminant plume, suggesting that the plume has not migrated this far (Fig. 6). Finally, Fig. 7 attempts to determine the leading edge of the migrating plume but the results are inconclusive beyond the fact that past the slough (see fig. 1), the contaminant occurs deeper beneath the surface.

Conclusions (Norman Landfill Study)

The conductive leachate plume from the landfill concentrates along preferential pathways. Between the landfill and the slough, the contaminant is closer to the surface (0-6 m). Beyond the slough the contaminant dives down toward the bedrock and moves toward the Canadian River. However, beyond 300 m from the landfill, neither resistivity nor the conductivity probing detected any presence of this contaminant. The finding is consistent with conductivity measurements in monitoring wells

These results indicate that resistivity/conductivity methods could be used to detect and map groundwater contaminants in alluvial sediments. Further studies are needed to determine whether the rate of contaminants migration could be monitored using the same methods.

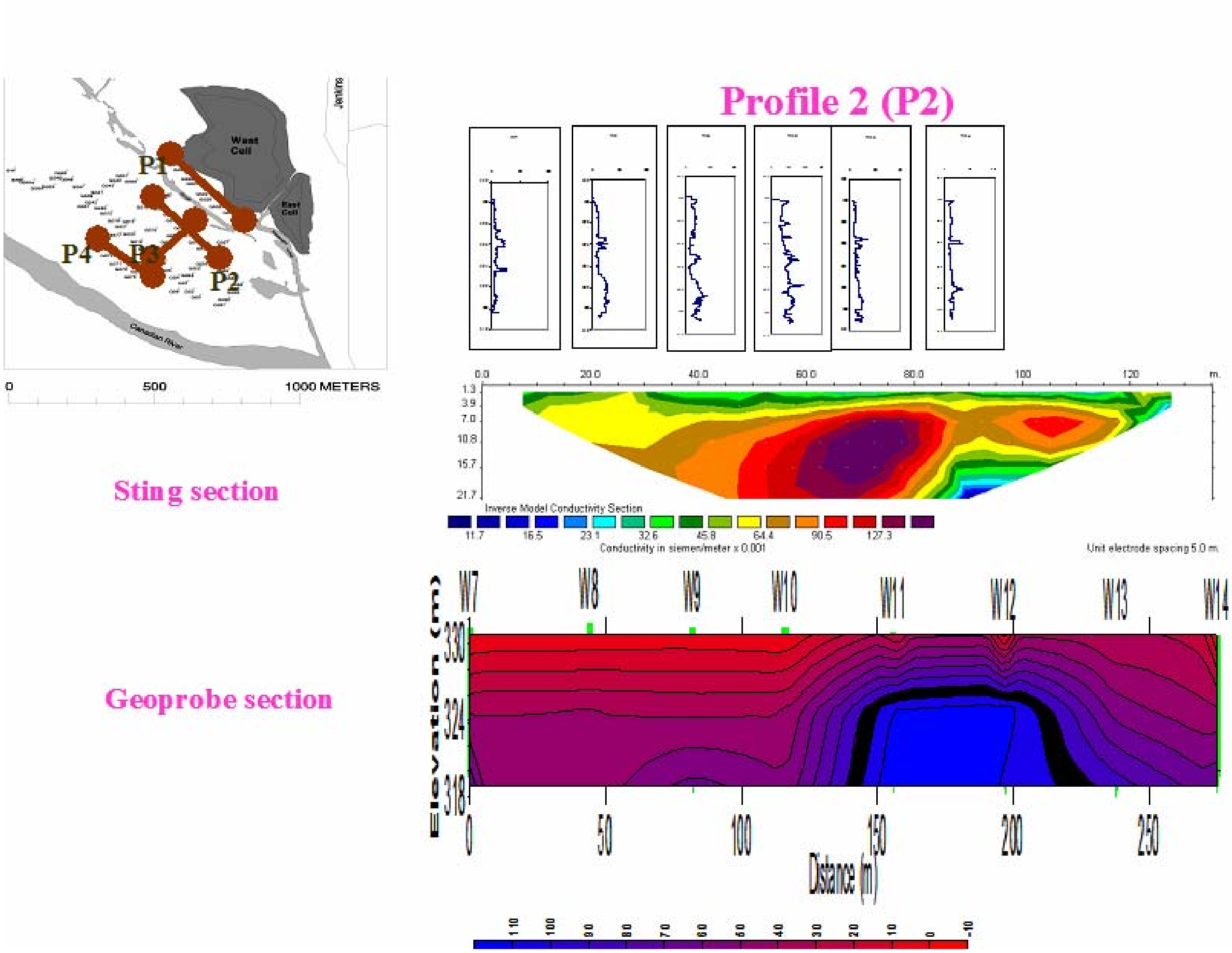


Figure 5. (Top panel): conductivity in a USGS monitoring wells along profile 2; (middle panel): RES2DINV model of the conductivity along profile 2; and (bottom panel): Geoproble profile along profile 2. The color scheme is the same as for profile 1 (fig. 4).

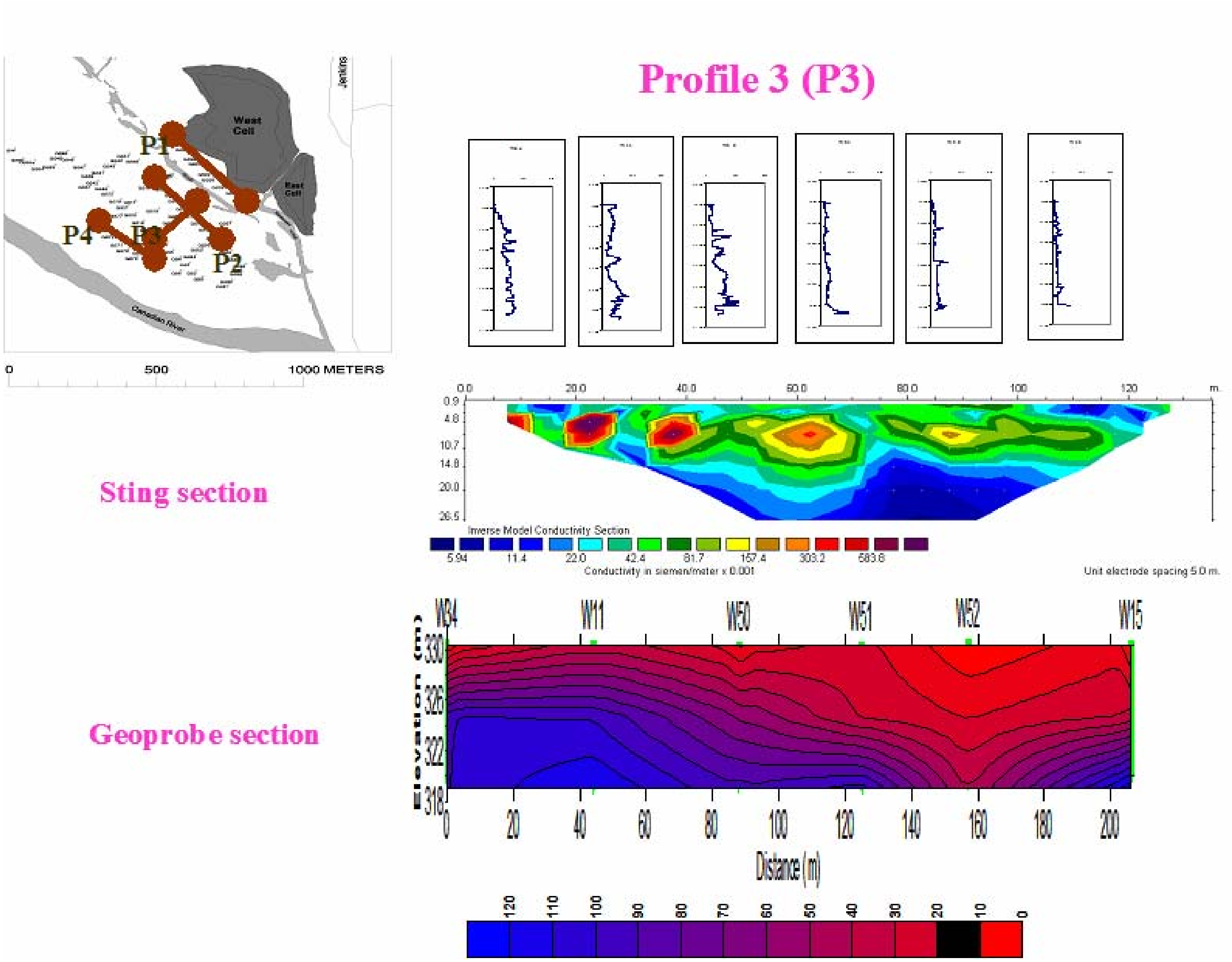


Figure 6. (Top panel): conductivity in a USGS monitoring wells along profile 2; (middle panel): RES2DINV model of the conductivity along profile 2; and (bottom panel): Geoproble profile along profile 2. The color scheme is the same as for profile 1 (fig. 4). Notice that in all three profiles, the conductivity values diminish appreciably beyond 120 m.

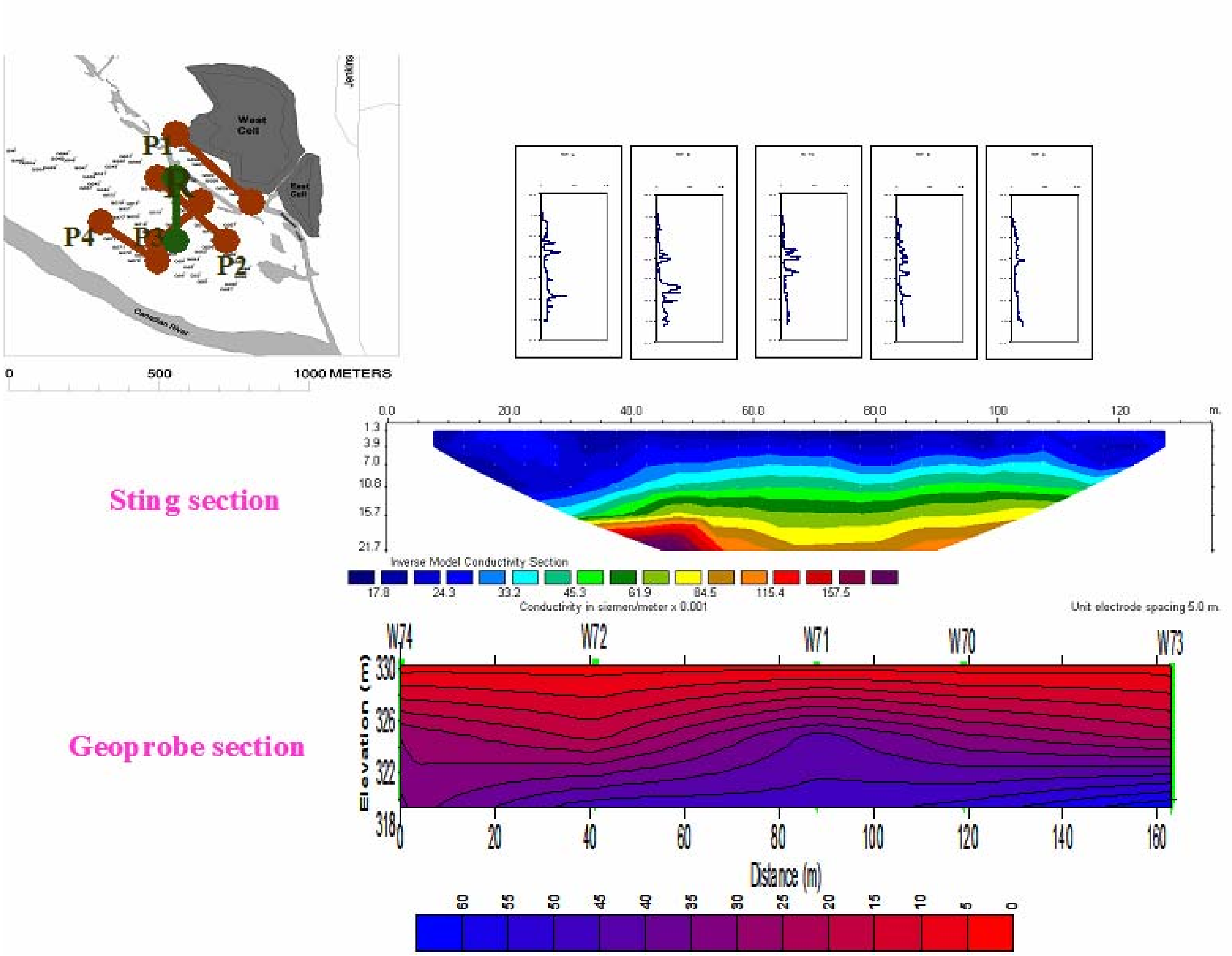


Figure 7. (Top panel): conductivity in a USGS monitoring wells along profile 2; (middle panel): RES2DINV model of the conductivity along profile 2; and (bottom panel): Geoproble profile along profile 2. The color scheme is the same as for profile 1 (fig. 4). None of the methods detected any evidence of the contaminant plume along this profile, next to the river channel and f arthest from the landfill.

Future Work

Approval of the ODEQ portion of the funding in August 2002 allowed us to begin substantive investigations on detecting solutional conduits in karst aquifers. Five (5) surveys were conducted between September and October 2002. The cave systems investigated are the Corn caves near Weatherfold, and Jester caves in southwestern Oklahoma.

Internal Cave Mapping

As specified in the proposal, our rationale for mapping large diameter cavities is to enable us develop confidence in the detection capability of resistivity methods. Consequently, the first step in the research is to produce an accurate and high-resolution image of the cave conduits.

A Trimble ProXRS system http://www.trimble.com/pathfinderproxrs.htm, LaserTech reflectorless rangefinder, and MapStar digital compass http://www.afds.net/lasertech.html#B (with a Compaq IPAQ running the SOLOField data logging software) were used together to generate accurate GPS and elevation position of the known cavities for comparison against the voids detected from modeled curves. This facilitates the assessment of the relative efficiency of each array configuration in detecting the voids.

To map the caves, the ProXRS GPS system was mounted on a tripod near an entrance to the cavern system being surveyed, along with the reflectorless laser rangefinder and digital compass. A DGPS carrier phase location was sited at this initial position. Differential corrections were obtained onsite using the OmniStar system and later via internet resources. A series of control points or stations were then located within the cavern itself spatially referenced to the GPS position by a series of offsets using mounted reflectors. Beginning at the entrance to the cave, the laser configuration occupied each of these control stations successively, permitting a survey of the surrounding cavern walls (consisting of locations referenced to the control points) to be conducted. Although positioning error invariably increases with each successive control point occupied within the cavern, we achieved sub-decimeter accuracy in distance and inclination from each control point, and confirmed the accuracy by reoccupying control stations. Positioning data was then stored and analyzed using GIS (e.g. ESRI ARCVIEW) and CAD.

One survey approximately 60 m long was completed at Corn caves. At Jester, only GPS points directly underneath the surface transect line was collected. This was possible because of a “window” or collapse that opened up into the cave near the survey transect. Figure 5 shows Gaylen Miller, staff of the Oklahoma Geological Survey setting up the laser system.

Resistivity surveys were carried out at the surface concurrent with the internal cave mapping, using a Sting R1-IP resistivity meter produced by AGI, in Austin, Texas. A total of six transects (3 at each location) were completed. Four of the transects utilized 28 electrodes at 5 m spacing, resulting in a survey length of 135 m. To investigate the effect of electrode spacing on resolution of target voids, two other transects were completed at 3 m spacing. For each survey transect, four array types (dipole-dipole, pole-dipole, Wenner, and Wenner-Schlumberger) were used. This was to determine which array type most consistently detected voids with the best resolution.

The internal cave mapping allowed us to determine the true positions of cave passages underneath the survey lines, which could then be compared with the voids detected by surface resistivity imaging. Figures 6a, b illustrates the concept.

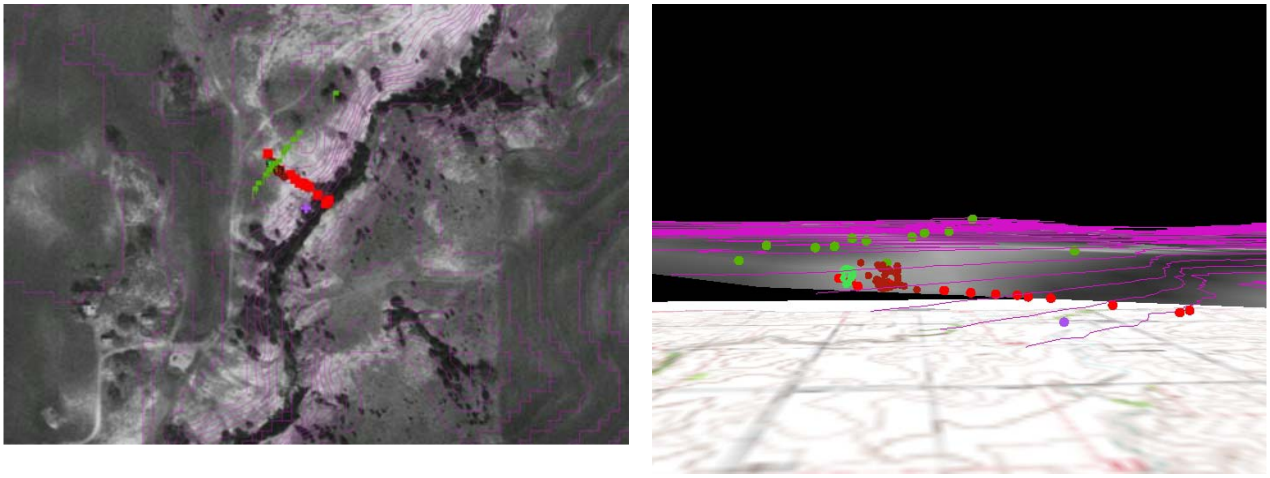


Fig. 6(a). Combined surface resistivity and GPS/laser mapping. The red dots are GPS positions inside the cave. The green line shows the survey transect line. (b). Side view of the image in Fig 4a. Notice the high density of GPS points underneath the survey line. These points were subsequently plotted on the modeled image of the resistivity survey to establish the accuracy of void detection with resistivity.

A quarterly report detailing the preliminary results achieved has been submitted to ODEQ.

Conclusions

Funding provided by OWRRI allowed us to

(i) acquire a Swift converter and smart electrodes to complete our Sting Swift resistivity system.

(ii) Support field investigations by one Ph.D graduate student to test the equipment

(iii) Map the migration of leachate plume from the old Norman landfill. The results of the test were corroborated by other methods and subsequently presented at the annual general meeting of the Geological Society of America in Denver, 2002. A manuscript is in preparation to be submitted to a reputable journal for publication.

(iv) Approval of supplementary funding by ODEQ was obtained in August and subsurface mapping as specified in the original proposal is in progress.

Acknowledgement

We are deeply grateful to the Oklahoma Water Resources Institute for providing the funding that made this study possible. We would also like to thank the Department of Geology and

Geophysics, University of Oklahoma, for permission to use the GPS/laser range finder system. Additional assistance was provided by the USGS, Oklahoma City and the OGS based at the University of Oklahoma.

Information Transfer Program

Activities for the efficient transfer and retrieval of information are an important part of the Environmental Institute/OWRRI program mandate. The Institute maintains a web site on the Internet at URL http://environ.okstate.edu/ that provides information on the OWRRI and supported research. The site provides links to information on publications of the Institute, grant opportunitites and deadlines and any upcoming events. A listing of technical reports and other publications generated by OWRRI and other Environmental Institute sponsored research is updated regularily and is accessible on the Institute web site. Abstracts of each publication are available.

The publication of the bi-monthly newsletter of the Institute,Prism, has continued. Prism is a valuable source of information on research activities sponsored by the Institute and research opportunities in water resources and environmental research. Current and past issues of the newsletter are made available on the web site.

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	0	0	0	0	0
Masters	3	0	0	0	2
Ph.D.	4	0	0	9	13
Post-Doc.	1	0	0	0	1
Total	7	0	0	9	16

Notable Awards and Achievements

Publications from Prior Projects